COBRA-IV PC: A Personal Computer Version of COBRA-IV-I for Thermal- Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements and Cores

B. J. Webb

January 1988

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COBRA-IV PC: A PERSONAL COMPUTER VERSION OF
COBRA-IV-I FOR THERMAL-HYDRAULIC ANALYSIS
OF ROD BUNDLE NUCLEAR FUEL ELEMENTS AND CORES

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ABSTRACT

COBRA-IV PC is a modified version of COBRA-IV-I, adapted for use with most IBM PC and PC-compatible desktop computers. Like COBRA-IV-I, COBRA-IV PC uses the subchannel analysis approach to determine the enthalpy and flow distribution in rod bundles for both steady-state and transient conditions. The steady-state and transient solution schemes used in COBRA-IIIC are still available in COBRA-IV PC as the implicit solution scheme option. An explicit solution scheme is also available, allowing the calculation of severe transients involving flow reversals, recirculations, expulsions, and reentry flows, with a pressure or flow boundary condition specified.

In addition, several modifications have been incorporated into COBRA-IV PC to allow the code to run on the PC. These include a reduction in the array dimensions, the removal of the dump and restart options, and the inclusion of several code modifications by Oregon State University, most notably, a critical heat flux correlation for boiling water reactor fuel and a new solution scheme for cross-flow distribution calculations.

The recommended system configuration for COBRA-IV PC implementation requires at least 512K RAM, a Intel 8087 math coprocessor, and two disk drives, or a hard disk and one disk drive.

SUMMARY

Significant new capability has been added to COBRA since the publication of COBRA-IIIC, and are present in COBRA-IV PC. These can be grouped into two primary areas: expanded COBRA capability and advanced numerical capability.

EXPANDED COBRA CAPABILITY

- COBRA-IV PC includes all the previous capability of COBRA-IIIC plus significantly expanded computational capability:
 - Core analysis problems can now consider a thermally conducting wall that can conduct heat between two channels on opposite sides of the wall.
 - The fuel rod heat conduction model now includes axial conduction and variable thermal conductivity. Also, each rod may now consist of several materials if desired. The storage requirement for the fuel model has been reduced by a factor of 2, with no loss in accuracy or increase in running time by using orthogonal collocation numerical procedure.
 - Correlations are now included to calculate the physical properties of superheated steam for water reactor applications. Heat transfer correlations are also included for subcooled, boiling, and superheated conditions.
 - Line printer plotting capability is included to plot pressure drop, mass flux, enthalpy, **and/or** crossflow versus axial position for all or a specified number of gaps and channels. While not suitable for hard copy, these plots can be of considerable aid in interpreting complex problems.
 - A Jens-Lottes critical heat flux correlation has been added for applications.

The two phase flow model and implicit computational approach used previously for COBRA-IIIC are retained.

ADVANCED NUMERICAL CAPABILITY

A significantly improved numerical solution procedure has been developed for COBRA-IV, to enhance its range of application. Although still under development, it allows analysis of problems previously not possible with COBRA-IIIC. The basic approach uses a pressure-velocity method, which is an adaptation of the MAC methodology (Harlow 1976) and the Chorin-Hirt iteration procedure (Hirt and Cook 1972). It differs from these approaches by an implicit coupling of the energy and momentum equation to account for convective influence on the time rate of change of density. The method is explicit relative to momentum convection; therefore, it requires a time-step limitation to maintain computational stability. The algorithm under development is called the Advanced Continuous-Fluid Eulerian (ACE) method.

This advanced numerical capability is currently limited to incompressible, but thermally-expandable, flows. Two-phase flows are limited to homogeneous, thermal equilibrium conditions. Applications involving compressibility, relative phase motion, and nonequilibrium are being pursued under contract with the U.S. Nuclear Regulatory Commission.

The advanced numerical procedures allow new capability:

- Arbitrary plenum pressure **and/or** flow boundary conditions can now be used to drive transients.
- The numerical solution has successfully considered buoyancy-dominated flow redistribution, flow reversals, coolant expulsion, reentry, and recirculation.
- Severe flow blockages can be considered.
- All of the expanded COBRA capability mentioned previously can be used for the advanced numerical procedures under the restriction of homogeneous two-phase flow in thermal equilibrium.
- The advanced procedure can be started from an arbitrary initial condition, one of which is the implicit COBRA-IIIC type of solution.

The following sections describe the basic features of COBRA-IV-I with major emphasis on the program description. Full documentation of details on

the mathematical models, numerical procedures, additional experimental comparison, and verification are to be presented in future reports.

ACKNOWLEDGMENTS

Conversion of COBRA-IV-I for the personal computer is supported by Pacific Northwest Laboratory Technology Transfer Directorate.

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COBRA-IV PC: A PC VERSION OF COBRA-IV-I FOR
THERMAL-HYDRAULIC ANALYSIS OF ROD BUNDLE
NUCLEAR FUEL ELEMENTS AND CORES

1.0 INTRODUCTION

This report presents a personal computer (PC) version of the COBRA-IV computer program developed at the Pacific Northwest Laboratory^(a). The COBRA-IV-I code (Wheeler et al. 1976) is an extended version of the COBRA-IIIC subchannel analysis code that computes the flow and enthalpy distributions in nuclear fuel rod bundles or cores for both steady state and transient conditions.

Original development of the COBRA computer code through the COBRA-IIIC version (Rowe 1973) was sponsored by the Atomic Energy Commission (AEC). Since the reorganization of the AEC, COBRA-IV has been under the sponsorship of both the Energy Research and Development Administration (ERDA) and the U.S. Nuclear Regulatory Commission (NRC). The ERDA sponsorship has been directed toward expanded code capability for the liquid metal fast breeder reactor (LMFBR), while the NRC sponsorship has been directed toward improved computational and two-phase modeling for application to water reactor safety.

The approach used in COBRA-IV-I is similar to that used in COBRA-IIIC. The bundle or core of the reactor was divided into computational cells. The balance laws of mass, energy, and momentum for the fluid are written for each cell where the independent variables of enthalpy, pressure, and velocity are appropriate averages. The cells may have fuel rods or other solid materials that in the current treatment, act as sources or sinks of heat and momentum to the fluid. The transient thermal response of the fuel or solids is included and is interfaced with the hydraulics through heat transfer coefficients. The use of the computational cell concept allows individual analyses of subchannel,

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core, and general flow field to be considered in a unified approach. The primary differences between the two programs are the level of detail included through averaging and the constitutive relationships used to close the set of equations.

COBRA-IIIC, COBRA-IV-I, and the family of COBRA codes are in rather wide use for the thermal-hydraulic analysis of rod bundle fuel elements and cores for water, liquid metal and gas cooled reactors. For example, design analysis for the LMFBR requires calculation of subchannel flow and temperature in a full 217-pin wire-wrapped bundle with provision for heat transfer to adjacent bundles or core structures. Analysis for both liquid metal and water-cooled reactors requires the transient response of coolant flow and enthalpy to changes of inlet and exit pressure as the driving boundary condition. This can lead to flow reversals, coolant expulsion, and reentry. Capability is also required for severe blockages where flow recirculation is possible. The application of COBRA-IV to water reactor safety currently requires more sophisticated two-phase flow modeling to account for relative motion of the liquid and vapor phases and the effects of thermal nonequilibrium. This is further complicated by the need to consider a wide range of pressure and velocity conditions. This poses a significant challenge to both the modeling of two-phase flow physical processes and the numerical procedure to solve the system of equations.

The advent of newer, more powerful, personal computers has afforded the professional engineer and the student alike the ability to operate sophisticated computer codes such as COBRA-IV without the expense and difficulties associated with large computer systems. It is with these aspects in mind that COBRA-IV PC is offered.

While it is recognized that speed and memory limitations of the PC will make certain problems unsuitable for the PC, it is **believed** that COBRA-IV PC will afford the user a readily available means for familiarization with the input requirements and model development. In doing so, the user is expected to find that the development of larger, more sophisticated input models will be viewed **as** less formidable. This report is structured primarily as a user manual, illustrating the use of COBRA-IV through a variety of sample input decks, with fundamental equations and solution techniques deferred to the

formal COBRA-IV documentation. It is hoped that this information will aid the user in learning and applying COBRA-IV to a broad range of problems.

2.0 COBRA-IV PC SYSTEM REQUIREMENTS, INSTALLATION, AND EXECUTION

COBRA-IV PC was originally developed for the IBM family of personal computers, but has since been tested on a variety of IBM PC compatibles such as Kaypro and Leading Edge. To operate COBRA-IV PC, the recommended computer is a PC or MSDOS-based machine equipped with 512K of RAM, an Intel 8087 math coprocessor, and a hard disk. Other system configurations are possible, but the operating speed and performance of COBRA-IV PC may be severely limited.

The COBRA-IV PC diskette contains the program executable, compiled and link using MicroSoft FORTRAN Version 4.01, an execution batch file, and nine sample problem input decks to assist the user. The files are listed and described as:

<u>Filename</u>	<u>Description</u>
COBRA.EXE	Executable version of COBRA-IV PC
CRUN.BAT	Batch file for running COBRA.EXE CRUN (input filename) (output filename)
BWR6SS.TXT	Sample Problem for Steady-State Operation of Boiling Water Reactor Fuel Element (Single Fuel Rod, Two Coolant Channels)
PWR16SS.TXT	Sample Problem for Steady-State Operation of Pressurized Water Reactor 16 x 16 Fuel Element Array (Single Fuel Rod, Two Flow Channels)
PWR16T1.TXT	Sample Problem for Rod Ejection Event for Pressurized Water Reactor 16 x 16 Fuel Element Array (Single Fuel Rod, Two Flow Channels) (a)
PWR16T2.TXT	Sample Problem for Locked Rotor Event for Pressurized Water Reactor 16 x 16 Fuel Element Array (one Fuel Rod, two Flow Channels) (a)

(a) See COBRA-IV PC examples for discussion of transient.

PWR16T3.TXT	Sample Problem for Total Loss of AC Power Event for Pressurized Water Reactor 16 x 16 Fuel Element Array (one Fuel Rod, two Flow Channels) (a)
RBMK.TXT	Problem for a RBMK-1000 Fuel Assembly (three Fuel Rods, seven Coolant Channels) (a)
WIRE.TXT	Example Problem for a Wire-Wrapped Fuel Element (seven Fuel Rods, 12 Coolant Channels) (a)
THERMAL.TXT	Example Problems for Annularly Cooled Fuel Can (three Fuel Rods, seven Coolant Cans, three Thermally Conducting Walls) (a)
UTUBE.TXT	Example Problem for a Damped U-Tube Manometer (two Fluid Channels) (a)

2.1. INSTALLING COBRA-IV PC

When you operate COBRA-IV PC, you should first make a backup copy of the diskette. Unlike other softwares that you may have received in the past, COBRA-IV PC does not incorporate any copy-protection devices. This is done intentionally to promote its use. If you are not familiar with personal computers, the following set of instructions are provide to assist you.

Insert DOS diskette into Drive A: and type;

FORMAT B: (return) You will then be instructed to insert a blank diskette into Drive B: for initialization. After formatting the diskette, indicate that no other diskettes are to be formatted by answering "NO. "

N (return)

Next place the COBRA-IV PC diskette into Drive A: and the initialized diskette into Drive B: and type;

(a) See COBRA-IV PC examples for discussion of transient.

COPY *.* B: The files contained on the COBRA-IV PC
diskette will now be copied to the backup
diskette.

Finally, place the COBRA-IV PC diskette in safe storage for future access.
Be sure to label the backup diskette so you can find it.

If your system is equipped with a hard disk, the procedure is as follows:

Insert COBRA-IV PC diskette into Drive A: and type;

MKDIR C:\COBRA (return) This will establish a subdirectory on the
hard disk in which to copy the COBRA-IV PC
files.

Next type;

COPY A:*.* C:\COBRA The files contained on the COBRA-IV PC
diskette will now be copied to the hard disk
subdirectory.

Finally, place the COBRA-IV PC diskette in safe storage for future access.
You are now ready to run COBRA-IV PC.

2.2. OPERATING COBRA-IV PC

Once COBRA-IV PC is installed, its operation is relatively straightforward and easy to execute. The input file for the executable must be labeled TAPE5.TXT. The program will then create an output file labeled TAPE6.TXT. Both of these files are standard text files and can be manipulated with any word processor program of your choice. Note that operating COBRA-IV PC will create several temporary files, requiring adequate storage space on either the hard disk or a floppy diskette for the code to execute. These files are TAPE8.TMP, TAPE9.TMP, TAPE16.TMP, and TAPE17.TMP. At the end of execution these files will be deleted.

2.2.1. Personal Computers with Two Disk Drives

COBRA-IV PC can be operated from the floppy disk in the following manner.

- Step 1: Copy the input file TAPE5.TXT on an input/output diskette and place the input/output diskette in Drive A.
- Step 2: Place the COBRA-IV PC backup diskette in Drive B.
- Step 3: Make sure the default drive is Drive A.
A: (return)
- Step 4: Execute COBRA-IV PC as follows:
B: COBRA (return)

All files will then be written to Drive A. COBRA-IV PC output will be listed as TAPE6.TXT.

2.2.2. Personal Computers with Hard Disk Drive

To operate COBRA-IV PC from the hard disk follow these steps.

- Step 1: Set the default directory to CD C:\COBRA
- Step 2: Make sure the input file is labeled TAPE5.TXT.
- Step 3: Execute COBRA-IV PC as follows:
C: \COBRA\COBRA (return)

All files will then be written to subdirectory C:\COBRA. COBRA-IV PC output will be listed as TAPE6.TXT.

If you are interested in working with multiple input files, a batch file called CRUN.BAT has been incorporated into the COBRA-IV PC diskette. This batch file allows the user to specify the input file and output filenames directly, converting the input file first to TAPE5.TXT, then reverting the TAPE5.TXT file back to the input file name, and TAPE6.TXT to the specified output file. The following example illustrates the use of the CRUN.BAT file for the input file PWR16SS.TXT and a user-specified output file of PWR16SS.OUT.

```
CRUN PWR16SS.TXT PWR16SS.OUT
      (input)      (outfile)
```

3.0 COBRA INPUT DESCRIPTION

The input instructions in this section are ordered as the input is encountered by the code. An identifying label is assigned to each data card or card type (if multiple cards are read). A list of the variables and the format under which they are read follows. The label is composed of the name of the subroutine where the read takes place and the relative order of occurrence in that subroutine (e.g., COBRA.I). Optional data are included in the order in which they are encountered, with the criterion for inclusion into the data deck stated in the description.

Beginning with card label SETUP.1, the data are clustered into 12 groups similar to the ILLC groups. Each group is accessed by reading a group control card of the form

```
READ(I2,1), NGROUP, N1,N2,N3,N4,N5,N6,N7,N8,N9
```

where NGROUP = group number

N1-N9 = integer options used in the group.

The group cards are labeled in the usual way (e.g., SETUP.2). The labeling of data read within that group follows the convention of appending a sequence number to the group label (e.g., SETUP.23 is the label of the third card or card type read in Group 2).

Several user-specified empirical correlations are input to COBRA. For details, you are referred to author(s) (date, App. B). To further assist you in setting up the input, many of the calculation parameters have been set to a default value that will be used by the code if you leave the parameter input field blank. The parameters that have defaulted values are specified in the input instructions, and the default value is given. Because most parameters with default values affect "stability" of the solution, it is recommended that the default value be used until familiarity with each parameter is reached. Finally, a number of sample problems have been included in Chapter 4.0 showing many of the options described in this report.

It is hoped that the information provided will aid you in utilizing COBRA-IV PC to its fullest potential. While COBRA-IV PC does not support all

of the capabilities of COBRA-IV PC, the structure of the input deck is identical to COBRA-IV-I. This is to allow you greater flexibility in transporting input files between the PC and larger computer systems. Note that COBRA-IV PC uses a formatted input file, with each card containing 80 characters. Input errors may result if the input file contains truncated lines (less than 80 characters). Furthermore, the final two lines of the input file should be blank. This is necessary, in that COBRA-IV PC is designed to perform multiple calculations with only a single input deck. These blank lines are then used to terminate this batch mode operation.

INPUT INSTRUCTIONS

DATA CARD OR GROUP CONTROL CARD

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
COBRA. 1	<u>MAXT</u>	FORMAT (15) Must be the first data card of the input deck. Read only once.
	MAXT (not applicable)	= The computer time limit (sec_{10}) allowed for problem calculations. Computer CP time limit must be greater than MAXT to allow for printing of results if MAXT is exceeded. Negative MAXT indicates a "Restart" problem from a previously stored solution. Disables for current applications, however, input deck must include dummy card. A blank card may be inserted here.
RESTR.T.1	<u>NJUMP, NA, IT, NTT, TTT</u>	Format (415, F5.0) Optional input - MAXT negative Restart options, where:

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
(Not Supported in PC Version of COBRA-IV)	NJUMP	= Restart flag. NJUMP = 0; continue calculations on a previous steady-state or transient solution, do not read in any additional data. NJUMP = 1, new problem calculation with a previous solution as the first computational guess or continue calculations on a previous solution reading additional data from subroutine setup. NJUMP = 2, read dump tape, print input and results then STOP. NJUMP = 3, same as NJUMP = 0, but all the input data is printed.
	NA	= Number of additional iterations for implicit solution scheme. May be reset in setup if NJUMP = 1.
	IT	= 1, begin a transient solution at time zero from a previous steady-state solution, must read in transient data from setup. For other restart cases, IT = 0.
	NTT	= Number of additional time steps allowed, regardless of IT. May begin a transient or continue a transient.
	TTT	= Total additional transient time (sec).
SETUP.0	<u>KASE, J1, TEXT</u>	Format (215, 17A4)
	Case control card, where:	
	KASE	= Problem case number. $K > 0$, begin case with core initialized to zero. $K < 0$, use previous case solution as first guess. $K = 0$, STOP.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	J1	= Print option for input data. J1 = 0, print only new input data. J1 = 1, print all input data. J1 = 2, print only operating conditions. J1 = 10, print all input data, then stop.
	TEXT	= Output text for problem identification, maximum 68 characters.

* * * * *

BEGIN GROUP INPUT DATA

* * * * *

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP. 1	<u>GROUP 1 PROPERTY TABLE</u>	Format (1015)
	N0	= Card Group Number.
	N1	= NPR0P, number of property cards to be read.
	N2	= ISTEAM, N2 = 0, no superheated steam properties. N2 = 1, N1 superheated steam properties are calculated.
	N3	= Superheated steam property range. Not applicable if N2 = 0. Default, for N3 = 0, code calculates N1 superheated steam properties from the saturation temperature at the system pressure to 1500°F. For N3 = 1, code calculates N1 properties over a temperature range specified by DTMAX (SETUP.1.2).
SETUP.I.I	<u>PP(I), TT(I), VVF(I), VVG(I), HHF(I), HHG(I), UUF, KKF(I), SSIGMA(I)</u>	(I = 1 to N1) Format (E5.2, F5.1, 7F10.0)
	Read in N1 saturated liquid and vapor property cards, where	
	PP	= system pressure (psia)
	TT	= Temperature (°F)

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	WF	= Liquid specific volume (ft^3/lb)
	VVG	= Vapor specific volume (ft^3/lb)
	HHF	= Liquid enthalpy (Btu/lb)
	HHG	= Vapor enthalpy (Btu/lb)
	UUF	= Liquid viscosity ($\text{lb}/\text{ft}\cdot\text{h}$)
	KKF	= Liquid thermal conductivity ($\text{Btu}/\text{h}\cdot\text{ft}\cdot^\circ\text{F}$)
	SSIGMA	= Surface tension (lb_f/ft)
SETUP.1.2	<u>DTMAX</u>	Format (F5.3) Optional Input - N2 = 1 and NB = 1 = The temperature range over which the superheated steam properties are to be calculated. DTMAX = $(T - T_{\text{saturation}})$, where T is the maximum temperature desired. Default for NB = 0 is $T = 1500^\circ\text{F}$.
SETUP.2	<u>GROUP 2 FRICTION FACTOR AND TWO PHASE FLOW CORRELATION</u> Format (1015)	
	NØ	= Card Group Number.
	N1	= J2. The Subcooled Void Formulation Correlation. N1 = 0, no subcooled voids. N1 = 1, subcooled voids are calculated using Levy's subcooled void model.
	N2	= J3. The Void Fraction Correlation. N2 = 0, the homogeneous model. N2 = 1, Modified Armand Model. N2 = 5, the slip model, must read in slip ratio. N2 = 6, read in number of terms and coefficient for up to a 6th order polynomial function of void fraction versus steam quality.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	N3	= J4 . Two Phase Friction Multiplier. N3 = 0, The Homogeneous Model. N3 = 1, Armand Model. N3 > 4, read in number of terms and coefficients for up to 6th order polynomial function of the two phase multiplier versus quality .
	N4	= NVISCW. Wall Viscosity Correlation. N4 = 0, no heated wall correlation in friction factor. N4 = 1, include heated wall correlation in friction factor.
	N5	= LAMNF, laminar friction factor. N5 = 0, no laminar correlation. N5 = 1, read in up to 4 sets of laminar friction factor correlation constants.
	N6	= Rod-to-coolant single phase heat transfer coefficient option. N6 = 0, Dittus-Boelter Correlation used. N6 > 0, read a user-supplied correlation .
SETUP.2.1	<u>AA(I), BB(I), CC(I)</u>	(I = 1 to 4) Format (12F5.3) Turbulent friction factor coefficients. Read up to four sets where: AA, BB, CC = the constants of the correlation in the form $f = AA(R_e)^{BB} + CC.$ The four sets correspond to up to four subchannel types.
SETUP.2.2	<u>AAL(I), BBL(I), CCL(I)</u>	(I = 1 to 4) Format (12F5.3) Optional input - N5 = 1. Laminar friction factor coefficients. AAL, BBL, CCL = Constants for laminar friction factor correlation. Same specification as SETUP.2.1.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.2.3	<u>AH(I)</u> (I = 1 to 4)	Format (12F5.3) Optional input - N6 > 0 AH = Coefficients for a single phase heat transfer correlation of the form: $h = (K/D)(AH(1)Re^{AH(2)}Pr^{AH(3)} + AH(4))$. For N6 ≤ 0, AH(I) defaults to 0.023, 0.8, 0.4, and 0.0 for AH(1) through AH(4), respectively.
SETUP. 2.4	<u>NV, AV(I)</u> (I) = 1 to 7)	Format (15, 7E10.5) Optional input N2 > 4. Slip ratio and void fraction correlation, where: NV = polynomial order for the void fraction correlation if N2 = 6. If N2 = 5, NV is not used. AV = If N2 = 5, AV(1) is a single term slip ratio. If N2 = 6, read (AV(I), I = 1 to NV) coefficients for up to 6th order polynomial function of void fraction versus steam quality.
SETUP.2.5	<u>NF, AF(I)</u> (I = 1 to 7)	Format (15, 7E10.5) Optional input - N3 > 4 Two phase friction multiplier, where: NF = The number of terms for the polynomial function of quality. AF = Constants for up to 6th order polynomial function of the two phase friction multiplier versus steam quality.
SETUP.3	<u>GROUP 3 AXIAL HEAT FLUX TABLE</u>	Format (1015) N0 = Card Group Number. N1 = NAX, number of entries in heat flux table.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.3.1	<u>Y(I), AXIAL(I)</u> (I = 1 to N1)	Format (12F5.3) Axial heat flux table, where: Y = Relative position (X/L) at which heat flux is given, where L is the total length of the bundle. Must include 0.0 and 1.0 as end points. AXIAL = Relative heat flux at (X/L). (Local flux/average flux.)
SETUP. 4	<u>GROUP 4 CHANNEL LAYOUT AND DIMENSIONS</u>	Format (1015) NØ = Card Group Number. N1 = Number of data cards of subchannel information to be read. One card for each subchannel, unless already assigned (e.g., restart case). N2 = Total number of subchannels, regardless of N1. N3 = Option to specify N3 relative direction angles for crossflow between adjacent subchannels. N4 = Number of thermal connections. N5 = Logical unit from which card set SETUP.4.1 is to be read. N5 = 0, read from input deck. N5 > 0, read cards from logical unit N5. Recommend N5 = 9 if cards are not specified. N6 = Logical unit from which card set SETUP.4.3 is to be read. N6 = 0, read from input deck. N6 > 0, read cards from logical unit N6. Recommend N6 = 9 if cards are not specified.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.4.1	<u>[N, ■, AC(I), PW(I), PH(I), LC(I,L) GAPS(I,L) DIST(I,L)</u> (L = 1 to 4, ■ = 1 to N1) Format [I1, I4, 3E5.2, 4(I5, 2E5.2)]	
	Read N1 cards of Channel Geometry, where:	
	N	= Subchannel type. If blank or zero, type 1 is assigned. If N > 0, type N is assigned. N ≠ 4. The subchannel type indicates the appropriate friction factor correlations to be used. (SETUP.2.1, SETUP.2.2)
	I	= Subchannel identification number.
	AC	= Nominal subchannel area (in. ²).
	PW	= Nominal subchannel wetted perimeter (in.).
	PH	= Nominal subchannel heated perimeter (in.).
	LC	= Adjacent subchannel identification number, for up to four subchannels adjacent to subchannel ■. If the subchannels are input with ascending identification numbers, only connections LC(I,L) > ■ need to be read in.
	GAPS	= The nominal GAP width between subchannel ■ and the adjacent subchannel specified by LC (in.).
	DIST	= Centroid-to-centroid distance between the adjacent subchannels specified by LC (in.). Required only if N1 = 3 in Group 10 (SETUP.IO).
SETUP.4.2	<u>KW, RHOLCP(KW), WIDTH(KW), IKW(KW), RWALL(1,KW), JKW(KW), RWALL(2,KW)</u> (KW = 1 to N4) Format [2X, I3, 2E5.2, 2(I5,E5.2)]	
	Optional input - N4 > 0	
	Thermal connection data for subchannels with thermal wall connections.	

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	KW	= Thermal connection number.
	RHOLCP	= Wall heat capacity parameter (Btu/ft ² -°F).
	WIDTH	= Width of wall (in.). Heat conduction area = WIDTH x DX.
	IKW, JW	= Subchannel numbers adjacent to wall.
	RWALL(1,KW), RWALL(2,KW)	= Conductive resistance of the wall associated with the IKW and JW subchannels, respectively (ft ² -sec-°F/Btu).
SETUP.4.3	<u>K, ANGLE(K)</u>	Format [5(I5, F5.0)]
	Optional input - N3 > 0	
	Read N3 pairs of values, where:	
	K	= GAP no. for which the directed crossflow is specified.
	ANGLE	= Relative direction of positive crossflow through GAP K, in positive degrees.
SETUP.5	<u>GROUP 5 SUBCHANNEL AREA VARIATION</u>	Format (10I5)
	N0	= Card Group Number
	N1	= NAFAC, number of subchannels for which area variation tables are to be read.
	N2	= NAXL, number of axial locations for subchannel area variation.
	N3	= NARAMP, the number of iterations for gradual insertion of area variations. If blank or zero, NARAMP = 1. For a "restart" case, NARAMP must be reread if desired.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.5.1	<u>AXL(I)</u> (I = 1 to N2)	Format (12F5.3) Table of axial locations, where: AXL = Axial location (X/L) where subchannel area variations will be specified. Read in N2 values which apply to all subchannels specified in SETUP.5.2.
SETUP.5.2	<u>[I, (AFACT(L,J)</u> L = 1 to N2), J = 1 to N1]	Format (I5/(12F5.3)) For N1 subchannels read area variation factors at N2 axial locations corresponding to (AXL), where: I = Identification Number of a subchannel for which area variations are being specified. Read according to (15) format, then skip to the next card and read a complete set of factors (AFACT) corresponding to the AXL locations. Repeat until factors for N1 subchannels are read. AFACT = Relative subchannel area (A_i/A_{nominal}) at each axial level (AXL).
SETUP.6	<u>GROUP 6 GAP SIZE VARIATION TABLE</u>	Format (215) NØ = Card Group Number. N1 = NGAPS, number of GAPS for which GAP variation tables are to be read. N2 = NGXL, number of axial locations for GAP variation.
SETUP.6.1	<u>GAPXL(L)</u> (L = 1, N2)	Format (12F5.3) Table of axial locations, where: GAPXL = Axial locations (X/L) where GAP variations will be specified. Read N2 values which apply to all GAPS K specified in SETUP.6.2.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.6.2	<u>[K,(GFACT(L,LL), L = 1 to N2), LL = 1 to N1]</u>	
	Format (I5/(12F5.3))	
	For N1.GAPS read GAP variations at N2 axial locations (GAPXL), where:	
	K	= GAP identification number of GAP to be varied. Read K [Format(I5)], then skip to next card and read N2 GAP variation factors. Repeat until factors for N1 GAPS are read.
	GFACT	= GAP variation factors for GAP K. Read N2 values for each K corresponding to each GAPXL location. $GFACT = (GAP_i / GAP_{nominal})$.
SETUP.7	<u>GROUP 7 WIRE WRAP AND SPACER DESIGN INFORMATION</u>	
	Format (10I5), where:	
	NØ	= Card Group Number.
	N1	= J6. N1 = 1 specifies wire wrap input only. N1 = 2 specifies grid spacer input only. N1 = 3 specifies both wire wrap and grid spacer loss coefficient input.
	N2	= Number of GAPS for which wire wrap crossing data is supplied.
	N3	= NGRID, number of axial locations for grid spacers.
	N4	= NGRIDT, number of grid types for which data will be supplied.
	N5	= NRAMP, number of iterations over which grid the loss terms are to be ramped into the solution. For a "restart" case, NRAMP must be reread if desired.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	N6	= Logical unit that card sets SETUP.7.2 and SETUP.7.3 are to be read. N6 = 0, read from input deck. N6 > 0, read from logical unit N6. Recommend N6 = 9 if cards are not specified.
SETUP.7.1	<u>PITCH, DIA, THICK</u>	Format (3E10.5) Optional input - N1 = 1 or 3 Wire wrap specifications, where: PITCH = Wire wrap pitch (in.). DIA = Rod or cladding outer diameter (in.). THICK = Wire wrap diameter (in.).
SETUP.7.2	<u>K, DUR(K), XCROSS(K,L)</u>	(L = 1 to 2) Format (15, 2E5.2) Optional input - N1 = 1 or 3 Wrap crossing data, where: K = GAP number. DUR = The effective fraction of a pitch length for forcing crossflow. Recommended value is derived from the equation $DUR = \Delta X / PITCH$ where: AX = the axial node length (in.). PITCH = the wire wrap pitch (in.). XCROSS = The wire wrap crossing angle. XCROSS is calculated by dividing the angle (θ) between the GAP and wire (at the bundle inlet) by 360°. The value is positive if the wrap is moving from a smaller to a higher number subchannel and negative if otherwise. If the wire wrap is on a GAP boundary at the bundle inlet, XCROSS = ± 1.0 not zero.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.7.3	<u>NWRAPS(I)</u> (I = 1 to NCHANL)	Format (1015) Optional input - N1 = 1 or 3 Wrap inventory where: NWRAPS = The number of wires initially in each subchannel. Read an integer value of the number of wires present at the bundle inlet. For wires located on the GAP boundary, the wrap is assumed to be in the subchannel into which it is proceeding. Read 10 values per data card until the inventory for all subchannels are read.
SETUP.7.4	<u>GRIDXL(I), IGRID(I)</u> (I = 1 to N3)	Format [6(E5.2,I5)] Optional input - N1 = 2 or 3 Axial location of grids and the type of grid at each axial location GRIDXL = The relative location (X/L) of grid spacers. IGRID = The grid type at axial location GRIDXL.
SETUP.7.5	<u>[(J, CD(J,II)), K, FXFLOW(K,I)]</u> , II = 1 to NCHNL, I = 1 to N4]	Format (15, E5.2, I5, E5.2) Optional input - N1 = 2 or 3 Read the loss coefficient and forced crossflow, if desired, in each subchannel for each grid type. NCHANL = Total number of subchannels. Read data for all subchannels for grid type 1, then repeat for succeeding grid types. J = Identification number of subchannel for which data are being supplied.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	CD	= Loss coefficient in subchannel J for grid type ■ -
	K	= GAP associated with subchannel J, through which forced diversion crossflow is specified. If blank, no forced crossflow.
	FXFLOW	= Fraction of axial glow which is diverted through GAP K for grid type ■ - If blank, no forced crossflow.
SETUP.8	<u>GROUP 8 ROD LAYOUT AND FUEL PROPERTIES</u> Format (1015)	
	NØ	= Card Group Number.
	N1	= The number of cards of rod data to be read. One card for each rod modeled. For RESTART cases or multiple case runs, it is only necessary to read new rod input.
	N2	= NROD , the total number of rods to be modeled regardless of N1 .
	N3	= NC , order of approximation used in fuel model. N3 = 0 , no fuel model. N3 = 2 , 2nd order collocation solution. N3 = 3 , 3rd order collocation. N3 > 3 or N3 = 1 is illegal.
	N4	= NFUEL , the number of fuel materials for which thermal properties are to be specified. Not applicable if N3 = 0 . If blank, NFUEL = 1 is assigned.
	N5	= NCHF , critical heat flux option. N5 = 0 , no CHF calculations are performed. N5 = 1 , BAW-2 correlation is used. N5 = 2 , the W-3 correlation is used. N5 = 3 , the CHF limit lines.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	N6	= NQAX, additional fuel model options. Not applicable if N3 = 0. N6 = 0, no additional options. N6 = 1, variable thermal conductivity only. N6 = 2, axial conductivity only. N6 = 3, both axial conduction and variable thermal conductivity. N6 = 2 or 3 also specifies fluid axial conduction.
	N7	= NHTC, heat transfer correlation option. N7 = 0, Dittus and Boelter or other correlation specified in SETUP.2.2 input is used throughout. N7 = 1, use a complete boiling and nonboiling correlation package similar to that of the RELAP-4 computer code.
	N8	= NRODTP, option for axially varying fuel material. N8 = 0, each fuel rod is constructed of a single material and no axially varying data are read. N8 > 0, must read fuel zone information (SETUP.8.4), for each fuel type N.
	N9	= Logical unit from which card set SETUP.8.1 is to be read. N9 = 0, read from input deck. N9 > 0, read from logical unit N9. Recommends N9 = 9 when not reading from cards.

SETUP.8.1 N, $\mathbf{I}$, DR(I), Radial, [LR(I,L), PHI(I,L)] (L = 1 to 6)]

Format [I2, I3, 2E5.2, 6(I5, E5.2)]

Read in NI cards of rod input data, where:

N = The fuel shape and fuel material options. N = 0 or positive, cylindrical fuel specified. N = negative, plate fuel specified. The absolute value of N determines the material property configuration of Fuel $\mathbf{I}$.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
		<p>For <u>$N8 = 0$</u> (Axially uniform fuel) ABS (N) corresponds to one of $N4$ materials (SETUP.8.2) of which Rod ■ is made.</p> <p>For <u>$N8 > 0$</u> (Axially varying fuel zones) ABS (N) corresponds to one of $N8$ material configurations specifying the fuel material versus axial height (SETUP.8.4).</p> <p>Note: If any rod is specified to have axially varying properties ($N8 > 0$), all rods (including axially uniform rods) must have an axial configuration specified (SETUP.8.4).</p>
	■	= Rod identification number.
	DR	= Outer rod diameter (in.). If cladding around rod, DR is the cladding outer diameter.
	RADIAL	= The radial power factor for rod (I) as a fraction of the average rod power (Group 11).
	LR	= Identification numbers of subchannels surrounding rod (I). Read in up to six subchannels.
	PHI	= The fraction of the total rod power input to adjacent subchannel (i.e., fraction of the outer rod perimeter facing subchannel identified by LR).
SETUP.8.2	<u>KFUEL(I), CFUEL(I), RFUEL(I), DFUEL(I), KCLAD(I), CCLAD(I), RCLAD(I), TCLAD(I), HGAP(I)</u> (I = 1 TO $N4$) Format (9E5.2)	
	Optional input $N4 > 0$ and $NC > 0$	
	Material properties. Read $N4$ cards corresponding to $N4$ materials for which thermal properties are specified. Each fuel rod consists of one or more of these materials. For $N8 = 0$, the fuel type N (SETUP.8.1) corresponds to the material type (1).	

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	KFUEL	= The thermal conductivity of the fuel (Btu/h-ft-°F).
	CFUEL	= Specific heat of fuel (Btu/lb-°F).
	RFUEL	= Fuel density (lb/ft ³).
	DFUEL	= The fuel diameter (in.).
	KCLAD	= Thermal conductivity of cladding (Btu/h-ft-°F).
	CCLAD	= Specific heat of clad (Btu/lb-°F).
	RCLAD	= Density of cladding (lb/ft ³).
	TCLAD	= Cladding thickness (in.).
	HGAP	= Fuel-clad gap conductance coefficient (Btu/h-ft ² -°F).

SETUP.8.3 TREF, BK(I) (I = 2 to 4) Format (F10.0, 3E10.4)

Optional input - NC > 0 and NQAX = 1 or 3

Variable thermal conductivity. Only applies to the material specified by the first card of SETUP.8.2.

TREF = The reference temperature where $K = KFUEL(1)$ (°F).

BK = The coefficients for up to 3rd order polynomial approximation for thermal conductivity versus temperature of the form:

$$K(I) = KFUEL(1) * [1 + BK(2) * (T - TREF) + BK(3) (T - TREF)^2 + BK(4) (T - TREF)^3]$$

SETUP.8.4 [NZONE(I), (ZEND(I,K), IZTYP(I,K), K = 1 to NZONE(I)), ■ = 1 to N8] Format [I5/(6(e5.2,I5))]

Optional input - N8 > 0

Option to specify axially varying fuel materials. Must read in a fuel zone configuration table for each rod type N (SETUP.8.1).

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	NZONE	= The number of axial zones to be read for a table of fuel materials versus axial distance for fuel type I.
	ZEND	= Relative axial location (X/L) of the end of a fuel zone. If fuel type I is axially uniform, $ZEND(I,1) = 1.0$.
	IZTYP	= Type of material in fuel zone ending at ZEND. Each IZTYP corresponds to a material specified in SETUP.8.2. Only material type 1 can have variable thermal conductivity.
SETUP.9	<u>GROUP 9 CALCULATIONAL VARIABLES</u> Format (1015)	
	NØ	= Card Group Number.
	N1	= NSKIPX, output print option. N1 = 0 or 1, print all axial levels. N1 > 1, print every N1 axial levels.
	N2	= NSKIPT, output print option. N2 = 0 or 1, print all time steps. N2 > 1, print every N2 time steps.
	N3	= K11, specifies the solution algorithm to solve the problem. N3 = 0 specifies the III-C implicit solution scheme for both steady-state and transient calculations. N3 = 1 specifies an implicit steady state and an explicit transient with a AP boundary condition. N3 = 2 specifies a standing start explicit transient with a zero flow initial condition, and a AP boundary condition. N3 = 3 specifies an implicit steady state and an explicit transient with the inlet flow boundary condition. N3 = 4 specifies a standing start

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
		explicit transient with a zero flow initial condition, and an inlet flow boundary condition.
	N4	= IROLL, problem roll option. N4 = 0, no roll option, all variables reside in core at all times. N4 = 1, only 3 axial levels of information - J-1, J, and J+1 - are stored in core at one time.
	N5	= ITSTEP, maximum time step table. N5 = 0, maximum transient time step is FDT (SETUP.9.3) for all time. For N5 > 0, read in N5 pairs of (time vs maximum time step) information for variable maximum time steps. Used only for K1170.
SETUP.9.1	<u>Z, TTIME, WERRX, WERRY, FERROR, KIJ, SL, FTM, THETA, USDON, DAMPNG, ACCELY, ACCELF</u>	<u>Format (16 E5.0)</u>
	Z	= The total axial length (in.) .
	TTIME	= Total transient time (s).
	WERRX	= The external crossflow convergence limit. Defined for implicit crossflow solution as the maximum allowable error in iterative crossflows at any axial level. If any error is greater than WERRX, the solution proceeds through another iterative sweep over the entire bundle. Default is 1.E-2.
	WERRY	= The internal crossflow convergence limit. Convergence limit for the iterative Gauss-Seidel solution scheme at axial level J. Default is 1.E-3.
	FERROR	= The external axial flow convergence limit. Defined for the implicit axial momentum equation as the maximum allowable error for iterative axial flows. If error is greater than FERROR,

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
		another iterative sweep of the entire bundle is made. Default is 1.E-3.
	KIJ	= Turbulent crossflow resistance factor. Default is 0.5.
	SL	= Transverse momentum parameter. Default is 0.5.
	FTM	= Turbulent momentum factor. Default is 0.0.
	THETA	= The bundle orientation. Blank or zero is vertical, otherwise read in to the nearest degree to the angle away from the vertical (degrees).
	USDON	= Specifies the contribution of velocity from the donor and receiver subchannels in U^* calculation. $USDON = 0$, $U^* = 1/2 [U(J) + U(I)]$ where J and I are donor and receiver subchannels. $USDON = 1.0$, $U^* = U(J)$ where J is the donor subchannel. Any value between 0.0 and 1.0 is acceptable. Default, $USDON = 0.0$.
	DAMPNG	= DAMPNG factor for iterative SP term. $SP(I,J)^N = DAMPNG * SP(I,J)^N + (1 - DAMPNG) * SP(I,J)^{N-1}$ where N and N-1 are the present and previous iterations, respectively.
	ACCELY	= Crossflow solution accelerator. $W(K,J)^N = ACCELY * W(K,J)^N + (1 - ACCELY) * W(K,J)^{N-1}$ where N is the iteration no. Default is 1.6.
	ACCELF	= DAMPNG factor for iterative axial flow. $F(I,J)^N = ACCELF * F(I,J)^N + (1 - ACCELF) * F(I,J)^{N-1}$ where N is the iteration no. Default is 1.0.
SETUP.9.2	<u>NDX, NDT, NTRIES, ITRY, ITRYM</u>	Format (515)
	NDX	= Number of axial nodes.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	NDT	= Total number of time steps allowed. For implicit transients the time step size is (TTIME/NDT). For explicit transients, the time step size depends on the problem with NDT and TIME being the limits on the total number of time steps and length of the transient.
	NTRIES	= The maximum number of external iterations allowed in implicit solution scheme, regardless of WERRX and FERROR. Default is 20.
	IITRY	= The maximum number of internal iterations allowed in implicit solution scheme, regardless of WERRY. Default is the maximum of 20, 2 * number of gaps.
	ITRYM	= The minimum number of iterations in the internal crossflow solution for implicit solution scheme, regardless of convergence. Default is 5.
SETUP.9.3	<u>FCOUR, FDT, XZERR, THX, THD, ACCEL1, ACCEL2</u>	Format (12E5.0)
	Optional input - K11 > 0	
	Parameters for the explicit solution scheme	
	FCOUR	= The courant time step limitation parameter. Default is 0.5. $FCOUR = \frac{(\text{velocity}) \Delta T}{\Delta X}$
	FDT	= The maximum time step regardless of FCOUR. Must read in. No default.
	XZERR	= The iterative flow field convergence limit in the explicit solution scheme. Default is 1.E-2.
	YZERR	= The iterative energy equation convergence limit in the explicit solution scheme. Default is 1.E-4.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	THX	= 1. The integrated liquid level is printed for each channel at each time step. THX=0. No liquid level printout. Default is THX=0.
	THD	= 1. Optional interface sharpening parameter, equivalent to the downward liquid velocity. Default is 0.
	ACCEL1	= Acceleration factor on current pressure change. Default is 1.3.
	ACCEL2	= Acceleration factor on pressure change from last iteration. Default is 0.
SETUP.9.4	<u>NTRYX, NTRY, KNODLO, JNOFLO</u>	Format (10IJ)
	Optional input - K11 > 0	
	Additional parameters for explicit solution	
	NTRYX	= The maximum number of allowable iteration in the flow solution of XZERR. Default is 50.
	NTRY	= The maximum number of allowable iterations in the energy equation regardless of YZERR. Default is 20.
	KNODLO, JNOFLO	= No crossflow permitted through gap number KNODLO or less at and above the axial node JNOFLO. Default for both is 0.
SETUP.9.5	<u>YT(I), FT(I)</u>	(I = 1 to N5) Format (12E5.))
	Optional input - N5 > 1	
	Read in N5 pairs of values for a table of time step size versus time, where:	
	YT	= Time (sec) for maximum time step. Must include time = 0.
	FT	= Maximum time step (sec) allowed at this time.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.10	<u>GROUP 10 TURBULENT MIXING CORRELATION</u>	Format (1015)
NØ		= Card Group Number.
N1		= NSCBC. Single-phase turbulent mixing option. Several forms of the equation for turbulent crossflow W' are possible: <ol style="list-style-type: none"> 1. $W'_K = ABETA * (S_K \overline{G})$ 2. $W'_K = ABETA * Re^{**} BBETA * (S_K \overline{G})$ 3. $W'_K = ABETA * Re^{**} BBETA * (\overline{DG})$ 4. $W'_K = ABETA * Re^{**} BBETA * (S_K / Z_K) (\overline{DG})$ where the constants ABETA and BBETA (SETUP.10.1) are applied to the equation selected by N1. (See Appendix D for definition of variables.) N1 = 0, use equation 1 N2 = 1, use equation 2 N3 = 2, use equation 3 N4 = 3, use equation 4
N2		= NBCC, the option for two-phase mixing. N2 = 0 or 1, two-phase mixing assumed to be the same as subcooled. N2 > 1, read in N2 pairs of data for a table of two-phase mixing Beta versus steam quality.
N3		= J5, an option for radial thermal conduction mixing. N3 = 0, no thermal conduction. N3 = 1, read thermal geometry factor, GK, for radial thermal conduction.
SETUP.IO.I	<u>ABETA, BBETA</u>	Format (12F5.3)
	ABETA, BBETA	= Constants coefficients for the turbulent mixing correlation selected, (see N1). BBETA is blank if N1 = 0.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.10.2	<u>XQUAL(I), BX(I)</u> (I = 1 to N2)	Format (12F5.3) Optional input - N2 > 1 Read in table of values of mixing Beta versus steam quality, where: XQUAL = Steam quality. BX = The mixing Beta at the corresponding steam quality.
SETUP.10.3	<u>GK</u>	Format (F5.3) Optional input - N3 = 1 GK = Geometry factor for radial thermal conduction mixing.
SETUP.II	<u>GROUP 11 OPERATING CONDITIONS AND TRANSIENT FORCING FUNCTIONS</u> Format (10I5) NØ = Card Group Number. N1 = IH, option for specified inlet enthalpy or temperature. N1 = 0, HIN (SETUP.11.1) is the inlet enthalpy. N1 = 1, HIN is the inlet temperature. N1 = 2, read in an inlet enthalpy for each subchannel. N1 = 3, read in an inlet temperature for each subchannel. N2 = IG, option to specify inlet mass flux. N2 = 0, GIN (SETUP.11.1) is the inlet mass flux for each subchannel. N2 = 1, GIN is the average bundle mass flux but the subchannel flow is split to give equal DP/DX across the first axial node. N2 = 2, GIN is the average bundle mass flux, but flow is split by flow fractions supplied in (SETUP.11.3).	

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	N3	= Transient forcing function for system pressure. Read in NP pairs or values for a table of system pressure factor versus time.
	N4	= Transient forcing function for inlet enthalpy or temperature. Read in NH pairs of values for a table of inlet H or T factor versus time.
	N5	= Transient forcing function for inlet mass flux or pressure drop. Read in NG pairs of values for a table of mass flux factor or AP versus time.
	N6	= Transient forcing function for average heat flux. Read in NQ pairs of values for a table of heat flux factor versus time.
	N7	= K10, an option for pressure drop boundary condition transients. If K11 (SETUP.9) is equal to 1 or 2, the transient forcing function for inlet mass flux (N5) becomes a transient pressure drop table. If K10 = 1, the tabular values are a fraction of the steady-state pressure drop.
	N8	= Transient forcing function for exit enthalpy. Read in NHX pairs of values for a table of exit enthalpy factor versus time.

SETUP.II.1 PEXIT, HIN, GIN, AFLUX, HOUT, DPS Format (6F10.0)

Operating conditions, where:

PEXIT	= The system pressure, (psia).
HIN	= Inlet enthalpy (Btu/lb) or temperature (°F) depending on N1. If HIN is negative, the inlet enthalpy will be either the absolute value of HIN or the last calculated first node enthalpy if the flow has reversed.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	GIN	= The inlet mass flux (MLBh-ft^2) to be distributed by the N2 option.
	AFLUX	= The average heat flux (MBtu/h-ft^2).
	HOUT	= The exit enthalpy. If HOUT is specified, and the flow reverses, the "new" exit enthalpy will be HOUT. Otherwise, for HOUT blank, the "new" exit enthalpy will be calculated exit enthalpy before reversal (Btu/lb).
	DPS	= An option to specify a pressure drop rather than a flow boundary condition in the steady-state implicit solution scheme. The code iterates on the total inlet flow rate until the calculated pressure drop is close to DPS (psi).
SETUP.11.2	<u>HINLET(I)</u> (I = 1 to NCHANL)	Format (12E5.0)
	Optional input N1 = 2 or 3	
	Inlet enthalpy or temperature, where:	
	HINLET	= The inlet enthalpy (N1 = 2) or inlet temperature (N1 = 3) of each individual subchannel; read one value for each subchannel.
SETUP.11.3	<u>FINLET(I)</u> (I = 1 to NCHNL)	Format (12E5.0)
	Optional input - N2 > 2	
	Inlet flow rate, where:	
	FINLET	= The individual subchannel inlet flow ($F(I)/F_{\text{TOTAL}}$) for each individual subchannel.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.11.4	<u>YP(I), FP(I)</u> (I = 1 to N3)	Format (12E5.0) Optional input - N3 > 1 Pressure transient table, where: YP = Transient time (sec) when factor is applied. FP = Fraction of steady-state <u>System Pressure</u> at transient time (YP).
SETUP.11.5	<u>YH(I), FH(I)</u> (I = 1 to N4)	Format (12E5.0) Optional input - N4 > 1 Enthalpy or temperature transient table. YH = The transient time (sec) when factor is applied. FH = The fraction of inlet enthalpy (N1 = 0 or 2) or the fraction of inlet temperature (N1 = 1 or 3) at the transient time (YH).
SETUP.11.6	<u>YG(I), FG(I)</u> (I = 1 to N5)	Format (12E5.0) Optional input - N5 > 1 Inlet flow or pressure drop boundary condition transient table. YG = The transient time (sec) when factor is applied. FG = The fraction of steady-state inlet flow at the transient time (YG) if inlet flow boundary condition is specified [K11 (Group 9) = 0, 3, or 4]. For pressure drop boundary conditions (K11 = 1 or 2), FG is either the fraction of the steady-state pressure drop (N7 = 1) or FG is the pressure drop in psi (N7 = 0) at the transient time (YG).

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.11.7	<u>YQ(I), FQ(I)</u>	(I = 1 to N6) Format (12E5.0) Optional input N6 > 1 Heat flux transient table. YQ = The transient time (sec) when factor is applied. FQ = The fraction of steady state heat flux at the transient time (YQ).
SETUP. 11.8	<u>YHX(I), FHX(I)</u>	(I = 1 to NHX) Optional input N8 > 1 Exit enthalpy transient table. YHX = The transient time (sec) when factor is applied. FHX = The fraction of steady state exit enthalpy (HOUT) at the transient time (YHX) to be used if the flow reverses.
SETUP. 12	<u>GROUP 12 OUTPUT OPTIONS FOR CALCULATIONS</u>	Format (10I5), where: N0 = Card Group Number N1 = NOUT, print option. N1 = 0, print subchannel data only. N1 = 1, print subchannel data and crossflows only. N1 = 2, print subchannel data and fuel rod temperatures only. N1 = 3, print subchannel data, crossflows, and fuel rod temperatures. N2 = NPCHAN, an option for subchannel data printout. N2 = 0, print all subchannel data. N2 > 0, read N2 subchannel identification numbers of subchannels to be printed.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
	N3	= NPROD , an option for fuel rod heat flux and/or temperature printout. N3 = 0 , data for all rods are printed if called for by N1 . N3 > 0 , read in N3 rod identification numbers of rods to be printed. IF NCHF (SETUP.8) is > 0 , CHF data is also printed along with the rod data.
	N4	= NPNODE , an option for interior fuel node temperature printout for all rods specified by N3 . Option only applies if interior rod temperatures are calculated using the fuel model (GROUP 8). N4 = 0 , print rod centerline, rod surface and cladding surface temperature. N4 = 3 to 7 , N4 equally spaced interior rod temperatures are printed along with the cladding surface temperature.
	N5	= NPGAP , an option for GAP crossflow printout if called for by N1 . N5 = 0 , print crossflow for all GAPS . N5 > 0 , read GAP numbers of GAPS to be printed.
	N6	= NSKPLT , an option for transient plotting. N6 = 0 , no plots are printed. N6 > 0 , plot data every N6 time steps. Must read four sets of maximum and minimum coordinates for the four variables plotted. (SETUP. 12.6)
	N7	= NPLTCH , option to plot channels if called for by N6 . N7 = 0 , plot all subchannels. N7 > 0 , read subchannel numbers of those plotted.
	N8	= NPLTGP , an option for GAP crossflow plotting if called for by N6 . N8 = 0 , plot all gaps. N8 > 0 , read GAP numbers to be plotted.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.12.1	<u>PRINTC(I)</u> (I= 1 to N2)	Format (2413)
	Optional input N2 > 0	
	PRINTC	= Read subchannel identification numbers of N2 subchannels for which data is to be printed. N2 = 0, print all subchannels.
SETUP.12.2	<u>PRINTR(I)</u> (I= 1 to N3)	Format (2413)
	Optional input - N3 > 0	
	PRINTR	= Read rod numbers of N3 rods for which heat flux and temperatures are to be printed if called for by N1.
SETUP.12.3	<u>PRINTG(I)</u> (I= 1 to N5)	Format (2413)
	Optional input - N5 > 0	
	PRINTG	= Read GAP numbers of N5 for which crossflows are to be printed if called for by N1.
SETUP.12.4	<u>IPLITCH(I)</u> (I= 1 to N7)	Format (2413)
	Optional input - N7 > 0	
	IPLITCH	= Read subchannel numbers of N7 subchannels for which line plots are to be printed if called for by N6.
SETUP.12.5	<u>IPLTGP(I)</u> (I= 1 to N8)	Format (2413)
	Optional input - N8 > 0	
	IPLTGP	= Read GAP numbers of those GAPS for which crossflows are to be plotted, if called for by N6.

<u>Card Label</u>	<u>Variables</u>	<u>Format and Explanation</u>
SETUP.12.6	<u>HIP(I),ZPT(I)</u> (I = 1 to 4)	Format (12F5.0)
	Optional input - N6 > 0	
	HIP, ZPT	= The maximum and minimum plot coordinates for the four kinds of plots available. The maximum and minimum are in the units of the variable plotted which are:
	HIP(1),ZPT(1)	- Mass flux (million lb/h-ft ²)
	HIP(2),ZPT(2)	- Enthalpy (1000 Btu/lb)
	HIP(3),ZPT(3)	- Pressure drop (psi)
	HIP(4),ZPT(4)	- Crossflow (lb/sec-ft)
	Mass flow rate, enthalpy and pressure drop are plotted for each subchannel specified (see N6 and N7). Crossflow is plotted for each GAP specified (see N6 and N8). If HIP(I) = 0, that quantity is not plotted.	

4.0 COBRA-IV PC EXAMPLE INPUT FILES

To familiarize you with the format of the input file for COBRA-IV PC, several sample files have been included on the diskette; this will assist you in a multitude of modeling problems. A listing of each input file and a description of the event that they portray is provided below. Prototypical fuel element dimensions and reactor core parameters have been obtained from Duderstadt and Hamilton (1976). It is suggested that you review the listing of each input file in reference with Chapter 3.0 of this manual, COBRA INPUT DESCRIPTION.

4.1. EXAMPLES OF STEADY-STATE OPERATIONS

Two of the sample problems provided on the COBRA-IV PC diskette represent steady-state operating conditions for a single fuel rod operating at the center of the reactor. The calculational model represents a single fuel (hot) rod with two coolant channels. Note that to insure calculational stability, the model needs to incorporate at least two coolant subchannels. This can be accomplished by splitting a single coolant channel into two identical subchannels (see Figure 4.1). These files are designated as BWR6SS.TXT and PWR16SS.TXT and are shown as follows, first the card group identifier label, where the label between () is not part of the input file, then the input file line as it appears in the input file. You should obtain a copy of the input file for comparison purposes.

4.1.1. 6 x 6 Boiling Water Reactor Fuel Element

BWR6SS.TXT file:

(COBRA.1)

100

(SETUP.O)

1 1 BWR 6 X 6 Steady State Case

(SETUP.1)

1 1 8 0 0

(SETUP.1.1 (repeat as needed))

14.7211.9	.01672	26.800	180.15	1150.50	.75234	.39059	.003792
100.327.9	.01774	4.4340	298.61	1187.80	.51171	.39247	.002990

FIGURE 4.1. Hot Channel Model

500.0467.1	.01975	.92830	449.50	1205.30	.27771	.36513	.002026
1000.544.8	.02159	.44590	542.40	1192.40	.23413	.33125	.001489
1250.572.6	.02250	.34540	578.60	1181.60	.22046	.31512	.001296
1500.596.4	.02346	.27690	611.50	1168.70	.20774	.29977	.001131
1750.617.3	.02450	.25680	642.30	1153.20	.19890	.28762	.000986
2000.636.0	.02565	.18813	671.90	1136.30	.19006	.27547	.000857
2100.642.9	.02616	.17491	683.60	1128.50	.18657	.27061	.000809
2200.649.6	.02670	.16270	695.30	1120.30	.18310	.26597	.000763
2300.656.1	.02728	.15133	707.00	1111.40	.18003	.26198	.000718
2400.662.3	.02791	.14067	718.80	1101.80	.17697	.25800	.000675
2500.668.3	.02860	.13059	730.90	1091.40	.17389	.25401	.000633
2750.682.5	.03077	.10717	763.00	1060.40	.16622	.24405	.000536
2850.687.8	.03192	.09811	777.30	1045.00	.16315	.24007	.000499
3000.695.5	.03431	.08404	802.50	1015.50	.10029	.11920	.000445
3100.700.5	.03701	.07322	825.40	986.80	.09351	.11881	.000411
3200.705.3	.04805	.05444	890.60	919.90	.10164	.13405	.000378
(SETUP.2)							
2	0	0	0	1			
(SETUP.2.1)							
.183 -.05							
(SETUP.3)							
3	11	0	0	0	0	0	0
(SETUP.3.1)							
0.0.3200	.1.6600	.2 .980	.31.320	.41.400	.51.380		
.61.300	.71.040	.8 .790	.9 .660	1.0 .460			
(SETUP. 4)							
4	2	2					
(SETUP.4.1)							
1.1083.7730.7730		2.0730					
2.1083.7730.7730							
(SETUP.7)							
7	2	0	9	1	1		
(SETUP.7.4)							
.1	1	.2	1	.3	1	.4	1
.7	1	.8	1	.9	1	.5	1
(SETUP.7.5)							
1	1.8						
2	1.8						
(SETUP.8)							
8	1	1	3	1	3	1	0
(SETUP.8.1)							
0	1.4921	1.59	1	.5	2	.5	
(SETUP.8.2)							
3.842.1145684.9.41577.610.0808409.6.03401200.							
(SETUP.8.3)							
0.0-.43095E-3.634742E-7.15816E-11							
(SETUP. 9)							
9	0	0	0	0	0		
(SETUP.9.1)							
150.	0.	.001	.001	.001	.5	.5	.0
					.0	.0	.0
					.8	1.6	1.0

```

(SETUP. 9.2)
  10  1  20  20  7
(SETUP. 10)
  1  0  0  0  0
(SETUP. 10.1)
.0035
(SETUP. 11)
  11  1  1  0  0  0  0  0  0  0
(SETUP. 11.1)
  1058.  516.2  1.490  .159488
(SETUP. 12)
  1  2  5  0  0  7

```

4.1.2. OE 16 x 16 Pressurized Water Reactor Fuel Element

PWR16SS.TXT is identical to BWR6SS.TXT with regards to the types of input cards used, only the fuel rod dimensions and flow and heat generation parameters have been changed.

```

(COBRA. 1)
  100
(SETUP.0)
  1  1  PWR 16 X 16 Steady State Case
(SETUP. 1)
  1  1  8  0  0
((SETUP. 1.1) (repeat as needed))
  14.7211.9 .01672 26.800 180.15 1150.50 .75234 .39059 .003792
  100.327.9 .01774 4.4340 298.61 1187.80 .51171 .39247 .002990
  500.0467.1 .01975 .92830 449.50 1205.30 .27771 .36513 .002026
  1000.544.8 .02159 .44590 542.40 1192.40 .23413 .33125 .001489
  1250.572.6 .02250 .34540 578.60 1181.60 .22046 .31512 .001296
  1500.596.4 .02346 .27690 611.50 1168.70 .20774 .29977 .001131
  1750.617.3 .02450 .25680 642.30 1153.20 .19890 .28762 .000986
  2000.636.0 .02565 .18813 671.90 1136.30 .19006 .27547 .000857
  2100.642.9 .02616 .17491 683.60 1128.50 .18657 .27061 .000809
  2200.649.6 .02670 .16270 695.30 1120.30 .18310 .26597 .000763
  2300.656.1 .02728 .15133 707.00 1111.40 .18003 .26198 .000718
  2400.662.3 .02791 .14067 718.80 1101.80 .17697 .25800 .000675
  2500.668.3 .02860 .13059 730.90 1091.40 .17389 .25401 .000633
  2750.682.5 .03077 .10717 763.00 1060.40 .16622 .24405 .000536
  2850.687.8 .03192 .09811 777.30 1045.00 .16315 .24007 .000499
  3000.695.5 .03431 .08404 802.50 1015.50 .10029 .11920 .000445
  3100.700.5 .03701 .07322 825.40 986.80 .09351 .11881 .000411
  3200.705.3 .04805 .05444 890.60 919.90 .10164 .13405 .000378
(SETUP.2)
  2  0  0  0  1

```

```

(SETUP. 2.1)
.183 -.05
(SETUP.3)
3 1 1 0 0 0 0 0 0
(SETUP.3.1)
0.0.3800 .1.9500 .21.280 .31.400 .41.550 .51.490
.61.430 .7.9600 .8.5100 .9.3600 1.0.2200
(SETUP. 4)
4 2 2
(SETUP.4.1)
1.0697.5999.5999 2.0610
2.0697.5999.5999
(SETUP. 7)
7 2 0 9 1 1
(SETUP.7.4)
.1 1 .2 1 .3 1 .4 1 .5 1 .6 1
.7 1 .8 1 .9 1
(SETUP. 7.5)
1 1.8
2 1.8
(SETUP.8)
8 1 1 3 1 2 1 0
(SETUP.8.1)
0 1.3819 1.55 1 .5 2 .5
(SETUP.8.2)
3.842.1145684.9.32487.610.0808409.6.02501200.
(SETUP.8.3)
0.0- .43095E-3.634742E-7.15816E-11
(SETUP. 9)
9 0 0 0 0 0
(SETUP.9.1)
150. 0. .001 .001 .001 .5 .5 .0 .0 .0 .8 1.6 1.0
(SETUP. .9.2)
10 1 20 20 7
(SETUP. 10)
1 0 0 0 0
(SETUP. 10.1)
.0035
(SETUP. 11)
11 1 1 0 0 0 0 0 0 0
(SETUP.11 - I)
2250. 564.8 2.2967 ,15850
(SETUP. 12)
1 2 5 0 0 7

```

4.2: TRANSIENT CASES

The following sample problems provided on the COBRA-IV PC diskette represent transient operating conditions for a single fuel rod operating at the center of the reactor. In each case, a hypothetical event has been devised that illustrates some of the capabilities of the COBRA-IV PC code and are not intended to represent credible accident scenarios, nor are they to be used as such. The calculational model represents a single fuel rod (hot rod) with two coolant subchannels (see Figure 4.1). Once again the coolant channel has been divided into two equal subchannels to insure calculational stability. These files are designated as PWR16T1.TXT, PWR16T2.TXT, and PWR16T3.TXT and are shown as follows, first the card group identifier label, where the label between () is not part of the input file, then the input file line as it appears in the input file. The user should obtain a copy of the input file for comparison purposes.

4.2.1. Event 1 - Rod Ejection

The ejection of a Control Element Assembly (CEA) results from physical failure of a pressure barrier component in the control rod drive assembly. The pressure differential acting on the control rod assembly rapidly ejects the assembly from the core region. The power excursion due to rapid increase in reactivity is limited by the negative Doppler reactivity feedback effect and terminated by reactor protection system trips. The general performance characteristics of such an event are shown in Figure 4.2 (the reactor trip is intentionally delayed to make this accident more eventful).

PWR16T1.TXT file:

```
(COBRA. 1)
100
(SETUP.0)
1 1 PWR 16 X 16 Transient Case #1 - Rod Ejection
(SETUP. 1)
1 1 8 0 0
((SETUP. 1.1) (repeat as needed))
14.7211.9 .01672 26.800 180.15 1150.50 .75234 .39059 .003792
100.327.9 .01774 4.4340 298.61 1187.80 .51171 .39247 .002990
500.0467.1 .01975 .92830 449.50 1205.30 .27771 .36513 .002026
```

FIGURE 4.2. Event 1 - Rod Ejection

1000.544.8	.02159	.44590	542.40	1192.40	.23413	.33125	.001489
1250.572.6	.02250	.34540	578.60	1181.60	.22046	.31512	.001296
1500.596.4	.02346	.27690	611.50	1168.70	.20774	.29977	.001131
1750.617.3	.02450	.25680	642.30	1153.20	.19890	.28762	.000986
2000.636.0	.02565	.18813	671.90	1136.30	.19006	.27547	.000857
2100.642.9	.02616	.17491	683.60	1128.50	.18657	.27061	.000809
2200.649.6	.02670	.16270	695.30	1120.30	.18310	.26597	.000763
2300.656.1	.02728	.15133	707.00	1111.40	.18003	.26198	.000718
2400.662.3	.02791	.14067	718.80	1101.80	.17697	.25800	.000675
2500.668.3	.02860	.13059	730.90	1091.40	.17389	.25401	.000633
2750.682.5	.03077	.10717	763.00	1060.40	.16622	.24405	.000536
2850.687.8	.03192	.09811	777.30	1045.00	.16315	.24007	.000499
3000.695.5	.03431	.08404	802.50	1015.50	.10029	.11920	.000445
3100.700.5	.03701	.07322	825.40	986.80	.09351	.11881	.000411
3200.705.3	.04805	.05444	890.60	919.90	.10164	.13405	.000378
(SETUP.2)							
2 0	0	0	1				
(SETUP.2.1)							
.183 -.05							
(SETUP.3)							
3 1 1 0 0	0	0	0	0			
(SETUP.3.1)							
0.0.3800	.1.9500	.21.280	.31.400	.41.550	.51.490		
.61.430	.7.9600	.8.5100	.9.3600	1.0.2200			
(SETUP.4)							
4 2 2							
(SETUP.4.1)							
1.0697.5999.5999		2.0610					
2.0697.5999.5999							
(SETUP. 7)							
7 2 0 9 1 1							
(SETUP. 7.4)							
.1 1 .2 1 .3 1 .4 1 .5 1 .6 1							
.7 1 .8 1 .9 1							
(SETUP. 7.5)							
1 1.8							
2 1.8							
(SETUP.8)							
8 1 1 3 1 2 1 0							
(SETUP.8.1)							
0 1.3819 1.55 1 .5 2 .5							
(SETUP.8.2)							
3.842.1145684.9.32487.610.0808409.6.02501200.							
(SETUP.8.3)							
0.0- .43095E-3.634742E-7.15816E-11							
(SETUP. 9)							
9 0 0 0 0 0							
(SETUP.9.1)							
150. 7. .001 .001 .001 .5 .5 .0 .0 .0 .8 1.6 1.0							
(SETUP. 9.2)							

```

    10    7    20    20    7
(SETUP.10)
    1    0    0    0    0
(SETUP.10.1)
.0035
(SETUP.11)
    1    1    1    1    0    0    0    5    0    0    0
(SETUP.11.1)
    2250.    564.8    2.2967    .15850
(SETUP.11.7)
    0.    1.0    1.    2.5    2.5    2.5    3.0    .10    7.0    .10
(SETUP.12)
    1    2    5    0    0    7

```

4.2.2 Event 2 - Locked Rotor

Following seizure and stoppage of the reactor coolant pump shaft, the core flow rate rapidly decreases. An increase results in the average coolant temperature in the core; thereby leading to a reactor scram by plant safety systems. Following scram, heat stored in the fuel rods continues to pass into the core coolant, causing the coolant to increase in temperature and expand. At the same time, heat transfer to the secondary side of the steam generator is reduced because the reduced flow results in a decreased surface heat transfer coefficient and because the reactor coolant temperature in the tube decreases. This happens while the coolant temperature in the secondary side increases (turbine steam flow is reduced by zero upon trip). The rapid expansion of coolant in the reactor core, combined with the reduced heat transfer in the steam generator, causes an **insurge** of coolant into the pressurizer and a pressure increase throughout the reactor coolant system. The relative histories of key parameters in such an event are shown in Figure 4.3.

PWR16T2.TXT file:

```

(COBRA. 1)
100
(SETUP.0)
    1    1    PWR 16 X 16 Transient Case #2 - Locked Rotor
((SETUP.1.1) (repeat as needed))
    1    18    0    0
14.7211.9    .01672    26.800    180.15    1150.50    .75234    .39059    .003792

```

FIGURE 4.3. Event 2 - Locked Rotor

100.0327.9	.01774	4.4340	298.61	1187.80	.51171	.39247	.002990
500.0467.1	.01975	.92830	449.50	1205.30	.27771	.36513	.002026
1000.544.8	.02159	.44590	542.40	1192.40	.23413	.33125	.001489
1250.572.6	.02250	.34540	578.60	1181.60	.22046	.31512	.001296
1500.596.4	.02346	.27690	611.50	1168.70	.20774	.29977	.001131
1750.617.3	.02450	.25680	642.30	1153.20	.19890	.28762	.000986
2000.636 .0	.02565	.18813	671.90	1136.30	.19006	.27547	.000857
2100.642.9	.02616	.17491	683.60	1128.50	.18657	.27061	.000809
2200.649.6	.02670	.16270	695.30	1120.30	.18310	.26597	.000763
2300.656.1	.02728	.15133	707.00	1111.40	.18003	.26198	.000718
2400.662.3	.02791	.14067	718.80	1101.80	.17697	.25800	.000675
2500.668.3	.02860	.13059	730.90	1091.40	.17389	.25401	.000633
2750.682.5	.03077	.10717	763.00	1060.40	.16622	.24405	.000536
2850.687.8	.03192	.09811	777.30	1045.00	.16315	.24007	.000499
3000.695.5	.03431	.08404	802.50	1015.50	.10029	.11920	.000445
3100.700.5	.03701	.07322	825.40	986.80	.09351	.11881	.000411
3200.705.3	.04805	.05444	890.60	919.90	.10164	.13405	.000378

(SETUP.2)

2 0 0 0 1

(SETUP. 2.1)

.183 -.05

(SETUP.3)

3 1 1 0 0 0 0 0 0

(SETUP.3.1)

0.0.3800 .1.9500 .21.280 .31.400 .41.550 .51.490

.61.430 .7.9600 .8.5100 .9.3600 1.0.2200

(SETUP. 4)

4 2 2

(SETUP.4.1)

1.0697.5999.5999 2.0610

2.0697.5999.5999

(SETUP.7)

7 2 0 9 1 1

(SETUP. 7.4)

.1 1 .2 1 .3 1 .4 1 .5 1 .6 1

.7 1 .8 1 .9 1

(SETUP. 7.5)

1 1.8

2 1.8

(SETUP.8)

8 1 1 3 1 2 1 0

(SETUP.8.1)

0 1.3819 1.55 1 .5 2 .5

(SETUP.8.2)

3.842.1145684.9.32487.610.0808409.6.02501200.

(SETUP.8.3)

0.0- .43095E-3.634742E-7.15816E-11

(SETUP.9)

9 0 0 0 0 0

(SETUP. 9.1)

```

150.  7. .001 .001 .001  .5  .5  .0  .0  .0  .8 1.6 1.0
(SETUP. 9.2)
  10   7   20   20   7
(SETUP. 10)
   1   0   0   0   0
(SETUP. 10.1)
.0035
(SETUP. 11)
  11   1   1   2   3   0   4   0   0   0
(SETUP. 11.1)
 2250.  564.8  2.2967  .15850
(SETUP. 11.3)
  0.  1.0  7.  1.10
(SETUP. 11.4)
  0.  1.0  1.  .75  7.  .75
(SETUP. 11.7)
  0.  1.0  5.  1.0  5.5  .10  7.  .10
(SETUP. 12)
  1   2   5   0   0   7

```

4.2.3 Event 3 - Total Loss of AC Power

Total loss of **AC** power, or station blackout, followed by loss of auxiliary feedwater pumps for an extended period, could result in inadequate core cooling with potentially serious core degradation or core melt consequences. Although this is a low probability event sequence, it could be a significant contributor to the overall risk of core melt accidents.

The total loss of electrical power allows the control rods to immediately drop into the core, adding sufficient negative reactivity to terminate most of the thermal power generation. Subsequent to the reactor trip, stored and fission product decay energy is dissipated by the reactor coolant and steam generator systems. The loss of electrical power trips the reactor coolant pumps as well as the main feedwater pumps. This results in a flow coastdown until natural circulation is initiated for convective heat transfer.

The total loss of electrical power trips the turbine and closes the turbine stop valves. The core decay energy continues to be transferred to the steam generator secondary side and increases the steam pressure. Since the turbine bypass system is not available due to lack of **AC** power, the residual water inventory in the steam generator is used to remove the heat. The resultant

steam is usually released to the atmosphere via the steam generator safety relief valves. The pressurizer heaters become deenergized and the Over Pressurization Relief Values (PORVs) would not be operable during such a transient.

For this project, in order to make this transient more eventful, the standby diesel generators are assumed to be unavailable or fail to start upon initiation of this transient. The emergency feedwater system, therefore, is not available to supply water to the steam generators. Although one of the emergency feedwater pumps is driven by a steam turbine, due to lack of AC power the control system would not properly function to start the pump. The relative histories of reactor power and thermal hydraulic conditions are shown in Figure 4.4.

PWR16T3.TXT file:

```
(COBRA. 1)
100
(SETUP.O)
1 1 PWR 16 X 16 Transient Case #3 - Total AC Power Loss
(SETUP. 1)
1 1 8 0 0
((SETUP. 1.1) (repeat as needed))
14.7211.9 .01672 26.800 180.15 1150.50 .75234 .39059 .003792
100.327.9 .01774 4.4340 298.61 1187.80 .51171 .39247 .002990
500.0467.1 .01975 .92830 449.50 1205.30 .27771 .36513 .002026
1000.544.8 .02159 .44590 542.40 1192.40 .23413 .33125 .001489
1250.572.6 .02250 .34540 578.60 1181.60 .22046 .31512 .001296
1500.596.4 .02346 .27690 611.50 1168.70 .20774 .29977 .001131
1750.617.3 .02450 .25680 642.30 1153.20 .19890 .28762 .000986
2000.636.0 .02565 .18813 671.90 1136.30 .19006 .27547 .000857
2100.642.9 .02616 .17491 683.60 1128.50 .18657 .27061 .000809
2200.649.6 .02670 .16270 695.30 1120.30 .18310 .26597 .000763
2300.656.1 .02728 .15133 707.00 1111.40 .18003 .26198 .000718
2400.662.3 .02791 .14067 718.80 1101.80 .17697 .25800 .000675
2500.668.3 .02860 .13059 730.90 1091.40 .17389 .25401 .000633
2750.682.5 .03077 .10717 763.00 1060.40 .16622 .24405 .000536
2850.687.8 .03192 .09811 777.30 1045.00 .16315 .24007 .000499
3000.695.5 .03431 .08404 802.50 1015.50 .10029 .11920 .000445
3100.700.5 .03701 .07322 825.40 986.80 .09351 .11881 .000411
3200.705.3 .04805 .05444 890.60 919.90 .10164 .13405 .000378
(SETUP. 2)
2 0 0 0 1
```

4.14

FIGURE 4.4. Event 3 - Total Loss of AC Power

(SETUP. 2.1)
 .183 -.05
 (SETUP.3)
 3 1 1 0 0 0 0 0 0
 (SETUP.3.1)
 0.0.3800 .1.9500 .21.280 .31.400 .41.550 .51.490
 .61.430 .7.9600 .8.5100 .9.3600 1.0.2200
 (SETUP. 4)
 4 2 2
 (SETUP.4.1)
 1.0697.5999.5999 2.0610
 2.0697.5999.5999
 (SETUP. 7)
 7 2 0 9 1 1
 (SETUP. 7.4)
 .1 1 .2 1 .3 1 .4 1 .5 1 .6 1
 .7 1 .8 1 .9 1
 (SETUP.7.5)
 1 1.8
 2 1.8
 (SETUP.8)
 8 1 1 3 1 2 1 0
 (SETUP.8.1)
 0 1.3819 1.55 1 .5 2 .5
 (SETUP.8.2)
 3.842.1145684.9.32487.610.0808409.6.02501200~
 (SETUP.8.3)
 0.0-.43095E-3.634742E-7.15816E-11
 (SETUP.9)
 9 0 0 0 0 0
 (SETUP. 9.1)
 150. 35. .001 .001 .001 .5 .5 .0 .0 .0 .8 1.6 1.0
 (SETUP. 9.2)
 10 14 20 20 7
 (SETUP. 10)
 1 0 0 0 0
 (SETUP. 10.1)
 .0035
 (SETUP. 11)
 1 1 1 3 3 3 0 4 0 0 0
 (SETUP.11.1)
 2250. 564.8 2.2967 .15850
 (SETUP.11.2)
 0. 1.0 20. 1.06 35. 1.03
 (SETUP.11.3)
 0. 1.0 10. 1.05 35. .85
 (SETUP.11.4)
 0. 1.0 20. 1.06 35. 1.03

```

(SETUP.11.7)
  0.  1.0  10. 1.20  20.  .10  35.  .10
(SETUP. 12)
  12   5   0   0   7

```

4.3. MULTI-ROD AND MULTI-SUBCHANNEL SAMPLE PROBLEM

The following examples are offered as an illustration of the techniques used to model a fuel array with multiple fuel elements and subchannels.

4.3.1. Chernobyl RBMK-1000 Fuel Element Model

After the 1986 accident at the Chernobyl Nuclear Power Plant in the Soviet Union, considerable interest was generated surrounding the operation of these types of facilities (Petrosyants 1979; Aden 1978). The RBMK-1000 is a graphite moderated reactor consisting of approximately 1661 process tubes. The active core region of the reactor is 7.0 m (275.5 in.). Fuel assemblies for the RBMK-1000 consist of an upper and lower subassembly of 18 fuel elements each 364.4 cm (143.5 in.) long. The upper and lower assemblies are then attached to a zircaloy traverse rod with a 20.0 cm (7.87 in.) free flow gap between the assemblies. The fuel elements in the assembly contain 10 spacer grids of the cellular type made of stainless steel. The cladding and the fuel assembly ends are made of zircalloy with 1% niobium. The fuel elements are 13.6 mm (0.5354 in.) in diameter, with a clad thickness of 0.825 mm (0.0354 in.). The fuel assembly contains a gas plenum and is pressurized to 98 kPa (14.21 psia). Reactor operational parameters are provide in Table 4.1.

From this information an input file is created, which will allow a preliminary analysis of the RBMK-1000 fuel assembly thermal operating characteristics under steady-state conditions. The model takes advantage of the 1/6 symmetry of the fuel assembly to reduce the size of the input problem, and allow for shorter running times. The model therefore contains three fuel pins, a central zircaloy transverse rod, seven flow channels with axially-varying dimensions to represent the spacing between fuel sections, and an axially-varying fuel element composition. Figure 4.5 shows the model cross section for a fueled region. The input file listed below is for tutorial

purposes only, and in no way is it intended to truly represent the complexity of the RBMK-1000 during accident conditions.

TABLE 4.1. Reactor Parameters

Thermal Power	3000 MW
Process Tubes	1661
Maximum Power/Tube	3000 kW
Fuel Elements/Assembly	18
Fuel Rod Diameter	13.6 mm (.5354 in.)
Cladding Thickness	.825 mm (.0354 in.)
Fuel Element Length	364.5 cm (143.5 in.)
Gap between Fuel Sections	20.0 cm (7.87 in.)
Peak/Average Radial Factor	1.48
Peak/Average Axial Factor	1.40
Inlet Temperature	544 K
Inlet Pressure	15.51 MPa
Outlet Temperature	598 K
Outlet Pressure	14.38 MPa
Coolant Flow Rate	38.19 Mkg/h
MDNBR	5.50

FIGURE 4.5. RBMK-1000 Fuel Assembly

(COBRA. 0)

100

(SETUP.O)

1 1

RUSSIAN REACTOR MODEL - Steady State Operation

(SETUP. 1)

1 1 8 0 0

((SETUP. 1.1) (repeat as needed))

14.7211.9	.01672	26.800	180.15	1150.50	.75234	.39059	.003792
100.327.9	.01774	4.4340	298.61	1187.80	.51171	.39247	.002990
500.0467.1	.01975	.92830	449.50	1205.30	.27771	.36513	.002026
1000.544.8	.02159	.44590	542.40	1192.40	.23413	.33125	.001489
1250.572.6	.02250	.34540	578.60	1181.60	.22046	.31512	.001296
1500.596.4	.02346	.27690	611.50	1168.70	.20774	.29977	.001131
1750.617.3	.02450	.25680	642.30	1153.20	.19890	.28762	.000986
2000.636.0	.02565	.18813	671.90	1136.30	.19006	.27547	.000857
2100.642.9	.02616	.17491	683.60	1128.50	.18657	.27061	.000809
2200.649.6	.02670	.16270	695.30	1120.30	.18310	.26597	.000763
2300.656.1	.02728	.15133	707.00	1111.40	.18003	.26198	.000718
2400.662.3	.02791	.14067	718.80	1101.80	.17697	.25800	.000675
2500.668.3	.02860	.13059	730.90	1091.40	.17389	.25401	.000633
2750.682.5	.03077	.10717	763.00	1060.40	.16622	.24405	.000536
2850.687.8	.03192	.09811	777.30	1045.00	.16315	.24007	.000499
3000.695.5	.03431	.08404	802.50	1015.50	.10029	.11920	.000445
3100.700.5	.03701	.07322	825.40	986.80	.09351	.11881	.000411
3200.705.3	.04805	.05444	890.60	919.90	.10164	.13405	.000378

(SETUP. 2)

2 1 1 1 1

(SETUP.2.1)

.183 -.05

(SETUP.3)

3 1 4 0 0 0 0 0 0

(SETUP.3.1)

0.0.3000	.1	.800	.21.220	.31.340	.41.380	.4631.400
.464 .000	.536	.000	.5371.400	.61.380	.71.340	.81.220
.9 .800	1.0.3000					

(SETUP.4)

4 7 7

(SETUP. 4.1)

1.0938.8411.5607	2.0709.6772	4.0709.6772
2.0938.8411.8411	3.0709.6772	5.0709.6772
3.0662.8411.8411	4.0709.6772	6.0709.4283
4.0938.8411.8411	7.0709.6772	
5.0595.9730.5607	6.0964.6961	
6.11901.9461.121	7.0964.6961	
7.0595.9730.5607		

(SETUP. 5)

5 6 6 1

(SETUP. 5.1)

0. .456 .457 .514 .515 1.0

(SETUP. 5.2)

```

2
1.0 1.0 2.12 2.12 1.00 1.00
3
1.0 1.0 1.92 1.92 1.00 1.00
4
1.0 1.0 2.12 2.12 1.00 1.00
5
1.0 1.0 1.55 1.55 1.00 1.00
6
1.0 1.0 1.55 1.55 1.00 1.00
7
1.0 1.0 1.55 1.55 1.00 1.00
(SETUP.7)
7 2 0 1 0 1 1
(SETUP.7.4)
.05 1 .15 1 .25 1 .35 1 .45 1 .55 1
.65 1 .75 1 .85 1 .95 1
(SETUP.7.5)
1 1.8
2 1.8
3 1.8
4 1.8
5 1.8
6 1.8
7 1.8
(SETUP.8)
8 4 4 3 3 2 3 0 2
(SETUP.8.1)
1 2.5354 1.00 1 .333 2 .25 3 .167 4 .25
1 3.5354 1.08 2 .25 3 .167 5.2915 6.2915
1 4.5354 1.08 3.167 4 .25 6.2915 7.2915
2 1.5354 0.05 1 .167
(SETUP.8.2)
10.7.1145684.9.45357.610.0808409.6.03541800.
7.610.0808409.6.53537.610.0808409.6.00091800.
(Next line represents material #3 "Void", fill in with zeros if you wish)

(SETUP.8.3)
0.0 -6.00E-5 0.0E00 0.0E00
(SETUP.8.4)
3
.457 1 .514 3 1.00 1
3
.457 2 .514 2 1.00 2
(SETUP.9)
9 0 0 0 0 0
(SETUP.9.1)
275.6 0. .01 .010 .001 .5 .5 .0 .0 .0 .8 1.52 1.0
(SETUP.9.2)
19 1 30 20 7

```

```

(SETUP. 10)
  1  0  0  0  0
(SETUP. 10.1)
.0035
(SETUP. 11)
  1  1  1  1  0  0  0  0  0  0  0
(SETUP. 11.1)
  2250.    520.0    2.07269    .107365
(SETUP. 12)
  1  2  5  0  0  7

```

4.3.2. 7-Pin Wire-Wrapped Bundle

To provide a benchmark for the forced-flow mixing problem, a 7-pin wire-wrapped problem is included. The geometry is shown in Figure 4.6. This 7-pin bundle has 0.584 cm (0.23-in.) diameter fuel pins on a 0.726 cm (0.286-in.) pitch [0.142 cm (0.056 in.) gap spacing]. The wire wraps are assumed to start at the top and move clockwise with one rotation every 30.48 cm (12 in.). The bundle is 90.44 cm (36 in.) long to allow flow through three pitch lengths. Uniform radial and axial power is assumed with a heat flux of 1.577 MW/m^2 ($0.5 \times 10^{-6} \text{ Btu/h-ft}^2$). The inlet temperature is 699.4 K (800°F), and the mass flux is 0.1267 Mkg/h-m^2 ($3.0 \times 10^6 \text{ lb/h-ft}^2$). Coolant is liquid sodium.

```

(COBRA. 0)
  100
(SETUP.O)
  1          7-PIN WIRE WRAP SAMPLE PROBLEM
(SETUP. 1)
  1  2  4  0  0
((SETUP. 1.1) (repeat as needed))
52E-6 500.    .01801 1000000.    303.76    2204.80    .9235    45.43    .01238
16E-5 550.    .01801 1000000.    319.44    2212.90    .8591    44.60    .01219
48E-5 600.    .01828 1000000.    335.01    2220.50    .8038    43.79    .01200
.0012 650.    .01842 409876.    350.49    2227.60    .7558    42.98    .01181
.0030 700.    .01856 178120.    365.88    2234.10    .7138    42.18    .01162
.0067 750.    .01870 83102.    381.19    2240.20    .6767    41.39    .01143
.0139 800.    .01885 41266.    396.43    2245.80    .6437    40.62    .01124
.0241 840.    .01887 24533.    408.58    2249.90    .6198    40.00    .01109
.0404 880.    .01909 15060.    420.69    2253.90    .5980    39.39    .01094

```

FIGURE 4.6. Subchannel Layout and Wire Wrap Positions Looking in the Direction of Flow at the Inlet

.0655 920.	.01921	9519.	432.77	2257.60	.5778	38.79	.01078
.1035 960.	.01933	6180.	444.83	2261.10	.5592	38.20	.01063
.15931000.	.01946	4111.	456.86	2264.40	.5419	37.61	.01048
.23951040.	.01959	2798.	465.88	2267.60	.5259	37.03	.01033
.35261080.	.01971	1944.	480.88	2270.80	.5110	36.46	.01018
.50871120.	.01985	1376.	492.87	2273.80	.4970	35.89	.01002
.72061160.	.01998	992.0	504.86	2276.70	.4840	35.33	.00987
.85211180.	.02005	847.5	510.86	2278.20	.4778	35.05	.00979
1.0031200.	.02011	726.9	516.85	2279.60	.4717	34.78	.00972
2.1471300.	.02046	356.3	546.85	2266.70	.4442	33.42	.00934
4.2281400.	.02082	169.1	576.95	2293.90	.4204	32.11	.00896
7.7571500.	.02119	107.4	607.21	2301.10	.3995	30.84	.00858
13.401600.	.02157	64.63	637.70	2308.50	.3811	29.61	.00819
14.781619.	.02165	59.34	643.40	2310.20	.3779	29.38	.00812
124.22145.	.02388	8.522	810.92	2351.70	.3094	23.64	.00612
(SETUP.2)							
2	0	0	0				
(SETUP.2.1)							
.316 -.25	.316 -.25	.316 -.25	.316 -.25				
(SETUP.3)							
3	2						
(SETUP.3.1)							
0	1.	1.	1.				
(SETUP. 4)							
4	12	12					
(SETUP.4.1)							
1.0146.3613.3613	2.0560.0000	6.0560.0000	7.0560.0000				
2.0146.3613.3613	3.0560.0000	8.0560.0000					
3.0146.3613.3613	4.0560.0000	9.0560.0000					
4.0146.3613.3613	5.0560.0000	10.0560.0000					
5.0146.3613.3613	6.0560.0000	11.0560.0000					
6.0146.3613.3613	12.0560.0000						
7.0312.9499.4813	8.0560.0000	12.0560.0000					
8.0312.9499.4813	9.0560.0000						
9.0312.9499.4813	10.0560.0000						
10.0312.9499.4813	11.0560.0000						
11.0312.9499.4813	12.0560.0000						
12.0312.9499.4813							
(SETUP.7)							
7	1	18					
(SETUP.7.1)							
12.	.230	.056					
(SETUP. 7.2)							
1	.06	.250-.750					
2	.06	.584-.084					
3	.06	.917-.417					
4	.06	.417-.917					
5	.06	.084-.584					
6	.06	.584-.084					
7	.06	.250-.750					

```

8 .06 .750-.250
9 .06 .417-.917
10 .06 .917-.417
11 .06 .584-.084
12 .06 .750-.250
13 .06 .250-.000
14 .06-.084-.000
15 .06 .417-.000
16 .06 .584-.000
17 .06 .750-.000
18 .06 .917-.000
(SETUP.7.3)
0 1 0 1 1 0 0 0
1 2
(SETUP. 8)
8 7 7
(SETUP.8.1)
1 1.23001.00 1.1667 2.1667 3.1667 4.1667 5.1667 6.1667
1 2.23001.00 1.1667 6.1667 7.3333 12.3333
1 3.2300 1.00 1.1667 2.1667 7.3333 8.3333
1 4.2300 1.00 2.1667 3.1667 8.3333 9.3333
1 5.2300 1.00 3.1667 4.1667 9.3333 10.3333
1 6.23001.00 4.1667 5.1667 10.3333 11.3333
1 7.23001.00 5.1667 6.1667 11.3333 12.3333
(SETUP.9)
9
(SETUP. 9.1)
36.
(SETUP. 9.2)
18
(SETUP. 10)
10 0 0
(SETUP.10.1)
.02
(SETUP.11)
11 1 0
(SETUP. 11.1)
60. 800. 3. .5
(SETUP. 12)
12 1 3
(SETUP. 12.1)
1 7 12

```

4.3.3. Thermal Modeling

Since thermal modeling capabilities have been increased substantially over COBRA-111, a separate sample problem is necessary. This problem is intended to illustrate the following features of the COBRA-IV thermal model:

- axial conduction in both the coolant and fuel
- conducting wall model
- axially heterogeneous fuel types, including a "blank" zone
- use of the steady-state equal pressure drop model.

The geometry shown in Figure 4.7 consists of a three-rod configuration immersed in flowing liquid sodium surrounded by a thermally conducting can. The can is cooled by an outer annular region of liquid sodium. Each rod consists of a central UO_2 fuel zone with a stainless steel zone on each end. The last 10 in. of the model is a "blank" zone, free of rod material.

After the steady state is calculated, the model is subjected to a short transient, which represents an immediate power shutoff, followed 1/2 s later by a linear pressure drop decay to zero assembly (Δp at 1-1/2 s).

(COBRA. 0)

100

(SETUP.0)

1

FUEL THERMAL MODEL TEST PROBLEM

(SETUP.1)

1 2 0 0 0

((SETUP.1.1) (repeat as needed))

52E-4 500.	.01801	999999.	303.76	2204.80	.9235	45.43	.01238
.1000 960.	.01933	6180.	444.83	2261.10	.5592	38.20	.01063
.1300 980.	.01940	5026.	450.85	2282.80	.5504	37.91	.01056
.16001000.	.01946	4111.	456.86	2264.40	.5419	37.61	.01048
.20001020.	.01952	3382.	462.87	2266.10	.5338	37.42	.01040
.24001040.	.01959	2798.	465.88	2267.60	.5259	37.03	.01033
.29001060.	.01965	2326.	474.88	2269.20	.5183	36.74	.01025
.35001080.	.01971	1944.	480.88	2270.80	.5110	36.46	.01018
.47001100.	.01959	1632.	486.88	2272.30	.5004	36.03	.01006
.54001120.	.01985	1376.	492.87	2273.80	.4970	35.89	.01002
.61001140.	.01991	1166.	498.87	2275.20	.4904	35.61	.00995
.72001160.	.01998	992.0	504.86	2276.70	.4840	35.33	.00987
.85001180.	.02005	847.5	510.86	2278.20	.4778	35.05	.00979
1.0001200.	.02011	726.9	516.85	2279.60	.4717	34.78	.00972
2.1001300.	.02046	356.3	546.85	2266.70	.4442	33.42	.00934

FIGURE 4.7. Geometry of Thermal Model Sample Problem

4.2001400.	.02082	169.1	576.95	2293.90	.4204	32.11	.00896
7.8001500.	.02119	107.4	607.21	2301.10	.3995	30.84	.00858
14.001600.	.02157	64.63	637.70	2308.50	.3811	29.61	.00819
15.001619.	.02165	59.34	643.40	2310.20	.3779	29.38	.00812
120.02145.	.02388	8.522	810.92	2351.70	.3094	23.64	.00612

(SETUP. 2)

2 0 0 0 1

(SETUP. 2.1)

.316 -.25

(SETUP.2.2)

84. -1.

(SETUP.3)

3 8

(SETUP.3.1)

0. 0.. 1665 0.. 1667 .5.3333 1.25 .5 1.25.6666 .5
.6667 0. 1. 0.

(SETUP. 4)

4 7 7 9 3

(SETUP. 4.1)

1.90371.5711.571 2 .732 1.5 3 .732 1.5 4 .732 1.5
22.5946.5452.618 3 .375 3.1 4 .375 3.1
32.5946.5452.618 4 .375 3.1
42.5946.5452.618
52.3569.425 1. 6 1. 4.71 7 1. 4.71
62.3569.425 1. 7 1. 4.71
72.3569.425 1.

(SETUP. 4.2)

1 .424 4.06 2 8.14 5 8.14
2.4244.06 3 8.14 6 8.14
3 .424 4.06 4 8.14 7 8.14

(SETUP.4.3)

1 0. 2 120. 3 240. 4 150. 5 210.
6 270. 7 150. 8 210. 9 270.

(SETUP. 5)

5 4 4

(SETUP.5.1)

0. .79 .8 1.

(SETUP. 5.2)

1
1. 1. 1.43 1.43
2
1. 1. 1.25 1.25
3
1. 1. 1.25 1.25
4
1. 1. 1.25 1.25

(SETUP. 6)

6 6 4

```

(SETUP.6.1)
0. .79 .8 1.
(SETUP. 6.2)
1
1. 1. 2.37 2.37
2
1. 1. 2.37 2.37
3
1. 1. 2.37 2.37
4
1. 1. 2.33 2.33
5
1. 1. 2.33 2.33
6
1. 1. 2.33 2.33
(SETUP. 7)
7 2 3 3
(SETUP.7.4)
.0125 1.7292 2.8125 3
(SETUP. 7.5)
1 .5
2 .75
3 .75
4 .75
5 2.
6 2.
7 2.
1 .5
2 .75
3 .75
4 .75
5 0.
6 0.
7 0.
1 0.
2 0.
3 0.
4 0.
5 1.
6 1.
7 1.
(SETUP.8)
8 3 3 2 3 0 3 0 1
(SETUP.8.1)
1 1 1. 1.50 1.1667 3.4166 4.4167
1 2 1. 1.00 1.1667 2.4167 4.4166
1 3 1. .50 1.1667 2.4166 3.4167

```

(SETUP.8.2)
 1.958 .0671152. .836 12. .122 489. .0821000.
 12. .122 489. .836 12. .122 489. .082 500.
 (next card left intentionally blank)

(SETUP.8.3)
 1472. -.5299E-3 .2338E-6-.2169E-10

(SETUP.8.4)
 4
 .1667 2.6667 1.7917 2 1. 3

(SETUP. 9)
 9 0 2 0 1

(SETUP.9.1)
 48. 1. .01 .001 .001 .5 .25 0. 0.

(SETUP.9.2)
 16 400 25 25 5

(SETUP. 9.3)
 .4 .1

(SETUP. 9.4)
 50 20

(SETUP. 10)
 1 0 0 0 1

(SETUP. 10.1)
 .02

(SETUP. 10.2)
 .5

(SETUP. 11)
 1 1 3 1 0 0 3 3 1

(SETUP.11.1)
 15. 1200. .4 .12 516. 1.60

(SETUP.11.2)
 1100.1100.1100.1100.1000.1000.1000.

(SETUP. 11.6)
 0. 1. .5 1. 1.5 0.

(SETUP. 11.7)
 0. 1. .001 0. 5. 0.

(SETUP. 12)
 1 2 3 3 1 4 40

(SETUP. 12.1)
 1 2 5

(SETUP. 12.2)
 1

(SETUP. 12.6)
 0. 0. .5 .45

4.3.4. Damped U-Tube Manometer Oscillation

One of the most important new capabilities of COBRA-IV is that of considering density gradients approaching steam-water interface conditions. The modeling of a U-tube oscillation is an ideal way to demonstrate this capability. The model also employs the code's new ability to arbitrarily block lateral flows in transient calculations.

The geometry chosen for the U-tube is illustrated in Figure 4.8. The flow area of 232.3 cm^2 (36 in.^2), the 15.24 cm (6 in.) gap and the axial node length of 7.62 cm (3 in.) were chosen to provide the same area for lateral flow as for axial flow and thus a uniform velocity all the way around the "U." All gaps except the first two are closed at the 36.57 cm (14.4 in.) level in channel 1. One channel is initially filled with saturated liquid and the other with saturated vapor at 0.414 MPa (60 psia). The calculation is carried out to 4.0s , which allows two full oscillations (natural period is 1.92 s).

The intermediate output for this problem shown "surface level" in addition to the normal transient output. This is a post-calculated quantity that is not determined by integrating the previously calculated density and is not used elsewhere in the code. Refer to the channel results page for the actual density gradient calculated.

```
(COBRA. 0)
100
(SETUP.0)
1      ISOHERMAL U-TUBE MANOMETER DEMONSTRATION
(SETUP.1)
1 2 0 1 0
((SETUP.1.1) (repeat as needed))
.1780 50. .01602 1704.8000 18.054 1083.4 3.150 .3360 0.
.2501 60. .01603 1207.6000 28.060 1087.7 2.680 .3420 0.
.3629 70. .01605 868.4000 38.052 1092.1 2.320 .3460 0.
.5088 80. .01607 633.3000 48.037 1096.4 2.050 .3530 0.
.5981 90. .01610 468.1000 58.018 1100.8 1.851 .3580 0.
.9492 100. .01613 350.4000 67.999 1105.1 1.643 .3620 0.
1.673 120. .01620 234.3000 87.97 1113.6 1.321 .3700 0.
2.889 140. .01629 123.0000 107.95 1122.0 1.110 .3780 0.
4.741 160. .01640 77.2900 127.96 1130.2 .949 .3830 0.
7.511 180. .01661 50.2200 148.00 1138.2 .770 .3880 0.
11.53 200. .01664 33.6400 168.09 1146.0 .720 .3910 0.
```

FIGURE 4.8. U-Tube Manometer Model

24.97	240.	.01693	16.3200	208.45	1160.6	.579	.3960	0.
50.00	281.	.01727	8.5140	250.20	1174.1	.491	.3959	.003012
100.0627	.8	.01774	4.4310	298.50	1187.2	.410	.3936	.002606
150.0358	.4	.01809	3.0139	330.60	1194.1	.369	.3893	.002350
200.0381	.8	.01839	2.2873	355.50	1198.3	.345	.3852	.002090
250.0401	.0	.01865	1.8432	376.10	1201.1	.326	.3806	.001930
300.0417	.4	.01889	1.5427	394.00	1201.9	.313	.3760	.001800
350.0431	.7	.01912	1.3255	409.80	1204.0	.301	.3718	.001680
400.0444	.6	.01934	1.1610	424.20	1204.6	.290	.3682	.001580

(SETUP. 2)

2

((SETUP.2.1) (card left intentionally blank)

(SETUP.3)

3 2

(SETUP. 3.1)

0. 1. 1. 1.

(SETUP.4)

4 2 2

(SETUP.4.1)

1 36. 24. 24. 2 6.

2 36. 24. 24.

(SETUP.8)

8 1 1

(SETUP.8.1)

1 1. 1. 1 1.

(SETUP.9)

9 0 3 0 4 3

(SETUP.9.1)

72. 2. 0. 0. 0.1.E-9 1.

(SETUP. 9.2)

20 400

(SETUP. 9.3)

.2 .005.0005 .1 20. 1. 0.

(SETUP. 9.4)

200 0 1 4

(SETUP. 9.5)

0. .001 .5 .02 10. .025

(SETUP. 11)

11 2

(SETUP.11.1)

50. 1174. 0. 0. 1174.

(SETUP. 11.2)

250.21174.

(SETUP. 12)

12 1

5.0 REFERENCES

- Aden, V. G., et al. 1978. "Fuel Elements of the RBMK-1000 Reactor." Soviet Atomic Energy, April, pp. 8650870.
- Duderstadt and Hamilton. 1976. Nuclear Reactor Analysis, pp. 634-635. John Wiley and Sons, New York, New York.
- Harlow, F. H., et al. 1966. The MAC Method, A Computing Technique for Solving Viscous Incompressible, Transient Fluid-Flow Problems Involving Free Surfaces. LA-3425, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
- Hirt, C. W., and J. L. Cook. 1972. "Calculating Three-Dimensional Flows Around Structures and Over Rough Terrain." Journal of Computational Physics. 10:324-340.
- Petrosyants, A. M. 1979. Problems of Nuclear Science and Technology: The Soviet Union as a World Nuclear Power, pp. 110-121. Pergamon Press, 4th Edition.
- Rowe, D. S. 1973. COBRA-IIIC: A Digital Computer Program for Steady-State and Transient Thermal-Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements. BNWL-1695, Pacific Northwest Laboratory, Richland, Washington.
- Wheeler, C. L., C. W. Stewart, R. J. Cena, D. S. Rowe and A. M. Sutey. 1976. COBRA-IV-I: An Interim version of COBRA for Thermal-Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements and Cores. BNWL-1962/UC-32. Pacific Northwest Laboratory, Richland, Washington.

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