ANALYSIS OF OPERATING DATA RELATED TO POWER AND FLOW DISTRIBUTION IN A PWR

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* Yankee Atomic Electric Co.

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ABSTRACT

The analysis of the effects of the uncertainties associated with temperature and power measurements in the Connecticut Yankee Reactor leads to the evaluation of the uncertainty associated with the effective flow factor. The effective flow factor is defined as the normalized ratio of the average assembly power to the coolant temperature use in each instrumented fuel assembly. Analysis of operating data indicates that the effective flow factor is a measure of the quality of agreement between the reactor physics and the thermal hydraulic analysis of the core. The methods given are also used for the evaluation of the uncertainties associated with the peaking factors, including the results of a sensitivity analysis developed with the code INCORE.

Flow calculations have been performed with the code COBRA III C. The original version of the code COBRA III C has been expanded and a method is given to easily handle any further change in the code. A sensitivity analysis, using the code COBRA III C shows the weak sensitivity of

the exit conditions of the coolant on most input parameters and on the inlet flow distribution of the coolant selected for the calculation. This low sensitivity indicates that the information obtained from the assembly exit thermocouple cannot be used for the determination of the cross flow pattern between the fuel assemblies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General Remark

The designer of a reactor is constrained by the requirement that the maximum values of certain design parameters do not exceed critical values. Specific methods are used by the designer such as statistical treatment of hot channel factors, to evaluate the maximum value of a given quantity and the associated confidence level for not exceeding this maximum value.

The reactor operator is provided with different means of control, allowing either a continuous or a discrete monitoring of the critical parameters that can be measured or evaluated from other quanitities. The goal is then, to achieve the production of the maximum thermal power, within the limits imposed by the technical specifications. From the reactor operation point of view, it is important to know the actual values of the critical parameters and to see how they compared to the design values. It is also important to include the fact that each parameter can only be evaluated within some uncertainty, since they are either measured or calculated.

The uncertainty in each value comes from the inaccuracy of the control instruments, the inaccuracy due to the calculation method used, and even round off errors due to the use of the computer.

For safety purposes, it is very important to always maintain, an efficient capability for cooling the fuel. The fuel temperatures should be kept as low as possible for a given power level, including the hot spot location. One factor in achieving this requirement is an adequate coolant flow distribution.

This flow distribution depends on specific factors such as: the fuel bundle geometry, the pressure drop distribution, the coolant phase change, the power distribution, etc. Most of the reactor manufacturers orifice the lower core plate, which provides the fuel assembly inlet distribution. The orificing is designed to yield a rather flat temperature distribution of the coolant across the core at the assembly outlet (1).

Unfortunately the flow distribution among the fuel assemblies cannot be measured directly. The problem is even more complex in PWR's than in BWR's, since the PWR fuel assembly is an open geometry assembly type allowing flow and energy exchange between assemblies. In this case the real flow is made up of:

- an axial flow which represents the most important fraction of the total flow,
- a transverse flow or diversion cross flow, representing only a small fraction of the total flow.

As it will be seen later, the flow distribution can be related somewhat to the power distribution. The power distribution among the fuel assemblies is obtained by interpretation of axial neutron flux measurements in instrumented assemblies. This evaluation depends on the accuracy of the flux detectors and the interpretative computation.

1.2 Problem Definition

This study has been developed to obtain a better understanding of the effects of the various uncertainties in the control instruments and in the methods of interpretation of the control data in terms of parameters such as peaking factors, power distribution, effective flow factors.

The data used throughout this study came from measurements taken at the Connecticut Yankee Reactor. They have been used to provide actual values of parameters for comparison with the design values of these parameters. Periodically, measurements are made in the Connecticut Yankee Reactor at full power to evaluate and control the time evolution of:

- the power distribution,
- the location and value of peaking factors: F_q^N, F_z, $F_{\Delta H}^N$,
- the effective flow factors.

The values obtained do not include the effect of the different uncertainties due to the control instruments or the calculation methods and are given in an absolute manner. However, the limits are set to conservatively include these uncertainties.

The problem is to evaluate the effect of these uncertainties on the following quantities:

- local peaking factors,
- effective flow factors,
- power distribution.

Table 1 summarizes the main characteristics of the Connecticut Yankee Reactor.

1.3 In-Core Instrumentation of the Connecticut Yankee Reactor

The in-core instrumentation of this reactor is designed to give information on:

- neutron flux distribution using movable neutron flux detectors,

General characteristics		
Thermal power	(MWth)	1825
Electrical power	(MWe)	617
Reactor manufacturer		Westinghouse
Number of loops		4
Core design		
Number of fuel assemblies		157
Height of the core	(in)	126.7
Mass flow for heat transfer	(Mlb/hr)	92.7
Fraction of the total flow by-passing the core		0.09
Fraction of the total heat generated within the fuel		0.974
Fuel design		
Fuel rod OD	(in)	0.422
Pellet diameter	(in)	0.3835
Active length of fuel	(in)	121.8
Fuel array		15 x 15
Fuel pitch	(in)	0.563
Fuel type		UO_2 sintered

Table 1 Summary of the Main Characteristics of the Connecticut Yankee Reactor

- fuel assembly outlet temperatures using Chromel-Alumel thermocouples,

at certain selected locations. Figure 1 shows the in-core instrumentation pattern. One may see that one quadrant of the core is well instrumented, this assumes that the quadrant symmetry holds during the plant life, however, the octant symmetry which exists during the life of the first core, is no longer true after the first refueling.

1.3.1 Thermocouples

The forty-eight Chromel-Alumel thermocouples penetrate the reactor vessel head through guide-tubes. The guide-tubes are located in some of the support columns which provide adequate rigidity for the upper core plate, whose main function is to hold in position all the fuel assemblies constituting the core.

The thermocouples hot junction are located about 7 inches above the top of the fuel rods and about 13 inches above the top of the heated length. Figures 2 and 3a, b, c, show the thermocouples arrangement in the Connecticut Yankee Reactor. When the coolant lives the top of the fuel rods it is channeled until it passes the upper core plat and the hot junction of the exit thermocouple. Along this flow path, almost no cross flow ex-

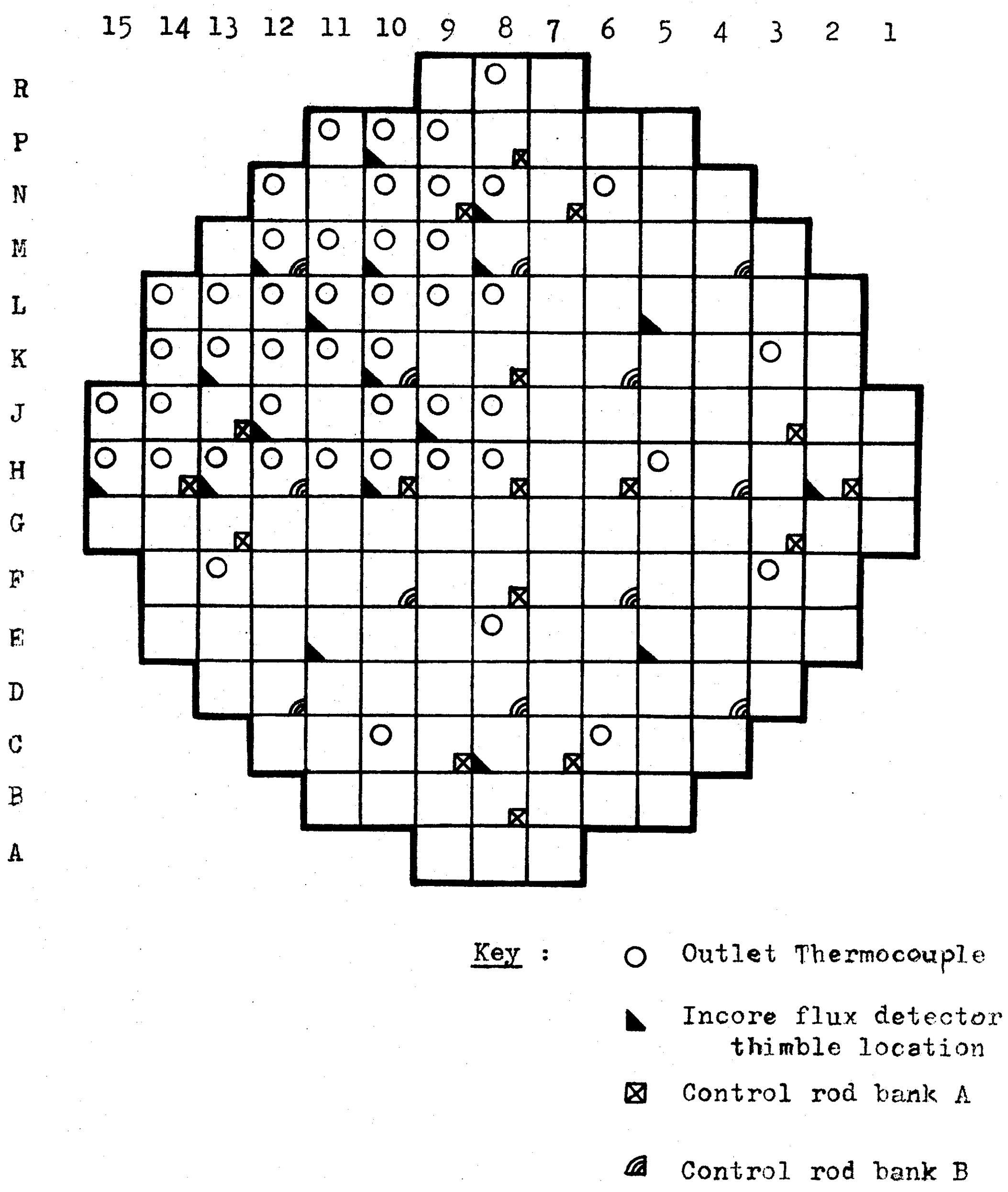


Fig. 1 In-core instrumentation in the Connecticut Yankee Reactor. (From Ref. 2)

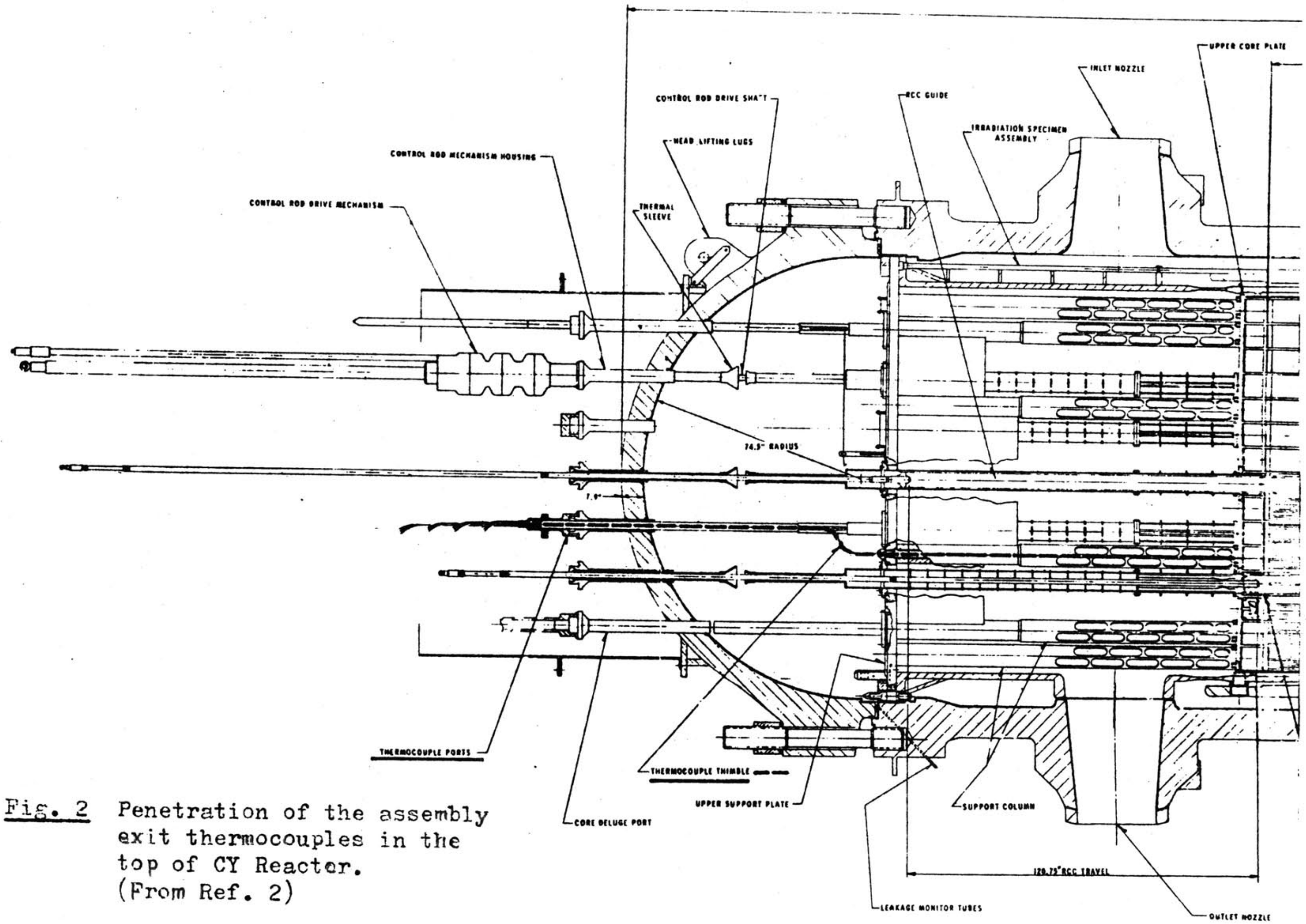


Fig. 2 Penetration of the assembly exit thermocouples in the top of CY Reactor. (From Ref. 2)

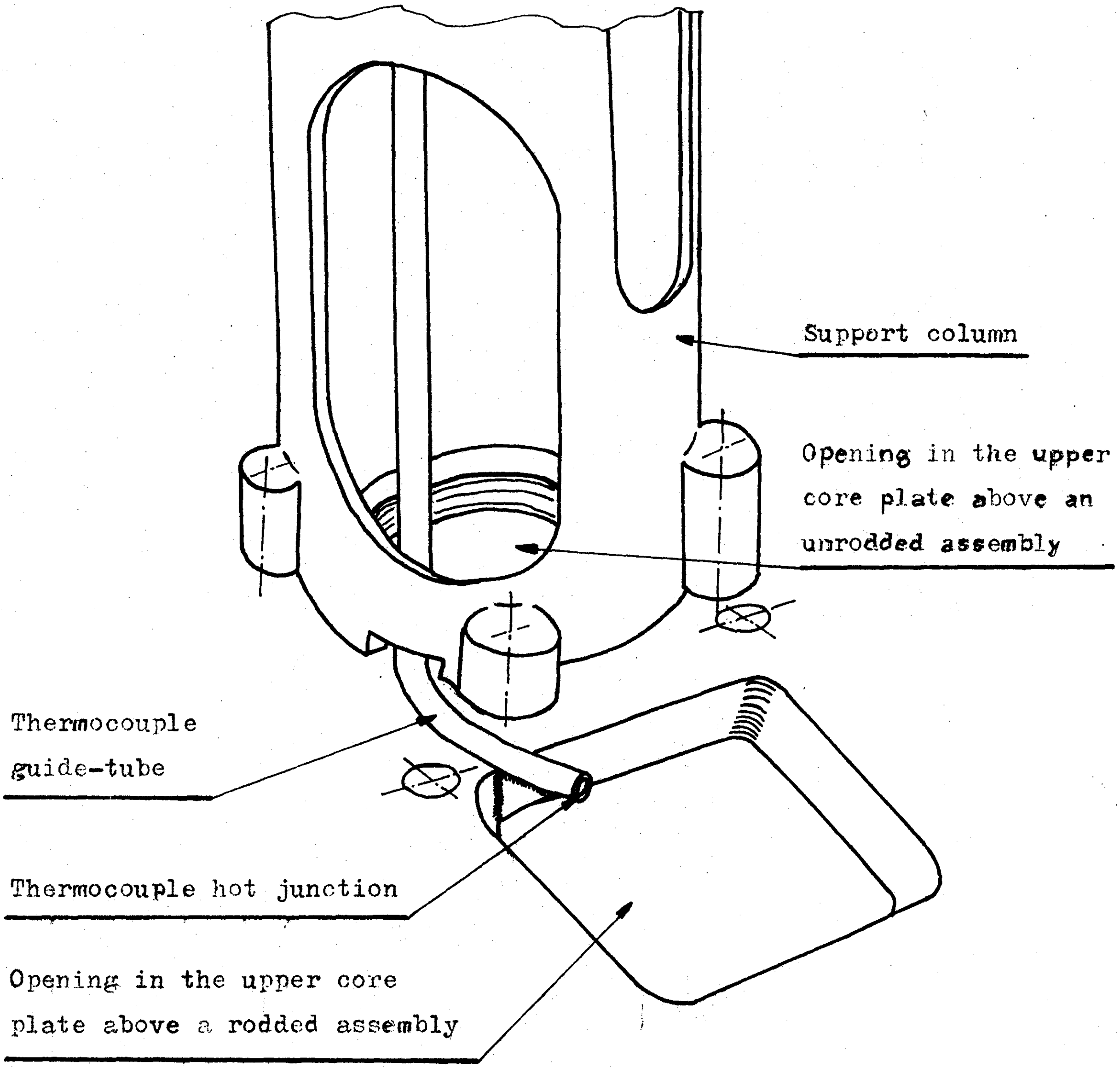


Fig. 3.a Arrangement of the assembly exit thermocouple on the upper core plate. (From Ref. 5)

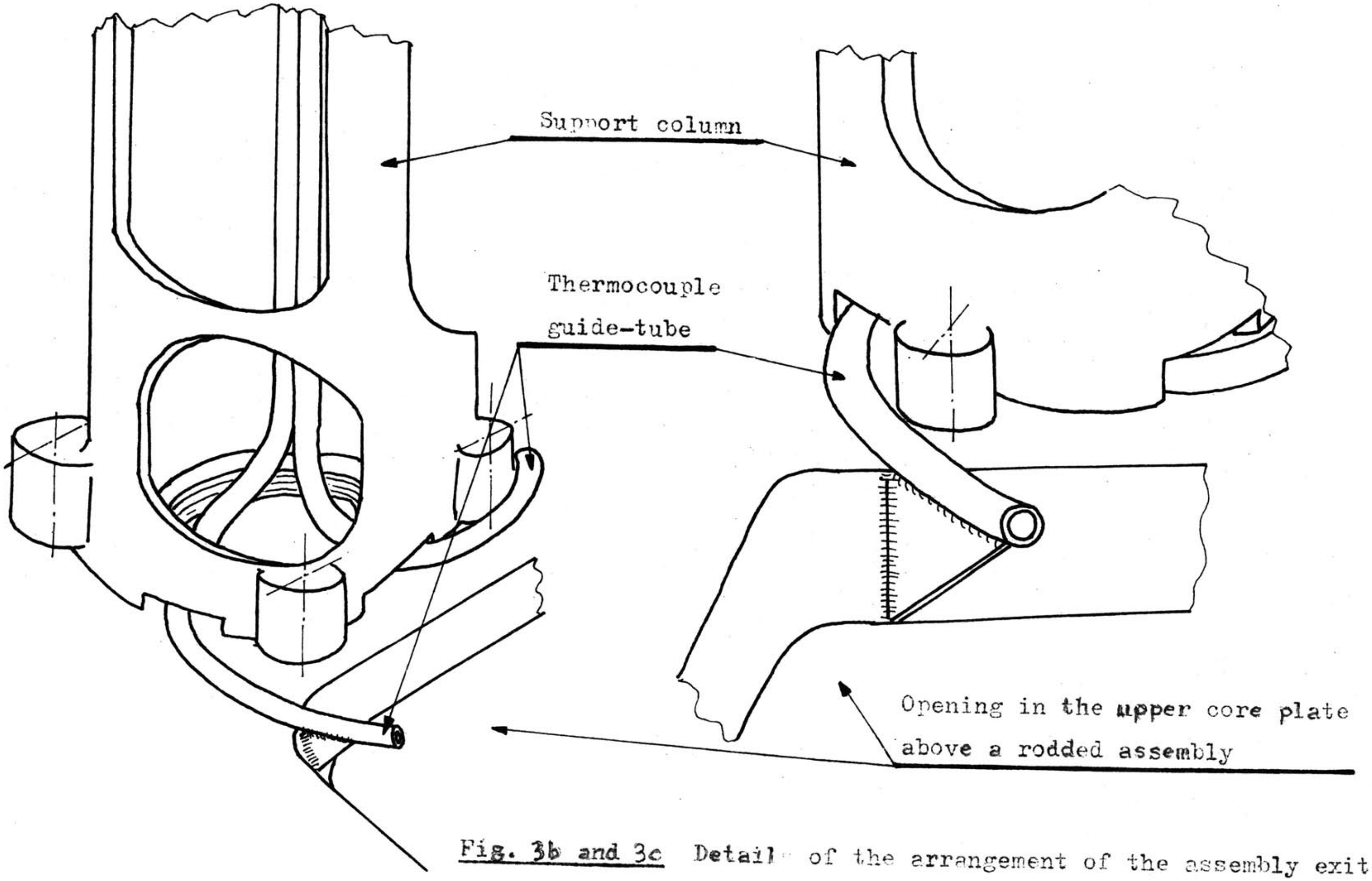


Fig. 3b and 3c Details of the arrangement of the assembly exit thermocouple on the upper core plate.

change with the other fuel assemblies takes place. Therefore the coolant flowing around the hot junction of the exit thermocouple comes only from the top of the fuel rods of the fuel assembly below the thermocouple.

It is interesting to note that in actual operating experience (3) it was not possible to easily replace the defective thermocouples, mainly because they are bent several times in the guide tubes. Design improvements have been made in future reactors so that replacement can be done with less problems.

1.3.2 Movable Miniature Neutron Flux Detectors

Two fission chamber detectors are used to measure the axial neutron flux. They are made of U_3O_8, enriched at 90% in U^{235}. Some of their characteristics are listed below:

Outside diameter:	0.188 in.
Length:	2.0 in.
Minimum neutron sensitivity:	2×10^{-17} amp/nv
Maximum gamma sensitivity:	3×10^{-14} amp/nv
Operating thermal neutron flux range:	1×10^{11} to 4×10^{13} nv.

The two fission chambers are under remote control. A complete flux mapping of the core takes about two hours. Each instrumentation thimble in the fuel assemblies is monitored at least once by a flux detector. The neutron flux detector is pushed by a mechanism up to the top of the fuel assembly. Then the detector is pulled, and while it is going from the top to the bottom of the fuel assembly, the neutron flux is recorded. This is done from the top, to be sure of the axial location of the flux detector while the flux is being measured. Otherwise, if the flux were recorded while the flux detector were moving from the bottom to the top of the fuel assembly, there would be a large uncertainty in the detector axial position. Figure 4 represents a typical drive mechanism for in-core movable flux detectors (4). Figure 5 shows a side view of the bottom part of the Connecticut Yankee Reactor (2) with the in-core instrumentation system.

During the flux mapping of the core, it happens that the flux can be measured several times at the same location by the two detectors (each enters the same flux thimble at least once). This allows normalization of the two detectors, to account for the fact that they may not have the same cross-section or the same response for a given flux.

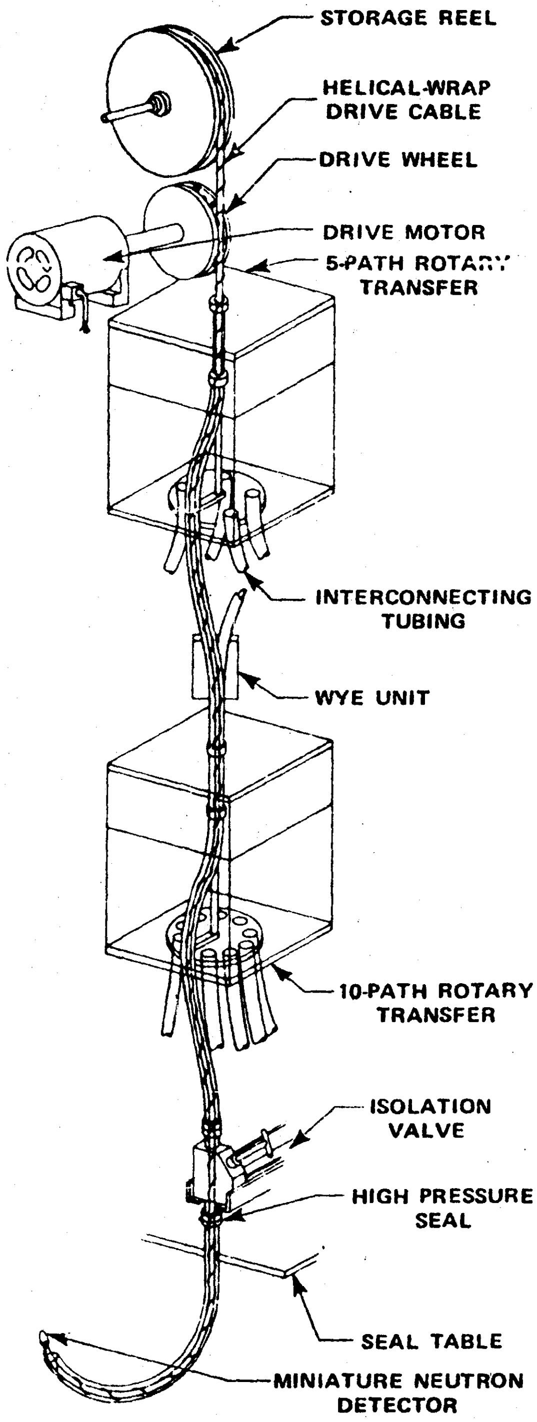


Fig. 4 Typical Drive System for In-Core Instrumentation

(From Ref. 4)

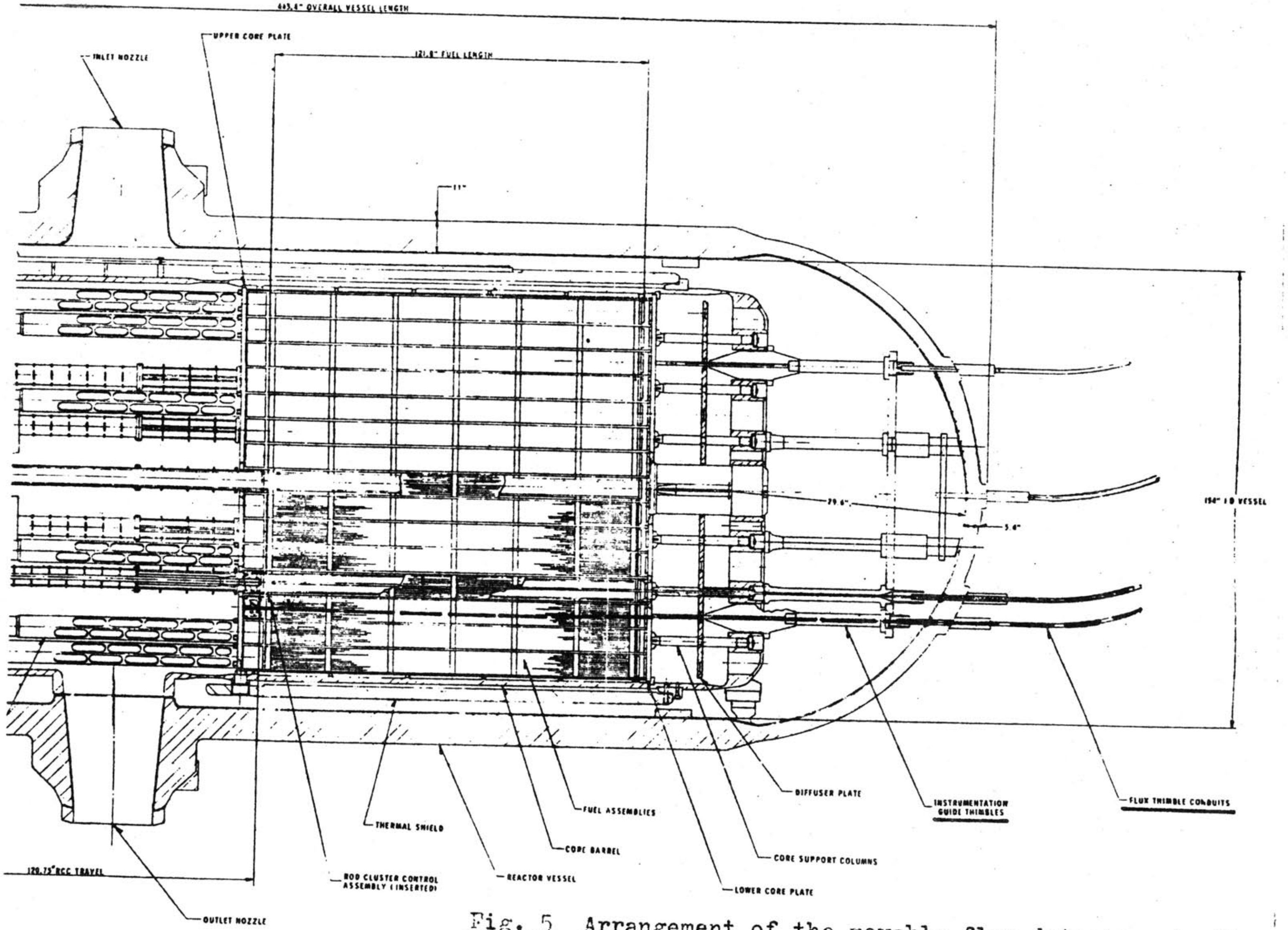


Fig. 5 Arrangement of the movable flux detectors in the bottom of the Connecticut Yankee Reactor. (From Ref. 2)

1.4 Other Instrumentation of the Connecticut Yankee Reactor

1.4.1 Limits of the Description

The description of the rest of the reactor instrumentation used at Connecticut Yankee, will be limited to only the control instruments whose information will be used in this study, i.e. measurement of the reactor pressure, and coolant temperature at the vessel inlet.

1.4.2 Pressure Measurement

The reactor coolant pressure is measured on the hot leg number 4, between the reactor outlet and the stop valve. Two pressure transmitters are used:

- for pressurization and depressurization, a 0 - 1,000 psig pressure transmitter,
- for normal operation, a 0 - 3,000 psig pressure transmitter.

Since the reactor coolant pressure is taken at a location close to the reactor outlet, it may be assumed that this pressure can be taken as the coolant pressure at the core exit.

1.4.3 Inlet Temperature Measurement

The reactor coolant temperature at the vessel inlet is measured by a precision platinum resistance temperature bulb located on each loop downstream of the steam generator. Other bulbs of this type located upstream and downstream of the steam generator give the loop average temperature and the loop difference temperature.

CHAPTER 2

EFFECTIVE FLOW FACTORS

2.1 Definition

It was thought a few years ago, that the time evolution of the "effective flow factor" (defined below) for a given assembly, might give some information on the time history of the coolant flow in this assembly. Further, by considering all the instrumented assemblies in the core, the effective flow factors might also give some indications on the overall core coolant distribution. More precisely, it was expected that a reduction of the value of the effective flow factor in a given assembly, could indicate a change in the channel geometry which caused a partial flow redistribution and a consequent change in the cross flow distribution.

To date only very small variations with time were observed among the effective flow factors, indicating that the channel geometry is unchanged, a fact which has been verified at each refueling.

In the assembly of coordinates I, J, the effective flow factor $EFF^*_{i,j}$ can be defined as:

---

* see Nomenclature of the terms used in this study in Appendix D.

- the ratio of the relative power $q_{i,j}$ (assembly power/ core average power), to the coolant temperature axial rise $\Delta t_{i,j}$ in this assembly, over the area of the core limited to the assemblies instrumented with an outlet thermocouple.

where:

$$\Delta t_{i,j} = t_{ou,i,j} - t_{in,i,j}, \tag{2.1}$$

and the effective flow factor $EFF_{i,j}$ is given by:

$$EFF_{i,j} = \frac{q_{i,j}}{\Delta t_{i,j}} \times \frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)} , \quad * \tag{2.2}$$

where $\frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)}$ represents the normalization factor over the area of the core limited to the assemblies instrumented with an outlet thermocouple which in the Connecticut Yankee

---

* The notation $\sum_{1}^{38}$ has the meaning of a sum carried over the instrumented assemblies in the instrumented quadrant (i.e., 38 assemblies).

case is the area of the core within the instrumented quadrant. This quadrant corresponds to the upper left quadrant on Fig. 1, which shows that 38 assemblies have outlet thermocouples. No credit is taken for the six remaining instrumented assemblies located in the three other quadrants.

2.2 Assumption of the Effective Flow Factor

The above effective flow factor definition assumes implicitly the temperature independence of the coolant heat capacity. At a pressure of 2,000 psia a temperature increase of 50°F above an average temperature of 550°F (conditions which are typical of the Connecticut Yankee Reactor), produces a 9% variation of the heat capacity of the coolant.

The temperature dependence of the heat capacity of the water can be taken into account in the computation of the effective flow factors, by replacing the temperature rise $\Delta t_{i,j}$ by the enthalpy rise $\Delta h_{i,j}$, where:

$$\Delta h_{i,j} = h_{ou,i,j} - h_{in,i,j} \quad . \qquad (2.3)$$

Similar definition of the effective flow factor will lead to:

$$\mathrm{EFF}_{i,j} = \frac{q_{i,j}}{\Delta h_{i,j}} \times \frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)} \quad . \tag{2.4}$$

For the same collection of data (relative power distribution and temperature rise distribution), the comparison between the two values of the effective flow factor for a given assembly shows:

- the effective flow factor using the temperature rise is generally not as close to 1.000 as the effective flow factor using the enthalpy rise (a difference of the order of 1% or less).

This comparison is summarized in Fig. 6 for data collected at BOC in Core III. Other comparisons done in Core I and II (not presented here) agree with this observation.

2.3 Sensitivity Analysis

Since the effective flow factors are computed from measured and calculated values, it is interesting to determine the contribution of each value used in the calculation of these effective flow factors. In particular the evaluation of the accuracy of the effective flow

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R								51.50 0.769 0.8081 0.8110	1 2 3 4
P					49.30 0.737 0.8086 0.8138	53.40 1.012 1.0254 1.0268	65.90 1.200 0.9859 0.9721		
N				49.90 0.790 0.8562 0.8611		56.20 0.935 0.9001 0.8986	54.10 1.016 1.0160 1.0165	52.00 1.023 1.0645 1.0677	
M				60.40 1.062 0.9515 0.9447	61.40 1.178 1.0387 1.0299	55.50 1.158 1.1297 1.1280	61.60 1.157 1.0166 1.0077		
L		52.50 0.709 0.7303 0.7321	62.40 1.236 1.0716 1.0612	63.90 1.182 1.0008 0.9892	52.80 0.949 0.9728 0.9748	53.00 0.973 0.9936 0.9953	54.30 0.985 0.9817 0.9821	56.40 1.088 1.0443 1.0423	
K		51.20 0.978 1.0340 1.0380	53.00 0.929 0.9488 o.9505	51.10 1.163 1.2321 1.2371	53.40 0.980 0.9933 0.9946	52.20 1.103 1.1430 1.1461			
J	44.10 0.731 0.8971 0.9081	64.10 1.238 1.0453 1.0329		61.20 1.180 1.0434 1.0349		58.80 1.137 1.0460 1.0410	49.90 0.926 1.0041 1.0098	53.70 1.026 1.0336 1.0346	
H	46.10 0.796 0.9340 0.9435	50.20 0.957 1.0319 1.0373	50.30 1.199 1.2905 1.2971	53.60 0.977 0.9864 0.9875	58.60 1.126 1.0402 1.0355	48.00 0.855 0.9639 0.9718	55.20 1.032 1.0121 1.0114	47.00 0.803 0.9242 0.9328	

1: Measured temperature rise (°F)

2: Relative power of the assembly

3: Effective flow factor (C_p = constant)

4: Effective flow factor ($C_p = f(T)$)

Fig. 6 Comparison of the effective flow factor calculation.

factors and the breakdown of this accuracy due to the relative power distribution and temperature rise distribution gives a better understanding of the problems related to the in-core instrumentation.

2.3.1 Sensitivity Analysis for Constant Heat Capacity of the Coolant

The effective flow factor is given by Eq. 2.2, which can also be written as:

$$EFF_{i,j} = \frac{q_{i,j}}{\Delta t_{i,j}} \times k \ , \qquad (2.5)$$

where:

$$k = \frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)} \ . \qquad (2.6)$$

If we define:

$\sigma_r q_{i,j}$ = relative standard deviation of the relative power,

$\sigma t_{ou,i,j}$ = standard deviation of the assembly outlet temperature,

$\sigma t_{in,i,j}$ = standard deviation of the assembly inlet temperature.

The square of the relative standard deviation of the effective flow factor is given by:

$$\sigma_r^{\,2}\mathrm{EFF}_{i,j} = \frac{\sum_{1}^{38} \sigma^2\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)}{\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} + \sigma_r^{\,2} q_{i,j}$$

$$+ \frac{\sigma^2 t_{ou,i,j}}{\Delta t_{i,j}^{\,2}} + \frac{\sigma^2 t_{in,i,j}}{\Delta t_{i,j}^2} \quad . \quad * \qquad (2.7)$$

The square of the standard deviation of the effective flow factor is given by:

$$\sigma^2\mathrm{EFF}_{i,j} = \left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]^2 \times \frac{k^2}{\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} \qquad (2.8)$$

---

* See Appendix E for the derivation of Eqs. 2.7, 2.8, and 2.9.

$$x \sum_{1}^{38} \sigma^2 \left(\frac{q_{i,j}}{\Delta t_{i,j}} \right)$$

component due to the
normalization

$$+ \left[\frac{k}{\Delta t_{i,j}} \right]^2 (\sigma_r^{\ 2}\ q_{i,j})\ q_{i,j}^{\ 2}$$

component due to the
power distribution

$$+ \left[\frac{k\ q_{i,j}}{\Delta t_{i,j}^{\ 2}} \right]^2 \sigma^2\ t_{ou,i,j}$$

component due to the
outlet temperature

$$+ \left[\frac{k\ q_{i,j}}{\Delta t_{i,j}^{\ 2}} \right]^2 \sigma^2\ t_{in,i,j}\ .$$

component due to the
inlet temperature

(2.8)
(continued)

But the component due to the normalization can be split into:

$$\left[\frac{q_{i,j}}{\Delta t_{i,j}} \right]^2 \times \frac{k^2}{\left[\sum_{1}^{38} \left(\frac{q_{i,j}}{\Delta t_{i,j}} \right) \right]^2} \times \sum_{1}^{38} \sigma^2 \left(\frac{q_{i,j}}{\Delta t_{i,j}} \right) = \qquad (2.9)$$

$$\left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]^2 \times \frac{k^2}{\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} \times \sum_1^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)^2$$

$$\left[\begin{array}{ll} & \sigma_r^2\; q_{i,j} \\[2em] + & \dfrac{\sigma^2 t_{ou,i,j}}{\Delta t^2_{i,j}} \\[2em] + & \dfrac{\sigma^2 t_{in,i,j}}{\Delta t^2_{i,j}} \end{array}\right] \begin{array}{l} \text{———} \left\{ \text{term due to the power} \right. \\[2em] \text{———} \left\{ \begin{array}{l} \text{term due to the outlet} \\ \text{temperature} \end{array} \right. \\[2em] \text{———} \left\{ \begin{array}{l} \text{term due to the inlet} \\ \text{temperature.} \end{array} \right. \end{array}$$

(2.9)
(continued)

The total contribution of the power distribution, the outlet and inlet temperatures is the sum of the corresponding terms in Eqs. 2.8 and 2.9.

A code called FLOFA I has been written to calculate the standard deviation on the effective flow factor (see Appendix B for the code listing and sample input and output). From the data, relative power and temperatures distributions, the code is used to compute:

- the effective flow factor distribution,
- the standard deviation of the effective flow factor,
- the breakdown of the square of the standard deviation of the effective flow factor into components due to:
  - normalization,
  - power distribution,
  - outlet temperature,
  - inlet temperature.

This is done for assumed values of standard deviation on relative power distribution and inlet and outlet temperatures. These values can be varied by the user.

2.3.2 Sensitivity Analysis for Temperature Dependent Heat Capacity of the Coolant

Similar work has been done in this section as in 2.3.1. By using Eq. 2.4 to define the effective flow factor:

$$EFF_{i,j} = \frac{q_{i,j}}{\Delta h_{i,j}} \times \frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)} = \frac{q_{i,j}}{\Delta h_{i,j}} \times k_t \quad , \qquad (2.10)$$

where:

$$k_t = \frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)} \quad .$$

The square of the relative standard deviation of the effective flow factor is given by:

$$\sigma_r^2\ EFF_{i,j} = \frac{\sum_{1}^{38}\sigma^2\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)}{\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)\right]^2} + \sigma_r^2\ q_{i,j}$$

$$+ \frac{\sigma^2\ h_{ou,i,j}}{\Delta h^2_{i,j}} + \frac{\sigma^2\ h_{in,i,j}}{\Delta h^2_{i,j}} \quad * \quad . \qquad (2.11)$$

---

* See Appendix E for derivation of Eqs. 2.11, 2.12, and 2.13.

The square of the standard deviation of the effective flow factor is given by:

$$\sigma^2\ \mathrm{EFF}_{i,j} = \left[\frac{q_{i,j}}{h_{i,j}}\right]^2 \times \frac{k_t^2}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)} \times \sum_{1}^{38} \sigma^2\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right) \quad \left\{\begin{array}{l}\text{component due to the}\\ \text{normalization}\end{array}\right.$$

$$+ \left[\frac{k_t}{\Delta h_{i,j}}\right]^2 \left[\sigma_r{}^2 q_{i,j}\right] q_{i,j}^2 \quad \left\{\begin{array}{l}\text{component due to}\\ \text{the power}\end{array}\right.$$

$$+ \left[\frac{k_t q_{i,j}}{\Delta h_{i,j}{}^2}\right]^2 \left[\frac{\partial h_{ou,i,j}}{\partial t_{ou,i,j}}\right]^2 \sigma^2 t_{ou,i,j} \quad \left\{\begin{array}{l}\text{component due}\\ \text{to the outlet}\\ \text{temperature}\end{array}\right.$$

$$+ \left[\frac{k_t q_{i,j}}{\Delta h_{i,j}{}^2}\right]^2 \left[\frac{\partial h_{in,i,j}}{\partial t_{in,i,j}}\right]^2 \sigma^2 t_{in,i,j} \quad \left\{\begin{array}{l}\text{component due}\\ \text{to the inlet}\\ \text{temperature .}\end{array}\right. \qquad (2.12)$$

Splitting the component due to the normalization would lead to:

$$\left[\frac{q_{i,j}}{\Delta h_{i,j}}\right]^2 \times \frac{k_t^2}{\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)\right]^2} \times \sum_1^{38} \sigma^2\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right) =$$

$$\left[\frac{q_{i,j}}{\Delta h_{i,j}}\right]^2 \times \frac{k_t^2}{\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)\right]^2} \times \sum_1^{38} \left(\frac{q_{i,j}}{\Delta h_{i,j}}\right)^2$$

$$\left[\begin{array}{l} \sigma_r^2 \, q_{i,j} \\[3em] + \left(\frac{\partial h_{ou,i,j}}{\partial t_{ou,i,j}}\right)^2 \frac{\sigma^2 t_{ou,i,j}}{\Delta h^2_{ou,i,j}} \end{array}\right] \begin{array}{l} \text{———}\left\}\begin{array}{l}\text{term due to the}\\ \text{power}\end{array}\right. \\[3em] \text{———}\left\}\begin{array}{l}\text{term due to the}\\ \text{outlet temperature}\end{array}\right. \end{array} \tag{2.13}$$

$$\left[+ \left(\frac{\partial h_{in,i,j}}{\partial t_{in,i,j}} \right)^2 \frac{\sigma t^2_{in,i,j}}{\Delta h^2_{in,i,j}} \right] \text{— } \left\{ \begin{array}{l} \text{term due to the} \\ \text{inlet temperature.} \end{array} \right.$$

(2.13)
(continued)

The above derivation assumes that the coolant stays subcooled and the evaluation of σh can be obtained from:

$$\sigma^2 h = \left[\frac{\partial h}{\partial t} \right]^2 \sigma^2 t \quad . \tag{2.14}$$

A code called FLOFA II has been written to compute the same information as FLOFA I (see 2.3.1) with the effective flow factors obtained from the enthalpy rise. (see Appendix B).

2.3.3 Evaluation of Uncertainties

In order to calculate the uncertainties associated with the effective flow factors, it is necessary to have the values of the control instrument uncertainties (thermocouples, flux detectors). Research done in this area showed that very little data exists.

Thermocouples:

The assembly exit thermocouple is made with Chromel-Alumel. This type of thermocouple has a good resistance to radiation damage and has a characteristic curve which stays linear with time (6)(7)(8). However the accuracy of this type is not very good. The standards of the American National Standard Institute require that the thermocouple manufacturers meet the following specification for the Chromel-Alumel type:

- for temperatures between 0 and 530°F
  - limits of errors of standard thermocouple ± 4°F
  - limits of errors of special thermocouple ± 2°F
- for temperatures above 530°F
  - limits of errors of standard thermocouple ± 0.75%
  - limits of errors of special thermocouple ± 0.375%

However these standards do not indicate the confidence level associated with these values of possible errors. In fact this gives only a value of the thermocouple uncertainty due to the reading accuracy. Other values of uncertainty need to be found concerning:

- calibration error,
- gamma heating of the hot junction,

- hot junction drift due to nuclear permutations,
- hot junction position with respect to the center of the fuel assembly.

A study done for the San Onofre Reactor (9) gives some numerical values for the different uncertainties:

- calibration error (statistical) evaluated as ± 0.3°F which is due to the fact that the isothermal calibration of the thermocouples is done at an average temperature of 530°F which is about 40°F below the operating temperatures of the thermocouples (a check on the calibration curve of the thermocouples shows that the correction at 530°F is the same at 570-580°F). This calibration error is used to take into account also a possible human error and is conservative in that respect,
- gamma heating (non-statistical) evaluated as + 0.5°F to take into account absorption of gamma rays energy by the hot junction at full power which gives higher readings,
- hot junction drift due to nuclear permutations (non-statistical) evaluated as +1°F. The records concerning the thermocouples off-sets for Connecticut Yankee

Reactor between two isothermal calibrations, show a maximal drift of 1.55°F in Core III (1.75°F in Core IV) and also show that these drifts may occur in opposite directions, which indicates that this error is of a non-statistical character,

- hot junction position with respect to the fuel assembly (statistical) evaluated as ± 3°F. This tends to take into account the fact that the coolant temperature at the plane where the temperature is taken, is not uniform,
- reading accuracy (statistical) evaluated as ± 2.0°F due to the instrumentation.

The vessel inlet temperature of the coolant is measured by a precision platinium resistance temperature bulb in each loop. This type of instrument can be used in this case because the hot junction is not exposed to the full neutron flux and the exposure damage is less in this case than for the exit thermocouples. Based on the engineering experience, it is common to consider an inaccuracy of ± 0.2°F associated with the reading of such RTD (Resistor Temperature Device).

Power Distribution:

The movable miniature flux detectors are supposed to give their signal with a ± 2.0% accuracy and Westinghouse estimated the accuracy of the power map on the order of ± 5% (10). Both values are related to a two sigma confidence level.

2.3.4 Results of the Sensitivity Analysis

At the time the sensitivity analysis was developed, the uncertainties associated with the control instruments were not known with enough precision, and the standard deviations of the effective flow factors were calculated with assumed values for these uncertainties, based on engineering experience and judgment.

The results obtained assumed for the one sigma confidence level:

- relative standard deviation of the power: 0.0275
- standard deviation of the outlet temperature: 2.50°F
- standard deviation of the inlet temperature: 0.10°F

For the one sigma confidence level the relative standard deviation of the effective flow factor was in the range 4.5 - 7.0%, and was an inverse function of the coolant temperature rise in the fuel assembly. The relative standard deviation of the effective flow factor is also strongly influenced by the standard deviation of the outlet temperature as it can be seen on Table 2. Table 2 gives the breakdown of the standard deviation of the effective flow factor and the comparison between the two types of analysis (C_p temperature dependent and independent).

2.4 Physical Meaning of the Effective Flow Factors

If no cross flow between the assemblies is assumed, it is obvious that in this case the effective flow factor is the same as the normalized inlet flow distribution. But the real case of PWR is more complex and the assumption of no cross flow does not necessarily hold.

The energy equation can be written as:

$$C_p(m_{in,i,j}+\Delta m_{i,j})t_{ou,i.j} - C_p\, m_{in,i,j}\, t_{in,i,j}$$

$$= Q_{i,j} - C_p\, \Delta m_{i,j} t_{l,i,j} \quad . \qquad (2.15)$$

where t_l represents the effective temperature for the energy due to the cross flow exchange, $C_p\, \Delta m\, t_{l,i,j}$.

Type of case	C_p=constant	C_p=f(T)
Four components due to:		
- normalization factor	2.60 %	2.61 %
- power	23.38 %	30.09 %
- outlet temperature	73.91 %	67.17 %
- inlet temperature	0.11 %	0.13 %
	100.00 %	100.00 %
Three total contributions due to:		
- power	24.00 %	30.88 %
- outlet temperature	75.87 %	68.97 %
- inlet temperature	0.13 %	0.15 %
	100.00 %	100.00 %

Table 2 Breakdown of the Standard Deviation of the Effective Flow Factor for BOC in Core III of Connecticut Yankee Reactor

Solving for $m_{in,i,j}$ we obtain:

$$m_{in,i,j} = \frac{Q_{i,j}/C_p - \Delta m_{i,j}(t_{1,i,j} + t_{ou,i,j})}{t_{ou_{ij}} - t_{in_{ij}}} \quad . \tag{2.16}$$

And if these ratios are normalized over the area of instrumented assemblies:

$$EFF_{i,j} = \frac{\frac{Q_{i,j}}{C_p} - \Delta m_{i,j}(t_{1,i,j} + t_{ou,i,j})}{t_{ou_{ij}} - t_{in_{ij}}}$$

$$\times \frac{38}{\sum_{1}^{38} m_{in,i,j}} \quad . \tag{2.17}$$

A similar equation can be derived for the case where the heat capacity of the coolant is assumed to be temperature dependent. The evaluation of the term corresponding to the energy exchange between the assembly i,j, with its neighbors can be reduced to a net energy exchange which corresponds to a cross flow exchange and thermal mixing. It is rather difficult to evaluate this net energy exchange, because it implies knowledge of the temperature or enthalpy distribution along the fuel assemblies and also an idea where the cross flow exchange takes place. One way to get the feeling for this process is to run calculations with a thermal hydraulic code like COBRA III C which yields the temperature enthalpy axial flow and cross flow of the coolant. Results of this type of analysis will be presented in Chapter 3.

CHAPTER 3

POWER DISTRIBUTION CALCULATIONS AND USE OF THE CODE "INCORE"

3.1 Introduction

The power distribution and the corresponding peaking factors F^N_H, F^N_q, F_q, are calculated by the code INCORE. This code uses as main inputs:

- the flux detectors readings measuring the axial flux in the assemblies instrumented with an in-core thimble, and the flux at each thimble location,
- the prediction of the core wide power distribution and flux thimble obtained from the code PDQ (11), in which the results of depletion calculations using the code LEOPARD(12), are fed.

In the Connecticut Yankee core there are two flux detectors which can be moved within all of the 18 flux thimbles located in 18 different assemblies.

The power distribution calculations using the computer code PDQ, is generally done stepwise each 2,000 MWD/MTU. Some of the INCORE results are used to determine the:

- maximum linear heat generation rate and its location,
- average linear heat generation rate,
- peaking factors and their locations,
- effective flow factors.

3.2 Purpose of the Calculation

A sensitivity analysis has been developed for the code INCORE for two purposes:

- it was found interesting to know the sensitive effect of the major inputs on the results, since no information so far, was not readily available on this type of analysis,
- the sensitivity analysis is needed for good information on the accuracy of the results of the power distribution calculations from the knowledge of the inputs accuracies.

The code INCORE is a proprietary code from Westinghouse, and information beyond input and output is not included in this study.

3.3 Modification of the Major Inputs

As mentioned in 3.2, because of the proprietary character of INCORE, no numerical values relative directly to the inputs or outputs are given in this work. But to understand what has been done, some explanations are given how the inputs have been treated.

The sensitivity analysis has been developed from the variation of:

- flux detectors readings given by the movable incore flux detectors,

- PDQ flux predictions of the flux at the flux thimble locations,
- power distribution prediction given by the PDQ code, for hot channel and assembly.

This study, of course, uses numerical values of the inputs for a given cycle, at a given time in the cycle, however the time effect has been considered. The parameters were varied one at a time, to see their corresponding effect on the entire output.

3.3.1 Variation of the Flux Detector Readings

For a given thimble, the detectors readings have been varied by the same factor (5% increase has been used to be sure of having enough variation in the outputs without too much distortion of the power pattern).

It has been verified for the first thimble, that an increase and a decrease of the flux detector readings by the same factor, would give output changes equal in absolute value. This was done to check that the change was small enough to be considered a linear effect.

3.3.2 Variation of the Flux Thimble Information

This part of the sensitivity study was treated in a very similar fashion as for the flux detectors readings. For a given thimble, both the thermal flux information and the fast flux information, were varied by the same factor

(5% increase has been used for the same reasons as 3.2.1, after having verified the linearity of the changes in the outputs with the changes in the inputs).

3.3.3 Variation of the Predicted Power

The sensitivity analysis for this part has been conducted in a different way, because for a given cycle the power distribution changes only with time. Therefore, comparisons have been done between collection of power predictions at BOC, MOC and EOC of CORE III.

3.4 Results of the Sensitivity Study

The results of this study depend upon the kind of input that has been varied. The results are presented in a relative value, expressing the percentage change in the assemblies for a change of one percent in a given location for a given type of input. To handle the calculation of the variations, a code VARY has been written and all the details are given in Appendix B. All the results have been summarized in curves for easy use.

3.4.1 Variation of the Flux Detectors Readings

The increase of the flux detector readings in a given flux thimble, gives the following results:

- $F^N_{\Delta H}$, F^N_q are increased locally by variable amounts depending on the relative position of the assemblies with respect to the location where the increase takes place:

- for the assembly in which the increase is made, $F_{\Delta H}^{N}$, F_{q}^{N} are increased by almost the same amount (1% increase of the flux detector readings gives 0.9% increase for $F_{\Delta H}^{N}$ and F_{q}^{N}),
- for the assemblies immediately surrounding the assembly where the increase is made, $F_{\Delta H}^{N}$, F_{q}^{N} are increased by amounts depending on the relative position of the assemblies (they may share one side with the assembly where the increase is done, or just share a corner), and are found to be a function of the distance from the center of the core,
- $F_{\Delta H}^{N}$, F_{q}^{N} are decreased throughout the rest of the core by a fairly constant amount,
- F_z is unchanged.

Figure 7 summarizes the results of flux detector, giving the relative variation of $F_{\Delta H}^{N}$ or F_{q}^{N} normalized to a percent increase in the flux detectors readings as a function of the radial position of the assembly from the center of the core and as a function of the position in which the increase in the flux detector readings takes place.

Key to Fig. 7a, 7b, 9a, 9b

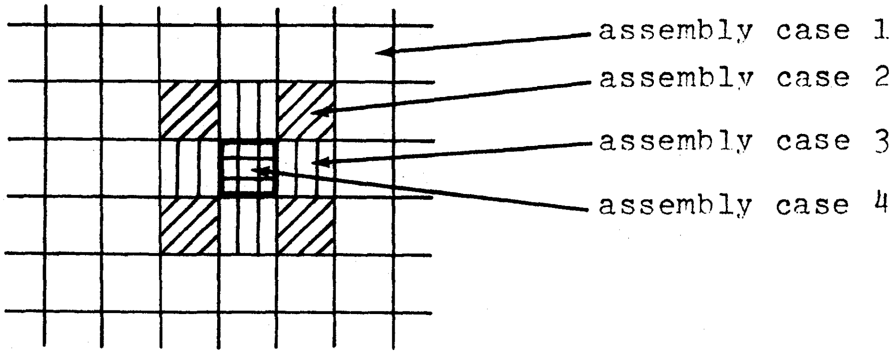
Curve A = relative variation of the peaking factors for the assemblies which are not the neighbors of the assemblies where the variation (flux detector readings or flux thimble prediction) is done, (assembly case 1)

Curve B = relative variation of the peaking factors for the assemblies sharing a common corner with the assemblies where the variation is done, (assembly case 2)

Curve C = relative variation of the peaking factors for the assemblies sharing a common side with the assemblies where the variation is done, (assembly case 3)

Curve D = relative variation of the peaking factors for the assemblies where the variation is done, (assembly case 4).

Radiale distance from core center = distance between the center of an assembly and the center of the assembly H 8.



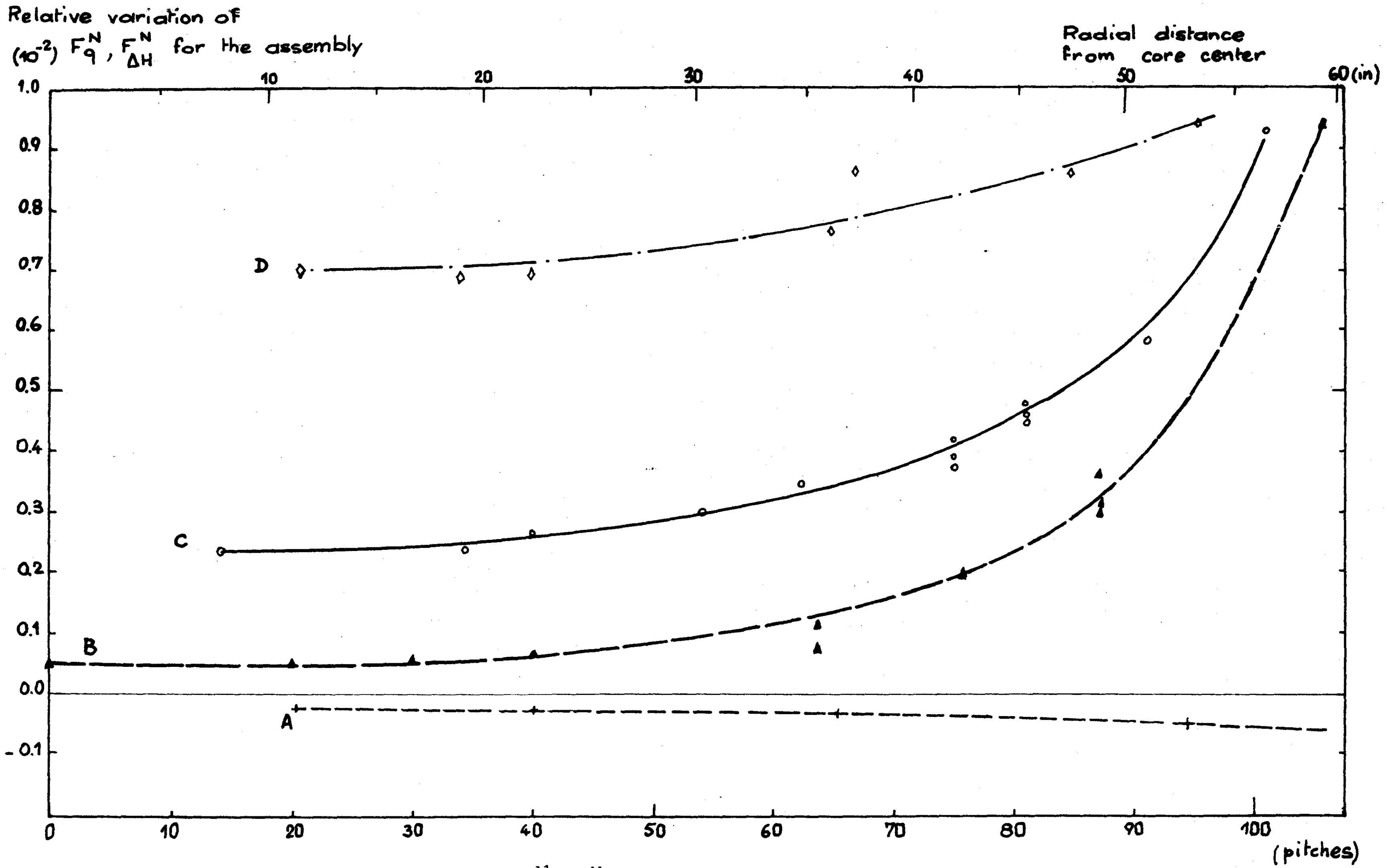


Fig. 7a Relative variation of F_q^N, $F_{\Delta N}^N$ for 1 % increase in the flux detector readings. Assembly averaged values.

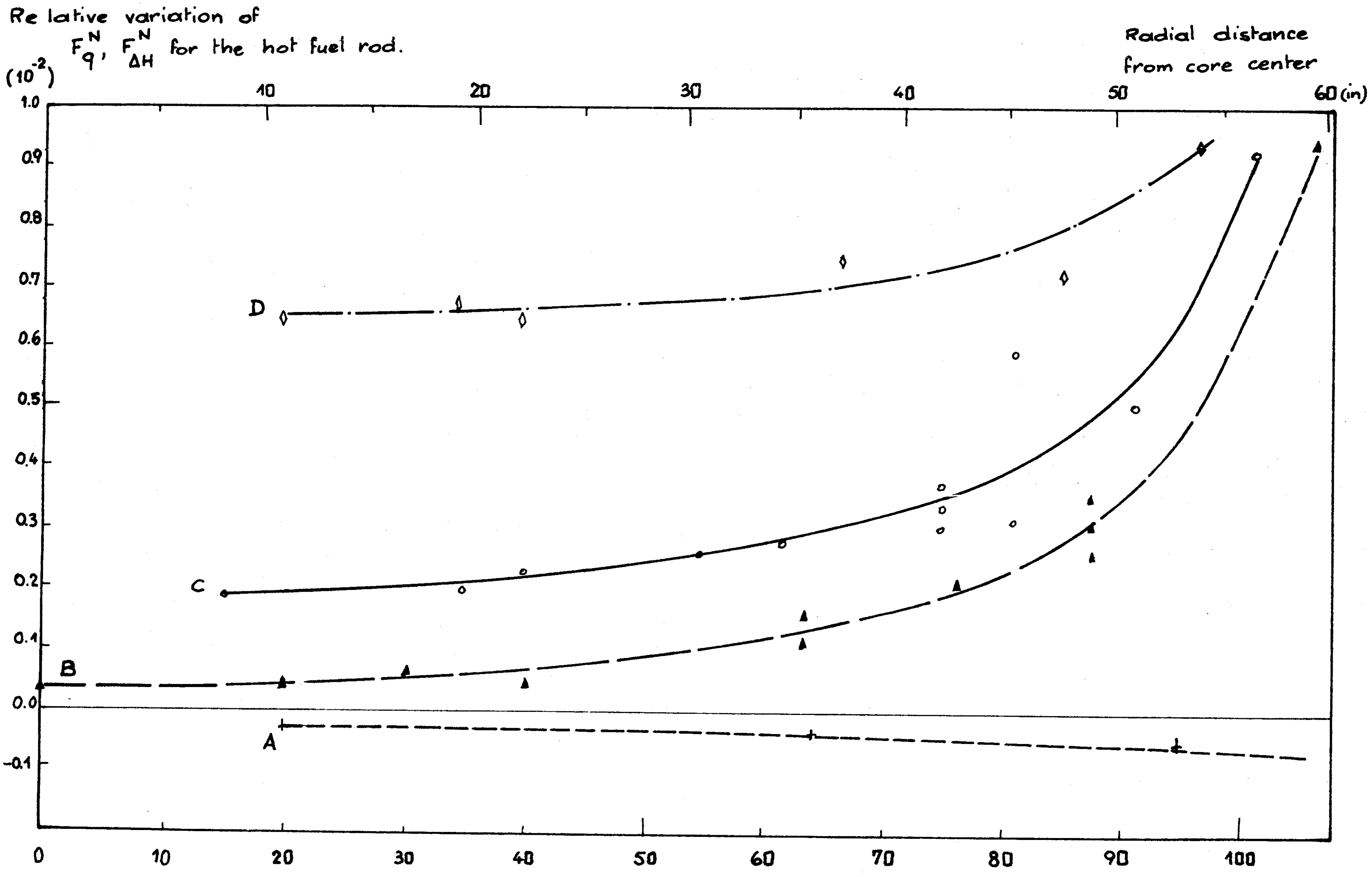


Fig. 7b Relative variation of F_q^N, $F_{\Delta H}^N$ for 1 % increase in the flux detector readings.
Hot fuel rods values.

As an example, an increase in the flux detector reading of 1% in assembly M10 (radial distance = 67.08 pitches) leads to:

- increase of $F^N_{\Delta H}$ or F^N_q of: 0.42 in N 10 (radial distance = 80.78 pitches, sharing one common side with M 10, curve B)
  0.32 in N 11 (radial distance = 87.46 pitches sharing one common corner with M 10, curve C).

Now it should be mentioned that INCORE computes the power distribution from the flux detector readings, and the number of thimbles used for the calculation of the power in a given assembly, apparently may vary from 1 to several thimbles.

It has been found that the curves of Fig. 7 are time independent for a given core, a given assembly has its power changing with burn-up, however the relative variation of $F^N_{\Delta H}$ or F^N_q stays constant while burn-up increases.

Some of the calculated relative variations of $F^N_{\Delta H}$ or F^N_q may not behave as shown in Fig. 7. This is apparently due to the way INCORE treats the problem and it has been found that the calculated power is inferred from the information related to a fairly far thimble as shown in Fig. 8. For this case there has been a one percent increase in the flux detector readings in M 12 and the corresponding variation in N 12 should be 0.73 according to Fig. 7, but instead it is - 0.028 corresponding to the variation of the rest of the core. This is due to the fact that the power in N 12 is given from the information in L 5, which in this case does not see the effect of the one percent increase in M 12.

3.4.2 Variation of the Flux Thimble Prediction

Very similar results have been obtained for this part as in 3.3.1, except that in this case the variations of $F^N_{\Delta H}$ and F^N_q are in the opposite direction to the way they varied in 3.3.1.

The increase of the flux thimble prediction in a given thimble, gives the following results:

- $F^N_{\Delta H}$, F^N_q are decreased locally by variable amounts depending on the relative position of the assemblies with respect to the location where the increase takes place:
  - for the assembly where the increase is done, $F^N_{\Delta H}$, F^N_q are decreased by almost the same amount,

```
VARIATION OF FCN AND FCHN FOR A VARIATION OF 10 E-03 IN CASE #  008

        15     14     13     12     11     10      9      8      7      6      5      4      3      2      1

                                               **********************
R                                              *-0.251|-0.280|-0.279*                      VARIATION OF DETECTORS READINGS
                                               *-0.260|-0.260|-0.245*
                                 ***************------+------+------***************
P    VARIATION OF FCN . . . . .  *-0.258|-0.266|-0.268|-0.264|-0.272|-0.278|-0.262*        IN ASSEMBLY  M12
     VARIATION OF FCHN. . . . .  *-0.272|-0.277|-0.266|-0.273|-0.259|-0.272|-0.292*
                          ********------+------+------+------+------+------+------********
N    UNITS = 1.0 E-03     *-0.289| 2.984|-0.277|-0.273|-0.258|-0.279|-0.273|-0.270|-0.289*
     ----------------     *-0.279| 2.994|-0.278|-0.276|-0.274|-0.260|-0.263|-0.265|-0.279*
                   ********------+------+------+------+------+------+------+------+------********
M                  * 9.645| 8.657| 3.084|-0.271|-0.269|-0.279|-0.268|-0.269|-0.265|-0.263|-0.267*
                   * 9.742| 8.739| 3.072|-0.259|-0.259|-0.260|-0.277|-0.261|-0.257|-0.266|-0.278*
            ********------+------+------+------+------+------+------+------+------+------+------********
L           *-0.253| 3.627| 3.494| 0.585|-0.271|-0.266|-0.281|-0.263|-0.269|-0.277|-0.280|-0.269|-0.260*
            *-0.254| 3.626| 3.466| 0.565|-0.267|-0.264|-0.276|-0.266|-0.268|-0.277|-0.275|-0.264|-0.261*
            *------+------+------+------+------+------+------+------+------+------+------+------+------*
K           *-0.266|-0.281|-0.267|-0.268|-0.255|-0.268|-0.277|-0.263|-0.265|-0.265|-0.268|-0.267|-0.272*
            *-0.266|-0.280|-0.275|-0.265|-0.272|-0.269|-0.260|-0.255|-0.253|-0.265|-0.277|-0.277|-0.264*
     ********------+------+------+------+------+------+------+------+------+------+------+------+------********
J    *-0.277|-0.274|-0.270|-0.264|-0.263|-0.264|-0.271|-0.261|-0.252|-0.259|-0.257|-0.273|-0.272|-0.278|-0.271*
     *-0.273|-0.275|-0.270|-0.271|-0.278|-0.264|-0.259|-0.273|-0.280|-0.265|-0.276|-0.278|-0.268|-0.267|-0.266*
     *------+------+------+------+------+------+------+------+------+------+------+------+------+------+------*
H    *-0.275|-0.270|-0.264|-0.271|-0.265|-0.252|-0.258|-0.271|-0.258|-0.267|-0.258|-0.270|-0.268|-0.275|-0.272*
     *-0.277|-0.272|-0.267|-0.266|-0.266|-0.257|-0.271|-0.274|-0.270|-0.274|-0.258|-0.263|-0.271|-0.263|-0.271*
     *------+------+------+------+------+------+------+------+------+------+------+------+------+------+------*
G    *-0.277|-0.269|-0.265|-0.267|-0.276|-0.276|-0.269|-0.261|-0.252|-0.263|-0.277|-0.273|-0.272|-0.278|-0.271*
     *-0.273|-0.270|-0.281|-0.272|-0.274|-0.281|-0.260|-0.273|-0.280|-0.267|-0.278|-0.278|-0.268|-0.267|-0.266*
     ********------+------+------+------+------+------+------+------+------+------+------+------+------********
F           *-0.265|-0.261|-0.269|-0.266|-0.266|-0.266|-0.276|-0.267|-0.268|-0.269|-0.258|-0.267|-0.272*
            *-0.264|-0.271|-0.259|-0.284|-0.270|-0.267|-0.262|-0.271|-0.273|-0.267|-0.262|-0.277|-0.264*
            *------+------+------+------+------+------+------+------+------+------+------+------+------*
E           *-0.234|-0.270|-0.267|-0.261|-0.269|-0.264|-0.257|-0.267|-0.255|-0.281|-0.269|-0.273|-0.287*
            *-0.239|-0.279|-0.274|-0.275|-0.267|-0.281|-0.270|-0.264|-0.270|-0.279|-0.277|-0.266|-0.263*
            ********------+------+------+------+------+------+------+------+------+------+------********
D                  *-0.268|-0.264|-0.280|-0.270|-0.260|-0.267|-0.260|-0.273|-0.269|-0.267|-0.271*
                   *-0.277|-0.265|-0.272|-0.259|-0.275|-0.255|-0.275|-0.280|-0.276|-0.268|-0.254*
                   ********------+------+------+------+------+------+------+------+------********
C                         *-0.269|-0.271|-0.260|-0.268|-0.263|-0.268|-0.260|-0.260|-0.251*             *-*-*-*-*-*-*-*-*-*
                          *-0.277|-0.264|-0.265|-0.259|-0.275|-0.259|-0.265|-0.267|-0.281*             | ENTIRE ASSEMBLY |
                          ********------+------+------+------+------+------+------********             *-*-*-*-*-*-*-*-*-*
B                                *-0.263|-0.266|-0.263|-0.270|-0.263|-0.266|-0.265*
                                 *-0.262|-0.275|-0.261|-0.252|-0.261|-0.275|-0.265*
                                 ***************------+------+------***************
A                                              *-0.259|-0.264|-0.259*
                                               *-0.277|-0.262|-0.277*
                                               **********************
```

Fig. 8 Typical example of assembly power not behaving as the general rule.

- for the assemblies immediately surrounding the assembly where the increase is done, $F^N_{\Delta H}$, F^N_q are decreased by amounts depending on the relative pssition of the assemblies and are functions of the distance from the center of the core,
- $F^N_{\Delta H}$, F^N_q are increased throughout the rest of the core by a fairly constant amount,
- F_z in unchanged.

Figure 9 summarizes the results for this second part of the sensitivity study, giving the relative variation of $F^N_{\Delta H}$, F^N_q for one percent increase of the flux thimble prediction as a function of the radial position of the assembly from the center of the core and as a function of the position where the increase in the flux thimble prediction takes place.

The same remarks concerning the way to compute the relative variation in a given assembly from the variations generated by the individual assemblies used to compute the power in that assembly, are still applicable.

It has been found that the curves of Fig. 8 are time independent for a given core.

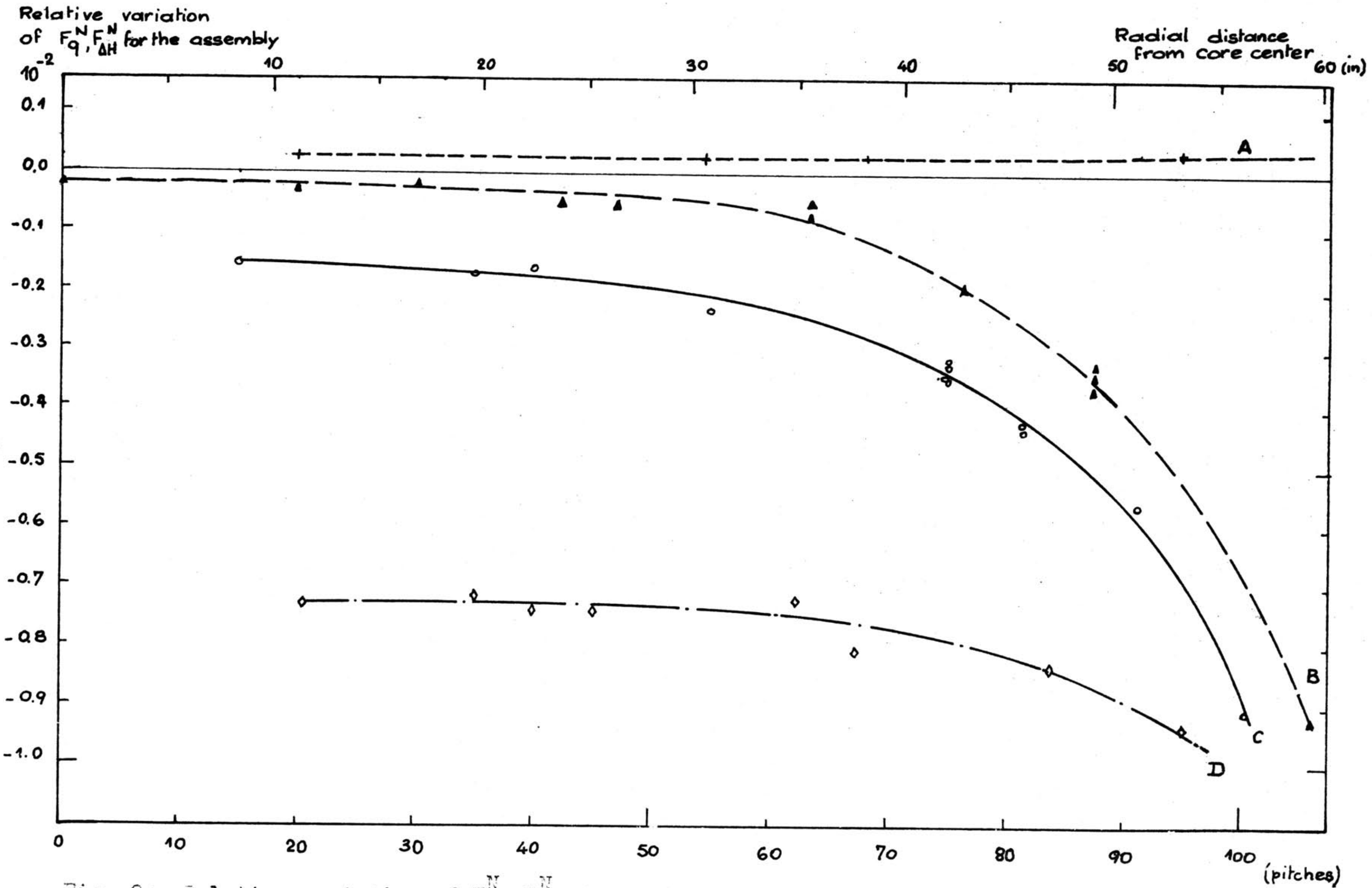


Fig. 9a Relative variation of F_q^N, $F_{\Delta H}^N$ for 1 % increase in the flux thimble prediction. Assembly averaged values.

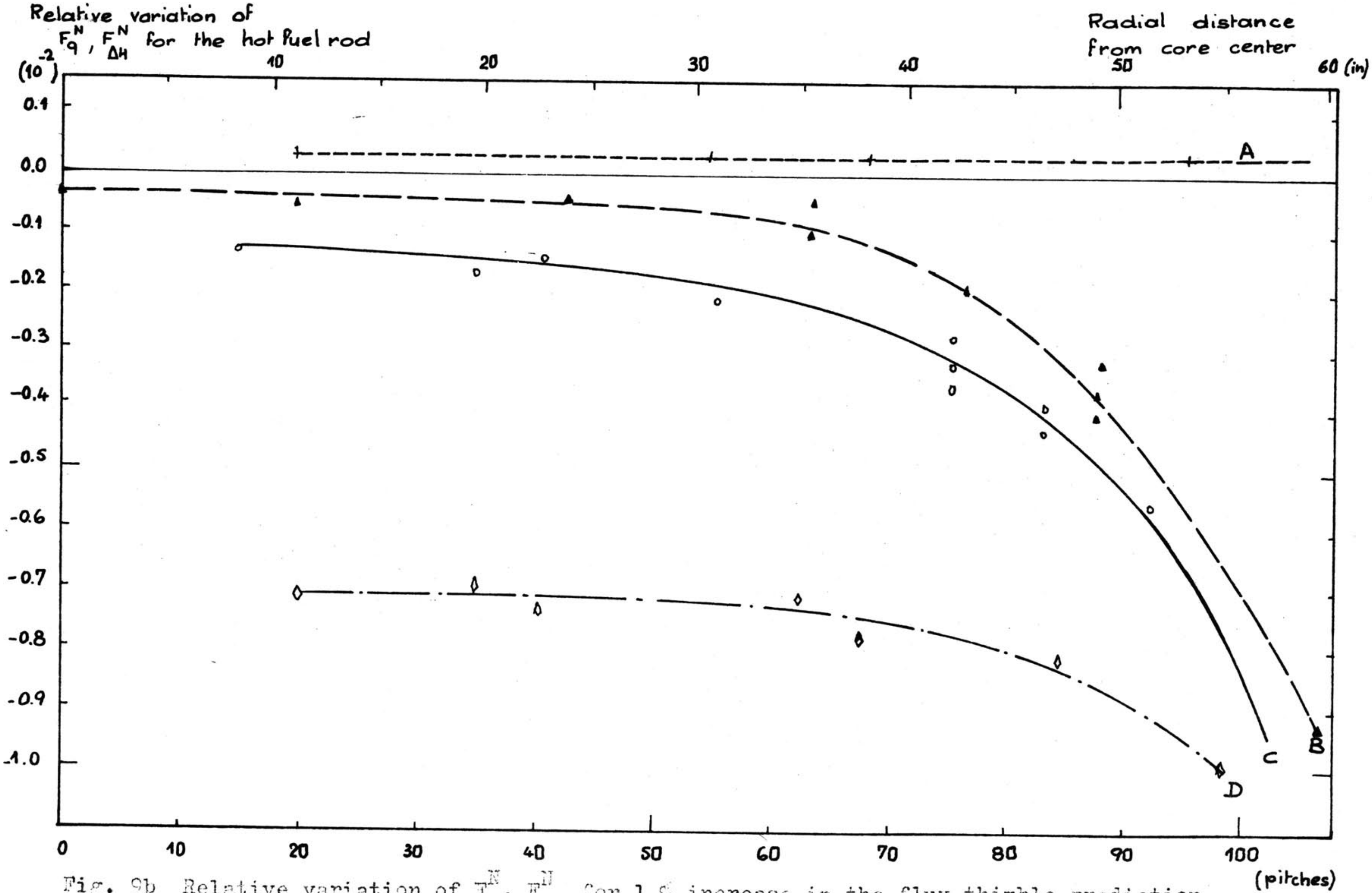


Fig. 9b Relative variation of F_q^N, $F_{\Delta H}^N$ for 1 % increase in the flux thimble prediction. Hot fuel rods values.

3.4.3 Variation of the Predicted Power

The relative variation of the calculated values for $F^N_{\Delta H}$, F^N_q compared to the relative variation of the predicted values for these two quantities is in the ratio of one.

An increase of one percent in the predicted power in any assembly produces an increase of one percent of the calculated power for that assembly.

3.4.4 Combined Variations

The relative variation of $F^N_{\Delta H}$, F^N_q in a given assembly can be obtained from the relative variations in this assembly due to:

- the detector uncertainty,
- the flux thimble prediction uncertainty,
- the power prediction uncertainty,

and combine these uncertainties with each of the thimbles used for the computation of the power in this assembly.

It would be conservative to say that the relative variation is roughly the sum of each individual relative variations in this given assembly, and since these uncertainties are independent, they can properly be combined statistically.

3.4.5 Uncertainties Values

The uncertainty of the flux detector is simple to evaluate, it is given by the detector manufacturer specifications: ± 1.0% for one sigma confidence level (2)(10).

The uncertainty in the flux thimble prediction or the uncertainty of the predicted power cannot be evaluated easily. Since the flux thimble and the power predictions come from PDQ, it would be necessary to develop a sensitivity analysis on the PDQ code as a function of the various inputs. It can be assumed, based on engineering experience and judgment, that the flux thimble uncertainty and the predicted power uncertainty (for the hot channel and the assemblies) are in the order of 4% for one sigma confidence level.

CHAPTER 4

FLOW CALCULATIONS AND USE OF THE CODE "COBRA III C"

4.1 Application of "COBRA III C" to the Connecticut Yankee Case

In Chapter 2 the possible importance of the cross flow pattern was noted. This cross flow distribution can be predicted by some thermal hydraulic analysis codes, the choice was oriented to the latest version of COBRA III C (13), because of its availability. Most of the reactor vendors have established very sophisticated codes for thermal hydraulic calculations, most of these codes are, however, classified as proprietary information.

The latest version of the COBRA code presents an improved modeling of the transverse momentum equation, including temporal and spatial acceleration of the diversion cross flow. The code can handle steady state and transients calculations for:

- enthalpy, temperature, pressure drop of the fluid,
- axial flow and diversion cross flow,
- fuel and clad temperatures,
- heat flux and critical heat flux ratio.

The original version (13) is written to accommodate:

- 15 subchannels,

- 25 fuel rods,
- 30 subchannel connections,
- 2 types of fuel.

The main idea in using COBRA III C lies in the fact that a code written for subchannel thermal hydraulic analysis can be used to treat a problem dealing with:

- flow regions which may represent either subchanels or lumped subchannels (all the subchannels of a fuel assembly may be lumped in one flow region) or a combination of both types of subchannels and lumped subchannels,
- fuel regions which may represent either a fuel rod or lumped fuel rods (all the fuel rods of a fuel assembly may be lumped in one fuel region) or a combination of both types of fuel rods and lumped fuel rods.

This approach allows representation of a rather large fraction of the reactor core without loosing the detailed information on some selected subchannels, for instance the hottest subchannels and the hottest fuel rod. This type of analysis can work either way:

- several assemblies can be lumped together and consider only the detailed analysis of the hottest subchannels in the core,

- treat the hottest subchannel in each assembly individually and lump the rest of the subchannels in each assembly. In this case, regions of different assemblies would not be lumped. Therefore in general for the same core, more flow regions would be defined in this approach that the above approach.

The trade-off stands between the computation time and size required in the computer to solve the problem, and the degree of detailed analysis desired.

The choice for this work was to treat an octant of the core, using the assembly as the unit flow region, except for the hottest assembly, where the four subchannels surrounding the hottest fuel rod were treated as four separate flow regions, and the rest of the fuel assembly was lumped into one flow region. This allowed the calculation of the values of:

- minimum DNBR and its location,
- maximum fuel center line temperature and its location,
- maximum clad surface temperature and its location.

4.2 Changes Made in "COBRA III C"

The original version of COBRA III C did not allow the treatment of the Connecticut Yankee case as it is described in 4.1. Some necessary changes have been made such as:

- the maximum number of flow regions has been increased from 15 to 30,
- the maximum number of fuel regions has been increased from 15 to 30,
- the number of connected flow regions has been increased from 30 to 47,
- the number of nodes for the axial heat flux distribution has been increased from 30 to 39 (to allow the use of the axial heat flux distribution given by INCORE = 35 nodes + 4 nodes for the two ends of the fuel rod),
- the axial node number has been reduced from 60 to 30, since an axial node length of 6 inches seems to be optimal (precision of the results does not increase for smaller axial node length, see later the sensitivity analysis).

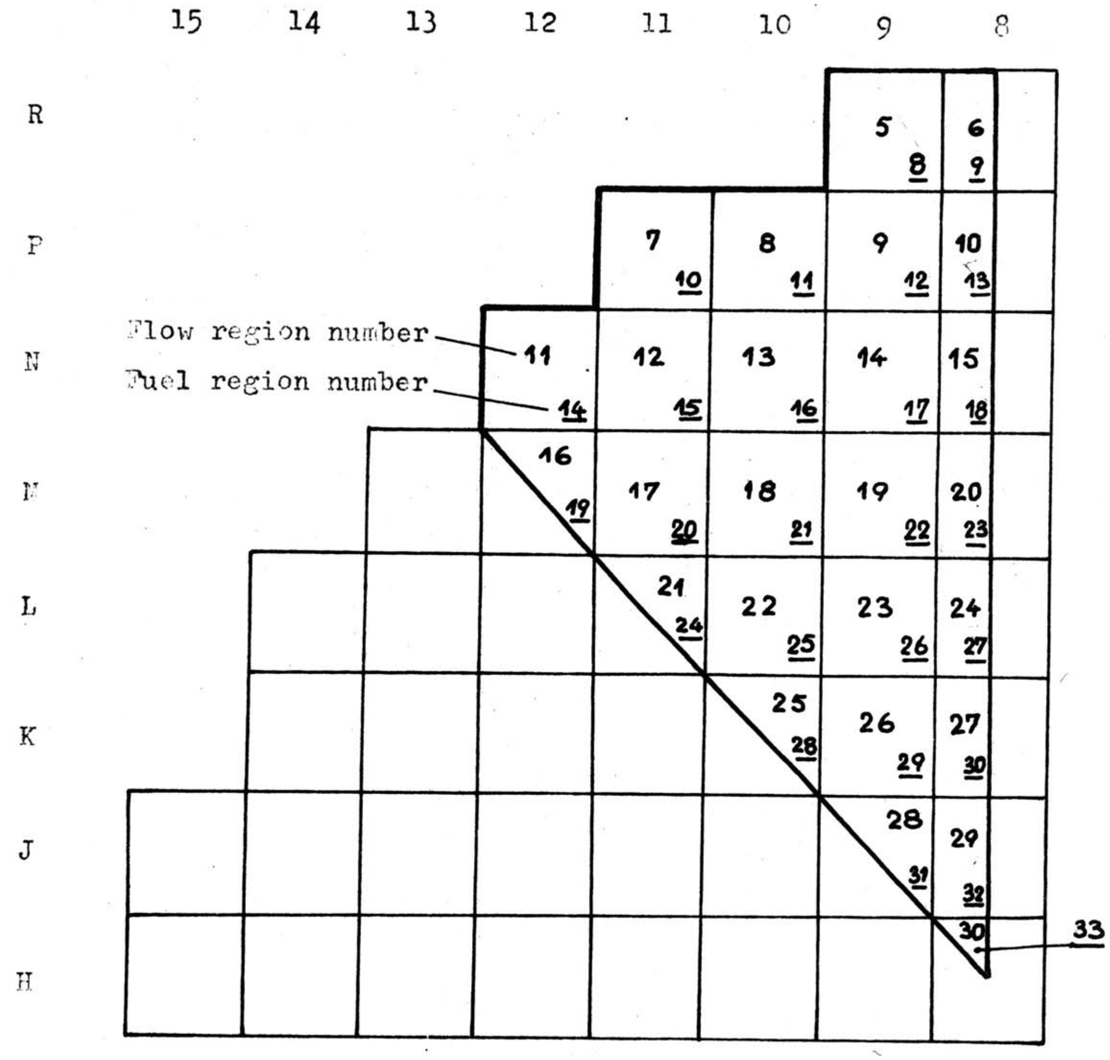
The axial number can be reduced in order to save space in the computer, however the reduction may be too important in some cases, especially when this affects the axial node length(14).

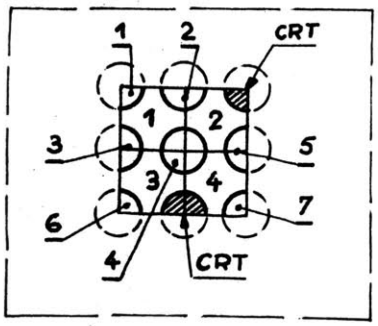
This work deals only with steady state calculations, but the transients part of the original version has been kept for a possible use. Appendix C lists the changes made and tells how new changes can be handled as a function of the parameters changed (flow region number, fuel region number, fuel type number, etc.).

4.3 Connecticut Yankee Model

As mentioned in 4.1, the code COBRA III C once modified, has been applied to the octant of the Connecticut Yankee Reactor containing the hottest fuel assembly. The calculations were done for a given power distribution obtained from INCORE, corresponding to the beginning of cycle III. Figure 10 shows how the core octant was modeled.

It was assumed that there was no net cross flow across the boundaries of the octant. One may argue with this assumption and say that the net cross flow through the boundary is not zero. But the cross flow represents only few percents of the axial flow and as it will be seen later on in the sensitivity analysis, the assembly exit conditions (temperature and axial flow) are not strong functions of the amount of cross flow. Therefore, this assumption even if not completely true, can be





CRT = Control rod
thimble (water
hole)

Detail of the hot
fuel rod surrounded
by four subchannels
in the hot assembly
(N 11)

Fig. 10 Model of the Connecticut Yankee to be used in a COBRA III C calculation.

taken without introducing large errors on the entire results. However, it would not be a good assumption if the hottest channel were located very close to the boundary, or even if the hottest fuel assembly were split by the boundary. In this case it would be necessary to change the pattern for the model, and perhaps consider a quadrant of the core instead of the octant.

It is obvious also that the only rigorous solution would be to treat the entire core and this would allow a solution to the problem of any assymetry existing in the core, but this is a too expensive solution for the point-of-view of computation.

4.4 Input Deck

A sample input deck is given in Appendix B, however a few remarks are given in order to explain how different types of flow regions such as subchannels and assemblies (or lumped assemblies) can be used under a common node of computation.

The geometry of the flow region has to be described as it is physically for either a subchannel or for lumped subchannels. In that respect the hydraulic diameter of the flow region will keep a physical meaning. It is also important to input the real diameter of the fuel rods, to have a model which stays consistent with the flow region geometry and allows realistic fuel temperatures calculations.

The power generated in a particular fuel region deposited in a given flow region can be determined by using the following rules:

- Power from the hottest fuel rod to the hot channel:

$$f_P = f_G \times \frac{1}{\alpha} \times \frac{1}{F_q^N} \times F_{\Delta H}^{stat} , \qquad (4.1)$$

where:

$$F_{\Delta H}^{stat} = \frac{F_{\Delta H}^E}{F_{LP} \times F_R \times F_M} , \qquad (4.2)$$

(see Ref. 15)

- Power from the hottest rod to other flow regions:

$$f_P = f_G \times \frac{1}{\alpha} \times \frac{1}{F_q^N} , \qquad (4.3)$$

- Power from other fuel regions to the hot channel:

$$f_P = f_G \times \frac{1}{\alpha} \times F_{\Delta H}^{stat} , \qquad (4.4)$$

- Power from other fuel regions to other flow regions:

$$f_P = f_G \times \frac{1}{\alpha} \quad , \tag{4.5}$$

- Power from lumped fuel rods to lumped subchannels:

$$f_P = \frac{1}{\alpha} \times N_{rod} \quad . \tag{4.6}$$

The detailed instructions concerning how to set up the data deck can be found in front of the COBRA III C deck. The options selected to treat the Connecticut Yankee case are listed below:

- friction factor correlation:

$$f = 0.184 \, Re^{-0.2} \, (15) \quad , \tag{4.7}$$

- subcooled void correlation: Levy correlation,
- bulk void correlation: homogeneous model,
- two phase friction multiplier: homogeneous model,
- wall viscosity correction to the friction factor included,
- spacer pressure losses included,
- subcooled mixing correlation: Rowe correlation (16)

$$\beta = 0.0062 \, \frac{D}{S} \, Re^{-0.1} \quad , \tag{4.8}$$

- two phase mixing correlation: same as the subcooled mixing correlation,
- no thermal conduction mixing assumed,

for the rest of the details of the data deck, see the sample input in Appendix B.

4.5 Sensitivity Study

Some of the input parameters to COBRA III C, such as the cross flow resistance factor, turbulent momentum factor, S/L parameter defining the control volume*, are not very easy to estimate or to measure. Some measurements of the cross flow resistance factor have been done(17) but they are related to particular conditions which do not correspond to this case. It was decided to develop a sensitivity study, of the selected parameters, and see how sensitive the results are sensitive to the choice of these parameters. In addition, the results of this sensitivity analysis are used to optimize the computation between the precision of the results and the computation time.

This sensitivity study has been performed on the following parameters:

---

* (where S is the gap spacing between fuel regions and L the length of the control volume, see Ref. 13)

- axial node length, using node lengths of 7.9, 6.0, 4.2 in.,
- flow convergence factor, using factors of 0.020, 0.010, 0.005,
- S/L parameter for the control volume, using values of 0.10, 0.25, 0.50,
- turbulent momentum factor, using values of 0.0, 0.5, 0.9,
- cross flow resistance factor, using values of 0.1, 0.5, 0.9.

The best set of values to be used for the Connecticut Yankee Reactor is the set which has been used in the reference case.

4.6 Results of the Sensitivity Analysis

4.6.1 General Remarks

It is important to keep in mind that the results are valid for the calculational model used to represent the Connecticut Yankee Reactor and it would probably be unwise to generalize on these results to all the PWR's without any further checks on other reactors.

It has been found that the assembly exit conditions of the coolant are not greatly affected by the values chosen for each parameter. Some differences exist as far as computation time is concerned, and therefore the choice of each parameter can, in general, be established for minimum computation time.

4.6.2 Results

For each type of sensitivity study, two figures are used to summarize the results. These figures give:

- assembly exit temperature of the coolant,
- normalized flow distribution of the coolant at the assembly exit.

In addition, Table 5 lists the comparison of the following computed parameters for each case:

- minimum DNBR and its axial location from the inlet,
- maximum fuel center line temperature and its location,
- maximum clad temperature and its location,
- core pressure drop and hot channel pressure drop,
- number of iterations required to obtain the flow solution,
- computation time.

Table 3 lists the possible bounds of the parameters used for this study and the physical significants of these limits. Table 4 gives the correspondence between the case numbers and the type of variation done in each case. Figures 11 through 20 summarize the comparison of the

Parameters	Bounds of Parameters mini/maxi		Physical Significance
Axial node length	number of nodes = 2 node separation = 126.7 in. number of nodes = 30 node separation = 4.23 in.		node 1 at core inlet node 2 at core outlet (depends on code conditions)
Flow convergence factor	no bounds		in (%) represents the allowed derivation between axial mass flow rates between two iterations
S/L parameter	0	1	corresponds to the volume through which cross flow exchange is calculated
Turbulent momentum factor	0	1	accounts for imperfect analogy between eddy diffusivity of heat and momentum
Cross flow resistance factor	0	1	k = 0 no cross flow resistance k = 1 full cross flow resistance

Table 3 Physical Significance and Bounds on the Parameters Used In the Sensitivity Study on COBRA III C

Case No.	Type of Varied Parameter	Value of the Parameter
1	Reference case	
2	Axial node length	7.919 in.
1	Axial node length (ref. case)	6.023 in.
3	Axial node length	4.223 in.
4	Flow convergence factor	0.020
1	Flow convergence factor (ref. case)	0.010
5	Flow convergence factor	0.005
6	S/L parameter	0.10
1	S/L parameter (ref. case)	0.25
7	S/L parameter	0.50
8	Turbulent momentum factor	0.0
1	Turbulent momentum factor (ref. case)	0.5
9	Turbulent momentum factor	0.9
10	Cross flow resistance factor	0.1
1	Cross flow resistance factor (ref. case)	0.5
11	Cross flow resistance factor	0.9
12	Forced inlet flow distribution	-
13	Equal pressure gradient at the inlet	-
14	Uniform mass flux at the inlet	-

Table 4 Correspondence Between the Case Numbers and the Type of Sensitivity Study Done

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.20 562.19 562.16 -	565.72 565.75 565.74 573.8	1 2 3 4
P					564.64 564.62 564.55 571.6	579.03 579.05 579.01 575.7	588.61 588.65 588.63 588.2	571.86 571.91 571.96 -	
N				567.53 567.52 567.44 572.2	591.74 591.76 591.70 -	574.82 574.89 574.95 578.5	579.04 579.11 579.13 576.4	579.31 579.35 579.36 574.3	
M				581.37 581.39 581.34 582.7	587.59 587.66 587.68 583.7	586.51 586.56 586.56 577.8	586.45 586.50 586.51 583.9	574.54 574.50 574.70 -	
L					575.61 575.72 575.80 575.1	576.79 576.88 576.93 575.3	577.43 577.53 577.59 576.6	582.64 582.63 582.61 578.7	
K						583.58 583.63 583.64 574.5	584.31 584.37 584.38 -	570.29 570.50 570.50 -	
J							574.28 574.38 574.39 572.2	579.31 579.32 579.38 579.4	
H								567.80 567.90 567.89 567.9	

1: Calculated value for axial node length=7.9in. (case n° 2)

2: Calculated value for axial node length=6.0in. (reference case)

3; Calculated value for axial node length=4.2in. (case n° 3)

4; Measured value (From outlet thermocouple)

595.03 595.10 595.09 -	591.62 591.69 591.70 -
591.80 591.87 591.88 -	591.18 591.28 591.32 -

Hot subchannels

Fig. 11 Comparison of outlet temperatures as a function of axial node length.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0069 1.0063 1.0059	1.0062 1.0058 1.0059	1 2 3 4
P					1.0057 1.0051 1.0044	0.9978 0.9974 0.9974	0.9929 0.9927 0.9931	1.0047 1.0044 1.0049	
N				1.0039 1.0034 1.0027	0.9909 0.9906 0.9906	1.0031 1.0029 1.0033	1.0000 1.0000 1.0000	0.9997 0.9997 1.0003	
M				0.9982 0.9980 0.9979	0.9940 0.9940 0.9945	0.9951 0.9952 0.9959	0.9951 0.9954 0.9960	1.0065 1.0066 1.0064	
L					1.0027 1.0028 1.0033	0.9993 0.9996 1.0000	1.0021 1.0024 1.0026	0.9981 0.9986 0.9986	
K						0.9975 0.9980 0.9982	0.9975 0.9980 0.9979	1.0072 1.0076 1.0068	
J							1.0045 1.0050 1.0040	1.0009 1.0015 1.0000	
H								1.0098 1.0098 1.0098	

1: Calculated value for axial node length=7.9 in. (case n° 2)

2: Calculated value for axial node length=6.0 in. (reference case)

3: Calculated value for axial node length=4.2 in. (case n° 3)

4: -

0.9935 0.9934 0.9935	0.9785 0.9781 0.9780
0.9784 0.9781 0.9780	0.9790 0.9786 0.9784

Hot subchannels

Fig. 12 Comparison of the normalized outlet flow distribution as a function of the axial node length.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.19 562.19 562.23 -	565.75 565.75 565.79 573.8	1 2 3 4
P					564.62 564.62 564.68 571.6	579.05 579.05 579.11 575.7	588.65 588.65 588.73 588.2	571.91 571.91 571.93 -	
N				567.52 567.52 567.57 572.2	591.76 591.76 591.10 -	574.89 574.89 574.88 578.5	579.11 579.11 579.11 576.4	579.35 579.35 579.37 574.3	
M				581.39 581.39 581.50 582.7	587.66 587.66 587.67 583.7	586.56 586.56 586.59 577.8	586.50 586.50 586.51 583.9	574.65 574.65 574.57 -	
L					575.72 575.72 575.62 575.1	576,88 576.88 576.82 575.3	577.53 577.53 577.46 576.6	582.63 582.63 582.68 578.7	
K						583.63 583.63 583.63 574.5	584.37 584.37 584.35 -	570.50 570.50 570.33 -	
J							574.38 574.38 574.30 572.2	579.32 579.32 579.31 579.4	
H								567.50 567.90 567.82 567.9	

1: **Calculated value for flow convergence factor FCF** = 0.020 (case n° 4)

2: **Calculated value for flow convergence factor FCF** = 0.010 (reference case)

3: **Calculated value for flow convergence factor FCF** = 0.005 (**case** n° 5)

4: **Measured value** (From **outlet** thermocouple)

595.10 595.10 595.16 -	591.69 591.69 591.74 -
591.87 591.87 591.93 -	591.28 591.28 591.33 -

Hot subchannels

Fig. 13 Comparison of outlet temperatures as a function of the flow convergence factor.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0063 1.0063 1.0074	1.0058 1.0058 1.0064	1 2 3 4
P					1.0051 1.0051 1.0064	0.9974 0.9974 0.9979	0.9927 0.9927 0.9927	1.0044 1.0044 1.0046	
N				1.0034 1.0034 1.0046	0.9906 0.9906 0.9908	1.0029 1.0029 1.0030	1.0000 1.0000 0.9998	0.9997 0.9997 0.9995	
M				0.9980 0.9980 1.0012	0.9940 0.9940 0.9938	0.9952 0.9952 0.9947	0.9954 0.9954 0.9947	1.0066 1.0066 1.0062	
L					1.0028 1.0028 1.0026	0.9996 0.9996 0.9992	1.0024 1.0024 1.0018	0.9986 0.9986 1.0030	
K						0.9980 0.9980 0.9981	0.9980 0.9980 0.9975	1.0076 1.0076 1.0073	
J							1.0059 1.0059 1.0059	1.0015 1.0015 1.0013	
H								1.0098 1.0098 1.0098	

1: **Calculated value for flow convergence factor**
FCF = 0.020 (case n° 4)
2: **Calculated value for flow convergence** factor
FCF = 0.010 (**reference case**)
3: **Calculated value for flow convergence factor**
FCF = 0.005 (case n° 5)
4: -

0.9934 0.9934 0.9932	0.9781 0.9781 0.9781
0.9781 0.9781 0.9781	0.9786 0.9786 0.9790

Hot subchannels

Fig. 14 Comparison of the normalized outlet flow distribution as a function of the flow convergence factor.

Hottest assembly= N11

	15	14	13	12	11	10	9	8	
R							562.20 562.19 562.27 -	565.80 565.75 565.76 573.8	1 2 3 4
P					564.70 564.62 564.72 571.6	579.05 579.05 579.06 575.7	588.73 588.65 588.60 588.2	571.98 571.91 571.90 -	
N				567.45 567.52 567.61 572.2	591.87 591.76 591.71 -	574.93 574.89 574.88 578.5	579.12 579.11 579.11 576.4	579.37 579.35 579.36 574.3	
M				581.44 581.39 581.39 582.7	587.65 587.66 587.65 583.7	586.57 586.56 586.57 577.8	586.50 586.50 586.51 583.9	574.63 574.65 574.60 -	
L					575.67 575.72 575.66 575.1	576.86 576.88 576.85 575.3	577.51 577.53 577.50 576.6	582.63 582.63 582.71 578.7	
K						583.68 583.63 583.66 574.5	584.35 584.37 584.39 -	570.19 570.50 570.29 -	
J							574.25 574.38 574.33 572.2	579.43 579.32 579.40 579.4	
H								567.72 567.90 567.84 567.90	

1: Calculated value for parameter S/L = 0.10
(case n° 6)

2: Calculated value for parameter S/L = 0.25
(reference case)

3: Calculated value for parameter S/L = 0.50
(case n° 7)

4: Measured value (From outlet thermocouple)

595.12 595.10 595.09 -	591.71 591.69 591.67 -
591.90 591.87 591.85 -	591.30 591.28 591.26 -

Hot subchannels

Fig. 15 Comparison of outlet temperatures as a function of the S/L parameter.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0069 1.0063 1.0069	1.0066 1.0058 1.0064	1 2 3 4
P					1.0054 1.0051 1.0057	1.0001 0.9974 0.9979	0.9935 0.9927 0.9932	1.0054 1.0044 1.0048	
N				1.0036 1.0034 1.0039	0.9910 0.9906 0.9912	1.0038 1.0029 1.0032	0.9999 1.0000 1.0001	1.0005 0.9997 0.9998	
M				0.9983 0.9980 0.9984	0.9947 0.9940 0.9942	0.9959 0.9952 0.9951	0.9959 0.9954 0.9951	1.0068 1.0066 1.0063	
L					1.0034 1.0028 1.0027	0.9998 0.9996 0.9993	1.0022 1.0024 1.0019	0.9978 0.9986 0.9980	
K						0.9975 0.9980 0.9974	0.9970 0.9980 0.9973	1.0055 1.0076 1.0066	
J							0.9993 1.0050 1.0037	0.9968 1.0015 1.0002	
H								1.0053 1.0098 1.0108	

1: **Calculated value for parameter S/L = 0.10**
(case n° 6)
2: **Calculated value for parameter S/L = 0.25**
(**reference** case)
3: **Calculated value for parameter S/L = 0.50**
(case n° 7)
4: -

0.9935 0.9934 0.9935	0.9783 0.9781 0.9783
0.9783 0.9781 0.9783	0.9787 0.9786 0.9788

Hot subchannels

Fig. 16 Comparison of the normalized outlet flow distribution as a function of the S/L parameter.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.19 562.19 562.19 -	565.75 565.75 565.75 573.8	1 2 3 4
P					564.62 564.62 564.62 571.6	579.05 579.05 579.05 575.7	588.67 588.65 588.67 588.2	571.91 571.91 571.91 -	
N				567.51 567.52 567.51 572.2	591.78 591.76 591.79 -	574.88 574.89 574.88 578.5	579.10 579.11 579.10 576.4	579.37 579.35 579.37 574.3	
M				581.40 581.39 581.40 582.7	587.67 587.66 587.67 583.7	586.58 586.56 586.58 577.8	586.52 586.50 586.52 583.9	574.61 574.65 574.61 -	
L					575.69 575.72 575.69 575.1	576.86 576.88 576.86 575.3	577.52 577.53 577.52 576.6	582.68 582.63 582.68 578.7	
K						583.65 583.63 583.65 574.5	584.38 584.37 584.38 -	570.41 570.50 570.41 -	
J							574.37 574.38 574.37 572.2	579.36 579.32 579.36 579.4	
H								567.88 567.90 567.88 567.9	

1: Calculated value for turbulent momentum factor TMF = 0.5 (reference case)
2: Calculated value for turbulent momentum factor TMF = 0.0 (case n° 8)
3: Calculated value for turbulent momentum factor TMF = 0.9 (case n° 9)
4: Measured value (From outlet thermocouple)

595.17 595.10 595.22 -	591.59 591.69 591.54 -
591.78 591.87 591.73 -	591.18 591.28 591.12 -

Hot subchannels

Fig. 17 Comparison of outlet temperatures as a function of the turbulent momentum factor.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0063 1.0063 1.0063	1.0059 1.0058 1.0059	1 2 3 4
P					1.0052 1.0051 1.0052	0.9975 0.9974 0.9975	0.9927 0.9927 0.9927	1.0044 1.0044 1.0044	
N				1.0035 1.0034 1.0035	0.9906 0.9906 0.9906	1.0030 1.0029 1.0030	0.9927 0.9927 0.9927	1.0003 1.0003 1.0003	
M				0.9980 0.9980 0.9980	0.9945 0.9945 0.9945	0.9952 0.9952 0.9952	0.9954 0.9954 0.9954	1.0066 1.0066 1.0066	
L					1.0029 1.0028 1.0029	0.9996 0.9996 0.9996	1.0024 1.0024 1.0024	0.9985 0.9986 0.9985	
K						0.9979 0.9980 0.9979	0.9979 0.9980 0.9979	1.0076 1.0076 1.0076	
J							1.0056 1.0050 1.0056	1.0013 1.0015 1.0013	
H								1.0098 1.0098 1.0098	

1: Calculated value for turbulent momentum factor TMF = 0.5 (reference case)
2: Calculated value for turbulent momentum factor TMF = 0.0 (case n° 8)
3: Calculated value for turbulent momentum factor TMF = 0.9 (case n° 9)
4: -

0.9935 0.9934 0.9935	0.9781 0.9781 0.9781
0.9781 0.9781 0.9781	0.9786 0.9786 0.9786

Hot subchannels

Fig. 18 Comparison of the normalized outlet flow distribution as a function of the turbulent momentum factor.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.19 562.19 562.19 -	565.75 565.75 565.75 573.8	1 2 3 4
P					564.62 564.62 564.62 571.6	579.05 579.05 579.05 575.7	588.65 588.65 588.65 588.2	571.91 571.91 571.91 -	
N				567.52 567.52 567.52 572.2	591.76 591.76 591.76 -	574.89 574.89 574.89 578.5	579.11 579.11 579.11 576.4	579.35 579.35 579.35 574.3	
M				581.39 581.39 581.39 582.7	587.66 587.66 587.66 583.7	586.56 586.56 586.56 577.8	586.50 586.50 586.50 583.9	574.65 574.65 574.65 -	
L					575.72 575.72 575.72 575.1	576.88 576.88 576.88 575.3	577.53 577.53 577.53 576.6	582.63 582.63 582.63 578.7	
K						583.63 583.63 583.63 574.5	584.37 584.37 584.37 -	570.50 570.50 570.50 -	
J							574.38 574.38 574.38 572.2	579.32 579.32 579.32 579.4	
H								567.91 567.91 567.91 567.9	

1: Calculated value for cross flow resistance K = 0.1 (case n° 10)

2: Calculated value for cross flow resistance K = 0.5 (reference case)

3: Calculated value for cross flow resistance K = 0.9 (case n° 11)

4: Measured value (From outlet thermocouple)

595.09 595.10 595.10 -	591.68 591.69 591.69 -
591.87 591.87 591.87 -	591.28 591.28 591.28 -

Hot subchannels

Fig. 19 Comparison of outlet temperatures as a function of the cross flow resistance.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0063 1.0063 1.0063	1.0058 1.0058 1.0058	1 2 3 4
P					1.0051 1.0051 1.0051	0.9974 0.9974 0.9974	0.9927 0.9927 0.9927	1.0044 1.0044 1.0044	
N				1.0034 1.0034 1.0034	0.9906 0.9906 0.9906	1.0029 1.0029 1.0029	1.0000 1.0000 1.0000	0.9997 0.9997 0.9997	
M				0.9980 0.9980 0.9980	0.9940 0.9940 0.9940	0.9952 0.9952 0.9952	0.9954 0.9954 0.9954	1.0066 1.0066 1.0066	
L					1.0028 1.0028 1.0028	0.9996 0.9996 0.9996	1.0024 1.0024 1.0024	0.9986 0.9986 o.9986	
K						0.9980 0.9980 0.9980	0.9980 0.9980 0.9980	1.0076 1.0076 1.0076	
J							1.0050 1.0050 1.0050	1.0015 1.0015 1.0015	
H								1.0098 1.0098 1.0098	

1: Calculated value for cross flow resistance K = 0.1 (case n° 10)
2: Calculated value for cross flow resistance K = 0.5 (reference case)
3: Calculated value for cross flow resistance K = 0.9 (case n° 11)
4: -

0.9934 0.9934 0.9934	0.9781 0.9781 0.9781
0.9781 0.9781 0.9781	0.9786 0.9786 0.9786

Hot subchannels

Fig. 20 Comparison of the normalized outlet flow distribution as a function of the cross flow resistance.

results obtained for the sensitivity study where the different parameters listed above have been varied for the same coolant distribution at the core inlet (equal pressure gradient in all the flow regions).

This part of the sensitivity study has been done by using the inlet flow distribution given by the subroutine SPLIT, which splits the flow to get the same pressure gradient at the core inlet. It assumed that there is no spatial acceleration component of pressure drop (13). It is recalled that COBRA III C allows the use of three possible options for the flow inlet distribution:

- same mass flux everywhere at the core inlet,
- same pressure gradient at the core inlet,
- forced inlet distribution at the core inlet(18).

By using the reference values of parameters, the three inlet flow distributions were tested against each other. Figures 21 through 24 and Table 5 summarize the results of this comparison.

Figure 25 gives a comparison of the axial mass flux and the diversion cross flow for the hot channel as a function of the flow inlet distribution. Figure 26 gives a plot of the mass flux in the hot assembly and in the assembly at the center of the core.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.18 562.19 562.20 -	565.97 565.75 566.00 573.8	1 2 3 4
P					564.61 564.62 564.63 571.6	579.05 579.05 579.05 575.7	588.63 588.65 588.67 588.2	571.88 571.91 571.92 -	
N				567.52 567.52 567.51 572.2	591.75 591.75 591.82 -	574.88 574.89 574.88 578.5	579.12 579.11 579.13 576.4	579.32 579.35 579.37 574.3	
M				581.37 581.39 581.45 582.7	587.66 587.66 587.67 583.7	586.53 586.56 586.59 577.8	586.48 586.50 586.53 583.9	574.64 574.65 574.59 -	
L					575.73 575.72 575.61 575.1	576.89 576.88 576.84 575.3	577.55 577.53 577.49 576.6	582.63 582.63 582.76 578.7	
K						583.60 583.63 583.69 574.5	584.33 584.37 584.38 -	570.30 570.50 570.12 -	
J							574.46 574.38 574.36 572.2	579.43 579.32 579.51 579.4	
H								567.90 567.90 567.81 567.9	

1: Forced inlet distribution.
(case n° 12)
2: Equal pressure gradient distribution.
(case n° 13)
3: Uniform mass flux distribution.
(case n° 14)
4: Measured value (From outlet thermocouple)

595.09 595.10 595.05 -	591.68 591.69 591.67 -
591.87 591.87 591.57 -	591.28 591.28 591.12 -

Hot subchannels

Fig. 21 Comparison of outlet temperatures as a function of the inlet distribution.

Hottest assembly- N 11

	15	14	13	12	11	10	9	8	
R							1.0129 1.0150 -.0021	1.0118 0.9017 0.1101	1 2 3 4
P					1.0081 0.9634 0.0447	1.0007 0.9737 0.0270	0.9967 0.9327 0.0640	1.0081 0.8915 0.1166	
N				1.0053 1.0150 -.0097	0.9918 0.9532 0.0386	1.0040 1.0040 0.0000	1.0011 0.8917 0.1094	1.0014 0.9632 0.0382	
M				0.9986 1.0967 -.0981	0.9939 1.0560 -.0621	0.9942 0.9122 0.0820	0.9944 0.9942 0.0002	1.0024 1.0658 -.0634	
L					1.0007 0.9632 0.0375	0.9995 1.0350 -.0355	0.9987 0.9737 0.0250	0.9958 1.1377 -.1419	
K						0.9936 1.0248 -.0312	0.9933 1.0970 -.1037	1.0026 1.1987 -.1961	
J							0.9991 0.9940 0.0051	0.9959 1.1067 -.1108	
H								1.0037 1.0850 -.0823	

1: Normalized outlet distribution.

2: Normalized inlet distribution.

3: Difference between outlet and inlet distributions.

4: -

0.9937 0.9532 0.0405	0.9805 0.9533 0.0272
0.9804 0.9533 0.0271	0.9810 0.9510 0.0300

Hot subchannels

Fig. 22 Flow distributions for the forced inlet distribution case (case n° 12).

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0063 0.9735 0.0328	1.0058 0.9891 0.0167	1 2 3 4
P					1.0051 0.9735 0.0316	0.9974 0.9895 0.0079	0.9927 1.0065 -.0138	1.0044 1.0059 -.0015	
N				1.0034 0.9735 0.0299	0.9906 1.0067 -.0161	1.0029 1.0065 -.0036	1.0000 1.0065 -.0065	0.9997 1.0059 -.0062	
M				0.9980 1.0059 -.0079	0.9940 1.0065 -.0125	0.9952 1.0065 -.0113	0.9954 1.0065 -.0111	1.0066 1.0059 0.0007	
L					1.0028 1.0059 -.0031	0.9996 1.0065 -.0069	1.0024 1.0065 -.0041	0.9986 1.0059 -.0073	
K						0.9980 1.0059 -.0079	0.9980 1.0065 -.0085	1.0076 1.0059 0.0017	
J							1.0050 1.0059 -.0009	1.0015 1.0059 -.0044	
H								1.0098 1.0064 0.0034	

1: Normalized outlet distribution.

2: Normalized inlet distribution.

3: Difference between outlet and inlet distributions.

4: -

0.9934 1.0464 -.0530	0.9781 0.9197 0.0584
0.9781 0.9197 0.0584	0.9786 0.9197 0.0589

Hot subchannels

Fig. 23 Flow distributions for the equal pressure gradient inlet distribution case (case n° 13).

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							1.0068 1.0001 0.0067	1.0063 0.9998 0.0065	1 2 3 4
P					1.0055 1.0001 0.0054	0.9978 1.0001 -.0023	0.9931 1.0001 -.0032	1.0048 0.9998 0.0050	
N				1.0038 1.0001 0.0037	0.9909 1.0001 -.0092	1.0032 1.0001 0.0031	1.0003 1.0001 0.0002	0.9998 0.9998 0.0000	
M				0.9982 0.9998 -.0016	0.9942 1.0001 -.0059	0.9952 1.0001 -.0049	0.9953 1.0001 -.0048	1.0036 0.9998 0.0038	
L					1.0028 0.9998 0.0030	1.0024 1.0001 0.0023	1.0020 1.0001 0.0019	0.9980 0.9998 -.0018	
K						0.9974 0.9998 -.0024	0.9972 1.0001 -.0029	1.0069 0.9998 0.0071	
J							1.0041 0.9998 0.0043	1.0004 0.9998 0.0006	
H								1.0087 1.0000 0.0087	

1: Normalized outlet distribution.

2: Normalized inlet distribution.

3: Difference between outlet and inlet distributions.

4: -

0.9937 1.0000 -.0063	0.9786 1.0000 -.0214
0.9784 1.0000 -.0216	0.9790 1.0000 -.0210

Hot subchannels

Fig. 24 Flow distributions for the uniform mass flux inlet distribution case (case n° 14).

Key to Table 5:

A: Case number (see Table 4 for the type of study done)

B: Minimum DNBR

C: Location of the MDNBR from the inlet (in.)

D: Maximum fuel centerline temperature (°F)

E: Location of the maximum fuel centerline temperature from inlet (in)

F: Maximum clad outside temperature (°F)

G: Location of the maximum clad outside temperature from inlet (in)

H: Core pressure drop (psi)

I: Hot channel pressure drop (psi)

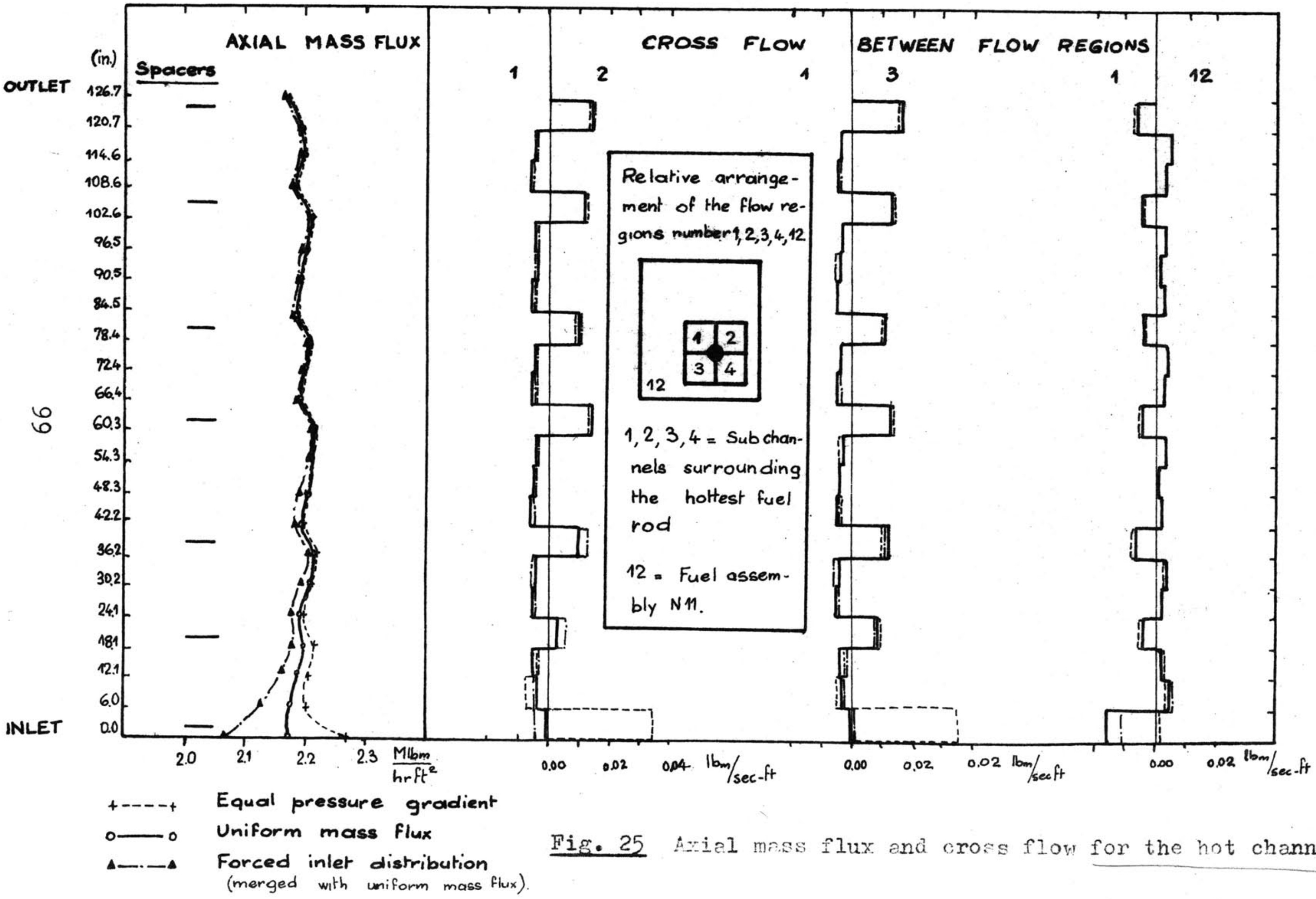
J: Number of iterations to obtain the flow solution

K: Computation time - CPU time - (sec)

NOTE: All the values of the MDNBR are related to fuel rod No. 4 facing the subchannel No. 1. All the temperatures (fuel centerline and clad outside) are related to the fuel rod No. 4.

A	B	C	D	E	F	G	H	I	J	K
1	3.891	90.5	2724.9	54.3	637.1	96.5	19.55	19.53	2	89.558
2	3.895	95.0	2723.8	55.4	636.8	95.0	19.55	19.53	2	69.417
3	3.888	92.9	2725.2	54.9	637.4	97.1	19.54	19.51	2	124.886
4	3.891	90.5	2724.9	54.3	637.1	96.5	19.54	19.52	2	89.558
5	3.887	90.5	2724.9	54.3	637.1	96.5	19.54	19.52	3	132.296
6	3.891	90.5	2724.9	54.3	637.1	96.5	19.55	19.52	2	89.258
7	3.891	90.5	2724.9	54.3	637.1	96.5	19.55	19.53	2	89.245
8	3.881	90.5	2724.9	54.3	636.9	96.5	19.55	19.53	2	91.581
9	3.876	90.5	2724.9	54.3	636.9	96.5	19.55	19.53	2	91.688
10	3.891	90.5	2724.9	54.3	637.1	96.5	19.54	19.51	2	89.558
11	3.891	90.5	2724.9	54.3	637.1	96.5	19.55	19.51	2	89.279
12	3.876	90.5	2724.9	54.3	637.1	96.5	19.55	19.45	4	183.902
13	3.891	90.5	2724.9	54.3	637.0	96.5	19.55	19.53	2	92.723
14	3.890	90.5	2724.9	54.3	637.1	96.5	19.55	19.55	2	95.060

Table 5 Summary of the Results of the Sensitivity Analysis on COBRA 3C



Relative arrangement of the flow regions number 1, 2, 3, 4, 12.

1, 2, 3, 4 = Subchannels surrounding the hottest fuel rod

12 = Fuel assembly N 11.

Fig. 25 Axial mass flux and cross flow for the hot channel.

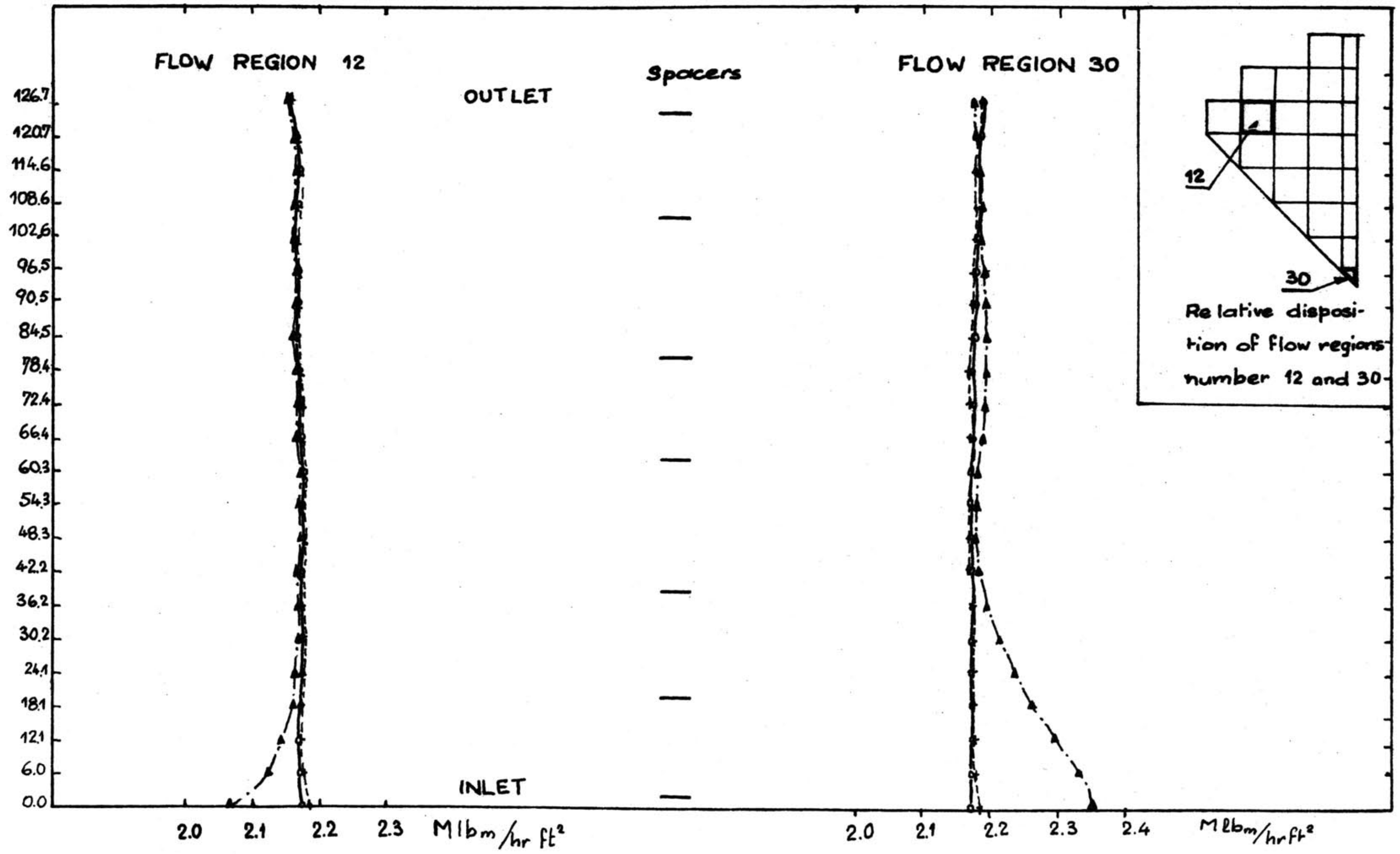


Fig. 26 Comparison of the axial mass fluxes in the hot assembly and in the assembly at the core center.

4.6.3 Conclusions Given by the Sensitivity Study

A general remark can be made concerning the outlet conditions for each assembly:

- the assembly outlet conditions (axial flow, temperature) are not very sensitive to either the different parameters used for the computation, or the inlet flow distribution.

In particular the cross flow resistance factor has very little effect on the flow distribution at the outlet, but of course the cross flow pattern inside of the core depends on this cross flow resistance factor.

As stated it would be probably unwise to generalize these results to all the PWR, but it should be mentioned that very similar results have been obtained from a sensitivity study done with COBRA III C on the Yankee Rowe Reactor (19).

From Figure 25 and 26 it appears that the inlet flow distribution does not effect the outlet conditions and the coolant seems to perform a self-redistribution leading to achievement of an equilibrium distribution after 2 to 4 feet from the core inlet.

However this study shows that the use of the values of a measured inlet flow distribution (18) is not very advantageous, since it tends to introduce a flow instability in the computation increasing the computation time without any increase in the accuracy of the results. This inlet flow distribution is related to measurements taken on a seventh scale model and correspond to isothermal conditions.

The best inlet distribution suitable for this model is probably the distribution given by the use of the pressure gradient option, since it represents a reduction of the axial flow in the hot channel and an increase of the axial flow in the neighboring channels, as opposed to the uniform mass flux case where the axial flow is reduced in all the channels in the hot zone.

4.7 Validity of the Model

It was implicitly assumed that the Connecticut Yankee Reactor is highly subcooled when the options in COBRA III C were chosen. It is possible to check where the subcooled boiling occurs by predicting the location of incipient nucleation from available correlation. Three correlations were investigated: Bergles-Rohsenow (20) Jens and Lottes(15) and Thom (15). It is anticipated, based on review of the formulation of the correlations, that the Bergles-Rohsenow correlation predicts the earliest onset of subcooled boiling.

Figure 27 gives a plot of the incipient boiling criteria for the Connecticut Yankee case, assuming that the inlet flow distribution is obtained by using the pressure gradient option in COBRA III C. The results show that subcooled boiling may occur in two spots located on fuel rods No. 3 and 4 at 96.5 in. from the core inlet according to Bergles-Rohsenow. It should be noticed that Westinghouse uses the THOM correlation (21) to predict the onset of subcooled boiling. According to this correlation, no subcooled boiling occurs in the Connecticut Yankee reactor as it can be seen in Fig. 27. Therefore the assumption of very little subcooled voids in the core seems valid.

Furthermore the equilibrium exit quality in each flow region corroborates this conclusion, Fig. 28 gives the assembly outlet distribution of the steam quality, and the highest equilibrium quality is -0.088 in the hot channel.

The comparison between the measured temperature rise of the coolant through a given channel and the expected rise obtained from COBRA III C might also give an indication on the validity of the model. To do this comparison, the measured temperature and the associated uncertainties

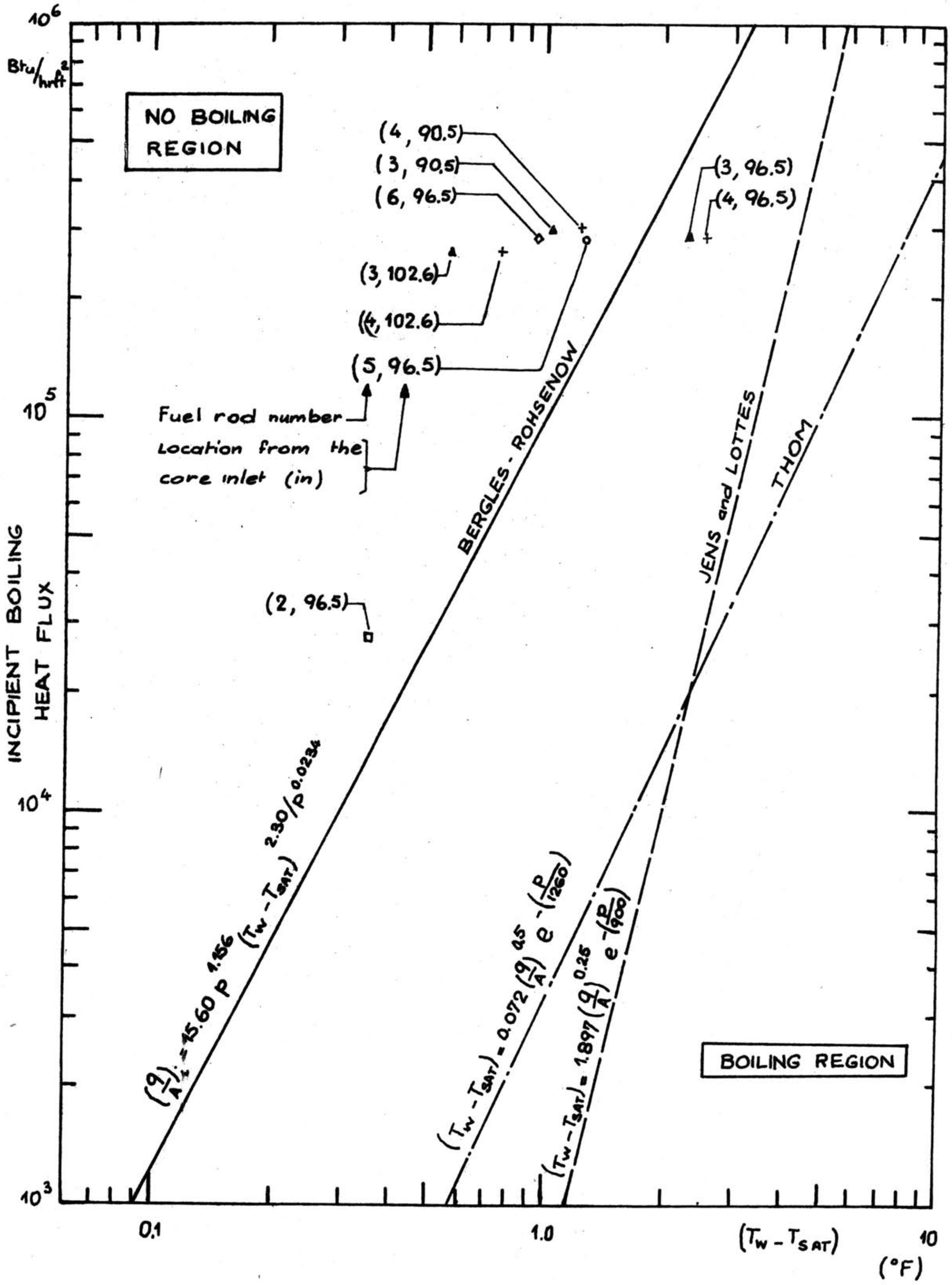


Fig. 27 Incipient boiling criteria applied to the CY case.

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.18 564.83 -.1552	565.97 569.83 -.1477	1 2 3 4
P					564.61 568.04 -.1504	579.05 587.39 -.1215	588.63 600.48 -.1019	571.88 577.64 -.1360	
N				567.52 571.86 -.1447	591.75 604.89 -.0953	574.88 581.70 -.1300	579.12 587.47 -.1213	579.32 587.75 -.1209	
M				581.37 590.56 -.1167	587.66 599.10 -.1039	586.53 597.56 -.1063	586.48 597.49 -.1064	574.64 581.38 -.1305	
L					575.73 582.86 -.1282	576.89 584.43 -.1259	577.55 585.33 -.1245	582.63 592.28 -.1141	
K						583.60 593.59 -.1122	584.33 594.58 -.1107	570.30 575.55 -.1392	
J							574.46 581.13 -.1308	579.43 587.90 -.1207	
H								567.90 572.36 -.1439	

1: Assembly outlet temperature (from COBRA III C) (°F)

2: Assembly outlet enthalpy (Btu/lb$_m$)

3: Assembly exit quality

4: -

595.09 609.63 -.0882	591.68 604.80 -.0954
591.87 605.06 -.0950	591.28 604.22 -.0963

Hot subchannels

Fig. 28 Coolant quality distribution at the assembly outlet.

must be obtained as discussed in 2.3.3. The study developed for the San Onofre Reactor (9) uses:

$$t_{corrected} = t_{measured} - 0.5 \pm 3.62 \quad (^\circ F) \qquad (4.9)$$

This relation is based on the assumption of ref. (9) that an error of ± 3.0 °F is due to the imperfect flow mixing or due to the fact that the hot function location is not in a plane where the coolant temperature is uniform. The hot junction of the thermocouple is located 7 inches above the top of the fuel rods. As it is shown on Fig. 29, the top part of the fuel assembly is fitted with a kind of channel constituting a closed geometry which limits the cross flow exchange with the neighboring fuel assemblies. The only process which takes place in the coolant when it leaves the top of the fuel rods, is thermal mixing. How good is this thermal mixing, is a difficult question to answer.

In a very conservative assumption we may admit that the temperature profile of the coolant leaving the top of the fuel rods is the same when the coolant crosses the plane where the hot junction of the thermocouple is located.

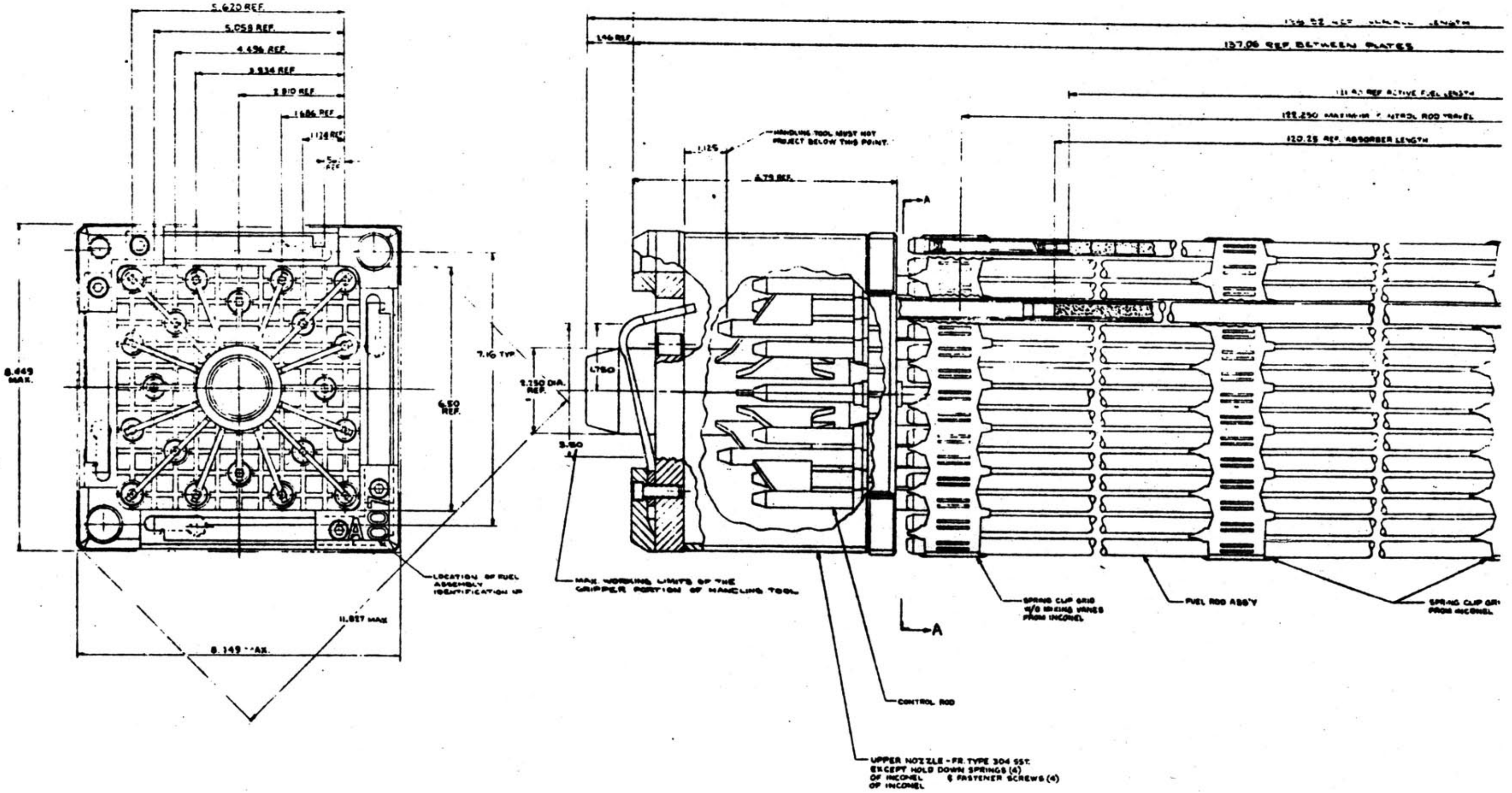


Fig. 29a Fuel assembly (upper part).

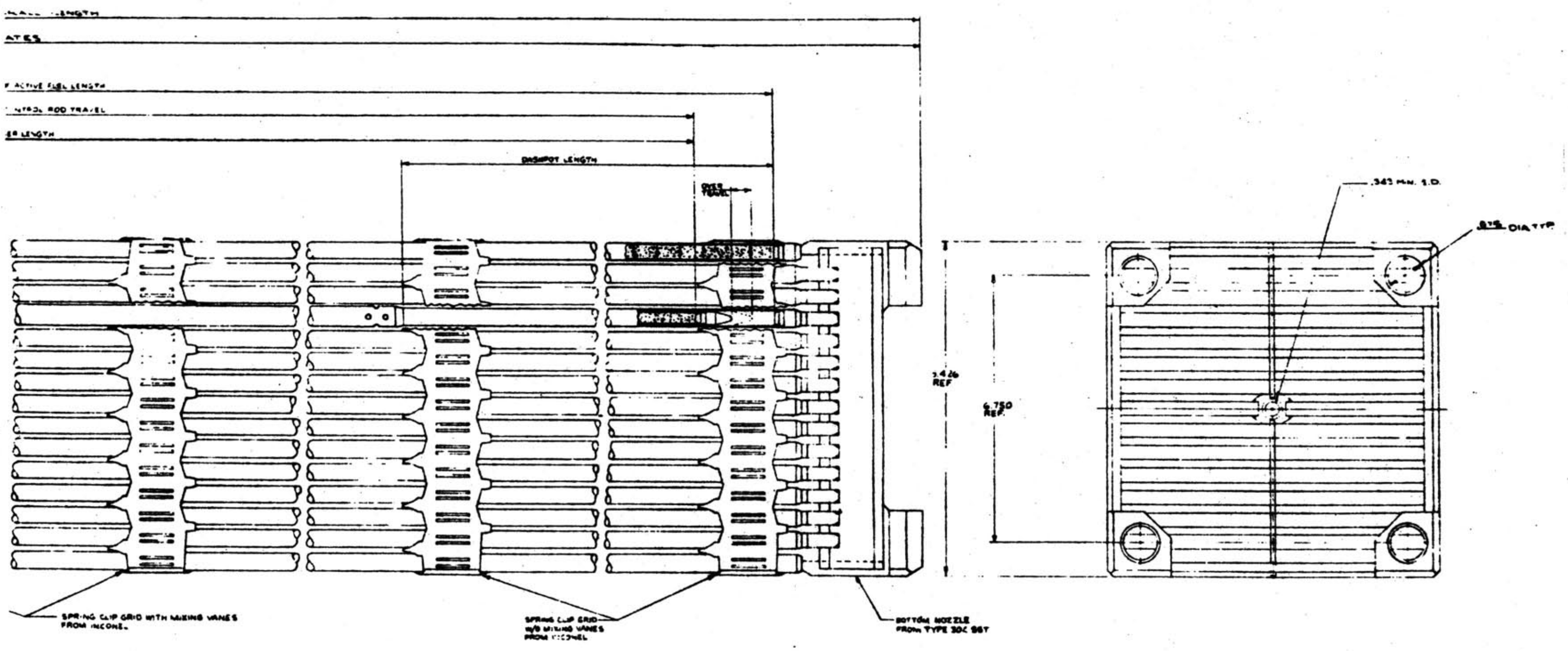


Fig. 29b Fuel assembly (lower part).

As an example COBRA III C has been used to treat the case of the hot assembly and obtain the temperature profile of the coolant at the top of the fuel rods. Figure 30 gives the power distribution used in COBRA III C, and Fig. 31 gives the temperature distribution of the coolant at the top of the fuel rods.

Figure 29 shows that the top of the fuel assembly is engineered with a square opening of 6.50 x 6.50 inches. Therefore the coolant in the peripheral channels is diverted toward the bundle center altering the radial coolant temperature distribution. Figure 31 presents the calculated temperature distribution at the core exit before the flow contraction. It is very difficult to estimate the actual radial coolant temperature profile as a function of axial position. It can be said that the coolant temperature may vary from 595.26°F down to 582.16°F at least. Since the hot assembly in this case is not instrumented with an outlet thermocouple it is difficult to see how exactly the measured temperature compares with the predicted temperature profile.

Thus there is not a good method for evaluation of the thermal mixing in a duct when temperature streaming exists at the duct inlet. One might suggest a possible

```
                                                      EDIT OF ASSEMBLY NUMBER    8

                              ASSEMBLY LOCATION  COLUMNS  71 TO  87, ROWS  39 TO  55, PLANES   0 TO   1
                                                  ALL OF THIS ASSEMBLY IS IN PDQ
                                            NUMBER OF FUEL RODS ALONG COLUMNS  15 AND ROWS  15

                                          FUEL ROD POWERS FOR ASSEMBLY   8 FROM PLANE   0 TO   1
```

Core edge

```
  .746   .807   .862   .900   .937   .973   .994 1.010 1.036 1.058 1.063 1.068 1.071 1.053 1.029
  .914   .959   .979  1.001  1.041  1.097  1.097 1.091 1.138 1.179 1.159 1.159 1.175 1.122 1.057
  .876 [illegible] 0.000 1.107 1.153 0.000 1.228 1.237 1.267 0.000 1.264 1.253 0.000 1.186 1.085
  .922  1.017  1.115  1.173  1.237  1.263  1.272 0.000 1.306 1.332 1.337 1.302 1.269 1.185 1.098
  .967  1.065  1.171  1.246  0.000  1.247  1.222 1.267 1.250 1.306 0.000 1.350 1.302 1.206 1.114
 1.012  1.131  0.000  1.283  1.258  1.211  1.182 1.195 1.205 1.258 1.330 1.379 0.000 1.251 1.132
 1.041  1.135  1.266  1.303  1.243  1.193  1.202 1.235 1.221 1.231 1.302 1.382 1.359 1.235 1.135
 1.065  1.142  1.296  0.000  1.301  1.216  1.245 0.000 1.260 1.247 1.350 0.000 1.359 1.216 1.138
[illegible] [illegible] 1.324 1.362 1.295 1.239 1.243 1.272 1.256 1.264 1.334 1.414 1.388 1.260 1.156
 1.133 [illegible] 0.000 1.401 1.367 1.307  1.268 1.274 1.278 1.329 1.399 1.444 0.000 1.301 1.173
 1.147  1.244  1.349  1.420  0.000  1.397  1.357 1.396 1.366 1.416 0.000 1.454 1.386 1.278 1.175
 1.160  1.254  1.351  1.396  1.450  1.464  1.457 0.000 1.465 1.480 1.472 1.423 1.380 1.280 1.180
 1.172  1.263  0.000  1.377  1.405  0.000  1.450 1.439 1.457 0.000 1.424 1.399 0.000 1.304 1.185
[illegible] 1.236 1.334 1.366 1.319 1.362  1.336 1.307 1.342 1.372 1.334 1.319 1.325 1.254 1.172
 1.142  1.177  1.239  1.223  1.237  1.252  1.250 1.245 1.254 1.261 1.250 1.239 1.227 1.194 1.155

                                  MAXIMUM FUEL ROD POWER IS        1.480
                                  AVERAGE POWER IN ASSEMBLY        1.112 WITH WATER
                                  MAXIMUM ROD/AVERAGE POWER        1.331 WITH WATER
                                  AVERAGE POWER IN ASSEMBLY        1.227 FUEL ONLY.
                                  MAXIMUM ROD/AVERAGE POWER        1.206 FUEL ONLY
```

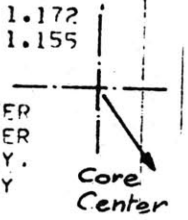


Fig. 30 Power distribution in the hottest fuel assembly (H 11).

Core edge

568.94	572.46	576.07	578.72	579.69	581.14	582.47	583.91	584.42	585.06	585.70	585.07	583.89	581.76
572.78	574.29	578.21	582.42	582.18	583.87	586.57	588.06	586.33	587.35	589.32	586.64	585.20	584.39
576.22	578.71	582.16	586.03	586.15	587.66	587.94	589.39	590.26	590.71	592.37	590.55	587.65	586.21
579.30	583.26	586.93	586.96	588.36	590.99	589.77	591.10	593.47	592.05	593.55	593.63	591.02	587.77
581.23	583.48	587.17	589.16	589.43	591.54	591.61	592.61	593.33	593.38	593.71	592.72	589.98	588.26
583.26	585.75	589.08	592.13	592.16	591.59	591.23	591.96	594.10	594.80	594.16	593.59	590.92	588.93
584.93	588.77	589.73	591.09	592.57	591.83	589.19	590.79	593.41	594.46	594.31	593.71	593.23	589.59
587.20	591.08	592.10	593.12	592.74	592.50	591.88	592.17	594.47	594.07	594.52	594.88	594.22	590.42
588.11	590.20	593.37	594.34	589.21	591.72	594.94	594.28	594.57	594.50	594.07	594.64	592.77	594.68
589.27	591.34	594.43	594.93	591.55	594.33	594.22	594.37	594.57	594.84	594.56	594.22	593.26	591.18
590.40	593.91	594.78	594.30	594.64	594.83	594.36	594.52	595.26	592.43	595.00	594.37	594.49	591.82
590.23	591.58	594.33	594.67	594.70	594.77	594.70	594.46	591.62	591.19	594.90	594.29	592.80	591.28
589.48	589.96	593.32	594.65	594.30	594.88	595.01	594.75	594.77	594.44	595.05	594.18	592.09	590.28
587.41	590.62	592.42	593.89	594.21	594.61	595.00	595.01	594.76	594.59	594.64	593.33	591.56	588.78

Core center

Fig. 31 Temperature distribution at the top of fuel assembly N 11. (BOC) solution, using COBRA III C for an assembly equipped with a control rod cluster, in which case a possible set of flow regions could be defined above the top of the fuel rods. But the study would be less detailed in this case, since one flow region wolld have to correspond to several subchannels. This type of analysis would still only lead to average results.

Figure 32 is a plot of the measured temperature rise of the coolant versus the predicted temperature rise. The uncertainty associated with the temperature measurement is also plotted (Eq. 4.9). The least square fit analysis of the data on Fig. 32 leads to:

$$t_{\text{corrected}} = 0.854\ t_{\text{measured}} + 7.43 \pm 4.27\ (^{\circ}\text{F}), \quad (4.10)$$

It is important to recognize that the power distribution in the fuel assembly is time dependent for a given assembly and at a given time varies from assembly to assembly. Therefore the temperature profiles that may be obtained from the different power distributions would considerably vary.

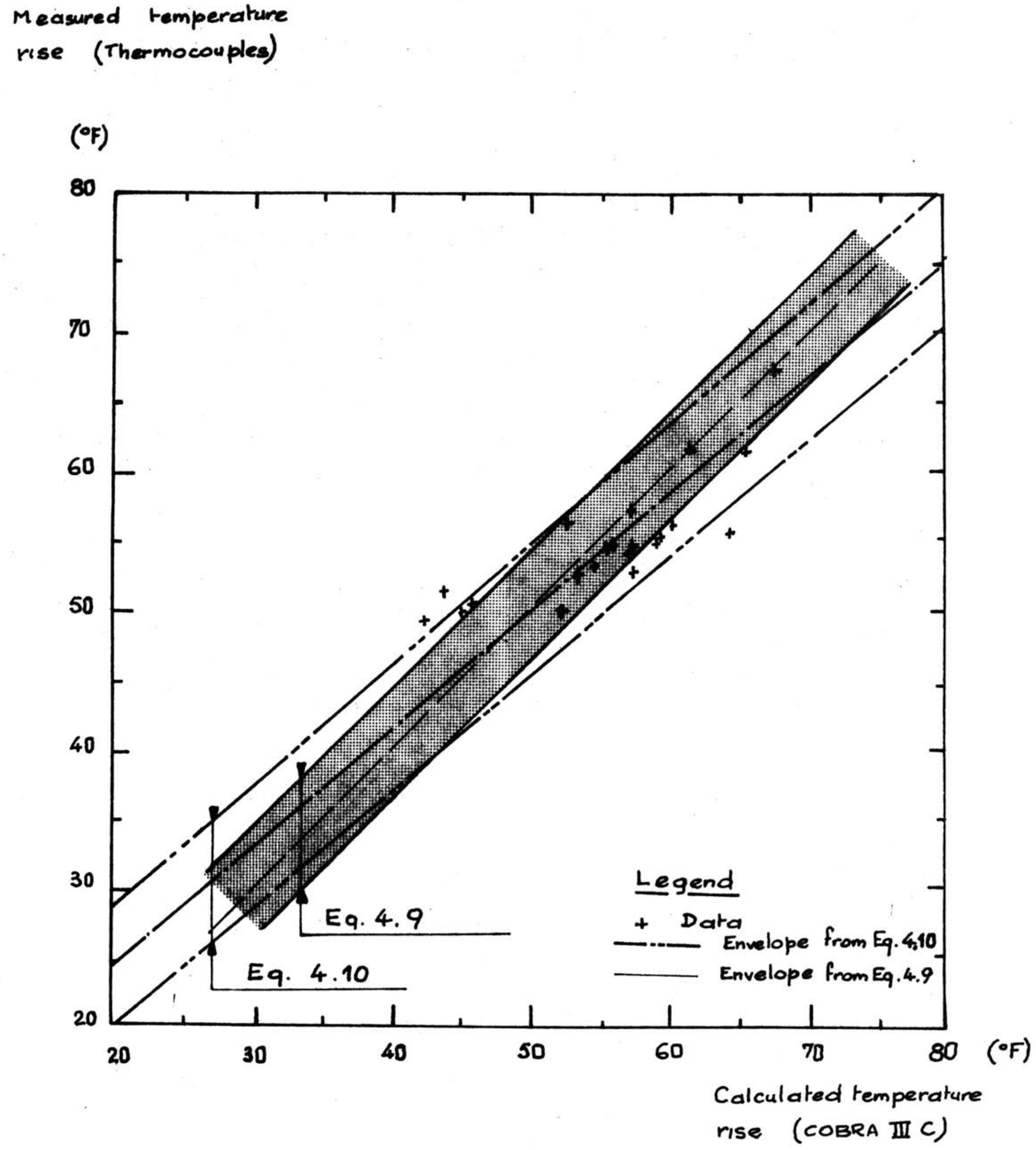


Fig. 32 Measured temperature rises versus calculated temperature rises.

It may be concluded that the treatment of the core octant by COBRA III C is valid and gives satisfactory information. Furthermore, it should be mentioned that the actual MDNBR, the maximum clad surface temperature, the maximum fuel centerline temperature are within the limits of the PSAR (2) as it can be seen below:

	Calculated value (from COBRA III C) (for a two sigma confidence level)	Reference (from PSAR)
MDNBR	3.891 ± 0.243	2.03
Max clad surface temp. (°F)	637.1 ± 5.1	652
Max fuel centerline temp (°F)	2,724.9 ± 109.9	3,920

These extra margins for the steady state operation of the Connecticut Yankee Reactor can be explained by the fact that the core is slightly subcooled, the actual average temperature of the coolant in the core is about 550°F instead of the 575°F design value (2). This conservative operation is very favorable for the fuel and clad operation since it tends to limit the number of clad failures.

The COBRA results indicate also that the cross flow exchange has very little effect on the assembly exit conditions, and therefore will not be possible to obtain cross flow exchange information between assemblies from the assembly exit thermocouples readings. Furthermore, the inlet flow distribution at the bottom of the core does not greatly influence the assembly exit conditions, is due to the fact that the core is slightly subcooled with very little subcooled boiling taking place.

CHAPTER 5

FINAL ANALYSIS OF THE CONNECTICUT YANKEE DATA

5.1 Introduction

From the results developed in Chapters 3 and 4 a method of evaluation of the uncertainty associated with the peaking factors can be established.

The flow calculations done with COBRA III C give the results for the assembly exit conditions that have been shown to be independent of several parameters or inlet flow distribution used for the computation. This indicates that the flow pattern is relatively stable and the core is operated under highly subcooled conditions. Also it is found to be difficult to predict the cross flow pattern from the information given by the thermocouples and the power distribution.

In this chapter a new version of FLOTA 1 and 2 is given which allows the use of uncertainties associated with each measurement that may vary from assembly to assembly.

5.2 Determination of the Uncertainty of the Peaking Factors

From the results of the sensitivity analysis done on the code "INCORE" (see Chapter 3), the uncertainties associated with:

- the same type of information (for example all the flux detector readings used in the calculation of the peaking factors in a given assembly) are combined according to Eq. 28 of Ref. 22:

$$p\,\bar{x} = \frac{1}{\sqrt{\sum_{n=1}^{N}\left(\frac{1}{p_n\bar{x}^2}\right)}} ,$$

where: $p\,\bar{x}$ = the probable error on $\bar{x}$

$p_n\bar{x}$ = the probable error on $\bar{x}_n$

N = the number of measurements on x used to compute $\bar{x}$,

- the different informations used to compute the peaking factors in a given assembly are combined statistically, since these informations are independent from each other.

As an example, taking the case of a specific collection of data at BOC of Core III (run 89):

- the code "INCORE" gives:

  - Maxi $F^N_{\Delta H}$ = 1.5026 for the hottest fuel rod in N 11,

- Maxi F_q^N = 1.8584 for the hottest fuel rod in N 11,
- the peaking factors for the hottest fuel rod in N 11 are calculated from the information given by three flux thimbles P 10, M 10, M 12.

For one sigma confidence level it may be established:

- Radial distance of the hottest fuel rod: 83.01 pitches in N 11 or 46.73 inches.
- For 1% increase in the flux detector readings:
  - uncertainty due to P 10 (curve B Fig. 7b) = 0.00325
  - uncertainty due to M 10 (curve B Fig. 7b) = 0.00325
  - uncertainty due to M 12 (curve B Fig. 7b) = 0.00325
  - uncertainty for the hottest fuel rod in N 11 due to flux detectors = 0.001876.
- For 4% decrease in the flux thimble prediction:
  - uncertainty due to P 10 (crrve B Fig. 9b) = 0.01320
  - uncertainty due to M 10 (curve B Fig. 9b) = 0.01320
  - uncertainty due to M 12 (curve B Fig. 9b) = 0.01320
  - uncertainty for the hottest fuel rod in N 11 due to flux thimble prediction uncertainties = 0.007621
- For 4% increase in the power prediction:
  - uncertainty due to P 10 (see 3.4.3) = 0.04000
  - uncertainty due to M 10 (see 3.4.3) = 0.04000

- uncertainty due to M 12 (see 3.4.3) = 0.04000
- uncertainty due to the power prediction uncertainties = 0.023094

- For 1 sigma confidence level the relative uncertainty in N 11 is given by:
  - uncertainty due to flux detector readings = 0.001876
  - uncertainty due to flux thimble prediction = 0.007621
  - uncertainty due to power prediction = 0.023094
  - relative uncertainty for the hottest fuel rod in N 11 = 0.024391

Absolute uncertainty on $F^N_{\Delta H}$ for two sigma confidence level:

$$0.02439 \times 2 \times 1.5026 = 0.0733.$$

The maximum $F^N_{\Delta H}$ for a two sigma confidence level is given by:

$$F^N_{\Delta H} = 1.5026 \pm 0.0733.$$

Similarly the uncertainty on F^N_q for two sigma confidence level is given by the statistical combination of:

- relative uncertainty associated with $F^N_{\Delta H}$,
- relative uncertainty associated with the local peaking factor F_z (taken equal to the uncertainty due to the flux detector reading).

This combination leads to:

$$F_q^N = 1.8584 \pm 0.0980 \ .$$

Since $F_q{}^E = 1.04$ (2)

$$F_q = 1.04 \times 1.8584 \pm 0.0980 = 1.9327 \pm 0.1019 \ .$$

The maximum linear heat generation rate is then:

$$\text{MLHGR} = F_q \times \frac{\text{kW}}{\text{MW}} \times \frac{1}{\text{total heated length(ft)}}$$

$$\times \text{ thermal power (MWt)}$$

$$= (1.9327 \pm 0.1019) \times 0.003096 \times 1825$$

$$= 10.920 \pm 0.576 \text{ kW/ft} \ .$$

This value is related to a two sigma confidence level.

The thermal power is taken as the rated power in a conservative manner even if the real power was below this value while the flux map was recorded. If the thermal power is taken as 1813.5 MWth power at which the data were collected, the MLGHR is then: 10.851 ± 0.529 kW/ft.

This gives a method for evaluating the uncertainty associated with the peaking factors. This same method may also be used to evaluate the uncertainties in the power distribution by taking each fuel assembly individually. This method shows that the uncertainty becomes smaller when the number of thimbles used for the calculation of the peaking factor in a given assembly, is increased.

The uncertainty evaluation is based on the assumption that the uncertainty due to the power prediction is estimated to be ± 4% and ± 4% for the flux thimble prediction, for one sigma confidence level. This should be confirmed by further work, by doing a sensitivity analysis on the main parameters of the PDQ code.

5.3 Second Sensitivity Analysis on the Effective Flow Factors

Using the method developed in 5.2, the uncertainty on the power prediction can be evaluated for each assembly. The uncertainty on the coolant assembly exit temperature has been evaluated in a global manner by Eq. 4.10, however one may provide in the future a more detailed analysis of the temperature uncertainty.

The two versions of the code developed in Chapter 2 FLOFA 1 and 2, have been remodeled to allow the use of the uncertainties on the power distribution and the exit temperature of the coolant for each assembly. This differs from the versions in Chapter 2, where only a unique value of the accuracy for each quantity was used for all the assemblies.

FLOFA 3 and FLOFA 4 are the new versions of the codes used for the evaluation of the uncertainties in the effective flow factors. They give very similar information to the one given by the original versions. (See Appendix B for the codes listings and sample input and output.)

The results for the two types of calculations are compared with the original versions on Fig. 33 and 34. The remarks and the conclusions remain unchanged from those obtained in Chapter 2. However the main interest with the new versions of FLOFA is constituted by the fact that individual inaccuracies can be selected.

5.4 Other Remarks on the Connecticut Yankee Data

5.4.1 Core Symmetry

The dissymmetric effect which appears in the power distribution is due to the fact that the only symmetry which can be maintained in the core is a quadrant symmetry. This is due to the fact that the changes in isotopic compositions for fuel elements in geometrical symmetrical positions in the core, are not the same in these fuel

Hottest assembly= N 11

All the uncertainties are related to a one sigma confidence level.

	15	14	13	12	11	10	9	8	
R							– – – –	0.8081 5.6515 5.8334 4.001	1 2 3 4
P					0.8086 5.8389 7.0651 5.506	1.0254 5.5036 6.8914 5.539	0.9859 4.7698 4.6098 3.157	– – – –	
N				0.8563 5.7859 6.5419 4.863	– – – –	0.9001 5.3063 4.9418 3.029	1.0160 5.4520 4.6869 2.360	1.0645 5.6114 5.1995 3.057	
M			– – – –	0.9515 5.0493 4.7828 3.095	1.0387 4.9941 4.2686 2.309	1.1291 5.3534 4.8775 2.859	1.0165 4.9834 4.2714 2.331	– – – –	
L		0.7304 5.5721 6.4745 4.955	1.0716 4.9410 4.6939 3.087	1.0008 4.8649 4.1988 2.382	0.9728 5.5490 4.6660 2.143	0.9936 5.5337 4.7446 2.336	0.9817 5.4376 4.6605 2.332	1.0443 5.5879 5.5879 4.010	
K		1.0340 5.6760 6.3849 4.743	0.9488 5.5337 5.1003 2.993	1.2321 5.6842 4.8757 2.341	0.9933 5.5036 4.7144 2.327	1.1431 5.5956 4.7868 2.314	– – – –	– – – –	
J	0.8971 6.3659 7.5710 5.745	1.0453 4.8551 4.3514 2.655	– – – –	1.0434 5.0050 4.2899 2.331	– – – –	1.0460 5.1422 4.4078 2.332	1.0041 5.7859 4.9486 2.311	1.0336 5.4813 5.7327 4.029	
H	0.9340 6.1476 7.4375 5.745	1.0319 5.7510 5.3184 3.059	1.2905 5.7514 5.2328 2.920	0.9864 5.4887 5.0049 2.891	1.0402 5.1542 4.7066 2.841	0.9639 5.9587 5.3553 2.836	1.0121 5.3741 4.8918 2.855	0.9242 6.0560 6.1244 4.002	

1: Effective flow factor: EFF

2: Relative uncertainty on EFF (%), assuming: relative power uncertainty=2.75%, outlet temp. uncertainty= 2.5°F, inlet temp. uncert.=0.1°F
3: Relative uncertainty on EFF (%), assuming: relative power uncertainty= value given in 4:, outlet temp. uncertainty= 2.14 °F, inlet temp. uncertainty= 0.1°F
4: Relative power uncertainty (%) used to compute 3:

Fig. 33 Comparison of the uncertainties associated with the effective flow factors. Heat capacity of the coolant independent of the temperature.

Hottest assembly= N 11

All the uncertainties are related to a one sigma confidence level.

	15	14	13	12	11	10	9	8	
R							- - - -	0.8110 5.9173 6.0232 4.001	1 2 3 4
P					0.8138 6.1048 7.2277 5.506	1.0268 5.7699 7.0490 5.539	0.9721 5.0507 4.8239 3.157	- - - -	
N				0.8611 6.0517 6.7156 4.863	- - - -	0.8986 5.5738 5.1529 3.029	1.0165 5.7186 4.9139 2.360	1.0677 5.8773 5.4102 3.057	
M			- - - -	0.9447 5.3216 4.9943 3.095	1.0299 5.2680 4.5032 2.309	1.1280 5.6206 5.0927 2.859	1.0077 5.2575 4.5056 2.331	- - - -	
L		0.7321 5.8381 6.6439 4.995	1.0612 5.2163 4.9072 3.087	0.9892 5.1427 4.4345 2.382	0.9748 5.8151 4.8974 2.143	0.9953 5.7999 4.9719 2.336	0.9821 5.7042 4.8882 2.332	1.0423 5.5607 5.7750 4.010	
K		1.0381 5.9418 6.5595 4.743	0.9505 5.7999 5.3123 2.993	1.2371 5.9580 5.1025 2.341	0.9946 5.7699 4.9420 2.327	1.1462 5.8615 5.0144 2.314	- - - -	- - - -	
J	0.9082 6.6259 7.7325 5.745	1.0329 5.1331 4.5791 2.655	- - - -	1.0349 5.2785 4.5235 2.331	- - - -	1.0410 5.4122 4.6384 2.332	1.0098 6.0518 5.1760 2.311	1.0347 5.7477 5.9206 4.029	
H	0.9436 6.4111 7.5986 5.745	1.0374 6.0258 5.5298 3.059	1.2971 6.0172 5.4472 2.920	0.9875 5.7551 5.2193 2.891	1.0355 5.4239 4.9235 2.841	0.9718 6.2252 5.5726 2.836	1.0114 5.6411 5.1071 2.855	0.9328 6.3213 6.3175 4.002	

1: Effective flow factor: EFF

2: Relative uncertainty on EFF (%), assuming: relative power uncertainty=2.75%, outlet temp. uncertainty=2.5°F, inlet temp. uncert.=0.1°F
3: Relative uncertainty on EFF (%), assuming: relative power uncertainty= value given in 4:, outlet temp. uncertainty=2.14°F, inlet temp. uncertainty=0.1°F
4: Relative power uncertainty (%) used to compute 3:

Fig. 34 Comparison of the uncertainties associated with the effective flow factors. Heat capacity of the coolant temperature dependent.

elements. In fact the coolant temperature at the core inlet is not uniform, and the corresponding variation is about ± 2.5 °F, as it can be seen on data collected at the plant.

Furthermore, as it is shown iy Fig. 35 the relative disposition of the inlet nozzles and outlet nozzles tends to favor asymmetry in the inlet temperature distribution and therefore in the power distribution. If the inlet nozzles were located at 90° from each other, instead of 45° and 135°, the inlet temperature of the coolant would probably be more symmetric.

5.4.2 Effective Flow Factors Variations

An arbitrary increase of the power in assembly N 9 by 10% has been done to compare the variations of:

- the flow distribution at the assembly exit, using COBRA III C,
- the coolant temperature distribution at the assembly exit,
- the effective flow factor distribution, assuming that the measured coolant temperature rise in assembly N 9 stays constant,

between the "reference case" (power in N 9 unchanged) and a "new core" (power in N 9 increased by 10%).

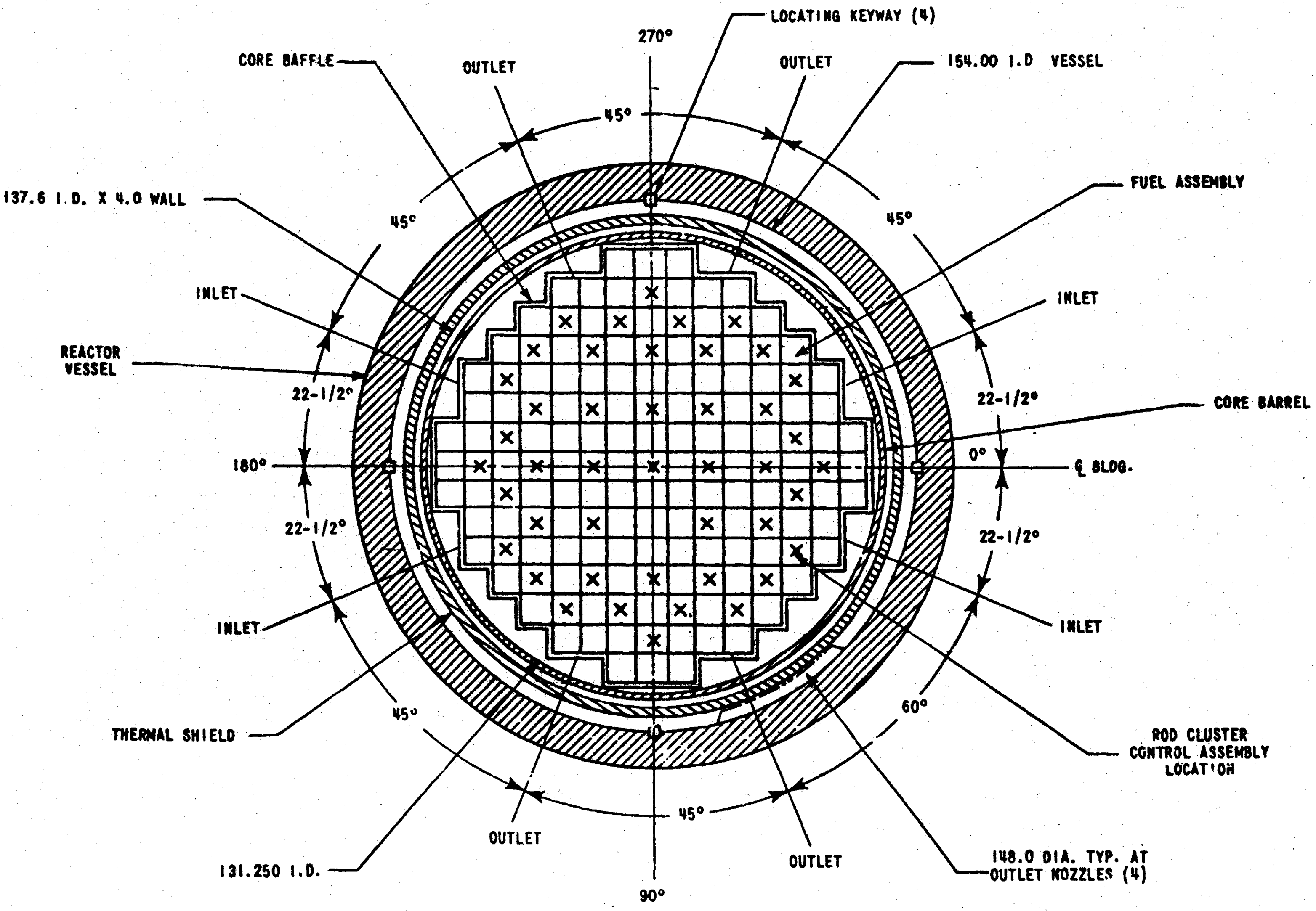


Fig. 35 REACTOR CORE CROSS SECTION

coolant for the assemblies on the edge of the core is lower than the measured temperature. But the computation of the temperature is based on the power distribution obtained from INCORE.

It is noticeable that the calculated value of the power for the assemblies on the edge of the core is, in most of the cases, greater than the predicted value obtained from the PDQ calculation. Combining this remark with the fact that the COBRA calculations would lead to higher coolant temperatures at the exit of the peripheral assemblies if higher power distribution were used, would seem to indicate that the power distribution of the assemblies at the edge of the core may be underestimated. There is no absolute evidence to support this argument, however it is also difficult to explain the low values of the effective flow factors. More than a flow distribustion, the effective flow factors seems to give an indication of the quality of the match between the core physics analysis and the thermal hydraulic analysis. An effective flow factor of one would tell that both analysis agree with each other.

5.4.3 Round Off Errors

Since all the information is treated by the computer, one may worry about the round off problem. The problem is

When the power in N 9 is increased by 10%:

- Fig. 36 shows that the coolant temperature distribution at the assembly exit is unchanged, except in assembly N 9, Table 6 indicates a relative increase of 9.47% for the calculated coolant temperature rise,
- Fig. 37 shows that the normalized flow distribution at the assembly exit is increased by a constant quantity = 0.0002 in each assembly, except in N 9 where it is reduced by a constant quantity = 0.0035,
- Fig. 37 indicates a decrease of the effective flow factor by about 0.003, except in N 9 where it is increased by 0.0994.

It is important to recognize that, the effective flow factor and the coolant flow distribution at the assembly exit varies in opposite directions for a local variation of power (as in this case in one assembly).

The values of the effective flow factors for the assembly on the edge of the core are always lower than the values for assembly well within the core. This would mean that either the estimated coolant temperature rise is too large or the calculated relative power is too small for the fuel assemblies on the edge of the core. The study developed in Chapter 4, using COBRA III C seems to indicate that the calculated exit temperature of the

Hottest assembly= N 11

	15	14	13	12	11	10	9	8	
R							562.20 562.19 -	565.75 565.75 573.8 0.769	1 2 3 4
P					564.63 564.62 571.6 0.737	579.03 579.05 575.7 1.012	588.67 588.65 588.2 1.201	571.93 571.91 -	
N				567.51 567.52 572.2 0.790	591.77 591.76 -	574.89 574.89 578.5 0.935	584.49 579.11 576.4 1.016	579.37 579.35 574.3 1.023	
M			-	581.40 581.39 582.7 1.062	587.66 587.66 583.7 1.178	586.59 586.56 577.8 1.158	586.53 586.50 583.9 1.157	574.66 574.65 -	
L		574.8 0.709	584.7 1.236	586.2 1.182	575.71 575.72 575.1 0.949	576.84 576.88 575.3 0.973	577.66 577.53 576.6 0.985	582.68 582.63 578.7 1.068	
K		573.5 0.978	575.3 0.929	573.4 1.163	575.7 0.980	583.68 583.63 574.5 1.103	584.38 584.37 -	570.51 570.50 -	
J	566.4 0.731	586.4 1.238	-	583.5 1.180	-	580.8 1.137	574.36 574.38 572.2 0.926	579.30 579.32 576.0 1.026	
H	568.4 0.796	572.5 0.957	572.6 1.199	575.9 0.977	580.9 1.126	570.3 0.855	577.5 1.032	567.86 567.90 569.3 0.803	

1: Coolant temperature at the assembly outlet
(power in N 9 increased by 10 %)
2: Coolant temperature at the assembly outlet
(reference case)
3: Coolant temperature at the assembly outlet
(measured value by outlet thermocouple)
4: Relative power of the assembly

595.09 595.10 -	591.66 591.69 -
591.75 591.87 -	591.21 591.28 -

Hot subchannels

Fig. 36 Coolant temperature distribution at the assembly exit. Power increase in N 9 case.

Hottest assembly- N 11

	15	14	13	12	11	10	9	8	
R							1.0063 1.0065 – –	1.0058 1.0060 0.8081 0.8060	1 2 3 4
P					1.0051 1.0053 0.8086 0.8069	0.9974 0.9976 1.0254 1.0229	0.9927 0.9929 0.9859 0.9829	1.0044 1.0046 – –	
N				1.0034 1.0036 0.8562 0.8534	0.9906 0.9908 – –	1.0029 1.0031 0.9001 0.8980	1.0000 0.9965 1.0160 1.1154	0.9997 0.9999 1.0645 1.0619	
M			– –	0.9980 0.9982 0.9515 0.9490	0.9940 0.9942 1.0387 1.0355	0.9952 0.9954 1.1297 1.1262	0.9954 0.9956 1.0166 1.0138	1.0066 1.0068 – –	
L		0.7303 0.7289	1.0716 1.0691	1.0008 0.9984	1.0028 1.0030 0.9728 0.9701	0.9996 0.9998 0.9936 0.9909	1.0024 1.0026 0.9817 0.9791	0.9986 0.9988 1.0443 1.0412	
K		1.0340 1.0310	0.9498 0.9461	1.2321 1.2284	0.9933 0.9906	0.9980 0.9982 1.1430 1.1405	0.9980 0.9982 – –	1.0076 1.0078 – –	
J	0.8971 0.8947	1.0453 1.0425	– –	1.0434 1.0407	– –	1.0460 1.0437	1.0050 1.0052 1.0041 1.0016	1.0015 1.0017 1.0336 1.0313	
H	0.9340 0.9320	1.0319 1.0290	1.2890 1.2867	0.9864 0.9838	1.0402 1.0371	0.9639 0.9614	1.0121 1.0091	1.0098 1.0100 0.9242 0.9222	

1: Normalized flow distribution at assembly outlet (reference case)
2: Normalized flow distribution at assembly outlet (power in N 9 increased by 10 %)
3: Effective flow factor (C_p=ct) (reference case)
4: Effective flow factor (C_p=ct) (power in N 9 increased by 10 %)

0.9934 0.9936 – –	0.9781 0.9782 – –
0.9784 0.9785	0.9790 0.9792

Hot subchannels

Fig. 37 Normalized flow distribution at the assembly exit. Power increase in N 9 case.

	Reference Case	New Case	Relative Variation
Relative assembly power	1.016	1.118	+ 10 %
Effective flow factor	1.0160	1.1154	+ 9.78 %
Normalized assembly outlet flow	1.0000	0.9965	- 0.35 %
Normalized assembly inlet flow	1.0065	1.0065	
Measured coolant temperature rise	54.1°F	--	
Calculated coolant temperature rise	56.81°F	62.19°F	+ 9.47 %

Table 6 Relative Variation of the Effective Flow Factor and Normalized Assembly Outlet Flow in N 9

not very difficult to treat but rather long. It may be recognized that most of the results in the computations are presented according to a normalized distribution which tends to limit the round off error problem. Varying the last figure of the temperature rise or of the power prediction in the calculation of the effective flow factor influenced the values of the effective flow factors by less than a percent, because of the normalization of the results. As far as the uncertainty problem is concerned, the round off problem is of a second order as compared to the other sources of inaccuracy.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The study which has been developed here can be divided in different areas:

- sensitivity studies on the codes INCORE and COBRA III C,
- uncertainties evaluation of
  - temperature measurement
  - peaking factors (assembly power distribution)
  - effective flow factors,
- modification of COBRA III C to accommodate the size of the Connecticut Yankee problem,
- analysis of operating data from Connecticut Yankee.

6.1 Sensitivity Studies

6.1.1 Sensitivity Study on the Code "INCORE"

The study has been performed to evaluate the uncertainty associated with:

- peaking factors $F^N_{\Delta H}$, F^N_q, F_z (results of the INCORE calculation) for assembly averaged values and hot fuel rod in each assembly from the knowledge of the inputs of the code INCORE:

- flux detector readings (measured values),
- flux thimble prediction,
- power distribution prediction

$\left.\begin{array}{l}\text{flux thimble prediction,}\\ \text{power distribution prediction}\end{array}\right\}$ obtained from the code PDQ.

This sensitivity study leads to the following results:

-- flux measurements uncertainty (flux detector reading)

- $F_{\Delta H}^{N}$ and F_{q}^{N} are affected, their change behavior is corrolated by Fig. 7a and 7b for 1% change in the flux detector reading,
- F_{z} is unaffected,

-- flux prediction uncertainty (flux thimble prediction)

- $F_{\Delta H}^{N}$ and F_{q}^{N} are affected, their change behavior is corrolated by Fig. 9a and 9b for 1% change in the flux thimble prediction,
- F_{z} is unaffected,

-- power distribution prediction

- $F_{\Delta H}^{N}$ and F_{q}^{N} are affected, they undergo 1% change for 1% change in the power prediction,
- F_{z} is unaffected.

These results allow the evaluation of the uncertainty associated with the peaking factors.

6.1.2 Sensitivity Study on the Code "COBRA III C"

The study has been done to determine the most adequate value of the parameters to be selected for the calculations. The parameters used in the study are:

- axial node length,
- flow covergence factor,
- S/L parameter defining the control volume,
- turbulent momentum factor,
- cross flow resistance factor,
- type of coolant flow distribution at the core inlet.

The results of this study leads to the conclusions:

- as a general conclusion the coolant conditions (axial flow, temperature, enthalpy) are weak functions of these parameters and do not vary greatly as can be seen in Chapter 4,
- the following values of the parameters provide the best accuracy of the results that can be achieved without any unnecessary increase of the computing time:

axial node length = 6 in,

flow convergence factor = 0.01,

- S/L parameter defining the control volume = 0.25,
- turbulent momentum factor = 0.5,

- cross flow resistance factor = 0.5,
- type of coolant distribution at core inlet
  = equal pressure gradient at core inlet.

For the operation point of view, it may be concluded that because of the insensitivity of the coolant conditions at the core exit a cross flow pattern change cannot be directly observed from the outlet thermocouples. However, further work in this area by simulation of flow blockage at the core inlet for one assembly, then for one subchannel, using COBRA III C should be useful and provide a check of the previous conclusion.

6.2 Evaluation of Uncertainties

6.2.1 Temperature Measurement

Very little data exists now on the uncertainty associated with temperature measurement in a reactor. However by using the results developed for the San Onofre Reactor(9), and by comparing the measured values and calculated values (using "COBRA III C") of the coolant temperatures at the core exit, the uncertainty on the temperature measurement of the coolant at core exit can be evaluated by Eq. 4.10.

$$t_{\text{corrected}} = 0.854\, t_{\text{measured}} + 7.43 \pm 4.27 \qquad (^\circ\mathrm{F})$$

This uncertainty on the temperature is to be used in the evaluation of the uncertainty associated with the effective flow factor.

6.2.2 Peaking Factors

By using the results of the sensitivity analysis done on the code "INCORE", the uncertainty associated with the peaking factors is calculated according to the procedure described in Chapter 5. As an example, using data taken on the Connecticut Yankee Reactor at BOC of Core III (run 89), for the hottest assembly N 11 it has been found:

$$F^N_{\Delta H} = 1.5026 \pm 0.0733$$

$$F^N_q = 1.8584 \pm 0.0980$$

$$F_q = 1.9327 \pm 0.1019$$

for a two sigma confidence level, or 4.87% and 5.27% of relative uncertainty on $F^N_{\Delta H}$ and F_q respectively.

The evaluation of these uncertainties associated with the peaking factors, allows the evaluation of the uncertainty associated with the maximum linear generation, in this particular case it has been found:

$$\text{MLHGR} = 10.920 \pm 0.576 \text{ kW/ft}$$

for a two sigma confidence level.

The evaluation of the uncertainty associated with each peaking factor is based on the assumption that the uncertainty associated with the flux thimble prediction and the power distribution prediction is 4% for one sigma confidence level. Further work on the code PDQ should be done to evaluate the uncertainty associated with flux thimble and power distribution predictions, due to the uncertainty associated with the fuel enrichment or other quantities (such as mesh spacing) used as inputs in the code "PDQ". Further work can be done also to check the time independence of the curves in Fig. 7 and 9 from one core to another.

6.2.3 Effective Flow Factors

The uncertainty associated with the effective flow factors has been evaluated from the knowledge of the uncertainties associated with temperature measurements and power distribution calculations.

For one sigma confidence an average 6% uncertainty has been found for the effective flow factor. A large fraction (about 70%) is due to the uncertainty on the coolant temperature measurement at the assembly outlet. This uncertainty is rather large compared to the possible variations of the coolant flow distribution from one assembly to another.

6.3 Modification of the Code "COBRA III C"

The original version of the code "COBRA III C" was too small to accommodate the size of the Connecticut Yankee problem. The changes have been made on:

- flow channels number increase from 15 to 30,
- flow channels connections number increase from 30 to 47,
- fuel rods number increase from 15 to 35,
- fuel types number increase from 2 to 3,
- axial node number decrease from 60 to 30,
- axial heat flux nodes number increase from 30 to 39.

Appendix C of this work presents a method to handle easily further changes in the code and should be useful for a future user of the code "COBRA III C".

6.4 Analysis of Operating Data From Connecticut Yankee

The analysis of the operating data from Connecticut Yankee gave an opportunity to evaluate uncertainties associated with the information obtained from the core instrumentation or quantities derived from the core instrumentation.

The sensitivity study done on the code "COBRA III C", applied to the Connecticut Yankee case shows the weak dependence of the assembly exit conditions of the coolant. This is due to the fact that the core is operated with a fair degree of subcooling. Hence, the actual values of some critical parameters like DNBR, MLHGR, maximum clad outside temperature, maximum fuel centerline temperature are conservatively within the limits of the technical specifications.

The effective flow factor concept in fact gives more information on the quality of the agreement between the reactor physics analysis and the thermal hydraulic analysis of the core, than on the coolant distribution through the core. A good agreement between reactor physics and thermal hydraulic analysis in a given assembly would lead to an effective flow factor near 1.0 for that assembly. The low values of the effective flow factors for the assemblies located on the core edge, seem to indicate underprediction of the average assembly power. Further work on the power distribution calculation for the peripheral assemblies, using different power predictions should clarify this point.

APPENDIX A

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APPENDIX B

The following section contains the codes listings, samples inputs and outputs of the codes used in this work.

```
C     PROGRAM FLOFA 1
C*******************
C CASE EFFECTIVE FLOW FACTOR DISTRIBUTION
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL *8 LEFT, RIGHT, ASPEC, FSPEC, BLANKS
      REAL*8 LEFTA, RIGHTA, ASPECA, FSPECA,BLANKA
      DIMENSION RESUL1(8,8,4), RESUL2(8,8,5), RESUL3(8,8,8),
     1SIRTIN(8,8), Q(8,8), TOUT(8,8), Y(8,8), X(8,8), SIRTOU(8,8), SPO(8
     2,8), STO(8,8), STI(8,8), SI2Y(8,8), SI2RFL(8,8),
     3SIFLO(8,8,5), FLOFA(8,8,5), SI2FLO(8,8,5), SIPFLO(8,8,5),
     4CONOR(8,8,8), COPO1(8,8,8), COTO1(8,8,8), COTI1(8,8,8), COPO2(8,8,
     58), COTO2(8,8,8), COTI2(8,8,8),
     6SIRPO(10), SITOUT(10), SITIN(10), SUMY(1) , FANOR(1) , SPOSUM(10),
     7STOSUM(10), STISUM(10), S2YSUM(10), A(10), COLUMN(4),
     8FORM(10), RUN(3), FORMA(10), COLUMI(8), COLUMK(5), COLUMM(8)
      READ (5,8) RUN
    8 FORMAT(5A8)
      READ (5,9) POWER
    9 FORMAT (A8)
      READ(5,10) NUM, TIN, NUM2
   10 FORMAT(I2,7X,F10.0,4X,I3)
      READ(5,11) LEFTA, RIGHTA, ASPECA, FSPECA, BLANKA
   11 FORMAT(5A8)
      READ (5,12) LEFT,RIGHT, ASPEC, FSPEC, BLANKS
   12 FORMAT(5A8)
      READ (5,13) (COLUMI(I), I=1,8)
   13 FORMAT(8A8)
      READ (5,18) (COLUMK(K), K=1,5)
   18 FORMAT(5A8)
      READ (5,19) (COLUMM(M), M=1,8)
   19 FORMAT(8A8)
      READ (5,5) (COLUMN(N), N=1,4)
   5  FORMAT(4A8)
      DO 14 I=1,8
      DO 14 J=1,8
      TOUT(I,J)=0.0
      Q(I,J)=0.0
      Y(I,J) = 0.0
      X(I,J) =0.0
      SIRTOU(I,J)=0.0
      SIRTIN(I,J)=0.0
      SPO(I,J)=0.0
      STO(I,J)=0.0
      STI(I,J)=0.0
      SI2Y(I,J) =0.0
   14 CONTINUE
      DO 16 IN = 1, NUM2
      READ (5,15) I, J, XQ, XTOUT
   15 FORMAT(2(I2,1X),2(F10.0,4X))
      Q(I,J) = XQ
      TOUT(I,J) = XTOUT
   16 CONTINUE
      READ (5,17) (SIRPO(L), SITOUT(L), SITIN(L), L = 1, NUM)
   17 FORMAT(3F10.0)
      SUMY(1)=0.0
      DO 20 I = 1,8
      DO 20 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 20
      X(I,J) = TOUT(I,J) - TIN
```

```
      Y(I,J) = Q(I,J)/X(I,J)
      SUMY(1)=SUMY(1)+Y(I,J)
 20   CONTINUE
      FANOR(1)=38./SUMY(1)
      DO 998 L = 1, NUM
      SPOSUM(L) = 0.0
      STOSUM(L) = 0.0
      STISUM(L) = 0.0
      S2YSUM(L) = 0.0
      DO 30 I =1,8
      DO 30 J =1,8
      DO 25 K = 1,5
      FLOFA(I,J,K) =0.0
      SI2FLO(I,J,K) =0.0
      SIFLO(I,J,K) =0.0
      SIRFLO(I,J,K) =0.0
      RESUL2(I,J,K) = 0.0
 25   CONTINUE
      DO 30 M = 1,8
      RESUL3(I,J,M) = 0.0
 30   CONTINUE
      DO 501I = 1,8
      DO 50 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 50
      SIRTOU(I,J) = (SITOUT(L)/X(I,J))*(SITOUT(L)/X(I,J))
      SIRTIN(I,J) = (SITIN(L)/X(I,J))*(SITIN(L)/X(I,J))
      SPO(I,J) = Y(I,J)*SIRPO(L)* Y(I,J)* SIRPO(L)
      STO(I,J) = Y(I,J)* Y(I,J)* SIRTOU(I,J)
      STI(I,J) = Y(I,J)* Y(I,J)* SIRTIN(I,J)
      SI2Y(I,J) = SPO(I,J) + STO(I,J) +STI(I,J)
      SPOSUM(L) = SPOSUM(L) + SPO(I,J)
      STOSUM(L) = STOSUM(L) + STO(I,J)
      STISUM(L) = STISUM(L) + STI(I,J)
      S2YSUM(L) = S2YSUM(L) + SI2Y(I,J)
      A(L)=S2YSUM(L)/(SUMY(1)*SUMY(1))
 50   CONTINUE
501   CONTINUE
      DO 521I=1,8
      DO 52 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 52
      SI2RFL(I,J)    = A(L) + SIRPO(L)* SIRPO(L) + SIRTOU(I,J)
     1+ SIRTIN(I,J)
      K = 1
      FLOFA(I,J,K)=FANOR(1)*Y(I,J)
      K = 2
      SI2FLO(I,J,K) = (Y(I,J)* FANOR(1))**2*A(L)+(FANOR(1)*Y(I,J)
     1* SIRPO(L))**2 + (FANOR(1)* Y(I,J)/X(I,J)* SITOUT(L))
     2**2 + (FANOR(1)* Y(I,J)/X(I,J)* SITIN(L))**2
      K = 3
      SIFLO(I,J,K)= DSQRT(SI2FLO(I,J,2))
      K = 4
      SIRFLO(I,J,K) = SIFLO(I,J,3)/FLOFA(I,J,1)* 100.
      DO 522K=1,4
      RESUL2(I,J,K) = FLOFA(I,J,K) + SI2FLO(I,J,K) + SIFLO(I,J,K)
     1 + SIRFLO(I,J,K)
522   CONTINUE
 52   CONTINUE
521   CONTINUE
      DO 531I=1,8
```

```
      DO 53 J=1,8
      DO 53 M=1,8
      CONOR(I,J,M)=0.0
      COPO1(I,J,M)=0.0
      COTO1(I,J,M)=0.0
      COTI1(I,J,M)=0.0
      COPO2(I,J,M)=0.0
      COTO2(I,J,M)=0.0
      COTI2(I,J,M)=0.0
      RESUL3(I,J,M)=0.0
53    CONTINUE
531   CONTINUE
      DO 551I=1,8
      DO 55 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 55
      M = 1
      CONOR(I,J,M) = A(L)/SI2RFL(I,J)* 100.
      M = 2
      COPO1(I,J,M)=SIRPO(L) * SIRPO(L)/ SI2RFL(I,J)* 100.
      M = 3
      COTO1(I,J,M) = SIRTOU(I,J)/SI2RFL(I,J)* 100.
      M = 4
      COTI1(I,J,M) = SIRTIN(I,J)/SI2RFL(I,J)* 100.
      M = 5
      COPO2(I,J,M)=CONOR(I,J,1)*SPOSUM(L)/S2YSUM(L)+COPO1(I,J,2)
      M = 6
      COTO2(I,J,M)=CONOR(I,J,1)*STOSUM(L)/S2YSUM(L)+COTO1(I,J,3)
      M = 7
      COTI2(I,J,M)=CONOR(I,J,1)*STISUM(L)/S2YSUM(L)+COTI1(I,J,4)
      DO 552M=1,7
      RESUL3(I,J,M) = CONOR(I,J,M) + COPO1(I,J,M) + COTO1(I,J,M)
     1+ COTI1(I,J,M) + COPO2(I,J,M) + COTO2(I,J,M) + COTI2(I,J,M)
552   CONTINUE
 55   CONTINUE
551   CONTINUE
      WRITE(6,60) RUN(1), RUN(1)
60    FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION #',2X,A8,15X,'R
     1UN # ',A8,'PAGE 1',////)
      WRITE(6,61)
61    FORMAT(1X,'EFF = CONSTANT * RELATIVE POWER / TEMPERATURE DIFFERENC
     1E ACROSS THE FUEL ASSEMBLY',////)
      WRITE(6,62) SIRPO(L), SITOUT(L), SITIN(L)
62    FORMAT(1X,'PARAMETERS : RELATIVE POWER STD.',5X,'=',F10.4,/14X,'OU
     1TLET TEMPERATURE STD. =',F8.2,2X,'DEG. F. ',/14X,'INLET TEMPERATUR
     2E STD.  =',F8.2,2X,'DEG. F.',////)
      WRITE(6,63) SUMY(1), FANOR(1), S2YSUM(L), SPOSUM(L), STOSUM(L),
     1STISUM(L)
63    FORMAT(1X,'RESULTS: SUM OF THE RATIOS',6X,'=',2X,F14.10,/10X,'NORM
     1ALIZATION FACTOR   =',2X,F14.10,/10X,'SUM OF THE STD. SQUARE =',2X
     2,F14.10,/10X,'CONTRIBUTION OF POWER  =',2X,F14.10,/10X,'CONTRIBUTI
     3ON OF T. OUT =',2X,F14.10,/10X,'CONTRIBUTION OF T. INL =',2X,F14.1
     40,///)
      WRITE(6,640) POWER
640   FORMAT(1H ,'THERMAL POWER =',A8,' MWTH')
      WRITE(6,64) RUN(1)
 64   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 2',/)
      WRITE (6, 65) SIRPO(L), SITOUT(L), SITIN(L)
65    FORMAT(1H ,'RELATIVE POWER STD.',5X,'=',F10.4,/1H ,'CUTLET TEMPERA
     1TURE STD. =',F8.2,2X,'DEG. F.',/1H ,'INLET TEMPERATURE STD.  =',F8
```

```
     2.2,2X,'DEG. F.',///)
      WRITE(6, 66)
 66   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 100 I = 1,8
      DO 95 K = 1,5
      DO 90 J=1,8
      IF (RESUL2(I,J,K).EQ.0.0) GOTO 85
      FORM(J+1) = FSPEC
      GO TO 90
 85   FORM(J+1) = ASPEC
      RESUL2(I,J,K) = BLANKS
 90   CONTINUE
      WRITE(6, FORM)(RESUL2(I,J,K),J=1,8)
      WRITE(6,971)COLUMK(K)
971   FORMAT(1H+,122X,A8)
      IF(K.NE.2.0) GO TO 95
      WRITE (6,96) COLUMI(I)
96    FORMAT(1H+,126X,A4)
95    CONTINUE
100   CONTINUE
      WRITE(6, 120)
120   FORMAT(//,1X,'TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:',/,
     11X,'1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES W
     2ITH OUTLET THERMOCOUPLES',/1X,'2* SQUARE OF THE STANDARD DEVIATION
     3 OF THE EFFECTIVE FLOW FACTOR',/1X,'3* STANDARD DEVIATION OF THE E
     4FFECTIVE FLOW FACTOR',/1X,'4* RELATIVE STANDARD DEVIATION OF THE E
     5FFECTIVE FLOW FACTOR')
      WRITE(6,140) RUN(1)
140   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 3',/)
      WRITE (6,141) SIRPO(L), SITOUT(L), SITIN(L)
141   FORMAT(1H ,'RELATIVE POWER STD.',5X,'=',F10.4,/1H ,'OUTLET TEMPERA
     1TURE STD. =',F8.2,2X,'DEG. F.',/1H ,'INLET TEMPERATURE STD.  =',F8
     2.2,2X,'DEG. F.',///)
      WRITE(6,142)
142   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 200 I = 1,5
      DO 190 M = 1,8
      DO 180 J=1,8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO  170
      FORM(J+1) = FSPEC
      GO TO 180
170   FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
180   CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,191) COLUMM(M)
191   FORMAT(1H+,122X,A4)
      IF(M.NE.4.0) GO TO 190
      WRITE (6,192) COLUMI(I)
192   FORMAT(1H+,126X,A4)
190   CONTINUE
 200  CONTINUE
      WRITE (6,210) RUN(1)
```

```
210   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 4',/)
      WRITE (6,211) SIRPO(L), SITOUT(L), SITIN(L)
211   FORMAT(1H ,'RELATIVE POWER STD.',5X,'=',F10.4,/1H ,'OUTLET TEMPERA
     1TURE STD. =',F8.2,2X,'DEG. F.',/1H ,'INLET TEMPERATURE STD.  =',F8
     2.2,2X,'DEG. F.',///)
      WRITE(6,212)
212   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 300 I = 6, 8
      DO 285 M = 1,8
      DO 270 J =1, 8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO 255
      FORM(J+1) = FSPEC
      GO TO 270
255   FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
270   CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,286) COLUMM(M)
286   FORMAT(1H+,122X,A4)
      IF(M.NE.4.0) GO TO 285
      WRITE (6,288) COLUMI(I)
288   FORMAT(1H+,126X,A4)
285   CONTINUE
300   CONTINUE
      WRITE(6,400)
400   FORMAT(//,1X,'TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MA
     1DE UP OF:           ',//1X,'1* CONTRIBUTION OF NORMALIZATION FACTOR'
     2,/1X,'2* CONTRIBUTION OF POWER',/1X,'3* CONTRIBUTION OF OUTLET TEM
     3PERATURE',/1X,'4* CONTRIBUTION OF INLET TEMPERATURE',/1X,'5* TOTAL
     4 CONTRIBUTION OF POWER',/1X,'6* TOTAL CONTRIBUTION OF OUTLET TEMPE
     5RATURE',/1X,'7* TOTAL CONTRIBUTION OF INLET TEMPERATURE')
998   CONTINUE
      DO 450 I=1,8
      DO 450 J=1,8
      DO 450 N=1,4
      RESUL1(I,J,N)=0.0
450   CONTINUE
      DO 460 I=1,8
      DO 460 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 460
      N=1
      RESUL1(I,J,N)=TOUT(I,J)
      N=2
      RESUL1(I,J,N)=X(I,J)
      N=3
      RESUL1(I,J,N)=Q(I,J)
460   CONTINUE
      WRITE(6,500) RUN(1)
500   FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION # ',A8,////1H ,
     1'THESE VALUES ARE THE INPUT DATA USED FOR THE COMPUTATION',////1H
     2,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14X,'9',14X,
     3'8',///)
      FORMA(1)=LEFTA
      FORMA(10)=RIGHTA
      DO 510 I=1,8
      DO 505 N=1,4
```

```
      DO 504 J=1,8
      IF(RESUL1(I,J,N).EQ.0.0) GO TO 503
      FORMA(J+1)=FSPECA
      GO TO 504
  503 FORMA(J+1)= ASPECA
      RESUL1(I,J,N)=BLANKA
  504 CONTINUE
      WRITE(6,FORMA) (RESUL1(I,J,N),J=1,8)
      WRITE(6,507)COLUMN(N)
  507 FORMAT(1H+,122X,A4)
      IF(N.NE.2.0) GO TO 505
      WRITE(6,506) COLUMI(I)
  506 FORMAT(1H+,126X,A4)
  505 CONTINUE
  510 CONTINUE
      WRITE(6,530)
  530 FORMAT(////1H ,'THE ABOVE DATA ARE: 1* OUTLET TEMPERATURE (DEG. F.
     1.)',/1H ,20X,'2* TEMPERATURE DIFFERENCE ACROSS THE FUEL ASSEMBLY (
     2DEG. F.)',/1H ,20X,'3* RELATIVE POWER OF THE ASSEMBLY',///)
      WRITE(6,535) TIN
  535 FORMAT(1H ,'INLET TEMPERATURE =',F6.2,'DEG. F.')
      STOP
      END
```

```
 SAMPLE INPUT FOR FLOFA 1
*************************


089
1813.5
10         522.3         38
(          ' ')     A8,7X,  F15.3,
(          ' ')     A8,7X,  F15.10,
R          P        N       M         L          K          J          H
1*         2*       3*      4*
1*         2*       3*      4*        5*         6*         7*
1*         2*       3*
 1   8  0.7690            573.8
 2   5  0.7366            571.6
 2   6  1.0118            575.7
 2   7  1.2005            588.2
 3   4  0.7895            572.2
 3   6  0.9347            578.5
 3   7  1.0156            576.4
 3   8  1.0228            574.3
 4   4  1.0619            582.7
 4   5  1.1784            583.7
 4   6  1.1579            577.8
 4   7  1.1570            583.9
 5   2  0.7085            574.8
 5   3  1.2356            584.7
 5   4  1.1817            586.2
 5   5  0.9491            575.1
 5   6  0.9730            575.3
 5   7  0.9850            576.6
 5   8  1.0883            578.7
 6   2  0.9762            573.5
 6   3  0.9292            575.3
 6   4  1.1633            573.4
 6   5  0.9801            575.7
 6   6  1.1025            574.5
 7   1  0.731             566.4
 7   2  1.238             586.4
 7   4  1.1799            583.5
 7   6  1.1365            581.1
 7   7  0.9258            572.2
 7   8  1.0256            576.0
 8   1  0.7956            568.4
 8   2  0.9572            572.5
 8   3  1.1994            572.6
 8   4  0.9769            575.9
 8   5  1.1263            580.9
 8   6  0.8549            570.3
 8   7  1.0323            577.5
 8   8  0.8026            569.3
 0.0250      2.0          0.1
 0.0250      2.5          0.1
 0.0250      2.5          0.2
 0.0275      2.0          0.1
 0.0275      2.5          0.1
 0.0275      2.0          0.2
 0.0275      2.5          0.2
 0.0300      2.0          0.1
 0.0300      2.5          0.1
 0.0300      2.5          0.2
```

```
                              EFFECTIVE FLOW FACTOR DISTRIBUTION #  089                  RUN # 089     PAGE 1


EFF = CONSTANT * RELATIVE POWER / TEMPERATURE DIFFERENCE ACROSS THE FUEL ASSEMBLY


PARAMETERS : RELATIVE POWER STD.      =    0.0275
             OUTLET TEMPERATURE STD. =    2.50  DEG. F.
              INLET TEMPERATURE STD.  =    0.10  DEG. F.


RESULTS: SUM OF THE RATIOS      =    0.7021423057
         NORMALIZATION FACTOR   =   54.1200831974
         SUM OF THE STD. SQUARE =    0.0000381581
         CONTRIBUTION OF POWER  =    0.0000099162
         CONTRIBUTION OF T. OUT =    0.0000281968
         CONTRIBUTION OF T. INL =    0.0000000451


THERMAL POWER =1813.5   MWTH
```

```
                                                                                                  RUN #  089        PAGE 2
RELATIVE POWER STD.        =    0.0275
OUTLET TEMPERATURE STD. =       2.50  DEG. F.
INLET TEMPERATURE STD.     =    0.10  DEG. F.


       15                14                13                12                11                10                 9                 8


                                                                                                                           0.8081231841   1*
                                                                                                                           0.0020858243   2*   R
                                                                                                                           0.0456708252   3*
                                                                                                                           5.6514682551   4*

                                                                         0.8086177137      1.0254438236      0.9859053092                   1*
                                                                         0.0022291886      0.0031850353      0.0022114302                   2*   P
                                                                         0.0472142841      0.0564361165      0.0470258458                   3*
                                                                         5.8388881754      5.5035795472      4.7698136266                   4*

                                                       0.8562686510                        0.9001075047      1.0159770147      1.0645004057   1*
                                                       0.0024545168                        0.0022812135      0.0030682386      0.0035680274   2*   N
                                                       0.0495430805                        0.0477620511      0.0553916837      0.0597329674   3*
                                                       5.7859271649                        5.3062607332      5.4520607127      5.6113616394   4*

                                                       0.9514919925      1.0386825088      1.1291107087      1.0165087055                   1*
                                                       0.0023082316      0.0026908359      0.0036537761      0.0025660509                   2*   M
                                                       0.0480440588      0.0518732672      0.0604464729      0.0506562029                   3*
                                                       5.0493392628      4.9941408259      5.3534584711      4.9833516105                   4*

                     0.7303634085      1.0716470320    1.0008404118      0.9728289955      0.9935630368      0.9817363158      1.0443064990   1*
                     0.0016562229      0.0028037128    0.0023707365      0.0029140631      0.0030229046      0.0028497531      0.0030553672   2*   L
                     0.0406967182      0.0529500973    0.0486902094      0.0539820628      0.0549809477      0.0533830786      0.0552753763   3*
                     5.5721189378      4.9410016326    4.8649323921      5.5489775736      5.5337150931      5.4376188130      5.2930223366   4*

                     1.0339895583      0.9498373832    1.2320526964      0.9933163585      1.1430534813                                      1*
                     0.0034443765      0.0027569756    0.0049045168      0.0029885854      0.0040909161                                      2*   K
                     0.0586888108      0.0525059575    0.0700322552      0.0546679559      0.0639602701                                      3*
                     5.6759577832      5.5337150931    5.6841931727      5.5035795472      5.5955623363                                      4*

   0.8970925355      1.0452521529                      1.0434033687                        1.0460454856      1.0040956518      1.0336230415   1*
   0.0032513287      0.0025753686                      0.0027271862                        0.0028933540      0.0033751735      0.0032099150   2*   J
   0.0571080443      0.0507480918                      0.0522224679                        0.0537899064      0.0580962431      0.0566561113   3*
   6.3655034330      4.8551052196                      5.0050123690                        5.1422148615      5.7859271649      5.4813127286   4*

   0.9    116744     1.0319470344      1.2904896180    0.9863789044      1.0401953875      0.9639012318      1.0121043820      0.9241867824   1*
   0.0  2969255      0.0035331065      0.0055098049    0.0029310761      0.0028744772      0.0032989409      0.0029584426      0.0031324986   2*   H
   0.0574188601      0.0594399437      0.0742213240    0.0541394133      0.0536141508      0.0574364074      0.0543915671      0.0559687291   3*
   6.1475527217      5.7599798103      5.7514080641    5.4887034807      5.1542384717      5.9587440592      5.3741064684      6.0559975753   4*


TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:
1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES WITH OUTLET THERMOCOUPLES
2* SQUARE OF THE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
3* STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
4* RELATIVE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
```

```
                                                                                              RUN #  089      PAGE 3
RELATIVE POWER STD.     =    0.0275
OUTLET TEMPERATURE STD. =    2.50  DEG. F.
INLET TEMPERATURE STD.  =    0.10  DEG. F.


        15            14            13            12            11            10             9             8

                                                                                                   2.4233370156   1*
                                                                                                  23.6778793192   2*
                                                                                                  73.7807344900   3*
                                                                                                   0.1180491752   4*  P
                                                                                                  24.3076342601   5*
                                                                                                  75.5714514176   6*
                                                                                                   0.1209143223   7*

                                                         2.2702625507  2.5553235939  3.4019942957                 1*
                                                        22.1822232538 24.9674904024 33.2401188354                 2*
                                                        75.4268312654 72.3614077513 63.2566761871                 3*
                                                         0.1206829300  0.1157782524  0.1012106819                 4*  P
                                                        22.7721985850 25.6315448234 34.1241983929                 5*
                                                        77.1044343201 74.2496557274 65.7705686972                 6*
                                                         0.1233670949  0.1187994492  0.1052329099                 7*

                                           2.3120140896                2.7489018203  2.6038444362  2.4581019041   1*
                                          22.5901681211               26.8588995842 25.4415766070 24.0175592020   2*
                                          74.9778532242               70.2797509939 71.8396355399 73.4068878734   3*
                                           0.1199645652                0.1124476016  0.1149434169  0.1174510206   4*  N
                                          23.1909934652               27.5732593667 26.1182401864 24.6563485281   5*
                                          76.6863084413               72.3110429645 73.7637378330 75.2232942011   6*
                                           0.1226980935                0.1156976687  0.1180219805  0.1203572707   7*

                                           3.0357590441  3.1032361940  2.7006451556  3.1166980759                 1*
                                          29.6617168087 30.3210208186 26.3873945995 30.4524561217                 2*
                                          67.1950121277 66.4693919602 70.7986823531 66.3247362245                 3*
                                           0.1075120194  0.1063510271  0.1132778918  0.1061195780                 4*  M
                                          30.4506224562 31.1274618185 27.0892138757 31.2623928751                 5*
                                          69.4387763017 68.7625181524 72.7943152199 68.6278026406                 6*
                                           0.1111012421  0.1100200290  0.1164709044  0.1098044842                 7*

               2.4928470751  3.1703441318  3.2702637659  2.5136827324  2.5275677771  2.6176940269  2.7626695920   1*
              24.3570464300 30.9767173407 31.9530095450 24.5606269371 24.6962945770 25.5768078330 26.9934213757   2*
              73.0332532897 65.7477421401 64.6732494899 72.8091956175 72.6598818350 71.6907030153 70.1316983150   3*
               0.1168532053  0.1051963874  0.1034771992  0.1164947130  0.1162558109  0.1147051248  0.1122107173   4*  L
              25.0048650174 31.8005977455 32.8028561620 25.2138601071 25.3531360670 26.2571605189 27.7113590024   5*
              74.8753344475 68.0904575225 67.0898001577 74.6666732158 74.5276197414 73.6250394180 72.1731639353   6*
               0.1198005351  0.1089447320  0.1073436803  0.1194666771  0.1192441916  0.1178000631  0.1154770623   7*
```

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                                                                                              RUN #  089      PAGE 4

RELATIVE POWER STD.     =    0.0275
OUTLET TEMPERATURE STD. =    2.50  DEG. F.
INLET TEMPERATURE STD.  =    0.10  DEG. F.


       15            14            13            12            11            10             9             8


               2.4024706336  2.5275677771  2.3955141674  2.5553235939  2.4720026070                                1*
              23.4739986074 24.6962945770 23.4060285461 24.9674904024 24.1533798342                                2*
              74.0051225629 72.6598818350 74.0799293994 72.3614077513 73.2574057097                                3*
               0.1184081961  0.1162558109  0.1185278870  0.1157782524  0.1172118491                                4*  K
              24.0983309814 25.3531360670 24.0285531365 25.6315449234 24.7957815496                                5*
              75.7804203460 74.5276197414 75.8500867248 74.2496556274 75.0840839162                                6*
               0.1212486726  0.1192441916  0.1213601388  0.1187994492  0.1201345343                                7*

 1.9099249923  3.2835157938                3.0897695391                2.9270892358  2.3120140896  2.5761268214  1*
18.6614462555 32.0824920022               30.1894411715               28.5999286255 22.5901681211 25.1707540445  2*
79.3017455587 64.5307430052               66.6142065589               68.3636003781 74.9778532242 72.1376988160  3*
 0.1268827935  0.1032491988                0.1065827305                0.1093817606  0.1199645652  0.1154203181  4*  J
19.1577803159 32.9357824540               30.9923825787               29.3605941445 23.1909934652 25.8402146205  5*
80.7130787581 66.9570862081               68.8973816107               70.5265633542 76.6863084413 74.0413192687  6*
 0.1291409260  0.1071313379                0.1102358106                0.1128425014  0.1226980935  0.1184661108  7*

 2.0480090766  2.3328911666  2.3398501068  2.5691937830  2.9134487610  2.1798516421  2.6799325813  2.1104011544  1*
20.0105346947 22.7941533314 22.8621475664 25.1030128904 28.4666506232 21.2988386607 26.1850167082 20.6202536123  2*
77.8169492659 74.7533501417 74.6785167000 72.2122537207 68.5102841612 76.3990711832 71.0214164442 77.1459117744  3*
 0.1245069538  0.1196053602  0.1194856267  0.1155396060  0.1096164547  0.1222385139  0.1136342663  0.1234334588  4*  H
20.5428528000 23.4004040218 23.4702066834 25.7706717709 29.2237713788 21.8653188215 26.8814533877 21.1686856074  5*
79.3302188499 76.4772324063 76.4075412506 74.1107510275 70.6631675532 78.0098653939 73.0017438222 78.7053857754  6*
 0.1269283502  0.1223635719  0.1222520660  0.1185772016  0.1130610681  0.1248157846  0.1168027901  0.1259286172  7*

TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MADE UP OF:

1* CONTRIBUTION OF NORMALIZATION FACTOR
2* CONTRIBUTION OF POWER
3* CONTRIBUTION OF OUTLET TEMPERATURE
4* CONTRIBUTION OF INLET TEMPERATURE
5* TOTAL CONTRIBUTION OF POWER
6* TOTAL CONTRIBUTION OF OUTLET TEMPERATURE
7* TOTAL CONTRIBUTION OF INLET TEMPERATURE
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                              EFFECTIVE FLOW FACTOR DISTRIBUTION # 089

      THESE VALUES ARE THE INPUT DATA USED FOR THE COMPUTATION


        15          14          13          12          11          10           9           8


                                                                                         573.800    1*
                                                                                          51.500    2*  R
                                                                                           0.769    3*

                                                           571.600     575.700     588.200             1*
                                                            49.300      53.400      65.900             2*  P
                                                             0.737       1.012       1.200             3*

                                               572.200                 578.500     576.400   574.300   1*
                                                49.900                  56.200      54.100    52.000   2*  N
                                                 0.789                   0.935       1.016     1.023   3*

                                               582.700     583.700     577.800     583.900             1*
                                                60.400      61.400      55.500      61.600             2*  M
                                                 1.062       1.178       1.158       1.157             3*

                      574.800     584.700      586.200     575.100     575.300     576.600   578.700   1*
                       52.500      62.400       63.900      52.800      53.000      54.300    56.400   2*  L
                        0.709       1.236        1.182       0.949       0.973       0.985     1.088   3*

                      573.500     575.300      573.400     575.700     574.500                         1*
                       51.200      53.000       51.100      53.400      52.200                         2*  K
                        0.978       0.929        1.163       0.980       1.103                         3*

          566.400     586.400                  583.500                 581.100     572.200   576.000   1*
           44.100      64.100                   61.200                  58.800      49.900    53.700   2*  J
            0.731       1.238                    1.180                   1.137       0.926     1.026   3*

          568.400     572.500     572.600      575.900     580.900     570.300     577.500   569.300   1*
           46.100      50.200      50.300       53.600      58.600      48.000      55.200    47.000   2*  H
            0.796       0.957       1.199        0.977       1.126       0.855       1.032     0.803   3*


      THE ABOVE DATA ARE: 1* OUTLET TEMPERATURE (DEG. F..)
                          2* TEMPERATURE DIFFERENCE ACROSS THE FUEL ASSEMBLY (DEG. F.)
                          3* RELATIVE POWER OF THE ASSEMBLY


      INLET TEMPERATURE =522.300DEG. F.
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C     PROGRAM FLOFA 2
C********************
C CASE EFFECTIVE FLOW FACTOR DISTRIBUTION
      IMPLICIT RFAL*8 (A-H,O-Z)
      REAL *8 LEFT, RIGHT, ASPEC, FSPEC, BLANKS
      REAL*8 LEFTA, RIGHTA, ASPECA, FSPECA,BLANKA
      DIMENSION RESUL1(8,8,5), RESUL2(8,8,5), RESUL3(8,8,8),
     1SIRHIN(8,8), Q(8,8), TOUT(8,8), Y(8,8), X(8,8), SIRHOU(8,8), SPO(8
     2,8), STO(8,8), STI(8,8), SI2Y(8,8), SI2RFL(8,8),
     3SIFLO(8,8,5), FLOFA(8,8,5), SI2FLO(8,8,5), SIRFLO(8,8,5),
     4CONOR(8,8,8), COPO1(8,8,8), COTO1(8,8,8), COTI1(8,8,8), COPO2(8,8,
     58), COTO2(8,8,8), COTI2(8,8,8),  DERHIN(1),
     6SIRPO(10), SITOUT(10), SITIN(10),SPOSUM(10), SUMY(1), FANOR(1),
     7STOSUM(10), STISUM(10), S2YSUM(10), A(10), COLUMN(5),
     8FORM(10), RUN(3), FORMA(10), COLUMI(8), COLUMK(5), COLUMM(8),
     9ENT(11), TEMP(11), HOUT(8,8), HIN(1), DERENT(11), DERHOU(8,8)
      READ (5,8) RUN
  8   FORMAT(5A8)
      READ (5,9) POWER
  9   FORMAT (A8)
      READ(5,10) NUM, TIN, NUM2
 10   FORMAT(I2,7X,F10.0,4X,I3)
      READ(5,11) LEFTA, RIGHTA, ASPECA, FSPECA, BLANKA
 11   FORMAT(5A8)
      READ (5,12) LEFT,RIGHT, ASPEC, FSPEC, BLANKS
 12   FORMAT(5A8)
      READ (5,13) (COLUMI(I), I=1,8)
 13   FORMAT(8A8)
      READ (5,18) (COLUMK(K), K=1,5)
 18   FORMAT(5A8)
      READ (5,19) (COLUMM(M), M=1,8)
 19   FORMAT(8A8)
      READ (5,5) (COLUMN(N), N=1,5)
 5    FORMAT(5A8)
      DO 14 I=1,8
      DO 14 J=1,8
      TOUT(I,J)=0.0
      Q(I,J)=0.0
      Y(I,J) = 0.0
      X(I,J) =0.0
      SIRHOU(I,J)=0.0
      SIRHIN(I,J)=0.0
      SPO(I,J)=0.0
      STO(I,J)=0.0
      STI(I,J)=0.0
      SI2Y(I,J) =0.0
      HOUT(I,J)=0.0
      DERHOU(I,J)=0.0
 14   CONTINUE
      DO 16 IN = 1, NUM2
      READ (5,15) I, J, XQ, XTOUT
 15   FORMAT(2(I2,1X),2(F10.0,4X))
      Q(I,J) = XQ
      TOUT(I,J) = XTOUT
 16   CONTINUE
      TOUT(1,1)=TIN
      READ (5,17) (SIRPO(L), SITOUT(L), SITIN(L), L = 1, NUM)
 17   FORMAT(3F10.0)
C CARDS DEFINING ENTHALPY OF H2O AS A FUNCTION OF TEMP @ P=2,000 PSIA
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```
      DO 21 II=1,11
      READ(5,22) ENT(II), TEMP(II), DERENT(II), SENT
22    FORMAT(3F10.4, I1)
21    CONTINUE
      DO 231I=1,8
      DO 23 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 23
      IF(TOUT(I,J).LT.TEMP(1)) STOP
      JJ=2
24    IF(TOUT(I,J) - TEMP(JJ)) 28, 27, 26
26    JJ=JJ+1
      IF(JJ.LT.II) GO TO 24
      STOP
27    HOUT(I,J)= ENT(JJ)
      DERHOU(I,J)= DERENT(JJ)
      GO TO 23
28    HOUT(I,J)= ENT(JJ-1)+(ENT(JJ)-ENT(JJ-1))/(TEMP(JJ)-TEMP(JJ-1))*(TO
     1UT(I,J)-TEMP(JJ-1))
      DERHOU(I,J)=DERENT(JJ-1)+(DERENT(JJ)-DERENT(JJ-1))/(TEMP(JJ)-TEMP(
     1JJ-1))*(TOUT(I,J)-TEMP(JJ-1))
23    CONTINUE
231   CONTINUE
      TOUT(1,1)=0.0
      HIN(1)=HOUT(1,1)
      HOUT(1,1)=0.0
      DERHIN(1)=DERHOU(1,1)
      DERHOU(1,1)=0.0
      SUMY(1)=0.0
      DO 201I = 1,8
      DO 20 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 20
      X(I,J) = HOUT(I,J)-HIN(1)
      Y(I,J) = Q(I,J)/X(I,J)
      SUMY(1)=SUMY(1)+Y(I,J)
20    CONTINUE
201   CONTINUE
      FANOR(1)= 38./ SUMY(1)
      DO 998 L = 1, NUM
      SPOSUM(L) = 0.0
      STOSUM(L) = 0.0
      STISUM(L) = 0.0
      S2YSUM(L) = 0.0
      DO 30 I =1,8
      DO 30 J =1,8
      DO 25 K = 1,5
      FLOFA(I,J,K) =0.0
      SI2FLO(I,J,K) =0.0
      SIFLO(I,J,K) =0.0
      SIRFLO(I,J,K) =0.0
      RESUL2(I,J,K) = 0.0
25    CONTINUE
      DO 30 M = 1,8
      RESUL3(I,J,M) = 0.0
30    CONTINUE
      DO 501I = 1,8
      DO 50 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 50
      SIRHOU(I,J)=DERHOU(I,J)*DERHOU(I,J)*SITOUT(L)*SITOUT(L)/(X(I,J)*X(
     1I,J))
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```
      SIRHIN(I,J)=DERHIN(1)*DERHIN(1)*SITIN(L)*SITIN(L)/(X(I,J)*X(I,J))
      SPO(I,J) = Y(I,J)*SIRPO(L)* Y(I,J)* SIRPO(L)
      STO(I,J) = Y(I,J)* Y(I,J)* SIRHOU(I,J)
      STI(I,J) = Y(I,J)* Y(I,J)* SIRHIN(I,J)
      SI2Y(I,J) = SPO(I,J) + STO(I,J) +STI(I,J)
      SPOSUM(L) = SPOSUM(L) + SPO(I,J)
      STOSUM(L) = STOSUM(L) + STO(I,J)
      STISUM(L) = STISUM(L) + STI(I,J)
      S2YSUM(L) = S2YSUM(L) + SI2Y(I,J)
      A(L) = S2YSUM(L)/(SUMY(1)*SUMY(1))
   50 CONTINUE
  501 CONTINUE
      DO 521I=1,8
      DO 52 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 52
      SI2RFL(I,J)    = A(L) + SIRPO(L)* SIRPO(L) + SIRHOU(I,J)
     1+ SIRHIN(I,J)
      K = 1
      FLOFA(I,J,K) = FANOR(1)*Y(I,J)
      K = 2
      SI2FLO(I,J,K) = (Y(I,J)* FANOR(1))**2*A(L)+(FANOR(1)*Y(I,J)*SIRPO(
     1L))**2+(FANOR(1)*Y(I,J)/X(I,J)*DERHOU(I,J)*SITOUT(L))**2+(FANOR(1)
     2*Y(I,J)/X(I,J)*SITIN(L))**2
      K = 3
      SIFLO(I,J,K)= DSQRT(SI2FLO(I,J,2))
      K = 4
      SIRFLO(I,J,K) = SIFLO(I,J,3)/FLOFA(I,J,1)* 100.
      DO 522K=1,4
      RESUL2(I,J,K) = FLOFA(I,J,K) + SI2FLO(I,J,K) + SIFLO(I,J,K)
     1 + SIRFLO(I,J,K)
  522 CONTINUE
   52 CONTINUE
  521 CONTINUE
      DO 53 I=1,8
      DO 53 J=1,8
      DO 53 M=1,8
      CONOR(I,J,M)=0.0
      COPO1(I,J,M)=0.0
      COTO1(I,J,M)=0.0
      COTI1(I,J,M)=0.0
      COPO2(I,J,M)=0.0
      COTO2(I,J,M)=0.0
      COTI2(I,J,M)=0.0
      RESUL3(I,J,M)=0.0
  53  CONTINUE
      DO 551I=1,8
      DO 55 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 55
      M = 1
      CONOR(I,J,M) = A(L)/SI2RFL(I,J)* 100.
      M = 2
      COPO1(I,J,M)=SIRPO(L) * SIRPO(L)/ SI2RFL(I,J)* 100.
      M = 3
      COTO1(I,J,M) = SIRHOU(I,J)/SI2RFL(I,J)* 100.
      M = 4
      COTI1(I,J,M) = SIRHIN(I,J)/SI2RFL(I,J)* 100.
      M = 5
      COPO2(I,J,M)=CONOR(I,J,1)*SPOSUM(L)/S2YSUM(L)+COPO1(I,J,2)
      M = 6
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      COTO2(I,J,M)=CONOR(I,J,1)*STOSUM(L)/S2YSUM(L)+COTO1(I,J,3)
      M = 7
      COTI2(I,J,M)=CONOR(I,J,1)*STISUM(L)/S2YSUM(L)+COTI1(1,J,4)
      DO 552M=1,7
      RESUL3(I,J,M) = CONOR(I,J,M) + COPO1(I,J,M) + COTO1(I,J,M)
     1+ COTI1(I,J,M) + COPO2(I,J,M) + COTO2(I,J,M) + COTI2(I,J,M)
552   CONTINUE
 55   CONTINUE
551   CONTINUE
      WRITE(6,60) RUN(1), RUN(1)
60    FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION #',2X,A8,15X,'R
     1UN # ',A8,'PAGE 1',////)
      WRITE(6,61)
61    FORMAT(1X,'EFF = CONSTANT * RELATIVE POWER / ENTHALPY DIFFERENCE A
     1CROSS THE FUEL ASSEMBLY',////)
      WRITE(6,62) SIRPO(L), SITOUT(L), SITIN(L)
62    FORMAT(1X,'PARAMETERS : RELATIVE POWER STD.',5X,'=',F10.4,/14X,'OU
     1TLET TEMPERATURE STD. =',F8.2,2X,'DEG. F. ',/14X,'INLET TEMPERATUR
     2E STD.  =',F8.2,2X,'DEG. F.',////)
      WRITE(6,63) SUMY(1), FANOR(1), S2YSUM(L), SPOSUM(L), STOSUM(L),
     1STISUM(L)
63    FORMAT(1X,'RESULTS: SUM OF THE RATIOS',6X,'=',2X,F14.10,/10X,'NORM
     1ALIZATION FACTOR   =',2X,F14.10,/10X,'SUM OF THE STD. SQUARE =',2X
     2,F14.10,/10X,'CONTRIBUTION OF POWER  =',2X,F14.10,/10X,'CONTRIBUTI
     3ON OF T. OUT =',2X,F14.10,/10X,'CONTRIBUTION OF T. INL =',2X,F14.1
     40,///)
      WRITE(6,640) POWER
640   FORMAT(1H ,'THERMAL POWER =',A8,' MWTH')
      WRITE(6,64) RUN(1)
 64   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 2',/)
      WRITE (6, 65) SIRPO(L), SITOUT(L), SITIN(L)
65    FORMAT(1H ,'RELATIVE POWER STD.',5X,'=',F10.4,/1H ,'CUTLET TEMPERA
     1TURE STD. =',F8.2,2X,'DEG. F.',/1H ,'INLET TEMPERATURE STD.  =',F8
     2.2,2X,'DEG. F.',/)
      WRITE(6, 66)
66    FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',/)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 100 I = 1,8
      DO 95 K = 1,5
      DO 90 J=1,8
      IF (RESUL2(I,J,K).EQ.0.0) GOTO 85
      FORM(J+1) = FSPEC
      GO TO 90
 85   FORM(J+1) = ASPEC
      RESUL2(I,J,K) = BLANKS
 90   CONTINUE
      WRITE(6, FORM)(RESUL2(I,J,K),J=1,8)
      WRITE(6,971)COLUMK(K)
971   FORMAT(1H+,122X,A8)
      IF(K.NE.2.0) GO TO 95
      WRITE (6,96) COLUMI(I)
96    FORMAT(1H+,126X,A4)
95    CONTINUE
100   CONTINUE
      WRITE(6, 120)
120   FORMAT(//,1X,'TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:',////
     11X,'1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES W
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     2ITH OUTLET THERMOCOUPLES',/1X,'2* SQUARE OF THE STANDARD DEVIATION
     3 OF THE EFFECTIVE FLOW FACTOR',/1X,'3* STANDARD DEVIATION OF THE E
     4FFECTIVE FLOW FACTOR',/1X,'4* RELATIVE STANDARD DEVIATION OF THE E
     5FFECTIVE FLOW FACTOR')
      WRITE(6,140) RUN(1)
140   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 3',/)
      WRITE (6,141) SIRPO(L), SITOUT(L), SITIN(L)
141   FORMAT(1H ,'RELATIVE POWER STD.',5X,'=',F10.4,/1H ,'OUTLET TEMPERA
     1TURE STD. =',F8.2,2X,'DEG. F.',/1H ,'INLET TEMPERATURE STD.  =',F8
     2.2,2X,'DEG. F.',///)
      WRITE(6,142)
142   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 200 I = 1,5
      DO 190 M = 1,8
      DO 180 J=1,8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO  170
      FORM(J+1) = FSPEC
      GO TO 180
170   FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
180   CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,191) COLUMM(M)
191   FORMAT(1H+,122X,A8)
      IF(M.NE.4.0) GO TO 190
      WRITE (6,192) COLUMI(I)
192   FORMAT(1H+,126X,A4)
190   CONTINUE
 200  CONTINUE
      WRITE (6,210) RUN(1)
210   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 4',/)
      WRITE (6,211) SIRPO(L), SITOUT(L), SITIN(L)
211   FORMAT(1H ,'RELATIVE POWER STD.',5X,'=',F10.4,/1H ,'OUTLET TEMPERA
     1TURE STD. =',F8.2,2X,'DEG. F.',/1H ,'INLET TEMPERATURE STD.  =',F8
     2.2,2X,'DEG. F.',///)
      WRITE(6,212)
212   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 300 I = 6, 8
      DO 285 M = 1,8
      DO 270 J =1, 8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO 255
      FORM(J+1) = FSPEC
      GO TO 270
255   FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
270   CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,286) COLUMM(M)
286   FORMAT(1H+,122X,A8)
      IF(M.NE.4.0) GO TO 285
      WRITE (6,288) COLUMI(I)
288   FORMAT(1H+,126X,A4)
285   CONTINUE
```

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300   CONTINUE
      WRITE(6,400)
400   FORMAT(//,1X,'TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MA
     1DE UP OF:          ',//1X,'1* CONTRIBUTION OF NORMALIZATION FACTOR'
     2,/1X,'2* CONTRIBUTION OF POWER',/1X,'3* CONTRIBUTION OF OUTLET TEM
     3PERATURE',/1X,'4* CONTRIBUTION OF INLET TEMPERATURE',/1X,'5* TOTAL
     4 CONTRIBUTION OF POWER',/1X,'6* TOTAL CONTRIBUTION OF OUTLET TEMPE
     5RATURE',/1X,'7* TOTAL CONTRIBUTION OF INLET TEMPERATURE')
998   CONTINUE
      DO 450 I=1,8
      DO 450 J=1,8
      DO 450 N=1,5
      RESUL1(I,J,N)=0.0
450   CONTINUE
      DO 460 I=1,8
      DO 460 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 460
      N=1
      RESUL1(I,J,N)=TOUT(I,J)
      N=2
      RESUL1(I,J,N)=HOUT(I,J)
      N=3
      RESUL1(I,J,N)=X(I,J)
      N=4
      RESUL1(I,J,N)=Q(I,J)
460   CONTINUE
      WRITE(6,500) RUN(1)
500   FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION # ',A8,//1H ,
     1'THESE VALUES ARE THE INPUT DATA USED FOR THE COMPUTATION',//1H ,
     2 8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14X,'9',14X,
     3'8',///)
      FORMA(1)=LEFTA
      FORMA(10)=RIGHTA
      DO 510 I=1,8
      DO 505 N=1,5
      DO 504 J=1,8
      IF(RESUL1(I,J,N).EQ.0.0) GO TO 503
      FORMA(J+1)=FSPECA
      GO TO 504
503   FORMA(J+1)= ASPECA
      RESUL1(I,J,N)=BLANKA
504   CONTINUE
      WRITE(6,FORMA) (RESUL1(I,J,N),J=1,8)
      WRITE(6,507)COLUMN(N)
507   FORMAT(1H+,122X,A8)
      IF(N.NE.2.0) GO TO 505
      WRITE(6,506) COLUMI(I)
506   FORMAT(1H+,126X,A4)
505   CONTINUE
510   CONTINUE
      WRITE(6,530)
530   FORMAT( /1H ,'THE ABOVE DATA ARE: 1*OUTLET TEMPERATURE    (DEG. F.
     1) ',/1H ,20X,'2* OUTLET ENTHALPY (BTU/LB)',/1H ,20X,'3* ENTHALPY D
     2IFFERENCE ACROSS THE FUEL ASSEMBLY (BTU/LB)',/1H ,20X,'4* RELATIVE
     3 POWER OF THE FUEL ASSEMBLY')
      WRITE(6,535) TIN   , HIN(1)
535   FORMAT(1H ,'INLET TEMPERATURE =',F6.2,'DEG. F.',10X,'INLET ENTHALPY
     1 =',F10.5,'BTU/LB')
      STOP
      END
```

SAMPLE INPUT FOR FLOFA 2

```
*************************

089
1813.5
10         522.3          38
(          ' ')    A8,7X,   F15.3,
(          ' ')    A8,7X,   F15.10,
R          P       N        M         L         K         J         H
1*         2*      3*       4*
1*         2*      3*       4*        5*        6*        7*
1*         2*      3*       4*
 1  8  0.7690          573.8
 2  5  0.7366          571.6
 2  6  1.0118          575.7
 2  7  1.2005          588.2
 3  4  0.7895          572.2
 3  6  0.9347          578.5
 3  7  1.0156          576.4
 3  8  1.0228          574.3
 4  4  1.0619          582.7
 4  5  1.1784          583.7
 4  6  1.1579          577.8
 4  7  1.1570          583.9
 5  2  0.7085          574.8
 5  3  1.2356          584.7
 5  4  1.1817          586.2
 5  5  0.9491          575.1
 5  6  0.9730          575.3
 5  7  0.9850          576.6
 5  8  1.0883          578.7
 6  2  0.9782          573.5
 6  3  0.9292          575.3
 6  4  1.1633          573.4
 6  5  0.9801          575.7
 6  6  1.1025          574.5
 7  1  0.731           566.4
 7  2  1.238           586.4
 7  4  1.1799          583.5
 7  6  1.1365          581.1
 7  7  0.9258          572.2
 7  8  1.0256          576.0
 8  1  0.7956          568.4
 8  2  0.9572          572.5
 8  3  1.1994          572.6
 8  4  0.9769          575.9
 8  5  1.1263          580.9
 8  6  0.8549          570.3
 8  7  1.0323          577.5
 8  8  0.8026          569.3
0.0250      2.0        0.1
0.0250      2.5        0.1
0.0250      2.5        0.2
0.0275      2.0        0.1
0.0275      2.5        0.1
0.0275      2.0        0.2
0.0275      2.5        0.2
0.0300      2.0        0.1
```

```
 0.0300    2.5      0.1
 0.0300    2.5      0.2
487.3     500.0    1.154
498.9     510.0    1.170
510.7     520.0    1.185
522.6     530.0    1.205
534.8     540.0    1.230
547.2     550.0    1.250
559.8     560.0    1.280
572.8     570.0    1.315
586.1     580.0    1.350
599.8     590.0    1.395
614.0     600.0    1.450      1
```

```
                              EFFECTIVE FLOW FACTOR DISTRIBUTION #  089                    RUN # 089     PAGE 1


EFF = CONSTANT * RELATIVE POWER / ENTHALPY DIFFERENCE ACROSS THE FUEL ASSEMBLY


PARAMETERS : RELATIVE POWER STD.      =    0.0275
             OUTLET TEMPERATURE STD. =    2.50  DEG. F.
             INLET TEMPERATURE STD.  =    0.10  DEG. F.


RESULTS: SUM OF THE RATIOS       =    0.5593390775
         NORMALIZATION FACTOR    =   67.9373237565
         SUM OF THE STD. SQUARE =    0.0000266880
         CONTRIBUTION OF POWER   =    0.0000062919
         CONTRIBUTION OF T. OUT =    0.0000203703
         CONTRIBUTION OF T. INL =    0.0000000258


THERMAL POWER =1813.5   MWTH
```

```
                                                                                              RUN #  089      PAGE 2

RELATIVE POWER STD.      =     0.0275
OUTLET TEMPERATURE STD. =     2.50  DEG. F.
INLET TEMPERATURE STD.   =     0.10  DEG. F.

      15             14             13             12             11             10              9              8

                                                                                                          0.8110250705   1*
                                                                                                          0.0023031205   2*  R
                                                                                                          0.0479908377   3*
                                                                                                          5.9173063104   4*

                                                                0.8138204400   1.0268132197   0.9721296014                 1*
                                                                0.0024683384   0.0035100525   0.0024107233                 2*  P
                                                                0.0496823756   0.0592456957   0.0490991172                 3*
                                                                6.1048326107   5.7698610201   5.0506760754                 4*

                                                 0.8610913180                 0.8985823359   1.0165325379   1.0676730085   1*
                                                 0.0027155779                 0.0025085277   0.0033792632   0.0039375729   2*  N
                                                 0.0521112068                 0.0500852040   0.0581314304   0.0627500826   3*
                                                 6.0517631241                 5.5738024212   5.7186000676   5.8772753546   4*

                                                 0.9447453458   1.0299148654   1.1280185150   1.0076594558                 1*
                                                 0.0025276801   0.0029436742   0.0040197857   0.0028066271                 2*  M
                                                 0.0502760386   0.0542556372   0.0634017800   0.0529776096                 3*
                                                 5.3216497824   5.2679730131   5.6206329187   5.2574914320                 4*

                   0.7321032729   1.0612039801   0.9892127048   0.9748029205   0.9953474676   0.9820557946   1.0423237015   1*
                   0.0018268109   0.0030643350   0.0025879420   0.0032132487   0.0033326212   0.0031381078   0.0033593876   2*  L
                   0.0427412080   0.0553564358   0.0508718197   0.0566855246   0.0577288594   0.0560188166   0.0579602244   3*
                   5.8381391776   5.2163803436   5.1426573365   5.8150753727   5.7998700253   5.7042397110   5.5606741283   4*

                   1.0383375707   0.9505414870   1.2370899073   0.9946428509   1.1461850315                                1*
                   0.0038045134   0.0030393357   0.0054179587   0.0032935559   0.0045136641                                2*  K
                   0.0616807380   0.0551301708   0.0736067840   0.0573895101   0.0671838086                                3*
                   5.9417563585   5.7998700253   5.9499947099   5.7698610201   5.8615150901                                4*

    0.9081832318   1.0328548932                 1.0348737161                 1.0409972826   1.0097509084   1.0346512517   1*
    0.0036210956   0.0028109010                 0.0029840219                 0.0031742564   0.0037341550   0.0035365195   2*  J
    0.0601755402   0.0530179305                 0.0546262016                 0.0563405398   0.0611077331   0.0594686426   3*
    6.6259250410   5.1331441511                 5.2785379318                 5.4121697292   6.0517631241   5.7476992839   4*

    0.9435772355   1.0373533419   1.2970826016   0.9874716795   1.0354796978   0.9718486342   1.0114468158   0.9328263057   1*
    0.0036595361   0.0039073359   0.0060915128   0.0032295954   0.0031543347   0.0036601563   0.0032535080   0.0034770403   2*  H
    0.0604940996   0.0625086867   0.0780481444   0.0568295291   0.0561634642   0.0604992254   0.0570570593   0.0589664338   3*
    6.4111444497   6.0257854454   6.0172069484   5.7550540742   5.4239078063   6.2251695639   5.6411329168   6.3212661828   4*

TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:


1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES WITH OUTLET THERMOCOUPLES
2* SQUARE OF THE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
3* STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
4* RELATIVE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
```

```
RELATIVE POWER STD.      =     0.0275
OUTLET TEMPERATURE STD. =     2.50  DEG. F.
INLET TEMPERATURE STD.   =     0.10  DEG. F.


         15              14              13              12              11              10               9               8

                                                                                                                2.4355260981   1*
                                                                                                               21.5920169543   2*
                                                                                                               75.8750861460   3*
                                                                                                                0.0973708017   4*   R
                                                                                                               22.1662090728   5*
                                                                                                               77.7340634743   6*
                                                                                                                0.0997274529   7*

                                                                    2.2881764821    2.5616124690    3.3432244027                   1*
                                                                   20.2856973933   22.7098284451   29.6391642200                   2*
                                                                   77.3257331527   74.6337331670   66.9388143899                   3*
                                                                    0.1003929820    0.0948259189    0.0787969873                   4*   P
                                                                   20.8251508109   23.3137462974   30.4273524903                   5*
                                                                   79.0722421335   76.5889491294   69.4906155687                   6*
                                                                    0.1026070555    0.0973045732    0.0820319410                   7*

                                                    2.3284893594                    2.7450207382    2.6077494248    2.4688214080   1*
                                                   20.6430888852                   24.3358239372   23.1188529808   21.8871946145   2*
                                                   76.9288609300                   72.8279674744   74.1794938042   75.5472887940   3*
                                                    0.0995608254                    0.0911878503    0.0939037901    0.0956951835   4*   N
                                                   21.1920463525                   24.9829815571   23.7336479395   22.4692363326   5*
                                                   78.7061397412                   74.9231744698   76.1699249733   77.4316796157   6*
                                                    0.1018139064                    0.0938439731    0.0964270872    0.0990840518   7*

                                                    3.0113637397    3.0730552630    2.6994617703    3.0853229798                   1*
                                                   26.6970725434   27.2439952052   23.9319235198   27.3527539453                   2*
                                                   70.2058904011   69.5985757269   73.2765299821   69.4778065030                   3*
                                                    0.0856733159    0.0843738049    0.0920847277    0.0841165718                   4*   M
                                                   27.4070223676   27.9684892326   24.5683402981   28.0801401718                   5*
                                                   72.5043904762   71.9441634285   75.3369629348   71.8327578520                   6*
                                                    0.0885871562    0.0873473369    0.0946967671    0.0871019762                   7*

                    2.5020369470    3.1341557997    3.2246775585    2.5219264757    2.5351691106    2.6208979237    2.7579996350   1*
                   22.1816650710   27.7856785096   28.5891939716   22.3579945468   22.4753963676   23.2354202435   24.4508876030   2*
                   75.2202742049   68.9970692157   68.1059069197   75.0244560146   74.8940779203   74.0500399689   72.7001796087   3*
                    0.0960237771    0.0830964750    0.0812215501    0.0956229629    0.0953566015    0.0936418639    0.0909331533   4*   L
                   22.7715375820   28.5245774110   29.3484340036   22.9525561518   23.0730800153   23.8533150517   25.1011050876   5*
                   77.1300176328   71.3892934582   70.5672242003   76.9493806318   76.8291103159   76.0505070647   74.8052930776   6*
                    0.0984447852    0.0861291308    0.0843417961    0.0980632164    0.0978096688    0.0961778837    0.0936018347   7*
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                                                                                                            RUN # 089      PAGE 4

RELATIVE POWER STD.       =    0.0275
OUTLET TEMPERATURE STD. =      2.50  DEG. F.
INLET TEMPERATURE STD.    =    0.10  DEG. F.


          15             14             13             12             11             10              9              8

                   2.4155121695   2.5351691106   2.4088349190   2.5616124690   2.4821174008                                1*
                  21.4145946175  22.4753963676  21.3553878365  22.7098284451  22.0050694762                                2*
                  76.0721250275  74.8940779203  76.1378629299  74.6337331670  75.4163870086                                3*
                   0.0977781855   0.0953566015   0.0979143146   0.0948259189   0.0964261144                                4*  K
                  21.9840583140  23.0730800153  21.9232873250  23.3137462974  22.5902458165                                5*
                  77.9158262150  76.8291103159  77.9764675360  76.5889491294  77.3109263354                                6*
                   0.1001154710   0.0978096688   0.1002451391   0.0973045732   0.0988278481                                7*

   1.9423818442   3.2366434747                  3.0607639023                  2.9114562754   2.3284893594   2.5814074680   1*
  17.2200743508  26.6942771147                 27.1350268523                 25.8113486478  20.6430888852  22.8853198729   2*
  80.7297809949  67.9881041648                 69.7195773201                 71.1893958559  76.9238609300  74.4388429631   3*
   0.1077623101   0.0809752459                  0.0846319253                  0.0877992210   0.0995608254   0.0944296960   4*  J
  17.6780048016  29.4573381941                 27.8566231064                 26.4977445965  21.1920463525  23.4939045331   5*
  82.2123534108  70.4585547356                 72.0557833276                 73.4116390142  78.7061397412  76.4091679627   6*
   0.1096417877   0.0841070702                  0.0875935660                  0.0906163893   0.1018139064   0.0969275042   7*

   2.0747232778   2.3486121231   2.3553144971   2.5748127613   2.8988660382   2.2005555911   2.6798745726   2.1341491490   1*
  18.3933402415  20.8214360930  20.8809056052  22.8268548794  25.6997306217  19.5088993988  23.7582743424  18.9201768943   2*
  79.4270436951  76.7307549203  76.6647705583  74.5037707596  71.3133343060  78.1883289714  73.4693793949  78.8420528790   3*
   0.1048927855   0.0991449635   0.0990093394   0.0945615997   0.0880690341   0.1022160387   0.0924716901   0.1036210777   4*  H
  18.8824706003  21.3751876410  21.4361372841  23.4338847919  26.3831583350  20.0276955955  24.3900733034  19.4233173131   5*
  81.0100290810  78.5233928435  78.4625243392  76.4690621813  73.5259676450  79.8679590755  75.5148619201  80.4709965747   6*
   0.1059003186   0.1014195155   0.1012983767   0.0970530268   0.0908740200   0.1043453290   0.0950647765   0.1056861122   7*

TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MADE UP OF:

1* CONTRIBUTION OF NORMALIZATION FACTOR
2* CONTRIBUTION OF POWER
3* CONTRIBUTION OF OUTLET TEMPERATURE
4* CONTRIBUTION OF INLET TEMPERATURE
5* TOTAL CONTRIBUTION OF POWER
6* TOTAL CONTRIBUTION OF OUTLET TEMPERATURE
7* TOTAL CONTRIBUTION OF INLET TEMPERATURE
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                         EFFECTIVE FLOW FACTOR DISTRIBUTION # 089

THESE VALUES ARE THE INPUT DATA USED FOR THE COMPUTATION

      15          14          13          12          11          10           9           8

                                                                                     573.800   1*
                                                                                     577.854   2*  R
                                                                                      64.417   3*
                                                                                       0.769   4*

                                                         571.600     575.700     588.200           1*
                                                         574.928     580.381     597.334           2*  P
                                                          61.491      66.944      83.897           3*
                                                           0.737       1.012       1.200           4*

                                             572.200                 578.500     576.400     574.300   1*
                                             575.726                 584.105     581.312     578.519   2*  N
                                              62.289                  70.668      67.875      65.082   3*
                                               0.789                   0.935       1.016       1.023   4*

                                             582.700     583.700     577.800     583.900           1*
                                             589.799     591.169     583.174     591.443           2*  M
                                              76.362      77.732      69.737      78.006           3*
                                               1.062       1.178       1.158       1.157           4*

                 574.800     584.700     586.200     575.100     575.300     576.600     578.700   1*
                 579.184     592.539     594.594     579.583     579.849     581.578     584.371   2*  L
                  65.747      79.102      81.157      66.146      66.412      68.141      70.934   3*
                   0.709       1.236       1.182       0.949       0.973       0.985       1.088   4*

                 573.500     575.300     573.400     575.700     574.500                       1*
                 577.455     579.849     577.322     580.381     578.785                       2*  K
                  64.018      66.412      63.885      66.944      65.348                       3*
                   0.978       0.929       1.163       0.980       1.103                       4*

     566.400     586.400                 583.500                 581.100     572.200     576.000   1*
     568.120     594.868                 590.895                 587.607     575.726     580.780   2*  J
      54.683      81.431                  77.458                  74.170      62.289      67.343   3*
       0.731       1.238                   1.180                   1.137       0.926       1.026   4*

     568.400     572.500     572.600     575.900     580.900     570.300     577.500     569.300   1*
     570.720     576.125     576.258     580.647     587.333     573.199     582.775     571.890   2*  H
      57.283      62.688      62.821      67.210      73.896      59.762      69.338      58.453   3*
       0.796       0.957       1.199       0.977       1.126       0.855       1.032       0.803   4*

THE ABOVE DATA ARE: 1*OUTLET TEMPERATURE    (DEG. F.)
                    2* OUTLET ENTHALPY (BTU/LB)
                    3* ENTHALPY DIFFERENCE ACROSS THE FUEL ASSEMBLY (BTU/LB)
                    4* RELATIVE POWER OF THE FUEL ASSEMBLY
INLET TEMPERATURE =522.300DEG. F.          INLET ENTHALP = 513.437008TU/LB
```

PROGRAM FLOFA 3
****

```
C CASE EFFECTIVE FLOW FACTOR DISTRIBUTION
       IMPLICIT REAL*8 (A-H,O-Z)
       REAL *8 LEFT, RIGHT, ASPEC, FSPEC, BLANKS
       REAL*8 LEFTA, RIGHTA, ASPECA, FSPECA,BLANKA
       DIMENSION RESUL1(8,8,7), RESUL2(8,8,5), RESUL3(8,8,8),
      1STRTIN(8,8), Q(8,8), TOUT(8,8), Y(8,8), X(8,8), STRTOU(8,8), SPO(8
      2,8), STO(8,8), STI(8,8), SI2Y(8,8), SI2RFL(8,8),
      3STFLO(8,8,5), FLOFA(8,8,5), SI2FLO(8,8,5), SIRFLO(8,8,5),
      4CONOR(8,8,8), COPO1(8,8,8), COTO1(8,8,8), COTI1(8,8,8), COPO2(8,8,
      58), COTO2(8,8,8), COTI2(8,8,8),
      6STRPO(8,8),SITOUT(8,8),SITIN(8,8),SPOSUM(1), SUMY(1),FANOR(1),
      7STOSUM(1),  STISUM(1),  S2YSUM(1),  A(1) , COLUMN(7),
      8FORM(10), RUN(3), FORMA(10), COLUMI(8), COLUMK(5), COLUMM(8)
       READ (5,8) RUN
    8  FORMAT(5A8)
       READ (5,9) POWER
    9  FORMAT (A8)
       READ(5,10) NUM2, TIN
   10  FORMAT(I2,7X,F10.0)
       READ(5,11) LEFTA, RIGHTA, ASPECA, FSPECA, BLANKA
   11  FORMAT(5A8)
       READ (5,12) LEFT,RIGHT, ASPEC, FSPEC, BLANKS
   12  FORMAT(5A8)
       READ (5,13) (COLUMI(I), I=1,8)
   13  FORMAT(8A8)
       READ (5,18) (COLUMK(K), K=1,5)
   18  FORMAT(5A8)
       READ (5,19) (COLUMM(M), M=1,8)
   19  FORMAT(8A8)
       READ (5,5) (COLUMN(N), N=1,7)
   5   FORMAT(7A8)
       DO 14 I=1,8
       DO 14 J=1,8
       TOUT(I,J)=0.0
       Q(I,J)=0.0
       Y(I,J) = 0.0
       X(I,J) =0.0
       STRTOU(I,J)=0.0
       STRTIN(I,J)=0.0
       SPO(I,J)=0.0
       STO(I,J)=0.0
       STI(I,J)=0.0
       SI2Y(I,J) =0.0
   14  CONTINUE
       DO 16 IN = 1, NUM2
       READ (5,15) I, J, XQ, XTOUT,XSTRPO,XSITOU,XSITIN
   15  FORMAT(2(I2,1X),5(F10.0,2X))
       Q(I,J) = XQ
       TOUT(I,J) = XTOUT
       STRPO(I,J)=XSTRPO
       SITOUT(I,J)=XSITOU
       SITIN(I,J)=XSITIN
   16  CONTINUE
       SUMY(1)=0.0
       DO 20 I = 1,8
       DO 20 J = 1,8
```

```
      IF(TOUT(I,J).EQ.0.0) GO TO 20
      X(I,J) = TOUT(I,J) - TIN
      Y(I,J) = Q(I,J)/X(I,J)
      SUMY(1)=SUMY(1)+Y(I,J)
 20   CONTINUE
      FANOR(1)=38./SUMY(1)
      SPOSUM(1)=0.0
      STOSUM(1)=0.0
      STISUM(1)=0.0
       S2YSUM(1)=0.0
      DO 30 I =1,8
      DO 30 J =1,8
      DO 25 K = 1,5
      FLOFA(I,J,K) =0.0
      SI2FLO(I,J,K) =0.0
      SIFLO(I,J,K) =0.0
      SIRFLO(I,J,K) =0.0
      RESUL2(I,J,K) = 0.0
 25   CONTINUE
      DO 30 M = 1,8
      RESUL3(I,J,M) = 0.0
 30   CONTINUE
      DO 501I = 1,8
      DO 50 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 50
      SIRTOU(I,J)=(SITOUT(I,J)/X(I,J))*(SITOUT(I,J)/X(I,J))
      SIRTIN(I,J)=(SITIN(I,J)/X(I,J))*(SITIN(I,J)/X(I,J))
      SPO(I,J)=Y(I,J)*SIRPO(I,J)*Y(I,J)*SIRPO(I,J)
      STO(I,J) = Y(I,J)* Y(I,J)* SIRTOU(I,J)
      STI(I,J) = Y(I,J)* Y(I,J)* SIRTIN(I,J)
      SI2Y(I,J) = SPO(I,J) + STO(I,J) +STI(I,J)
       SPOSUM(1)=SPOSUM(1)+SPO(I,J)
       STOSUM(1)=STOSUM(1)+STO(I,J)
      STISUM(1)=STISUM(1)+STI(I,J)
      S2YSUM(1)=S2YSUM(1)+SI2Y(I,J)
      A(1)=S2YSUM(1)/(SUMY(1)*SUMY(1))
 50   CONTINUE
501   CONTINUE
      DO 521I=1,8
      DO 52 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 52
      SI2RFL(I,J)=A(1)+SIRPO(I,J)*SIRPO(I,J)+SIRTOU(I,J)+SIRTIN(I,J)
      K = 1
      FLOFA(I,J,K)=FANOR(1)*Y(I,J)
      K = 2
      SI2FLO(I,J,K)=(Y(I,J)*FANOR(1))**2*A(1)+(FANOR(1)*Y(I,J)*SIRPO(I,J
     1))**2+(FANOR(1)*Y(I,J)/X(I,J)*SITOUT(I,J))**2+(FANOR(1)*Y(I,J)/X(I
     2,J)*SITIN(I,J))**2
      K = 3
      SIFLO(I,J,K)= DSQRT(SI2FLO(I,J,2))
      K = 4
      SIRFLO(I,J,K) = SIFLO(I,J,3)/FLOFA(I,J,1)* 100.
      DO 522K=1,4
      RESUL2(I,J,K) = FLOFA(I,J,K) + SI2FLO(I,J,K) + SIFLO(I,J,K)
     1 + SIRFLO(I,J,K)
522   CONTINUE
 52   CONTINUE
521   CONTINUE
      DO 531I=1,8
      DO 53 J=1,8
```

```
      DO 53 M=1,8
      CONOR(I,J,M)=0.0
      COPO1(I,J,M)=0.0
      COTO1(I,J,M)=0.0
      COTI1(I,J,M)=0.0
      COPO2(I,J,M)=0.0
      COTO2(I,J,M)=0.0
      COTI2(I,J,M)=0.0
      RESUL3(I,J,M)=0.0
53    CONTINUE
531   CONTINUE
      DO 551I=1,8
      DO 55 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 55
      M = 1
       CONOR(I,J,M)=A(1)/SI2REL(I,J)*100.
      M = 2
      COPO1(I,J,M)=SIRPO(I,J)*SIRPO(I,J)/SI2REL(I,J)*100.
      M = 3
      COTO1(I,J,M) = SIRTOU(I,J)/SI2REL(I,J)* 100.
      M = 4
      COTI1(I,J,M) = SIRTIN(I,J)/SI2REL(I,J)* 100.
      M = 5
      COPO2(I,J,M)=CONOR(I,J,1)*SPOSUM(1)/S2YSUM(1)+COPO1(I,J,2)
      M = 6
      COTO2(I,J,M)=CONOR(I,J,1)*STOSUM(1)/S2YSUM(1)+COTO1(I,J,3)
      M = 7
      COTO2(I,J,M)=CONOR(I,J,1)*STISUM(1)/S2YSUM(1)+COTO1(I,J,4)
      DO 552M=1,7
      RESUL3(I,J,M) = CONOR(I,J,M) + COPO1(I,J,M) + COTO1(I,J,M)
     1+ COTI1(I,J,M) + COPO2(I,J,M) + COTO2(I,J,M) + COTI2(I,J,M)
552   CONTINUE
 55   CONTINUE
551   CONTINUE
      WRITE(6,60) RUN(1), RUN(1)
60    FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION #',2X,A8,15X,'R
     1UN # ',A8,'PAGE 1',////)
      WRITE(6,61)
61    FORMAT(1X,'EFF = CONSTANT * RELATIVE POWER / TEMPERATURE DIFFERENC
     1E ACROSS THE FUEL ASSEMBLY',////)
      WRITE(6,63) SUMY(1), FANOR(1), S2YSUM(1), SPOSUM(1), STOSUM(1),
     1STISUM(1)
63    FORMAT(1X,'RESULTS: SUM OF THE RATIOS',6X,'=',2X,F14.10,/10X,'NORM
     1ALIZATION FACTOR    =',2X,F14.10,/10X,'SUM OF THE STD. SQUARE =',2X
     2,F14.10,/10X,'CONTRIBUTION OF POWER  =',2X,F14.10,/10X,'CONTRIBUTI
     3ON OF T. OUT =',2X,F14.10,/10X,'CONTRIBUTION OF T. INL =',2X,F14.1
     40,///)
      WRITE(6,640) POWER
640   FORMAT(1H ,'THERMAL POWER =',A8,' MWTH')
      WRITE(6,64) RUN(1)
 64   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 2',/)
      WRITE(6, 66)
 66   FORMAT(1H ,9X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 100 I = 1,8
      DO 95 K = 1,5
      DO 90 J=1,8
      IF (RESUL2(I,J,K).EQ.0.0) GOTO 85
```

```
      FORM(J+1) = ESPEC
      GO TO 90
 85   FORM(J+1) = ASPEC
      RESUL2(I,J,K) = BLANKS
 90   CONTINUE
      WRITE(6, FORM)(RESUL2(I,J,K),J=1,8)
      WRITE(6,971)COLUMK(K)
971   FORMAT(1H+,122X,A8)
      IF(K.NE.2.0) GO TO 95
      WRITE (6,96) COLUMI(I)
96    FORMAT(1H+,126X,A4)
95    CONTINUE
100   CONTINUE
      WRITE(6, 120)
120   FORMAT(//,1X,'TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:',/,
     11X,'1# EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES W
     2ITH OUTLET THERMOCOUPLES',/1X,'2# SQUARE OF THE STANDARD DEVIATION
     3 OF THE EFFECTIVE FLOW FACTOR',/1X,'3# STANDARD DEVIATION OF THE E
     4EFFECTIVE FLOW FACTOR',/1X,'4# RELATIVE STANDARD DEVIATION OF THE E
     5EFFECTIVE FLOW FACTOR')
      WRITE(6,140) RUN(1)
140   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 3',/)
      WRITE(6,142)
142   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 200 I = 1,5
      DO 190 M = 1,8
      DO 180 J=1,8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO  170
      FORM(J+1) = ESPEC
      GO TO 180
170   FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
180   CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,191) COLUMM(M)
191   FORMAT(1H+,122X,A4)
      IF(M.NE.4.0) GO TO 190
      WRITE (6,192) COLUMI(I)
192   FORMAT(1H+,126X,A4)
190   CONTINUE
 200  CONTINUE
      WRITE (6,210) RUN(1)
210   FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 4',/)
      WRITE(6,212)
212   FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 300 I = 6, 8
      DO 285 M = 1,8
      DO 270 J =1, 8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO 255
      FORM(J+1) = ESPEC
      GO TO 270
 255  FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
 270  CONTINUE
```

```
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,286) COLUMM(M)
286   FORMAT(1H+,122X,A4)
      IF(M.NE.4.0) GO TO 295
      WRITE (6,288) COLUMI(I)
288   FORMAT(1H+,126X,A4)
295   CONTINUE
300   CONTINUE
      WRITE(6,400)
400   FORMAT(//,1X,'TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MA
     1DE UP OF:            ',//1X,'1* CONTRIBUTION OF NORMALIZATION FACTOR'
     2,/1X,'2* CONTRIBUTION OF POWER',/1X,'3* CONTRIBUTION OF OUTLET TEM
     3PERATURE',/1X,'4* CONTRIBUTION OF INLET TEMPERATURE',/1X,'5* TOTAL
     4 CONTRIBUTION OF POWER',/1X,'6* TOTAL CONTRIBUTION OF OUTLET TEMPE
     5RATURE',/1X,'7* TOTAL CONTRIBUTION OF INLET TEMPERATURE')
      DO 450 I=1,8
      DO 450 J=1,8
      DO 450 N=1,7
      RESUL1(I,J,N)=0.0
450   CONTINUE
      DO 460 I=1,8
      DO 460 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 460
      N=1
      RESUL1(I,J,N)=TOUT(I,J)
      N=2
      RESUL1(I,J,N)=X(I,J)
      N=3
      RESUL1(I,J,N)=Q(I,J)
      N=4
      RESUL1(I,J,N)=SIRPO(I,J)
      N=5
      RESUL1(I,J,N)=SITOUT(I,J)
      N=6
      RESUL1(I,J,N)=SITIN(I,J)
460   CONTINUE
      WRITE(6,500) RUN(1)
500   FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION # ',A8,27X,'PAG
     1E 5',//1H ,'THESE VALUES ARE THE INPUTS USED FOR THE COMPUTATION',
     2/1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14X,'9',
     314X,'8',//)
      FORMA(1)=LEFTA
      FORMA(10)=RIGHTA
      DO 510 I=1,5
      DO 505 N=1,7
      DO 504 J=1,8
      IF(RESUL1(I,J,N).EQ.0.0) GO TO 503
      FORMA(J+1)=ESPECA
      GO TO 504
503   FORMA(J+1)= ASPECA
      RESUL1(I,J,N)=BLANKA
504   CONTINUE
      WRITE(6,FORMA) (RESUL1(I,J,N),J=1,8)
      WRITE(6,507)COLUMN(N)
507   FORMAT(1H+,122X,A4)
      IF(N.NE.3) GO TO 505
      WRITE(6,506) COLUMI(I)
506   FORMAT(1H+,126X,A4)
505   CONTINUE
510   CONTINUE
```

```
      WRITE(6,520) RUN(1)
520   FORMAT(1H1, 100X,'RUN *',2X,A8,2X,'PAGE 6',/)
      WRITE (6,212)
      FORMA(1)=LEFTA
      FORMA(10)=RIGHTA
      DO 610 I=6,8
      DO 605 N=1,7
      DO 604 J=1,8
      IF(RESUL1(I,J,N).EQ.0.0) GO TO 603
      FORMA(J+1)=ESPECA
      GO TO 604
603   FORMA(J+1)= ASPECA
      RESUL1(I,J,N)=BLANKA
604   CONTINUE
      WRITE(6,FORMA) (RESUL1(I,J,N),J=1,8)
      WRITE(6,607)COLUMN(N)
607   FORMAT(1H+,122X,A4)
      IF(N.NE.3) GO TO 605
      WRITE(6,606) COLUMT(I)
606   FORMAT(1H+,126X,A4)
605   CONTINUE
610   CONTINUE
      WRITE(6,530)
530   FORMAT( /1H ,'THE ABOVE DATA ARE: 1* OUTLET TEMPERATURE    (DEG. F.
     1)',/1H ,20X,'2* TEMPERATURE DIFFERENCE ACROSS THE FUEL ASSEMBLY (D
     2EG. F.)',/1H ,20X,'3* RELATIVE POWER OF THE ASSEMBLY',/1H ,20X,'4*
     3 RELATIVE POWER UNCERTAINTY',/1H ,20X,'5* OUTLET TEMPERATURE UNCER
     4TAINTY  (DEG. F.)',/1H ,20X,'6* INLET TEMPERATURE UNCERTAINTY
     5(DEG. F.)',//1H ,'NOTE: THE UNCERTAINTIES ARE RELATED TO A ONE SIG
     6MA CONFIDENCE LEVEL.',//)
      WRITE(6,535) TIN
535   FORMAT(1H ,'INLET TEMPERATURE =',F6.2,'DEG. F.')
      STOP
      END
```

```
INPUT FOR FLOFA 3
*****************


089
1813.5
38         522.3
(          ' ')    A8.7X.  F15.5.
(          ' ')    A8.7X.  F15.10.
P          P       N       M         L          K        J       H
1*         2*      3*      4*
1*         2*      3*      4*        5*         6*       7*
1*         2*      3*      4*        5*         6*
 1  8  0.7690          573.8     0.04001      2.14          0.1
 2  5  0.7366          571.6     0.05506      2.14          0.1
 2  6  1.0118          575.7     0.05539      2.14          0.1
 2  7  1.2005          588.2     0.03157      2.14          0.1
 3  4  0.7895          572.2     0.04863      2.14          0.1
 3  6  0.9347          578.5     0.03029      2.14          0.1
 3  7  1.0156          576.4     0.02360      2.14          0.1
 3  8  1.0228          574.3     0.03057      2.14          0.1
 4  4  1.0619          582.7     0.03095      2.14          0.1
 4  5  1.1784          583.7     0.02309      2.14          0.1
 4  6  1.1579          577.8     0.02859      2.14          0.1
 4  7  1.1570          583.9     0.02331      2.14          0.1
 5  2  0.7085          574.8     0.04955      2.14          0.1
 5  3  1.2356          584.7     0.03087      2.14          0.1
 5  4  1.1817          586.2     0.02382      2.14          0.1
 5  5  0.9491          575.1     0.02143      2.14          0.1
 5  6  0.9730          575.3     0.02336      2.14          0.1
 5  7  0.9850          576.6     0.02332      2.14          0.1
 5  8  1.0883          578.7     0.04010      2.14          0.1
 6  2  0.9782          573.5     0.04748      2.14          0.1
 6  3  0.9292          575.3     0.02993      2.14          0.1
 6  4  1.1633          573.4     0.02341      2.14          0.1
 6  5  0.9801          575.7     0.02327      2.14          0.1
 6  6  1.1025          574.5     0.02314      2.14          0.1
 7  1  0.731           566.4     0.05745      2.14          0.1
 7  2  1.238           586.4     0.02655      2.14          0.1
 7  4  1.1799          583.5     0.02331      2.14          0.1
 7  6  1.1365          581.1     0.02332      2.14          0.1
 7  7  0.9258          572.2     0.02311      2.14          0.1
 7  8  1.0256          576.0     0.04029      2.14          0.1
 8  1  0.7956          568.4     0.05745      2.14          0.1
 8  2  0.9572          572.5     0.03059      2.14          0.1
 8  3  1.1994          572.6     0.02920      2.14          0.1
 8  4  0.9769          575.9     0.02891      2.14          0.1
 8  5  1.1263          580.9     0.02841      2.14          0.1
 8  6  0.8549          570.3     0.02836      2.14          0.1
 8  7  1.0323          577.5     0.02955      2.14          0.1
 8  8  0.8026          569.3     0.04002      2.14          0.1
/*
```

```
                    EFFECTIVE FLOW FACTOR DISTRIBUTION #  089                    RUN # 089     PAGE 1

EFF = CONSTANT * RELATIVE POWER / TEMPERATURE DIFFERENCE ACROSS THE FUEL ASSEMBLY

RESULTS: SUM OF THE RATIOS        =    0.7021423057
         NORMALIZATION FACTOR     =   54.1200831974
         SUM OF THE STD. SQUARE   =    0.0000352856
         CONTRIBUTION OF POWER    =    0.0000145797
         CONTRIBUTION OF T. OUT   =    0.0000206608
         CONTRIBUTION OF T. INL   =    0.0000000451

THERMAL POWER =1813.5   MWTH
```

```
     15            14            13            12            11            10             9             8

                                                                                                  0.8081231841  1*
                                                                                                  0.0022222614  2*  R
                                                                                                  0.0471408678  3*
                                                                                                  5.8333764819  4*

                                                        0.8086177137  1.0254438236  0.9859053092                1*
                                                        0.0032637682  0.0049938764  0.0020655828                2*  P
                                                        0.0571293986  0.0706673644  0.0454486832                3*
                                                        7.0650688935  6.8913930500  4.6098426283                4*

                                          0.8562686510                0.9001075047  1.0159770147  1.0645104057  1*
                                          0.0031378260                0.0019786378  0.0022674092  0.0030634273  2*  N
                                          0.0560163013                0.0444818819  0.0476173199  0.0553482369  3*
                                          6.5419072855                4.9418410251  4.6869501160  5.1994566277  4*

                                          0.9514919925  1.0386825088  1.1291107087  1.0165087055                1*
                                          0.0020709893  0.0019658303  0.0030329271  0.0018851857                2*  M
                                          0.0455081233  0.0443376845  0.0550720177  0.0434187250                3*
                                          4.7828172673  4.2686464969  4.8774683721  4.2713579137                4*

              0.7303634085  1.0716470320  1.0008404118  0.9728289955  0.9935630368  0.9817363158  1.0443064990  1*
              0.0022361075  0.0025302566  0.0017659473  0.0020604089  0.0022222655  0.0020933760  0.0034052339  2*  L
              0.0472874986  0.0503016561  0.0420231755  0.0453917268  0.0471409111  0.0457534260  0.0583543821  3*
              6.4745163850  4.6938641729  4.1987888344  4.6659512582  4.7446321339  4.6604597618  5.5878597080  4*

              1.0339895583  0.9488373832  1.2320526964  0.9933163585  1.1430534813                              1*
              0.0043585580  0.0023419024  0.0036085610  0.0021929602  0.0029938619                              2*  K
              0.0660193758  0.0483932061  0.0600712992  0.0468290526  0.0547161939                              3*
              6.3849170717  5.1002634330  4.8757085913  4.7144147218  4.7868446004                              4*

0.8970925355  1.0452521529                1.0434033687                1.0460454856  1.0041956518  1.0336230415  1*
0.0046129682  0.0020687360                0.0020035306                0.0021258896  0.0024689506  0.0035111436  2*  J
0.0679188355  0.0454833600                0.0447608157                0.0461073700  0.0496885364  0.0592549032  3*
7.5709955046  4.3514246627                4.2898860634                4.4077786885  4.9485859527  5.7327382234  4*

0.9340116744  1.0319470844  1.2904896180  0.9863789044  1.0401953875  0.9639012318  1.0121043820  0.9241867824  1*
0.0048257093  0.0030121773  0.0045601305  0.0024371034  0.0023968970  0.0026645598  0.0024512043  0.0032036851  2*  H
0.0694673253  0.0548833058  0.0675287380  0.0493670274  0.0489581150  0.0516193743  0.0495096381  0.0566011052  3*
7.4375221612  5.3184224887  5.2327957865  5.0048746186  4.7066268107  5.3552555803  4.8917521722  6.1244227102  4*

TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:
1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES WITH OUTLET THERMOCOUPLES
2* SQUARE OF THE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
3* STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
4* RELATIVE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
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```
                                                                                                   RUN # 089      PAGE 3
         15             14             13             12             11             10              9              8

                                                                                                        2.1033311619   1*
                                                                                                       47.0432253550   2*
                                                                                                       50.7426420114   3*
                                                                                                        0.1108014718   4*   R
                                                                                                       47.9123031212   5*
                                                                                                       51.9742061674   6*
                                                                                                        0.0026892396   7*

                                                             1.4338867997   1.5070707045   3.3680262657                1*
                                                            60.7350805558  64.6024054570  46.9004451242                2*
                                                            37.7486049108  33.8166818395  49.6231716103                3*
                                                             0.0824277337   0.0738419990   0.1083569998                4*   P
                                                            61.3275498539  65.2251136949  48.2920836816                5*
                                                            38.5881890991  34.6991174226  51.5952530878                6*
                                                             0.0018333134   0.0019268835   0.0043062308                7*

                                              1.6723951494                  2.9306916581   3.2582585132   2.6474742780   1*
                                             55.2585862299                 37.5682535113  25.3548984605  34.5680560790   2*
                                             42.9751781582                 59.3714116050  71.2313025805  62.6476723847   3*
                                              0.0938404624                  0.1296432256   0.1555404458   0.1367972592   4*   N
                                             55.9496050610                 38.7791892907  26.7011919568  35.6619689509   5*
                                             43.9544162155                 61.0874204123  73.1391117114  64.1978499305   6*
                                              0.0021382611                  0.0037470714   0.0041658860   0.0033849604   7*

                                              3.1288164907   3.9279620895   3.0085604715   3.9229768074                1*
                                             41.8748948692  29.2595393475  34.3589107187  29.7819149253                2*
                                             54.8764605752  66.6669248778  62.4960626061  66.1506618923                3*
                                              0.1198280648   0.1455736852   0.1364662036   0.1444463750                4*   M
                                             43.1676940709  30.8825384171  35.6020212007  31.4028541206                5*
                                             56.7084774780  68.9668657541  64.2576659642  68.4476837348                6*
                                              0.0040003863   0.0050221436   0.0038466315   0.0050157696                7*

                1.7073910494   3.2485281356   4.0597529089   3.2875114455   3.1793810194   3.2952634676   2.7922220245   1*
               58.5696527406  43.2526003674  32.1836611471  21.0942430966  24.2404448275  25.0379960675  51.4988768318   2*
               39.6364062793  53.3823060631  63.6176706007  75.4534854669  72.4220336308  71.5105901675  46.1082193824   3*
                0.0865499307   0.1165654338   0.1389153433   0.1647599910   0.1581405224   0.1561502973   0.1006817613   4*   L
               59.2751315668  44.5948633582  33.8611150135  22.4526136449  25.5541368435  26.3995696826  52.4460026259   5*
               40.6361354969  55.2844177630  65.9947789969  77.3784230765  74.2836575979  73.4400668210  47.4503848646   6*
                0.0021830055   0.0041534451   0.0051906463   0.0042032876   0.0040550362   0.0042131991   0.0029307483   7*
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         15             14             13             12             11             10              9              8

                   1.7556467911   2.7514552400   3.0107326121   3.2202686226   3.1235539486                                1*
                  55.2981877456  34.4372304572  23.0529944280  24.3633608705  23.3683501566                                2*
                  42.8525926782  62.6744585544  73.7751777163  72.2585868863  73.3479335802                                3*
                   0.0935727851   0.1368557484   0.1610952435   0.1577836206   0.1601623146                                4*  K
                  56.0236054160  35.5741073396  24.2970024192  25.6939472813  24.6589749225                                5*
                  43.8805770953  64.2855190055  75.5380529286  74.1441517846  75.1768691051                                6*
                   0.0022447035   0.0035179065   0.0038494087   0.0041173135   0.0039936578                                7*

  1.2486527912   3.7799384765                  3.8891630719                  3.6839023301   2.9227080312   2.1778273486   1*
 57.5803220276  37.2276920786                 29.5252124659                 27.9909430494  21.8090955372  49.3935582242   2*
 41.0813201411  58.8638345629                 66.4405450991                 68.1762851010  75.1041991411  48.3230962679   3*
  0.0897050400   0.1285348820                  0.1450793630                  0.1488695194   0.1639972905   0.1055181594   4*  J
 58.0962542775  38.7895291052                 31.1321801258                 29.5130987928  23.0167325529  50.2934171535   5*
 41.8124442023  61.0771031266                 68.7177679745                 70.3333215898  76.8155332928  49.5992801995   6*
  0.0015964802   0.0048328862                  0.0049725366                  0.0047100980   0.0037369638   0.0027844976   7*

  1.2938714302   2.5303581762   2.6138426023   2.8573356832   3.2309343989   2.4956706069   2.9910162730   1.9081712689   1*
 59.6655324368  33.0821164187  31.1384840923  33.3664328325  36.4353494073  28.0447806890  34.0630343192  42.6996044669   2*
 38.9555329551  64.2472353462  66.1033302835  63.6372733366  60.2022587329  69.3082075225  62.8088003111  55.2715335193   3*
  0.0850631779   0.1402900588   0.1443430218   0.1389581477   0.1314574608   0.1513411816   0.1371490967   0.1206907449   4*  H
 60.2001486270  34.1276379569  32.2185006543  34.5470585742  37.7703428222  29.0759696315  35.2988056941  43.4980438977   5*
 39.7131339001  65.7288367641  67.6338143636  65.3103299969  62.0940687666  70.7694993170  64.5601310091  56.3888256419   6*
  0.0016542950   0.0032352201   0.0033419602   0.0036532812   0.0041339534   0.0031908699   0.0038242001   0.0024397155   7*

TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MADE UP OF:

1* CONTRIBUTION OF NORMALIZATION FACTOR
2* CONTRIBUTION OF POWER
3* CONTRIBUTION OF OUTLET TEMPERATURE
4* CONTRIBUTION OF INLET TEMPERATURE
5* TOTAL CONTRIBUTION OF POWER
6* TOTAL CONTRIBUTION OF OUTLET TEMPERATURE
7* TOTAL CONTRIBUTION OF INLET TEMPERATURE
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                               EFFECTIVE FLOW FACTOR DISTRIBUTION # 089                                PAGE 5
THESE VALUES ARE THE INPUTS USED FOR THE COMPUTATION
      15           14           13           12           11           10            9            8

                                                                                              573.80000   1*
                                                                                               51.50000   2*
                                                                                                0.76900   3*  R
                                                                                                0.04001   4*
                                                                                                2.14000   5*
                                                                                                0.10000   6*

                                                        571.60000    575.70000    589.20000               1*
                                                         49.30000     53.40000     65.90000               2*
                                                          0.73660    • 1.01180      1.20050               3*  P
                                                          0.05506      0.05539      0.03157               4*
                                                          2.14000      2.14000      2.14000               5*
                                                          0.10000      0.10000      0.10000               6*

                                           572.20000                 578.50000    576.40000   574.30000   1*
                                            49.90000                  56.20000     54.10000    52.00000   2*
                                             0.78950                   0.93470      1.01560     1.02290   3*  N
                                             0.04863                   0.03029      0.02360     0.03057   4*
                                             2.14000                   2 14000      2 14000     2.14000   5*
                                             0.10000                   0.10000      0.10000     0.10000   6*

                                           582.70000    583.70000    577.80000    583.90000               1*
                                            60,40000     61.40000     55.50000     51.60000               2*
                                             1.06190      1.17840      1.15790      1.15700               3*  M
                                             0.03095      0.02309      0.02859      0.02331               4*
                                             2.14000      2.14000      2.14000      2.14000               5*
                                             0.10000      0.10000      0.10000      0.10000               6*

                 574.80000    584.70000    586.20000    575.10000    575.30000    576.60000   578.70000   1*
                  52.50000     62.40000     63,90000     52.80000     53.00000     54.30000    56.40000   2*
                   0.70850      1.23560      1.18170      0.94910      0.97300      0.98500     1.08830   3*  L
                   0.04955      0.03087      0,02382      0.02143      0.02336      0.02332     0.04010   4*
                   2.14000      2.14000      2.14000      2.14000      2.14000      2.14000     2.14000   5*
                   0.10000      0.10000      0.10000      0.10000      0.10000      0.10000     0.10000   6*
```

```
    15           14           13           12           11           10            9            8

             573.50000    575.30000    573.40000    575.70000    574.50000                            1*
              51.20000     53.00000     51.10000     53.40000     52.20000                            2*
               0.97820      0.92920      1.16330      0.98010      1.10250                            3*  K
               0.04748      0.02993      0.02341      0.02327      0.02314                            4*
               2.14000      2.14000      2.14000      2.14000      2.14000                            5*
               0.10000      0.10000      0.10000      0.10000      0.10000                            6*

566.40000    586.40000                 583.50000                 581.10000    572.20000    576.00000  1*
 44.10000     64.10000                  61.20000                  58.80000     49.90000     53.70000  2*
  0.73100      1.23800                   1.17990                   1.13650      0.92580      1.02560  3*  J
  0.05745      0.02655                   0.02331                   0.02332      0.02311      0.04029  4*
  2.14000      2.14000                   2.14000                   2.14000      2.14000      2.14000  5*
  0.10000      0.10000                   0.10000                   0.10000      0.10000      0.10000  6*

568.40000    572.50000    572.60000    575.90000    580.90000    570.30000    577.50000    569.30000  1*
 46.10000     50.20000     50.30000     53.60000     58.60000     48.00000     55.20000     47.00000  2*
  0.79560      0.95720      1.19940      0.97690      1.12630      0.85490      1.03230      0.80260  3*  H
  0.05745      0.03059      0.02920      0.02891      0.02841      0.02836      0.02855      0.04002  4*
  2.14000      2.14000      2.14000      2.14000      2.14000      2.14000      2.14000      2.14000  5*
  0.10000      0.10000      0.10000      0.10000      0.10000      0.10000      0.10000      0.10000  6*

THE ABOVE DATA ARE: 1* OUTLET TEMPERATURE   (DEG. F.)
                    2* TEMPERATURE DIFFERENCE ACROSS THE FUEL ASSEMBLY (DEG. F.)
                    3* RELATIVE POWER OF THE ASSEMBLY
                    4* RELATIVE POWER UNCERTAINTY
                    5* OUTLET TEMPERATURE UNCERTAINTY  (DEG. F.)
                    6* INLET TEMPERATURE UNCERTAINTY     (DEG. F.)

NOTE: THE UNCERTAINTIES ARE RELATED TO A ONE SIGMA CONFIDENCE LEVEL.

INLET TEMPERATURE =522.30DEG. F.
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PROGRAM FLOFA 4
***************

C CASE EFFECTIVE FLOW FACTOR DISTRIBUTION
       IMPLICIT REAL*8 (A-H,O-Z)
       REAL *8 LEFT, RIGHT, ASPEC, FSPEC, BLANKS
       REAL*8 LEFTA, RIGHTA, ASPECA, FSPECA,BLANKA
       DIMENSION RESUL1(8,8,5), RESUL2(8,8,5), RESUL3(8,8,8),
      1STRHIN(8,8), Q(8,8), TOUT(8,8), Y(8,8), X(8,8), STRHOU(8,8), SPO(8
      2,8), STO(8,8), STI(8,8), SI2Y(8,8), SI2RFL(8,8),
      3STFLO(8,8,5), FLOFA(8,8,5), SI2FLO(8,8,5), STRFLO(8,8,5),
      4CONOR(8,8,8), COPO1(8,8,8), COTO1(8,8,8), COTI1(8,8,8), COPO2(8,8,
      58), COTO2(8,8,8), COTI2(8,8,8),  DERHIN(1),
      6STRPO(8,8),STTOUT(8,8),SITIN(8,8),SROSUM(1), SUMY(1),FANOR(1),
      7STOSUM(1),  STISUM(1),  S2YSUM(1),  A(1) , COLUMN(5),
      8FORM(10), RUN(3), FORMA(10), COLUMI(8), COLUMK(5), COLUMM(8),
      9ENT(11), TEMP(11), HOUT(8,8), HIN(11), DERENT(11), DERHOU(8,8)
       READ (5,8) RUN
   8   FORMAT(5A8)
       READ (5,9) POWER
   9   FORMAT (A8)
       READ(5,10) NUM2, TIN
  10   FORMAT(I2,7X,F10.0)
       READ(5,11) LEFTA, RIGHTA, ASPECA, FSPECA, BLANKA
  11   FORMAT(5A8)
       READ (5,12) LEFT,RIGHT, ASPEC, FSPEC, BLANKS
  12   FORMAT(5A8)
       READ (5,13) (COLUMI(I), I=1,8)
  13   FORMAT(8A8)
       READ (5,18) (COLUMK(K), K=1,5)
  18   FORMAT(5A8)
       READ (5,19) (COLUMM(M), M=1,8)
  19   FORMAT(8A8)
       READ (5,5) (COLUMN(N), N=1,5)
   5   FORMAT(5A8)
       DO 14 I=1,8
       DO 14 J=1,8
       TOUT(I,J)=0.0
       Q(I,J)=0.0
       Y(I,J) = 0.0
       X(I,J) =0.0
       STRHOU(I,J)=0.0
       STRHIN(I,J)=0.0
       SPO(I,J)=0.0
       STO(I,J)=0.0
       STI(I,J)=0.0
       SI2Y(I,J) =0.0
       HOUT(I,J)=0.0
       DERHOU(I,J)=0.0
  14   CONTINUE
       DO 16 IN = 1, NUM2
       READ (5,15) I, J, XQ, XTOUT,XSTRPO,XSTTOU,XSITIN
  15   FORMAT(2(I2,1X),5(F10.0,2X))
       Q(I,J) = XQ
       TOUT(I,J) = XTOUT
       STRPO(I,J)=XSTRPO
       STTOUT(I,J)=XSTTOU
       SITIN(I,J)=XSITIN
  16   CONTINUE
```

```
      TOUT(1,1)=TIN
C CARDS DEFINING ENTHALPY OF H2O AS A FUNCTION OF TEMP @ P=2,000 PSIA
      DO 21 II=1,11
      READ(5,22) ENT(II), TEMP(II), DERENT(II), SENT
 22   FORMAT(3F10.4, I1)
  21  CONTINUE
      DO 231I=1,8
      DO 23 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 23
      IF(TOUT(I,J).LT.TEMP(1)) STOP
      JJ=2
  24  IF(TOUT(I,J) - TEMP(JJ)) 28, 27, 26
  26  JJ=JJ+1
      IF(JJ.LT.II) GO TO 24
      STOP
  27  HOUT(I,J)= ENT(JJ)
      DERHOU(I,J)= DERENT(JJ)
      GO TO 23
 28   HOUT(I,J)= ENT(JJ-1)+(ENT(JJ)-ENT(JJ-1))/(TEMP(JJ)-TEMP(JJ-1))*(TO
     1UT(I,J)-TEMP(JJ-1))
      DERHOU(I,J)=DERENT(JJ-1)+(DERENT(JJ)-DERENT(JJ-1))/(TEMP(JJ)-TEMP(
     1JJ-1))*(TOUT(I,J)-TEMP(JJ-1))
 23   CONTINUE
 231  CONTINUE
      TOUT(1,1)=0.0
      HIN(1)=HOUT(1,1)
      HOUT(1,1)=0.0
      DERHIN(1)=DERHOU(1,1)
      DERHOU(1,1)=0.0
      SUMY(1)=0.0
      DO 201I = 1,8
      DO 20 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 20
      X(I,J) = HOUT(I,J)-HIN(1)
      Y(I,J) = Q(I,J)/X(I,J)
      SUMY(1)=SUMY(1)+Y(I,J)
  20  CONTINUE
 201  CONTINUE
      FANOP(1)= 38./ SUMY(1)
      SPOSUM(1)=0.0
      STOSUM(1)=0.0
      STISUM(1)=0.0
       S2YSUM(1)=0.0
      DO 30 I =1,8
      DO 30 J =1,8
      DO 25 K = 1,5
      FLOEA(I,J,K) =0.0
      ST2FLO(I,J,K) =0.0
      STFLO(I,J,K) =0.0
      STEFLO(I,J,K) =0.0
      RESUL2(I,J,K) = 0.0
  25  CONTINUE
      DO 30 M = 1,8
      RESUL3(I,J,M) = 0.0
  30  CONTINUE
      DO 501I = 1,8
      DO 50 J = 1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 50
      STPHOU(I,J)=DERHOU(I,J)*DERHOU(I,J)*SITOUT(I,J)*SITOUT(I,J)/(X(I,J
     1)*Y(I,J))
```

```
      SIRHIN(I,J)=DERHIN(1)*DERHIN(1)*SITIN(I,J)*SITIN(I,J)/(X(I,J)*Y(I,
     1J))
      SPO(I,J)  =  Y(I,J)*SIRPPO(I,J)*Y(I,J)*SIRPPO(I,J)
      STO(I,J)  =  Y(I,J)* Y(I,J)* SIRHOU(I,J)
      STI(I,J)  =  Y(I,J)* Y(I,J)* SIRHIN(I,J)
      SI2Y(I,J)  =  SPO(I,J)  + STO(I,J)  +STI(I,J)
       SPOSUM(1)=SPOSUM(1)+SPO(I,J)
       STOSUM(1)=STOSUM(1)+STO(I,J)
      STISUM(1)=STISUM(1)+STI(I,J)
      S2YSUM(1)=S2YSUM(1)+SI2Y(I,J)
      A(1)=S2YSUM(1)/(SUMY(1)*SUMY(1))
 50   CONTINUE
501   CONTINUE
      DO 521I=1,8
      DO 52 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 52
      SI2PFL(I,J)=A(1)+SIRPPO(I,J)*SIRPPO(I,J)+SIRHOU(I,J)+SIRHIN(I,J)
      K = 1
      FLOFA(I,J,K)  =  FANOR(1)*Y(I,J)
      K = 2
      SI2FLO(I,J,K)=(Y(I,J)*FANOR(1))**2*A(1)+(FANOR(1)*Y(I,J)*SIRPPO(I,J
     1))**2+(FANOR(1)*Y(I,J)/X(I,J)*DERHOU(I,J)*SITOUT(I,J))**2+(FANOR(1
     2)*Y(I,J)/X(I,J)*SITIN(I,J))**2
      K = 3
      SIFLO(I,J,K)= DSQRT(SI2FLO(I,J,2))
      K = 4
      SIRFLO(I,J,K)  =  SIFLO(I,J,3)/FLOFA(I,J,1)* 100.
      DO 522K=1,4
      RESUL2(I,J,K)  =  FLOFA(I,J,K)  +  SI2FLO(I,J,K)  +  SIFLO(I,J,K)
     1 + SIRFLO(I,J,K)
522   CONTINUE
 52   CONTINUE
521   CONTINUE
      DO 53 I=1,8
      DO 53 J=1,8
      DO 53 M=1,8
      CONOR(I,J,M)=0.0
      COPO1(I,J,M)=0.0
      COTO1(I,J,M)=0.0
      COTI1(I,J,M)=0.0
      COPO2(I,J,M)=0.0
      COTO2(I,J,M)=0.0
      COTI2(I,J,M)=0.0
      RESUL3(I,J,M)=0.0
 53   CONTINUE
      DO 551I=1,8
      DO 55 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 55
      M = 1
       CONOR(I,J,M)=A(1)/SI2PFL(I,J)*100.
      M = 2
      COPO1(I,J,M)=SIRPPO(I,J)*SIRPPO(I,J)/SI2PFL(I,J)*100.
      M = 3
      COTO1(I,J,M)  =  SIRHOU(I,J)/SI2PFL(I,J)* 100.
      M = 4
      COTI1(I,J,M)  =  SIRHIN(I,J)/SI2PFL(I,J)* 100.
      M = 5
      COPO2(I,J,M)=CONOR(I,J,1)*SPOSUM(1)/S2YSUM(1)+COPO1(I,J,2)
      M = 6
      COTO2(I,J,M)=CONOR(I,J,1)*STOSUM(1)/S2YSUM(1)+COTO1(I,J,3)
```

```
      M = 7
      COTO2(I,J,M)=CONOR(I,J,1)*STISUM(1)/S2YSUM(1)+COTO1(I,J,4)
      DO 552M=1,7
      RESUL3(I,J,M) = CONOR(I,J,M) + COPO1(I,J,M) + COTO1(I,J,M)
     1+ COTI1(I,J,M) + COPO2(I,J,M) + COTO2(I,J,M) + COTI2(I,J,M)
  552 CONTINUE
   55 CONTINUE
  551 CONTINUE
      WRITE(6,60) RUN(1), RUN(1)
   60 FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION #',2X,A8,15X,'R
     1UN # ',A8,'PAGE 1',////)
      WRITE(6,61)
   61 FORMAT(1X,'EFF = CONSTANT * RELATIVE POWER / ENTHALPY DIFFERENCE A
     1CROSS THE FUEL ASSEMBLY',////)
      WRITE(6,63) SUMY(1), FANOR(1), S2YSUM(1), SPOSUM(1), STOSUM(1),
     1STISUM(1)
   63 FORMAT(1X,'RESULTS: SUM OF THE RATIOS',6X,'=',2X,F14.10,/10X,'NORM
     1ALIZATION FACTOR   =',2X,F14.10,/10X,'SUM OF THE STD. SQUARE =',2X
     2,F14.10,/10X,'CONTRIBUTION OF POWER  =',2X,F14.10,/10X,'CONTRIBUTI
     3ON OF T. OUT =',2X,F14.10,/10X,'CONTRIBUTION OF T. IN  =',2X,F14.1
     40,///)
      WRITE(6,640) POWER
  640 FORMAT(1H ,'THERMAL POWER =',A8,' MWTH')
      WRITE(6,64) RUN(1)
   64 FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 2',/)
      WRITE(6, 66)
   66 FORMAT(1H ,9X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',/)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 100 I = 1,8
      DO 95 K = 1,5
      DO 90 J=1,8
      IF (RESUL2(I,J,K).EQ.0.0) GOTO 85
      FORM(J+1) = FSPEC
      GO TO 90
   85 FORM(J+1) = ASPEC
      RESUL2(I,J,K) = BLANKS
   90 CONTINUE
      WRITE(6, FORM)(RESUL2(I,J,K),J=1,8)
      WRITE(6,971)COLUMK(K)
  971 FORMAT(1H+,122X,A8)
      IF(K.NE.2.0) GO TO 95
      WRITE (6,96) COLUMI(I)
   96 FORMAT(1H+,126X,A4)
   95 CONTINUE
  100 CONTINUE
      WRITE(6, 120)
  120 FORMAT(//,1X,'TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:',////
     11X,'1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES W
     2ITH OUTLET THERMOCOUPLES',/1X,'2* SQUARE OF THE STANDARD DEVIATION
     3 OF THE EFFECTIVE FLOW FACTOR',/1X,'3* STANDARD DEVIATION OF THE E
     4FFECTIVE FLOW FACTOR',/1X,'4* RELATIVE STANDARD DEVIATION OF THE E
     5FFECTIVE FLOW FACTOR')
      WRITE(6,140) RUN(1)
  140 FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 3',/)
      WRITE(6,142)
  142 FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
```

```
      FORM(10)=RIGHT
      DO 200 I = 1,5
      DO 190 M = 1,8
      DO 180 J=1,8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO  170
      FORM(J+1) = FSPEC
      GO TO 180
 170  FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
 180  CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,191) COLUMM(M)
 191  FORMAT(1H+,122X,A8)
      IF(M.NE.4.0) GO TO 190
      WRITE (6,192) COLUMI(I)
 192  FORMAT(1H+,126X,A4)
 190  CONTINUE
  200 CONTINUE
      WRITE (6,210) RUN(1)
 210  FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 4',/)
      WRITE(6,212)
 212  FORMAT(1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14
     1X,'9',14X,'8',//)
      FORM(1)=LEFT
      FORM(10)=RIGHT
      DO 300 I = 6, 8
      DO 285 M = 1,8
      DO 270 J =1, 8
      IF (RESUL3(I,J,M).EQ.0.0) GO TO 255
      FORM(J+1) = FSPEC
      GO TO 270
 255  FORM (J+1) = ASPEC
      RESUL3(I,J,M) = BLANKS
 270  CONTINUE
      WRITE (6,FORM)(RESUL3(I,J,M),J=1,8)
      WRITE(6,286) COLUMM(M)
 286  FORMAT(1H+,122X,A8)
      IF(M.NE.4.0) GO TO 285
      WRITE (6,288) COLUMI(I)
 288  FORMAT(1H+,126X,A4)
 285  CONTINUE
 300  CONTINUE
      WRITE(6,400)
 400  FORMAT(//,1X,'TABLE # 2 THE SQUARE OF THE STANDARD DEVIATION IS MA
     1DE UP OF:            ',//1X,'1* CONTRIBUTION OF NORMALIZATION FACTOR'
     2,/1X,'2* CONTRIBUTION OF POWER',/1X,'3* CONTRIBUTION OF OUTLET TEM
     3PERATURE',/1X,'4* CONTRIBUTION OF INLET TEMPERATURE',/1X,'5* TOTAL
     4 CONTRIBUTION OF POWER',/1X,'6* TOTAL CONTRIBUTION OF OUTLET TEMPE
     5RATURE',/1X,'7* TOTAL CONTRIBUTION OF INLET TEMPERATURE')
      DO 450 I=1,8
      DO 450 J=1,8
      DO 450 N=1,8
      RESUL1(I,J,N)=0.0
 450  CONTINUE
      DO 460 I=1,8
      DO 460 J=1,8
      IF(TOUT(I,J).EQ.0.0) GO TO 460
      N=1
      RESUL1(I,J,N)=TOUT(I,J)
      N=2
```

```
      RESUL1(I,J,N)=HOUT(I,J)
      N=3
      RESUL1(I,J,N)=X(I,J)
      N=4
      RESUL1(I,J,N)=Q(I,J)
      N=5
      RESUL1(I,J,N)=SIRRO(I,J)
      N=6
      RESUL1(I,J,N)=SITOUT(I,J)
      N=7
      RESUL1(I,J,N)=SITIN(I,J)
  460 CONTINUE
      WRITE(6,500) RUN(1)
  500 FORMAT(1H1,35X,'EFFECTIVE FLOW FACTOR DISTRIBUTION # ',A8,27X,'PAG
     1E 5',//1H ,'THESE VALUES ARE THE INPUTS USED FOR THE COMPUTATION',
     2/1H ,8X,'15',13X,'14',13X,'13',13X,'12',13X,'11',13X,'10',14X,'9',
     314X,'8',//)
      FORMA(1)=LEFTA
      FORMA(10)=RIGHTA
      DO 510 I=1,5
      DO 505 M=1,8
      DO 504 J=1,8
      IF(RESUL1(I,J,M).EQ.0.0) GO TO 503
      FORMA(J+1)=ESPECA
      GO TO 504
  503 FORMA(J+1)= ASPECA
      RESUL1(I,J,M)=BLANKA
  504 CONTINUE
      WRITE(6,FORMA) (RESUL1(I,J,M),J=1,8)
      WRITE(6,507)COLUMM(M)
  507 FORMAT(1H+,122X,A8)
      IF(M.NE.4) GO TO 505
      WRITE(6,506) COLUMI(I)
  506 FORMAT(1H+,126X,A4)
  505 CONTINUE
  510 CONTINUE
      WRITE(6,520) RUN(1)
  520 FORMAT(1H1, 100X,'RUN #',2X,A8,2X,'PAGE 6',/)
      WRITE (6,212)
      FORMA(1)=LEFTA
      FORMA(10)=RIGHTA
      DO 610 I=6,8
      DO 605 M=1,8
      DO 604 J=1,8
      IF(RESUL1(I,J,M).EQ.0.0) GO TO 603
      FORMA(J+1)=ESPECA
      GO TO 604
  603 FORMA(J+1)= ASPECA
      RESUL1(I,J,M)=BLANKA
  604 CONTINUE
      WRITE(6,FORMA) (RESUL1(I,J,M),J=1,8)
      WRITE(6,607)COLUMM(M)
  607 FORMAT(1H+,122X,A8)
      IF(M.NE.4) GO TO 605
      WRITE(6,606) COLUMI(I)
  606 FORMAT(1H+,126X,A4)
  605 CONTINUE
  610 CONTINUE
      WRITE(6,530)
  530 FORMAT( /1H ,'THE ABOVE DATA ARE: 1* OUTLET TEMPERATURE    (DEG. F.
```

```
     1) ',/1H ,20X,'2* OUTLET ENTHALPY (BTU/LB)',/1H ,20X,'3* ENTHALPY D
     2IFFERENCE ACROSS THE FUEL ASSEMBLY (BTU/LB)',/1H ,20X,'4* RELATIVE
     3 POWER OF THE FUEL ASSEMBLY',/1H ,20X,'5* RELATIVE POWER UNCERTAIN
     4TY',/1H ,20X,'6* OUTLET TEMPERATURE UNCERTAINTY  (DEG. F)',/1H ,20
     5X,'7* INLET TEMPERATURE UNCERTAINTY     (DEG. F)',//1H ,'NOTE: THE
     6UNCERTAINTIES ARE RELATED TO A ONE SIGMA CONFIDENCE LEVEL.',/)
      WRITE(6,535) TIN    , HIN(1)
535   FORMAT(1H ,'INLET TEMPERATURE =',F6.2,'DEG. F.',10X,'INLET ENTHALPY
     1Y=',F10.5,'BTU/LB')
      STOP
      END
```

```
INPUT FOR FLOFA 4
*****************


089
1813.5
38         522.3
(          ' ')     A8,7X,   F15.5,
(          ' ')     A8,7X,   F15.10,
P          P        N        M        L         K         J         H
1*         2*       3*       4*
1*         2*       3*       4*       5*        6*        7*
1*         2*       3*       4*
  1   8   0.7690          573.8     0.04001      2.14          0.1
  2   5   0.7366          571.6     0.05506      2.14          0.1
  2   6   1.0118          575.7     0.05539      2.14          0.1
  2   7   1.2005          588.2     0.03157      2.14          0.1
  3   4   0.7895          572.2     0.04863      2.14          0.1
  3   6   0.9347          578.5     0.03029      2.14          0.1
  3   7   1.0156          576.4     0.02360      2.14          0.1
  3   8   1.0228          574.3     0.03057      2.14          0.1
  4   4   1.0619          582.7     0.03095      2.14          0.1
  4   5   1.1784          583.7     0.02309      2.14          0.1
  4   6   1.1579          577.8     0.02859      2.14          0.1
  4   7   1.1570          583.9     0.02331      2.14          0.1
  5   2   0.7085          574.8     0.04955      2.14          0.1
  5   3   1.2356          584.7     0.03087      2.14          0.1
  5   4   1.1817          586.2     0.02382      2.14          0.1
  5   5   0.9401          575.1     0.02143      2.14          0.1
  5   6   0.9730          575.3     0.02336      2.14          0.1
  5   7   0.9850          576.6     0.02332      2.14          0.1
  5   9   1.0883          578.7     0.04010      2.14          0.1
  6   2   0.9782          573.5     0.04748      2.14          0.1
  6   3   0.9292          575.3     0.02993      2.14          0.1
  6   4   1.1633          573.4     0.02341      2.14          0.1
  6   5   0.9801          575.7     0.02327      2.14          0.1
  6   6   1.1025          574.5     0.02314      2.14          0.1
  7   1   0.731           566.4     0.05745      2.14          0.1
  7   2   1.238           586.4     0.02655      2.14          0.1
  7   4   1.1799          583.5     0.02331      2.14          0.1
  7   6   1.1365          581.1     0.02332      2.14          0.1
  7   7   0.9258          572.2     0.02311      2.14          0.1
  7   8   1.0256          576.0     0.04029      2.14          0.1
  8   1   0.7956          568.4     0.05745      2.14          0.1
  8   2   0.9572          572.5     0.03059      2.14          0.1
  8   3   1.1994          572.6     0.02920      2.14          0.1
  8   4   0.9769          575.9     0.02891      2.14          0.1
  8   5   1.1263          580.9     0.02841      2.14          0.1
  8   6   0.8549          570.3     0.02836      2.14          0.1
  8   7   1.0323          577.5     0.02855      2.14          0.1
  8   8   0.8026          569.3     0.04002      2.14          0.1
497.3        500.0      1.154
498.9        510.0      1.170
510.7        520.0      1.185
522.6        530.0      1.205
534.8        540.0      1.230
547.2        550.0      1.250
559.8        560.0      1.280
572.8        570.0      1.315
586.1        580.0      1.350
599.8        590.0      1.395
614.0        600.0      1.450      1
/*
```

```
                         EFFECTIVE FLOW FACTOR DISTRIBUTION #  089                RUN # 089     PAGE 1


   EFF = CONSTANT * RELATIVE POWER / ENTHALPY DIFFERENCE ACROSS THE FUEL ASSEMBLY


   RESULTS: SUM OF THE RATIOS       =    0.5593390775
            NORMALIZATION FACTOR    =   67.9373237565
            SUM OF THE STD. SQUARE  =    0.0000242401
            CONTRIBUTION OF POWER   =    0.0000092882
            CONTRIBUTION OF T. OUT  =    0.0000149260
            CONTRIBUTION OF T. INL  =    0.0000000258


   THERMAL POWER =1813.5   MWTH
```

```
                                                                                                RUN #  089       PAGE 2

       15            14            13            12            11            10             9             8

                                                                                                  0.8110250705    1*
                                                                                                  0.0023863109    2*  R
                                                                                                  0.0488498808    3*
                                                                                                  6.0232269748    4*

                                                            0.8138204400  1.0268132197  0.9721296014                1*
                                                            0.0034598650  0.0052388991  0.0021991437                2*  P
                                                            0.0588206169  0.0723802397  0.0468950283                3*
                                                            7.2277143715  7.0490171237  4.8239481867                4*

                                              0.8610913180                0.8985823359  1.0165325379  1.0676730085  1*
                                              0.0033440438                0.0021440007  0.0024951034  0.0033366103  2*  N
                                              0.0578277077                0.0463033548  0.0499510102  0.0577633991  3*
                                              6.7156300999                5.1529340077  4.9138624085  5.4102144251  4*

                                              0.9447453458  1.0299148654  1.1280185150  1.0076594568                1*
                                              0.0022262796  0.0021510311  0.0033001689  0.0020612260                2*  M
                                              0.0471834678  0.0463792093  0.0574470969  0.0454007271                3*
                                              4.9943054015  4.5032080673  5.0927441494  4.5055625477                4*

                0.7321032729  1.0612039801  0.9892127048  0.9748029205  0.9953474676  0.9820557946  1.0423237015  1*
                0.0023658542  0.0027118316  0.0019243045  0.0022791074  0.0024490035  0.0023044588  0.0036233642  2*  L
                0.0486400468  0.0520752489  0.0438668958  0.0477399977  0.0494874073  0.0480047792  0.0601943868  3*
                6.6438777992  4.9071856033  4.4345261215  4.8973999475  4.9718725280  4.8881926563  5.7750185210  4*

                1.0380875707  0.9505414870  1.2370899073  0.9946428509  1.1461850315                              1*
                0.0046367430  0.0025498197  0.0039845113  0.0024162075  0.0033032885                              2*  K
                0.0680936341  0.0504957390  0.0631229851  0.0491549341  0.0574742424                              3*
                6.5595269656  5.3122130023  5.1025382027  4.9419682729  5.0143947771                              4*

  0.9081832318  1.0328548932                1.0348737161                1.0409972826  1.0097509084  1.0346512517  1*
  0.0049315929  0.0022368934                0.0021914741                0.0023314738  0.0027316673  0.0037525272  2*  J
  0.0702253011  0.0472958078                0.0468131825                0.0482853377  0.0522653543  0.0612578743  3*
  7.7325036057  4.5791338274                4.5235647350                4.6383730775  5.1760641069  5.9206301795  4*

  0.9435772355  1.0373533419  1.2970826016  0.9874716795  1.0354796978  0.9718486342  1.0114468158  0.9328263057  1*
  0.0051407295  0.0032905496  0.0049920206  0.0026562625  0.0025991425  0.0029330497  0.0026682953  0.0034729339  2*  H
  0.0716988809  0.0573633125  0.0706542030  0.0515389413  0.0509817859  0.0541576379  0.0516555448  0.0589316039  3*
  7.5986234303  5.5297756505  5.4471652678  5.2192829759  4.9234944955  5.5726412564  5.1070945126  6.3175323774  4*


   TABLE # 1: THE FOLLOWING VALUES INCLUDED ARE:


   1* EFFECTIVE FLOW FACTOR NORMALIZED TO 1 OVER THE ASSEMBLIES WITH OUTLET THERMOCOUPLES
   2* SQUARE OF THE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
   3* STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
   4* RELATIVE STANDARD DEVIATION OF THE EFFECTIVE FLOW FACTOR
```

```
                                                                                                    RUN # 089        PAGE 3
          15             14             13             12             11             10              9              8
                                                                                                              2.1350367974   1*
                                                                                                             44.1122181590   2*
                                                                                                             53.6587677974   3*
                                                                                                              0.0939772461   4*   R
                                                                                                             44.9303139539   5*
                                                                                                             54.9734342825   6*
                                                                                                              0.0022745175   7*

                                                                 1.4828265038   1.5589977208   3.3266508282                  1*
                                                                58.0201949056  61.7340315979  42.8187350913                  2*
                                                                40.4253501381  36.6434316625  53.7662379553                  3*
                                                                 0.0716284525   0.0635390187   0.0863761252                  4*   P
                                                                58.5883790834  62.3314027913  44.0941956588                  5*
                                                                41.3384127654  37.6033973438  55.8158821064                  6*
                                                                 0.0015796987   0.0016608462   0.0035461097                  7*

                                                  1.7175406020                  2.9170136677   3.2075655486   2.6461180472   1*
                                                 52.4242204108                 34.5424740505  23.0576995296  31.9165927093   2*
                                                 45.7773847777                 62.4338253554  73.6075679893  65.3231839549   3*
                                                  0.0808542095                  0.1066869264   0.1271669325   0.1141052887   4*   N
                                                 53.0823415007                 35.6602049571  24.2867630709  32.9305227969   5*
                                                 46.8349745433                 64.2300005360  75.5826528826  66.9525529270   6*
                                                  0.0018297465                  0.0031075805   0.0034171140   0.0028189874   7*

                                                  3.1053419930   3.8193760798   2.9863240789   3.8153957287                  1*
                                                 38.3925698948  26.2818976094  31.5051590228  26.7571938825                  2*
                                                 58.4048203951  69.7822717535  65.3963592860  69.3128849638                  3*
                                                  0.0972687170   0.1154545573   0.1121576123   0.1145254250                  4*   M
                                                 39.5824627782  27.7453925308  32.6494480458  28.2191636271                  5*
                                                 60.3169602925  72.1350840182  67.2352129229  71.6622462945                  6*
                                                  0.0033082122   0.0040688937   0.0031814189   0.0040646534                  7*

                    1.7548735080   3.2166140793   3.9386732865   3.2290937192   3.1331288980   3.2413390764   2.3225730359   1*
                   55.6095735665  39.5629481473  28.8436290207  19.1395774292  22.0668513001  22.7508688258  48.2030539591   2*
                   42.5614027342  57.1265427941  67.1084741327  77.4961282542  74.6702709619  73.8802875135  49.3900630574   3*
                    0.0741501914   0.0938949793   0.1092235601   0.1348005975   0.1297488401   0.1275045843   0.0843099475   4*   L
                   56.2819997463  40.7954788724  30.3528358207  20.3772900582  23.2673924707  23.9928735872  49.0930092219   5*
                   43.6419805439  59.1071993947  69.5337446345  79.4844692957  76.5995208747  75.8761687346  50.8202065252   6*
                    0.0018695184   0.0034267536   0.0041959846   0.0034430406   0.0033378144   0.0034530929   0.0024743054   7*
```

```
         15              14              13              12              11              10               9               8

                   1.8002644069    2.7445517899    2.9746878471    3.1711659471    3.0801980720                                    1*
                  52.3810433939   31.7322811403   21.0407228525   22.1629805416   21.2873589448                                    2*
                  45.7384596795   65.4095055485   75.8514635892   74.5366084394   75.5006985163                                    3*
                   0.0802325197    0.1136571214    0.1331257113    0.1292450719    0.1317444669                                    4*  K
                  53.0708622966   32.7839267189   22.1805531456   23.3780966133   22.4676182702                                    5*
                  46.8469873090   67.0994903060   77.6831521206   76.4892799784   77.3973558373                                    6*
                   0.0019178747    0.0029238518    0.0031690225    0.0033783364    0.0032814257                                    7*

   1.2955150954    3.6939179719                    3.7850804925                    3.5999785074    2.8907522062    2.2097050201    1*
  55.1872779024   33.6072307058                   26.5445945322                   25.2681490175   19.9263239279   46.2961915702    2*
  43.4380742715   62.5971032824                   69.5550962118                   71.0123466665   77.0468400468   51.4051079760    3*
   0.0791327307    0.1017480398                    0.1152287635                    0.1195258086    0.1360838190    0.0889954337    4*  J
  55.6836887619   35.0226530363                   27.9949481926                   26.6475759586   21.0339920612   47.1428984687    5*
  44.2357983570   64.8716636844                   71.8857906863                   73.2290630697   78.8268445163   52.7657520339    6*
   0.0013801504    0.0039352395                    0.0040323576                    0.0038351630    0.0030796034    0.0023540638    7*

   1.3415861732    2.5329028586    2.6102885822    2.8432522233    3.1952178363    2.4940138955    2.9695594546    1.9406911422    1*
  57.1498466029   30.5910171456   28.7257023396   30.6710045270   33.2858283011   25.8897437067   31.2406944571   40.1168681929    2*
  41.4338904746   66.7583551729   68.5432006668   66.3707781721   63.4120786600   71.4886963627   65.6769308555   57.8386971035    3*
   0.0746767493    0.1177248229    0.1208084114    0.1149650776    0.1068752026    0.1275460351    0.1128152328    0.1037435615    4*  H
  57.6639108139   31.5615658406   29.7259034205   31.7604717860   34.5101604900   26.8453910673   32.3785596712   40.8604953119    5*
  42.2599832055   68.3180109606   70.1505073509   68.1215341361   65.3795603478   73.0244059512   67.5054615369   59.0336936513    6*
   0.0014292312    0.0026903760    0.0027808172    0.0030290003    0.0034039596    0.0026569464    0.0031635591    0.0020674754    7*


TABLE # 2 THE SQUARE OF THE STANDARD DEVIATICN IS MADE UP OF:

1* CONTRIBUTION OF NORMALIZATICN FACTCR
2* CONTRIBUTION OF POWER
3* CONTRIBUTION OF OUTLET TEMPERATURE
4* CONTRIBUTION OF INLET TEMPERATURE
5* TOTAL CONTRIBUTICN OF POWER
6* TOTAL CONTRIBUTICN OF OUTLET TEMPERATURE
7* TOTAL CONTRIBUTION OF INLET TEMPERATURE
```

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                    EFFECTIVE FLOW FACTOR DISTRIBUTION # 089                                 PAGE 5

 THESE VALUES ARE THE INPUTS USED FOR THE COMPUTATION
      15          14          13          12          11          10           9           8

                                                                                      573.80000   1*
                                                                                      577.85400   2*
                                                                                       64.41700   3*
                                                                                        0.76900   4*  R
                                                                                        0.04001   5*
                                                                                        2.14000   6*
                                                                                        0.10000   7*

                                                 571.60000   575.70000   588.20000                1*
                                                 574.92800   580.38100   597.33400                2*
                                                  61.49100    66.94400    83.89700                3*
                                                   0.73660     1.01180     1.20050                4*  P
                                                   0.05506     0.05539     0.03157                5*
                                                   2.14000     2.14000     2.14000                6*
                                                   0.10000     0.10000     0.10000                7*

                                     572.20000               578.50000   576.40000    574.30000   1*
                                     575.72600               584.10500   581.31200    578.51900   2*
                                      62.28900                70.66800    67.87500     65.08200   3*
                                       0.78950                 0.93470     1.01560      1.02280   4*  N
                                       0.04863                 0.03029     0.02360      0.03057   5*
                                       2.14000                 2.14000     2.14000      2.14000   6*
                                       0.10000                 0.10000     0.10000      0.10000   7*

                                     582.70000   583.70000   577.80000   583.90000                1*
                                     589.79900   591.16900   583.17400   591.44300                2*
                                      76.36200    77.73200    69.73700    78.00600                3*
                                       1.06190     1.17840     1.15790     1.15700                4*  M
                                       0.03095     0.02309     0.02859     0.02331                5*
                                       2.14000     2.14000     2.14000     2.14000                6*
                                       0.10000     0.10000     0.10000     0.10000                7*

             574.80000   584.70000   586.20000   575.10000   575.30000   576.60000    578.70000   1*
             579.18400   592.53900   594.59400   579.58300   575.84900   581.57800    584.37100   2*
              65.74700    79.10200    81.15700    66.14600    66.41200    68.14100     70.93400   3*
               0.70850     1.23560     1.18170     0.94910     0.97300     0.98500      1.08830   4*  L
               0.04955     0.030F7     0.02382     0.02143     0.02336     0.02332      0.04010   5*
               2.14000     2.14000     2.14000     2.14000     2.14000     2.14000      2.14000   6*
               0.10000     0.10000     0.10000     0.10000     0.10000     0.10000      0.10000   7*
```

```
                                                                                              RUN #  089        PAGE 6
       15                14                13                12                11                10                 9                 8

                     573.50000         575.30000         573.40000         575.70000         574.50000                                    1*
                     577.45500         579.84900         577.32200         580.38100         578.78500                                    2*
                      64.01800          66.41200          63.88500          66.94400          65.34800                                    3*
                       0.97820           0.92920           1.16330           0.98010           1.10250                                    4*  K
                       0.04748           0.02993           0.02341           0.02327           0.02314                                    5*
                       2.14000           2.14000           2.14000           2.14000           2.14000                                    6*
                       0.10000           0.10000           0.10000           0.10000           0.10000                                    7*

   566.40000         586.40000                             583.50000                           581.10000         572.20000         576.00000  1*
   568.12000         594.96800                             590.89500                           587.60700         575.72600         580.78000  2*
    54.68300          81.43100                              77.45800                            74.17000          62.28900          67.34300  3*
     0.73100           1.23800                               1.17990                             1.13650           0.92580           1.02560  4*  J
     0.05745           0.02655                               0.02331                             0.02332           0.02311           0.04029  5*
     2.14000           2.14000                               2.14000                             2.14000           2.14000           2.14000  6*
     0.10000           0.10000                               0.10000                             0.10000           0.10000           0.10000  7*

   568.40000         572.50000         572.60000         575.90000         580.90000         570.30000         577.50000         569.30000  1*
   570.72000         576.12500         576.25800         580.64700         587.33300         573.19900         582.77500         571.85000  2*
    57.28300          62.68800          62.82100          67.21000          73.89600          59.76200          69.33800          58.45300  3*
     0.79560           0.95720           1.19940           0.97690           1.12630           0.85490           1.03230           0.80260  4*  H
     0.05745           0.03059           0.02920           0.02891           0.02841           0.02836           0.02855           0.04002  5*
     2.14000           2.14000           2.14000           2.14000           2.14000           2.14000           2.14000           2.14000  6*
     0.10000           0.10000           0.10000           0.10000           0.10000           0.10000           0.10000           0.10000  7*

THE ABOVE DATA ARE: 1* OUTLET TEMPERATURE   (DEG. F.)
                    2* OUTLET ENTHALPY (BTU/LB)
                    3* ENTHALPY DIFFERENCE ACROSS THE FUEL ASSEMBLY (BTU/LB)
                    4* RELATIVE POWER OF THE FUEL ASSEMBLY
                    5* RELATIVE POWER UNCERTAINTY
                    6* OUTLET TEMPERATURE UNCERTAINTY  (DEG. F)
                    7* INLET TEMPERATURE UNCERTAINTY    (DEG. F)

NOTE: THE UNCERTAINTIES ARE RELATED TO A ONE SIGMA CONFIDENCE LEVEL.

INLET TEMPERATURE =522.30DEG. F.          INLET ENTHALPY= 513.43700BTU/LB
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```
C      PROGRAM VARY
C*****************
       REAL *8 LEFT, RIGHT, ASPEC, FSPEC, BLANK, FORM
       REAL FQNO, FDHNO, FQN, FDHN
       INTEGER *2 AM, AN
       DIMENSION FQNO(204), FDHNO(204), FQN(204), FDHN(204), CASE(10),
      1AM(204), AN(204), COLUM(15),TITLEA(3,6), TITLEB(3,6)
       DIMENSION OUT(46,16), GRAPH(46,32), OUT1(24,16)
       COMMON LEFT, RIGHT, ASPEC, FSPEC, BLANK, FORM(18)
       READ(5,1) LEFT, RIGHT, ASPEC, FSPEC, BLANK
   1   FORMAT(5A7)
       READ(5,2) (AM(I), AN(I),I=1,204)
   2   FORMAT(36I2)
       READ(5,3) (FDHNO(I), FQNO(I),I=1,204)
   3   FORMAT(12F6.4)
       READ(5,4) (COLUM(M),M=1,15)
   4   FORMAT(15A2)
       READ(5,5)((GRAPH(IY,IX),IX=1,15),IY=1,23)
   5   FORMAT(15A4)
       READ(5,51)((GRAPH(IY,IX),IX=16,32),IY=1,23)
 51    FORMAT(17A4)
       READ(5,52)((TITLEA(K,L),L=1,6),K=1,3)
  52   FORMAT(6A4)
       READ(5,52)((TITLEB(K,L),L=1,6),K=1,3)
       DO 11 IB=24,46
       DO 11 IA =1,32
       IY=47 - IB
       GRAPH(IB,IA)=GRAPH(IY,IA)
  11   CONTINUE
       M = 1
       DO 12 IB =2,44,3
       GRAPH(IB,1) =COLUM(M)
       M = M+1
  12   CONTINUE
       READ(5,53)((GRAPH(IY,IX),IX=24,26),IY=2,5)
  53   FORMAT(3A4)
       READ(5,54)((GRAPH(IY,IX),IX=2,8),IY= 5, 9)
  54   FORMAT(7A4)
       READ(5,6) LL
   6   FORMAT(I5)
       DO 800 II=1,LL
       DO 16 IX=1,16
       DO 15 IY=1,46
       OUT(IY,IX)=0.0
  15   CONTINUE
       DO 16 IY=1,24
       OUT1(IY,IX)=0.0
  16   CONTINUE
       READ(5,7) CASE(II)
   7   FORMAT(A3)
       READ(5,52)(GRAPH(2,IX),IX=27,32)
       READ(5,52)(GRAPH(5,IX),IX=27,32)
       READ(5,3)(FDHN(I),FQN(I),I=1,204)
       DO 20 I=1,157
       IX=AM(I)
       IY=AN(I)
       IY1=IY+1
       OUT  (IY,IX)=((FQN(I)/FQNO(I))-1.)*200.
       OUT  (IY1,IX)=((FDHN(I)/FDHNO(I))-1.)*200.
```

```
 20   CONTINUE
      DO 30 I=158,204
      IX=AM(I)
      IC=AN(I)
      IC1=IC+1
      OUT1(IC,IX)=((FQN(I)/FQNO(I))-1.)*200.
      OUT1(IC1,IX)=((FDHN(I)/FDHNO(I))-1.)*200.
 30   CONTINUE
      DO 150 IY=38,40
      DO 150 IX=27,32
      IK=IY-37
      IL=IX-26
      GRAPH(IY,IX)=TITLEA(IK,IL)
150   CONTINUE
      WRITE(6,8) CASE(II)
  8   FORMAT(1H1,' VARIATION OF FQN AND FDHN FOR A VARIATION OF 10 E-03
     1IN CASE #',2X,A3,/)
      WRITE(6,9)
  9   FORMAT(1H ,9X,'15',5X,'14',5X,'13',5X,'12',5X,'11',5X,'10',6X,'9',
     16X,'8',6X,'7',6X,'6',6X,'5',6X,'4',6X,'3',6X,'2',6X,'1',/)
      DO 500 IA=1,46
      CALL PRESEN(OUT,46,16,IA,J,16)
500   WRITE(6,200)(GRAPH(IA,IB),IB=1,32)
 200  FORMAT(1H+,32A4)
      WRITE(6,8) CASE(II)
      WRITE(6,9)
      DO 160 IY=38,40
      DO 160 IX=27,32
      IK=IY-37
      IL=IX-26
      GRAPH(IY,IX)=TITLEB(IK,IL)
160   CONTINUE
      DO 700 IA=1,24
      CALL PRESEN(OUT1,24,16,IA,J,16)
700   WRITE(6,200)(GRAPH(IA,IB),IB=1,32)
      DO 400 IA=25,46
      WRITE(6,100)(GRAPH(IA,IB),IB=1,32)
100   FORMAT(1H ,32A4)
400   CONTINUE
800   CONTINUE
      STOP
      END
      SUBROUTINE PRESEN(ARRAY,IY1,IX1,I,J,ID)
      REAL *8 LEFT, RIGHT, ASPEC, FSPEC, BLANK, FORM
      DIMENSION ARRAY(IY1,IX1)
      COMMON LEFT, RIGHT, ASPEC, FSPEC, BLANK, FORM(18)
      FORM(1)=LEFT
      FORM(18)=RIGHT
      DO 170 J=1,ID
      IF(ARRAY(I,J).EQ.0.0) GO TO 155
      FORM(J+1)=FSPEC
      GO TO 170
155   FORM(J+1)=ASPEC
      ARRAY(I,J)=BLANK
170   CONTINUE
      WRITE(6,FORM)(ARRAY(I,J),J=1,ID)
      RETURN
      END
```

SAMPLE INPUT FOR VARY

```
(       . .)   A7.    F7.3.
 8 2 9 210 2 6 5 7 5 8 5 9 510 511 512 5 5 8 6 8 7 8 8 8 9 810 811 812 8
13 8 411 511 611 711 811 9111011111112111311411 314 414 514 614 714 814
 914101411141214131414141514 317 417 517 617 717 817 9171017111712171317
14171517 220 320 420 520 620 720 820 9201020112012201320142015201620 223
 323 423 523 623 723 823 9231023112312231323142315231623 226 326 426 526
 626 726 826 9261026112612261326142615261626 329 429 529 629 729 829 929
102911291229132914291529 332 432 532 632 732 832 93210321132123213321432
1532 435 535 635 735 835 93510351135123513351435 538 638 738 838 9381038
113812381338 641 741 841 941104111411241 844 9441044 8 2 9 2 6 5 7 5 8 5
 9 5 5 8 6 8 7 8 8 8 9 8 411 511 611 711 811 911 314 414 514 614 714 814
 914 317 417 517 617 717 817 917 220 320 420 520 620 720 820 920 223 323
 423 523 623 723 823 923
 .6931 .8761 .7690 .9270 .6537 .7880 .7366 .93111.01181.27391.20051.4907
 .87881.05931.15811.3960 .95431.1503 .6842 .8408 .7895 .97031.24241.5414
 .93471.15591.01561.24651.02281.2383 .99951.2193 .91161.09891.20571.4817
 .7895 .9703 .7986 .99741.06191.32381.17841.44631.15791.40331.15701.4116
 .92811.14821.15401.41681.15061.41401.16791.43531.05221.2931 .7916 .9728
 .7085 .87021.23561.52751.18171.4594 .94911.1622 .97301.1821 .98501.2022
1.08831.3525 .97761.2149 .96971.1917 .93981.15501.16431.43091.21061.4878
 .6891 .8468 .97821.2014 .92921.14061.16331.4247 .98011.19371.10251.3328
1.11731.3429 .84471.01111.09971.36671.10671.3601 .98131.20591.15291.4168
 .93781.1235 .98331.1780 .7313 .93771.23821.53021.03561.25801.17991.4381
1.00841.21771.13651.3640 .92581.10901.02561.2276 .92831.11111.13111.3900
1.01391.24601.22251.46461.04521.25221.19981.4374 .6776 .8118 .79521.0196
 .95721.18641.19941.4399 .97691.18011.12631.3612 .85491.03181.03231.2413
 .8026 .96071.03591.2399 .87651.05001.16451.3951 .98801.18361.18121.4151
 .91111.0915 .7368 .8827 .7313 .93771.26051.56231.06831.28661.24941.4978
1.02151.23411.13961.3767 .92181.11361.02561.2276 .92831.11111.12351.3705
1.00711.22861.22251.46461.04521.25221.19981.4374 .6776 .81181.06121.3607
 .95841.14891.15871.4115 .98631.20141.11241.35501.12181.3552 .83881.0134
1.10601.34921.09931.3410 .97471.18901.14511.3969 .93781.1235 .98331.1780
 .6926 .84371.21681.48221.17021.4255 .94461.1506 .97461.1872 .99481.2118
1.11031.3227 .98311.1993 .96311.1749 .93351.13881.15651.41081.20251.4669
 .6844 .8350 .7956 .96911.05761.28831.17391.43001.15641.40871.16441.3872
 .94291.12341.16441.38721.14291.39421.16011.41521.04521.2750 .7862 .9592
 .7935 .96661.21181.4762 .90461.07771.00261.19451.01901.21401.00261.1945
 .90461.07771.19761.4609 .7842 .9566 .6876 .8376 .94691.12811.14921.3691
 .87201.03891.14921.3691 .94691.1281 .6795 .8290 .6487 .7728 .7631 .9091
 .6487 .77281.06461.34571.03361.24581.15061.45441.32971.68081.42261.7571
 .99861.21301.20801.50881.50261.8584 .99371.21931.13061.38911.13431.3788
1.21121.51281.24731.55051.30721.60161.29781.57441.30281.5925 .97621.2051
1.10701.35961.49951.85341.31741.62631.07101.31491.08981.32471.10341.3457
1.20631.49921.28791.5818 .98821.21211.30341.59521.09951.33751.24481.5002
1.27671.5350 .89901.07611.11711.43231.47791.81791.16921.41631.33221.6200
1.11991.36291.29061.54841.04281.25001.17621.40791.07981.38451.04871.2809
1.31641.58351.03061.24531.24421.5040 .91091.09871.14161.3712 .8330 .9971
 R P N M L K J H G F E D C B A
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*-*-*-*-*-*-*-*-*-*-*
| ENTIRE ASSEMBLY |
*-*-*-*-*-*-*-*-*-*-*
=======================
| HOTTEST ROD ONLY |
=======================
VARIATION OF


IN ASSEMBLY
  VARIATION OF FQN . . . . .
  VARIATION OF FDHN. . . . .
                          *****
  UNITS = 1.0 E-03        *,
  --------------- .       *
     1
008
 DETECTORS READINGS
 M12
 .6922 .8750 .7680 .9257 .6529 .7869 .7356 .92991.01041.27721.19891.4887
```

```
 .87761.05791.15661.3941 .95301.1487 .6832 .8397 .7884 .96891.26101.5644
 .93341.15431.01421.24481.02141.2367 .99821.2176 .91041.09741.20411.4797
 .7884 .9689 .83751.04551.10831.38111.19651.46861.15641.40141.15551.4097
 .92681.14661.15241.41491.14911.41211.16641.43341.05081.2914 .7905 .9715
 .7076 .86911.25801.55521.20231.4849 .95181.1656 .97171.1805 .98371.2006
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 .6882 .8457 .97691.1998 .92791.13901.16171.4228 .97881.19211.10101.3311
1.11581.3411 .84361.00971.09831.36491.10531.3583 .98001.20431.15131.4149
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1.00701.21611.13501.3622 .92461.10751.02421.2260 .92701.10971.12961.3882
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 .95591.18481.19781.4380 .97561.17851.12481.3594 .85381.03051.03091.2397
 .8015 .95941.03451.2383 .87531.04861.16301.3933 .98671.18201.17961.4132
 .90991.0900 .7358 .8815 .7303 .93641.25881.56021.06681.27891.24771.4958
1.02011.23241.13801.3748 .92061.11211.02421.2260 .92701.10971.12201.3687
1.00571.22691.22081.46261.04381.25051.19821.4354 .6767 .81071.05981.3589
 .95711.14741.15721.4096 .98491.19981.11091.35321.12031.3534 .83771.0120
1.10451.34741.09781.3392 .97341.18741.14361.3951 .93651.1220 .98201.1764
 .6916 .84251.21511.48021.16861.4236 .94331.1491 .97331.1856 .99341.2102
1.10881.3210 .98181.1977 .96181.1734 .93221.13721.15491.40891.20091.4649
 .6835 .8338 .7945 .96781.05621.28661.17231.42801.15491.40681.16281.3854
 .94171.12191.16281.38541.14131.39231.15851.41331.04381.2733 .7852 .9579
 .7924 .96531.21021.4742 .90341.07631.00131.19291.01761.21241.00131.1929
 .90341.07631.19601.4590 .7831 .9554 .6867 .8365 .94561.12661.14771.3673
 .87091.03751.14771.3673 .94561.1266 .6786 .8279 .6478 .7718 .7621 .9079
 .6478 .77181.06321.34391.03221.24411.14901.45241.32791.67851.42071.7547
 .99721.21141.26691.58151.52451.8855 .99231.21771.12911.38721.13271.3770
1.27021.58571.29231.60601.32571.62451.29601.57231.30111.5904 .97491.2035
1.10551.35781.52571.88581.33801.65171.08101.32731.08831.32291.10191.3439
1.20471.49721.28621.5797 .98691.21051.30161.59311.09801.33571.24311.4982
1.27501.5329 .89781.07461.11561.43041.47591.81541.16771.41441.33041.6178
1.11841.36101.28891.54631.04141.24841.17461.40601.07841.38261.04731.2792
1.31461.58141.02931.24361.24261.5019 .90971.09721.14001.3693 .8319 .9957
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VARIATION OF FQN AND FDHN FOR A VARIATION OF 10 E-03 IN CASE #  008

        15     14     13     12     11     10      9      8      7      6      5      4      3      2      1

                                               **********************
R                                              *-0.251|-0.280|-0.279*                      VARIATION OF DETECTORS READINGS
                                               *-0.260|-0.260|-0.245*
                                 ***************------+------+------***************
P    VARIATION OF FQN . . . . .  *-0.258|-0.266|-0.268|-0.264|-0.272|-0.278|-0.262*        IN ASSEMBLY  M12
     VARIATION OF FDHN. . . . .  *-0.272|-0.277|-0.266|-0.273|-0.259|-0.272|-0.292*
                          ********------+------+------+------+------+------+------********
N    UNITS = 1.0 E-03     *-0.289| 2.984|-0.277|-0.273|-0.258|-0.279|-0.273|-0.270|-0.289*
     ----------------     *-0.279| 2.994|-0.278|-0.276|-0.274|-0.260|-0.263|-0.265|-0.279*
                   ********------+------+------+------+------+------+------+------+------********
M                  * 9.645| 8.657| 3.084|-0.271|-0.269|-0.279|-0.268|-0.269|-0.265|-0.263|-0.267*
                   * 9.742| 8.739| 3.072|-0.259|-0.259|-0.260|-0.277|-0.261|-0.257|-0.266|-0.278*
            ********------+------+------+------+------+------+------+------+------+------+------********
L           *-0.253| 3.627| 3.494| 0.585|-0.271|-0.266|-0.281|-0.263|-0.269|-0.277|-0.280|-0.269|-0.260*
            *-0.254| 3.626| 3.486| 0.565|-0.267|-0.264|-0.276|-0.266|-0.268|-0.277|-0.275|-0.264|-0.261*
            *------+------+------+------+------+------+------+------+------+------+------+------+------*
K           *-0.266|-0.281|-0.267|-0.268|-0.255|-0.268|-0.277|-0.263|-0.265|-0.265|-0.268|-0.267|-0.272*
            *-0.266|-0.280|-0.275|-0.265|-0.272|-0.269|-0.260|-0.255|-0.253|-0.265|-0.277|-0.277|-0.264*
     ********------+------+------+------+------+------+------+------+------+------+------+------+------********
J    *-0.277|-0.274|-0.270|-0.264|-0.263|-0.264|-0.271|-0.261|-0.252|-0.259|-0.257|-0.273|-0.272|-0.278|-0.271*
     *-0.273|-0.275|-0.270|-0.271|-0.278|-0.264|-0.259|-0.273|-0.280|-0.265|-0.276|-0.278|-0.268|-0.267|-0.266*
     *------+------+------+------+------+------+------+------+------+------+------+------+------+------+------*
H    *-0.275|-0.270|-0.264|-0.271|-0.265|-0.252|-0.258|-0.271|-0.258|-0.267|-0.258|-0.270|-0.268|-0.275|-0.272*
     *-0.277|-0.272|-0.267|-0.266|-0.266|-0.257|-0.271|-0.274|-0.270|-0.274|-0.258|-0.263|-0.271|-0.263|-0.271*
     *------+------+------+------+------+------+------+------+------+------+------+------+------+------+------*
G    *-0.277|-0.269|-0.265|-0.267|-0.276|-0.276|-0.269|-0.261|-0.252|-0.263|-0.277|-0.273|-0.272|-0.278|-0.271*
     *-0.273|-0.270|-0.281|-0.272|-0.274|-0.281|-0.260|-0.273|-0.280|-0.267|-0.278|-0.278|-0.268|-0.267|-0.266*
     ********------+------+------+------+------+------+------+------+------+------+------+------+------********
F           *-0.265|-0.261|-0.269|-0.266|-0.266|-0.266|-0.276|-0.267|-0.268|-0.269|-0.258|-0.267|-0.272*
            *-0.264|-0.271|-0.259|-0.284|-0.270|-0.267|-0.262|-0.271|-0.273|-0.267|-0.262|-0.277|-0.264*
            *------+------+------+------+------+------+------+------+------+------+------+------+------*
E           *-0.234|-0.270|-0.267|-0.261|-0.269|-0.264|-0.257|-0.267|-0.255|-0.281|-0.269|-0.273|-0.287*
            *-0.289|-0.279|-0.274|-0.275|-0.267|-0.281|-0.270|-0.264|-0.270|-0.279|-0.277|-0.266|-0.263*
            ********------+------+------+------+------+------+------+------+------+------+------********
D                  *-0.269|-0.264|-0.280|-0.270|-0.260|-0.267|-0.260|-0.273|-0.269|-0.267|-0.271*
                   *-0.277|-0.265|-0.272|-0.259|-0.275|-0.255|-0.275|-0.280|-0.276|-0.268|-0.254*
                   ********------+------+------+------+------+------+------+------+------********
C                         *-0.263|-0.271|-0.260|-0.268|-0.263|-0.268|-0.260|-0.260|-0.251*             *-*-*-*-*-*-*-*-*-*
                          *-0.277|-0.264|-0.265|-0.259|-0.275|-0.259|-0.265|-0.267| 0.281*             | ENTIRE ASSEMBLY |
                          ********------+------+------+------+------+------+------********             *-*-*-*-*-*-*-*-*-*
B                                *-0.263|-0.266| 0.263|-0.270|-0.253|-0.266|-0.265*
                                 *-0.262|-0.275|-0.261|-0.252|-0.261|-0.275|-0.265*
                                 ***************------+------+------***************
A                                              *-0.259|-0.264|-0.259*
                                               *-0.277|-0.262|-0.277*
                                               **********************
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VARIATION OF FQN AND FDHN FOR A VARIATION OF 10 E-03 IN CASE *  008

        15     14     13     12     11     10      9      8      7      6      5      4      3      2      1

                                               **********************
R                                              *-0.268|-0.273|      *                     VARIATION OF DETECTORS READINGS
                                               *-0.263|-0.271|      *
                                 ***************------+------+------***************
P    VARIATION OF FQN . . . . .  *-0.275|-0.274|-0.273|-0.264|      |      |      *       IN ASSEMBLY  M12
     VARIATION OF FDHN. . . . .  *-0.278|-0.271|-0.267|-0.280|      |      |      *
                          ********------+------+------+------+------+------+------********
N    UNITS = 1.0 E-03     * 9.637| 2.916|-0.262|-0.274|-0.261|      |      |      |      *
     ----------------     * 9.752| 2.915|-0.262|-0.265|-0.262|      |      |      |      *
                   ********------+------+------+------+------+------+------+------+------********
M                  * 9.638| 7.159| 2.860|-0.267|-0.264|-0.266|      |      |      |      |      *
                   * 9.742| 7.215| 2.830|-0.277|-0.261|-0.266|      |      |      |      |      *
            ********------+------+------+------+------+------+------+------+------+------+------********
L           *-0.265| 3.496| 3.124| 1.886|-0.272|-0.268|-0.267|      |      |      |      |      |      *
            *-0.271| 3.494| 3.127| 1.867|-0.275|-0.272|-0.265|      |      |      |      |      |      *
            *------+------+------+------+------+------+------+------+------+------+------+------+------*
K           *-0.266|-0.264|-0.263|-0.265|-0.267|-0.274|-0.279|      |      |      |      |      |      *
            *-0.264|-0.263|-0.276|-0.273|-0.273|-0.266|-0.267|      |      |      |      |      |      *
     ********------+------+------+------+------+------+------+------+------+------+------+------+------********
J    *-0.265|-0.275|-0.268|-0.272|-0.279|-0.271|-0.256|-0.270|      |      |      |      |      |      |      *
     *-0.269|-0.271|-0.257|-0.270|-0.268|-0.263|-0.269|-0.272|      |      |      |      |      |      |      *
     *------+------+------+------+------+------+------+------+------+------+------+------+------+------+------*
H    *-0.274|-0.266|-0.265|-0.273|-0.279|-0.273|-0.277|-0.281|      |      |      |      |      |      |      *
     *-0.255|-0.257|-0.273|-0.252|-0.257|-0.263|-0.280|-0.264|      |      |      |      |      |      |      *
     *------+------+------+------+------+------+------+------+------+------+------+------+------+------+------*
G    *      |      |      |      |      |      |      |      |      |      |      |      |      |      |      *
     *      |      |      |      |      |      |      |      |      |      |      |      |      |      |      *
     ********------+------+------+------+------+------+------+------+------+------+------+------+------********
F           *      |      |      |      |      |      |      |      |      |      |      |      |      *
            *      |      |      |      |      |      |      |      |      |      |      |      |      *
            *------+------+------+------+------+------+------+------+------+------+------+------+------*
E           *      |      |      |      |      |      |      |      |      |      |      |      |      *
            *      |      |      |      |      |      |      |      |      |      |      |      |      *
            ********------+------+------+------+------+------+------+------+------+------+------********
D                  *      |      |      |      |      |      |      |      |      |      |      *
                   *      |      |      |      |      |      |      |      |      |      |      *
                   ********------+------+------+------+------+------+------+------+------********
C                         *      |      |      |      |      |      |      |      |      *            ********************
                          *      |      |      |      |      |      |      |      |      *            | HOTTEST ROD ONLY |
                          ********------+------+------+------+------+------+------********            ********************
B                                *      |      |      |      |      |      |      *
                                 *      |      |      |      |      |      |      *
                                 ***************------+------+------***************
A                                              *      |      |      *
                                               *      |      |      *
                                               **********************
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*DECK,MAIN
      PROGRAM COBRA3C (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEMAIN3060
C     MAJOR SUBROUTINES OF COBRA-IIIC.                                  MAIN3070
      COMMON  KIJ, FIM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    MAIN3080
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       MAIN3090
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          MAIN3100
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        MAIN3110
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           MAIN3120
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       MAIN3130
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   MAIN3140
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              MAIN3150
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   MAIN3160
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  MAIN3170
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               MAIN3180
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             MAIN3190
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                MAIN3200
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             MAIN3210
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        MAIN3220
     2 HPERIM(30), NTYPE(30)                                            MAIN3230
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       MAIN3240
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      MAIN3250
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  MAIN3260
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), MAIN3270
     2 NGAP( 9), BX(30), XQUAL(30)                                      MAIN3280
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          MAIN3290
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            MAIN3300
      LOGICAL FDIV, GRID                                                MAIN3310
      REAL  KIJ, LENGTH, KF, KKF                                        MAIN3320
      DIMENSION OUTPUT(10)                                              MAIN3330
       DIMENSION TEXT(17),LC(30,4),GAPS(30,4),AC(30),PW(30),            MAIN3400
     2 PH(30), DR(35), DC(30), DIST(30,4), IM( 9), JM( 9)               MAIN3410
      DIMENSION PRINT(12), PRINTC(30), SIGNAL(18)                       MAIN3420
      DIMENSION TDUMY(10), PRINTN(10), PRINTR(35)                       MAIN3430
      DIMENSION  DATE(2), TIME(2)                                       MAIN3440
      DIMENSION TINLET(30)                                              MAIN3441
      DIMENSION  YP(30), FP(30), YH(30), FH(30), YG(30), FG(30),        MAIN3450
     1 FQ(30), YQ(30)                                                   MAIN3460
      DIMENSION CROSS(6), NWRAPS(30)                                    MAIN3470
      DIMENSION CHFCOR(5)                                               MAIN3471
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         MAIN3472
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,                         MAIN3473
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),                 MAIN3474
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),                       MAIN3475
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF                MAIN3476
      COMMON /BWRAP/ XCROSS(47,6),DUR(47),DIA,THICK,NWRAP(47),PITCH     MAIN3480
      COMMON /RSP/ SP(47,31)                                            MAIN3490
      COMMON/BCHF/ CHFR(35,31), CCHANL(35,31), MCHFR(31), MCHFRC(31),   MAIN3491
     1 MCHFRR(31),NCHF                                                  MAIN3492
      REAL MCHFR                                                        MAIN3493
      REAL KFUEL, KCLAD                                                 MAIN3494
      LOGICAL PRINT                                                     MAIN3500
      INTEGER PRINTC                                                    MAIN3510
      INTEGER PRINTN, PRINTR                                            MAIN3520
      INTEGER  CCHANL                                                   MAIN3521
      DATA CHFCOR /4HBAW2,4HW-3 ,4H    ,4H    ,4H    /                  MAIN3522
       DATA H1,H2,H3,H4,H5 / 1H(, 1H,, 1H), 4H  W(, 4H)WP( /            MAIN3530
      DATA H6, H7, H8 /1HW, 1HX, 2HT( /                                 MAIN3540
      DATA SIGNAL /4HMAIN,4HDIFF,4HDVRT,4HMIX ,                         MAIN3550
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  14HSCHM,4HFORC,4HVOID,4HSPLT,4HAREA,4HCURV,4HPROP,
  24HDCOM,4HSOLV,4HHEAT,4HTEMP,4HHCOL,4HGAUS,4HCIJ /
 1 FORMAT(7I5)
 2 FORMAT(2I5,17A4)
 3 FORMAT(15H1INPUT FOR CASE          I6,5X,16A4,A2,
  19H   DATE  2A6,7H TIME  2A6        )
 4 FORMAT (E5.2,F5.1,7F10.0)
 5 FORMAT (12F5.3)
 6 FORMAT (23H0HEAT FLUX DISTRIBUTION  /23H  X/L     RELATIVE FLUX /
  1(F7.3,F12.3))
 7 FORMAT(I1,I4,3E5.2,4(I5,2E5.2))
 8 FORMAT ( I5/(12F5.3))
 9 FORMAT (6F10.0)
10 FORMAT(12E5.0)
11 FORMAT(I1,I4,2E5.2,6(I5,E5.2))
12 FORMAT(22H0SUBCHANNEL INPUT DATA  /
   1109H CHANNEL   TYPE   AREA   WETTED    HEATED    HYDRAULIC    (ADJ
   2ACENT CHANNEL NO., SPACING, CENTROID DISTANCE)         /
   3 55H   NO.             (SQ-IN) PERIM.    PERIM.    DIAMETER        /
   4 25X,                       30H (IN)      (IN)       (IN)          /
   5 (I5,I7,4F10.6,4X,4(1H(I3,1H,F5.3,1H,F5.3,1H))))
13 FORMAT(22H0FLUID PROPERTY TABLE   /
   1 60H     P          T          VF          VG          HF         HG
   1 30H  VISC.         KF       SIGMA      /
   1 (F8.1,F10.2,F8.5,F12.5,2F10.2,3F10.5))
14 FORMAT(4E5.2,2I5,E5.2,I5,4E5.2)
15 FORMAT(15H0ROD INPUT DATA  /   96H   ROD  TYPE  DIA  RADIAL POWER
   1     FRACTION OF POWER TO ADJACENT CHANNELS (ADJ. CHANNEL NO.)    /
   2 30H   NO.  NO.     (IN)    FACTOR   /(2I5,F8.4,F9.4,F11.4,1H(I2,
   11H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,
   11H(I2,1H)))
17 FORMAT (36I2)
18 FORMAT (23H0CALCULATION PARAMETERS /
   2 28H   CROSSFLOW RESISTANCE,KIJ F8.3/
   4 28H   MOMENTUM TURBULENT FACTORF8.4  /
   3 28H   PARAMETER, (S/L)           F8.3/
   4 28H   CHANNEL LENGTH             F8.2,8H INCHES /
   4 28H   CHANNEL ORIENTATION        F8.1,8H DEGREES/
   5 28H   NUMBER OF AXIAL NODES      I8/
   6 28H   NODE LENGTH                F8.3,7H INCHES /
   7 28H   NUMBER OF TIME STEPS       I8/
   8 28H   TOTAL TRANSIENT TIME       F8.3,8H SECONDS/
   X 28H   TIME STEP                  F8.4,8H SECONDS/
   1 28H   ALLOWABLE ITERATIONS       I8/
   2 28H   FLOW CONVERGENCE FACTOR   E10.5/)
19 FORMAT (50H0 X/L     AREA VARIATION FACTORS FOR SUBCHANNEL (I) /
   1  7X,10(3X,A1,I2,A1,1X))
20 FORMAT (69H0 X/L     GAP SPACING VARIATION FACTORS FOR ADJACENT SUB
   1CHANNELS (I,J) / 7X,10(1X,A1,I2,A1,I2,A1))
21 FORMAT (22H0OPERATING CONDITIONS  /
   1 25H   SYSTEM PRESSURE     =  ,F8.1,5H PSIA /
   2 25H   INLET ENTHALPY      =  ,F8.1,7H BTU/LB /
   3 25H   AVG. MASS VELOCITY =  ,F8.3,21H MILLION LB/(HR-SQFT) /
   2 25H   INLET TEMPERATURE   =        ,F8.1,10H DEGREES F /
   4 25H   AVG. HEAT FLUX      =  ,F8.6,22H MILLION BTU/(HR-SQFT)  )
22 FORMAT (23H0FAILURE INTEGRATION IN,I4,17H ITERATIONS AT X=
   1F8.4,2I10)
25 FORMAT(17H1CHANNEL RESULTS   /
   1  5H CASEI5,5X17A4,  9H   DATE   2A6,7H TIME    2A6/)
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 28 FORMAT (/29H FRICTION FACTOR CORRELATION     )                      MAIN4160
 29 FORMAT ( 16H    CHANNEL TYPE I3,11H   FRICT = F5.3,6H*RE**(F5.3,    MAIN4170
   14H) + F6.4  )                                                       MAIN4180
 30 FORMAT(F7.1,10F10.5)                                                MAIN4190
 31 FORMAT (68H1DIVERSION CROSSFLOW BETWEEN ADJACENT CHANNELS, W(I,J),MAIN4200
   1 (LB/SEC-FT).                                                       MAIN4210
   1    // 5H CASEIS , 5X, 17A4,                                        MAIN4220
   29H   DATE  2A6,7H  TIME  2A6 ///                                    MAIN4230
   3 5X,A1,2X,10(2X,A1,A1,I2,A1,I2,A1))                                 MAIN4240
 32 FORMAT(31H     SUBCOOLED MIXING,   BETA = F6.4)                     MAIN4250
 33 FORMAT(31H     SUBCOOLED MIXING,   BETA = F6.4,6H*RE**(F6.4,1H))    MAIN4260
 34 FORMAT(31H     SUBCOOLED MIXING,   BETA = F6.4,12H*(D/S)*RE**(F6.4,MAIN4270
   1 1H))                                                               MAIN4280
 35 FORMAT(20H0MIXING CORRELATIONS )                                    MAIN4290
 36 FORMAT(54H     BOILING MIXING, BETA IS ASSUMMED SAME AS SUBCOOLED) MAIN4300
 37 FORMAT(55H     BOILING MIXING, BETA IS A FUNCTION OF STEAM QUALITY/MAIN4310
   1            25H          X          BETA(X)  / (F12.3,F13.6))       MAIN4320
 38 FORMAT  (F6.3,10F8.3)                                               MAIN4330
 39 FORMAT(31H     SUBCOOLED MIXING,   BETA = F6.4;12H*(D/L)*RE**(F6.4,MAIN4340
   1 1H))                                                               MAIN4350
 40 FORMAT( F7.3,F10.3;2F10.2,4F10.4)                                   MAIN4360
 41 FORMAT (I5,7E10.5)                                                  MAIN4370
 42 FORMAT(8E10.5)                                                      MAIN4380
 43 FORMAT(2I5,6F5.4)                                                   MAIN4390
 44 FORMAT( /   28H TWO-PHASE FLOW CORRELATIONS  )                      MAIN4400
 45 FORMAT(     33H    NO SUBCOOLED VOID CORRELATION  )                 MAIN4410
 46 FORMAT(     35H    LEVY SUBCOOLED VOID CORRELATION)                 MAIN4420
 47 FORMAT(     31H    HOMOGENEOUS BULK VOID MODEL)                     MAIN4430
 48 FORMAT(     41H    MODIFIED ARMAND BULK VOID CORRELATION )          MAIN4440
 49 FORMAT(     50H    HOMOGENEOUS BULK VOID MODEL WITH SLIP RATIO OF, MAIN4450
   1 F6.2 )                                                             MAIN4460
 50 FORMAT(20I5)                                                        MAIN4470
 51 FORMAT (8E12.3)                                                     MAIN4480
 52 FORMAT (I5,6E12.6)                                                  MAIN4490
 53 FORMAT (I5,3E12.6)                                                  MAIN4500
 54 FORMAT(//' INPUT DATA ERROR, THIS RUN STOPPED, CHECK INPUT')        MAIN4510
 55 FORMAT (10H ERROR IN  A6,40H  **  CALCULATION FOR THIS CASE STOPPEMAIN4520
   1D. )                                                                MAIN4530
 56 FORMAT(10H ERROR IN  A6,65H  **  INITIAL CONDITION NOT ESTABLISHEDMAIN4540
   1, CALCULATION STOPPED               )                               MAIN4550
 57 FORMAT(     33H    BULK VOID FRACTION GIVEN AS A I2,56H TERM POLYNOMAIN4560
   1MIAL FUNCTION OF QUALITY WITH COFFICIENTS OF/ 10X,7E10.4)           MAIN4570
 58 FORMAT(     41H    HOMOGENEOUS MODEL FRICTION MULTIPLIER )          MAIN4580
 59 FORMAT(     30H    ARMAND FRICTION MULTIPLIER)                      MAIN4590
 60 FORMAT(     34H    FRICTION MULTIPLIER GIVEN AS A I2,57H TERM POLYNMAIN4600
   1OMIAL FUNCTION OF QUALITY WITH COEFFICIENTS OF/ 10X,7E10.4)         MAIN4610
 61 FORMAT(65H     WALL VISCOCITY CORRECTION TO FRICTION FACTOR IS NOT MAIN4620
   1INCLUDED      )                                                     MAIN4630
 62 FORMAT(65H     WALL VISCOSITY CORRECTION TO FRICTION FACTOR IS INCLMAIN4640
   1UDED           )                                                    MAIN4650
 64 FORMAT(I5,10E5.2)                                                   MAIN4660
 65 FORMAT(42H     CONDUCTION MIXING,  GEOMETRY FACTOR = F6.4)          MAIN4670
 66 FORMAT (6( E5.2,I5))                                                MAIN4680
 67 FORMAT (I5,E5.2,I5,E5.2)                                            MAIN4690
 68 FORMAT(10I5)                                                        MAIN4700
 69 FORMAT ( /62H WIRE WRAP SPACER DATA FOR FORCED DIVERSION CROSSFLOWMAIN4710
   1 MIXING     //20H    WRAP PITCH     = F6.1,7H INCHES /              MAIN4720
   2              20H    WRAP THICKNESS = F6.4,7H INCHES /              MAIN4730
   3              20H    PIN DIAMETER   = F6.4,7H INCHES //)            MAIN4740
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 70 FORMAT (23H    WRAP CROSSING DATA /                                     MAIN4750
   1    60H        GAP    SUBCHANNEL    MIXING          RELATIVE LOCATION MAIN4760
   2 / 60H         NO.    PAIR NO.    PARAMETER         OF WRAP CROSSINGS MAIN4770
   3 /(I10,4X,A1,I2,A1,I2,A1,F11.4,6F10.4))                                 MAIN4780
 71 FORMAT( /12H SPACER DATA / 20H    SPACER TYPE NO.   ,10I6 )             MAIN4790
 72 FORMAT(  21H    LOCATION (X/L)      ,10F6.3)                            MAIN4800
 73 FORMAT (15H0   SPACER TYPE I2 /                                         MAIN4810
   1 62H      CHANNEL DRAG   CHANNEL DRAG   CHANNEL DRAG   CHANNEL DRAGMAIN4820
   2/64H         NO.   COEFF.   NO.    COEFF.   NO.    COEFF.   NO.   COEFMAIN4830
   3F.    /(3X,4(I6,F9.3)))                                                 MAIN4840
 74 FORMAT (46H    INITIAL WRAP INVENTORY FOR EACH SUBCHANNEL /(10I5))MAIN4850
 75 FORMAT (// 14H ITERATIONS =     I4)                                     MAIN4860
 76 FORMAT (43H0   FLOW DIVERSION FACTORS FOR SPACER TYPE  I2/              MAIN4870
   1 5X    46HGAP  CHANNEL FRACTION     GAP  CHANNEL FRACTION  /            MAIN4880
   25X     46HNO.   PAIR   DIVERTED     NO.    PAIR   DIVERTED  /           MAIN4890
   3  (2(5X,I3,1X,A1,I2,A1,I2,A1,F9.4)))                                    MAIN4900
 77 FORMAT(39H THERMAL PROPERTIES FOR FUEL MATERIAL                         MAIN4910
   1 I8,18H RADIAL FUEL NODES  /                                            MAIN4920
   1 37H                         FUEL PROPERTIES 25X15HCLAD PROPERTIES / MAIN4930
   2 50H      TYPE     COND.     SP. HEAT    DENSITY   DIA.                 MAIN4940
   3                50H  COND.     SP. HEAT    DENSITY  THICK.   GAP COND. / MAIN4950
   4 49H       NO. (B/HR-FT-F) (B/LB-F)     (LB/FT3)   (IN.)                MAIN4960
   5               52H(B/HR-FT-F) (B/LB-F)     (LB/FT3)   (IN.)   (B/HR-FT2-F))MAIN4970
 78 FORMAT(I7,2X,F7.2,F11.4,F11.1,F9.4,2X,F7.2,F11.4,F11.1,F9.4,2X,    MAIN4980
   1 F9.2)                                                                  MAIN4990
 79 FORMAT ( 9F5.2)                                                         MAIN5000
 80 FORMAT(8H TIME =  F8.5,  9H SECONDS                                     MAIN5010
   1  20H     DATA FOR CHANNEL    I3/)                                      MAIN5020
 81 FORMAT(F6.1,F12.2,2F12.2,F10.2,2F9.3,F11.4,F12.4)                       MAIN5030
 82 FORMAT (' DISTANCE    DELTA-P     ENTHALPY   TEMPERATURE DENSITY    MAIN5040
   1EQUIL     VOID          FLOW       MASS FLUX'/ '  (IN.)        (PSI)      (MAIN5050
   1BTU/LB)      (DEG-F)    (LB/CU-FT) QUALITY FRACTION    (LB/SEC) (MLB/HMAIN5060
   1R-FT2)')                                                                MAIN5070
 83 FORMAT (33H   FORCING FUNCTION FOR PRESSURE /                           MAIN5080
   1          23H       TIME       PRESSURE /                               MAIN5090
   2          23H      (SEC)       FACTOR   /  (F10.4,F13.4))               MAIN5100
 84 FORMAT (38H   FORCING FUNCTION FOR INLET ENTHALPY/                      MAIN5110
   1          28H       TIME  INLET ENTHALPY              /                 MAIN5120
   2          23H      (SEC)       FACTOR   /  (F10.4,F13.4))               MAIN5130
 85 FORMAT (38H   FORCING FUNCTION FOR INLET FLOW      /                    MAIN5140
   1          28H       TIME  INLET FLOW               /                    MAIN5150
   2          23H      (SEC)       FACTOR   /  (F10.4,F13.4))               MAIN5160
 86 FORMAT (38H   FORCING FUNCTION FOR HEAT FLUX       /                    MAIN5170
   1          38H       TIME   HEAT FLUX               /                    MAIN5180
   2          23H      (SEC)       FACTOR   /  (F10.4,F13.4))               MAIN5190
 87 FORMAT(30H    UNIFORM INLET ENTHALPY        )                           MAIN5200
 88 FORMAT(35H    UNIFORM INLET TEMPERATURE          )                      MAIN5210
 89 FORMAT(45H    INDIVIDUAL SUBCHANNEL ENTHALPY SPECIFIED     )            MAIN5220
 90 FORMAT(50H    INDIVIDUAL SUBCHANNEL TEMPERATURE SPECIFIED        ) MAIN5230
 91 FORMAT(35H    UNIFORM INLET MASS VELOCITY           )                   MAIN5240
 92 FORMAT(50H    FLOWS SPLIT TO GIVE EQUAL PRESSURE GRADIENT        ) MAIN5250
 93 FORMAT(45H    INDIVIDUAL SUBCHANNEL FLOWS SPECIFIED           )         MAIN5260
 94 FORMAT(5H1CASEI5,5X17A4,9H   DATE   2A6,7H TIME     2A6//               MAIN5270
   1  8H TIME =  F8.5,9H SECONDS                                            MAIN5280
   2 28H     TEMPERATURE DATA FOR ROD  I3,                                  MAIN5290
   3 12H,  FUEL TYPE  I2//                                                  MAIN5300
   4 ' DISTANCE  FLUX        DNBR  CHANNEL                 TEMPERATURE(F)'/ MAIN5310
   5 22H  (IN.)  (MBTU/HR-FT2)  13X,10(4X,A2,I2,A1))                        MAIN5320
 95 FORMAT(F8.1,F9.4,F9.3,I4,5X,10(F9.1))                                   MAIN5321
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   96 FORMAT(5H1CASEI5,5X17A4,9H   DATE   2A6,7H TIME    2A6//           MAIN5322
     1 8H TIME =  F8.5,9H SECONDS  //                                    MAIN5323
     2A7,  ' CRITICAL HEAT FLUX SUMMARY'/                                MAIN5324
     3 ' DISTANCE   FLUX   MDNBR     ROD    CHANNEL')                    MAIN5325
   97 FORMAT(F8.1,2F8.3,2I8)                                             MAIN5326
   99 FORMAT('1CHANNEL EXIT SUMMARY RESULTS'/                            MAIN5327
     1  5H CASEI5,5X17A4,  9H   DATE   2A6,7H TIME    2A6//              MAIN5328
     2' MASS BALANCE - -       '17X,                                     MAIN5329
     410X'ENERGY BALANCE - -      '/                                     MAIN5330
     3'      MASS FLOW IN      ' E12.5,' LB/SEC'                         MAIN5331
     410X'   FLOW ENERGY IN        'E12.5,' BTU/SEC'/                    MAIN5332
     3'      MASS FLOW OUT     ' E12.5,' LB/SEC'                         MAIN5333
     410X'   ENERGY ADDED          'E12.5,' BTU/SEC'/                    MAIN5334
     3'      MASS FLOW ERROR   ' E12.5,' LB/SEC'                         MAIN5335
     410X'   FLOW ENERGY OUT       'E12.5,' BTU/SEC'/                    MAIN5336
     449X'   ENERGY ERROR          'E12.5,' BTU/SEC'//                   MAIN5337
     7' CHANNEL ENTHALPY TEMPERATURE DENSITY   EQUIL      VOID      FLOW MAIN5338
     8  MASS FLUX'/                                                      MAIN5339
     9'  (NO.) (BTU/LB)  (DEG-F)     (LB/FT3) QUALITY  FRACTION  (LB/SEC)MAIN5340
     1 (MLB/FR-FT2)')                                                    MAIN5341
  100 FORMAT(I6,2F10.2,F10.2,2F9.3,F10.4,F12.4)                          MAIN5342
  101 FORMAT(' BUNDLE AVERAGED RESULTS'/)                                MAIN5343
 102  FORMAT(///* - - - ABNORMAL EXIT THROUG MAXIMUM TIME - - - *//)     MAIN5344
C                                                                        MAIN5365
C     THE UNIVAC 1108 SETS THE CORE TO ZERO AT THE START OF EACH JOB     MAIN5370
C     THE INITIALIZATION BELOW IS TO INITIALIZED FOR OTHER MACHINES      MAIN5380
C     UNITS I2,I3, AND I8 ARE THE INPUT, OUTPUT, AND SAVE TAPE UNITS     MAIN5390
      MC=30                                                              MAIN5400
      MG=30                                                              MAIN5410
      MX=31                                                              MAIN5420
      MN=10                                                              MAIN5430
      MR=35                                                              MAIN5440
      I2=5                                                               MAIN5450
      I3=6                                                               MAIN5460
      PI = 355./113.                                                     MAIN5470
      I8=8                                                               MAIN5475
      GC = 32.2                                                          MAIN5480
      NAXL = 0                                                           MAIN5490
      NGXL = 0                                                           MAIN5500
      NGRID = 0                                                          MAIN5510
      NAX = 0                                                            MAIN5520
      IERROR = 0                                                         MAIN5530
      NGAPS = 0                                                          MAIN5540
      NAFACT = 0                                                         MAIN5550
      NSCRC = 0                                                          MAIN5560
      NBRC = 0                                                           MAIN5570
      J5 = 0                                                             MAIN5580
      J6 = 0                                                             MAIN5590
      NGRIDT = 0                                                         MAIN5600
      JUMP = 0                                                           MAIN5602
      NJUMP = 0                                                          MAIN5604
      NROD = 0                                                           MAIN5610
      NRAMP = 1                                                          MAIN5620
      NOTESF = 0                                                         MAIN5630
      NFUELT = 0                                                         MAIN5640
      NOUT = 0                                                           MAIN5650
      NPCHAN = 0                                                         MAIN5660
      NPNODE = 0                                                         MAIN5670
      NARAMP = 1                                                         MAIN5675
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      IG = 0                                                            MAIN5680
      ISAVE = 0                                                         MAIN5685
      IH = 0                                                            MAIN5690
      GRID = .FALSE.                                                    MAIN5700
      DO 900 I=1,MC                                                     MAIN5710
      HINLET(I) = 0.                                                    MAIN5720
      FINLET(I) = 0.                                                    MAIN5730
  900 QPRIM(I) = 0.                                                     MAIN5740
      DO 905 K=1,MG                                                     MAIN5750
  905 FDIV(K) = .FALSE.                                                 MAIN5760
      DO 930 J=1,MX                                                     MAIN5770
      DO 910 I=1,MC                                                     MAIN5780
      P(I,J) = 0.                                                       MAIN5790
      H(I,J) = 0.                                                       MAIN5800
      F(I,J) = 0.                                                       MAIN5810
      RHO(I,J) = 0.                                                     MAIN5820
      HOLD(I,J) = 0.                                                    MAIN5830
      FOLD(I,J) = 0.                                                    MAIN5840
  910 RHOOLD(I,J) = 0.                                                  MAIN5850
      DO 915 K=1,MG                                                     MAIN5860
      W(K,J) = 0.                                                       MAIN5870
      WOLD(K,J) = 0.                                                    MAIN5880
  915 SP(K,J) = 0.                                                      MAIN5890
      DO 920 N=1,MR                                                     MAIN5900
      FLUX(N,J) = 0.                                                    MAIN5910
       CCHANL(N,J) = 0                                                  MAIN5915
      DO 918 L=1,MN                                                     MAIN5920
  918 TROD(L,N,J) = 0.                                                  MAIN5930
  920 CONTINUE                                                          MAIN5940
  930 CONTINUE                                                          MAIN5950
      READ (I2,52) MAXT                                                 MAIN5960
      IF(MAXT.LT.1) MAXT = 1000                                         MAIN5970
C                                                                       MAIN5980
C  READ CASE CONTROL CARD                                               MAIN5990
  990 READ(I2,2) KASE,J1,TEXT                                           MAIN6000
       IERROR = 0                                                       MAIN6010
       ISAVE = 0                                                        MAIN6015
      DO 991 I = 1,11                                                   MAIN6020
      PRINT(I) = .FALSE.                                                MAIN6030
      IF(J1.EQ.1) PRINT(I) = .TRUE.                                     MAIN6040
  991 CONTINUE                                                          MAIN6050
C  CHECK FOR CONTINUATION OF CALCULATIONS                               MAIN6060
      IF(KASE.LT.1) STOP                                                MAIN6070
      CALL DOY(DATE)                                                    MAIN6080
      CALL TOD(TIME)                                                    MAIN6090
      WRITE(I3, 3) KASE,TEXT,DATE,TIME                                  MAIN6100
C                                                                       MAIN6110
C  READ GROUP CONTROL CARD                                              MAIN6120
  995 READ(I2,1) NGROUP,N1,N2,N3,N4,N5,N6                               MAIN6130
      IF(NGROUP.LT.1) GO TO 250                                         MAIN6150
      IF(NGROUP.GT.12) GO TO 240                                        MAIN6160
      IF(NGROUP.LT. 0) GO TO 240                                        MAIN6170
      GO TO (110,120,130,140,150,160,170,180,190,200,210,220),NGROUP    MAIN6180
C                                                                       MAIN6190
C  INPUT FOR CARD GROUP 1, PROPERTY TABLE                               MAIN6200
  110 READ (I2,4) (PP(I),TT(I),VVF(I),VVG(I),HHF(I),HHG(I),UUF(I),KKF(I)MAIN6210
     1,SSIGMA(I),I=1,N1)                                                MAIN6220
      NPROP = N1                                                        MAIN6230
      IF(J1.LE.1) PRINT(1)=.TRUE.                                       MAIN6240
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      GO TO 995                                                         MAIN6250
C                                                                       MAIN6260
C  INPUT FOR CARD GROUP 2, FRICTION FACTOR AND TWO-PHASE FLOW CORRELATIOMAIN6270
  120 READ (I2,5) (AA(I),BB(I),CC(I),I=1,4)                             MAIN6280
      J2 = N1                                                           MAIN6290
      J3 = N2                                                           MAIN6300
      J4 = N3                                                           MAIN6310
      NVISCW = N4                                                       MAIN6320
      IF(J3.GT.4) READ(I2,41) NV,AV                                     MAIN6330
      IF(J4.GT.4) READ(I2,41) NF,AF                                     MAIN6340
      IF(J1.LE.1) PRINT(2) = .TRUE.                                     MAIN6350
      GO TO 995                                                         MAIN6360
C                                                                       MAIN6370
C  INPUT FOR CARD GROUP 3, AXIAL HEAT FLUX TABLE                         MAIN6380
  130 READ(I2,5) (Y(I),AXIAL(I),I=1,N1)                                 MAIN6390
      NAX = N1                                                          MAIN6400
      IF(J1.LE.1) PRINT(3) = .TRUE.                                     MAIN6410
      GO TO 995                                                         MAIN6420
C                                                                       MAIN6430
C  INPUT FOR CARD GROUP 4, CHANNEL LAYOUT AND DIMENSIONS                 MAIN6440
  140 DO 141 J=1,N1                                                     MAIN6450
      READ(I2,7) N,I,AC(I),PW(I),PH(I),(LC(I,L),GAPS(I,L),DIST(I,L),    MAIN6460
     1 L=1,4)                                                           MAIN6470
      NTYPE(I) = N                                                      MAIN6480
      IF(N.LE.1) NTYPE(I) = 1                                           MAIN6490
  141 CONTINUE                                                          MAIN6500
      PHTOT = 0.                                                        MAIN6510
      ATOTAL = 0.                                                       MAIN6520
      K=0                                                               MAIN6530
      NCHANL = N2                                                       MAIN6540
      DO 147 I=1,NCHANL                                                 MAIN6550
      DO 146 L=1,4                                                      MAIN6560
      IF(LC(I,L))144,146,143                                            MAIN6570
  143 J=LC(I,L)                                                         MAIN6580
      IF(J.LE.I) GO TO 146                                              MAIN6590
      K=K+1                                                             MAIN6600
      FACTOR(K)=1.                                                      MAIN6610
      GO TO 145                                                         MAIN6620
  144 J=-LC(I,L)                                                        MAIN6630
      IF(J.LE.I) GO TO 146                                              MAIN6640
      K=K+1                                                             MAIN6650
      FACTOR(K) = .5                                                    MAIN6660
  145 JK(K) = J                                                         MAIN6670
      IK(K) = I                                                         MAIN6680
      GAPN(K) = GAPS(I,L)/12.                                           MAIN6690
      GAP(K) = GAPN(K)                                                  MAIN6700
      LENGTH(K) = DIST(I,L)/12.                                         MAIN6710
  146 CONTINUE                                                          MAIN6720
      PERIM(I) = PW(I)/12.                                              MAIN6730
      HPERIM(I) = PH(I)/12.                                             MAIN6740
      AN(I) = AC(I)/144.                                                MAIN6750
      A(I) = AN(I)                                                      MAIN6760
      DC(I) = 4.*AC(I)/PW(I)                                            MAIN6770
      DHYD(I) = DC(I)/12.                                               MAIN6780
      DHYDN(I) = DHYD(I)                                                MAIN6790
      PHTOT = PHTOT + HPERIM(I)                                         MAIN6800
  147 ATOTAL = ATOTAL +AN(I)                                            MAIN6810
      NK=K                                                              MAIN6820
      IF(J1.LE.1) PRINT(4) = .TRUE.                                     MAIN6830
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      GO TO 995                                                         MAIN6840
C                                                                       MAIN6850
C   INPUT FOR CARD GROUP 5, CHANNEL AREA VARIATION TABLE                MAIN6860
  150 DO 151 I=1,NCHANL                                                 MAIN6870
  151 IDAREA(I) = 0                                                     MAIN6880
      NAXL = N2                                                         MAIN6890
      NARAMP = N3                                                       MAIN6894
      IF(NARAMP.LE.0) NARAMP = 1                                        MAIN6895
      IF(N2.LT.1) GO TO 995                                             MAIN6900
      READ(I2,5) (AXL(I),I=1,N2)                                        MAIN6910
      NAFACT=N1                                                         MAIN6920
      DO 152 J=1,N1                                                     MAIN6930
      READ(I2,8)  I,(AFACT(J,L),L=1,N2)                                 MAIN6940
      IDAREA(I) = J                                                     MAIN6950
  152 NCH(J)= I                                                         MAIN6960
      IF(J1.LE.1) PRINT(5) = .TRUE.                                     MAIN6970
      GO TO 995                                                         MAIN6980
C                                                                       MAIN6990
C   INPUT FOR CARD GROUP 6, GAP SIZE VARIATIONS TABLE                   MAIN7000
  160 DO 161 K=1,NK                                                     MAIN7010
  161 IDGAP(K) = 0                                                      MAIN7020
      NGXL = N2                                                         MAIN7030
      IF(N2.LT.1) GO TO 995                                             MAIN7040
      READ(I2,5) (GAPXL(L),L=1,NGXL)                                    MAIN7050
      NGAPS = N1                                                        MAIN7060
      DO 162 LL=1,NGAPS                                                 MAIN7070
      READ(I2,1) K                                                      MAIN7080
      IDGAP(K) = LL                                                     MAIN7090
      NGAP(LL) = K                                                      MAIN7100
      READ (I2, 5) (GFACT(LL,L),L=1,NGXL)                               MAIN7110
  162 CONTINUE                                                          MAIN7120
      IF(J1.LE.1) PRINT(6) = .TRUE.                                     MAIN7130
      GO TO 995                                                         MAIN7140
C                                                                       MAIN7150
C   INPUT FOR CARD GROUP 7, SPACER DESIGN INFORMATION                   MAIN7160
  170 J6 = N1                                                           MAIN7170
      NRAMP = N4                                                        MAIN7180
      IF(NRAMP.LT.1) NRAMP = 1                                          MAIN7190
      GRID = .FALSE.                                                    MAIN7200
      NGRID = 0                                                         MAIN7210
      IF(J6.EQ.0) GO TO 995                                             MAIN7220
      IF(J6.EQ.1) GO TO 171                                             MAIN7230
      IF(J6.EQ.2) GO TO 176                                             MAIN7240
      GO TO 995                                                         MAIN7250
  171 READ(I2,42) PITCH,DIA,THICK                                       MAIN7260
      PITCH = PITCH/12.                                                 MAIN7270
      DIA = DIA/12.                                                     MAIN7280
      THICK = THICK/12.                                                 MAIN7290
      NJUMP = N5                                                        MAIN7300
      DO 172 M=1,NK                                                     MAIN7310
      READ(I2,64) K,DUM,CROSS                                           MAIN7320
      DUR(K) = DUM                                                      MAIN7330
      DO 172 L=1,6                                                      MAIN7340
  172 XCROSS(K,L) = CROSS(L)                                            MAIN7350
      READ(I2,68) (NWRAP(I),I=1,NCHANL)                                 MAIN7360
      DO 173 I=1,NCHANL                                                 MAIN7370
  173 NWRAPS(I) = NWRAP(I)                                              MAIN7380
      IF(J1.LE.1) PRINT(7) = .TRUE.                                     MAIN7390
      IF(NJUMP.EQ.3) JUMP = 3                                           MAIN7391
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      IF(NJUMP.NE.3) GO TO 995                                          MAIN7392
      REWIND I8                                                         MAIN7393
      READ(I8) W,P,RHO,F                                                MAIN7394
      REWIND I8                                                         MAIN7395
      GO TO 995                                                         MAIN7400
  176 NGRID = N2                                                        MAIN7410
      NGRIDT = N3                                                       MAIN7420
      READ(I2,66) (GRIDXL(I),IGRID(I),I=1,NGRID)                        MAIN7430
      DO 178 I=1,NGRIDT                                                 MAIN7440
      DO 177 K=1,NK                                                     MAIN7450
  177 FXFLOW(K,I) = 0.                                                  MAIN7460
      DO 178 II=1,NCHANL                                                MAIN7470
  178 READ(I2,67) J,CD(J,I),K,FXFLOW(K,I)                               MAIN7480
      IF(J1.LE.1) PRINT(7) = .TRUE.                                     MAIN7490
      GO TO 995                                                         MAIN7500
C                                                                       MAIN7510
C   INPUT FOR CARD GROUP 8, ROD LAYOUT, DIMENSIONS, AND POWER FACTORS   MAIN7520
  180 NROD = N2                                                         MAIN7530
      DO 181 J=1,N1                                                     MAIN7540
      READ 11, N,I,DR(I),RADIAL(I),(LR(I,L),PHI(I,L),L=1,6)             MAIN7550
      IDFUEL(I) = N                                                     MAIN7560
      IF(N.LT.1) IDFUEL(I) = 1                                          MAIN7570
  181 CONTINUE                                                          MAIN7580
      DO 182 I=1,MC                                                     MAIN7590
      DO 182 J=1,MR                                                     MAIN7600
  182 PWRF(I,J) =0.                                                     MAIN7610
      DO 185 I=1,NROD                                                   MAIN7620
      DO 184 L=1,6                                                      MAIN7630
      IF(LR(I,L))184,184,183                                            MAIN7640
  183 K = LR(I,L)                                                       MAIN7650
      PWRF(K,I)=PHI(I,L)                                                MAIN7660
  184 CONTINUE                                                          MAIN7670
  185 D(I) = DR(I)/12.                                                  MAIN7680
      IF(J1.LE.1) PRINT(8) = .TRUE.                                     MAIN7690
      NODESF = N3                                                       MAIN7730
      NFUELT = N4                                                       MAIN7740
      NCHF = N5                                                         MAIN7745
      IF(NODESF.EQ.0) GO TO 995                                         MAIN7750
      READ 79, (KFUEL(I), CFUEL(I), RFUEL(I), DFUEL(I),                 MAIN7760
     1 KCLAD(I), CCLAD(I), RCLAD(I), TCLAD(I), HGAP(I),I=1,NFUELT)      MAIN7770
       DO 187 I = 1,NFUELT                                              MAIN7771
       KFUEL(I) = KFUEL(I)/3600.                                        MAIN7772
       KCLAD(I) = KCLAD(I)/3600.                                        MAIN7773
       DFUEL(I) = DFUEL(I)/12.                                          MAIN7774
       TCLAD(I) = TCLAD(I)/12.                                          MAIN7775
       HGAP(I) = HGAP(I)/3600.                                          MAIN7776
  187  CONTINUE                                                         MAIN7777
      GO TO 995                                                         MAIN7780
C                                                                       MAIN7790
C   INPUT FOR CARD GROUP  9, CALCULATION VARIABLES                      MAIN7800
  190 READ 14, KIJ,FTM,Z,THETA,NDX,NDT,TTIME,NTRIES,FERROR,SL           MAIN7810
      IF(SL.LT.1.E-5) SL = .5                                           MAIN7820
      ELEV = COS(THETA*PI/180.)                                         MAIN7830
      IF(NTRIES.LT.1) NTRIES=20                                         MAIN7840
      IF(FERROR.LE.0) FERROR = 1.E-3                                    MAIN7850
       NDXP1 = NDX + 1                                                  MAIN7860
      NSKIPX = N1                                                       MAIN7870
      NSKIPT = N2                                                       MAIN7880
      KDEBUG = N3                                                       MAIN7890
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      IF(NSKIPT.LT.1) NSKIPT = 1                                        MAIN7895
      IF(NSKIPX.LT.1) NSKIPX = 1                                        MAIN7900
      ZZ = Z                                                            MAIN7910
      Z = Z/12.                                                         MAIN7920
      IF(Z.LE.0.) GO TO 240                                             MAIN7930
      IF(NDX.LT.1) GO TO 240                                            MAIN7940
      DX = Z/FLOAT(NDX)                                                 MAIN7950
      DT = 0.                                                           MAIN7960
      IF(NDT.GT.0 .AND. TTIME.LE.0.) NDT = 0                            MAIN7970
      IF(NDT.GT.0) DT = TTIME/FLOAT(NDT)                                MAIN7980
      SAVEDT = DT                                                       MAIN7990
      DXX = DX*12.                                                      MAIN8000
      IF(J1.LE.1) PRINT(9) = .TRUE.                                     MAIN8010
      GO TO 995                                                         MAIN8020
C                                                                       MAIN8030
C  INPUT FOR CARD GROUP 10, MIXING PARAMETERS                           MAIN8040
  200 NSCBC = N1                                                        MAIN8050
      READ(I2,5) ABETA,BBETA                                            MAIN8060
      NBBC =N2                                                          MAIN8070
      J5 = N3                                                           MAIN8080
      IF(N2.GE.2) READ(I2,5) (XQUAL(I),BX(I),I=1,N2)                    MAIN8090
      IF(J5.EQ.0) GK = 0.                                               MAIN8100
      IF(J5.EQ.1) READ(I2,5) GK                                         MAIN8110
      IF(J1.LE.1) PRINT(10) = .TRUE.                                    MAIN8120
      GO TO 995                                                         MAIN8130
C                                                                       MAIN8140
C  INPUT FOR CARD GROUP 11, OPERATING CONDITIONS AND TRANSIENT FORCING FMAIN8150
  210 READ(I2,9) PEXIT,HIN,GIN,AFLUX                                    MAIN8160
      PREF = PEXIT                                                      MAIN8170
      CALL PROP(1,1)                                                    MAIN8180
      IF(IERROR.GT.1) GO TO 240                                         MAIN8190
      IH = N1                                                           MAIN8200
C  FOR N1=0, HIN IS THE INLET H.  FOR N1=1, HIN IS THE INLET T.         MAIN8210
C  FOR N1=2, READ IN CHANNEL H.   FOR N1=3, READ IN CHANNEL T.          MAIN8220
      IF(N1.GE.2) GO TO 214                                             MAIN8230
      IF(N1.EQ.1) GO TO 211                                             MAIN8240
      TIN = TF                                                          MAIN8250
      IF(HIN.LT.HF) CALL CURVE(TIN,HIN,TT,HHF,NPROP,IERROR,1)           MAIN8260
      IF(IERROR.GT.1) GO TO 240                                         MAIN8270
      GO TO 212                                                         MAIN8280
  211 TIN = HIN                                                         MAIN8290
      CALL CURVE(HIN,TIN,HHF,TT,NPROP,IERROR,1)                         MAIN8300
      IF(IERROR.GT.1) GO TO 240                                         MAIN8310
  212 DO 213 I=1,NCHANL                                                 MAIN8320
  213 HINLET(I) = HIN                                                   MAIN8330
      GO TO 216                                                         MAIN8340
  214 READ(I2,10) (HINLET(I),I=1,NCHANL)                                MAIN8350
      IF(N1.LE.2) GO TO 216                                             MAIN8360
      DO 215 I=1,NCHANL                                                 MAIN8370
      CALL CURVE  (HINLET(I),HINLET(I),HHF,TT,NPROP,IERROR,1)           MAIN8380
      IF(IERROR.GT.1) GO TO 240                                         MAIN8390
  215 CONTINUE                                                          MAIN8400
  216 DO 2160 I=1,NCHANL                                                MAIN8410
      TINLET(I) = TF                                                    MAIN8412
      IF(HINLET(I).LT.HF)                                               MAIN8414
     1 CALL CURVE(TINLET(I),HINLET(I),TT,HHF,NPROP,IERROR,1)            MAIN8416
      IF(IERROR.GT.1) GO TO 240                                         MAIN8417
 2160 CONTINUE                                                          MAIN8418
      IG = N2                                                           MAIN8419
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C   FOR N2=0, GIN IS THE INLET G FOR EACH CHANNEL.  FOR N2=1, GIN IS THE MAIN8420
C   AVERAGE G BUT THE CHANNEL FLOWS ARE SPLIT TO GIVE EQUAL DP/DX.  FOR NMAIN8430
C   INDIVIDUAL CHANNEL TOTAL FLOW FRACTION IS READ AS INPUT              MAIN8440
      FLO = GIN/.0036*ATOTAL                                             MAIN8450
      DO 217 I=1,NCHANL                                                  MAIN8460
  217 FINLET(I) = GIN*AN(I)/.0036                                        MAIN8470
      IF(N2.EQ.1) CALL SPLIT                                             MAIN8480
      IF(IERROR.GT.1) GO TO 240                                          MAIN8490
      IF(N2.LT.2) GO TO 219                                              MAIN8500
      READ(I2,10) (FSPLIT(I),I=1,NCHANL)                                 MAIN8510
      DO 218 I=1,NCHANL                                                  MAIN8520
  218 FINLET(I) = GIN*AN(I)*FSPLIT(I)/.0036                              MAIN8530
  219 NP = N3                                                            MAIN8540
      IF(NP.GT.1) READ(I2,10) (YP(I),FP(I),I=1,NP)                       MAIN8550
      NH = N4                                                            MAIN8560
      IF(NH.GT.1) READ(I2,10) (YH(I),FH(I),I=1,NH)                       MAIN8570
      NG = N5                                                            MAIN8580
      IF(NG.GT.1) READ(I2,10) (YG(I),FG(I),I=1,NG)                       MAIN8590
      NQ = N6                                                            MAIN8600
      IF(NQ.GT.1) READ(I2,10) (YQ(I),FQ(I),I=1,NQ)                       MAIN8610
      IF(J1.LE.2) PRINT(11) = .TRUE.                                     MAIN8620
      GO TO 995                                                          MAIN8630
C                                                                        MAIN8640
C   INPUT FOR CARD GROUP 12, OUTPUT OPTIONS FOR CALCULATIONS             MAIN8650
  220 NOUT = N1                                                          MAIN8660
      NPCHAN = N2                                                        MAIN8670
      IF(N2.LT.1) GO TO 221                                              MAIN8680
      READ(I2,17)(PRINTC(I),I=1,N2)                                      MAIN8690
  221 NPROD = N3                                                         MAIN8700
      NPNODE = N4                                                        MAIN8710
      IF(N3.LT.1) GO TO 222                                              MAIN8720
      READ 17, (PRINTR(I),I=1,N3)                                        MAIN8730
  222 IF(N4.LT.1) GO TO 225                                              MAIN8740
      READ 17, (PRINTN(I),I=1,N4)                                        MAIN8750
  225 GO TO 995                                                          MAIN8760
C                                                                        MAIN8770
C   INPUT DATA ERROR MESSAGE                                             MAIN8780
  240 PRINT 54                                                           MAIN8790
      STOP                                                               MAIN8800
C                                                                        MAIN8810
C   END OF INPUT                                                         MAIN8820
C                                                                        MAIN8830
C   SET UP VARIABLES FOR OUTPUT PRINTOUT                                 MAIN8840
C                                                                        MAIN8850
  250 DO 251 I=1,NCHANL                                                  MAIN8860
      A(I) = AN(I)                                                       MAIN8870
  251 DHYD(I) = DHYDN(I)                                                 MAIN8880
      DO 252 K=1,NK                                                      MAIN8890
  252 GAP(K) = GAPN(K)                                                   MAIN8900
      IF(NPCHAN.GT.0) GO TO 257                                          MAIN8910
      NPCHAN = NCHANL                                                    MAIN8920
      DO 256 I=1,NCHANL                                                  MAIN8930
  256 PRINTC(I) = I                                                      MAIN8940
  257 IF(NPROD.GT.0) GO TO 259                                           MAIN8950
      NPROD = NROD                                                       MAIN8970
      DO 258 N=1,NROD                                                    MAIN8980
  258 PRINTR(N) = N                                                      MAIN8990
  259 IF(NPNODE.GT.0) GO TO 261                                          MAIN9000
      NN = NODESF+1                                                      MAIN9010
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      NPNODE = NN                                                       MAIN9020
      DO 260 I=1,NN                                                     MAIN9030
  260 PRINTN(I) = I                                                     MAIN9040
C                                                                       MAIN9050
C  OUTPUT OF INPUT DATA                                                 MAIN9060
C                                                                       MAIN9070
  261 IF(.NOT.PRINT(1)) GO TO 265                                       MAIN9080
      WRITE(I3,13)   (PP(I),TT(I),VVF(I),VVG(I),HHF(I),HHG(I),UUF(I),   MAIN9090
     1KKF(I),SSIGMA(I),I=1,NPROP)                                       MAIN9100
  265 IF(.NOT.PRINT(2)) GO TO 270                                       MAIN9110
      WRITE(I3,28)                                                      MAIN9120
      DO 266 J=1,4                                                      MAIN9130
      IF(AA(J).GT.0. .OR. CC(J).GT.0.) WRITE(I3,29)  J,AA(J),BB(J),CC(J)MAIN9140
  266 CONTINUE                                                          MAIN9150
      IF(NVISCW.EQ.0) WRITE(I3,61)                                      MAIN9160
      IF(NVISCW.EQ.1) WRITE(I3,62)                                      MAIN9170
      WRITE (I3,44)                                                     MAIN9180
      IF(J2.EQ.0) WRITE(I3,45)                                          MAIN9190
      IF(J2.EQ.1) WRITE(I3,46)                                          MAIN9200
      IF(J3.EQ.0) WRITE(I3,47)                                          MAIN9210
      IF(J3.EQ.1) WRITE(I3,48)                                          MAIN9220
      IF(J3.EQ.5) WRITE(I3,49) AV(1)                                    MAIN9230
      IF(J3.EQ.6) WRITE(I3,57) NV,(AV(I),I=1,NV)                        MAIN9240
      IF(J4.EQ.0) WRITE(I3,58)                                          MAIN9250
      IF(J4.EQ.1) WRITE(I3,59)                                          MAIN9260
      IF(J4.EQ.5) WRITE(I3,60) NF,(AF(I),I=1,NF)                        MAIN9270
  270 IF(.NOT.PRINT(3)) GO TO 275                                       MAIN9280
      WRITE(I3,6) (Y(I),AXIAL(I),I=1,NAX)                               MAIN9290
  275 IF(.NOT.PRINT(4)) GO TO 280                                       MAIN9300
      WRITE(I3,12)   ( I,NTYPE(I),AC(I),PW(I),PH(I),DC(I),(LC(I,L),     MAIN9310
     1 GAPS(I,L),DIST(I,L),L=1,4),I=1,NCHANL)                           MAIN9320
  280 IF(NAXL  .LT.1) GO TO 285                                         MAIN9330
      IF(.NOT.PRINT(5)) GO TO 285                                       MAIN9340
      N=1                                                               MAIN9350
      NN=10                                                             MAIN9360
      DO 284 LL=1,4                                                     MAIN9370
      IF(NN.GT.NAFACT) NN = NAFACT                                      MAIN9380
      WRITE (I3,19) ((H1,NCH(J),H3),J=N,NN)                             MAIN9390
      DO 283 I=1,NAXL                                                   MAIN9400
  283 WRITE(I3,38) AXL(I), (AFACT(J,I),J=N,NN)                          MAIN9410
      N=N+10                                                            MAIN9420
      NN=NN+10                                                          MAIN9430
      IF(N.GE.NAFACT) GO TO 285                                         MAIN9440
  284 CONTINUE                                                          MAIN9450
  285 IF(NGXL .LT.1) GO TO 290                                          MAIN9460
      IF(.NOT.PRINT(6)) GO TO 290                                       MAIN9470
      N = 1                                                             MAIN9480
      NN= 10                                                            MAIN9490
      DO 289 LL = 1,6                                                   MAIN9500
      IF(NN.GT.NGAPS) NN=NGAPS                                          MAIN9510
      DO 286 M=N,NN                                                     MAIN9520
      K = NGAP(M)                                                       MAIN9530
      IM(M) = IK(K)                                                     MAIN9540
  286 JM(M) = JK(K)                                                     MAIN9550
      WRITE (I3,20) ((H1,IM(M),H2,JM(M),H3),M=N,NN)                     MAIN9560
      DO 287 L=1,NGXL                                                   MAIN9570
  287 WRITE (I3,38)  GAPXL(L),(GFACT(M,L),M=N,NN)                       MAIN9580
      N=N+10                                                            MAIN9590
      NN=NN+10                                                          MAIN9600
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      IF(N.GE.NGAPS) GO TO 290                                          MAIN9610
  289 CONTINUE                                                          MAIN9620
  290 IF(.NOT.PRINT(7)) GO TO 300                                       MAIN9630
      IF(J6.EQ.0) GO TO 300                                             MAIN9640
      IF(J6.GT.1) GO TO 296                                             MAIN9650
      PITCH = PITCH*12.                                                 MAIN9660
      DIA = DIA*12.                                                     MAIN9670
      THICK = THICK*12.                                                 MAIN9680
      PRINT 69, PITCH, THICK,DIA                                        MAIN9690
      PITCH = PITCH/12.                                                 MAIN9700
      DIA = DIA/12.                                                     MAIN9710
      THICK = THICK/12.                                                 MAIN9720
      PRINT 70,  (K,H1,IK(K),H2,JK(K),H3,DUR(K),(XCPOSS(K,L),L=1,6),    MAIN9730
     1 K=1,NK)                                                          MAIN9740
      PRINT 74, (NWRAP(I),I=1,NCHANL)                                   MAIN9750
      GO TO 300                                                         MAIN9760
  296 PRINT 71, (IGRID(I),I=1,NGRID)                                    MAIN9770
      PRINT 72, (GRIDXL(I),I=1,NGRID)                                   MAIN9780
      DO 297 L=1,NGRIDT                                                 MAIN9790
  297 PRINT 73, L,(I,CD(I,L),I=1,NCHANL)                                MAIN9800
      DO 299 I=1,NGRIDT                                                 MAIN9810
      II = 0                                                            MAIN9820
      DO 298 K=1,NK                                                     MAIN9830
      IF(ABS(FXFLOW(K,I)).GT.0) II=1                                    MAIN9840
  298 CONTINUE                                                          MAIN9850
      IF(II.EQ.0) GO TO 299                                             MAIN9860
      PRINT 76, I,(KK,H1,IK(KK),H2,JK(KK),H3,FXFLOW(KK,I),KK=1,NK)      MAIN9870
  299 CONTINUE                                                          MAIN9880
  300 IF(.NOT.PRINT(8)) GO TO 305                                       MAIN9890
      PRINT 15, (I,IDFUEL(I),DR(I),RADIAL(I),(PHI(I,L),LR(I,L),         MAIN9900
     1 L=1,6),I=1,NROD)                                                 MAIN9910
      IF(NODESF.LT.1) GO TO 305                                         MAIN9920
       DO 301 I = 1,NFUELT                                              MAIN9921
       KFUEL(I) = KFUEL(I)*3600.                                        MAIN9922
       KCLAD(I) = KCLAD(I)*3600.                                        MAIN9923
       DFUEL(I) = DFUEL(I)*12.                                          MAIN9924
       TCLAD(I) = TCLAD(I)*12.                                          MAIN9925
       HGAP(I) = HGAP(I)*3600.                                          MAIN9926
  301  CONTINUE                                                         MAIN9927
      PRINT 77, NODESF                                                  MAIN9930
      PRINT 78, (J,KFUEL(J),CFUEL(J),RFUEL(J),DFUEL(J),KCLAD(J),CCLAD(J)MAIN9940
     1,RCLAD(J),TCLAD(J),HGAP(J),J=1,NFUELT)                            MAIN9950
       DO 302 I = 1,NFUELT                                              MAIN9960
      KFUEL(I) = KFUEL(I)/3600.                                         MAIN9970
      KCLAD(I) = KCLAD(I)/3600.                                         MAIN9980
       DFUEL(I) = DFUEL(I)/12.                                          MAIN9990
      TCLAD(I) = TCLAD(I)/12.                                           MAIN0000
      HGAP(I) = HGAP(I)/3600.                                           MAIN0010
  302  CONTINUF                                                         MAIN0020
  305 IF(.NOT.PRINT(9)) GO TO 310                                       MAIN0030
      PRINT 18, KIJ,FTM,SL,ZZ,THETA,NDX,DXX,NDT,TTIME,DT,NTRIES,FERROR   MAIN0040
  310 IF(.NOT.PRINT(10))GO TO 315                                       MAIN0050
      WRITE(I3,35)                                                      MAIN0060
      IF(NSCBC.LT.1) WRITE(I3, 32) ABETA                                MAIN0070
      IF(NSCBC.EQ.1) WRITE(I3, 33) ABETA, BBETA                         MAIN0080
      IF(NSCBC.EQ.2) WRITE(I3, 34) ABETA, BBETA                         MAIN0090
      IF(NSCBC.EQ.3) WRITE(I3,39) ABETA, BBETA                          MAIN0100
      IF(NSHC-1) 311,311,312                                            MAIN0110
  311 WRITE(I3,36)                                                      MAIN0120
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      GO TO 314                                                         MAIN0130
  312 WRITE (I3,37) (XQUAL(I),BX(I),I=1,NBBC)                           MAIN0140
  314 IF(JS.EQ.1) PRINT 65, GK                                          MAIN0150
  315 IF(.NOT.PRINT(11)) GO TO 318                                      MAIN0160
      WRITE(I3,21) PEXIT,HIN,GIN,TIN,AFLUX                              MAIN0170
      IF(IH.EQ.0) WRITE(I3,87)                                          MAIN0180
      IF(IH.EQ.1) WRITE(I3,88)                                          MAIN0190
      IF(IH.EQ.2) WRITE(I3,89)                                          MAIN0200
      IF(IH.EQ.3) WRITE(I3,90)                                          MAIN0210
      IF(IG.EQ.0) WRITE(I3,91)                                          MAIN0220
      IF(IG.EQ.1) WRITE(I3,92)                                          MAIN0230
      IF(IG.EQ.2) WRITE(I3,93)                                          MAIN0240
      IF(NP.GT.1) PRINT 83, (YP(I),FP(I),I=1,NP)                        MAIN0250
      IF(NH.GT.1) PRINT 84, (YH(I),FH(I),I=1,NH)                        MAIN0260
      IF(NG.GT.1) PRINT 85, (YG(I),FG(I),I=1,NG)                        MAIN0270
      IF(NQ.GT.1) PRINT 86, (YQ(I),FQ(I),I=1,NQ)                        MAIN0280
  318 IF(KDEBUG) 400,400,319                                            MAIN0290
  319 WRITE(I3,50) ((LC(I,L),I=1,NCHANL),L=1,4)                         MAIN0300
      WRITE (I3,50) (IK(K),JK(K),K=1,NK)                                MAIN0310
      WRITE (I3,51) (FACTOR(K),K=1,NK)                                  MAIN0320
      WRITE (I3,50) ((LR(NR,L),NR=1,NROD),L=1,6)                        MAIN0330
      WRITE (I3,51) ((PWRF(I,NR),NR=1,NROD ),I=1,NCHANL)                MAIN0340
      WRITE (I3,51) (D(NR),NR=1,NROD),(RADIAL(NR),NR=1,NROD)            MAIN0350
C                                                                       MAIN0360
C  START SUBCHANNEL FLOW AND ENTHALPY CALCULATIONS.                     MAIN0370
  400 KT = NSKIPT                                                       MAIN1280
      DT = SAVEDT                                                       MAIN1290
      DO 401 J=1,NDXP1                                                  MAIN1300
  401 X(J) = DX*FLOAT(J-1)                                              MAIN1302
      NDTP1 = NDT+1                                                     MAIN1304
      DO 500 NT=1,NDTP1                                                 MAIN1306
      IERROR = 0                                                        MAIN1310
      DT = SAVEDT                                                       MAIN1314
      IF(NT.EQ.1) DT = 1.E+10                                           MAIN1315
      ETIME = DT*FLOAT(NT-1)                                            MAIN1320
C  ESTABLISH CHANNEL BOUNDARY CONDITIONS AND FORCING FUNCTION VALUES.   MAIN1330
      DUMY = 1.                                                         MAIN1340
      IF(NP.GT.1)                                                       MAIN1350
     1CALL CURVE (DUMY,ETIME,FP,YP,NP,IERROR,1)                         MAIN1360
      IF(IERROR.GT.1) GO TO 505                                         MAIN1370
      PREF = DUMY*PEXIT                                                 MAIN1380
      CALL PROP(1,1)                                                    MAIN1390
      IF(IERROR.GT.1) GO TO 505                                         MAIN1400
      DUMY = 1.                                                         MAIN1410
      IF(NH.GT.1)                                                       MAIN1420
     1CALL CURVE (DUMY,ETIME,FH,YH,NH,IERROR,1)                         MAIN1430
      IF(IERROR.GT.1) GO TO 505                                         MAIN1440
      DO 402 I=1,NCHANL                                                 MAIN1450
      HOLD(I,1) = H(I,1)                                                MAIN1460
      H(I,1) = HINLET(I)*DUMY                                           MAIN1470
      IF(IH.EQ.1 .OR. IH.EQ.3)                                          MAIN1472
     1 CALL CURVE(H(I,1),TINLET(I)*DUMY,HHF,TT,NPROP,IERROR,1)          MAIN1476
  402 CONTINUE                                                          MAIN1478
      DUMY = 1.                                                         MAIN1480
      IF(NG.GT.1)                                                       MAIN1490
     1 CALL CURVE(DUMY,ETIME,FG,YG,NG,IERROR,1)                         MAIN1500
      IF(IERROR.GT.1) GO TO 505                                         MAIN1510
      DO 403 I=1,NCHANL                                                 MAIN1520
      FOLD(I,1) = F(I,1)                                                MAIN1530
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  403 F(I,1) = FINLET(I)*DUMY                                           MAIN1540
      DUMY = 1.                                                         MAIN1550
      IF(NQ.GT.1)                                                       MAIN1560
     1CALL CURVE (DUMY,ETIME,FQ,YQ,NQ,IERROR,1)                         MAIN1570
      IF(IERROR.GT.1) GO TO 505                                         MAIN1580
      POWER = DUMY                                                      MAIN1590
C                                                                       MAIN1600
C  BEGIN ITERATION TO OBTAIN SOLUTION.                                  MAIN1605
      DO 430 NN=1,NTRIES                                                MAIN1610
      DO 410 I=1,NCHANL                                                 MAIN1620
  410 NWRAP(I) = NWRAPS(I)                                              MAIN1630
      ITERAT = NN                                                       MAIN1640
      CALL SCHEMF(JUMP)                                                 MAIN1650
      IF(IERROR.GT.1) GO TO 440                                         MAIN1660
      CALL FLAP(MTIME)                                                  MAIN1662
      IF(MTIME.LT.MAXT) GO TO 429                                       MAIN1664
      PRINT 102                                                         MAIN1666
      GO TO 440                                                         MAIN1668
  429 IF(JUMP.LT.1 .OR. JUMP.GT.3) GO TO 505                            MAIN1670
      GO TO (430,440,440),JUMP                                          MAIN1680
  430 CONTINUE                                                          MAIN1690
      PRINT 22, NTRIES                                                  MAIN1700
      IERROR = 1                                                        MAIN1710
C  SET CONDITIONS FOR NEXT TIME STEP                                    MAIN1720
  440 IF(JUMP.EQ.3) GO TO 441                                           MAIN1730
      IF(NJUMP.GT.0) JUMP = 3                                           MAIN1731
      IF(NJUMP.NE.2) GO TO 441                                          MAIN1732
      REWIND I8                                                         MAIN1733
      WRITE(I8) W,P,RHO,F                                               MAIN1734
      END FILE I8                                                       MAIN1735
      REWIND I8                                                         MAIN1736
  441 DO 445 J=1,NDXP1                                                  MAIN1737
      DO 443 K=1,NK                                                     MAIN1740
      WOLD(K,J) = W(K,J)                                                MAIN1750
  443 CONTINUE                                                          MAIN1760
      DO 444 I=1,NCHANL                                                 MAIN1770
      FOLD(I,J) = F(I,J)                                                MAIN1780
      HOLD(I,J) = H(I,J)                                                MAIN1790
      RHOOLD(I,J) = RHO(I,J)                                            MAIN1800
  444 CONTINUE                                                          MAIN1810
  445 CONTINUE                                                          MAIN1820
      ISAVE = IERROR                                                    MAIN1822
      IERROR = 0                                                        MAIN1824
      IF(NCHF.GT.0 .AND. ISAVE.EQ.0) CALL CHF(3,NDXP1)                  MAIN1826
      KT = KT+1                                                         MAIN1830
      IF(KT.LT.NSKIPT) GO TO 500                                        MAIN1840
      CALL TOD(TIME)                                                    MAIN1850
C                                                                       MAIN1856
C  PRINT RESULTS                                                        MAIN1857
      IF(ETIME.GT.0.) GO TO 457                                         MAIN1858
C  COMPUTE MASS AND ENERGY BALANCE                                      MAIN1859
      FLOIN = 0.                                                        MAIN1860
      FLOOUT = 0.                                                       MAIN1861
      ENGIN = 0.                                                        MAIN1862
      ENGOUT = 0.                                                       MAIN1863
      NDXP1 = NDX+1                                                     MAIN1864
      DO 448 I=1,NCHANL                                                 MAIN1865
      FLOIN = FLOIN + F(I,1)                                            MAIN1866
      FLOOUT = FLOOUT + F(I,NDXP1)                                      MAIN1867
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      ENGIN = ENGIN + F(I,1)*H(I,1)
  448 ENGOUT = ENGOUT + F(I,NDXP1)*H(I,NDXP1)
      FLOERR = FLOOUT - FLOIN
      ENGADD = AFLUX*Z*PHTOT/.0036
      ENGERR =  ENGOUT - ENGIN - ENGADD
      PRINT 99, KASE,TEXT,DATE,TIME,FLOIN,ENGIN,FLOOUT,ENGADD,FLOERR,
     1ENGOUT,ENGERR
C  PREPARE CHANNEL EXIT SUMMARY
      J = NDXP1
      DO 450 I=1,NCHANL
      OUTPUT(1) = TF
      IF(H(I,J).LT.HF)CALL CURVE(OUTPUT(1),H(I,J),TT,HHF,NPROP,IERROR,1)
      OUTPUT(2) = (H(I,J)-HF)/HFG
      IF(OUTPUT(2).LT.0.) OUTPUT(2) = 0.
      OUTPUT(3) = (RHOF-RHO(I,J))/(RHOF-RHOG)
      IF(OUTPUT(3).LT.0.) OUTPUT(3) = 0.
      OUTPUT(4) = F(I,J)/AN(I)*.0036
      PRINT 100, I,H(I,J),OUTPUT(1),RHO(I,J),OUTPUT(2),OUTPUT(3),
     1 F(I,J),OUTPUT(4)
  450 CONTINUE
      IF(IERROR.GT.1) GO TO 505
C  COMPUTE BUNDLE AVERAGED RESULTS
  452 PRINT 25, KASE,TEXT,DATE,TIME
      PRINT 101
      PRINT 82
      DO 456 J=1,NDXP1,NSKIPX
      SAVE1 = 0.
      SAVE2 = 0.
      SAVE3 = 0.
      SAVE4 = 0.
      DO 454 I=1,NCHANL
      SAVE1 = SAVE1 + P(I,J)*AN(I)
      SAVE2 = SAVE2 + H(I,J)*F(I,J)
      SAVE3 = SAVE3 + F(I,J)
  454 SAVE4 = SAVE4 + RHO(I,J)*AN(I)
      OUTPUT(1) = X(J)*12.
      OUTPUT(2) = SAVE1/ATOTAL/144.
      OUTPUT(3) = SAVE2/SAVE3
      OUTPUT(4) = TF
      IF(OUTPUT(3).LT.HF) CALL CURVE(OUTPUT(4),OUTPUT(3),TT,HHF,NPROP,
     1 IERROR,1)
      IF(IERROR.GT.1) GO TO 505
      OUTPUT(5) = SAVE4/ATOTAL
      OUTPUT(6) = 0.
      IF(OUTPUT(3).GT.HF) OUTPUT(6) = (OUTPUT(3)-HF)/HFG
      OUTPUT(7) = 0.
      IF(OUTPUT(5).LT.RHOF) OUTPUT(7) = (RHOF-OUTPUT(5))/(RHOF-RHOG)
      OUTPUT(8) = SAVE3
      OUTPUT(9) = SAVE3/ATOTAL*.0036
      PRINT 81, (OUTPUT(II),II=1,9)
  456 CONTINUE
      IF(IERROR.GT.1) GO TO 505
C  PRINT CHANNEL AND ROD RESULTS AS DEFINED BY OUTPUT OPTIONS
  457 DO 460 JJ=1,NPCHAN
      I = PRINTC(JJ)
      PRINT 25, KASE, TEXT, DATE, TIME
      PRINT 80,ETIME,I
      PRINT 82
      DO 458 J=1,NDXP1,NSKIPX
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      OUTPUT(1) = X(J)*12.                                              MAIN1927
      OUTPUT(3) = H(I,J)                                                MAIN1930
      OUTPUT(2) = P(I,J)/144.                                           MAIN1940
      OUTPUT(4) = TF                                                    MAIN1950
      IF(H(I,J).LT.HF)CALL CURVE(OUTPUT(4),H(I,J),TT,HHF,NPROP,IERROR,1)MAIN1960
      IF(IERROR.GT.1) GO TO 505                                         MAIN1965
      OUTPUT(5) = RHO(I,J)                                              MAIN1970
      OUTPUT(6) = 0.                                                    MAIN1980
      IF(H(I,J).GT.HF) OUTPUT(6) = (H(I,J)-HF)/HFG                      MAIN1990
      OUTPUT(7) = 0.                                                    MAIN2000
      IF(RHO(I,J).LT.RHOF) OUTPUT(7) = (RHOF-RHO(I,J))/(RHOF-RHOG)      MAIN2010
      OUTPUT(8) = F(I,J)                                                MAIN2020
      OUTPUT(9) = F(I,J)/AN(I)*.0036                                    MAIN2030
      PRINT 81, (OUTPUT(II),II=1,9)                                     MAIN2040
  458 CONTINUE                                                          MAIN2050
  460 CONTINUE                                                          MAIN2060
      IF(NOUT.LT.1) GO TO 499                                           MAIN2070
      IF(NOUT.EQ.2) GO TO 470                                           MAIN2080
      DO 465 M=1,NK,10                                                  MAIN2090
      MM = M+9                                                          MAIN2100
      IF(NK.LE.MM) MM=NK                                                MAIN2110
      PRINT 31, KASE, TEXT, DATE, TIME, H7, (H6,H1,IK(K),H2,JK(K),      MAIN2120
     1 H3,K=M,MM)                                                       MAIN2130
      DO 465 J=1,NDXP1,NSKIPX                                           MAIN2140
      XDUMY = X(J)*12.                                                  MAIN2150
      PRINT 30, XDUMY, (W(K,J),K=M,MM)                                  MAIN2160
  465 CONTINUE                                                          MAIN2170
      IF(NOUT.EQ.1) GO TO 499                                           MAIN2180
  470 IF(NPROD.LT.1) GO TO 4990                                         MAIN2185
      DO 485 NN=1,NPROD                                                 MAIN2190
      N = PRINTR(NN)                                                    MAIN2200
      NDUMY = IDFUEL(N)                                                 MAIN2210
      PRINT 94, KASE, TEXT, DATE, TIME, ETIME, N, NDUMY,                MAIN2220
     1 (H8,PRINTN(I),H3,I=1,NPNODE)                                     MAIN2230
      DO 483 J=1,NDXP1,NSKIPX                                           MAIN2240
      XDUMY = X(J)*12.                                                  MAIN2250
      DO 480 II=1,NPNODE                                                MAIN2260
      I = PRINTN(II)                                                    MAIN2270
  480 TDUMY(II) = TROD(I,N,J)                                           MAIN2280
      DFLUX = FLUX(N,J)*.0036                                           MAIN2290
      IF(CCHANL(N,J).EQ.0) CHFR(N,J) = 0.                               MAIN2292
      IF(NODESF.GT.1) PRINT 95, XDUMY,DFLUX,CHFR(N,J),CCHANL(N,J),      MAIN2294
     1 (TDUMY(I),I=1,NPNODE)                                            MAIN2296
      IF(NODESF.LT.1) PRINT 95, XDUMY,DFLUX,CHFR(N,J),CCHANL(N,J)       MAIN2300
  483 CONTINUE                                                          MAIN2310
  485 CONTINUE                                                          MAIN2320
 4990 IF(NCHF.LT.1) GO TO 499                                           MAIN2321
      PRINT 96, KASE,TEXT,DATE,TIME,ETIME,CHFCOR(NCHF)                  MAIN2322
      DO 4995 J=1,NDXP1,NSKIPX                                          MAIN2323
      XDUMY = X(J)*12.                                                  MAIN2324
      N = MCHFRR(J)                                                     MAIN2325
      DFLUX = 0.                                                        MAIN2326
      IF(N.NE.0) DFLUX = FLUX(N,J)*.0036                                MAIN2327
      IF(N.EQ.0) MCHFR(J) = 0.                                          MAIN2328
      PRINT 97, XDUMY,DFLUX,MCHFR(J),MCHFRR(J),MCHFRC(J)                MAIN2329
 4995 CONTINUE                                                          MAIN2330
  499  PRINT 75, ITERAT                                                 MAIN2331
      KT = 0                                                            MAIN2340
      IF(ISAVE.GT.0) GO TO 505                                          MAIN2345
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      IF(IERROR.GT.0) GO TO 505                                         MAIN2350
  500 CONTINUE                                                          MAIN2360
C                                                                       MAIN2370
C  END OF PROBLEM,  LOOK FOR NEW CASE                                   MAIN2380
      GO TO 990                                                         MAIN2390
  505 PRINT 55, SIGNAL(IERROR)                                          MAIN2400
      PRINT 55, SIGNAL(ISAVE)                                           MAIN2405
      GO TO 990                                                         MAIN2410
      END                                                               MAIN2420
*DECK,SCHEME
      SUBROUTINE SCHEME(JUMP)                                           SCHM0010
C                                                                       SCHM0020
C  THIS SUBROUTINE SETS UP AND PERFORMS THE SOLUTION OF THE FINITE      SCHM0030
C  DIFFERENCE SCHEME AT EACH SPATIAL LOCATION X AT A SELECTED TIME T.   SCHM0040
C                                                                       SCHM0050
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THESCHM0060
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    SCHM0070
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    SCHM0080
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NSXL,       SCHM0090
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          SCHM0100
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        SCHM0110
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           SCHM0120
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       SCHM0130
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   SCHM0140
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              SCHM0150
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   SCHM0160
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  SCHM0170
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               SCHM0180
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             SCHM0190
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                SCHM0200
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             SCHM0210
     1 DHDX(30), DPDX(30), QPPIM(30), PERIM(30),                        SCHM0220
     2 HPERIM(30), NTYPE(30)                                            SCHM0230
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       SCHM0240
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      SCHM0250
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  SCHM0260
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), SCHM0270
     2 NGAP( 9), BX(30), XQUAL(30)                                      SCHM0280
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          SCHM0290
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            SCHM0300
      LOGICAL FDIV, GRID                                                SCHM0310
      REAL  KIJ, LENGTH, KF, KKF                                        SCHM0320
      REAL KFUEL, KCLAD                                                 SCHM0330
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         SCHM0340
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,                         SCHM0350
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),                 SCHM0360
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),                       SCHM0370
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF                SCHM0380
      DIMENSION WSAVE(47)                                               SCHM0390
      COMMON /BSP/ SP(47,31)                                            SCHM0400
    1 FORMAT('1ERROR DETECTED IN SUBROUTINE SCHEME AT NODE'I3,          SCHM0401
     1 '   X ='E10.5,' FEET'/' CALCULATION FOR THIS CASE STOPPED')      SCHM0402
    2 FORMAT(' NODE'I3,'   X ='E10.5)                                   SCHM0403
    3 FORMAT('     I       H(I,J)       F(I,J)       P(I,J)      H(I,J-1)     FSCHM0404
     1(I,J-1)     P(I,J-1)')                                            SCHM0405
    4 FORMAT('     I      QUAL(I)     ALPHA(I)     RHO(I,J)       VP(I)     SCHM0406
     1 V(I)      FMULT(I)')                                             SCHM0407
    5 FORMAT('     K    W(K,J-1)       W(K,J)        WP(K)     USTAR(K)    SPSCHM0408
     1(K,J-1)      SP(K,J)')                                            SCHM0409
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    6 FORMAT('    I      DHDX(I)       DFDX(I)      DPDX(I)     QPRIM(I)    FOSCHM0410
     1LD(I.J) RHOOLD(I.J)')                                                 SCHM0411
   16 FORMAT(3I5.4E12.6)                                                    SCHM0412
   52 FORMAT( I5.6E12.6)                                                    SCHM0420
      NCHANL = NCHANL                                                       SCHM0430
      FMIN = .0001                                                          SCHM0440
      NDXP1 = NDX+1                                                         SCHM0450
      IF(JUMP.EQ.3) GO TO 400                                               SCHM0460
      JUMP = 2                                                              SCHM0470
C                                                                           SCHM0480
C   BEGIN STEPPING THROUGH CHANNEL                                          SCHM0481
  400 DO 450 J=1.NDXP1                                                      SCHM0482
      JP1 = J+1                                                             SCHM0483
      JM1 = J-1                                                             SCHM0484
      IF(J.GT.1) GO TO 405                                                  SCHM0485
C   SET CONDITIONS AT START OF CHANNEL                                      SCHM0490
      DO 401 I=1.NCHANL                                                     SCHM0500
  401 QPRIM(I) = 0.                                                         SCHM0510
      CALL FORCE(1)                                                         SCHM0520
      IF(IERROR.GT.1) GO TO 440                                             SCHM0530
      CALL AREA(1)                                                          SCHM0540
      IF(IERROR.GT.1) GO TO 440                                             SCHM0550
      CALL PROP(2.1)                                                        SCHM0560
      IF(IERROR.GT.1) GO TO 440                                             SCHM0570
      CALL VOID(1)                                                          SCHM0580
      IF(IERROR.GT.1) GO TO 440                                             SCHM0590
      GO TO 450                                                             SCHM0595
  405 IF(JUMP.EQ.3) GO TO 420                                               SCHM0600
      IF(NGRID.LT.1) GO TO 410                                              SCHM0670
      GRID = .FALSE.                                                        SCHM0680
      DO 408 I=1.NGRID                                                      SCHM0690
      ZG = GRIDXL(I)*Z                                                      SCHM0700
      IF(ZG.GT.X(JM1) .AND. ZG.LE.X(J)) GO TO 409                           SCHM0710
  408 CONTINUE                                                              SCHM0720
      GO TO 410                                                             SCHM0730
  409 NGTYPE = IGRID(I)                                                     SCHM0740
      GRID = .TRUE.                                                         SCHM0750
C   CALCULATE PARAMETERS TO BE SAVED FROM PREVIOUS SPACE                    SCHM0760
  410 DO 411 I=1.NCHANL                                                     SCHM0770
      VPA(I) = VP(I)/A(I)                                                   SCHM0780
  411 CONTINUE                                                              SCHM0790
  420 CALL HEAT(J)                                                          SCHM0800
      IF(IERROR.GT.1) GO TO 440                                             SCHM0810
      CALL MIX(JM1)                                                         SCHM0820
      IF(IERROR.GT.1) GO TO 440                                             SCHM0830
      CALL DIFFER(1.JM1)                                                    SCHM0840
      IF(IERROR.GT.1) GO TO 440                                             SCHM0850
C                                                                           SCHM0860
C    CALCULATE ENTHALPY AND ESTIMATE FLOW AT X.                             SCHM0870
      DO 425 I=1.NCHANL                                                     SCHM0880
      IF(ITERAT.EQ.1 .AND. JUMP.NE.3) F(I.J) = F(I.JM1)                     SCHM0890
      H(I.J) =(H(I.JM1) + DX/DT/UH(I)*HOLD(I.J) + DX*DHDX(I))/              SCHM0900
     1 (1.+DX/DT/UH(I))                                                     SCHM0910
  425 CONTINUE                                                              SCHM0920
      IF(JUMP.EQ.3) GO TO 450                                               SCHM0930
      CALL FORCE(J)                                                         SCHM0940
      IF(IERROR.GT.1) GO TO 440                                             SCHM0950
      CALL AREA(J)                                                          SCHM0960
      IF(IERROR.GT.1) GO TO 440                                             SCHM0970
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      CALL PROP(2,J)                                                    SCHM0980
      IF(IERROR.GT.1) GO TO 440                                         SCHM0990
      CALL VOID(J)                                                      SCHM1010
      IF(IERROR.GT.1) GO TO 440                                         SCHM1020
      CALL DIFFER(3,J)                                                  SCHM1030
      IF(IERROR.GT.1) GO TO 440                                         SCHM1040
      DO 426 K=1,NK                                                     SCHM1050
      WSAVE(K) = W(K,J)                                                 SCHM1060
  426 CONTINUE                                                          SCHM1070
C  CALCULATE THE DIVERSION CROSSFLOW AT X.                              SCHM1080
      CALL DIVERT(J)                                                    SCHM1090
      IF(IERROR.GT.1) GO TO 440                                         SCHM1100
C  CALCULATE THE FLOW AT X AND CHECK FOR CONVERGENCE.                   SCHM1110
      CALL DIFFER(2,J)                                                  SCHM1160
      IF(IERROR.GT.1) GO TO 440                                         SCHM1170
      DO 4270 I=1,NCHANL                                                SCHM1180
      FSAVE = F(I,J)                                                    SCHM1185
      F(I,J) = F(I,JM1) + DX*DFDX(I) - DX/DT*(RHO(I,J)-RHOOLD(I,J))*A(I)SCHM1190
C  THE FOLLOWING STATEMENT PROVIDES DAMPING TO ASSIST IN MORE RAPID     SCHM1191
C  CONVERGENCE, ESPECIALLY WHEN USING THE SUBCOOLED VOID OPTION.        SCHM1192
C  USERS MAY WISH TO TRY OTHER COMBINATIONS OF CONSTANTS.               SCHM1193
      F(I,J) = .2*FSAVE + .8*F(I,J)                                     SCHM1194
      IF(ABS(F(I,J)-FSAVE)/FSAVE.GT.FERROR) JUMP = 1                    SCHM1195
      IF(F(I,J).LT.FMIN) F(I,J) = FMIN                                  SCHM1200
 4270 CONTINUE                                                          SCHM1210
C  CALCULATE SP AT X-DX.                                                SCHM1220
      CALL DIFFER(4,J)                                                  SCHM1230
      IF(IERROR.GT.1) GO TO 440                                         SCHM1240
C  THE FACTOR DAMPING WAS ADDED AFTER PUBLICATION.  A VALUE OF ZERO WAS SCHM1241
C  USED FOR THE SAMPLE PROBLEMS.  A VALUE OF 0.5 HAS BEEN FOUND TO SPEEDSCHM1242
C  CONVERGENCE FOR MANY PROBLEMS.  USERS MAY WISH TO TRY OTHER VALUES.  SCHM1243
       DAMPNG = 0.                                                      SCHM1244
      DO 430 K=1,NK                                                     SCHM1250
      II = IK(K)                                                        SCHM1260
      JJ = JK(K)                                                        SCHM1270
       SP(K,JM1) = DAMPNG*SP(K,JM1)                                     SCHM1280
     1 + (1.-DAMPNG)*(SP(K,J)-(DPDX(II)-DPDX(JJ))*DX)                   SCHM1285
  430 CONTINUE                                                          SCHM1290
      DO 428 I=1,NCHANL                                                 SCHM1300
      P(I,J) = P(I,JM1) + DX*DPDX(I)                                    SCHM1310
  428 CONTINUE                                                          SCHM1320
      IF(KDEBUG.LT.1) GO TO 450                                         SCHM1330
      GO TO 445                                                         SCHM1340
  440 PRINT 1, J, X(J)                                                  SCHM1342
      GO TO 446                                                         SCHM1344
  445 PRINT 2, J, X(J)                                                  SCHM1346
  446 PRINT 3                                                           SCHM1348
      PRINT 52, (I,H(I,J),F(I,J),P(I,J),H(I,JM1),F(I,JM1),P(I,JM1),     SCHM1350
     1 I=1,NCHANL)                                                      SCHM1360
      PRINT 4                                                           SCHM1365
      PRINT 52, (I,QUAL(I),ALPHA(I),RHO(I,J),  VP(I),V(I),FMULT(I),     SCHM1370
     1 I=1,NCHANL)                                                      SCHM1380
      PRINT 5                                                           SCHM1385
      PRINT 52, (K,W(K,JM1),W(K,J),WP(K),USTAR(K),SP(K,JM1),SP(K,J),    SCHM1390
     1 K=1,NK)                                                          SCHM1400
      PRINT 6                                                           SCHM1405
      PRINT 52,(I,DHDX(I),DFDX(I),DPDX(I),QPRIM(I),FOLD(I,J),RHOOLD(I,J)SCHM1410
     1 ,I=1,NCHANL)                                                     SCHM1420
      IF(IERROR.GT.1) RETURN                                            SCHM1425
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 450 CONTINUE                                                           SCHM1430
      IF(JUMP.EQ.3) RETURN                                              SCHM1440
C  CORRECT SUBCHANNEL PRESSURES TO ZERO EXIT PRESSURE.                  SCHM1450
C  PRESSURE P(I,J) IS THE PRESSURE ABOVE THE EXIT REFERENCE PRESSURE.   SCHM1460
      DO 460 I=1,NCHANL                                                 SCHM1470
      PEXIT = P(I,NDXP1)                                                SCHM1480
      DO 460 J=1,NDXP1                                                  SCHM1490
 460 P(I,J) = P(I,J) - PEXIT                                            SCHM1500
      RETURN                                                            SCHM1510
      END                                                               SCHM1520
*DECK,HEAT
      SUBROUTINE HEAT(J)                                                HEAT0010
C     CALCULATE THE HEAT INPUT TO EACH SUBCHANNEL AT POSITION J.        HEAT0020
C     IF NODES GREATER THAN ZERO, CALCULATE HEAT INPUT USING THERMAL    HEAT0030
C     CONDUCTION. OTHERWISE HEAT INPUT IS DEFINED BY HEAT GENERATION.   HEAT0040
C     POWER = AVERAGE INTERNAL HEAT GENERATION.                         HEAT0050
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEHEAT0060
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    HEAT0070
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    HEAT0080
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       HEAT0090
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          HEAT0100
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        HEAT0110
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           HEAT0120
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       HEAT0130
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   HEAT0140
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              HEAT0150
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   HEAT0160
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  HEAT0170
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               HEAT0180
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             HEAT0190
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                HEAT0200
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             HEAT0210
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        HEAT0220
     2 HPERIM(30), NTYPE(30)                                            HEAT0230
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       HEAT0240
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      HEAT0250
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  HEAT0260
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), HEAT0270
     2 NGAP( 9), BX(30), XQUAL(30)                                      HEAT0280
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          HEAT0290
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            HEAT0300
      LOGICAL FDIV, GRID                                                HEAT0310
      REAL  KIJ, LENGTH, KF, KKF                                        HEAT0320
      REAL KFUEL, KCLAD                                                 HEAT0330
      DIMENSION TDUMY(10)                                               HEAT0340
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         HEAT0350
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,                         HEAT0360
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),                 HEAT0370
     3 PARF(30,35), PHI(35,6), RADIAL(35), D(35),                       HEAT0380
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF                HEAT0390
      NP1 = NODESF+1                                                    HEAT0400
C  BYPASS THE HEAT FLUX CALCULATION IF BEYOND THE FIRST ITERATION AND   HEAT0410
C  IF FUEL TEMPERATURES ARE NOT TO BE CALCULATED.                       HEAT0420
      IF(ITERAT.GT.1 .AND. NODESF.LT.1) GO TO 60                        HEAT0430
C  BYPASS THE HEAT FLUX CALCULATION USING THE FUEL TEMPERATURE MODEL    HEAT0440
C  IF BEYOND THE FIRST ITERATION, AND IF FUEL TEMPERATURES HAVE BEEN    HEAT0450
C  CALCULATED AND IF A TRANSIENT CALCULATION IS BEING PERFORMED.        HEAT0460
      IF(ITERAT.GT.1 .AND. NODESF.GT.0 .AND. DT.LT.100.) GO TO 60       HEAT0470
      CALL CURVE(QAX,(X(J)-DX/2.)/Z,AXIAL,Y,NAX,IERROR,1)               HEAT0480
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C  DETERMINE THE HEAT FLUX FROM EACH ROD.                               HEAT0490
      DO 50 N=1,NROD                                                    HEAT0500
C     CALCULATE FORCED HEAT FLUX FROM EACH ROD.                         HEAT0510
      FLUX(N,J) = AFLUX*RADIAL(N)*QAX*POWER/.0036                       HEAT0520
      IF(NODESF.LT.1) GO TO 50                                          HEAT0530
C  CORRECT HEAT FLUX FOR THERMAL CAPACITY USING TRANSIENT FUEL MODEL.   HEAT0540
C     CALCULATE AVERAGE FLUID TEMPERATURE, HEAT TRANSFER COEFFICIENT.   HEAT0550
      SAVE = 0.                                                         HEAT0560
      TFLUID = 0.                                                       HEAT0570
      HSURF = 0.                                                        HEAT0580
      DO 15 L=1,6                                                       HEAT0590
      IF(LR(N,L)) 15,15,10                                              HEAT0600
   10 I = LR(N,L)                                                       HEAT0610
      DUMY = PHI(N,L)                                                   HEAT0620
      SAVE = SAVE + DUMY                                                HEAT0630
      TFLUID = TFLUID + T(I)*DUMY                                       HEAT0640
      HSURF = HSURF + DUMY*HCOOL(N,I,J-1)                               HEAT0650
      IF(IERROR.GT.1) RETURN                                            HEAT0660
   15 CONTINUE                                                          HEAT0670
      IF(SAVE.LE.0.) GO TO 1000                                         HEAT0680
      TFLUID = TFLUID/SAVE                                              HEAT0690
      HSURF = HSURF/SAVE                                                HEAT0700
C                                                                       HEAT0710
C     CALCULATE FUEL TEMPERATURE                                        HEAT0720
      DO 8 I=1,NP1                                                      HEAT0730
    8 TDUMY(I) = TROD(I,N,J)                                            HEAT0740
      CALL TEMP(TDUMY,DT,N,J)                                           HEAT0750
      IF(IERROR.GT.1) RETURN                                            HEAT0760
      DO 17 I=1,NP1                                                     HEAT0770
   17 TROD(I,N,J) = TDUMY(I)                                            HEAT0780
   20 FLUX(N,J) = HSURF*(TROD(NP1,N,J) - TFLUID)                        HEAT0790
      FLUX(N,J)=AMAX1(0.0,FLUX(N,J))                                    AEL
   50 CONTINUE                                                          HEAT0800
C     CALCULATE HEAT INPUT TO EACH CHANNEL.                             HEAT0810
   60 DO 100 I=1,NCHANL                                                 HEAT0820
      SAVE = 0.                                                         HEAT0830
      DO 90 N=1,NROD                                                    HEAT0840
      DUMY = PWRF(I,N)                                                  HEAT0850
      IF(DUMY.GT.0.) SAVE = SAVE + DUMY*FLUX(N,J)*PI*D(N)               HEAT0860
   90 CONTINUE                                                          HEAT0870
  100 QPRIM(I) = SAVE                                                   HEAT0880
      RETURN                                                            HEAT0890
 1000 IERROR = 14                                                       HEAT0900
      RETURN                                                            HEAT0910
      END                                                               HEAT0920
*DECK,TEMP
      SUBROUTINE TEMP (T,DT,N,JJ)                                       TEMP0010
C     SUBROUTINE TEMP CALCULATES THE TRANSIENT TEMPERATURE DISTRIBUTION TEMP0020
C     IN A CYLINDERICAL OR PLATE NUCLEAR FUEL ELEMENT WHERE THE LARGEST TEMP0030
C     NUMBER NODE IS THE CLADDING.  FOR TRANSIENT CALCULATIONS, FLUID   TEMP0040
C     DATA AT T IS USED TO CALCULATE THE TEMPERATURE AT T+DT BY USING   TEMP0050
C     A STABLE IMPLICIT NUMERICAL TECHNIQUE.                            TEMP0060
C     SIMULTANEOUS EQUATIONS ARE SOLVED USING A COMPACT ELIMINATION     TEMP0070
C     SCHEME FOR TRI-DIAGONAL MATRICES.                                 TEMP0080
C                                                                       TEMP0090
C     THE VALUE OF T UPON ENTRY IS THE TEMPERATURE AT ORIGINAL TIME.    TEMP0100
C     AT EXIT T IS THE TEMPERATURE DELTA-T LATER IN TIME.               TEMP0110
C                                                                       TEMP0120
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         TEMP0130
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     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF
      DIMENSION T(10), A(3,10), B(10)
      REAL KFUEL, KFDR2, KCLAD
C
C     SETUP A MATRIX OF THE FORM   A*T=B WHERE ONLY THE 3 DIAGONALS OF
C     A ARE STORED.
      NM1 = NODESF-1
      NP1 = NODESF+1
      IF(NODESF.LE.0) GO TO 1000
      J = IDFUEL(N)
      DR = DFUEL(J)*.5/FLOAT(NM1)
      DR2 = DR**2
      RCFUEL = RFUEL(J)*CFUEL(J)/DT
      KFDR2  = KFUEL(J)/DR2
      HGAP1 = 1./(1./HGAP(J) + TCLAD(J)/KCLAD(J))
      QCLAD = 0.
C  J IS THE FUEL TYPE CODE.  CYLINDERICAL FUEL, J=1.  PLATE FUEL, J=2.
      IF(J.EQ.2) GO TO 101
C
C  THIS SECTION FOR CYLIDERICAL FUEL RODS.
      QFUEL = FLUX(N,JJ)*4.*D(N)/DFUEL(J)**2
      DO 100 I=1,NP1
      IF(I.GT.1) GO TO 10
      A(2,I) = RCFUEL + 4.*KFDR2
      A(3,I) = -4.*KFDR2
      GO TO 80
   10 IF(I.GT.NM1) GO TO 20
      A(1,I) = -KFDR2*(1.-1./FLOAT(2*I-2))
      A(2,I) = RCFUEL + 2.*KFDR2
      A(3,I) = -KFDR2*(1.+1./FLOAT(2*I-2))
      GO TO 80
   20 IF(I.EQ.NP1) GO TO 30
      A(1,I) = -2.*KFDR2
      A(2,I) = RCFUEL + 2.*KFDR2 + 2.*HGAP1/DR + HGAP1/DR/FLOAT(I-1)
      A(3,I) = -(2.*HGAP1/DR + HGAP1/DR/FLOAT(I-1))
      GO TO 80
   30 A(1,I) = -HGAP1/TCLAD(J)*DFUEL(J)/D(N)
      A(2,I) = RCLAD(J)*CCLAD(J)/DT + HGAP1/TCLAD(J)*DFUEL(J)/D(N)
     1 + HSURF/TCLAD(J)
   80 IF(I.EQ.NP1) GO TO 90
      B(I) = QFUEL + RCFUEL*T(I)
      GO TO 100
   90 B(I) = QCLAD + RCLAD(J)*CCLAD(J)/DT*T(I) + HSURF/TCLAD(J)*TFLUID
  100 CONTINUE
C     SOLVE FOR TEMPERATURES
      CALL GAUSS(1,NP1,A,B,T)
      RETURN
C
C  THIS SECTION FOR FLAT PLATE FUEL.
  101 QFUEL = FLUX(N,JJ)*2./DFUEL(J)
      DO 200 I=1,NP1
      IF(I.GT.1) GO TO 110
      A(2,I) = RCFUEL + KFDR2*2.
      A(3,I) = -2.*KFDR2
      GO TO 180
  110 IF(I.GT.NM1) GO TO 120
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      A(1,I) = -KFDR2                                                   TEMP0730
      A(2,I) = RCFUEL + 2.*KFDR2                                        TEMP0740
      A(3,I) = -KFDR2                                                   TEMP0750
      GO TO 180                                                         TEMP0760
  120 IF(I.EQ.NP1) GO TO 130                                            TEMP0770
      A(1,I) = -2.*KFDR2                                                TEMP0780
      A(2,I) = RCFUEL + 2.*KFDR2 + 2.*HGAP1/DR                          TEMP0790
      A(3,I) = -2.*HGAP1/DR                                             TEMP0800
      GO TO 180                                                         TEMP0810
  130 A(1,I) = -HGAP1/TCLAD(J)                                          TEMP0820
      A(2,I) =  RCLAD(J)*CCLAD(J)/DT + HGAP1/TCLAD(J) + HSURF/TCLAD(J)  TEMP0830
  180 IF(I.EQ.NP1) GO TO 190                                            TEMP0840
      B(I) = QFUEL + RCFUEL*T(I)                                        TEMP0850
      GO TO 200                                                         TEMP0860
  190 B(I) = QCLAD + RCLAD(J)*CCLAD(J)/DT*T(I) + HSURF/TCLAD(J)*TFLUID  TEMP0870
  200 CONTINUE                                                          TEMP0880
C     SOLVE FOR TEMPERATURES                                            TEMP0890
      CALL GAUSS(1,NP1,A,B,T)                                           TEMP0900
      RETURN                                                            TEMP0910
 1000 IERROR = 15                                                       TEMP0920
      RETURN                                                            TEMP0930
      END                                                               TEMP0940
*DECK,HCOOL
      FUNCTION HCOOL(N,I,J)                                             HCOL0010
C  COMPUTES THE HEAT TRANSFER COEFFICIENT FOR ROD N FACING SUBCHANNEL I HCOL0020
C  AT AXIAL LOCATION J.                                                 HCOL0030
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEHCOL0040
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    HCOL0050
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    HCOL0060
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       HCOL0070
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          HCOL0080
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)         HCOL0090
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           HCOL0100
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       HCOL0110
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   HCOL0120
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              HCOL0130
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   HCOL0140
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  HCOL0150
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               HCOL0160
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             HCOL0170
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                HCOL0180
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             HCOL0190
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        HCOL0200
     2 HPERIM(30), NTYPE(30)                                            HCOL0210
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       HCOL0220
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      HCOL0230
      COMMON  AXIAL(39), Y(39), IDAPEA(30), IDGAP(47), AA( 4), BB( 4),  HCOL0240
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), HCOL0250
     2 NGAP( 9), BX(30), XQUAL(30)                                      HCOL0260
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          HCOL0270
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            HCOL0280
      LOGICAL FDIV, GRID                                                HCOL0290
      REAL  KIJ, LENGTH, KF, KKF                                        HCOL0300
C   THIS IS ONLY A DUMY ROUTINE AT THIS TIME PENDING SELECTION OF       HCOL0310
C   HEAT TRANSFER CORRELATIONS.  USERS SHOULD PROVIDE THEIR OWN CORRELATHCOL0320
C   HCOOL = SURFACE HEAT TRANSFER COEFFICIENT (BTU/SEC-FT2-F).          HCOL0330
      REAL KFUEL, KCLAD                                                 HCOL0340
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         HCOL0350
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,                         HCOL0360
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     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF
      IF(NODESF.LE.0) GO TO 1000
      HCOOL = 5000./3600.
      RETURN
 1000 IERROR = 16
      RETURN
      END
*DECK,CHF
      SUBROUTINE CHF(JSTART,JEND)
C   CHF SEARCHES COBRA-IIIC OUTPUT AT THE END OF EACH TIME STEP FOR
C   THE OCCURANCE OF CRITICAL HEAT FLUX.  THE SEARCH IS MADE ON EACH ROD
C   AT A SPECIFIED AXIAL LOCATION RANGE BY CONSIDERING EACH ROD AND THE
C   ADJACENT CHANNELS.
C   ALTHOUGH THE BAW-2 AND W-3 CORRELATIONS ARE INCLUDED, USERS SHOULD
C   PROGRAM OTHER CORRELATIONS OF THEIR CHOICE AS OPTIONS.
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),
     2 HPERIM(30), NTYPE(30)
      COMMON  P(30,31), H(30,31), F(30,31), X(31)
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10),
     2 NGAP( 9), BX(30), XQUAL(30)
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)
      LOGICAL FDIV, GRID
      REAL  KIJ, LENGTH, KF, KKF
      COMMON /BOIL/ JBOIL(30)
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF
      COMMON/BCHF/ CHFR(35,31), CCHANL(35,31), MCHFR(31), MCHFRC(31),
     1 MCHFRR(31),NCHF
      INTEGER  CCHANL
      INTEGER  CHFROD
      REAL MCHFR
      NDXP1 = NDX + 1
      DO 100 J=1,NDXP1
      MCHFR(J) = 10.
      MCHFRC(J) = 0
      MCHFRR(J) = 0
      DO 100 N=1,NROD
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      CHFR(N,J) = 10.                                                   CHF0500
      CCHANL(N,J) = 0                                                   CHF0510
  100 CONTINUE                                                          CHF0520
      DO 500 J=JSTART,JEND                                              CHF0530
      CHFROD = 0                                                        CHF0540
      DO 300 N=1,NROD                                                   CHF0550
      XMCHFR = 10.                                                      CHF0560
      IF(FLUX(N,J).LE.0.) GO TO 300                                     CHF0570
      DO 290 L=1,6                                                      CHF0580
      IF(LR(N,L)) 200,290,200                                           CHF0590
C  CALCULATE CHF RATIO FOR ROD N FACING CHANNEL I.                      CHF0600
  200 I = LR(N,L)                                                       CHF0610
      XCHF = 0.                                                         CHF0620
      IF(NCHF.EQ.1) XCHF = CHF1(N,I,J)                                  CHF0630
      IF(NCHF.EQ.2) XCHF = CHF2(N,I,J)                                  CHF0640
      IF(XCHF.LE.0.) GO TO 1000                                         CHF0650
      XCHFR = XCHF/FLUX(N,J)                                            CHF0660
C  CALCULATE MINIMUM CHF RATIO FOR ROD N FACING CHANNEL I.              CHF0670
      IF(XCHFR.GT.CHFR(N,J)) GO TO 290                                  CHF0680
      CHFR(N,J) = XCHFR                                                 CHF0690
      CCHANL(N,J) = I                                                   CHF0700
      CHFROD = N                                                        CHF0710
  290 CONTINUE                                                          CHF0720
C  DETERMINE MINIMUM CHF RATIO AT AXIAL LOCATION J.                     CHF0730
      XMCHFR = CHFR(N,J)                                                CHF0740
      IF(XMCHFR.GT.MCHFR(J)) GO TO 300                                  CHF0750
      MCHFR(J) = XMCHFR                                                 CHF0760
      MCHFRR(J) = CHFROD                                                CHF0770
      MCHFRC(J) = CCHANL(N,J)                                           CHF0780
  300 CONTINUE                                                          CHF0790
  500 CONTINUE                                                          CHF0800
      RETURN                                                            CHF0810
 1000 PRINT 1                                                           CHF0820
    1 FORMAT (' ERROR IN CHF ROUTINE')                                  CHF0830
      RETURN                                                            CHF0840
      END                                                               CHF0850
*DECK,CHF1
      FUNCTION CHF1(N,I,J)                                             CHF10010
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,   CHF10011
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,      CHF10012
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,         CHF10013
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)       CHF10014
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP          CHF10015
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),      CHF10016
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,  CHF10017
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                             CHF10018
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),  CHF10019
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30), CHF10020
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)              CHF10021
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),            CHF10022
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)               CHF10023
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),            CHF10024
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                       CHF10025
     2 HPERIM(30), NTYPE(30)                                           CHF10026
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                      CHF10027
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)     CHF10028
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4), CHF10029
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), CHF10030
     2 NGAP( 9), BX(30), XQUAL(30)                                     CHF10031
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      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          CHF10032
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            CHF10033
      LOGICAL FDIV, GRID                                                CHF10034
      REAL KIJ, LENGTH, KF, KKF, KD                                     CHF10035
      COMMON/BOIL/ JBOIL(30)                                            CHF10036
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         CHF10037
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,                         CHF10038
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),                 CHF10039
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),                       CHF10040
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF                CHF10041
C  BAW-2 CHF CORRELATION                                                CHF10042
      DATA A0, B0,A1,A2,A3,A4,A5,A6,A7,A8,A9 / 1.15509, 4.8844,         CHF10043
     1 0.3702E+8, 2.1289E-3, 0.83040, 0.68479E-3, 4.5756E+4, 1.0996E-2, CHF10044
     2 0.71186, 0.20729E-3, 547.49/                                     CHF10050
      DATA  A21,A22,A23,KD /  2.9840, 7.82293, 0.45758, 1.02508 /       CHF10070
      DE = 4.*A(I)/PERIM(I)                                             CHF10080
      XX = (H(I,J)-HF)/HFG                                              CHF10090
      CHF1  = (A0-B0*DE)*(A1*(A2*F(I,J)/A(I))**(A3+A4*(PREF-2000.))     CHF10100
     1 - A9*F(I,J)/A(I)*XX*HFG)/(A5*(A6*F(I,J)/A(I))**(A7+A8*(PREF-     CHF10110
     2  2000.)))                                                        CHF10120
C  AXIAL FLUX CORRECTION FACTOR                                         CHF10130
      FAXIAL = 1.                                                       CHF10140
      IF(J.EQ.1) GO TO 10                                               CHF10150
      C = A21*(1.-XX)**A22/(F(I,J)/A(I)*.0036)**A23                     CHF10160
      SUM = 0.                                                          CHF10170
      JS = 2                                                            CHF10180
      DO 5 JJ=JS,J                                                      CHF10190
    5 SUM = SUM + FLUX(N,JJ)*(EXP(C*X(JJ))-EXP(C*X(JJ-1)))              CHF10200
      FAXIAL = SUM*EXP(-C*X(J))/FLUX(N,J)/                              CHF10210
     1 (1.-EXP(-C*(X(J)-X(JS-1))))*KD                                   CHF10220
   10 CHF1 = CHF1/FAXIAL                                                CHF10230
      RETURN                                                            CHF10240
      END                                                               CHF10250
*DECK,CHF2
      FUNCTION CHF2(N,I,J)                                              CHF20010
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    CHF20011
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       CHF20012
     2 NAFACT, NODES, NSCBC, NBRC, J1, J2, J3, J4, J5, J6, J7,          CHF20013
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        CHF20014
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           CHF20015
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       CHF20016
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   CHF20017
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              CHF20018
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   CHF20019
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  CHF20020
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               CHF20021
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             CHF20022
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                CHF20023
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             CHF20024
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        CHF20025
     2 HPERIM(30), NTYPE(30)                                            CHF20026
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       CHF20027
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      CHF20028
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  CHF20029
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), CHF20030
     2 NGAP( 9), BX(30), XQUAL(30)                                      CHF20031
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          CHF20032
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            CHF20033
      LOGICAL FDIV, GRID                                                CHF20034
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      REAL  KIJ, LENGTH, KF, KKF                                        CHF20035
      COMMON /BOIL/ JBOIL(30)                                           CHF20036
      COMMON /FUEL/ KFUEL( 3), KCLAD( 3), RFUEL( 3), RCLAD( 3),         CHF20037
     1 CFUEL( 3), CCLAD( 3), TCLAD( 3), TFLUID,                         CHF20038
     2 FLUX(35,31), HGAP( 3), TROD(10,35,31), LR(35,6),                 CHF20039
     3 PWRF(30,35), PHI(35,6), RADIAL(35), D(35),                       CHF20040
     4 POWER, NODESF, NROD, DFUEL( 3), IDFUEL(35), HSURF                CHF20041
C  W-3 CORRELATION INCLUDING, SPACER FACTOR, UNHEATED WALL CORRECTION.  CHF20042
C AXIAL FLUX FACTOR                                                     CHF20043
C REEFERENCE, LS TONG, BOILING CRISIS AND CRYTICAL HEAT FLUX            CHF20044
C    AEC CRITICAL REVIEW SERIES,TID-25887(1972).                        CHF20050
      DE =4.*A(I)/PERIM(I)                                              CHF20060
      DH = 4.*A(I)/HPERIM(I)                                            CHF20070
      RU = 1.-DE/DH                                                     CHF20080
      XX = (H(I,J)-HF)/HFG                                              CHF20090
C  W-3 CORRELATION USING EQUILIBRIUM STEAM QUALITY                      CHF20100
      CHF2    = ((2.022 - 0.0004302*PREF) + (0.1722 - 0.0000984*PREF)   CHF20110
     1 *EXP((18.2 - 0.004129*PREF)*XX))                                 CHF20120
     2 *((0.1484 - 1.596*XX + 0.1729*XX*ABS(XX))*F(I,J)/A(I)            CHF20130
     3 *.0036 + 1.037)                                                  CHF20140
     4 *(1.157 - 0.869*XX)                                              CHF20150
     5 *(0.2664 + 0.8357*EXP(-37.812*DH))                               CHF20160
     6 *(0.8258 + 0.000794*(HF-HINLET(I)))/.0036                        CHF20170
C  UNHEATED WALL CORRECTION                                             CHF20180
      IF(RU.GT.0.) CHF2 = CHF2*(1. - RU*(13.76-1.372*EXP(1.78*XX)       CHF20190
     1-4.732/(F(I,J)/A(I)*.0036)**.0575-.619*(PREF/1000.)**.14          CHF20200
     2-102.11*DH**.107))                                                CHF20210
C  SPACER FACTOR CORRECTION                                             CHF20220
C  USER SHOULD SELECT PROPER VALUE OF TDC                               CHF20230
      TDC = .000                                                        CHF20240
      IF(NGRID.GT.0) CHF2 = CHF2                                        CHF20250
     1 *(1.0 + 0.03*F(I,J)/A(I)*.0036 * (TDC/0.019)**.35)               CHF20260
C  AXIAL FLUX PROFILE CORRECTION                                        CHF20270
      FAXIAL = 1.                                                       CHF20280
      IF(J.LE.JBOIL(I)) GO TO 10                                        CHF20290
      C =  1.8*(1.-XX)**4.31/(F(I,J)/A(I)*.0036)**.478                  CHF20300
      SUM = 0.                                                          CHF20310
      JS = JBOIL(I)+1                                                   CHF20320
      DO 5 JJ=JS,J                                                      CHF20330
    5 SUM = SUM + FLUX(N,JJ)*(EXP(C*X(JJ))-EXP(C*X(JJ-1)))              CHF20340
      FAXIAL = SUM*EXP(-C*X(J))/FLUX(N,J)/                              CHF20350
     1 (1.-EXP(-C*(X(J)-X(JS-1))))                                      CHF20360
   10 CHF2 = CHF2/FAXIAL                                                CHF20370
      RETURN                                                            CHF20380
      END                                                               CHF20390
*DECK,GAUSS
      SUBROUTINE GAUSS (N,M,A,B,T)                                      GAUS0010
C     SUBROUTINE SOLVES TRIDIAGONAL MATRIX BY GAUSS ELIMINATION         GAUS0020
      DIMENSION A(3,10), B(10), T(10)                                   GAUS0030
      MM          = M-1                                                 GAUS0040
      DO  10 K    = N,MM                                                GAUS0050
      AK          = A(1,K+1)/A(2,K)                                     GAUS0060
      A(2,K+1)    = A(2,K+1)-A(3,K)*AK                                  GAUS0070
   10 B(K+1)      = B(K+1)-B(K)*AK                                      GAUS0080
      T(M)        = B(M)/A(2,M)                                         GAUS0090
      DO  20 K    = N,MM                                                GAUS0100
      L           = MM-K+N                                              GAUS0110
   20 T(L)        = (B(L)-A(3,L)*T(L+1))/A(2,L)                         GAUS0120
      RETURN                                                            GAUS0130
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      END                                                               GAUS0140
*DECK,DIFFER
      SUBROUTINE DIFFER(IPART,J)                                        DIFF0010
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEDIFF0020
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    DIFF0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    DIFF0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       DIFF0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          DIFF0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        DIFF0070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           DIFF0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       DIFF0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   DIFF0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              DIFF0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   DIFF0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  DIFF0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               DIFF0140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             DIFF0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                DIFF0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             DIFF0170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        DIFF0180
     2 HPERIM(30), NTYPE(30)                                            DIFF0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       DIFF0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      DIFF0210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  DIFF0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), DIFF0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      DIFF0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          DIFF0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            DIFF0260
      LOGICAL FDIV, GRID                                                DIFF0270
      REAL  KIJ, LENGTH, KF, KKF                                        DIFF0280
      COMMON /DP/ DPK(30)                                               DIFF0290
      JM1 = J-1                                                         DIFF0300
      NKK = NK                                                          DIFF0310
      NCHAN = NCHANL                                                    DIFF0320
      IF(IPART.LT.1 .OR. IPART.GT.4) GO TO 1000                         DIFF0330
      GO TO (100,200,300,400),IPART                                     DIFF0340
C                                                                       DIFF0350
C  PART 1. CALCULATE DH/DX FOR STEADY STATE AT X AND T.                 DIFF0360
CC    IF(J.EQ.1) FLOWSQ = F(I,1)**2                                     DIFF0365
  100 DO 190 I=1,NCHAN                                                  DIFF0370
      SAVE = 0.                                                         DIFF0380
      DO 170 K=1,NKK                                                    DIFF0390
      SKI = S(K,I)                                                      DIFF0400
      IF(SKI) 120,170,120                                               DIFF0410
  120 II = IK(K)                                                        DIFF0420
      JJ = JK(K)                                                        DIFF0430
      HSTAR = H(II,J)                                                   DIFF0440
      IF(W(K,J).LT.0.) HSTAR = H(JJ,J)                                  DIFF0450
      DUMY = SKI*((H(JJ,J)-H(II,J))*WP(K) + (H(I,J)-HSTAR)*W(K,J)       DIFF0460
     1 + (T(JJ)-T(II))*COND(K))                                         DIFF0470
      SAVE = SAVE + DUMY                                                DIFF0480
  170 CONTINUE                                                          DIFF0490
      DHDX(I) = (SAVE + QPRIM(I))/F(I,J)                                DIFF0500
  190 CONTINUE                                                          DIFF0510
      GO TO 500                                                         DIFF0520
C                                                                       DIFF0530
C  PART 2. CALCULATE DF/DX FOR STEADY STATE AT X AND T                  DIFF0540
  200 DO 290 I=1,NCHAN                                                  DIFF0550
      SAVE = 0.                                                         DIFF0560
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      DO 270 K=1,NKK                                                    DIFF0570
      IF(S(K,I)) 220,270,230                                            DIFF0580
  220 SAVE = SAVE + W(K,J)                                              DIFF0590
      GO TO 270                                                         DIFF0600
  230 SAVE = SAVE - W(K,J)                                              DIFF0610
  270 CONTINUE                                                          DIFF0620
      DFDX(I) = SAVE                                                    DIFF0630
  290 CONTINUE                                                          DIFF0640
      GO TO 500                                                         DIFF0650
C                                                                       DIFF0660
C   PART 3, CALCULATE DP/DX WITHOUT W                                   DIFF0670
  300 DO 390 I=1,NCHAN                                                  DIFF0680
      SAVE = .5*FSP(I)*FMULT(I)*V(I)/DHYD(I)                            DIFF0690
     1 + (VP(I)/A(I)-VPA(I))*A(I)/DX                                    DIFF0700
      IF(.NOT.GRID) GO TO 310                                           DIFF0710
      IF(NRAMP.LE.0) GO TO 1000                                         DIFF0720
      DUMY = FLOAT(ITERAT)/FLOAT(NRAMP)                                 DIFF0730
      IF(DUMY.GT.1.) DUMY = 1.                                          DIFF0740
      SAVE = SAVE + .5*DUMY*CD(I,NGTYPE)*VP(I)/DX                       DIFF0750
  310 DPK(I) = SAVE/A(I)/A(I)                                           DIFF0760
      DUMY = 0.                                                         DIFF0770
      IF(FTM.LE.0.) GO TO 380                                           DIFF0780
      DO 370 K=1,NKK                                                    DIFF0790
      SKI = S(K,I)                                                      DIFF0800
      IF(SKI) 320,370,320                                               DIFF0810
  320 II = IK(K)                                                        DIFF0820
      JJ = JK(K)                                                        DIFF0830
      DUMY = DUMY + SKI*(U(II)-U(JJ))*WP(K)                             DIFF0840
  370 CONTINUE                                                          DIFF0850
  380 FLOWSQ = ABS(F(I,JM1))*F(I,JM1)                                   DIFF0860
      IF(J.EQ.1) FLOWSQ = F(I,1)**2                                     DIFF0865
      DPDX(I) = -DPK(I)*FLOWSQ/GC                                       DIFF0870
     1 - RHO(I,J)*ELEV - DUMY/A(I)/GC*FTM                               DIFF0880
      IF(DT.GT.100.) GO TO 390                                          DIFF0900
      RHODOT = (RHO(I,J)-RHOOLD(I,J))/DT                                DIFF0910
      DPDX(I) = DPDX(I) + RHODOT/GC*(2.*U(I)+DX/DT                      DIFF0920
     1 + DPK(I)*ABS(F(I,JM1)+F(I,J))*A(I)*DX)                           DIFF0930
     2 + (FOLD(I,J)-F(I,JM1))/A(I)/DT/GC                                DIFF0940
  390 CONTINUE                                                          DIFF0950
      GO TO 500                                                         DIFF0960
C                                                                       DIFF0970
C   PART 4, CALCULATE DP/DX WITH W                                      DIFF0980
  400 DO 490 I=1,NCHAN                                                  DIFF0990
      DUMY = 0.                                                         DIFF1000
      IF(J.EQ.1) GO TO 480                                              DIFF1010
      DO 470 K=1,NKK                                                    DIFF1020
      IF(S(K,I)) 420,470,430                                            DIFF1030
  420 DUMY = DUMY + ((2.*U(I)-USTAR(K)+DX/DT)/A(I)                      DIFF1040
     1 + DPK(I)*ABS(F(I,JM1)+F(I,J))*DX)*W(K,J)                         DIFF1050
      GO TO 470                                                         DIFF1060
  430 DUMY = DUMY - ((2.*U(I)-USTAR(K)+DX/DT)/A(I)                      DIFF1070
     1 + DPK(I)*ABS(F(I,JM1)+F(I,J))*DX)*W(K,J)                         DIFF1080
  470 CONTINUE                                                          DIFF1090
  480 DPDX(I) = DPDX(I) - DUMY/GC                                       DIFF1100
  490 CONTINUE                                                          DIFF1110
  500 RETURN                                                            DIFF1120
 1000 IERROR = 2                                                        DIFF1130
      RETURN                                                            DIFF1140
      END                                                               DIFF1150
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*DECK,DIVERT
      SUBROUTINE DIVERT(J)                                              DVRT0010
C     THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEDVRT0020
C     MAJOR SUBROUTINES OF COBRA-IIIC.                                  DVRT0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    DVRT0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       DVRT0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          DVRT0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)         DVRT0070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           DVRT0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       DVRT0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   DVRT0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              DVRT0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   DVRT0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  DVRT0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               DVRT0140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             DVRT0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                DVRT0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             DVRT0170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        DVRT0180
     2 HPERIM(30), NTYPE(30)                                            DVRT0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       DVRT0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      DVRT0210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  DVRT0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), DVRT0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      DVRT0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          DVRT0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            DVRT0260
      LOGICAL FDIV, GRID                                                DVRT0270
      REAL  KIJ, LENGTH, KF, KKF                                        DVRT0280
      COMMON /BUL/ AAA(47,47), ANSWER(47), B(47), IPS(47)               DVRT0290
      COMMON /BSP/ SP(47,31)                                            DVRT0300
      COMMON /DP/ DPK(30)                                               DVRT0310
      DIMENSION USAVE(47)                                               DVRT0320
      NKK = NK                                                          DVRT0330
      NCHAN = NCHANL                                                    DVRT0340
      JM1 = J-1                                                         DVRT0350
      SLDX = SL*DX                                                      DVRT0360
      DTGC = DT*GC                                                      DVRT0370
      DXGC = DX*GC                                                      DVRT0380
C   CALCULATE USTAR                                                     DVRT0390
      DO 5 K=1,NKK                                                      DVRT0400
      II = IK(K)                                                        DVRT0410
      JJ = JK(K)                                                        DVRT0420
      USAVE(K) = USTAR(K)                                               DVRT0430
      USTAR(K) = .5*(U(II)+U(JJ))                                       DVRT0440
    5 CONTINUE                                                          DVRT0450
C   SET UP THE SIMULTANEOUS EQUATIONS                                   DVRT0460
      DO 80 K=1,NKK                                                     DVRT0470
      DO 60 L=1,NKK                                                     DVRT0480
      SAVE = 0.                                                         DVRT0490
      DO 50 I=1,NCHAN                                                   DVRT0500
      IF(S(K,I)) 10,50,20                                               DVRT0510
   10 IF(S(L,I)) 30,50,40                                               DVRT0520
   20 IF(S(L,I)) 40,50,30                                               DVRT0530
   30 SAVE = SAVE + (2.*U(I)-USTAR(L)+DX/DT)/A(I)                       DVRT0540
     1 + DPK(I)*ABS(F(I,JM1)+F(I,J))*DX                                 DVRT0550
      GO TO 50                                                          DVRT0560
   40 SAVE = SAVE - (2.*U(I)-USTAR(L)+DX/DT)/A(I)                       DVRT0570
     1 - DPK(I)*ABS(F(I,JM1)+F(I,J))*DX                                 DVRT0580
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   50 CONTINUE                                                          DVRT0590
      AAA(K,L) = SAVE*SLDX/GC*FACTOR(L)                                 DVRT0600
   60 CONTINUE                                                          DVRT0610
      II = IK(K)                                                        DVRT0620
      JJ = JK(K)                                                        DVRT0630
      B(K) = (SP(K,J) - (DPDX(II)-DPDX(JJ))*DX)*SL*FACTOR(K)            DVRT0640
     1 + USAVE(K)*W(K,JM1)/DXGC + WOLD(K,J)/DTGC                        DVRT0650
      AAA(K,K) = AAA(K,K) + SL*CIJ(K,J)*FACTOR(K)                       DVRT0660
     1 + USTAR(K)/DXGC + 1./DTGC                                        DVRT0670
   80 CONTINUE                                                          DVRT0680
      IF(J6.LT.1) GO TO 105                                             DVRT0690
C                                                                       DVRT0700
C     MODIFY SIMULTANEOUS EQUATIONS TO ACCOUNT FOR SPECIFIED VALUES OF  DVRT0710
C     CROSSFLOW GIVEN IN SUBROUTINE FORCE                               DVRT0720
C                                                                       DVRT0730
      DO 90 K=1,NK                                                      DVRT0740
      IF(FDIV(K)) GO TO 90                                              DVRT0750
      DO 85 L=1,NK                                                      DVRT0760
      IF(L.EQ.K) GO TO 85                                               DVRT0770
      IF(FDIV(L)) B(K) = B(K) - AAA(K,L)*W(L,J)                         DVRT0780
   85 CONTINUE                                                          DVRT0790
   90 CONTINUE                                                          DVRT0800
      DO 100 K=1,NK                                                     DVRT0810
      IF(.NOT.FDIV(K)) GO TO 100                                        DVRT0820
      DO 95 L=1,NK                                                      DVRT0830
      AAA(K,L) = 0.                                                     DVRT0840
   95 AAA(L,K) = 0.                                                     DVRT0850
      AAA(K,K) = 1.                                                     DVRT0860
      B(K) = W(K,J)                                                     DVRT0870
  100 CONTINUE                                                          DVRT0880
  105 IF(KDEBUG.LT.1) GO TO 110                                         DVRT0890
      PRINT 2, ((AAA(K,L),L=1,NKK),B(K),K=1,NKK)                        DVRT0900
    2 FORMAT(7E14.7)                                                    DVRT0910
  110 CALL DECOMP(NKK,IERROR)                                           DVRT0920
      IF(IERROR.GT.1) GO TO 1000                                        DVRT0930
      CALL SOLVE(NKK)                                                   DVRT0940
      DO 150 K=1,NKK                                                    DVRT0950
  150 W(K,J) = ANSWER(K)                                                DVRT0960
      RETURN                                                            DVRT0970
 1000 PRINT 1                                                           DVRT0980
    1 FORMAT(24H ERROR IN DECOMP, DIVERT  )                             DVRT0990
      IERROR = 3                                                        DVRT1000
      RETURN                                                            DVRT1010
      END                                                               DVRT1020
*DECK,PROP
      SUBROUTINE PROP(IPART,J)                                          PROP0010
C     THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEPROP0020
C     MAJOR SUBROUTINES OF COBRA-IIIC.                                  PROP0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    PROP0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       PROP0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          PROP0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        PROP0070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           PROP0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       PROP0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   PROP0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              PROP0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   PROP0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  PROP0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               PROP0140
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      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             PROP0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                PROP0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             PROP0170
     1 DHDX(30), DPDX(30), OPRIM(30), PERIM(30),                        PROP0180
     2 HPERIM(30), NTYPE(30)                                            PROP0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       PROP0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      PROP0210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  PROP0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), PROP0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      PROP0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          PROP0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            PROP0260
      LOGICAL FDIV, GRID                                                PROP0270
      REAL  KIJ, LENGTH, KF, KKF                                        PROP0280
      COMMON /BOIL/ JBOIL(30)                                           PROP0285
    1 FORMAT(28H REYNOLDS NUMBER IN CHANNEL ,I2,19H IS TOO LOW.  RE = , PROP0290
     1 E10.4 )                                                          PROP0300
    5 FORMAT(60H FAILURE OF SUBROUTINE PROP, PRESSURE TOO LOW FOR TABLE PROP0310
     1P =    E12.5 /(10E10.4))                                          PROP0320
    6 FORMAT(61H FAILURE OF SUBROUTINE PROP, PRESSURE TOO HIGH FOR TABLEPROP0330
     1 P =    E12.5 /(10E10.4))                                         PROP0340
    7 FORMAT(40H TABLE LOOKUP FAILED IN SUBROUTINE PROP   )             PROP0350
      NPROP = NPROP                                                     PROP0360
      IF(IPART.LT.1 .OR. IPART.GT.2) GO TO 1001                         PROP0370
      GO TO (9,100),IPART                                               PROP0380
C                                                                       PROP0390
C   PART 1. CALCULATION OF SATURATATED PROPERTIES                       PROP0400
    9 DO 10 I=1,NPROP                                                   PROP0410
      IF(PREF.LT.PP(I)) GO TO 20                                        PROP0420
   10 CONTINUE                                                          PROP0430
      GO TO 200                                                         PROP0440
   20 IF(I.GT.1) GO TO 40                                               PROP0450
      GO TO 210                                                         PROP0460
   40 VALUE = (PREF-PP(I-1))/(PP(I)-PP(I-1))                            PROP0470
      HF     =     HHF(I-1) + VALUE*(    HHF(I)-    HHF(I-1))           PROP0480
      HG     =     HHG(I-1) + VALUE*(    HHG(I)-    HHG(I-1))           PROP0490
      VF     =     VVF(I-1) + VALUE*(    VVF(I)-    VVF(I-1))           PROP0500
      VG     =     VVG(I-1) + VALUE*(    VVG(I)-    VVG(I-1))           PROP0510
      UF     =     UUF(I-1) + VALUE*(    UUF(I)-    UUF(I-1))           PROP0520
      TF     =      TT(I-1) + VALUE*(     TT(I)-     TT(I-1))           PROP0530
      KF     =     KKF(I-1) + VALUE*(    KKF(I)-    KKF(I-1))           PROP0540
      SIGMA = SSIGMA(I-1) + VALUE*(SSIGMA(I)-SSIGMA(I-1))               PROP0550
      HFG = HG-HF                                                       PROP0560
      VFG = VG-VF                                                       PROP0570
      RHOG = 1./VG                                                      PROP0580
      RHOF = 1./VF                                                      PROP0590
      RETURN                                                            PROP0600
C                                                                       PROP0610
C   PART 2. CALCULATE LIQUID PROPERTIES AND PARAMETERS                  PROP0620
  100 NCHAN = NCHANL                                                    PROP0630
      IF(J.GT.1) GO TO 102                                              PROP0640
      DO 101 I=1,NCHAN                                                  PROP0644
  101 JBOIL(I) = 0                                                      PROP0645
  102 DO 150 I=1,NCHAN                                                  PROP0646
      VISCW(I) = UF                                                     PROP0650
      VISC(I) = UF                                                      PROP0660
      T(I) = TF                                                         PROP0670
      CON(I) = KF                                                       PROP0680
      V(I) = VF                                                         PROP0690
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      HH = H(I,J)                                                       PROP0700
      IF(HH.GT.HF) GO TO 105                                            PROP0710
      CALL CURVE (VISC(I),HH,UUF,HHF,NPROP,IERROR,1)                    PROP0720
      IF(IERROR.GT.1) GO TO 1000                                        PROP0730
      CALL CURVE (V(I),HH,VVF,HHF,NPROP,IERROR,2)                       PROP0740
      CALL CURVE (T(I),HH,TT,HHF,NPROP,IERROR,2)                        PROP0750
      CALL CURVE (CON(I),HH,KKF,HHF,NPROP,IERROR,2)                     PROP0760
  105 TM = T(I)-1.                                                      PROP0770
      CALL CURVE (HM,TM,HHF,TT,NPROP,IERROR,1)                          PROP0780
      IF(IERROR.GT.1) GO TO 1000                                        PROP0790
      CP(I) = HH-HM                                                     PROP0800
      IF(HH.GT.HF) CP(I) = HF-HM                                        PROP0810
      VISC(I) = VISC(I)/3600.                                           PROP0820
      CON(I) = CON(I)/3600.                                             PROP0840
      RE = F(I,J)/A(I)*DHYD(I)/VISC(I)                                  PROP0850
      IF(RE.LT.0.) PRINT 1, I,RE                                        PROP0860
      IF(RE.LT.2000.) RE = 2000.                                        PROP0870
      PR = CP(I)*VISC(I)/CON(I)                                         PROP0880
      IF(H(I,J).GT.HF) GO TO 120                                        PROP0890
      HFILM(I) = 0.023*CON(I)/DHYD(I)*RE**.8*PR**.4                     PROP0900
      DTWALL = QPRIM(I)/HPERIM(I)/HFILM(I)                              PROP0910
C  DETERMINE THE START OF NUCLEATE BOILING                              PROP0920
      IF(JBOIL(I).GT.0) GO TO 110                                       PROP0930
      TLBOIL = TF - DTWALL + 60.*EXP(-PREF/900.)*(QPRIM(I)/HPERIM(I)    PROP0940
     1 *.0036)**.25                                                     PROP0941
      IF(T(I).GE.TLBOIL) JBOIL(I) = J                                   PROP0945
  110 TWALL = T(I) + DTWALL                                             PROP0946
      IF(TWALL.LT.TF) CALL CURVE(VISCW(I),TWALL,UUF,TT,NPROP,IERROR,1)  PROP0947
      IF(IERROR.GT.1) GO TO 1000                                        PROP0950
  120 L = NTYPE(I)                                                      PROP0970
      FSP(I) = AA(L)*RE**BB(L)+CC(L)                                    PROP0980
      VISCW(I) = VISCW(I)/3600.                                         PROP0985
      IF(NVISCW.EQ.1)                                                   PROP0990
     1FSP(I)= FSP(I)*(1.+HPERIM(I)/PERIM(I)*((VISCW(I)/VISC(I))**.6-1.))PROP1005
  150 CONTINUE                                                          PROP1010
      RETURN                                                            PROP1020
  200 WRITE(I3,6) PREF,PP                                               PROP1030
      GO TO 1001                                                        PROP1040
  210 WRITE(I3,5) PREF,PP                                               PROP1050
      GO TO 1001                                                        PROP1060
 1000 WRITE(I3,7)                                                       PROP1070
 1001 IERROR = 11                                                       PROP1080
      RETURN                                                            PROP1090
      END                                                               PROP1100
*DECK,VOID
      SUBROUTINE VOID (J)                                               VOID0010
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    VOID0020
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       VOID0030
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          VOID0040
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        VOID0050
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           VOID0060
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       VOID0070
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   VOID0080
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              VOID0090
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   VOID0100
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  VOID0110
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               VOID0120
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             VOID0130
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                VOID0140
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      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),                 VOID0150
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                            VOID0160
     2 HPERIM(30), NTYPE(30)                                                VOID0170
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                           VOID0180
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)          VOID0190
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),      VOID0200
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10),     VOID0210
     2 NGAP( 9), BX(30), XQUAL(30)                                          VOID0220
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),              VOID0230
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                                VOID0240
      LOGICAL FDIV, GRID                                                    VOID0250
      REAL  KIJ, LENGTH, KF, KKF                                            VOID0260
      DIMENSION PHI(30)                                                     VOID0270
       EQUIVALENCE (FMULT(1),PHI(1))                                        VOID0280
      NCHAN = NCHANL                                                        VOID0290
      DO 200 I=1,NCHAN                                                      VOID0300
      PSI = 0.                                                              VOID0310
      DPSIDH = 0.                                                           VOID0320
      IF(J3.EQ.0) GO TO 40                                                  VOID0330
      H(I,J) = H(I,J) - .1                                                  VOID0340
      QUAL(I) = (H(I,J)-HF)/HFG                                             VOID0350
      IF(J2.EQ.1) QUAL(I) = SCQUAL(I,J)                                     VOID0360
      IF(QUAL(I).LE.0.) QUAL(I) = 0.                                        VOID0370
      ALPHA(I) = BVOID(I,J)                                                 VOID0380
      PSI = RHOF*QUAL(I)*(1.-ALPHA(I))-RHOG*ALPHA(I)*(1.-QUAL(I))           VOID0390
      H(I,J) = H(I,J) + .1                                                  VOID0400
   40 QUAL(I) = (H(I,J)-HF)/HFG                                             VOID0410
      IF(J2.EQ.1) QUAL(I) = SCQUAL(I,J)                                     VOID0420
      IF(QUAL(I).LE.0.) GO TO 150                                           VOID0430
      XP = QUAL(I)                                                          VOID0440
      ALPHA(I) = BVOID(I,J)                                                 VOID0450
C   CALCULATE TWO-PHASE DENSITY.                                            VOID0460
      RHO(I,J) = RHOG*ALPHA(I)+RHOF*(1.-ALPHA(I))                           VOID0470
C   CALCULATE TWO-PHASE SPECIFIC VOLUME FOR MOMENTUM.                       VOID0480
      VP(I) = VF*(1.-XP)**2/(1.-ALPHA(I))+VG*XP**2/ALPHA(I)                 VOID0490
C   TWO-PHASE FRICTIONAL PRESSURE GRADIENT MULTIPLIERS.                     VOID0500
      PHI(I) = 1.                                                           VOID0510
      IF(J4.EQ.0) PHI(I) = RHOF/RHO(I,J)                                    VOID0520
      IF(J4.NE.1) GO TO 50                                                  VOID0530
      PHI(I) = 1.                                                           VOID0540
      IF(ALPHA(I).GT.0..AND.ALPHA(I).LE..6) PHI(I)=(1.-XP)**2/(1.-          VOID0550
     1 ALPHA(I))**1.42                                                      VOID0560
      IF(ALPHA(I).GT..6.AND.ALPHA(I).LE..9) PHI(I)= .478*(1.-XP)**2/        VOID0570
     1 (1.-ALPHA(I))**2.2                                                   VOID0580
      IF(ALPHA(I).GT..9.AND.ALPHA(I).LE.1.) PHI(I)= 1.73*(1.-XP)**2/        VOID0590
     1 (1.-ALPHA(I))**1.64                                                  VOID0600
   50 IF(J4.NE.5) GO TO 140                                                 VOID0610
      PHI(I) = AF(1)                                                        VOID0620
      XX = QUAL(I)                                                          VOID0630
      DO 130 K=2,NF                                                         VOID0640
      PHI(I) = PHI(I)+AF(K)*XX                                              VOID0650
  130 XX = XX*QUAL(I)                                                       VOID0660
  140 U(I) = F(I,J)/A(I)*VP(I)                                              VOID0670
      IF(J3.EQ.0) GO TO 145                                                 VOID0680
      DPSIDH =-10.*(PSI-RHOF*QUAL(I)*(1.-ALPHA(I))+RHOG*ALPHA(I)*           VOID0690
     1 (1.-QUAL(I)))                                                        VOID0700
  145 UH(I) = F(I,J)/A(I)/(RHO(I,J)-HFG*DPSIDH)                             VOID0710
      GO TO 200                                                             VOID0720
C   TWO-PHASE FLOW PARAMETERS WITHOUT BOILING.                              VOID0730
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  150 ALPHA(I) = 0.                                                     VOID0740
      RHO(I,J) = 1./V(I)                                                VOID0750
      VP(I) = V(I)                                                      VOID0760
      U(I) = F(I,J)/A(I)*VP(I)                                          VOID0770
      UH(I) = U(I)                                                      VOID0780
      PHI(I) = 1.                                                       VOID0790
      QUAL(I) = 0.                                                      VOID0800
  200 CONTINUE                                                          VOID0810
      RETURN                                                            VOID0820
      END                                                               VOID0830
*DECK,MIX
      SUBROUTINE MIX(J)                                                 MIX00010
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEMIX00020
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    MIX00030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    MIX00040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       MIX00050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          MIX00060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        MIX00070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           MIX00080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       MIX00090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   MIX00100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              MIX00110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   MIX00120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  MIX00130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               MIX00140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             MIX00150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                MIX00160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             MIX00170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        MIX00180
     2 HPERIM(30), NTYPE(30)                                            MIX00190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       MIX00200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      MIX00210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  MIX00220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), MIX00230
     2 NGAP( 9), BX(30), XQUAL(30)                                      MIX00240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          MIX00250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            MIX00260
      LOGICAL FDIV, GRID                                                MIX00270
      REAL  KIJ, LENGTH, KF, KKF                                        MIX00280
      NKK = NK                                                          MIX00290
      DO 240 K=1,NKK                                                    MIX00300
      COND(K) = 0.                                                      MIX00310
      II = IK(K)                                                        MIX00320
      JJ = JK(K)                                                        MIX00330
      DAVG = 4.*(A(II)+A(JJ))/(PERIM(II)+PERIM(JJ))                     MIX00340
      GAVG = (F(II,J)+F(JJ,J))/(A(II)+A(JJ))                            MIX00350
      XAVG = 0.                                                         MIX00360
      IF(AMAX1(QUAL(II),QUAL(JJ)) .GT. 0.) XAVG =.5*(QUAL(II)+QUAL(JJ)) MIX00370
      IF(XAVG.GT.0..AND.NBBC.GE.2) GO TO 80                             MIX00380
      UAVG = 0.5*(VISC(II)+VISC(JJ))                                    MIX00390
      IF(NSCBC.GE.1) RE =  GAVG*DAVG/UAVG                               MIX00400
      IF(NSCBC.EQ.0) WP(K) = GAP(K)*GAVG*ABETA                          MIX00410
      IF(NSCBC.EQ.1) WP(K) = GAP(K)*GAVG*ABETA*RE**BBETA                MIX00420
      IF(NSCBC.EQ.2) WP(K) = DAVG*GAVG*ABETA*RE**BBETA                  MIX00430
      IF(NSCBC.EQ.3 .AND. LENGTH(K).LE.0.) GO TO 1000                   MIX00440
      IF(NSCBC.EQ.3) WP(K) = GAP(K)/LENGTH(K)*DAVG*GAVG*ABETA*RE**BBETA MIX00450
      WP(K) = WP(K)*FACTOR(K)                                           MIX00460
      GO TO 100                                                         MIX00470
   80 CALL CURVE (XBETA,XAVG,BX,XQUAL,NBBC,IERROR,1)                    MIX00480
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      IF(IERROR.GT.1) GO TO 1000                                        MIX00490
      WP(K) = GAVG*DAVG*XBETA*FACTOR(K)                                 MIX00500
  100 IF(J5.EQ.0) GO TO 240                                             MIX00510
      CAVG = 0.5*(CON(II)+CON(JJ))                                      MIX00520
      IF(LENGTH(K).LE.0.) GO TO 1000                                    MIX00530
      COND(K) = CAVG*GAP(K)/LENGTH(K)*GK*FACTOR(K)                      MIX00540
  240 CONTINUE                                                          MIX00550
      RETURN                                                            MIX00560
 1000 IERROR = 4                                                        MIX00570
      RETURN                                                            MIX00580
      END                                                               MIX00590
*DECK.AREA
      SUBROUTINE AREA(J)                                                AREA0010
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEAREA0020
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    AREA0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    AREA0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       AREA0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          AREA0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        AREA0070
     4 , FLEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           AREA0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       AREA0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   AREA0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              AREA0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   AREA0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  AREA0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               AREA0140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             AREA0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                AREA0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             AREA0170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        AREA0180
     2 HPERIM(30), NTYPE(30)                                            AREA0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       AREA0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      AREA0210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  AREA0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), AREA0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      AREA0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          AREA0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            AREA0260
      LOGICAL FDIV, GRID                                                AREA0270
      REAL  KIJ, LENGTH, KF, KKF                                        AREA0280
      COMMON /BWRAP/ XCROSS(47,6),DUR(47),DIA,THICK,NWRAP(47),PITCH     AREA0290
      DIMENSION  AFAC(10), GFAC(10)                                     AREA0300
C                                                                       AREA0310
C  CALCULATE CHANNEL AREA IF REQUIRED.                                  AREA0320
      DO 5 I=1,NCHANL                                                   AREA0330
      A(I) = AN(I)                                                      AREA0340
    5 DHYD(I) = DHYDN(I)                                                AREA0350
      IF(NAXL.EQ.0) GO TO 101                                           AREA0360
      DO 100 I=1,NCHANL                                                 AREA0370
      JJ = IDAREA(I)                                                    AREA0380
      IF(JJ.LT.1) GO TO 100                                             AREA0390
      DO 10 K=1,NAXL                                                    AREA0400
   10 AFAC(K) = AFACT(JJ,K)                                             AREA0410
      CALL CURVE (FF,X(J)/Z,AFAC,AXL,NAXL,IERROR,1)                     AREA0420
      IF(IERROR.GT.1) GO TO 1000                                        AREA0430
      IF(DT.LT.100.) GO TO 20                                           AREA0440
      DUMY = FLOAT(ITERAT)/FLOAT(NARAMP)                                AREA0441
      IF(DUMY.GT.1.) DUMY = 1.                                          AREA0442
      IF(FF.LE.0.) GO TO 1000                                           AREA0443
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      FF = 1.-(1.-FF)*DUMY                                              AREA0444
   20 A(I) = AN(I)*FF                                                   AREA0445
      DHYD(I) = DHYDN(I)*FF                                             AREA0450
  100 CONTINUE                                                          AREA0460
  101 IF(J6.NE.1) GO TO 110                                             AREA0470
C   MODIFY AREA AND HYDRAULIC DIAMETER FOR WIRE WRAPS IN SUBCHANNELS.   AREA0480
      DO 102 I=1,NCHANL                                                 AREA0490
      A(I) = A(I)-FLOAT(NWRAP(I))*PI*THICK**2*0.25                      AREA0500
  102 DHYD(I) = 4.*A(I)/(PERIM(I)+FLOAT(NWRAP(I))*PI*THICK)             AREA0510
C                                                                       AREA0520
C   CALCULATE GAP SPACING IF REQUIRED.                                  AREA0530
  110 IF(NGXL.EQ.0) GO TO 210                                           AREA0540
      DO 200 K=1,NK                                                     AREA0550
      GAP(K) = GAPN(K)                                                  AREA0560
      L = IDGAP(K)                                                      AREA0570
      IF(L.LT.1) GO TO 200                                              AREA0580
      DO 120 I=1,NGXL                                                   AREA0590
  120 GFAC(I) = GFACT(L,I)                                              AREA0600
      CALL CURVE (FF,X(J)/Z,GFAC,GAPXL,NGXL,IERROR,1)                   AREA0610
      IF(IERROR.GT.1) GO TO 1000                                        AREA0620
      IF(FF.LE.0.) GO TO 1000                                           AREA0625
      GAP(K) = GAPN(K)*FF                                               AREA0630
  200 CONTINUE                                                          AREA0640
  210 RETURN                                                            AREA0650
 1000 IERROR = 9                                                        AREA0660
      RETURN                                                            AREA0670
      END                                                               AREA0680
*DECK,FORCE
      SUBROUTINE FORCE(J)                                               FORC0010
C    THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THEFORC0020
C    MAJOR SUBROUTINES OF COBRA-IIIC.                                   FORC0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    FORC0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       FORC0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          FORC0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        FORC0070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           FORC0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       FORC0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   FORC0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              FORC0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   FORC0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  FORC0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               FORC0140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             FORC0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                FORC0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             FORC0170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        FORC0180
     2 HPERIM(30), NTYPE(30)                                            FORC0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       FORC0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      FORC0210
      COMMON  AXIAL(39), Y(39), IQAREA(30), IDGAP(47), AA( 4), BB( 4),  FORC0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), FORC0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      FORC0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          FORC0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            FORC0260
      LOGICAL FDIV, GRID                                                FORC0270
      REAL  KIJ, LENGTH, KF, KKF                                        FORC0280
      COMMON /BWRAP/ XCROSS(47,6),DUR(47),DIA,THICK,NWRAP(47),PITCH     FORC0290
      NKK = NK                                                          FORC0300
      DO 10 K=1,NKK                                                     FORC0310
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      FDIV(K) =.FALSE.                                                  FORC0320
   10 CONTINUE                                                          FORC0330
      IF(J6.EQ.0) RETURN                                                FORC0340
      JM1 = J-1                                                         FORC0350
      GO TO (100,200),J6                                                FORC0360
C  FORCED DIVERSION CROSSFLOW FROM WIRE WRAPS                           FORC0370
  100 IF(PITCH.LE.0.) GO TO 1000                                        FORC0380
      NN = Z/PITCH                                                      FORC0390
      NN = NN+1                                                         FORC0400
      DO 115 K=1,NN                                                     FORC0410
      IF(X(J).LE.PITCH*FLOAT(K)) GO TO 118                              FORC0420
  115 CONTINUE                                                          FORC0430
  118 PL = K-1                                                          FORC0440
C  PL IS THE PITCH LENGTH CONTAINING X(J).                              FORC0450
C  FIND THE WRAP CROSSINGS IN DX.                                       FORC0460
      DO 130 K=1,NK                                                     FORC0470
      II = IK(K)                                                        FORC0480
      JJ = JK(K)                                                        FORC0490
      DO 130 L=1,6                                                      FORC0500
      IF(XCROSS(K,L))119,130,119                                        FORC0510
  119 XC = (ABS(XCROSS(K,L))+PL)*PITCH                                  FORC0520
      IF(XC.GT.X(J) .OR. XC.LE.X(JM1)) GO TO 130                        FORC0530
      FDIV(K) = .TRUE.                                                  FORC0540
C  ADD AND SUBSTRACT WIRE WRAPS FROM SUBCHANNEL AT EACH WRAP CROSSING.  FORC0550
      IF(XCROSS(K,L)) 120,130,121                                       FORC0560
  120 NWRAP(II)= NWRAP(II)+1                                            FORC0570
      NWRAP(JJ)= NWRAP(JJ)-1                                            FORC0580
      GO TO 123                                                         FORC0590
  121 NWRAP(II) = NWRAP(II)-1                                           FORC0600
      NWRAP(JJ) = NWRAP(JJ)+1                                           FORC0610
      IF(NRAMP.LE.0) GO TO 1000                                         FORC0620
  123 DUMY = FLOAT(ITERAT)/FLOAT(NRAMP)                                 FORC0630
      IF(DUMY.GT.1.) DUMY = 1.                                          FORC0640
      W(K,J) = GAP(K)*PI*(DIA+THICK)*DUR(K)/DX*DUMY                     FORC0650
      IF(XCROSS(K,L)) 124,130,125                                       FORC0660
  124 W(K,J) = -W(K,J)*F(JJ,J)/A(JJ)                                    FORC0670
       W(K,J) = W(K,J)*FACTOR(K)                                        FORC0675
      GO TO 130                                                         FORC0680
  125 W(K,J) =  W(K,J)*F(II,J)/A(II)                                    FORC0690
       W(K,J) = W(K,J)*FACTOR(K)                                        FORC0695
  130 CONTINUE                                                          FORC0700
      RETURN                                                            FORC0710
  200 IF(.NOT.GRID) RETURN                                              FORC0720
      DO 230 K=1,NKK                                                    FORC0730
      IF(ABS(FXFLOW(K,NGTYPE)).LT.1.E-10) GO TO 230                     FORC0740
C  ZERO FORCED FLOW FRACTION DOES NOT BLOCK THE NATURAL DIVERSION CROSSFFORC0750
      II = IK(K)                                                        FORC0760
      JJ = JK(K)                                                        FORC0770
      FDIV(K) = .TRUE.                                                  FORC0780
      IF(NRAMP.LE.0) GO TO 1000                                         FORC0790
      DUMY = FLOAT(ITERAT)/FLOAT(NRAMP)                                 FORC0800
      IF(DUMY.GT.1.) DUMY = 1.                                          FORC0810
      DUMY = DUMY*FXFLOW(K,NGTYPE)/DX                                   FORC0820
      IF(DUMY.GT.0.) W(K,J) = DUMY*F(II,J)                              FORC0830
      IF(DUMY.LT.0.) W(K,J) = DUMY*F(JJ,J)                              FORC0840
       W(K,J) = W(K,J)*FACTOR(K)                                        FORC0845
  230 CONTINUE                                                          FORC0850
      RETURN                                                            FORC0860
 1000 IERROR = 6                                                        FORC0870
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      RETURN                                                            FORC0880
      END                                                               FORC0890
*DECK,CIJ
      FUNCTION CIJ(K,J)                                                 CIJ00010
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THECIJ00020
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    CIJ00030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    CIJ00040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       CIJ00050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          CIJ00060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        CIJ00070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           CIJ00080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       CIJ00090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   CIJ00100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              CIJ00110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   CIJ00120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  CIJ00130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               CIJ00140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             CIJ00150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                CIJ00160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             CIJ00170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        CIJ00180
     2 HPERIM(30), NTYPE(30)                                            CIJ00190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       CIJ00200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      CIJ00210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  CIJ00220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), CIJ00230
     2 NGAP( 9), BX(30), XQUAL(30)                                      CIJ00240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          CIJ00250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            CIJ00260
      LOGICAL FDIV, GRID                                                CIJ00270
      REAL  KIJ, LENGTH, KF, KKF                                        CIJ00280
      IF(GAP(K).LE.0.) GO TO 1000                                       CIJ00290
      II = IK(K)                                                        CIJ00300
      JJ = JK(K)                                                        CIJ00310
      RSTAR = RHO(II,J)                                                 CIJ00320
      IF(W(K,J).LT.0.) RSTAR = RHO(JJ,J)                                CIJ00330
      WMIN = ABS(W(K,J))                                                CIJ00340
      IF(WMIN.LT..001) WMIN = .001                                      CIJ00350
      CIJ = KIJ*WMIN/2./GC/RSTAR/GAP(K)/GAP(K)                          CIJ00360
       CIJ = CIJ/FACTOR(K)**2                                           CIJ00365
      RETURN                                                            CIJ00370
 1000 IERROR = 18                                                       CIJ00380
      RETURN                                                            CIJ00390
      END                                                               CIJ00400
*DECK,SPLIT
      SUBROUTINE SPLIT                                                  SPLT0010
C   THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THESPLT0020
C   MAJOR SUBROUTINES OF COBRA-IIIC.                                    SPLT0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    SPLT0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       SPLT0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          SPLT0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        SPLT0070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           SPLT0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       SPLT0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   SPLT0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              SPLT0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   SPLT0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  SPLT0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               SPLT0140
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      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             SPLT0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                SPLT0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             SPLT0170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        SPLT0180
     2 HPERIM(30), NTYPE(30)                                            SPLT0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       SPLT0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      SPLT0210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  SPLT0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), SPLT0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      SPLT0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          SPLT0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            SPLT0260
      LOGICAL FDIV, GRID                                                SPLT0270
      REAL  KIJ, LENGTH, KF, KKF                                        SPLT0280
      COMMON /DP/ DPK(30)                                               SPLT0290
      NCHAN = NCHANL                                                    SPLT0300
C  CORRECT FLOW ESTIMATE BY ITERATION. THIS PROCEDURE ASSUMES THERE IS NSPLT0310
C  DENSITY CHANGE WITH LENGTH AND THAT NO DIVERSION CROSSFLOW IS OCCURRISPLT0320
C  CONVERGENCE TOLERANCE IS E.                                          SPLT0330
      E=0.005                                                           SPLT0340
      SAVEDT = DT                                                       SPLT0350
      DT = 1.E+10                                                       SPLT0360
      DO 10 I=1,NCHANL                                                  SPLT0370
      F(I,1) = FINLET(I)                                                SPLT0380
   10 H(I,1) = HINLET(I)                                                SPLT0390
      DO 100 K=1,200                                                    SPLT0400
      CALL PROP(2,1)                                                    SPLT0410
      IF(IERROR.GT.1) GO TO 1000                                        SPLT0420
      CALL VOID(1)                                                      SPLT0430
      DO 15 I=1,NCHANL                                                  SPLT0440
   15 VPA(I) = VP(I)/A(I)                                               SPLT0450
      IF(IERROR.GT.1) GO TO 1000                                        SPLT0460
      IF(FTM.GT.0.) CALL MIX(1)                                         SPLT0470
      IF(IERROR.GT.1) GO TO 1000                                        SPLT0480
      CALL DIFFER(3,1)                                                  SPLT0490
      IF(IERROR.GT.1) GO TO 1000                                        SPLT0500
      DPAVG = 0.                                                        SPLT0510
      DO 20 I=1,NCHANL                                                  SPLT0520
   20 DPAVG = DPAVG + DPDX(I)*A(I)                                      SPLT0530
      DPAVG = DPAVG/ATOTAL                                              SPLT0540
      J=2                                                               SPLT0550
      FTOT = 0.                                                         SPLT0560
      DO 30 I=1,NCHANL                                                  SPLT0570
      DELTAF = (DPAVG-DPDX(I))/2./DPDX(I)*F(I,1)                        SPLT0580
      IF(FTM.GT.0.) DELTAF = DELTAF*0.5                                 SPLT0590
      FSAVE = F(I,1)                                                    SPLT0600
      F(I,1) = F(I,1) + DELTAF                                          SPLT0610
      IF(F(I,1).LT.0.) GO TO 1000                                       SPLT0620
      IF(ABS(F(I,1)-FSAVE)/FSAVE .GT. E) J=1                            SPLT0630
      FTOT = FTOT + F(I,1)                                              SPLT0640
   30 CONTINUE                                                          SPLT0650
      DO 40 I=1,NCHANL                                                  SPLT0660
      F(I,1) = F(I,1)*FLO/FTOT                                          SPLT0670
   40 FINLET(I) = F(I,1)                                                SPLT0680
      IF(J.GT.1) GO TO 120                                              SPLT0690
  100 CONTINUE                                                          SPLT0700
 1000 WRITE(I3,1) (I,F(I,1),DPDX(I),I=1,NCHAN)                          SPLT0710
    1 FORMAT(40H FLOW SPLIT TO GIVE EQUAL DP/DX FAILED  /(I5,2E14.6))   SPLT0720
      IERROR = 8                                                        SPLT0730
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  120 DT = SAVEDT                                                       SPLT0740
      RETURN                                                            SPLT0750
      END                                                               SPLT0760
*DECK,S
      FUNCTION S(K,I)                                                   S0000010
C     THIS PROCEDURE CONTAINS THE COMMON AND TYPE STATEMENTS SHARED BY THES0000020
C     MAJOR SUBROUTINES OF COBRA-IIIC.                                  S0000030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    S0000040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       S0000050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          S0000060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        S0000070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           S0000080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       S0000090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   S0000100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              S0000110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   S0000120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  S0000130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               S0000140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             S0000150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                S0000160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             S0000170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        S0000180
     2 HPERIM(30), NTYPE(30)                                            S0000190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       S0000200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      S0000210
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  S0000220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), S0000230
     2 NGAP( 9), RX(30), XQUAL(30)                                      S0000240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          S0000250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            S0000260
      LOGICAL FDIV, GRID                                                S0000270
      REAL  KIJ, LENGTH, KF, KKF                                        S0000280
      S = 0.                                                            S0000290
      IF(I.EQ.IK(K)) S = 1.                                             S0000300
      IF(I.EQ.JK(K)) S =-1.                                             S0000310
      RETURN                                                            S0000320
      END                                                               S0000330
*DECK,SCQUAL
      FUNCTION SCQUAL(I,J)                                              SCQL0010
C   LEVY SUBCOOLED MODEL.  CALCULATES TRUE QUALITY AS A CORRECTION TO   SCQL0020
C   THE EQUILIBRIUM QUALITY.                                            SCQL0030
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    SCQL0040
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       SCQL0050
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          SCQL0060
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        SCQL0070
     4 , ELEV, NDX, SL, FERROR, ITERAT, NRAMP, NVISCW, NARAMP           SCQL0080
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       SCQL0090
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   SCQL0100
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              SCQL0110
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   SCQL0120
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  SCQL0130
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               SCQL0140
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             SCQL0150
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                SCQL0160
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             SCQL0170
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        SCQL0180
     2 HPERIM(30), NTYPE(30)                                            SCQL0190
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       SCQL0200
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      SCQL0210
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      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  SCQL0220
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), SCQL0230
     2 NGAP( 9), BX(30), XQUAL(30)                                      SCQL0240
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          SCQL0250
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            SCQL0260
      LOGICAL FDIV, GRID                                                SCQL0270
      REAL  KIJ, LENGTH, KF, KKF                                        SCQL0280
      XP = QUAL(I)                                                      SCQL0290
      SCQUAL = XP                                                       SCQL0300
      IF(QPRIM(I).LE.0.) RETURN                                         SCQL0310
      CNC = 0.015                                                       SCQL0320
      YB = CNC/VISC(I)*SQRT(SIGMA*GC*DHYD(I)/V(I))                      SCQL0330
      TAUW = FSP(I)*.125*V(I)*(F(I,J)/A(I))**2/GC                       SCQL0340
      PR = CP(I)*VISC(I)/CON(I)                                         SCQL0350
      Q = QPRIM(I)/(HPERIM(I)/V(I)*CP(I)*SQRT(TAUW*GC*V(I)))            SCQL0360
      DELTAT = QPRIM(I)/HPERIM(I)/HFILM(I)                              SCQL0370
      IF(YB.GE.5..AND. YB.LT.30.)DELTAT = DELTAT - 5.*Q*(PR+ALOG(1.+PR*(SCQL0390
     1 YB*.2-1.)))                                                      SCQL0400
      IF(YB.GE.30.) DELTAT = DELTAT - 5.*Q*(PR+ALOG(1.+5.*PR)           SCQL0410
     1 + .5*ALOG(YB/30.))                                               SCQL0420
      XD = -CP(I)*DELTAT/HFG                                            SCQL0430
      IF(QUAL(I).LT.XD) GO TO 140                                       SCQL0440
      ARG = QUAL(I)/XD - 1.                                             SCQL0450
      IF(ARG.GT.0.) ARG = 0.                                            SCQL0460
      XP = QUAL(I) - XD*EXP(ARG)                                        SCQL0470
  140 SCQUAL = XP                                                       SCQL0480
      RETURN                                                            SCQL0490
      END                                                               SCQL0500
*DECK,BVOID
      FUNCTION BVOID(I,J)                                               BVOD0010
C  BVOID CALCULATES THE BULK VOID FRACTION GIVEN A QUALITY.             BVOD0020
      COMMON  KIJ, FTM, ABETA, BBETA, AFLUX, Z, THETA, PI, NAX, FLO,    BVOD0030
     1 GC, I3, I2, NCHANL, NK, IERROR, KDEBUG, NAXL, NGAPS, NGXL,       BVOD0040
     2 NAFACT, NODES, NSCBC, NBBC, J1, J2, J3, J4, J5, J6, J7,          BVOD0050
     3 ATOTAL, DX, DT, GK, NV, NF, AV(7), AF(7), QAX, FSPLIT(30)        BVOD0060
     4 , ELEV, NDX, SL, FERPOR, ITERAT, NRAMP, NVISCW, NARAMP           BVOD0070
      COMMON  PP(30), TT(30), VVF(30), VVG(30), HHF(30), HHG(30),       BVOD0080
     1 UUF(30), KKF(30), SSIGMA(30), NPROP, PREF, TF, VF, VG, HF, HG,   BVOD0090
     2 UF, KF, SIGMA, HFG, VFG, RHOF, RHOG                              BVOD0100
      COMMON  V(30), VP(30), VISC(30), VISCW(30), HFILM(30), CON(30),   BVOD0110
     1 CP(30), FSP(30), FMULT(30), U(30), UH(30), ALPHA(30), QUAL(30),  BVOD0120
     2 RHO(30,31), VPA(30), T(30), HINLET(30), FINLET(30)               BVOD0130
      COMMON COND(47), WP(47), GAP(47), FACTOR(47), IK(47),             BVOD0140
     1 JK(47), GAPN(47), LENGTH(47), USTAR(47), W(47,31)                BVOD0150
      COMMON  A(30), AN(30), DHYD(30), DHYDN(30), DFDX(30),             BVOD0160
     1 DHDX(30), DPDX(30), QPRIM(30), PERIM(30),                        BVOD0170
     2 HPERIM(30), NTYPE(30)                                            BVOD0180
      COMMON  P(30,31), H(30,31), F(30,31), X(31)                       BVOD0190
      COMMON  WOLD(47,31), RHOOLD(30,31), FOLD(30,31), HOLD(30,31)      BVOD0200
      COMMON  AXIAL(39), Y(39), IDAREA(30), IDGAP(47), AA( 4), BB( 4),  BVOD0210
     1 CC( 4), AFACT(10,10), NCH(10), AXL(10), GAPXL(10), GFACT( 9,10), BVOD0220
     2 NGAP( 9), BX(30), XQUAL(30)                                      BVOD0230
      COMMON  NGRID, NGRIDT, GRIDXL(10), IGRID(10), CD(30, 5),          BVOD0240
     1 FXFLOW(47, 5), NGTYPE, GRID, FDIV(47)                            BVOD0250
      LOGICAL FDIV, GRID                                                BVOD0260
      REAL  KIJ, LENGTH, KF, KKF                                        BVOD0270
      XP = QUAL(I)                                                      BVOD0280
      BVOID = 0.                                                        BVOD0290
      IF(XP.LE.0.) RETURN                                               BVOD0300
```

```
      ALPHA(I) = 0.
      IF(J3.EQ.0) ALPHA(I) = XP*VG/((1.-XP)*VF+XP*VG)
      IF(J3.EQ.1) ALPHA(I) = (0.833+0.167*XP)*XP*VG/((1.-XP)*VF+XP*VG)
      IF(J3.EQ.5) ALPHA(I) = XP*VG/((1.-XP)*VF*AV(1)+XP*VG)
      IF(J3.NE.6) GO TO 90
      ALPHA(I) = AV(1)
      XX = QUAL(I)
      DO 80 K=2,NV
      ALPHA(I) = ALPHA(I)+AV(K)*XX
   80 XX = XX*QUAL(I)
   90 BVOID = ALPHA(I)
      RETURN
      END
*DECK,DECOMP
      SUBROUTINE DECOMP (NN,IERROR)
C  SIMULTANEOUS LINEAR EQUATION SOLVER. REF - G. FORSYTHE AND C.B. MOLER
C  COMPUTER SOLUTION OF LINEAR ALGEBRAIC SYSTEMS. PRENTICE-HALL(1967).
      COMMON /BUL/ UL(47,47), X(47), B(47), IPS(47)
      DIMENSION SCALES(47)
      N = NN
C
C     INITIALIZE IPS, UL AND SCALES
      NOUT = 6
      N = N
      DO 5 I = 1,N
        IPS(I) = I
        ROWNRM = 0.0
      N = N
        DO 2 J = 1,N
          IF(ROWNRM-ABS(UL(I,J))) 1,2,2
    1     ROWNRM = ABS(UL(I,J))
    2   CONTINUE
        IF (ROWNRM) 3,4,3
    3   SCALES(I) = 1.0/ROWNRM
        GO TO 5
    4   WRITE (NOUT,111)
  111 FORMAT(54HOMATRIX WITH ZERO ROW IN DECOMPOSE.                     )
        IERROR = 12
      GO TO 100
    5 CONTINUE
C
C     GAUSSIAN ELIMINATION WITH PARTIAL PIVOTING
      NM1 = N-1
      DO 17  K = 1,NM1
        BIG = 0.0
        DO 11 I = K,N
          IP = IPS(I)
          SIZE = ABS(UL(IP,K))*SCALES(IP)
          IF (SIZE-BIG) 11,11,10
   10       BIG = SIZE
            IDXPIV = I
   11   CONTINUE
        IF (BIG) 13,18,13
   13   IF (IDXPIV-K) 14,15,14
   14     J = IPS(K)
          IPS(K) = IPS(IDXPIV)
          IPS(IDXPIV) = J
   15   KP = IPS(K)
        PIVOT = UL(KP,K)
```

```
      KP1 = K+1                                                         DCOM0460
      DO 16 I = KP1,N                                                   DCOM0470
         IP = IPS(I)                                                    DCOM0480
         EM = -UL(IP,K)/PIVOT                                           DCOM0490
         UL(IP,K) = -EM                                                 DCOM0500
         IF (EM) 20,16,20                                               DCOM0510
C  INNER LOOP.  CHECK EFFICIENCY OF COMPILED CODE.                      DCOM0520
C  IT MAY BE NECESSARY TO USE DOUBLE PRECISION WHEN COMPUTING THIS      DCOM0530
C  LOOP TO PREVENT ROUNDOFF ERRORS DUE TO POORLY CONDITIONED MATRICES.  DCOM0540
   20       DO 21 J = KP1,N                                             DCOM0550
   21          UL(IP,J) = UL(IP,J) + EM*UL(KP,J)                        DCOM0560
   16    CONTINUE                                                       DCOM0570
   17 CONTINUE                                                          DCOM0580
      KP = IPS(N)                                                       DCOM0590
      IF (UL(KP,N)) 19,18,19                                            DCOM0600
   18 PRINT 112                                                         DCOM0610
  100 PRINT 113, ((UL(K,L),L=1,NN),K=1,NN)                              DCOM0620
  113 FORMAT(7E14.8)                                                    DCOM0630
  112 FORMAT(54H0SINGULAR MATRIX IN DECOMPOSE.  ZERO DIVIDE IN SOLVE.   )DCOM0640
      IERROR = 12                                                       DCOM0650
   19 RETURN                                                            DCOM0660
      END                                                               DCOM0670
*DECK,SOLVE
      SUBROUTINE SOLVE(NN)                                              SOLV0010
      COMMON /BUL/ UL(47,47), X(47), B(47), IPS(47)                     SOLV0020
      N = NN                                                            SOLV0030
      NP1 = N+1                                                         SOLV0040
C                                                                       SOLV0050
      IP = IPS(1)                                                       SOLV0060
      X(1) = B(IP)                                                      SOLV0070
      DO 2 I = 2,N                                                      SOLV0080
         IP = IPS(I)                                                    SOLV0090
         IM1 = I-1                                                      SOLV0100
         SUM = 0.0                                                      SOLV0110
C  DOUBLE PRECISION MAY BE REQUIRED FOR INNER LOOP.                     SOLV0120
         DO 1 J = 1,IM1                                                 SOLV0130
    1       SUM = SUM + UL(IP,J)*X(J)                                   SOLV0140
    2 X(I) = B(IP) - SUM                                                SOLV0150
C                                                                       SOLV0160
      IP = IPS(N)                                                       SOLV0170
      X(N) = X(N)/UL(IP,N)                                              SOLV0180
      DO 4 IBACK = 2,N                                                  SOLV0190
      I = NP1-IBACK                                                     SOLV0200
C        I GOES (N-1),....,1                                            SOLV0210
         IP = IPS(I)                                                    SOLV0220
         IP1 = I+1                                                      SOLV0230
         SUM = 0.0                                                      SOLV0240
C  DOUBLE PRECISION MAY BE REQUIRED FOR INNER LOOP.                     SOLV0250
         DO 3 J = IP1,N                                                 SOLV0260
    3       SUM = SUM + UL(IP,J)*X(J)                                   SOLV0270
    4 X(I) = (X(I)-SUM)/UL(IP,I)                                        SOLV0280
      RETURN                                                            SOLV0290
      END                                                               SOLV0300
*DECK,CURVE
      SUBROUTINE CURVE (FX,X,F,Y,N,J,ISAVE)                             CURV0010
      DIMENSION F(47), Y(47)                                            CURV0020
C                                                                       CURV0030
C  FX - QUANTITY TO BE FOUND                                            CURV0040
C   X - INDEPENDENT VARIABLE                                            CURV0050
```

```
C   F - INPUT ARRAY FOR THE ORDINATE(MONOTONIC WITH Y)                  CURV0060
C   Y - INPUT ARRAY FOR THE ARCISSA (MONOTONIC INCREASE)                CURV0070
C   N - NUMBER OF F(I) OR Y(I) VALUES                                   CURV0080
C   J - ERROR SIGNAL, J=10                                              CURV0090
C                                                                       CURV0100
    1 FORMAT(49H TABULAR LOOKUP FAILED IN SUBROUTINE CURVE, FX = E12.6, CURV0110
     1 6H    X = E12.6 / (10E12.4))                                     CURV0120
      IF(ISAVE.LT.1 .OR. ISAVE.GT.2) GO TO 70                           CURV0130
      GO TO (10,50),ISAVE                                               CURV0140
   10 DO 20 I=1,N                                                       CURV0150
      IF(X-Y(I)) 30,15,20                                               CURV0160
   15 IF(I.EQ.N) GO TO 40                                               CURV0170
   20 CONTINUE                                                          CURV0180
      GO TO 60                                                          CURV0190
   30 IF(I.EQ.1) GO TO 60                                               CURV0200
   40 B = (X-Y(I-1))/(Y(I)-Y(I-1))                                      CURV0210
   50 FX = F(I-1) + B*(F(I)-F(I-1))                                     CURV0220
      RETURN                                                            CURV0230
   60 PRINT 1, FX,X,(F(I),Y(I),I=1,N)                                   CURV0240
   70 J = 10                                                            CURV0250
      RETURN                                                            CURV0260
      END                                                               CURV0270
*DECK,TOD
      SUBROUTINE TOD(A)                                                 TOD00010
      DIMENSION TIME(2), A(2)                                           TOD00020
      DATA  TIME  / 6H        , 6H        /                             TOD00030
      A(1) = TIME(1)                                                    TOD00040
      A(2) = TIME(2)                                                    TOD00050
      RETURN                                                            TOD00060
      END                                                               TOD00070
*DECK,DOY
      SUBROUTINE DOY(A)                                                 DOY00010
      DIMENSION DATE(2), A(2)                                           DOY00020
      DATA  DATE / 6H        , 6H       /                               DOY00030
      A(1) = DATE(1)                                                    DOY00040
      A(2) = DATE(2)                                                    DOY00050
      RETURN                                                            DOY00060
      END                                                               DOY00070
*DECK,ELAP
      SUBROUTINE ELAP(MTIME)                                            ELAP0010
      MTIME = 0                                                         ELAP0020
      RETURN                                                            ELAP0030
      END                                                               ELAP0040
```

SAMPLE INPUT COBRA III C
****

```
 2000
    1     CY-RUN III 7-(89). UPPER QUADRANT                          RUN 026
    1   30
 640.493.3   0.02028     0.7203      479.8     1203.3      0.260      0.3521  0.00122
 680.500.0   0.02043     0.6761      487.7     1202.5      0.256      0.3494  0.00117
 720.506.4   0.02058     0.6366      495.3     1201.5      0.253      0.3463  0.00113
 760.512.5   0.02073     0.6011      502.6     1200.4      0.250      0.3434  0.00108
 800.518.4   0.02087     0.5691      509.7     1199.3      0.247      0.3405  0.00102
 840.524.0   0.02101     0.5400      516.6     1198.0      0.244      0.3377  0.00098
 880.529.5   0.02116     0.5134      523.3     1196.7      0.240      0.3350  0.00096
 920.534.7   0.02130     0.4890      529.8     1195.4      0.238      0.3325  0.00094
 960.539.9   0.02145     0.4666      536.2     1193.9      0.235      0.3299  0.00087
1000.544.8   0.02159     0.4459      542.4     1192.4      0.233      0.3273  0.00083
1050.550.7   0.02177     0.4222      550.0     1190.4      0.230      0.3242  0.00080
1100.556.5   0.02195     0.4005      557.4     1188.3      0.227      0.3209  0.00075
1150.562.0   0.02214     0.3806      564.6     1186.2      0.224      0.3177  0.00071
1200.567.4   0.02232     0.3623      571.7     1183.9      0.222      0.3145  0.00068
1250.572.6   0.02250     0.3454      578.6     1181.6      0.220      0.3113  0.00064
1300.577.6   0.02269     0.3297      585.4     1179.2      0.218      0.3080  0.00061
1350.582.5   0.02288     0.3152      592.1     1176.7      0.216      0.3047  0.00058
1400.587.3   0.02307     0.3016      598.6     1174.1      0.215      0.3015  0.00056
1450.591.9   0.02326     0.2888      605.1     1171.4      0.213      0.2982  0.00054
1500.596.4   0.02346     0.2769      611.5     1168.7      0.211      0.2947  0.00052
1550.600.8   0.02366     0.2657      617.8     1165.9      0.210      0.2913  0.00050
1600.605.1   0.02386     0.2552      624.0     1162.9      0.207      0.2878  0.00048
1650.609.2   0.02407     0.2452      630.2     1159.9      0.205      0.2845  0.00045
1700.613.3   0.02428     0.2358      636.2     1156.9      0.203      0.2811  0.00043
1750.617.3   0.02450     0.2268      642.3     1153.7      0.201      0.2776  0.00041
1800.621.2   0.02494     0.2102      654.2     1147.0      0.200      0.2742  0.00040
1900.628.8   0.02517     0.2025      660.1     1143.5      0.197      0.2673  0.00037
1950.632.4   0.02541     0.1952      666.0     1140.0      0.194      0.2639  0.00035
2000.636.0   0.02565     0.1881      671.9     1136.3      0.192      0.2604  0.00033
2050.639.5   0.02590     0.1814      677.7     1132.5      0.190      0.2570  0.00031
    2    1    0    0    1
 .184   -.2
    3   39
   0.    0..0054    0..0055.3630.0333.6160.0611.8190.0390.9550
.11691.042.14471.024.17261.149.20041.192.22831.218.25621.233
.28401.237.31191.138.33971.256.36761.271.39551.281.42331.281
.45121.270.47911.157.50691.268.53481.270.56261.266.59051.254
.61831.229.64621.123.67411.199.70191.182.72981.152.75761.105
.78551.031.8133.9000.8412.8620.8691.7280.8969.5480.9248.3710
.9524.1750.95270.0001.0000.000
    4   30   30
1    1.17711.3261.326     2 .141           3 .141           12 .282
1    2.15421.421.9943     4 .141          12.0805
1    3.15421.421.9943     4.0805          12.2215
1    4.15421.421.9943    12.2215
1    538.37322.8270.5     62.136           92.136
1    619.12157.2135.2    101.068
1    738.37322.8270.5     82.136          122.136
1    838.37314.4270.5     92.136          132.136
1    938.37306.9270.5    102.136          142.136
1   1019.18153.0135.2    151.068
1   1138.37322.8270.5    122.136          162.136
```

```
1  1237.73300.3267.5   132.136         172.136
1  1338.37305.9270.5   142.136         182.136
1  1438.37305.9270.5   152.136         192.136
1  1519.18153.0135.2   201.068
1  1619.18153.0135.2   172.136
1  1738.37305.9270.5   182.136         212.136
1  1838.37305.9270.5   192.136         222.136
1  1938.37305.9270.5   202.136         232.136
1  2019.18153.0135.2   241.068
1  2119.18153.0135.2   222.136
1  2238.37305.9270.5   232.136         252.136
1  2338.37305.9270.5   242.136         262.136
1  2419.18153.0135.2   271.068
1  2519.18153.0135.2   262.136
1  2638.37305.9270.5   272.136         282.136
1  2719.18153.0135.2   291.068
1  2819.18153.0135.2   292.136
1  2919.18153.0135.2   301.068
1  304.79638.2433.81
     7    2    7    3    1
.0050    1.1590    2 .325    3 .492    3 .658    3 .824    3
 .995    1
     14.011
     24.011
     34.011
     44.011
     54.011
     64.011
     74.011
     84.011
     94.011
    104.011
    114.011
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    191.565
    201.565
    211.565
    221.565
    231.565
    241.565
    251.565
    261.565
    271.565
    281.565
    291.565
    301.565
      8   33   33     4    2     2
 1    1 .4221.366     1.2772   12.7700
 1    2 .4221.416     1.2772    2.2567   12.5133
 1    3 .4221.465     1.2772    3.2567   12.5133
 1    4 .4221.480     1.1492    2.1381    3.1381      4.1381
 1    5 .4221.472     2.2772    4.2772   12.5133
```

```
1   6 .4221.457     3.2772   12.7700
1   7 .4221.424     4.2772   12.7700
1   8 .422.6931     5209.4
1   9 .422.7690     6104.7
1  10 .422.7366     7209.4
1  11 .4221.012     8209.4
1  12 .4221.201     9209.4
1  13 .422.8788    10104.7
1  14 .422.7895    11209.4
1  15 .4221.239    12205.6
1  16 .422.9347    13209.4
1  17 .4221.016    14209.4
2  18 .4221.023    15104.7
1  19 .4221.062    16104.7
1  20 .4221.178    17209.4
1  21 .4221.158    18209.4
1  22 .4221.157    19209.4
1  23 .422.9281    20104.7
1  24 .422.9491    21104.7
1  25 .422.9730    22209.4
1  26 .422.9850    23209.4
1  27 .4221.088    24104.7
1  28 .4221.103    25104.7
1  29 .4221.117    26209.4
1  30 .422.8447    27104.7
1  31 .422.9258    28104.7
1  32 .4221.026    29104.7
1  33 .422.8026    3026.18
1.649.0789660.1.383511.50  .12494.4~~.01651~~000.
1.809.0789660.1.3680 7.58.0806410.2.02401000.
   9    1    0    0
  .5   0.126.7   0.   21    0    0.   30 .010 .250
  10    2    0    0
.0062 -0.1
  11    1    0
    1972.     522.3  2.170334  .1694937
  12    3    0    0    3
 1 4 5
```

Sample Output for COBRA III C

Since there has been no change made in the output of the original version of COBRA III C, no sample output is given in this work. For further details, the reader is referred to Ref. 13.

APPENDIX C

COBRA III C CONNECTICUT YANKEE VERSION

C.1 Summary of the Changes Made in COBRA III C

The original version of COBRA III C, as it has been set up (13) was too small to accommodate the Connecticut Yankee case. The extended version can treat a bigger problem size in terms of channels number, fuel rods number. However the number of possible axial nodes has been reduced to make the space required to run the code smaller. This has been proved not to be an undesirable change, since the sensitivity analysis developed on the axial node length showed that axial node of less than 6 in. did not improve the accuracy of results but only increased the computing time (see Table 5).

A comparison of the original version and the Connecticut Yankee version of COBRA III C is given below.

COBRA III C version	Original	Connect. Yankee
Flow channels number	15	30
Flow channels connections number	30	47
Fuel rods number	15	35
Fuel types number	2	3
Axial nodes number	60	30

Axial heat flux nodes number (inputs)	30	39

Important Remark: In the designation of the different parameters above, it is very important to recognize that:

- flow channel can be taken either as a flow subchannel or as a fuel assembly in which all or part of the constituting subchannels are lumped together as one flow channel,
- flow channel connection can be made by two interconnected subchannels, or by two interconnected fuel assemblies each of them represented by a flow channel or by a subchannel interconnected with a fuel assembly represented by a flow channel,
- fuel rod can be taken as a physical fuel rod as it exists, or as an hypothetical fuel rod representing lumped fuel rods when a fuel assembly (or part of it) is represented as a flow channel.

C.2 Procedure to Vary the Size of the Code

The remaining part of this section lists the changes made and tells a future user how to handle a change in the code as a function of the main code parameters.

The logic of the code has not been changed, only the size of some of the arrays has been altered.

The changes made are explained for each case:

- the cards are listed in the order they appear in the code (main program and then the subroutines or functions),
- in each section of the code the cards are listed with their number,
- for each card only the altered arrays are mentioned, with the new dimension used and the indication of the relation between this dimension and the code parameters (noted from 1 to 7).

Key for the following pages:

SUBROUTINE SCHEME Name of the section of the code

Card No	Array Name	1	2	3	4	5	6	7
0180	RHO(30,-), VPA(30)	x						
	RHO(-,31)					x		

In the subroutine SCHEME, the card number 0180 has been modified as the following:

- the array VPA is now dimensioned to 30 because it is related to the flow channel number (noted 1), and so does the array RHO for its first dimension,
- the second dimension of the array RHO is now 31 because it is related to the number of axial nodes (noted 5),

1 means the dimension depends on the flow channels number,

2 means the dimension depends on the flow channels connections number,

3 means the dimension depends on the fuel rods number,

4 means the dimension depends on the fuel types number,

5 means the dimension depends on the axial nodes number,

6 means the dimension depends on the axial heat flux nodes number,

7 means the dimension depends on the biggest parameter considered in the computation and indication is given on which parameter the dimension has been sized.

When an important part of the changes are identical to some made earlier in the code, reference is made to that part of the code to get the corresponding modifications. The number of the first and the last card defining a fraction of the code for which the changes have already been done, are inclusive.

MAIN PROGRAM

Card No.	Array Name	1	2	3	4	5	6	7
3110	FSPLIT(30)	x						
3160	V(30), VP(30), VISC(30), VISCW(30)	x						
	HFILM(30), CON(30)	x						
3170	CP(30), FSP(30), FMULT(30), U(30)	x						
	UH(30), ALPHA(30), QUAL(30)	x						
3180	RHO(30,-), VPA(30), T(30),	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
3190	COND(47), WP(47), GAP(47), IK(47)		x					
	FACTOR(47)		x					
3200	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
3210	A(30), AN(30), DHYD(30), DHYDN(30)	x						
	DFDX(30)	x						
3220	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
3230	HPERIM(30), NTYPE(30)	x						
3240	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		

MAIN PROGRAM

Card No.	Array Name	1	2	3	4	5	6	7
3250	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
3250	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
3260	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
3290	CD(30,-)	x						
3300	FXFLOW(47,-), FDIV(47)		x					
3400	LC(30,-), GAPS(30,-), AC(30),	x						
	PW(30)	x						
3410	PH(30), DC(30), DIST(30,-)	x						
	DR(35)			x				
3420	PRINTC(30)	x		x				
3430	PRINTR(35)			x				
3441	TINLET(30)	x						
3470	NWRAPS(30)	x						
3472	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)				x			
3473	CFUEL(3), CCLAD(3), TCLAD(3)				x			

MAIN PROGRAM

Card No.	Array Name	1	2	3	4	5	6	7
3474	FLUX(35,-), TROD(-,35,-)			x				
	LR(35,-)			x				
	FLUX(-,31), TROD(-,-,31)					x		
	HGAP(3)				x			
3475	PWRF(-,35), PHI(35,-),			x				
	RADIAL(35), D(35)			x				
	PWRF(30,-)	x						
3476	DFUEL(3)				x			
	IDFUEL(35)			x				
3480	XCROSS(47,-), DUR(47),		x					
	NWRAP(47)		x					
3490	SP(47,-)		x					
	SP(-,31)					x		
3491	CHFR(35,-), CCHANL(35,-)			x				
	CHFR(-,31), CCHANL(-,31),					x		
	MCHFR(31), MCHFRC(31),					x		
	MCHFRR(31)					x		
5400	MC = 30	x						
5420	MX = 31					x		
5440	MR = 35			x				

SUBROUTINE SCHEME

Card No.	Array Name	1	2	3	4	5	6	7
0110	FSPLIT(30)	x						
0160	V(30), VP(30), VISC(30),	x						
	VISCW(30), HFILM(30),	x						
	CON(30)	x						
0170	CP(30), FSP(30), FMULT(30),	x						
	U(30), UH(30), ALPHA(30),	x						
	QUAL(30)	x						
0180	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0190	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					
0200	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0210	A(30), AN(30), DHYD(30),	x						
	DHYDN(30), DFDX(30)	x						
0220	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0230	HPERIM(30), NTYPE(30)	x						

SUBROUTINE SCHEME

Card No.	Array Name	1	2	3	4	5	6	7
0240	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0250	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0260	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
0290	CD(30,-)	x						
0300	FXFLOW(47,-), FDIV(47)		x					
0340	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)				x			
0350	CFUEL(3), CCLAD(3), TCLAD(3)				x			
0360	FLUX(35,-), TROD(-,35,-), LR(35,-)			x				
	FLUX(-,31), TROD(-,-,31)					x		
	HGAP(3)				x			
0370	PWRF(-,35), PHI(35,-), RADIAL(35)			x				
	D(35)			x				
	PWRF(30,-)	x						

SUBROUTINE SCHEME

Card No.	Array Name	1	2	3	4	5	6	7
0380	DFUEL(3)				x			
	IDFUEL(35)			x				
0390	WSAVE(47)		x					
0400	SP(47,-)		x					
	SP(-,31)					x		

SUBROUTINE HEAT

Card No.	Array Name	1	2	3	4	5	6	7
0110	FSPLIT(30)	x						
0160	V(30), VP(30), VISC(30),	x						
	VISCW(30), HFILM(30), CON(30)	x						
0170	CP(30), FSP(30), FMULT(30),	x						
	U(30), UH(30), ALPHA(30),	x						
	QUAL(30)	x						
0180	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0190	COND(47), WP(47), GAP(47),		x					
	IK(47)		x					
0190	FACTOR(47)		x					

SUBROUTINE HEAT

Card No.	Array Name	1	2	3	4	5	6	7
0200	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0210	A(30), AN(30), DHYD(30),	x						
	DHYDN(30), DFDX(30)	x						
0220	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0230	HPERIM(30), NTYPE(30)	x						
0240	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0250	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0260	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
0290	CD(30,-)	x						
0300	FXFLOW(47), FDIV(47)		x					

SUBROUTINE HEAT

Card No.	Array Name	1	2	3	4	5	6	7
0350	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)							
0360	CFUEL(3), CCLAD(3), TCLAD(3)				x			
0370	FLUX(35,-), TROD(-,35,-),			x				
	LR(35,-)			x				
	FLUX(-,31), TROD(-,-,31)					x		
	HGAP(3)				x			
0380	PWRF(-,35), PHI(35,-),			x				
	RADIAL(35), D(35)			x				
	PWRF(30,-)	x						
0390	DFUEL(3)				x			
	IDFUEL(35)			x				

SUBROUTINE TEMP

Card No.	Array Name	1	2	3	4	5	6	7
0130	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)				x			
0140	CFUEL(3), CCLAD(3), TCLAD(3)				x			
0150	FLUX(35,-), TROD(-,35,-), LR(35,-)			x				
	FLUX(-,31), TROD(-,-,31)					x		
	HGAP(3)				x			

SUBROUTINE TEMP

Card NO.	Array Name	1	2	3	4	5	6	7
0160	PWRF(-,35), PHI(35,-), RADIAL(35)			x				
	D(35)			x				
	PWRF(30,-)	x						
0170	DFUEL(3)				x			
	IDFUEL(35)			x				

SUBROUTINE HCOOL

Card No.	Array Name	1	2	3	4	5	6	7
0090	FSPLIT(30)	x						
0140	V(30), VP(30), VISC(30),	x						
	VISCW(30), HFILM(30), CON(30)	x						
0150	CP(30), FSP(30), FMULT(30),	x						
	U(30), UH(30), ALPHA(30),	x						
	QUAL(30)	x						
0160	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0170	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					
0180	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					

SUBROUTINE HCOOL

Card No.	Array Name	1	2	3	4	5	6	7
0180	W(-,31)					x		
0190	A(30), AN(30), DHYD(30),	x						
	DHYDN(30), DFDX(30)	x						
0200	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0210	HPERIM(30), NTYPE(30)	x						
0220	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0230	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
0230	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0240	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
0270	CD(30,-)	x						
0280	FXFLOW(47,-), FDIV(47)		x					
0350	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)				x			

SUBROUTINE HCOOL

Card No.	Array Name	1	2	3	4	5	6	7
0360	CFUEL(3), CCLAD(3), TCLAD(3)				x			
0370	FLUX(35,-), TROD(-,35,-), LR(35)			x				
	FLUX(-,31), TROD(-,-,31)			x				
	HGAP(3)				x			
0380	PWRF(-,35), PHI(35,-), RADIAL(35)			x				
	D(35)			x				
	PWRF(30,-)	x						
0390	DFUEL(3)				x			
	IDFUEL(35)			x				

SUBROUTINE CHF

Card No.	Array Name	1	2	3	4	5	6	7
0110	FSPLIT(30)	x						
0160	V(30), VP(30), VISC(30),	x						
	VISCW(30)	x						
0160	HFILM(30), CON(30)	x						
0170	CP(30), FSP(30), FMULT(30), U(30)	x						
	UH(30), ALPHA(30), QUAL(30)	x						
0180	RHO(30,-), VPA(30), T(30),	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		

SUBROUTINE CHF

Card No.	Array Name	1	2	3	4	5	6	7
0190	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					
0200	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0210	A(30), AN(30), DHYD(30), DHYDN(30)	x						
	DFDX(30)	x						
0220	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0230	HPERIM(30), NTYPE(30)	x						
0240	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0250	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0260	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
0290	CD(30,-)	x						

SUBROUTINE CHF

Card No.	Array Name	1	2	3	4	5	6	7
0300	FXFLOW(47,-), FDIV(47)		x					
0330	JBOIL(30)	x						
0340	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)				x			
0350	CFUEL(3), CCLAD(3), TCLAD(3)				x			
0360	FLUX(35,-), TROD(-,35,-), LR(35,-)			x				
	FLUX(-,31), TROD(-,-,31)					x		
	HGAP(3)				x			
0370	PWRF(-,35), PHI(35,-), RADIAL(35)			x				
	D(35)			x				
	PWRF(30,-)	x						
0380	DFUEL(3)				x			
	IDFUEL(35)			x				
0390	CHFR(35,-), CCHANL(35,-)					x		
	MCHFR(31), MCHFRC(31), CHFR(-,31)					x		
	CCHANL(-,31)					x		
0400	MCHFRR(31)					x		

FUNCTION CHF1 AND CHF2

Card No.	Array Name	1	2	3	4	5	6	7
0014	FSPLIT(30)	x						
0019	V(30), VP(30), VISC(30),	x						
	VISCW(30), HFILM(30), CON(30)	x						
0020	CP(30), FSP(30), FMULT(30),	x						
	U(30), UH(30), ALPHA(30),	x						
	QUAL(30)	x						
0021	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0022	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					
0023	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0024	A(30), AN(30), DHYD(30),	x						
	DHYDN(30), DFDX(30)	x						
0025	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0026	HPERIM(30), NTYPE(30)	x						

FUNCTION CHF1 AND CHF2

Card No.	Array Name	1	2	3	4	5	6	7
0027	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0028	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
0028	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0029	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
0032	CD(30,-)	x						
0036	JBOIL(30)	x						
0037	KFUEL(3), KCLAD(3), RFUEL(3)				x			
	RCLAD(3)				x			
0038	CFUEL(3), CCLAD(3), TCLAD(3)				x			
0039	FLUX(35,-), TROD(-,35,-),			x				
	LR(35,-)			x				
	FLUX(-,31), TROD(-,-,31)					x		
	HGAP(3)				x			

FUNCTION CHF1 AND CHF2

Card No.	Array Name	1	2	3	4	5	6	7
0040	PWRF(-,35), PHI(35,-),			x				
	RADIAL(35), D(35)			x				
	PWRF(30,-)	x						
0041	DFUEL(3)				x			
	IDFUEL(35)			x				

SUBROUTINE DIFFER

Card No.	Array Name	1	2	3	4	5	6	7
0070	FSPLIT(30)	x						
0120	V(30), VP(30), VISC(30),	x						
	VISCW(30)	x						
0120	HFILM(30), CON(30)	x						
0130	CP(30), FSP(30), FMULT(30), U(30)	x						
	UH(30), ALPHA(30), QUAL(30)	x						
0140	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0150	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					
0160	JK(47), GAPN(47), LENGTH(47)		x					

SUBROUTINE DIFFER

Card No.	Array Name	1	2	3	4	5	6	7
0160	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0170	A(30), AN(30), DHYD(30),	x						
	DHYDN(30), DFDX(30)	x						
0180	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0190	HPERIM(30), NTYPE(30)	x						
0200	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0210	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						

SUBROUTINE DIFFER

Card No.	Array Name	1	2	3	4	5	6	7
0220	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					

SUBROUTINE DIFFER

Card No.	Array Name	1	2	3	4	5	6	7
0250	CD(30,-)	x						
0260	FXFLOW(47,-), FDIV(47)		x					
0290	DPK(30)	x						

SUBROUTINE DIVERT

Card No.	Array Name	1	2	3	4	5	6	7
0070								
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260								
0290	AAA(47,47), ANSWER(47), B(47)		x					x
	IPS(47)		x					x
0300	SP(47,-)		x					
	SP(-,31)		x					
0310	DPK(30)	x						
0320	USAVE(47)		x					x

SUBROUTINE PROP

Card No.	Array Name	1	2	3	4	5	6	7
0070								
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260								
0285	JBOIL(30)	x						

SUBROUTINE VOID

Card No.	Array Name	1	2	3	4	5	6	7
0050	FSPLIT(30)	x						
0100	V(30), VP(30), VISC(30),	x						
	VISCW(30), HFILM(30), CON(30)	x						
0110	CP(30), FSP(30), FMULT(30), U(30)	x						
	UH(30), ALPHA(30), QUAL(30)	x						
0120	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0130	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					

SUBROUTINE VOID

Card No.	Array Name	1	2	3	4	5	6	7
0140	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0150	A(30), AN(30), DHYD(30),	x						
	DHYDN(30)	x						
0150	DFDX(30)	x						
0160	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0170	HPERIM(30), NTYPE(30)	x						
0180	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-,31), F(-,31)					x		
0190	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0200	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					

SUBROUTINE VOID

Card No.	Array Name	1	2	3	4	5	6	7
0230	CD(30,-)	x						
0240	FXFLOW(47,-), FDIV(47)		x					
0270	PHI(30)	x						

SUBROUTINE MIX

Card No.	Array Name	1	2	3	4	5	6	7
0070	Same changes as ↑ in Subroutine							
	DIFFER, corresponding to the same							
0260	cards numbers ↓							

SUBROUTINE AREA

Card No.	Array Name	1	2	3	4	5	6	7
0070	↑							
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260	↓							
0280	XCROSS(47,-), DUR(47), NWRAP(47)		x					

SUBROUTINE FORCE

Card No.	Array Name	1	2	3	4	5	6	7
0070	↑							
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards number.							
0260	↓							
0290	XCROSS(47,-), DUR(47), NWRAP(47)		x					

FUNCTION CIJ

Card No.	Array Name	1	2	3	4	5	6	7
0070	↑							
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260	↓							

SUBROUTINE SPLIT

Card No.	Array Name	1	2	3	4	5	6	7
0070	↑							

SUBROUTINE SPLIT

Card No.	Array Name	1	2	3	4	5	6	7
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260	↓							
0290	DPK(30)	x						

FUNCTION S

Card No.	Array Name	1	2	3	4	5	6	7
0070	↑							
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260	↓							

FUNCTION SCQUAL

Card No.	Array Name	1	2	3	4	5	6	7
0070	↑							
0120	Same changes as in Subroutine							
	DIFFER, corresponding to the same							
0250	cards numbers.							
0260	↓							

FUNCTION BVOID

Card No.	Array Name	1	2	3	4	5	6	7
0060	FSPLIT(30)	x						
0110	V(30), VP(30), VISC(30),	x						
	VISCW(30), HFILM(30), CON(30)	x						
0120	CP(30), FSP(30), FMULT(30), U(30)	x						
	UH(30), ALPHA(30), QUAL(30)	x						
0130	RHO(30,-), VPA(30), T(30)	x						
	HINLET(30), FINLET(30)	x						
	RHO(-,31)					x		
0140	COND(47), WP(47), GAP(47)		x					
	FACTOR(47), IK(47)		x					
0150	JK(47), GAPN(47), LENGTH(47)		x					
	USTAR(47), W(47,-)		x					
	W(-,31)					x		
0160	A(30), AN(30), DHYD(30),	x						
	DHYDN(30), DFDX(30)	x						
0170	DHDX(30), DPDX(30), QPRIM(30)	x						
	PERIM(30)	x						
0180	HPERIM(30), NTYPE(30)	x						
0190	P(30,-), H(30,-), F(30,-)	x						
	P(-,31), H(-31), F(-,31)					x		

FUNCTION BVOID

Card No.	Array Name	1	2	3	4	5	6	7
0200	WOLD(47,-)		x					
	WOLD(-,31), RHOOLD(-,31)					x		
	FOLD(-,31), HOLD(-,31)					x		
0200	RHOOLD(30,-), FOLD(30,-)	x						
	HOLD(30,-)	x						
0210	AXIAL(39), Y(39)						x	
	IDAREA(30)	x						
	IDGAP(47)		x					
0240	CD(30,-)	x						
0250	FXFLOW(47,-), FDIV(47)		x					

SUBROUTINE DECOMP

Card No.	Array Name	1	2	3	4	5	6	7
0040	UL(47,47), X(47), B(47), IPS(47)		x					x
0050	SCALES(47)		x					x

SUBROUTINE SOLVE

Card No.	Array Name	1	2	3	4	5	6	7
0020	UL(47,47), X(47), B(47), IPS(47)		x					x

SUBROUTINE CURVE

Card No.	Array Name	1	2	3	4	5	6	7
0020	F(47), Y(47)		x					x

APPENDIX D

NOMENCLATURE

Letters	Explanation
C_p	Heat capacity of the coolant
D	Hydraulic diameter
$EFF_{i,j}$	Effective flow factor for the assembly of coordinates i,j
f	friction factor
f_G	geometric factor
f_p	fraction of power
$F^E_{\Delta H}$	Enthalpy rise engineering subfactor
F^N_H	Enthalpy rise nuclear subfactor
F^{stat}_H	Enthalpy rise statistical subfactor
F_{LP}	Low plenum factor
F_M	Mixing factor
F^E_q	Heat flux engineering subfactor
F^N_q	Heat flux nuclear subfactor
F_R	Flow redistribution factor
F_z	Axial factor

Letters	Explanation
h	enthalpy
Δh	enthalpy difference
k	normalization factor (Eq. 2.6)
k_t	normalization factor (Eq. 2.10)
m	mass flow
N_{rod}	number of rods
$q_{i,j}$	normalized power of the assembly of coordinates i,j
$Q_{i,j}$	energy generated by the assembly of coordinates i,j
$(q/A)_i$	Heat flux for incipient boiling
Re	Reynolds number
S	Gap spacing between rods
S/L	Parameter defining the control volume
t	temperature
Δt	temperature difference
T_w	Wall temperature
T_{sat}	Saturation temperature

Greek Letters

α	Fraction of power generated within the fuel
β	Turbulent mixing factor

σ	Standard deviation
σ_r	Relative standard deviation

Subscripts

i,j	Coordinates of the assembly
in	Inlet
ou	Outlet or exit
r	relative

APPENDIX E

DERIVATION OF EQUATIONS CHAPTER 2

E.1 Derivation of Eq. 2.7, 2.8, 2.9 in Chapter 2

Starting with Eq. 2.5 and 2.6

$$\mathrm{EFF}_{i,j} = \frac{q_{i,j}}{\Delta t_{i,j}} \times k \quad , \qquad (2.5)$$

$$k = \frac{38}{\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)} \quad . \qquad (2.6)$$

Recalling that for a function a such as:

$$a = f(b,c), \qquad (E.1)$$

$$\sigma^2 a = \left(\frac{\partial a}{\partial b}\right)^2 \sigma^2 b + \left(\frac{\partial a}{\partial c}\right)^2 \sigma^2 c \quad . \qquad (E.2)$$

We can express:

$$\sigma^2(\mathrm{EFF}_{i,j}) = \left[\frac{\partial \mathrm{EFF}_{i,j}}{\partial k}\right]^2 \sigma^2 k$$

$$+ \left[\frac{\partial \mathrm{EFF}_{i,j}}{\partial\ \alpha_{i,j}}\right]^2 \sigma^2 \alpha_{i,j} + \left[\frac{\partial \mathrm{EFF}_{i,j}}{\partial \Delta t_{i,j}}\right]^2 \sigma^2 \Delta t_{i,j} \quad , \qquad (\mathrm{E}.3)$$

$$= \left[\frac{\alpha_{i,j}}{\Delta t_{i,j}}\right]^2 \sigma^2 k + \left[\frac{k}{\Delta t_{i,j}}\right]^2 \sigma^2 \alpha_{i,j}$$

$$+ \left[\frac{k\ \alpha_{i,j}}{\Delta t_{i,j}{}^2}\right]^2 \sigma^2 \Delta t_{i,j} \quad , \qquad (\mathrm{E}.4)$$

where:

$$\sigma^2 k = \left[\frac{\partial k}{\partial\left[\sum_1^{38}\left(\frac{\alpha_{i,j}}{\Delta t_{i,j}}\right)\right]}\right]^2 \sigma^2\left[\sum_1^{38}\left(\frac{\alpha_{i,j}}{\Delta t_{i,j}}\right)\right] \quad , \qquad (\mathrm{E}.5)$$

with

$$\frac{\partial k}{\partial\left[\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)\right]} = \frac{\partial k}{\partial\left[\frac{38}{\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)}\right]} \times \frac{\partial\left[\frac{38}{\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)}\right]}{\partial\left[\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)\right]} \tag{E.6}$$

$$= 1 \times \left\{-\frac{38}{\left[\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)\right]^2}\right\} \tag{E.7}$$

$$= 1 \times \frac{-k}{\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)} \quad . \tag{E.8}$$

Now Eq. E.5 becomes:

$$\sigma^2 k = \left[\frac{-k}{\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)}\right]^2 \sigma^2\left[\sum_{1}^{38}\left(\frac{\sigma_{i,j}}{\Delta t_{i,j}}\right)\right] \quad . \tag{E.9}$$

Recalling that for a function:

$$y = \eta_1 + \eta_2 + \ldots + \eta_n = \sum_{\ell=1}^{n} \eta_\ell \quad , \tag{F.10}$$

we have

$$\sigma^2 y = \sigma^2\left[\sum_{\ell=1}^{n} \eta_\ell\right] = \sigma^2\eta_1 + \sigma^2\eta_2 + \ldots + \sigma^2\eta_n$$

$$= \sum_{\ell=1}^{n} \sigma^2\eta_\ell \quad . \tag{F.11}$$

Therefore:

$$\sigma^2\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right] = \sum_{1}^{38} \sigma^2 \left(\frac{q_{i,j}}{\Delta t_{i,j}}\right) \quad . \tag{E.12}$$

Putting Eq. E.9, E.12 into Eq. E.4 gives:

$$\sigma^2(EFF_{i,j}) = \left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)^2 \frac{k^2}{\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} \sum_{1}^{38}\sigma^2\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right) \tag{E.13}$$

$$+\left(\frac{k}{\Delta t_{i,j}}\right)^2 \sigma^2 q_{i,j} + \left(\frac{k\; q_{i,j}}{\Delta t_{i,j}{}^2}\right)^2 \sigma^2 \Delta t_{i,j} \quad . \qquad \begin{array}{r}(\text{E.13})\\ (\text{continued})\end{array}$$

Using Eq. 2.1 we may have:

$$\Delta t_{i,j} = t_{ou,i,j} - t_{in,i,j} \quad , \qquad (2.1)$$

and

$$\sigma^2 \Delta t_{i,j} = \sigma^2 t_{ou,i,j} + \sigma^2 \; t_{in,i,j} \quad . \qquad (\text{E.14})$$

We could also express:

$$\sigma^2 q_{i,j} = (\sigma_r \; q_{i,j})^2 \; q_{i,j}{}^2 \quad . \qquad (\text{E.15})$$

Using Eq. E.14, E.15 in Eq. E.13 gives Eq. 2.8:

$$\sigma^2(\mathrm{EFF}_{i,j}) = \left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)^2 \frac{k^2}{\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} \sum_1^{38} \sigma^2\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)$$

$$+\left(\frac{k}{\Delta t_{i,j}}\right)^2 \left(\sigma_r q_{i,j}\right)^2 \; q_{i,j}{}^2$$

$$+\left(\frac{k \; q_{i,j}}{\Delta t_{i,j}{}^2}\right)^2 \sigma^2 t_{ou,i,j} + \left(\frac{k \; q_{i,j}}{\Delta t_{i,j}{}^2}\right)^2 \sigma^2 t_{in,i,j} \quad . \qquad (2.8)$$

Now from Eq. E15 we may have:

$$\sigma_r{}^2(\mathrm{EFF}_{i,j}) = \frac{\sigma^2(\mathrm{EFF}_{i,j})}{\mathrm{EFF}_{i,j}{}^2}$$

$$= \frac{\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)^2 \frac{k^2}{\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} \sum_1^{38} \sigma^2\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)}{\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)^2 k^2} \qquad (E.16)$$

$$+\frac{\frac{k^2}{\Delta t_{i,j}^{2}}(\sigma_r q_{i,j})^2 q_{i,j}^{2}+\frac{k^2 q_{i,j}^2}{\Delta t_{i,j}^{4}}\sigma^2 t_{ou,i,j}+\frac{k^2 q_{i,j}^2}{\Delta t_{i,j}^{4}}\sigma^2 t_{in,i,j}}{\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)^2 k^2} \quad .$$

(E.16)
(continued)

This leads after simplification to Eq. 2.7

$$\sigma_r^{2}(EFF_{i,j})$$

$$= \frac{\sum_{1}^{38}\sigma^2\left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]}{\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} + \sigma_r^{2}\, q_{i,j}$$

$$+\frac{\sigma^2 t_{ou,i,j}}{\Delta t_{i,j}^{2}}+\frac{\sigma^2 t_{in,i,j}}{\Delta t_{i,j}^{2}} \quad . \qquad (2.7)$$

Recalling the fact that for a function

$$a = \frac{b}{c} , \tag{E.17}$$

$$\sigma^2 a = a^2 \left[\frac{\sigma^2 b}{b^2} + \frac{\sigma^2 c}{c^2}\right] , \tag{E.18}$$

we can express Eq. E.12 as:

$$\sigma^2\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right] = \sum_1^{38} \sigma^2\left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]$$

$$= \sum_1^{38}\left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]^2 \left[\frac{\sigma^2 q_{i,j}}{q_{i,j}^2} + \frac{\sigma^2 \Delta t_{i,j}}{\Delta t_{i,j}^2}\right] . \tag{E.19}$$

The first term of Eq. 2.8 can be expressed using Eq. E.14, 19 as Eq. (2.9):

$$\left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]^2 \frac{k^2}{\left[\sum_1^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2} \sum_1^{38} \sigma^2 \left[\frac{q_{i,j}}{\Delta t_{i,j}}\right] \tag{2.9}$$

$$= \left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]^2 \frac{k^2}{\left[\sum_{1}^{38}\left(\frac{q_{i,j}}{\Delta t_{i,j}}\right)\right]^2}$$

$$\times \sum_{1}^{38}\left[\frac{q_{i,j}}{\Delta t_{i,j}}\right]^2 \left[\sigma_r{}^2 q_{i,j} + \frac{\sigma^2 t_{ou,i,j}}{\Delta t_{i,j}{}^2} + \frac{\sigma^2 t_{in,i,j}}{\Delta t_{i,j}{}^2}\right] . \qquad \text{(2.9) (continued)}$$

E.2 Derivation of Eq. 2.11, 2.12, 2.13 in Chapter 2

Equation 2.11 can be obtained from Eq. 2.7 by using $\Delta h_{i,j}$ instead of $\Delta t_{i,j}$. Assuming Eq. 2.14 valid for subcooled coolant:

$$\sigma^2 h = \left[\frac{\partial h}{\partial t}\right]^2 \sigma^2 t \quad , \qquad (2.14)$$

we may express:

$$\sigma^2 h_{ou,i,j} = \left[\frac{\partial h_{ou,i,j}}{\partial t_{ou,i,j}}\right]^2 \partial^2 t_{ou,i,j} \, , \qquad (E.20)$$

$$\sigma^2 h_{in,i,j} = \left[\frac{\partial h_{in,i,j}}{\partial t_{in,i,j}} \right]^2 \sigma t_{in,i,j} \quad . \qquad (E.21)$$

Equation 2.12 can be obtained from Eq. 2.18 by using:

- $\sigma h^2_{ou,i,j}$ instead of $\sigma^2 t_{ou,i,j}$,
- $\sigma^2 h_{in,i,j}$ instead of $\sigma^2 t_{in,i,j}$,

and use Eq. E.20, E.21.

Equation E.13 is obtained from Eq. 2.9 by using the same procedure as above.