NUREG/CR-3262
PNL-5515
Vol. 4

COBRA-NC: A Thermal Hydraulics Code for Transient Analysis of Nuclear Reactor Components

Vol. 4: Users' Manual for Containment Analysis

Prepared by C. L. Wheeler, M. J. Thurgood, T. E. Guidotti, D. E. DeBellis

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

8609120171 860831
PDR NUREG
CR-3262 R PDR

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7082
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-3262
PNL-5515
Vol. 4
R4

COBRA-NC: A Thermal Hydraulics Code for Transient Analysis of Nuclear Reactor Components

Vol. 4: Users' Manual for Containment Analysis

Manuscript Completed: March 1986
Date Published: August 1986

Prepared by
C. L. Wheeler, M. J. Thurgood, T. E. Guidotti, D. E. DeBellis

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Reactor System Safety
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN B2466

RELATED DOCUMENTS

COBRA/TRAC - A Thermal Hydraulics Code for Transient Analysis of Nuclear Reactor Vessels and Primary Coolant Systems, NUREG/CR-3046, March 1983

Volume 1: Equations and Constitutive Models

Volume 2: Numerical Solution Methods

Volume 3: Users' Manual

Volume 4: Developmental Assessment and Data Comparison

Volume 5: Programmers' Manual

COBRA-NC: A Thermal-Hydraulics Code for Transient Analysis of Nuclear Reactor Components

Volume 1: Equations and Constitutive Models, NUREG/CR-3262

Volume 2: Numerical Solution Methods, NUREG/CR-3262

Volume 3: Users' Manual for General Two-Phase Thermal Hydraulics (to be published)

Volume 4: Users' Manual for Containment Analysis, NUREG/CR-3262

Volume 5: Users' Manual for Flow Blockage and Hot Bundle Analysis to be published)

Volume 6: Assessment Manual for General Two-Phase Thermal- Hydraulic Applications (to be published)

Volume 7: Assessment Manual for Containment Applications, NUREG/CR-3262

Volume 8: Assessment Manual for Flow Blockage and Hot Bundle Applications (to be published)

Volume 9: Programmers' Manual (to be published)

ABSTRACT

COBRA-NC is a digital computer program written in FORTRAN IV that simulates the response of nuclear reactor components and systems to thermal-hydraulic transients. The code solves the multicomponent, compressible, three-dimensional, two-fluid, three-field equations for two-phase flow. The three velocity fields are the vapor/gas field, the continuous liquid field, and the liquid drop field. This volume of the manual provides the user with an explanation of the input required to simulate the response of multicompartment nuclear containment systems to postulated loss-of-coolant accidents that result in the release of steam, water, and/or noncondensable gases into the containment.

CONTENTS

1.0 INTRODUCTION 1

2.0 INPUT INSTRUCTIONS 4

2.1 Main Problem Control Data 4

2.2 Geometry, Initial and Boundary Condition Data 5

2.3 Time Domain Data 43

2.4 SPECSET Redimensioning Program 45

2.4.1 SPECSET Input Instructions 50

2.5 Grafix Postprocessor Program 53

2.5.1 Measured Data File 55

3.0 USERS' GUIDE TO COBRA-NC 56

3.1 Solution Procedure 56

3.2 COBRA-NC Geometry Model 57

3.2.1 Group 2: Channel Input Data 67

3.2.2 Group 3: Transverse Channel Connection Data 71

3.2.3 Group 4: Section Data 78

3.2.4 Group 5 and Group 6: Variations in Channels and Gaps . 83

3.2.5 Group 7: Vertical Loss Coefficients 86

3.2.6 Group 12: Turbulent and Viscous Stress Data 90

3.3 Thermal Conductor Model 91

3.3.1 Group 8: Description of Thermal Conductors 91

3.3.2 Group 9: Geometry Description for Conduction Model . . 94

3.3.3 Group 10: Material Properties Table 96

3.4 Boundary and Initial Conditions 97

3.4.1 Group 1: Initial Conditions. 97

3.4.2 Group 13: Mesh Cell Boundary Conditions 102
3.5 Specification of Output of Results 106
3.5.1 Group 14: Line-Printer Output Options 107
3.5.2 Graphics Options 107
3.6 Using the Dump/Restart Option 109
4.0 CONTAINMENT SAMPLE PROBLEMS 112
4.1 HDR Containment Sample Problem 112
4.1.1 Description of the Experiment 112
4.1.2 COBRA-NC Model Description 142
4.2 CSTF Three-Dimensional Mesh Sample Problem 149
4.2.1 Description of the Experiment 149
4.2.2 COBRA-TF MODEL DESCRIPTION 180
REFERENCES 246

FIGURES

1 Basic mesh cell 57

2 Mesh cell for vertical velocities 58

3 Mesh cell for transverse velocities 59

4 Basic channel 59

5 Vertical cross section through HDR containment vessel (90° to 270°) 61

6 Vertical cross section through HDR containment vessel (0° to 180°) . 62

7 Possible breakdown of HDR containment into sections 63

8 Cross sectional view of section 5 64

9 Lumped parameter mesh for section 5 64

10 Multidimensional mesh for section 5 65

11 Lumped parameter mesh for the HDR containment 66

12 Channel node numbering convention 69

13 Channel connections at section boundaries allowed by the channel splitting logic 69

14 Typical configurations for convection of transverse momentum between sections 71

15 Vertical momentum mesh cell at section boundary 73

16 Global coordinate systems 74

17 Normal component of transverse momentum 75

18 Convection of transverse momentum by orthogonal transverse velocity 77

19 Allowable vertical connections between channels at section boundaries 79

20 Common channel splitting errors 81

21 Example of cell numbering scheme for simultaneous solution groups 82

22 Examples of vertical variations in continuity and momentum area and wetted perimeter of a channel 84

23 Typical flow path with local flow resistances 87

24 Vertical connections between sections 5 and 6 involving channels 30 and 37 87

25 Typical containment structures 92

26 Typical radial noding for containment 95

27 Control volume for pressure sink boundary condition 106

28 Liquid level calculation example geometry 110

29 Cutaway views of the reactor pressure vessel used in the experiment 113

30 Vertical cross section of containment building along 90° to 270° diameter 115

31 Vertical cross section of containment building along 0° to 180° diameter 116

32 Plan of HDR containment at level B-B (-0.8m) (34-zones model) . . . 117

33 Plan of HDR containment at level C-C (-5.0m) (34 zones model) . . . 117

34 Plan of HDR containment at level D-D (+0m) (34-zones model) 118

35 Plan of HDR containment at level E-E (+5.4m) (34 zones model) . . . 118

36 Plan of HDR containment at level F-F (+11.5m) (34-zones model) . . . 119

37 Plan of HDR containment at level G-G (+18.0m) (34 zones model) . . . 119

38 Plan of HDR containment at level H-H (+20.6m) (34-zones model) . . . 120

39 Plan of HDR containment at level J-J (+25.3m) (34 zones model) . . . 120

40 Plan of HDR containment at level K-K (+31.0m) (34-zones model) . . . 121

41 Schematic of compartments and vent flow openings 122

42 COBRA-TF nodalization of the HDR facility 143

43 Test compartment geometry 174

44 Test compartment air recirculation details 175

45 HM-5 nozzle flow rates and temperatures 177

46 Hydrogen concentration at blower discharge for test HM- 5 177

47 Nitrogen temperature at blower discharge for test HM- 5 180

48 COBRA-TF mesh for CSTF pretest predictions 181

49 Mesh for section 4 181

50 Mesh for section 5 182

51 Location of thermal conductor geometry types 194

TABLES

1 SPECSET dimensioning parameters 45

2 Sample input file TAPE2 for SPECSET program 51

3 Typical Load File for CDC Compiler 52

4 Input for thermal conducting wall example 97

5 Channel boundary condition types 102

6 Application of Boundary Conditions 104

7 Example Input Data for Liquid Level Calculation 111

8 List of original HDR compartments and their function 123

9 List of 34 containment zones 124

10 Compilation on the vent flow openings of the 34 zones model 125

11 Compilation of structural elements of the HDR-containment (34 zones) 132

12 Compilation of metal internals and equipment of HDR containment . . 136

13 Specification of flow openings in break compartment R 1603 142

14 Channel input data 145

15 Gap input data 147

16 Concrete conduction model input 150

17 Steel conduction model input 151

18 Alpha block conduction model input 153

19 Material properties 154

20 Initial conditions for test V44 154

21 Flow and energy boundary conditions for test V44 155

22 COBRA-TF input listing for test V44 157

23 Lower test compartment height locations 178

24 Instrumentation lower containment test compartment 178

25 Initial temperatures 179
26 Channel input data 184
27 Gap Input Data 186
28 Input data for thermal conductor geometry types 196
29 Nozzle boundary condition input for test HM-5 196
30 Blower discharge boundary condition input for test HM-5 197
31 COBRA-TF input listing for CSTF 197

ACKNOWLEDGEMENTS

COBRA-NC is the result of the efforts of a number of people. We wish to acknowledge the main contributors and to express our appreciation to those who have offered their advice and suggestions.

The main contributors to the program are listed below:

Fluid Dynamics:	M. J. Thurgood, T. L. George, and T. E. Guidotti
Heat Transfer:	J. M. Kelly and R. J. Kohrt
Turbulence Model:	K. R. Crowell
Graphics and Programming:	A. S. Koontz
Simulations:	D. E. DeBellis

We wish to thank Dr. T. Lee of the U.S. Nuclear Regulatory Commission for his patience, support, and suggestions during this large undertaking. We also wish to thank Drs. Tong, Shotkin, Lee, and Zuber of the U.S. Nuclear Regulatory Commission and members of the Advanced Code Review Group for their many helpful suggestions. We also express our gratitude to our manager, Dr. D. S. Trent, for his support, and Cathy Darby for typing this report.

SUMMARY

COBRA-NC is a digital thermal-hydraulic computer program that simulates the response of nuclear reactor components and systems to loss-of-coolant accidents. It utilizes a multicomponent, two-fluid, three-field representation of two-phase flow. Conservation equations are solved for water and its vapor and for a noncondensable gas mixture comprised of n species. The flow field may be modeled using a lumped parameter approach or a multidimensional finite-difference approach. This volume of the code documentation provides an explanation of the input parameters that are required to perform simulations of the response of multicompartment nuclear containment systems to postulated loss-of-coolant accidents that result in the release of steam, water, and/or noncondensable gases into the containment atmosphere. The code has been designed to predict two-phase jet impingement loads, room pressurization, and the migration of hydrogen and other noncondensable gases within the containment. Line-by-line input instructions are provided as well as detailed explanations and examples of the use of each of the input parameters. Example containment problems are also provided to aid the user in setting up his or her own input deck.

COBRA-NC: A THERMAL-HYDRAULICS CODE FOR TRANSIENT ANALYSIS OF NUCLEAR REACTOR COMPONENTS

VOLUME 4: USER'S MANUAL FOR CONTAINMENT ANALYSIS

1.0 INTRODUCTION

The COBRA-NC computer code was developed by the Pacific Northwest Laboratory for the United States Nuclear Regulatory Commission. The Pacific Northwest Laboratory is operated for the Department of Energy by Battelle Memorial Institute.

COBRA-NC was developed to perform analyses of thermal hydraulic transients in various components of light-water reactors including the reactor core, reactor vessel, steam generators, and the reactor containment building. It was also merged with a system code to provide a primary coolant system analysis capability (Ref. 1). The documentation for the code is broken up into several volumes because of its wide range of application. Volume 1, Equations and Constitutive Models, contains a description of the basic conservation equations and constitutive models used in the code. Volume 2 contains the finite-difference equations and a description of the procedures used for their numerical solution. Volumes 3 through 5 are the Users' Manuals. They contain line-by-line input instructions for COBRA-NC and user guidance for application of the code. Volume 3, the Users' Manual for General Two-Phase Thermal Hydraulics, contains an explanation for all of the input data required for general application of the code. Volume 4 is the Users' Manual for Containment Analysis and contains an explanation of the input data required for containment analysis only. It also provides examples of containment modeling procedures. Volume 5 is the Users' Manual for Flow Blockage and Hot Bundle Analysis and describes the input required for performing such analysis.

Volumes 6, 7, and 8 are the Assessment Manuals. They contain the results of simulations run to assess the performance of the code in each of the areas discussed above. Volume 9 is the Programmer's Manual. It explains the details of COBRA-NC's working parts from a programmers' viewpoint. The structure of the code is described along with a verbal description of the major variables and subroutines used in the code.

This volume, the Users' Manual for Containment Analysis, provides the users with a sufficient amount of information and background to enable them to perform several types of containment analyses. COBRA-NC is designed to predict room pressurization, pressure differentials between rooms, jet impingement forces, and asymmetric loads during a loss-of-coolant accident. It is also designed to predict the distribution of hydrogen and noncondensable gases within the containment building, both during and following a loss-of-coolant accident where hydrogen may be generated by metal-water reactions or by radiolysis.

The COBRA-NC code provides a two-component, two-fluid, three-field representation of two-phase flow. It is a two-component model to allow the modeling of water and its vapor as well as a noncondensable gas mixture. The

gas mixture may consist of any number of gas species. The properties of eight gases are currently coded.

The two-fluid capability is used to predict the two-phase flows associated with steam-water blowdown into the containment, condensation of steam in the containment atmosphere and on containment structural surfaces, flow through pressure suppression pools, containment sprays, etc. The three fields are 1) the vapor-gas mixture, 2) the continuous-liquid phase, and 3) the liquid-drop phase. The continuous-liquid phase is used to model liquid films on containment structures, pools on containment floors, and pressure suppression pools. The liquid-drop phase is used to model the two-phase jet, containment sprays, and drop entrainment between containment rooms.

Three momentum, four mass, and two energy equations are solved for the fluid. Momentum equations are solved for the vapor-gas mixture, the continuous liquid, and the liquid-drop fields. Thus, each of these may travel at different velocities. A liquid film flowing down walls with vapor flowing across it can be modeled. The vapor may also contain drops that travel at a still different velocity than the vapor.

Mass equations are solved for the noncondensable gas, the vapor, the continuous liquid, and the liquid drops. Thus, the mass of each phase can be accounted for. In addition, a mass-transport equation is solved for each species of the noncondensable gas mixture, so that the concentration of each species can be determined. Energy equations are solved for the vapor-gas mixture and for the continuous liquid-drop mixture. It is therefore assumed that both the vapor and gas in a given computational cell will have the same temperature, and that the liquid film and liquid drops within a given mesh cell will be at the same temperature. These two mixtures, however, can have different temperatures. This model permits the modeling of nonsaturated air (air with a relative humidity of less than 100%) and superheated vapor in the presence of subcooled liquid.

The code is a three-dimensional, compressible-flow, finite-difference code formulated in Cartesian coordinates. However, it features an extremely flexible noding scheme that allows it to be run in a lumped parameter, one-dimensional, two-dimensional, or three-dimensional mode. It has a finite-difference slab conduction model for structural heat transfer. Any number of materials may be used in each slab, and the number of heat transfer nodes through the thickness of the slab may be specified by the user.

A mixing-length turbulence model has also been included to allow the user to model turbulent shear flows and the turbulent diffusion of gas species due to concentration gradients.

A general set of boundary conditions has been included to facilitate the modeling of containment sprays, blowers, blowdown flows, etc.

The information presented in this manual is intended to facilitate the use of the code for containment analysis. Section 2.0 describes the input instructions and options that are generally required to set up a containment input deck. Every line of input is listed along with the required format and a brief explanation of the meaning and usage of each input variable. Instructions on how to redimension the variable common blocks are also provided along with input instructions for the postprocessing graphics program.

The Users' Guide, Section 3.0, is devoted to explaining the modeling conventions and input requirements. The computational mesh, heat conductor model, and boundary conditions are discussed. Examples of the different types of meshes that can be generated are given. The DUMP/RESTART capability is discussed in detail.

Finally, some sample problems are provided in Section 4.0 to assist the users in learning how to set up an input deck for various kinds of problems.

2.0 INPUT INSTRUCTIONS

The input instructions for COBRA-NC are provided in this section. The input may not be obvious for the new user. Users unfamiliar with the code should refer to Sections 3.0 and 4.0 for a more complete explanation of the input requirements before attempting to set up the data for a specific problem.

The input is divided into three major sections. The first section provides data for the overall problem control, such as the convergence criteria, maximum number of iterations, and restart data.

The second section defines the computational mesh, initial and boundary conditions for the simulation, and is the major part of the input. This section of input is divided into card groups. The user need only provide input for the card groups required for his particular problem. All other card groups may be ignored.

The third section provides necessary information to create graphics output, time intervals for printouts, restart dumps, graphics dumps, minimum and maximum time step sizes, and problem end time.

2.1 Main Problem Control Data, read by subroutine INPUT

INPUT.1: ICOBRA

FORMAT(I14)

Columns	Variable	Description
1-14	ICOBRA	Enter input units option: 0 = Use English units (default). 1 = Use metric units; code will convert the data to English units.

NOTE: The working units in the code are English. The user may input his data in either English or metric units, but the output will be in English units.

Restart Data:

INPUT.2: DSTEP, TIMET

FORMAT(I14,E14.0)

Columns	Variable	Description
1-14	DSTEP	Enter the time step number of the dump to be used for restarting. Enter zero (0) if this is not a restart.
15-28	TIMET	Enter the restart time for the problem. If this is not a restart, enter the start time for performing calculations. This may be a number equal to or greater than zero (0.0).

Iteration Control:

INPUT.3: EPSO,OITMAX,IITMAX

FORMAT(E14.0,2I14)

Columns	Variable	Description
1-14	EPSO	Enter the outer iteration convergence criterion; suggested value = 0.001.
15-28	OITMAX	Enter the maximum number of outer iterations; suggested value = 5.
29-42	IITMAX	Enter the maximum number of pressure iterations; suggested value = 40.

2.2 Geometry, Initial and Boundary Condition Data

The input data is organized in groups. Each group fulfills some general input requirement such as channel geometry, channel connections, or boundary conditions.

Calculation Control Data, read by subroutine COBRAI

COBRA.1 INIT,TEXT

FORMAT(2I5,17A4)

Columns	Variable	Description
6-10	INIT	Enter the initialization option. Valid entries are: 1 = initial start 4 = fill arrays with data obtained from a restart file
11-80	TEXT	Enter alphanumeric information to identify the simulation.

Restart Data, read by subroutine RESTRT

COBRA.2[(a)] IMEX, MAXIMP, ISET, ISTRT, DAMPIF, DAMPIH, DAMPIV

FORMAT (4I5,3F5.0)

Columns	Variable	Description
1-5	IMEX	Solution Procedure Flag Enter 0 for semi-implicit solution procedure Enter 1 for implicit solution procedure
6-10	MAXIMP	Enter maximum number of iterations per time step for implicit solution Suggested value = 10
11-15	ISET	Full implicit flag Enter 1 for explicit calculation of heat transfer and drag coefficients, and gas concentration Enter 0 for implicit calculation of heat transfer and drag coefficients, and gas concentration

(a) Not currently available on Cycle 15 version

16-20	ISTRT	Start up option for implicit solution Enter 0 for same initial conditions as semi-implicit scheme Enter 1 to initialize internal mesh velocities consistent with axial boundary velocities
21-25	DAMPIF	Enter logarithmic damping factor for interfacial drag coefficients
26-30	DAMPIH	Enter logarithmic damping factor for interfacial heat transfer coefficients
31-35	DAMPIV	Enter damping factor for transverse velocities in implicit solution scheme

Group 1: Calculation Variables and Initial Conditions, read by subroutine SETIN

CARD1.1. NGROUP,NGAS,IREF,NTGAS,NAL,NHF,NZS

FORMAT(8I5)

Columns	Variable	Description
1-5	NGROUP	Enter one (1).
6-10	NGAS	Enter the total number of noncondensable gas species to be used in the calculation.
11-15	IREF	Flag to specify if a uniform initial gas or if a uniform initial steam pressure is to be assumed. Enter 0 if a uniform initial steam pressure is desired. Enter 1 if a uniform initial gas pressure is desired.
16-20	NTGAS	Enter the number of initial gas temperature tables to be read. Enter -1 if a constant initial gas temperature is to be applied.
21-25	NAL	Enter the number of initial liquid volume fraction tables to be read.

26-30	NHF	Enter the number of fluid heat flux tables to be read.
31-35	NLE	Enter the number of initial liquid enthalpy tables to be read.
36-40	NZS	Enter the number of slab zero heat flux tables to be read.

CARD1.2 SCVL,SHVL,SCLL,SHLL

FORMAT(4F10.0)

Columns	Variable	Description
1-10	SCVL	Upper limit on product of interfacial heat transfer coefficient and interfacial area for subcooled vapor (suggested value 278.0). (Btu/sec)
11-20	SHVL	Upper limit on product of interfacial heat transfer coefficient and interfacial area for superheated vapor (suggested value 278.0). (Btu/sec)
21-30	SCLL	Upper limit on product of interfacial heat transfer coefficient and interfacial area for subcooled liquid (suggested value 27.8). (Btu/sec)
31-40	SHLL	Upper limit on product of interfacial heat transfer coefficient and interfacial area for superheated liquid (suggested value 278.0). (Btu/sec)

CARD1.3 PREF,HIN,GIN,AFLUX,HGIN,VFRAC(1),VFRAC(2)

FORMAT(8F10.0)

Columns	Variable	Description
1- 10	PREF	Enter the initial containment pressure, in psi (if ICOBRA = 0) or N/m^2 (if ICOBRA = 1).
11-20	HIN	Enter the steam/water enthalpy for fluid initialization, in Btu/lbm (if ICOBRA = 0) or J/kg (if ICOBRA = 1).

21-30	GIN	Leave blank.
31-40	AFLUX	Leave blank.
41-50	HGIN	Enter the initial noncondensable gas mixture enthalpy in Btu/lbm (if ICOBRA = 0) or J/kg (if ICOBRA = 1).
51-60	VFRAC(1)	Enter the initial liquid volume fraction.
61-70	VFRAC(2)	Enter the initial volume fraction of steam in the steam/gas mixture.

CARD1.4 ((GTYPE(I),VFRAC(I+2)),I=1,NGAS)

FORMAT(4(A8,2X,F10.0)

Columns	Variable	Description
1-8, 21-28, 41-48 61-68	GTYPE(I)	Enter alphanumeric descriptor for type of noncondensable gas. (Left justified). NGAS species of noncondensable gases must be specified. Options are: AIR ARGON HELIUM HYDROGEN KRYPTON NITROGEN OXYGEN XENON Up to four species may be specified per card. Card 1.4 is repeated if more than four species are specified. Species should be specified such that the species with the lowest concentration is specified first.
11-20, 31-40 51-60 71-80	VFRAC(I+2)	Enter the volume fraction of gas species GTYPE(I) present in the noncondensable gas mixture. (VFRAC(2) through VFRAC(NGAS+2) must sum to 1.0).

CARD1.5 is read NTGAS times and only if NTGAS is greater than zero.

CARD1.5 TGL,J,(IZDUM(M),M=1,12)

FORMAT(F5.0,13I5)

Columns	Variable	Description
1-5	TGL	Enter the gas temperature in °F (if ICOBRA = 0) or °K (if ICOBRA = 1).
6-10	J	Enter vertical mesh cell number to which temperature is to be applied.
11-15, 16-20, . . . 66-70	IZDUM(M)	Enter up to 12 channel numbers to which temperature is to be applied.

CARD1.6 is read NAL times and only if NAL is greater than zero.

CARD1.6 ALIQL,J,(IZDUM(M),M=1,12)

FORMAT(F5.0,13I5)

Columns	Variable	Description
1-5	ALIQL	Enter the liquid volume fraction.
6-10	J	Enter vertical mesh cell number to which liquid fraction is to be applied.
11-15, 16-20, . . . 66-70	IZDUM(M)	Enter up to 12 channel numbers to which liquid fraction is to be applied.

CARD 1.7 is read only if no thermal conductors are specified for the problem and a heat source to the fluid is required (NHF must be greater than zero). Card 1.7 is repeated NHF times.

CARD1.7 QMIXL, J, (IZDUM(M),M=1,12)

FORMAT (F5.0,13I5)

Columns	Variable	Description
1-5	QMIXL	Enter the heat to the fluid in BTU/SEC.
6-10	J	Enter vertical mesh cell number to which heat is to be added.
11-15, 16-20, . . . 66-70.	IZDUM(M)	Enter up to 12 channel numbers to which heat QMIXL is to be added.

CARD 1.8 is read only if NLE is greater than zero. Card 1.8 is repeated NLE times.

CARD1.8 HLS,J, (IZDUM(M),M=1,12)

FORMAT (F10.0,13I5)

Columns	Variable	Description
1-10	HLS	Enter the liquid enthalpy.
11-15	J	Enter vertical mesh cell number to which liquid enthalpy is to be applied.
16-20, 21-25, . . . 71-75.	IZDUM(M)	Enter up to 12 channel numbers to which liquid enthalpy is to be applied.

CARD 1.9 is read NZS times. If NZS is zero than Card 1.9 is not read.

CARD1.9 J,(IZDUM(M)M=1,12)

FORMAT (13I5)

Columns	Variable	Description
1-5	J	Enter vertical mesh cell number at which slab heat transfer is to be zeroed.

6-10, 11-15, . . . 61-65.	IZDUM(M)	Enter up to 12 thermal conductor identification numbers at which heat transfer is to be set to zero.

CARD Group 2: Channel Description, read by subroutine SETIN

CARD2.1 NGROUP,NCHANL,NCHANR

FORMAT(3I5)

Columns	Variable	Description
1-5	NGROUP	Enter two (2).
6-10	NCHANL	Enter the number of channels in the problem.
11-15	NCHANR	Enter the number of channels with thermal connections to conductors.

CARD2.2 and CARD2.3 are read in pairs, NCHANL times.

CARD2.2 I,AN(I),PW(I),ABOT(I),ATOP(I),NAMGAP

FORMAT(I5,4F5.0,I5)

Columns	Variable	Description
1-5	I	Enter the channel identification number. (Note: Channel index numbers must be unique, but they do not have to be sequential. Skipping numbers is permitted, so long as exactly NCHANL channels are identified.)
6-10	AN(I)	Enter the nominal channel area, in in^2 (if ICOBRA = 0) or m^2 (if ICOBRA = 1). (Do not enter 0.0.)
11-15	PW(I)	Enter the channel wetted perimeter, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). (Do not enter 0.0.)
16-20	ABOT(I)	Enter the area of the bottom of the channel for use in the momentum equation. Units are $in.^2$ (if ICOBRA = 0) or m^2 (if ICOBRA = 1). If ABOT(I) is entered as zero (0.0), it is set to AN(I).

21-25	ATOP(I)	Enter the area on the top of the channel for use in the momentum equation. Units are in.^{2} (if ICOBRA = 0) or m^2 (if ICOBRA = 1). If ATOP(I) is entered as zero (0), it is set to AN(I).
26-30	NAMGAP	Enter the number of gaps for which the vertical velocity of channel I convects transverse momentum between sections. NAMGAP must be set to zero when using the lumped parameter option. (Refer to Section 3.2.1 for further discussion.)

CARD2.3 is read only if NAMGAP > 0 for channel I.

CARD2.3 (INODE(I,N),KGAPB(I,N),KGAPA(I,N),N=1,NAMGAP)

FORMAT(15I5)

Columns	Variable	Description
1-5, 16-20, 31-35, 46-50, 61-65	INODE(I,N)	Enter the index number of the node where the vertical velocity of channel I convects transverse momentum across a section boundary. (Note: INODE will be either at the bottom of the channel (INODE(I,N) = 1), or the top of the channel, (INODE(I,N) = NONODE+1), where NONODE is the number of vertical levels in the section containing channel I. INODE is defined in the section where the vertical momentum equation is solved (see Section 3.2.1.)
6-10, 21-25, 36-40, 51-55, 66-70	KGAPB(I,N)	Enter the index number of the gap below the section boundary. Enter zero if there is no gap below the section boundary. (Note: If KGAPB is not zero, the positive velocity of channel I at INODE(I,N) convects transverse momentum out of KGAPB into KGAPA. The negative velocity of channel I at INODE(I,N) convects transverse momentum from KGAPA into KGAPB; if KGAPB is zero, this momentum is dissipated.)
11-15, 26-30, 41-45, 56-60,	KGAPA(I,N)	Enter the index number of the gap above the section boundary. Enter zero if there is no gap above the section boundary.

71-75		Note: If KGAPA is not zero, the positive velocity of channel I at INODE(I,N) convects transverse momentum from KGAPB (if KGAPB ≠ 0) into KGAPA. (If KGAPA is zero, this momentum is dissipated.) The negative velocity of channel I at INODE(I,N) convects transverse momentum from KGAPA to KGAPB if KGAPB ≠ 0; (if KGAPB is zero, this momentum is dissipated.)

CARD2.4 is read NCHANR times.

CARD2.4 I,(LR(I,L),L=1,6),(LS(I,L),L=1,8)

FORMAT(15I5)

Columns	Variable	Description
1-5	I	Enter the identification number of a channel with thermal connections with thermal conductors.
36-40, 41-45, 46-50, . . . 76-80	LS(I,L)	Enter the index numbers of the thermal conductors connected to channel I. Enter the negative of the index number if the channel is on the inside surface. Up to eight conductors may be specified for each channel.

Note: Within a given section thermal conductors can connect to only one channel on the outside surface. Those with tube or wall geometry types can also connect to one channel on the inside surface. Thermal conductors are defined only within a single section and cannot cross section boundaries.

CARD Group 3: Transverse Channel Connection (Gap) Data, read by subroutine SETIN

This group is omitted if there are no transverse connections between channels.

CARD3.1 NGROUP,NK

FORMAT(2I5)

Columns	Variable	Description
1-5	NGROUP	Enter three (3).
6-10	NK	Enter the number of transverse connections (gaps).

CARD3.2 and CARD3.3 are read in pairs NK times.

CARD3.2 K,IK(K),JK(K),GAPN(K),LENGTH(K),WKR(K),FWALL(K),IGAPB(K), IGAPA(K),FACTOR(K),(IGAP(K,N),JGAP(K,N),N=1,3)

FORMAT(3I5,4F5.0,2I5,F5.0,6I5)

Columns	Variable	Description
1-5	K	Enter the gap identification number. (Note: Gap numbers must be unique but they do not have to be sequential. NK gaps must be input.)
6-10	IK(K)	Enter the identification number of the lower-numbered channel of the pair that connect through gap K.
11-15	JK(K)	Enter the identification number of the higher-numbered channel of the pair that connect through gap K.
16-20	GAPN(K)	Enter the nominal gap width, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).
21-25	LENGTH(K)	Enter the distance between the center of channel IK(K) and the center of channel JK(K), in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).
26-30	WKR(K)	Enter the loss coefficient (velocity head) for gap K.
31-35	FWALL(K)	Enter the wall friction factor for the gap. Valid entries are: 0.0 = no walls 0.5 = one wall 1.0 = two walls 2.0 = two walls, floor, ceiling
36-40	IGAPB(K)	Enter the index number of the gap below gap K. Enter zero if there is no gap below gap K. (The velocity of IGAPB(K) convects vertical momentum at node 1 into (or out of) channel IK(K) out of (or into) channel JK(K).) Enter zero if the lumped parameter option is to be used.

41-45	IGAPA(K)	Enter the index number of the gap above gap K. Enter zero if there is no gap above gap K. (The velocity of IGAPA(K) convects vertical momentum at the top node of the section into (or out of) channel IK(K) out of (or into) channel JK(K).) Enter zero if the lumped parameter option is to be used. (NOTE: Refer to Section 3.1.2 for further discussion of this input convention.)
46-50	FACTOR(K)	Enter 1.0 if gap positive flow (from channel IK(K) to channel JK(K)) is in the same direction as positive flow for the global coordinate system. Enter -1.0 if gap positive flow is opposite to positive flow for the global coordinate system. (Default = 1.0). (See Section 3.1.2 for explanation of this input.)
51-55 61-65 71-75	IGAP(K,N)	Enter the index 10 numbers of gaps facing the IK(K) side of gap K. ENTER -4x10+MINJ if a mass source (Type 4) boundary condition faces the IK(K) side of GAPK, MINJ is the source boundary condition sequence number. Enter -5+MSK if a pressure sink (Type 5). Boundary condition faces the Ik(k) side of gap k. MSK is the sink boundary condition sequence number. Enter -1 if the gap faces a wall. Enter zero if the lumped parameter option is to be used.
56-60 66-70 76-80	JGAP(K,N)	Enter the gap numbers facing the JK(K) side of gap K. ENTER -4x10+MINJ. If a mass source (Type 4) boundary condition faces the JK(K) side of GAPK. MINJ is the source boundary condition sequence number. ENTER -5x10+MINJ. If a pressure sink (Type 5) boundary condition faces the JK(K) side of GAPK. MSK is the sink boundary condition sequence number.

	Enter-1 if the gap faces a wall. Enter zero if the lumped parameter option is to be used. Up to three (3) sets of (IGAP,JGAP) may be entered.

Note: The input for FACTOR, IGAP, and JGAP is required only if the three-dimensional form of the transverse momentum equation is desired.

CARD3.3. GMULT(K),ETANR(K)

FORMAT(2F5.0)

Columns	Variable	Description
1-5	GMULT(K)	Enter the number of actual gaps modeled by gap K.
6-10	ETANR(K)	Enter the crossflow de-entrainment fraction.

CARD3.4 NLMGAP

FORMAT(I5)

Columns	Variable	Description
1- 5	NLMGAP	Enter the number of gaps that convect orthogonal transverse momentum. This is required only for the three-dimensional form of the transverse momentum equation. Enter zero if the three-dimensional form of the transverse momentum equation is not desired.

CARD3.5 is read NLMGAP times.

CARD3.5 (KGAP1(N),KGAP2(N),KGAP3(N),N=1,NLMGAP) Read only if NLMGAP > 0.

FORMAT(12I5)

Columns	Variable	Description
1-5, 16-20, 31-35, 46-50	KGAP1(N)	Enter the index number of a gap whose velocity transports transverse momentum from one gap to another.

6-10, 21-25, 36-40, 51-55	KGAP2(N)	Enter the index number of the gap that receives the transverse momentum convected by the positive velocity of gap KGAP1. Enter zero if momentum is to be dissipated.
11-15, 26-30, 41-45, 56-60	KGAP3(N)	Enter the index number of the gap that the positive velocity of KGAP1 transports transverse momentum out of. (The positive velocity of KGAP1 transports momentum from KGAP3 to KGAP2. Note: The negative velocity of KGAP1 will transport transverse momentum in the opposite direction; i.e., from KGAP2 into KGAP3.) Enter zero if momentum is to be dissipated.

Up to four sets of (KGAP1, KGAP2, KGAP3) entries are specified per card. If NLMGAP > 4, repeat this card until all NLMGAP sets have been entered.

CARD Group 4: Vertical Channel Connection Data, read by subroutine SETIN

CARD4.1 NGROUP,NSECTS,NSIM,IREBAL

FORMAT(4I5)

Columns	Variable	Description
1-5	NGROUP	Enter four (4).
6-10	NSECTS	Enter the number of sections in this problem.
11-15	NSIM	Enter the number of simultaneous solution groups. Enter 0 if using implicit procedure.
16-20	IREBAL	Enter the rebalancing option. Valid entries are: 1 = rebalance 0 = no rebalancing

CARD4.2 through CARD4.4 are read in a group NSECTS times.

CARD4.2 ISEC,NCHN,NONODE,DXS(ISEC)

FORMAT(3I5,F10.0, I5)

Columns	Variable	Description
1-5	ISEC	Enter the section number. Begin with section number 1 on the bottom of the mesh and proceed toward the top, incrementing ISEC by 1.

6-10	NCHN	Enter the number of channels in section ISEC.
11-15	NONODE	Enter the number of vertical levels in section ISEC.
16-25	DXN	Enter the nominal vertical node length in this section, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). If DXN = 0.0, variable node lengths must be input on Card 4.3.
26-30	IFMOM(ISEC)	Momentum flux flag. Enter zero if momentum flux terms are to be included in the momentum solution. Enter one if the lumped parameter option to be used for this section.

CARD 4.3 is read only if DXN = 0.0.

CARD4.3 (DXS(ISEC,J+1),J=1,NONODE)

FORMAT (8F10.0)

Columns	Variable	Description
1-10, 11-20, etc.	DXS(ISEC,J)	Enter the cell length at the J level in section ISEC, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).

Repeat CARD 4.3 with eight values per card until NONODE values have been entered.

CARD4.4 is read NCHN times for each section.

CARD4.4 I,(KCHANA(I,J),J=2,7),(KCHANB(I,J),J=2,7)

FORMAT(13I5)

Columns	Variable	Description
1- 5	I	Enter the identification number of a channel in section ISEC.
6- 10, 11-15, etc.	KCHANA(I,J)	Enter the indices of channels in the section above ISEC that connect to channel I. If channel I does not connect to any channels above, enter I in KCHANA(I,2).

36-40 41-45, etc.	KCHANB(I,J)	Enter the indices of channels in the section below ISEC that connect to channel I. If channel I does not connect to any channels below, enter I in KCHANB(I,2).

CARD4.5 (MSIM(I),I=1,NSIM) Read only if NSIM > 0

FORMAT(12I5)

Columns	Variable	Description
1-5, 6-10, etc.	MSIM(I)	Enter the last cell number in each simultaneous solution group. (Note that this input asks for cell number, not vertical level number. Refer to Section 3.2.3.)

Twelve (12) values are entered per card. If NSIM is greater than 12, repeat CARD4.6 until NSIM values have been entered.

CARD Group 5: Geometry Variation Data, read by subroutine SETIN

The input for this group allows the user to specify vertical variations in the continuity area, momentum area or wetted perimeter for channels, and in the transverse width for gaps. It can be omitted if such variations are not needed.

CARD5.1 NGROUP,NAFACT

FORMAT(2I5)

Columns	Variable	Description
1-5	NGROUP	Enter five (5).
6-10	NAFACT	Enter the number of geometry variation tables to be entered.

CARD5.2 and CARD5.3 are read in a group NAFACT times.

CARD5.2 NAXL(I)

FORMAT(I5)

Columns	Variable	Description
1-5	NAXL(I)	Enter the number of points in this variation table.

CARD5.3 (JAXL(I,N),AFACT(I,N),N=1,NAXL(I))

FORMAT(8(I5,F5.0)

Columns	Variable	Description
1-5,11-15, 21-25,31-35 41-45,51-55	JAXL(I,N)	Enter the node number at which to apply the area variation factor for table I, point N.
6-10,16-20, 26-30,36-40 46-50,56-60	AFACT(I,N)	Enter the variation factor for table I, point N. Area = AFACT(I,N)*AN(I), or Gap width = AFACT(I,N)*GAPN(K)

Eight pairs of (JAXL,AFACT) are entered per card. Repeat CARD5.3 until NAXL pairs have been entered. The tables are numbered sequentially in the code, in the order they are read in on CARD5.2 and CARD5.3.

CARD Group 6: Channels and Gaps Affected by Variation Tables, read by subroutine SETIN

This group is read only if vertical variation tables have been specified in group 5.

VESSEL6.1 NGROUP,N1

FORMAT(2I5)

Columns	Variable	Description
1-5	NGROUP	Enter six (6).
6-10	N1	Enter the total number of channel and gap variation table cards to be read.

CARD6.2 is read N1 times.

CARD6.2 IACT,IAMT,IPWT,(ICRG(M),M=1,12)

FORMAT(15I5)

Columns	Variable	Description
1-5	IACT	Enter a positive integer, corresponding to a variation table number, for channel continuity area variation. Enter a negative integer, whose absolute value corresponds to a variation table number, for gap width variation.

6-10	IAMT	Enter a variation table number for channel momentum area variation. Enter zero (0) if IACT is negative.
11-15	IPWT	Enter a variation table number for wetted perimeter variation. Enter zero (0) if IACT is negative.
16-20 21-25, etc.	IZDUM(M)	Enter the index numbers of the channels (or gaps if IACT is negative) that the tables identified in IACT, IAMT and IPWT are to be applied to. (Up to 13 channels or gaps may be specified per card.)

CARD Group 7: Local Loss Coefficient Data, read by subroutine SETIN

CARD7.1 NGROUP,NCD,NCDDP

FORMAT(3I5)

Columns	Variable	Description
1-5	NGROUP	Enter seven (7).
6-10	NCD	Enter the number of loss coefficient specifications to be read. (These include vertical momentum losses only. Transverse losses are specified in group 3.)
11-15	NCDDP	Enter the number of loss coefficients that are a function of pressure drop.

CARD7.2 is read NCD times.

CARD7.2 CDL,J,(ICDUM(I),I=1,12)

FORMAT(F5.0,13I5)

Columns	Variable	Description
1-5	CDL	Enter the loss coefficient (velocity head).
6-10	J	Enter the node number where the loss coefficient is applied. (NOTE: The vertical node number is relative to the beginning of the section containing the channel(s) listed in ICDUM(I).)

11-15 16-20 . . . 66-70	IZDUM(I)	Enter the index number(s) of channel(s) the loss coefficient will be applied to at node J. (Up to twelve (12) channels may use the specified loss coefficient CDL at vertical node J.)

CARD7.3 is read NCDDP times.

CARD7.3 IDIT(L),ICD(L),JCD(L),ICD1(L),JCD1(L),ICD2(L),JCD2(L),DPCDP(L), DPCDM(L),CDFAB(L),CDFAA(L),L=1,NCDDP)

FORMAT(7I5,4F5.0)

Columns	Variable	Description
1-5	IDIT(L)	Enter one (1) if factor is to be applied to a vertical loss coefficient. Enter two (2) if factor is to be applied to a horizontal loss coefficient.
6-10	ICD(L)	Enter channel number (if IDIT(L) = 1) or gap number (if IDIT(L) = 2) to which factor is to be 13 applied.
11-15	JCD(L)	Enter vertical node number to which factor is to be applied.
16-20	ICD1(L)	Enter number of first channel in pressure difference pair. The pressure of channel ICD2(2) node JCD2(L) is subtracted from the pressure of channel ICD1(L) node JCD1(L) to obtain the pressure difference. If the pressure difference P(ICD1,JCD1) - P(ICD2,JCD2) is ever greater than DPCDP(L) or less than DPCDM(L), then the factor CDFAA(L) is applied to the loss coefficient of ICD(L),JCD(L) for the remainder of the calculation. If the pressure difference has never been greater than DPCDP(L) or has never been less than DPCDM(L) then the factor CDFAB(L) is applied to the loss coefficient of ICD(L),JCD(L).
21-25	JCD1(L)	Enter vertical node number of first channel in pressure difference pair.
26-30	ICD2(L)	Enter number of second channel in pressure difference pair.

31-35	JCD2(L)	Enter vertical node number of second channel in pressure difference pair.
36-40	DPCDP(L)	Enter positive differential pressure limit in psi (if ICOBRA = 0) or N/m^2 (if ICOBRA = 1).
41-45	DPCDM(L)	Enter negative differential pressure limit in PSI (if ICOBRA = 0) or N/m^2 (if ICOBRA = 1).
46-50	CDFAB(L)	Enter factor to be applied to drag coefficient before pressure limits are reached.
51-55	CDFAA(L)	Enter factor to be applied to drag coefficient after pressure limits have been reached.

CARD Group 8: Thermal Conductor Data, read by subroutine SETIN

CARD8.1 NGROUP,NROD,NSROD,NC,NRTAB

FORMAT(5I5)

Columns	Variable	Description
1-5	NGROUP	Enter eight (8).
6-10	NROD	Leave blank.
11-15	NSROD	Enter number of thermal conductors.
16-20	NC	Conduction model flag; Enter one (1) for radial conduction only.
21-25	NRTAB	Enter number of temperature initialization tables to be read.

THERMAL CONDUCTOR DATA

CARD8.2 HUMAX,HUMIN,IHTOP

FORMAT(2F10.0,I5)

Columns	Variable	Description
1-10	HUMAX	Enter upper limit for condensation heat transfer coefficient in Btu/hr-ft^2-°F (if ICOBRA = 0) or W/m^2K (if ICOBRA = 1). Recommended value is 280 Btu/hr-ft^2°F (1590 W/m^2K).

11-20	HUMIN	Enter lower limit for condensation heat transfer coefficient in Btu/hr-ft^2-°F (if ICOBRA = 0) or W/m^{2}K (if ICOBRA = 1).
21-25	IHTOP	Enter 0 to use the full heat transfer selection logic and the UCHIDA correlation for the subcooled liquid interfacial heat transfer coefficient for film flow. Enter 1 to use the full heat transfer logic and the normal two-phase interfacial heat transfer correlations for subcooled liquid films. Enter 2 to use the UCHIDA correlation for the wall-vapor heat transfer coefficient and the normal two-phase interfacial heat transfer correlations for subcooled liquid films.

This card is read for each of the NSROD conductor heat slabs.

CARD8.3 N,ISTYP(N),HPERIM(N),HPERIMI(N),RMULS(N) Read only if NSROD > 0.

FORMAT(2I5,3F10.0)

Columns	Variable	Description
1-5	N	Enter thermal conductor identification number. (Note: Thermal conductor index numbers must be entered sequentially, from 1 to NSROD. Skipping numbers is not permitted.)
6-10	ISTYP(N)	Enter geometry type identification number. (Refer to group 9 for geometry type input data.)
11-20	HPERIM(N)	Enter wetted perimeter on outside surface, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).
21-30	HPERIMI(N)	Enter wetted perimeter on inside surface, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). (Enter zero for a solid cylinder.)
31-40	RMULS(N)	Fraction (or multiple) of geometry that is in contact with the fluid.

THERMAL CONDUCTOR INITIALIZATION TABLES

CARD8.4 through CARD8.7 are read to specify which temperature tables apply to which conductors. The sequence is repeated NRTAB times, and all conductors must be accounted for.

CARD8.4 I,NRT1,NST1,NRAX1

FORMAT(4I5)

Columns	Variable	Description
1-5	I	Enter identification number of temperature table.
6-10	NRT1	Leave blank.
11-15	NST1	Enter number of conductors using Table I.
16-20	NRAX1	Enter number of pairs of elements in Table I.

CARD8.6 (ISTAB(I,L),L=1,NST1) Read only if NST1 > 0.

FORMAT(12I5)

Columns	Variable	Description
1-5 6-10 . . 56-60	ISTAB(I,L)	Enter identification numbers of thermal conductors using Table I for temperature initialization.

Note: A flat radial temperature profile is assumed initially in the thermal conductors.

CARD8.7 (AXIALT(I,L),TRINIT(I,L),L=1,NRAX1)

FORMAT(8F10.0)

Columns	Variable	Description
1-10 21-30 41-50 61-70	AXIALT(I,L)	Enter the vertical position relative to the bottom of the mesh, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).

11-20 31-40 51-60 71-80	TRINIT(I,L)	Enter the temperature to be applied at AXIALT(I,L), in °F (if ICOBRA = 0) or °K (if ICOBRA = 1).

Note: The vertical locations of the bottom and top of each thermal conductor using Table I must be contained within the range AXIALT(I,1) to AXIALT(I,NRAX1).

CARD Group 9: Conductor Geometry Description, read by subroutine SETIN

The geometry types are read in this group. The geometry types are numbered sequentially in the order they are read in.

CARD9.1 NGROUP,NFUELT

FORMAT(5I5)

Columns	Variable	Description
1-5	NGROUP	Enter nine (9).
6-10	NFUELT	Enter number of geometry types to be read in.

CARDS9.6 and 9.7 are repeated until NFUELT geometry types have been described.

CARD9.6 I,FTYPE(I),DROD,DIN,NFUEL,IMATOX(I),IMATIX(I)

FORMAT(I5,1X,A4,2F10.0,3I5)

Columns	Variable	Description
1-5	I	Enter geometry type identification number.
7-10	FTYPE(I)	Enter four-character alphanumeric geometry type flag: HROD = solid cylinder TUBE = hollow tube WALL = flat plate
11-20	DROD	Enter outside diameter 15 for HROD or TUBE geometries, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). Enter the wetted perimeter for WALL geometries, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).

21-30	DIN	Enter inside diameter for TUBE geometries, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). Enter thickness for WALL geometries, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). Enter zero (0.0) for (HROD) solid cylinder geometries.
31-35	NFUEL	Enter the number of regions within the conductor. (Each region consists of one material.)
36-40	IMATOX(I)	Enter the index number of the material property table for material in region NFUEL if there is no oxide present.
41-45	IMATIX(I)	Enter the index number of the material property table for material in region 1 if there is no oxide present.

Data sets for the NFUEL regions of geometry type I are entered starting at the centerline for HROD types and at the inside surface for TUBE and WALL types. Data sets are entered in sequence moving radially toward the outside surface.

CARD9.7 (NODER(L),MATR(L),TREG(L),QREG(L),L=1,NFUEL)

FORMAT(4(2I5,2F5.0))

Columns	Variable	Description
1-5 21-25 41-45 61-65	NODER(L)	Enter the number of radial heat transfer nodes in region L.
6-10 26-30 46-50 66-70	MATR(L)	Enter the material property table identification number for region L.
11-15 31-35 51-55 71-75	TREG(L)	Enter the thickness of region L, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1). Note: For TUBE and HROD geometry types, $\sum_{L=1}^{NFUEL} TREG(L) = 0.5\ (DROD - DIN)$

16-20 36-40 56-60 76-80	QREG(L)	Leave blank.

CARD Group 10: Material Properties Tables, read by subroutine SETIN

CARD10.1 NGROUP,NMAT

FORMAT(2I5)

Columns	Variable	Description
1-5	NGROUP	Enter ten (10).
6-10	NMAT	Enter number of material properties tables to be read in.

CARD10.2 and CARD10.3 are read in pairs NMAT times.

CARD10.2 N,NNTDP,RCOLD(N)

FORMAT(2I5,F10.0)

Columns	Variable	Description
1-5	N	Enter the material property table identification number.
6-10	NNTDP	Enter the number of entries in material properties table N.
11-20	RCOLD(N)	Enter the cold density in lbm/ft^3 (if ICOBRA = 0), or kg/m^3 (if ICOBRA = 1) for material N. (This value is used to define the mass in the heat transfer nodes composed of material type N.)

CARD10.3 (TPROP(I,N),CPF1(I,N),THCF(I,N) I=1,NNTDP)

FORMAT(6F10.0)

Columns	Variable	Description
1-10 31-40	TPROP(I,N)	Enter the temperature for entry I in material property table N. Units are $^{\circ}F$ (if ICOBRA = 0) or $^{\circ}K$ (if ICOBRA = 1).

11-20 41-50	CPF1(I,N)	Enter the specific heat for entry I in material property table N. Units are Btu/lb-°F (if ICOBRA = 0) or J/kg°C (if ICOBRA = 1).
21-30 51-60	THCF(I,N)	Enter the thermal conductivity for entry I in material property table N. Units are Btu/hr-ft-°F (if ICOBRA = 0) or W/m°C (if ICOBRA = 1).

CARD Group 12: Turbulence and Viscous Stress Data, read by subroutine SETIN

CARD12.1 NGROUP,N1

FORMAT(2I5)

Columns	Variable	Description
1-5	NGROUP	Enter twelve (12).
6-10	N1	Enter number of sections in which turbulence or viscous stress will be applied.

CARD12.2 is read N1 times, once for each section with turbulence or viscous stresses. For each section ISEC, CARD12.3 is read if ITURB(ISEC) = 1, and CARD12.4 is read if ITURB(ISEC) = 2.

CARD12.2 ISEC,IVIS(ISEC),ITURB(ISEC)

FORMAT(3I5)

Columns	Variable	Description
1-5	ISEC	Enter identification number of section using turbulence or viscous stress calculation.
6-10	IVIS(ISEC)	Enter viscous stress flag for section ISEC. Valid entries are: 0 = do not apply viscous stress 1 = apply viscous stress
11-15	ITURB(ISEC)	Enter turbulence flag for section ISEC. Valid entries are: 0 = do not apply turbulence 1 = apply turbulence with uniform turbulence properties 2 = apply turbulence with channel varying turbulence properties

CARD12.3 is read if ITURB(ISEC) = 1. This card is read only once for a section, and the same properties are applied to all channels within the section.

CARD12.3 ZLMXXL(ISEC),ZLMXXV(ISEC),F11(ISEC),F22(ISEC),TPRNOL(ISEC), TPRNOV(ISEC) Read only if ITURB(I) = 1.

FORMAT(6F5.0)

Columns	Variable	Description
1-5	ZLMXXL(ISEC)	Enter liquid mixing length for section ISEC, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).
6-10	ZLMXXV(ISEC)	Enter vapor mixing length for section ISEC, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).
11-15	F11(ISEC)	Enter vertical anisotropy factor for section ISEC.
16-20	F22(ISEC)	Enter transverse anisotropy factor for section ISEC.
21-25	TPRNOL(ISEC)	Enter liquid turbulent Prandtl number for section ISEC.
26-30	TPRNOV(ISEC)	Enter vapor turbulent Prandtl number for section ISEC.

CARD12.4 is read if ITURB(ISEC) = 2. The card is read once for each channel in section ISEC.

CARD12.4 I,ZLMXXL(I),ZLMXXV(I),F11(I),F22(I),TPRNOL(I),TPRNOV(I) Read only if ITURB(I) = 2.

FORMAT(I5,6F5.0)

Columns	Variable	Description
1-5	I	Enter identification number of a channel in section ISEC.
6-10	ZLMXXL(I)	Enter liquid mixing length for channel I, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).
11-15	ZLMXXV(I)	Enter vapor mixing length for channel I, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).

16-20	F11(I)	Enter vertical anisotropy factor for channel I.
21-25	F22(I)	Enter transverse anisotropy factor for channel I.
26-30	TPRNOL(I)	Enter liquid turbulent Prandtl number for channel I.
31-35	TPRNOV(I)	Enter vapor turbulent Prandtl number for channel I.

CARD Group 13: Boundary Condition Data, read by subroutine SETIN

CARD13.1 NGROUP,NIBND,NKBND,NFUNCT,NGBND

FORMAT(5I5)

Columns	Variable	Description
1-5	NGROUP	Enter thirteen (13).
6-10	NIBND	Enter the total number of 17 vertical mesh cell boundary conditions.
11-15	NKBND	Enter the total number of transverse momentum cells for which crossflow will be set to zero.
16-20	NFUNCT	Enter the number of forcing functions for the boundary conditions.
21-25	NGBND	Enter the number of groups of contiguous transverse momentum cells for which crossflows will be set to zero.

CARD13.2 (NPTS(K),K=1,NFUNCT) Read only if NFUNCT > 0.

FORMAT(16I5)

Columns	Variable	Description
1-5,...	NPTS(K)	Enter the number of points (pairs of values) in forcing function table K.

Sixteen (16) values are entered per card. Repeat CARD13.2 until NFUNCT values have been entered.

CARD13.3 is read NFUNCT times.

CARD13.3 ((ABSCIS(K,I),ORDINT(K,I),I=1,NPTS(K)),K=1,NFUNCT) Read only if NFUNCT > 0.

FORMAT(5(F5.0,F10.0))

Columns	Variable	Description
1-5,16-20, 31-35,46-50, 61-65	ABSCIS(K,I)	Enter the time, in seconds, the factor is applied.
6-15,21-30, 36-45,51-60, 66-75	ORDINT(K,I)	Enter the forcing function factor to be applied at time ABSCIS(K,I). The boundary value used by the code will be this factor times the boundary value input on CARD 13.4.

Five (5) pairs of (ABSCIS,ORDINT) are entered per card. Repeat CARD13.3 until NPTS(K) points have been entered for forcing function table K. Continue entering data until NFUNCT tables have been specified.
CARD13.4 through 13.6 are read as a group NIBND times.

CARD13.4 (IBOUND(L,M),L=1,2),ISPEC(M),NPFN(M),NHFN(M),PVALUE(M),HVALUE(M) XVALUE(M),NXFN(M),DROPS(M) Read only if NIBND > 0.

FORMAT(5I5,3F10.0,I5,F10.0)

Columns	Variable	Description
1-5	IBOUND(1,M)	Enter the index number of the channel boundary condition M applies to.
6-10	IBOUND(2,M)	Enter the vertical node number at which boundary condition M is applied. (NOTE: The node number is referenced to the beginning of the section that the channel identified in IBOUND(1,M) resides in.)
11-15	ISPEC(M)	Enter the boundary condition type. Valid options are: 1 = pressure and enthalpy boundary condition 2 = flow, enthalpy and pressure 3 = flow only 4 = mass source (flow rate, enthalpy and pressure) 5 = pressure sink and enthalpy

NOTE: Type 4 and Type 5 boundary conditions must be entered in the order that the mesh cells they are applied to are encountered in the solution scheme. The channels are encountered in the same order that they are read in on Card 4.4. After all channels in the first section at the first vertical level have been encountered the pointer then moves to the second vertical level of the first channel in the first section and so on. After all the mesh cells in the first section have been encountered, the pointer moves to the first vertical level of the first channel in section 2 and so on. Failure to enter type 4 and type 5 boundary conditions in this order will result in the wrong boundary condition being applied to the wrong cell. Warning: No more than one vertical boundary condition may be applied to a single channel/node pair. If more than one boundary condition is specified only the last one specified will be used.

16-20	NPFN(M)	Enter the index number of the forcing function table by which the first parameter of the boundary condition will be varied. (NOTE: The forcing function tables are numbered sequentially in the order they are read in on CARD13.3.) For example: If ISPEC(M) = 1 and 18 NPFN(M) = 3, the specified pressure will be adjusted according to the third forcing function entered on CARD13.3. Enter zero if the boundary condition is constant.
21-25	NHFN(M)	Enter the index number of the forcing function table by which the second parameter of the boundary condition will be varied. (For example: If ISPEC(M) = 1 and NHFN(M) = 6, the specified enthalpy will be adjusted according to the 6th forcing function specified on CARD13.3.) Enter zero if the boundary condition is constant.
26-35	PVALUE(M)	Enter the first boundary value. If ISPEC(M) = 1 or 5, enter pressure, in psia (if ICOBRA = 0) or N/m^2 (if ICOBRA = 1). If ISPEC(M) = 2, 3 or 4, enter flow rate, in lbm/sec (if ICOBRA = 0) or kg/sec (if ICOBRA = 1).

36-45	HVALUE(M)	Enter steam/water enthalpy in Btu/lbm (if ICOBRA = 0) or J/kg (if ICOBRA = 1). Enter zero (0) if ISPEC(M) = 3.
46-55	XVALUE(M)	Enter total pressure in psia (if ICOBRA = 0) or N/m^2 (if ICOBRA = 1), if ISPEC(M) = 2 or ISPEC(M) = 4. Otherwise leave blank.
56-60	NXFN(M)	Enter the index number of the forcing function table by which XVALUE(M) will be varied. Enter zero if the boundary condition pressure is constant.
61-70	DROPS(M)	Enter zero if all liquid entering the mesh through the boundary condition is assumed to enter the continuous liquid field. Enter the drop diameter in inches (if ICOBRA = 0) or m (if ICOBRA = 1) if all liquid entering the mesh through the boundary is assumed to enter the entrained drop field.

CARDS13.5 and 13.6 are read only if ISPEC(M) is not equal to 3.

CARD13.5 HMGA(M),(GVALUE(NGA,M),NGA=1,NGAS+2)

FORMAT(16F5.0)

Columns	Variable	Description
1-5	HMGA(M)	Enter noncondensable gas mixture enthalpy for the boundary condition M in Btu/lbm (if ICOBRA = 0) in J/kg (if ICOBRA = 1).
6-10	GVALUE(1,M)	Leave blank.
11-15	GVALUE(2,M)	Enter the volume fraction of steam in the steam/gas mixture for the boundary condition M.
16-20	GVALUE(3,M)	Enter the volume fraction of the first gas species in the noncondensable gas mixture for boundary condition M.

21-25	GVALUE(4,M) . . . GVALUE(NGAS+2,M)	Enter the volume fraction of the next gas specified in the noncondensable gas mixture for boundary condition M, etc., until all NGAS volume fractions have been entered. The gas species are assumed to be in the same order as they were entered on CARD1.4, GVALUE(2,M) through GVALUE(NGAS+2,M) should sum to 1.0.

CARD13.6 NHMF(M),NGFN(NGA,M),NGA=1,NGAS+2

FORMAT(12I5)

Columns	Variable	Description
1-5	NHMFN(M)	Enter the index number of the forcing function table by which the boundary condition gas mixture enthalpy will be varied. Enter zero if the gas mixture enthalpy is constant.
6-10	NGFN(1,M)	Leave blank.
11-15	NGFN(2,M)	Enter the index number of the forcing function table by which the boundary condition steam volume fraction will be varied. Enter zero if the steam volume fraction is constant.
16-20	NGFN(3,M)	Enter the index number of the forcing function by which the volume fraction of the first gas species in the boundary condition gas mixture will be varied. Enter zero if the gas volume fraction is constant.
21-25	NGFN(4,M) . . . NGFN(NGAS+2,M)	Enter the index number of the forcing function by which the volume fraction of the next gas species in the boundary condition gas mixture will be varied. Enter zero if the gas volume is constant. Repeat until forcing functions have been entered for all gas species.

CARD13.7 is read only if ISPEC(M) = 5.

CARD13.7 ASINK(K),SINKK(K),DXSINK(K)

FORMAT(3F5.0)

Columns	Variable	Description
1-5	ASINK(K)	Enter the flow area of the pressure sink, in $in.^2$ (if ICOBRA = 0) or m^2 (if ICOBRA = 1).
6-10	SINKK(K)	Enter the loss coefficient (velocity head) of the pressure sink.
11-15	DXSINK(K)	Enter the length of the momentum control volume for the sink, in inches (if ICOBRA = 0) or meters (if ICOBRA = 1).

CARD13.8 is read only if ISPEC(M) = 4.

CARD13.8 AINJT(K)

FORMAT(F5.0)

Columns	Variable	Description
1-5	AINJT(K)	Enter the flow area of the mass injection $in.^2$ (if ICOBRA = 0) or m^2 if (ICOBRA = 1).

CARD13.9 is read NGBND times only if NGBNG > 0.

CARD13.9 K,JSTART,JEND

FORMAT(3I5)

Columns	Variable	Description
1-5	K	Enter the gap number to which a zero (0.0) crossflow is to be applied.
6-10	JSTART	Enter the continuity cell number at which to start applying the zero crossflow.
11-15	JEND	Enter the continuity cell number at which to stop applying the zero crossflow. (Note: The crossflow will be set to zero for gap K between nodes JSTART and JEND. The node numbers are given relative to the beginning of the section containing gap K.)

This card may be repeated as many times as necessary for a given gap K, to identify all vertical levels that have zero crossflow. The total number of transverse momentum cells with zero crossflow boundary conditions specified by CARD13.9 must sum to NKBND.

CARD Group 14: Output Options, read by subroutine SETIN

CARD14.1 NGROUP,N1,NOUT1,NOUT2,NOUT3,NOUT4,IPROPP,IOPT

FORMAT(8I5)

Columns	Variable	Description
1-5	NGROUP	Enter fourteen (14).
6-10	N1	Enter the general output option. Valid entries are: 1 = print channels only 2 = print channels and gaps only 3 = print thermal conductors only 4 = thermal conductors and channels only 5 = print channels, gaps, thermal conductors
11-15	NOUT1	Enter the number of channels to be printed (used if N1 = 1, 2, 4 or 5). If NOUT1 = 0, all channels will be printed. If NOUT1 > 0, an array of NOUT1 channel numbers must be entered on CARD14.2.
16-20	NOUT2	Leave blank.
21-25	NOUT3	Enter the number of gaps to be printed (used if N1 = 2 or 5). If NOUT3 = 0, all gaps will be printed. If NOUT3 > 0, an array of NOUT3 gap numbers must be entered on CARD14.3.
26-30	NOUT4	Enter the number of thermal conductors to be printed (used if N1 > 2). If NOUT4 = 0, all unheated conductors will be printed. If NOUT4 > 0, an array of NOUT4 thermal conductor numbers must be entered on CARD14.5.

31-35	IPROPP	Enter the property table print option. Valid entries are: 0 = do not print the property table 1 = print the property table
36-40	IOPT	Enter the debug print option. Valid entries are: 0 = normal printout only 1 = debug printout (print extra data for channels, conductors and gaps)

CARD14.2 (PRINTC(I),I=1,NOUT1) Read only if N1 ≠ 3 and NOUT1 > 0.

FORMAT(16I5)

Columns	Variable	Description
1-5,...	PRINTC(I)	Enter the index numbers of channels to be printed. Sixteen values are entered per card. Repeat this card until NOUT1 values have been entered.

CARD14.3 (PRINTG(I),I=1,NOUT3) Read only if N1 = 2 or 5 and NOUT3 > 0.

FORMAT(16I5)

Columns	Variable	Description
1-5,...	PRINTG(I)	Enter the index numbers of gaps to be printed. Sixteen values are entered per card. Repeat this card until NOUT3 values have been entered.

CARD14.5 (PRINTS(I),I=1,NOUT4) Read only if NOUT4 > 0.

FORMAT(16I5)

Columns	Variable	Description
1-5,...	PRINHS(I)	Enter the index numbers of unheated conductors to be printed. Sixteen values are entered per card. Repeat this card until NOUT4 values have been entered.

CARD14.6 NDUMEND

FORMAT(I5)

Columns	Variable	Description
1-5	NDUMEND	Enter zero (0) to terminate CARD group control card input.

Graphics Options, read by subroutine IGRAF

GRAF.1 MOVIE,TMOVIE

FORMAT(I5,F10.2)

Columns	Variable	Description
1-5	MOVIE	Enter the movie process option. Valid entries are: 0 = no movie (recommended option) 1 = save data for particle tracker movie.

Note: The COBRA-NC code has the capability to dump data that can be used to make particle-tracker movies of simulations. However, the software to actually make the particle-tracker movies is not part of the COBRA-NC package and will be released and documented separately.

6-15	TMOVIE	Enter the time interval at which to save data for the movie. Valid only if MOVIE = 1.

GRAF.2 NCGRAF,MXGDMP,IGRFOP,NLLR

FORMAT(4I5)

Columns	Variable	Description
1-5	MXGDMP	Enter the maximum number of time steps for which graphics data will be saved. Absolute maximum is MI (RESPEC parameter). (Note: This cannot be changed on a restart.)
6-10	IGRFOP	Enter the graphics option, as follows: 0 for normal dump (all variables saved for all computational cells) N, where N is the number of user-selected variables to be saved for graphics

		(Note: This option is needed to reduce the graphics dump to manageable size for large problems.)
11-15	NLLR	Enter the number of liquid level calculations. (Number of GRAF.3 cards.) (Valid only if IGRFOP > 0.) (See Section 3.4.2 for discussion of this input.)

Card GRAF.3 is read once for a liquid level calculation in channels that are all in the same section. If a liquid level calculation includes channels in different sections, GRAF.3 is read once for each section involved. Card GRAF.3 is read a total of NLLR times.

GRAF.3 (NCHLL(N),JSLL(N),JCELL(N),(ICLL(I,N),I=1,NCHLL(N)) Read only if NLLR > 0.

FORMAT(16I5)

Columns	Variable	Description
1-5	NCHLL(N)	Enter the number of channels in a section to be used for liquid level calculation N.
6-10	JSLL(N)	Enter the starting vertical node number for the liquid level calculation. This value should be 21 negative if continuing input from previous sections of a liquid level calculation that crosses section boundaries.
11-15	JELL(N)	Enter the ending vertical node number (in the section containing channels ICLL(I,N)) to be included in the liquid level calculation.
16-20 21-25 etc.	ICLL(I,N)	Enter the index numbers of NCHLL(N) channels to use in the liquid level calculation. (Enter up to 13 values on the first line. If NCHLL(N) > 13, continue on the next line, entering values in the 16I5 format.)

GRAF.4 ((IGRF(I,J),J=1,2),GRFN(I),I=1,IGRFOP) Read only if IGRFOP > 0.

FORMAT(5(2I5,F5.0)

Columns	Variable	Description
1-5 16-20 31-35 46-50 61-65	IGRF(I,1)	Enter a number signifying the variable to be saved. Valid entries are: Channel variables-- 1 = pressure 2 = void fraction 3 = entrained liquid fraction 4 = liquid fraction 5 = liquid temperature 6 = vapor temperature 7 = liquid density 8 = vapor density 9 = vapor flow 10 = liquid flow 11 = entrained liquid flow 12 = vapor generation rate 13 = heat transfer rate to liquid 14 = heat transfer rate to vapor 15 = drop mass entrainment rate 16 = drop mass de-entrainment rate 17 = drop interfacial area density 18 = ETAENP 19 = HASHL 20 = HASCL 21 = HASHV 22 = flow regime 23 = boundary condition type 24 = interfacial drag coefficient (XK) 25 = interfacial drag coefficient (XKGE) 37 = mixture density Gap variables-- 26 = vapor crossflow 27 = liquid crossflow 28 = entrained liquid crossflow
6-10 21-25 36-40 51-55 66-70	IGRF(I,2)	Enter channel or gap number for which selected variable will be saved. Parameters 1-25 and 37 are channel variables and 26-28 are gap variables.

11-15 26-30 41-45 56-60 71-75	GRFN(I)	Enter the vertical node number for which the selected variable will be saved.

2.3 Time Domain Data, read by subroutine TIMSTP

After all component data has been entered the user must define the time domain for the simulation. The total time can be divided into several domains of specified duration. Each time domain can have different minimum and maximum time step sizes and different edit intervals. To terminate the calculation, a time domain with a negative time step size is entered. Two cards are required to specify the data for each time domain.

TIME.i DTMIN,DTMAX,TEND,RTWFP,TMAX

FORMAT(5E14.6)

Columns	Variable	Description
1-14	DTMIN	Enter the minimum time step allowed for this domain, in seconds. Enter a negative value to terminate the calculation.
15-28	DTMAX	Enter the maximum time step allowed for this domain, in seconds.
29-42	TEND	Enter the end of this time domain, in seconds.
43-56	RTWFP	Enter the ratio of conduction solution and fluid solution time step sizes. (Used to obtain steady-state conditions. The conduction solution can generally take time steps greater than the fluid solution. For transient calculations, RTWFP should be one.)
57-70	TMAX	Enter the maximum CPU time allowed for this run. If this CPU limit is reached during this simulation time domain, the run will terminate. (Dump files will be written, so the calculation can be restarted.)

TIME.2 EDINT,GFINT,DMPINT,SEDINT,TCKLEND

FORMAT(5E14.6)

Columns	Variable	Description
1-14	EDINT	Enter the print interval for this time domain. Output will be printed every EDINT seconds.
15-28	GFINT	Enter the graphics interval for this time domain. Data for graphics will be saved every GFINT seconds.
29-42	DMPINT	Enter the restart dump interval. Data for restarts will be saved every DMPINT seconds. (NOTE: For larger problems, the restart dumps create relatively large files, and can become unmanageable if too many dumps are written during a simulation. Regardless of the value for input DMPINT, the dump logic automatically writes dumps at the beginning of a calculation, at the end of a calculation, and after every 120 min of CPU time during the calculation. This is usually quite sufficient, and DMPINT can be set to a large value.)
43-56	SEDINT	Enter the "short edit" interval for this time domain. (A "short edit" is an abbreviated print.) Short edits will be performed every SEDINT seconds.
57-70	TCLKEND	Enter the wall clock time (decimal, 24 h clock) at which to stop the calculation and create a restart dump and edit. (This is useful for running the calculation during particular shifts; for example, TCLKEND can be entered as 7.5 to stop the calculation at 7:30 am. Enter zero if this feature is not used.

Repeat cards TIME.1 and TIME.2 for each time domain desired. A final time domain with a negative value for DTMIN must be entered to terminate the calculation.

2.4 SPECSET Redimensioning Program

The common blocks in COBRA-NC can be redimensioned using the scope UPDATE facility available on CDC machines. The COBRA-NC common blocks are contained in a set of COMDECKS that can be redimensioned using a preprocessor program, SPECSET.

This section discusses the procedure for redimensioning the COBRA-NC code on a CDC machine with the UPDATE facility. The procedure consists of a series of updates (outlined below) that define the sizes of the COMDECK arrays for COBRA-NC.

The COMDECKS for COBRA-NC consist of sets of common blocks with dimension parameters instead of numbers defining the arrays. An example of a typical COMDECK line is

```
COMMON/DUMMY/A(MC,MX),B(MT)
```

These common blocks are, obviously, unusable in this form. No computer would successfully compile them. The SPECSET program is used to convert the dimension parameter to numbers. The user supplies input to SPECSET to define the parameters (for example, MC = 20, MX = 100, MT = 5), and SPECSET creates a new COMDECKS file with lines such as

```
COMMON/DUMMY/ A(20,100), B(5)
```

This new COMDECK file is copied into the COBRA-NC code via UPDATE, and the code can then be compiled. The user must supply values for 38 dimension parameters for SPECSET to redimension COBRA-NC. The line-by-line input for SPECSET is listed in Section 2.5.1, and the 38 dimension parameters which must be defined are listed in Table 1.

Table 1 SPECSET dimensioning parameters

Parameter	Definition
MA	Maximum number of pairs of entries for the vertical variation tables. Each table will be dimensioned for MA pairs of elements. (This parameter should be equal to or greater than the maximum value of NAXL(I), entered in group 5 on CARD5.2.)
MB	Maximum number of channels per section. (This parameter should be equal to or greater than the maximum value for NCHN, entered in group 4 on 23 CARD4.2.)
MC	Maximum number of channels. (This parameter should be equal to or greater than the maximum value of I, entered in group 2 on CARD2.2).

(Table 1, continued)

Parameter	Definition
MD	Number of records read to describe transverse orthogonal convection. (This parameter should be equal to or greater than NLMGAP, entered in group 3 on CARD3.4.)
MH	Number of pressure- dependent form loss coefficient records. (This parameter should be equal to or greater than the parameter NCDPP entered on CARD7.1).
MI	Maximum number of graphics dumps to be made.
M5	Number of variables dumped for short graphics dump. (This parameter should be greater than or equal to IGRFOP input on card GRAF.2.)
MF	Maximum number of fuel geometry types. (This parameter should be equal to or greater than NFUELT, entered in group 9 on CARD9.1.)
MG	Maximum number of transverse connections between channels (i.e., gaps). (This parameter should be equal to or greater than the maximum value of K, entered in group 3 on CARD3.2.)
ML	Maximum number of vertical variation tables. (This parameter should be equal to or greater than NAFACT entered in group 5 on CARD5.1.)
MR	One (1). Not used for containment applications.
MS	Maximum number of pressure sink and mass source boundary conditions (i.e., up to MS type 4 boundary conditions and up to MS type 5 boundary conditions can be specified in input group 13.) (This parameter should be equal to or greater than the maximum number of either type 4 or type 5 boundary conditions specified in group 13 on CARD13.4.)
MT	Maximum number of material property types. (This parameter should be equal to or greater than NMAT, entered in group 10 on CARD10.1.)
MU	Maximum number of specified vertical boundary conditions. (This parameter should be equal to or greater than NIBND, entered on CARD13.1.)
MV	Maximum number of forcing functions on the specified cell boundary conditions. (This parameter should be equal to or greater than NFUNCT on CARD13.1.)

(Table 1, continued)

Parameter	Definition
MX	Maximum number of vertical nodes in a section. (This parameter should be equal to or greater than the maximum value of NONODE+2, entered in group 4 on CARD4.2.)
MY	Maximum number of locations plus 1, in any one channel, where vertical velocities convect transverse momentum across section boundaries. (This parameter should be at least 1 greater than the maximum value of NAMGAP, entered in group 2 on CARD2.2.)
MZ	Maximum number of liquid level records to be read by input line GRAF.3. This is the maximum number of groups of channels that can be considered in the liquid level graphics calculation.
NA	Maximum number of continuity cells. This parameter should be equal to or greater than the sum of all nodes in all channels: $\sum_{N=1}^{NSECTS} NCHN(N)*NONODE(N)$ where NSECTS = total number of sections (entered on CARD4.1.), NCHN(N) = number of channels in section N, (entered on CARD4.2.), NONODE(N) = number of vertical levels in section N, (entered on CARD4.2.)
NB	Maximum number of flow connections to a cell (including all connections for vertical flow and transverse flow).
NE	Maximum bandwidth of pressure solution matrix. Bandwidth for a given problem is (2*IWIDE+1), where IWIDE is specified in group 4 on CARD4.4. NE must be equal to or greater than (2*IWIDE+1).
NF	Maximum number of pairs of entries in tables of forcing functions on boundary 24 conditions. Each forcing function may have up to NF pairs of entries. (This parameter should be equal to or greater than the maximum of NPTS(K), entered on card CARD13.2.

(Table 1, continued)

Parameter	Definition
NI	Maximum number of cells in any one simultaneous solution group. (This parameter should be equal to or greater than the maximum difference between adjacent elements of the MSIM(I) array, entered in group 4 on CARD4.5.)
NL	Maximum number of transverse momentum cells that have crossflow set to zero. (This parameter should be equal to or greater than NKBND, entered in group 13 on CARD13.1.)
NM	Number of species in the noncondensable gas mixture. (This parameter should be equal to or greater than NGAS, entered in group 1 on CARD1.1).
NN	One (1). Not used for containment applications.
NP	Maximum number of entries in a material property table. (This parameter should be equal to or greater than the maximum value of NNTDP, entered in group 10 on CARD10.2.)
NQ	Maximum number of sections. (This parameter should be equal to or greater than NSECTS, entered in group 4 on CARD4.1.)
NR	One (1). Not used for containment applications.
NT	Maximum number of thermal conductors. (This parameter should be equal to or greater than NSROD, entered in group 8 on CARD8.1.)
NV	Maximum number of heat transfer surfaces on all thermal conductors, including both internal and external surfaces in contact with the fluid. (This parameter is not checked directly in the code. The user must check it against his input for the LS array in group 2 on CARD2.4. NV must be equal to or greater than the sum of NSROD on CARD8.1 plus the total number of connections to the inside surfaces of heat slabs.
NX	Maximum number of vertical nodes in thermal conductors.
NY	Maximum number of radial nodes for conduction in a thermal conductor. This parameter should be equal to or greater than the maximum value of the sum of all nodes in a thermal conductor.

(Table 1, continued)

Parameter	Definition
	$\left[\sum_{L=1}^{NFUEL(I)} NODER(L)\right]_{max}$
	where NFUEL(I) = number of regions in geometry type I (entered on CARD9.6).
	NODER(L) = number of nodes in region L of geometry type I, (entered on CARD9.7).
NZ	Maximum number of vertical levels in the mesh. (This parameter should be at least 2 greater than the total number of vertical mesh cells in the problem).
N3	One (1). Not used for containment applications.
N4	Maximum number of thermal conductor temperature initialization tables. (This parameter should be equal to or greater than NRTAB, entered in group 8 on CARD8.1.)
N5	Maximum number of entries in a given thermal conductor temperature initialization table. (This parameter should be equal to or greater than the maximum value of NRAX1, entered in group 8 on CARD8.4.)
N8	One (1). Not used for containment applications.
NC(a)	2 * NN
ND	25 + 5 * NB
NG	NN + 2
NH	NX + 2
NJ	NB + 1
NK	NB + 5
M6	6*MX

(a) The parameters NC through M6 are dimension parameters calculated internally by SPECSET, based on parameter values input by the user. These parameters are <u>not</u> specified directly in the input for SPECSET. They are listed here only to inform the user that these parameters are used in the common blocks to define certain array sizes.

The Job Control Language (JCL) and input files required for redimensioning COBRA-NC are as follows:

1) Create a compile file of program SPECSET and compile it.

```
UPDATE(I=SPEKS15,C,F)
FTN(I,CNAME=SPECS,S1=0,R=0)
```

2) Set the input and execute SPECSET. (Input file (see Table 2) and the replacement dimension file TAPE3 must be available).

```
COPY RPCD15 TAPE3
SPECS
```

SPECSET creates a file on TAPE4 that contains the COMDECK replacement directives.

3) Create a new program library from the COBRA-NC source deck.

```
UPDATE (F,I=CDC15S, N=COBRANC,C=),L=1)
```

4) Delete and replace the old COMDECKS with the new one created in Steps 1 and 2 above. Then make a compile file and a new program library.

```
UPDATE(F,I=TAPE4,L=1,P=COBRANC,C,N=CDC15U)
```

5) Use the FORTRAN 5 compiler to create a binary file (COBNCB) and an executable file (COBNCE). A typical load file (COBLOD) is shown in Table 3.

```
FTNS (I,B=COBNCB,CUAME=COBNCE,LF=COBLOD,RFLS=77777(SIZE=1400000)
```

The above described JCL is for the LANL LTSS system. Non-LTSS users will have to modify the above procedure to be consistent with their operating system.

2.4.1 SPECSET Input Instructions

SPEC.1 ISVS

FORMAT(A3)

Columns	Variable	Description
1-3	ISVS	Alphanumeric flag for specifying the type of machine COBRA-NC is being run on ISYS = CDC - CDC machine using large core memory = CRAY - CRAY computer = VAX - VAX computer

Table 2 Sample input file TAPE2 for SPECSET program

```
1     CDC
2      1
3     MA= 8
4     MB= 26
5     MC= 28
6     MD= 60
7     MI= 100
8     M5= 999
9     MF= 18
10    MG= 40
11    MJ= 40
12    ML= 8
13    MR= 1
14    MS= 4
15    MT= 5
16    MU= 65
17    MV= 11
18    MY= 6
19    MX= 13
20    MZ= 1
21    NA= 130
22    NB= 7
23    NE= 25
24    NF= 40
25    NI= 124
26    NL= 40
27    NM= 4
28    NN= 1
29    NP= 4
30    NA= 5
31    NR= 1
32    NS= 4
33    NX= 7
34    NZ= 19
35    NT= 16
36    NV= 16
37    NY= 20
38    N3= 1
39    N4= 2
40    N5= 5
41    N8= 1
42    MJ= 125000
43    MS= 360
```

Table 3 Typical Load File for CDC Compiler

```
 1 *OVERLAY(0.0)
 2 *F1 AFROMH CURVE GAUSS HGAS PROP SAT TGAS
 3 *F1 VOLLIQ VOLVAP SPLITIT GAPHTC GTHCON DEFORM TRANSP
 4 *F1 IGRAF
 5 *OVERLAY(1,0,EP=INPUT)
 6 *OVERLAY(1,2,EP=SETUP)
 7 *OVERLAY(1,3,EP=SETOUT)
 8 *OVERLAY(3,0,EP=DMPIT)
 9 *OVERLAY(4,0,EP=EDIT)
10 *OVERLAY(5,0,EP=GRAF)
11 *OVERLAY(5,0,EP=OUTER)
12 *OVERLAY(6,1,EP=XSCHEM)
13 *OVERLAY(11,0,EP=PREF3D)
14 *OVERLAY(12,0,EP=POST3D)
15 *OVERLAY(13,2,EP=BLKDAT)
```

SPEC.2 IFTURB

FORMAT(I5)

Columns	Variable	Description
1-5	IFTURB	Optional dimensioning of turbulence arrays; IFTURB = 0, code not dimensioned for turbulence model. IFTURB = 1, code dimensioned for turbulence model.

SPEC.3 MM=IVAL

Columns	Variable	Description
1-2	MM	Enter a two-character alphanumeric dimension parameter name. (See Table 1).
3		Enter an equal sign (optional).
4-8	IVAL	Enter the numerical value desired for the dimension parameter named in MM. The number entered may be right or left justified. The code extracts only the actual digits entered. For example, MC = 100 is interpreted as the same value as MC = 100.

Card SPEC.3 is repeated until all 41 dimension parameters have been specified. The SPECSET program will fail even if one has been omitted. The parameters can be entered in any order as long as none are left out. A sample SPECSET input file is given in Table 2. The equal sign between MM and IVAL is not read by the code, but it helps clarify the input for the user. On restarts, SPECSET parameters may not be changed from those used to create the restart dump; otherwise the dump will be read improperly.

2.5 Grafix Postprocessor Program

This section describes the input requirements of the GRAFIX postprocessor program. GRAFIX is an interactive program that reads the graphics dump file TAPE11 created by COBRA-NC and, under guidance from the user, translates the data into a plot file. This file contains the plot coordinates, axes labels, optional measured data coordinates, and calculated data. The GRAFIX program does not produce the plots; instead, it produces a file that can be read by a plotting program (NEWPLOT) using CALCOMP plot commands for final plotting. The Programmers' Manual (Volume 9 of this document) explains how GRAFIX and NEWPLOT work, and it should be consulted when modifying the COBRA-NC code package for a particular computer system.

GRAFIX can prepare data for five types of plots:

- variable versus time
- variable versus vertical level
- rod temperature versus radial location at specific elevations and at specified times
- contour plots
- velocity vector plots

The user can specify up to five separate calculated data curves on any one plot, plus optional measured data. The user can control the physical size of the plot, the scaling of the data, and the axis labels. GRAFIX will also perform some simple unit conversions on the calculated data if requested.

GRAFIX can be run in two different modes: 1) interactively prompting the user with questions and waiting for answers from the keyboard, or 2) "batch" mode, using a command file or data saved from a previous interactive session for input. In the interactive mode, the user's responses are entered in unformatted "free-field" mode. This eliminates the need to place the entries in specific column positions. Multiple entries on a line are separated by commas. The only restriction is that the user must include a decimal point for real variables.

If the user does not wish to be troubled with entering plot labels, GRAFIX will write three labels on the plot according to what it knows about the variables being plotted. These labels are necessarily somewhat vague, and for report-quality graphics the user should enter his own labels. The default labels are useful, however, for quick looks at the data.

Plot size and label locations are specified in inches. The origin of the axes is the (0.0 in., 0.0 in.) coordinate of the plot. Label positions are specified by an (x,y) coordinate at which the label is to start. (This coordinate is the position of the lower left corner of the first character of the label.)

The size of the label, also in inches, defines the height of the characters in the label. Labels may be rotated by specifying the angle of rotation, in degrees. (Usually, x-axis labels are rotated 0.0 degrees, y-axis labels are rotated 90.0 degrees, but any rotation is acceptable.) The length of each label can be determined by the following formula:

$$L = \frac{6}{7} * H * N$$

where L = length, in inches
H = height of the label in inches
N = number of characters in the label

Using this formula, it is possible to define a starting location for each label that will place it exactly where the user wants it.

If default scaling is used, GRAFIX will search for the minimum and maximum values and scale the data accordingly. This will not generally produce elegantly partitioned axes, but it is useful for scanning the data. The data to be plotted may also be scaled to fit between user-specified minima and maxima for the x and y axes for report quality plots. Unless a conversion factor is being used, the data will be plotted as found in the graphics dump file.

Because GRAFIX is normally run interactively, it is not possible to list the line-by-line input instructions in quite the same manner as for the other programs in the COBRA-NC package.

When running GRAFIX interactively, a file named TAPE3 is created which contains a log of the users input responses. This file can be saved and used later in the "batch" mode to recreate the same graphics output. GRAFIX is extremely easy to use. It prompts the user for all data needed, and the proper input for a given option is, in general, self-evident.

2.5.1 Measured Data File

If measured data is to be included in the GRAFIX-generated plots, the user must prepare a file prior to running GRAFIX. This file must have a 5-character alphanumeric name, and it must be available for GRAFIX to read while the program is being executed. The required format for a measured data file is shown below.

Record 1

Columns	Variable	Description
1-5	NPTS	The number of points of measured data in the file. (A point consists of two values; time and data value, or location and data value.)

Record 2, 3, ...

Columns	Variable	Description
1-10, 21-30, 41-50, 61-70,	XM(I)	The x-coordinate in data units, (not inches), for point I (e.g., time or axial distance)
11-20, 31-30, 51-60, 71-80	YM(I)	The y- coordinate in data units, (not inches), for point I (e.g., pressure or rod temperature)

There must be four (4) pairs of measured data per record to give a total of NPTS points. (The last record may have fewer than four points, however, if NPTS is not an even multiple of four.)

There is no limit to the number of plots that can be produced during any GRAFIX session. Nor is there any restriction on the order in which the plots are produced; axial profile plots can be freely interspersed with plots of variable versus time or radial profile plots. It should be noted that for each axial or radial profile plot, each contour plot, and each vector plot requested, many actual plots may be generated, since these are produced at specified time intervals.

For each plot, the size of the plot, the label information, and the coordinates to be plotted for the curves are written to logical unit 2 (TAPE2). This data is then sent to a mini-computer and plots are produced by a program (NEWPLOT) that reads TAPE2 and interprets the input for a CALCOMP plotter.

3.0 USERS' GUIDE TO COBRA-NC

This section is intended to aid the user in learning to set up the input model for COBRA-NC. There are three basic tasks the user must perform: 1) setting up the geometry data to describe the system, 2) specifying the fluid conditions and forcing functions to define the state of the system, and 3) running the code and interpreting the output.

The first two tasks are covered in Sections 3.2 through 3.4. The input is discussed in detail in Sections 3.2 through 3.4. Section 3.2 covers the geometry input data, Section 3.3 the input for the conduction model, and Section 3.4 the boundary and initial conditions. Section 3.5 discusses the various output options. The information presented in these subsections is intended to explain, amplify, and clarify the line-by-line input, as listed in Section 2.0.

The third task involves such endeavors as using the dump/restart feature to run the calculation in a series of steps and running the graphics postprocessor program to interpret the computational results. Sections 3.5 and 3.6 are devoted to explaining procedures for using these capabilities.

3.1 Solution Procedure

There are two solution procedures available in COBRA-NC to solve the fluid conservation equations: a semi-implicit scheme and an implicit scheme. The semi-implicit scheme has all of the modeling capabilities described in this manual. The semi-implicit scheme is still in the development process but can be used for some problems that are not affected by the current limitations of the scheme.

The implicit scheme can be used for problems that require only one axial section. The effects of turbulence are not included in the implicit solution procedure. All other capabilities described in this manual are available with the implicit option invoked.

A decision on whether to use the implicit solution or the semi-implicit scheme should be based on the nature of the problem and the current limitations of the implicit solution scheme. The implicit scheme can be especially efficient for steady state solutions since the solution can be achieved in one time step with a very large . The implicit scheme can also be effective for slowly evolving transients such as natural convection simulations. The user should be aware that the implicit scheme is not as robust as the semi-implicit scheme and may require some adjustment of the damping factors and time step size to get a successful run. The time steps should be controlled by setting DTMIN = DTMAX = Δt (card TIME.1) when using the implicit scheme.

3.2 COBRA-NC Geometry Model

COBRA-NC can be used to model flow in any region of the containment with a lumped parameter, one-dimensional, two-dimensional, or three-dimensional mesh. The entire containment building may be modeled using as many subcompartments as desired, or each compartment may be analyzed using a finer mesh within the compartment with appropriate boundary conditions specified at connections to other compartments, or only a small region of a compartment may be modeled to look at local flow details such as jet impingement or hydrogen distributions.

All geometries modeled are represented as a matrix of Eulerian mesh cells. The number of mesh cells used depends on the degree of detail required to resolve the flow field, the phenomena being modeled, and practical restrictions such as computing costs and core storage limitations. In two-phase flow, the mesh cell should be large compared to the characteristic size of the two-phase flow pattern. For example, the mesh cell size should be large relative to the drop size, so that the averaged quantities (drop size, drag, etc.) used in the calculation will be valid. In slug or film flow, the mesh cell size should be on the order of the hydraulic diameter or larger, since the physical models for these flow regimes are based on the physical dimensions of the flow path.

The equations for the flow field are solved using a staggered difference scheme on the Eulerian mesh. The velocities are obtained at mesh cell faces, and the state variables (e.g., pressure, density, enthalpy, gas concentration, and phasic volume fractions) are obtained at the cell center. The mesh cell is characterized by cross-sectional area A, height ΔX and the width of the connections to adjacent mesh cells, S. The basic mesh cell is shown in Figure 1. This cell is the control volume for the scaler continuity and energy equations. The momentum equations are solved on a staggered mesh with

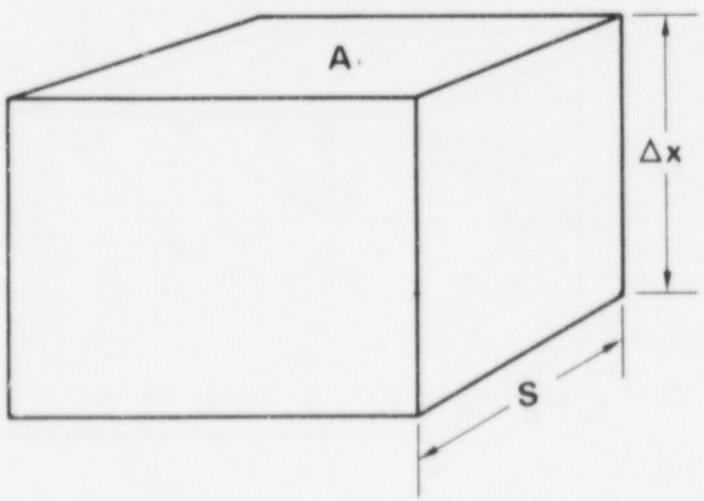


Figure 1 Basic mesh cell

the momentum cell centered on the scalar cell face. The momentum cell for vertical velocities is shown in Figure 2, and that for transverse velocities in Figure 3.

The input has been constructed to allow the user a great deal of flexibility in defining the mesh for the irregular geometries typical of reactor containment buildings. The mesh cells are defined by input in terms of channels. A channel is simply a vertical stack of mesh cells, as illustrated in Figure 4. A channel may represent a containment room, several rooms, or a portion of a three-dimensional mesh in a single room.

Boundary data for each channel are stored in phantom nodes at its top and bottom. Between these two phantom nodes are NDX nodes that actually enter into the calculation. Node J = 1 contains boundary conditions for the bottom of the channel, and node J = NDX + 2 contains boundary conditions for the top of the channel. Boundaries between mesh cells are identified in Figure 4 with the lower case j and refer to the location of the momentum cell center where velocities are obtained. The velocity corresponding to j = 1 is at the top of the continuity mesh cell corresponding to J = 1.

Nominal flow area and wetted perimeter are specified for each channel by input. Each mesh cell within the channel is assumed to have the nominal geometry unless the user specifies a variation for area or wetted perimeter. The mesh

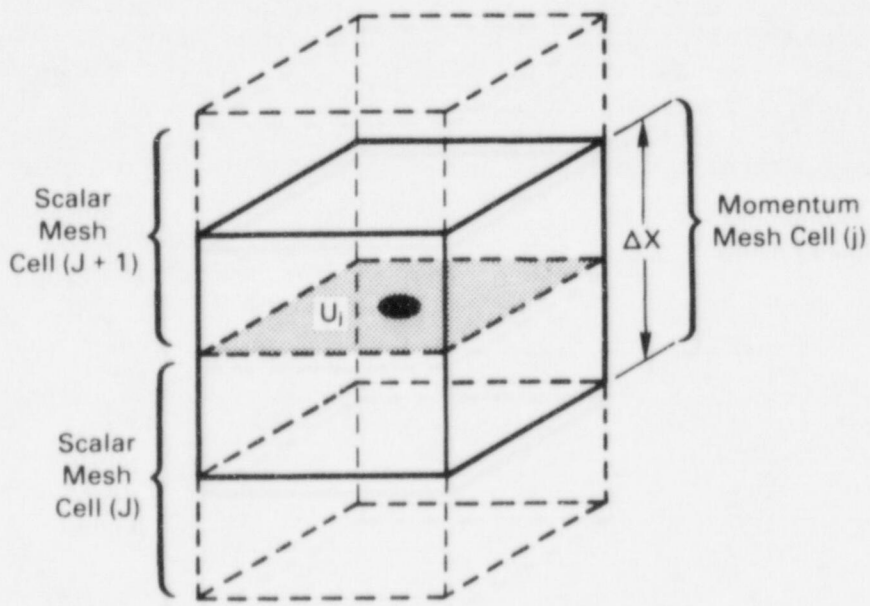


Figure 2 Mesh cell for vertical velocities

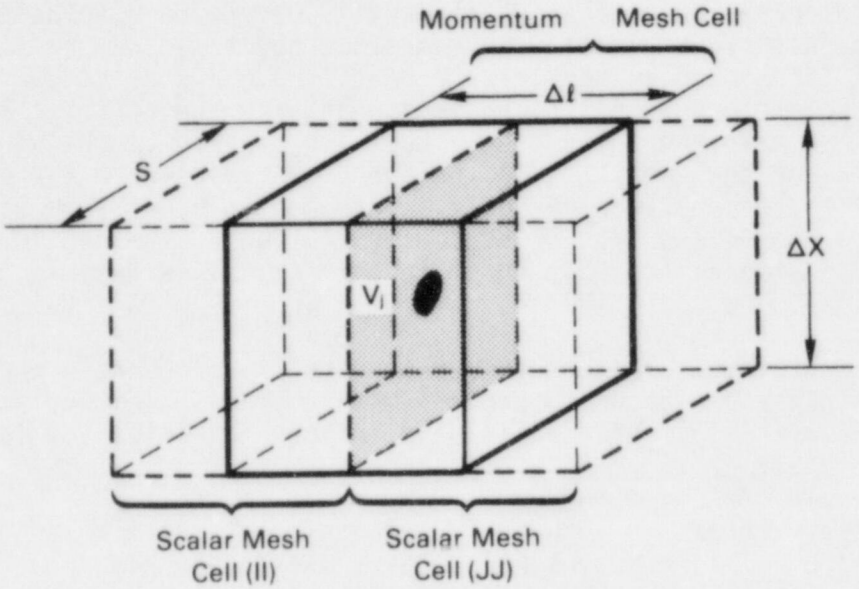


Figure 3 Mesh cell for transverse velocities

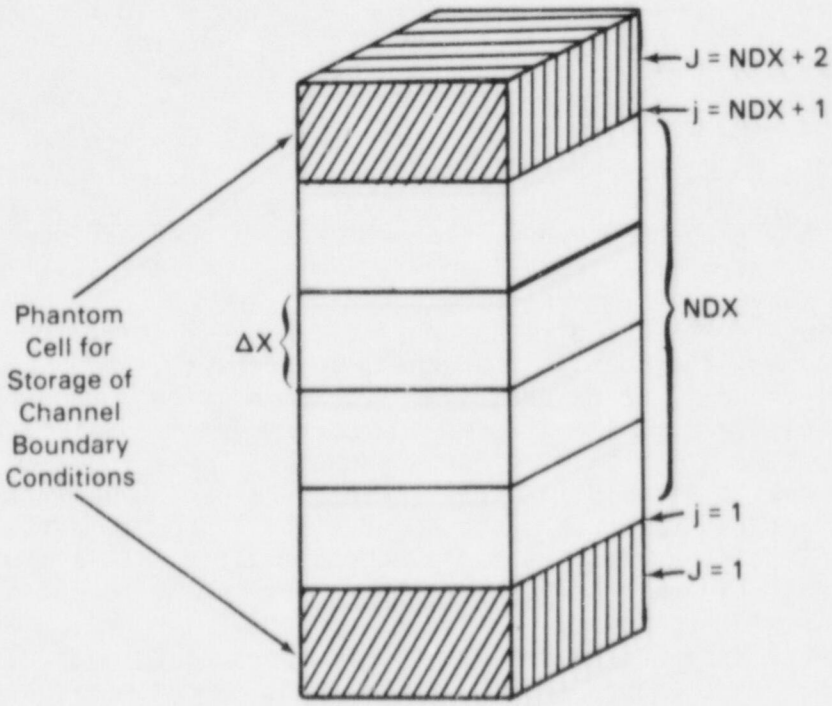


Figure 4 Basic channel

for a particular region of the containment is developed by placing a sufficient number of channels in the region to model the geometry and the important flow phenomena of the region. Transverse connections are specified between the channels to complete the multidimensional mesh for the region. These transverse connections are referred to as gaps. Gaps are defined by the width of the flow path between the two channels and the distance between the channel centers. The width of the gap between channels is assumed to be uniform along the total length of the channels unless a vertical variation of the gap is specified. The centroid distance is always equal to the nominal value for the gap; no variation is allowed.

Examples of containment regions formed by specifying channels and interchannel connections (gaps) are shown in Figures 9 through 11. The German project HDR large-scale containment building is used in these examples for illustrative purposes (Ref. 2).

Vertical cross sections through the HDR containment building are shown in Figures 5 and 6. This containment contains several subcompartments or rooms. The rooms are interconnected by doors, stairwells, pipe penetration ports, elevator shafts, duct work, etc. Since the containment contains so many rooms and is so large, it may be desirable to model it in lumped parameter fashion to minimize the number of computation cells and, hence, the amount of computer time required to complete the simulation. The COBRA-NC input model for the containment is developed by first dividing the containment into several vertical levels or sections. The section boundaries are generally located between the ceiling of a lower compartment and the floor of an upper compartment. A possible breakdown of the HDR containment by section is shown in Figure 7. Once the containment has been divided into sections, any number of channels may be placed within each section to model the various rooms in that section. The section may also be divided into one or more vertical levels to generate as fine a mesh as is desired. The only limitation is that all channels in a section must have the same number of vertical levels, and they must all have the same height. The height and number of vertical levels may vary from section to section as may the number of channels in each section. Let us consider Section 5 of Figure 7 as an example. A cross-sectional view of this section is shown in Figure 8. If a lumped parameter model is sufficient for the analysis, Section 5 may be modeled as shown in Figure 9. Room 23 is the room where the break is assumed to occur in this analysis. This room is divided into three channels to accommodate connections to rooms in the section above this one. All of the other rooms have been modeled with a single channel, and all channels in this section are three levels (or nodes) high. Transverse flow paths between rooms are modeled using gaps. The gaps are shown in Figure 9 as a horizontal dashed line between the two connecting channels. The large bold numbers in the figure are the containment room numbers corresponding to those in Figure 5, 6, and 8. Each box is a channel. The small number in the lower-right-hand corner of each box is the channel number. The number on each horizontal line is the gap number. The solid lines extending from

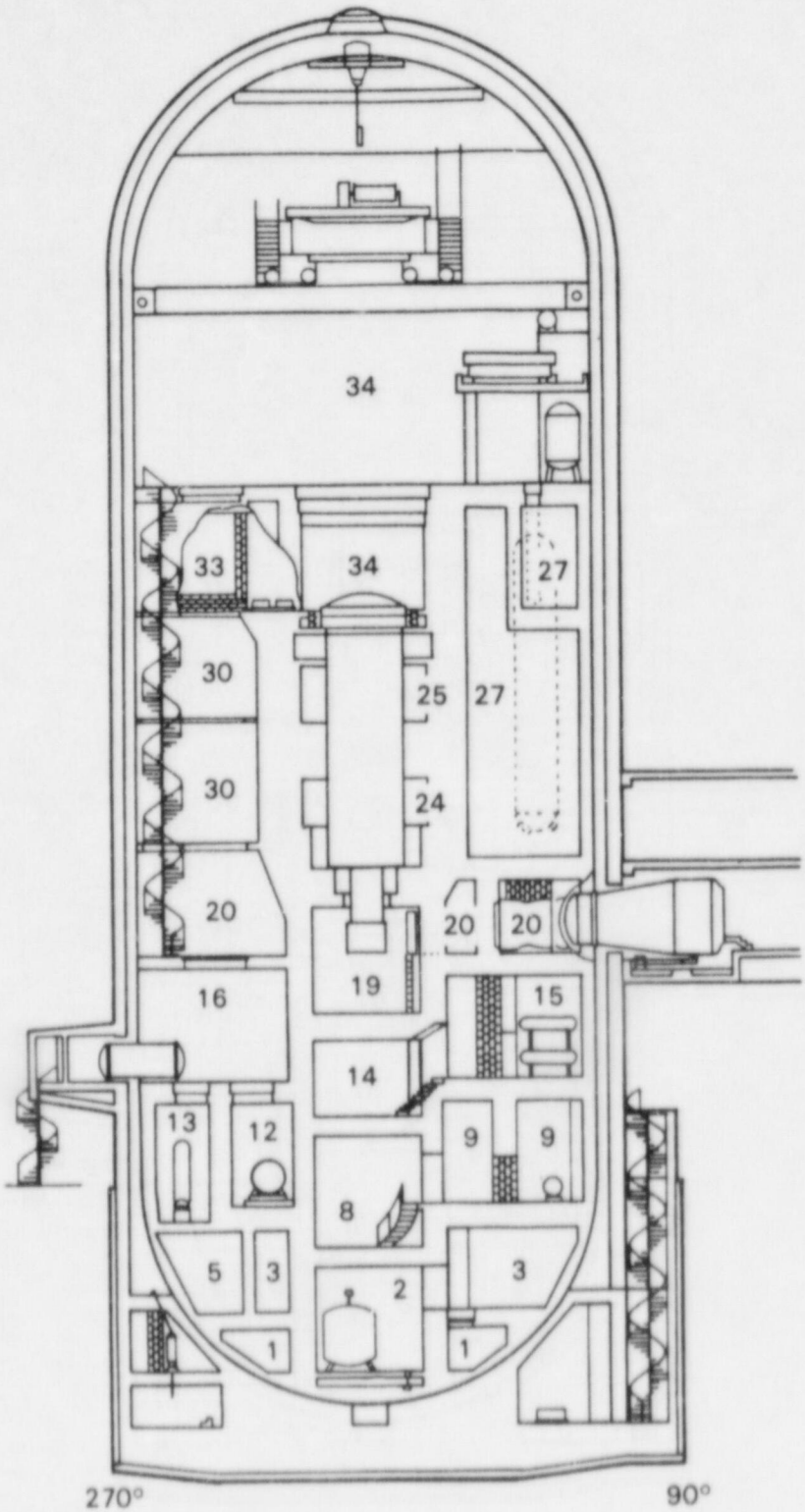


Figure 5 Vertical cross section through HDR containment vessel (90° to 270°)

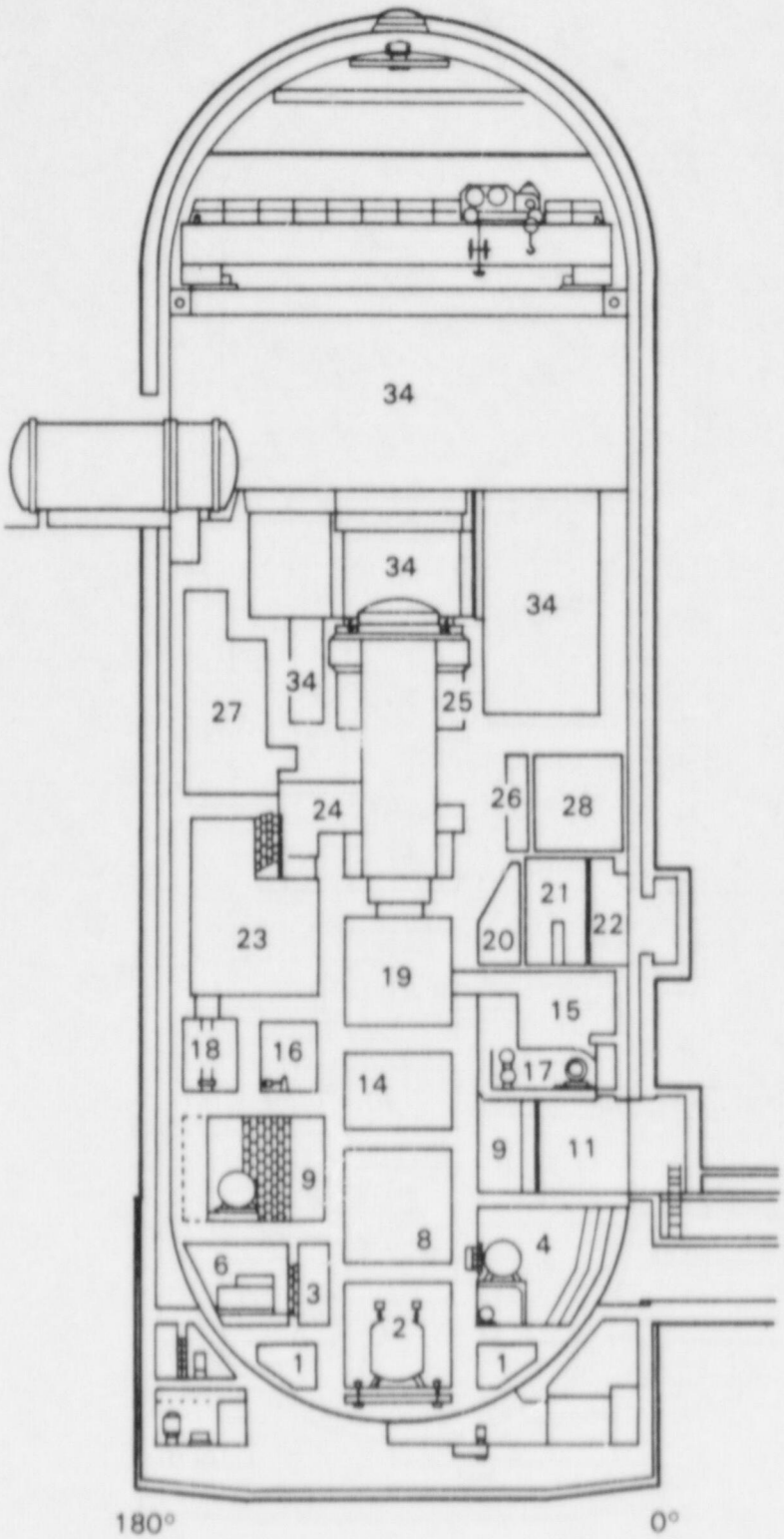


Figure 6 Vertical cross section through HDR containment vessel (0° to 180°)

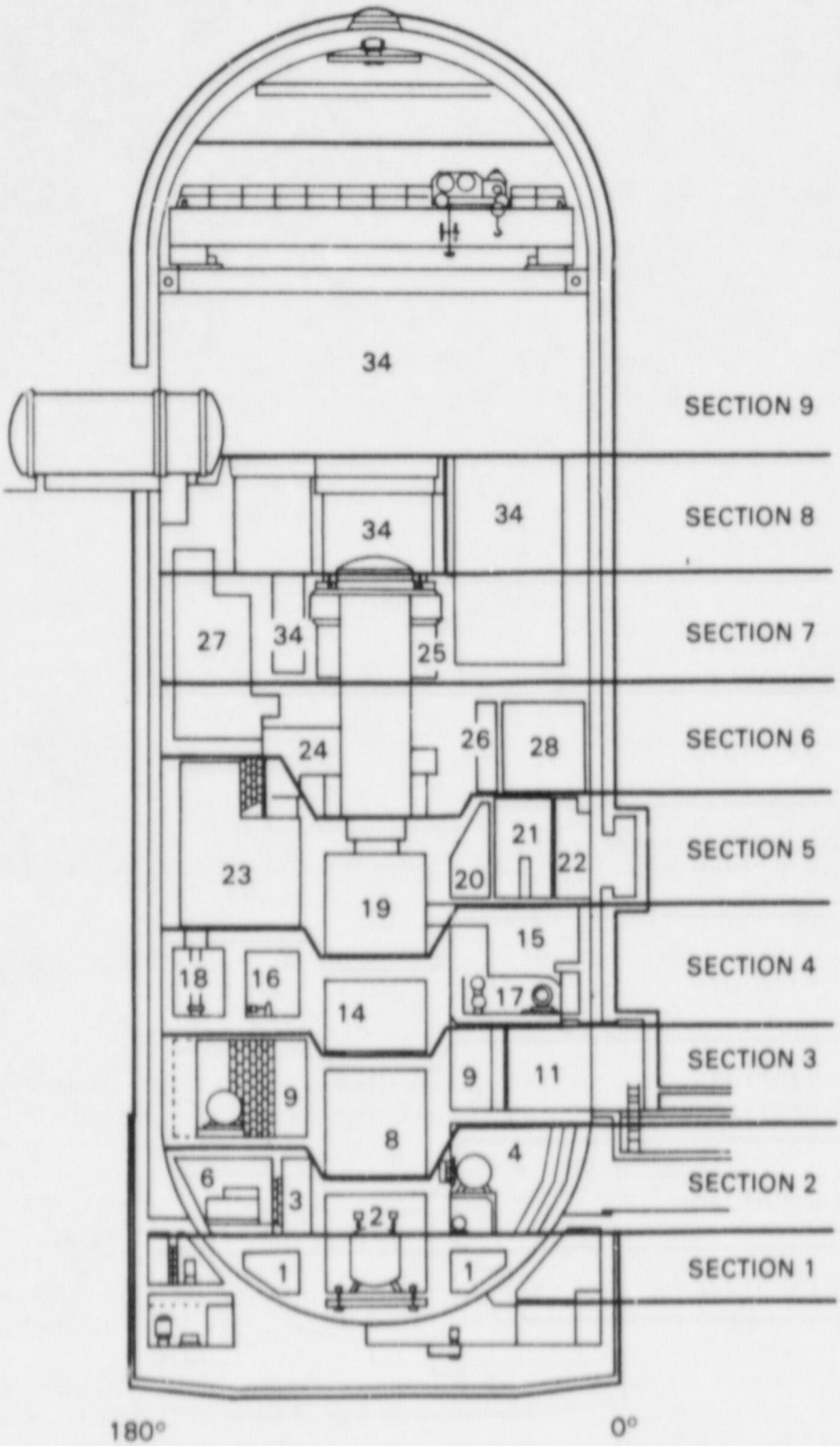


Figure 7 Possible breakdown of HDR containment into sections

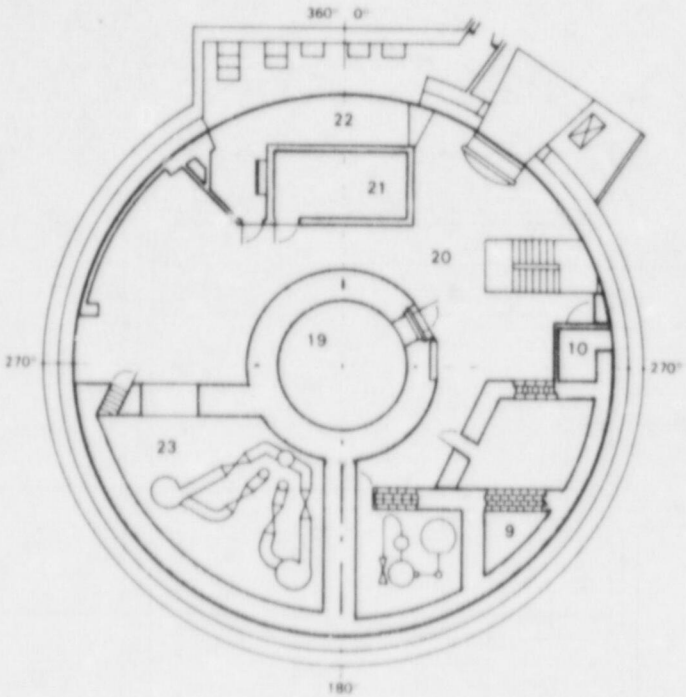


Figure 8 Cross sectional view of section 5

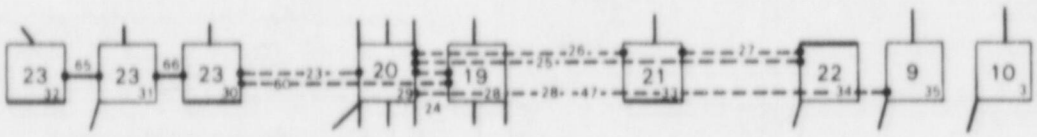


Figure 9 Lumped parameter mesh for section 5

the top and bottom of each channel represent connections to rooms in the sections immediately above or below Section 5.

If more detail is required to resolve the flow phenomena of importance, then more channels and vertical levels may be added to each room to produce a multidimensional mesh. Such a mesh for Section 5 of our example is shown in Figure 10. The blowdown room, room 23, has been divided into thirteen (13) channels each with four (4) vertical levels providing a 52-cell mesh for the room. Other rooms in this section are modeled with fewer channels, but they all must have four vertical levels. A finer mesh could be used for each room and the number of cells increased up to the memory limit of the user's computer resources. The computational cost rises rapidly with increasing cell numbers, however, and care should be taken to realize optimum return on the computational investment. Meshes similar to either Figure 9 or 10 can be developed to model

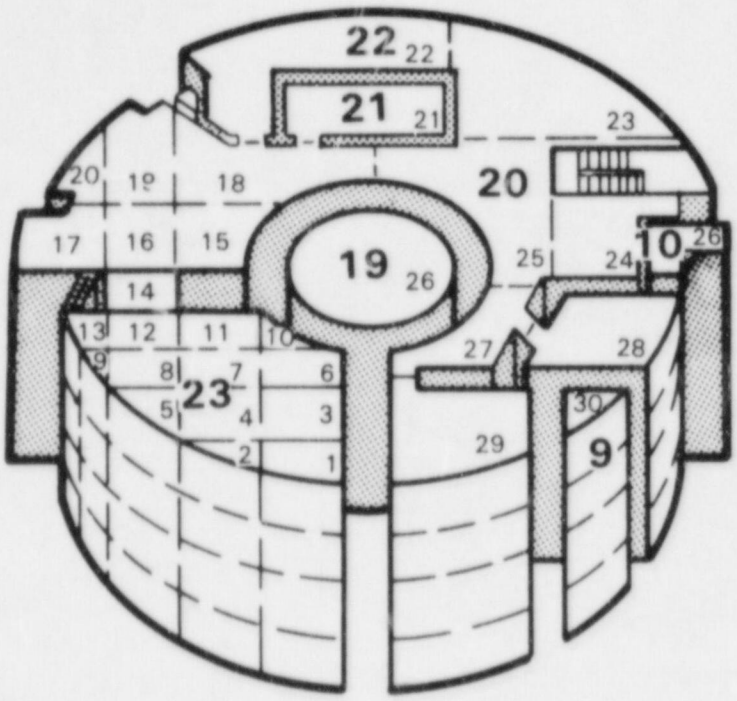


Figure 10 Multidimensional mesh for section 5

the remaining sections of the containment building. These sections are then connected together by specifying connections to the top and bottom of each channel in each section to channels in the section above or below. Appropriate boundary conditions are specified at either the inlet or outlet of channels that do not connect to other sections. A lumped parameter mesh for our example containment is shown in Figure 11.

The mesh shown in Figure 9 was used for Section 5 in this model. The mesh in Figure 10 could have been used, providing a finer mesh on the level of the pipe break and using the lumped parameter mesh for the remaining sections. This is a very useful feature of COBRA-NC when one is faced with modeling a complex facility, such as a containment building, and with modeling the details of the flow in a small portion of the facility while requiring feedback between the local and gross flow fields. The momentum flux terms of the momentum equations and the viscous and turbulent shear stress terms must be zeroed when a lumped parameter model is used. If a multidimensional mesh is used in conjunction with a lumped parameter mesh, the terms mentioned above may be computed in the fine-mesh section and zeroed in the lumped-parameter section. The containment geometrical model is completed by specifying one or more heat slabs for each room to model the structural surfaces within the room that may act as heat sinks or heat sources during the course of a transient. The user has a great deal of flexibility in modeling the geometries of the solid structures in the system. They can be represented as cylindrical rods, hollow tubes, or flat walls composed of any number of different materials with specified thermal properties. Each channel, gap, and heat slab (thermal

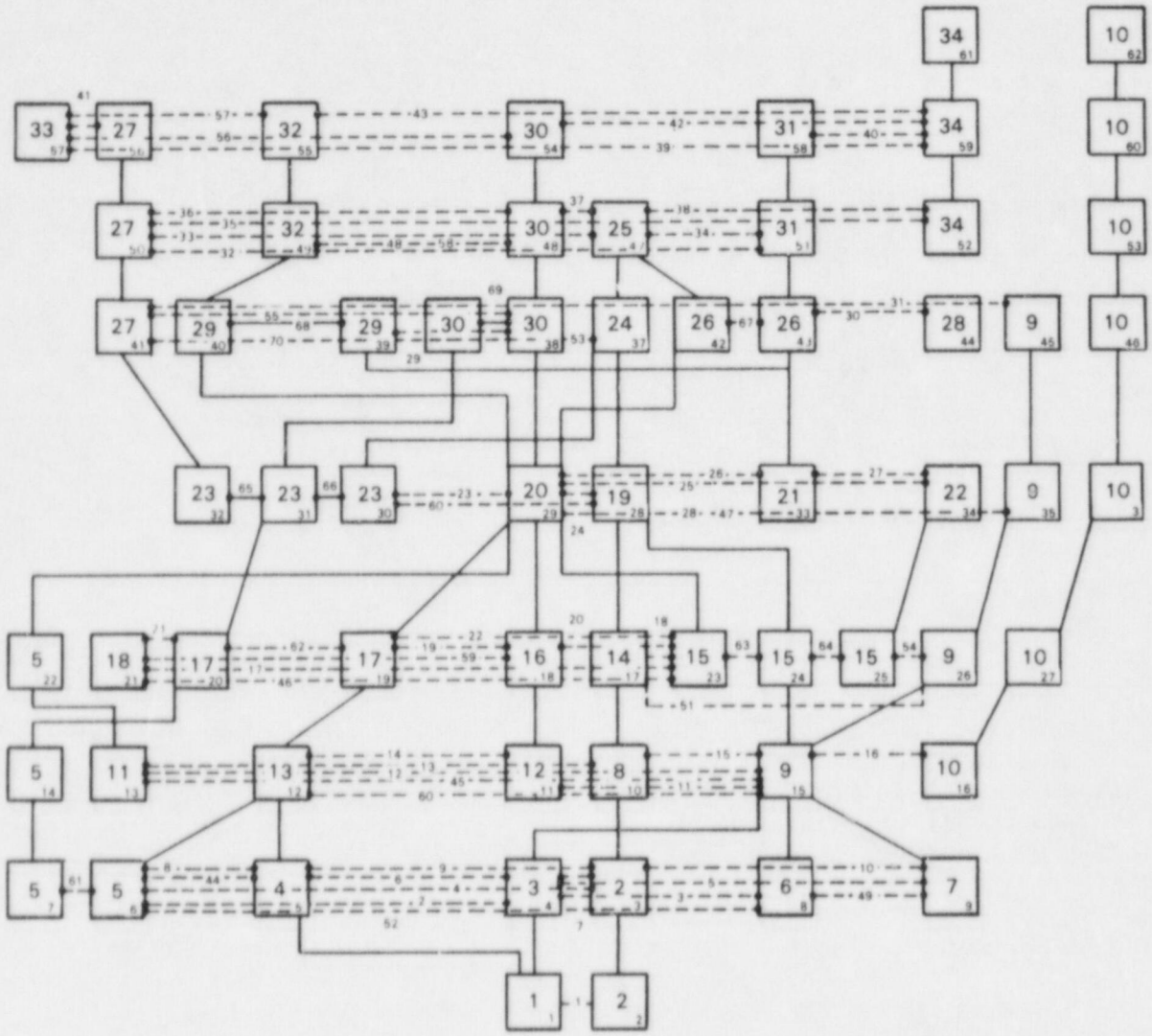


Figure 11 Lumped parameter mesh for the HDR containment

conductor) in the problem is assigned a unique identification number by the input. These numbers are used to identify the connections between channels, sections, and thermal conductors. Transverse or vertical connections are not specified unless a physical flow path exists between the regions represented by the channels.

To summarize, the basic building block for the containment mesh is the channel; a vertical stack of single mesh cells. Several channels can be connected together by gaps to model a region of the containment. Regions that occupy the same level form a section of the containment. Containment sections are

connected vertically to complete the mesh by specifying channel connections between sections. Heat transfer surfaces and solid structures that interact significantly with the fluid can be modeled with conductors.

The logic for setting up the containment mesh was demonstrated with the example of the HDR model containment. Because of the generality of the mesh description, the capability of the code extends beyond that of modeling dry containments. The geometry of other types of PWR as well as BWR containments can be modeled as readily. Several examples of systems that have been modeled using COBRA-NC are given in Volume 7 of this manual, Assessment Manual For Containment Applications.

While this method for defining the mesh is very versatile, it also places a burden on the user. The channel geometries and interchannel connections must be specified by input in some detail. The user must understand the modeling process and conventions in the code well enough to define correctly the input for his problem. The input will be easier to follow if the user first organizes the system he wishes to model into channels, gaps, sections, and heat transfer surfaces, as illustrated for the HDR containment. A detailed diagram of the system is an indispensable aid in this process.

The input is divided into groups, each of which fulfills some logical requirement of the input stream. The geometry of the mesh is specified in groups 2, 3, 4, 5, 6, and 7; group 2 describes the channels; group 3 the gaps; and group 4 the sections. Groups 5, 6, and 7 are optional and can be used to specify vertical variations in the geometry and to specify the local form drag loss coefficients.

3.2.1 Group 2: Channel Input Data

The input for group 2 tells the code how many channels are in the mesh and describes the nominal geometry of each channel. Each channel is uniquely identified by an index number I, flow area AN(I), and wetted perimeter PW(I), supplied on CARD2.2. The channel identification numbers are completely arbitrary, and although it is usually most convenient to number them sequentially, the user is not required to do so. The only constraint on channel numbers is that they must be unique. The total number of channels input with CARD2.2 must be NCHANL, the value of which is specified on CARD2.1.

The variables ABOT and ATOP are provided as optional input to model the area at the top and bottom of the channel for the momentum equation solution. ABOT and ATOP default to the nominal flow area, AN(I), and in most cases this will be sufficient. But when section boundaries are located at orifices, a stairwell, or other sudden changes in the geometry of the system, ABOT and ATOP can be used to supply the correct area at the bottom or top of the channel for the momentum solution. Nonzero values input for ABOT and ATOP replace the nominal channel area at those locations for the momentum solution. The mass cell area is unchanged by this input.

If the vertical velocities for a channel can convect transverse momentum between sections, the location of those velocities must be specified by the user. The user must realize that there can be no defaults for this input, since the channel numbering and interchannel connections at section boundaries are completely arbitrary. If this input is not provided, transverse momentum will accumulate in the affected cells of channel I at the section boundaries, causing errors in the pressure solution. The number of gaps for which channel I convects transverse momentum between sections is specified as the variable NAMGAP on CARD2.2. NAMGAP must be set to zero when using a lumped parameter approach.

The connections for vertical convection of transverse momentum across the section boundary by a given channel I are specified on CARD2.3. The connections are defined by the node number (INODE(I,N)) of the vertical velocity convecting momentum, and the index numbers of the gaps, above and below the section boundary, whose momentum is convected. The node numbering convention used in COBRA-NC is illustrated in Figure 12. The centers of the scalar mesh cells are identified by J = 1, etc., and the centers of the momentum cells are identified by j = 1, etc. The node number INODE(I,N) will be 1 for the channel velocity at the bottom boundary of the section, or NONODE+1 for the channel velocity at the top of the section. KGAPB(I,N) is the gap number on the lower side of the section boundary, and KGAPA(I,N) is the gap number on the upper side of the section boundary. If flow is positive, the vertical velocity of channel I convects transverse momentum from KGAPB to KGAPA. If the flow reverses, momentum is convected from KGAPA to KGAPB. This input is fairly obvious for cases where there is a gap both above and below the section boundary. But even if one or the other is nonexistent, this input must be provided to tell the code how to dissipate transverse momentum that is transported out of a gap across a section boundary. If there is a gap below, but no gap above the section boundary, KGAPA is entered as zero, and momentum convected out of KGAPB is considered dissipated. Similarly, if there is a gap above, but no gap below, KGAPB is entered as zero. Reverse flow convects momentum out of KGAPA, which is considered dissipated. The area through which momentum is convected is calculated in the code as the minimum of $S_k L_k/2$ for KGAPA and KGAPB, and one-half of the flow area of channel I. L_k is the distance between the centroids of the two connecting channels and S_k is the gap width.

A channel can convect transverse momentum to or from several gaps at the top and/or bottom of the section. In defining the input for CARD2.3, the user must understand how the momentum equation is solved at section boundaries, to determine if the vertical velocity will be solved in channel I at that section boundary. It does not do any good to specify the NAMGAP connections for channels that are not solved at the section boundary, and conversely, they must be specified for those that are. Regardless of the geometry being modeled, there are three basic patterns for channel-splitting connections. These are: 1) one channel below connected to one channel above, 2) one channel below connected to many channels above, and 3) multiple channels below connected to a single channel above. Figure 13 demonstrates these three patterns and shows the locations of the momentum cells solved at the boundary.

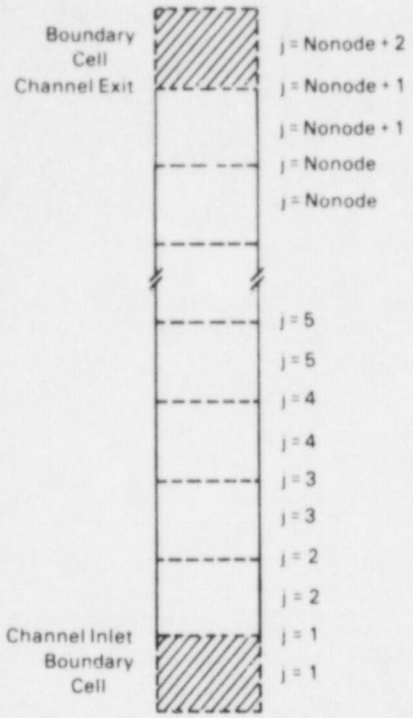


Figure 12 Channel node numbering convention

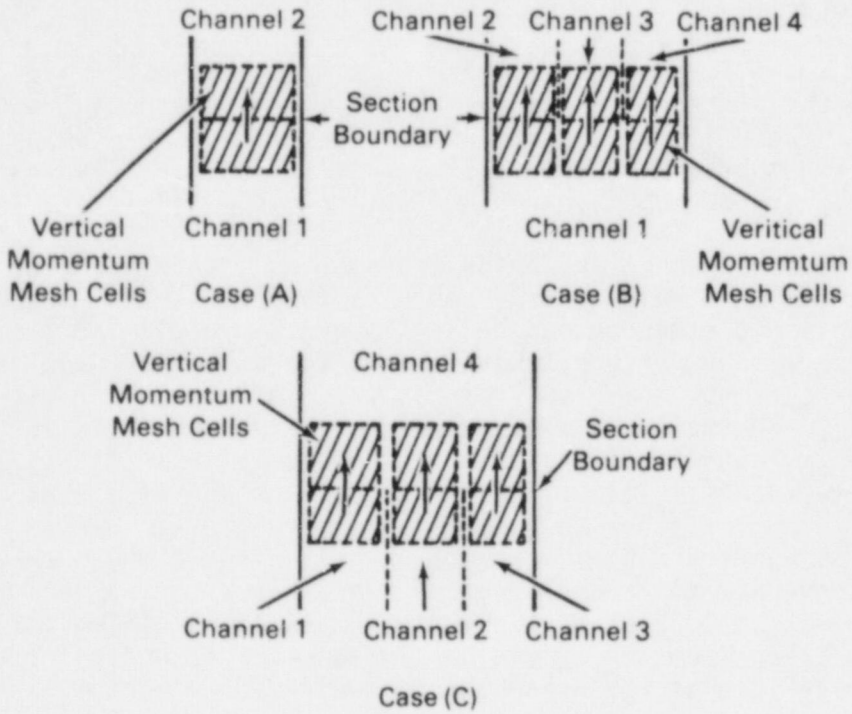


Figure 13 Channel connections at section boundaries allowed by the channel splitting logic

Transverse momentum convection input data is required only for channels where the momentum equation will be solved at the section boundary, and the velocities so obtained can convect transverse momentum from or to adjacent gaps. The momentum equation is solved at the top of channel 1 for case (a) in Figure 13 and is not solved at the bottom of channel 2. The momentum equation is solved at the bottom of channels 2, 3, and 4 in case (b), and at the top of channels 1, 2, and 3 in case (c).

The possible channel and gap configurations at section boundaries are outlined in Figure 14. The case where two channels below the section boundary connect to two channels above the section boundary, with no change in the number of mesh cells between sections, is illustrated in Figure 14a. The vertical momentum equation is solved in the top nodes of channels 1 and 2 to obtain vertical velocities at the section boundary. The velocity of channel 1 convects transverse momentum from the left side of the transverse momentum cell for gap 1 to the left side of the transverse momentum cell for gap 2. Similarly, the velocity of channel 2 convects momentum from the right side of the momentum cell for gap 1 to the right side of the momentum cell for gap 2. In this example, the input for card VESSEL2.3 would be supplied for both channel 1 and channel 2, with INODE(1,1) and INODE(2,1) equal to the index number of the top node in channels 1 and 2, KGAPB(1,1) and KGAPB(2,1) equal to 1 and KGAPA(1,1) and KGAPA(2,1) equal to 2. The user might be tempted to repeat this input for channels 3 and 4 at INODE(I,1) = 1, but since the vertical momentum equation is not solved at node 1 in channels 3 and 4, the redundant input is incorrect.

For the case shown in Figure 14b there is no gap on the top side of the section boundary, so the vertical velocities at the top of channels 1 and 2 convect momentum out of gap 1, but the momentum is assumed to be dissipated since there is no transverse momentum cell to receive it. In this case KGAPB(1,1) and KGAPB(2,1) are set to 1, and KGAPA(1,1) and KGAPA(2,1) are set to 0.

If a gap exists both above and below the section boundary as in Figure 14a, but there is a flow straightener (such as a long duct) at the section boundary, then the transverse momentum can be dissipated by specifying two connections for each channel, one for positive flow and the other for negative flow. Positive flow convects momentum from gap 1 and dissipates it, so KGAPB(1,1) and KGAPB(2,1) are specified as 1, KGAPA(1,1) and KGAPA(2,1) as 0. Negative flow convects momentum from gap 2 and dissipates it, so KGAPB(1,2) and KGAPB(2,2) are specified as 0, and KGAPA(1,2) and KGAPA(2,2) as 2.

If momentum is convected by a vertical velocity from one gap on one side of the section boundary to several gaps on the other side (variable mesh), then transverse momentum convection connections must be specified for each gap. The momentum taken from the single gap is apportioned among the connecting gaps by the relative size of the areas through which the momentum is convected.

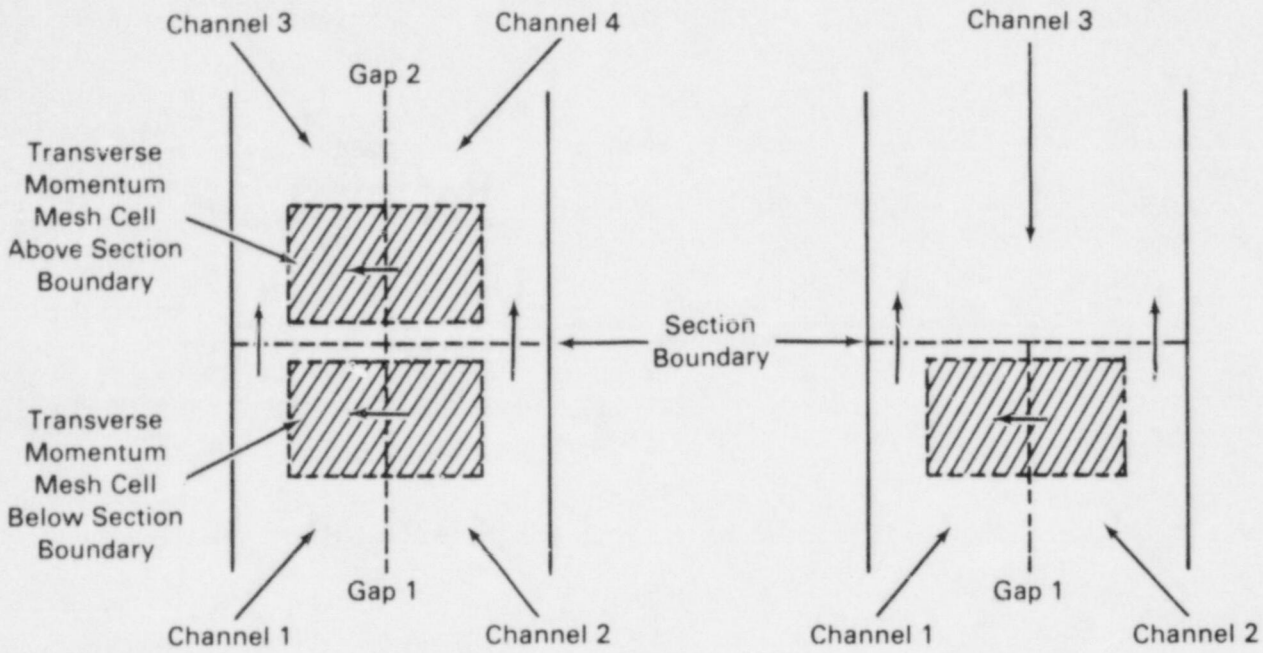


Figure 14 Typical configurations for convection of transverse momentum between sections

As part of the description of the physical geometry of the containment, the group 2 input data describes the channel connections to thermal conductors for heat transfer between the fluid and solid surfaces. The input supplied on CARD2.4 must be consistent with the data for the thermal conductors supplied in group 8 (see Section 3.3.). All thermal conductors must be connected to at least one channel, but not all channels need to be connected to a thermal conductor. NCHANR is the number of thermal connections between channels and thermal conductors. The LS(I,L) array contains the index numbers of the thermal conductors connected to channel I. If channel I connects to the inside surface of a thermal conductor, the index number of the thermal conductor is specified as its negative. Only one channel can be connected to the inside or outside surface of a given thermal conductor within a given section.

3.2.2 Group 3: Transverse Channel Connection Data

The input for group 3 describes the transverse connections between adjacent channels. These connections are referred to as gaps. The gap input data define the control volume for the transverse momentum equation. The input for the gaps falls into five main categories--the geometry input describing the gap and

identifying its connecting channels, the friction loss and form drag coefficients for flow through the gap, description of the vertical connections between gaps across section boundaries, data describing the optional three-dimensional layout of the gap, and special input to describe gaps between channels containing large amounts of structure.

The geometry data for each gap is read on CARD3.2. Each gap is identified by a unique number, K. Gap K connects channel IK(K) to channel JK(K). By convention, crossflow from channel IK(K) to JK(K) is defined to be positive. Flow the other way is negative. The nominal gap width is specified as GAPN(K), and the distance between the centers of the connecting channels is LENGTH(K). These variables define the width and length of the transverse momentum mesh cell. The flow area between the connecting channels is given by the product of the gap width and the vertical length increment for the mesh (this flow area is computed in the code from the input data). The gap width, GAPN(K), is equal to the total width for transverse flow between the two adjacent regions modeled by channels IK(K) and JK(K).

Form and wall drag in gap K is specified for the transverse momentum equations using the parameters WKR(K) and FWALL(K). WKR(K) is the form drag loss coefficient (velocity head $\Delta P \frac{C_D}{2}\rho V^2$) and is specified by the user. The value of WKR(K) for a gap depends on the geometry of the flow path modeled by the gap.

Wall friction in the gap may be included in the WKR parameter or, for gaps that are formed by walls rather than short orifices, the wall friction may be modeled using a loss friction factor. Wall friction factors in a gap are computed internally in the code according to the user-specified value of the FWALL(K) parameter. If FWALL(K) is zero, no wall friction is calculated. If FWALL(K) is set equal to 0.5, a wall with a surface area of ΔX*LENGTH(K) is assumed (i.e., one side of the control volume is a solid wall). A wall surface area of 2*ΔX*LENGTH(K) (i.e., a wall on each side of the control volume), is assumed if FWALL(K) is set equal to 1.0. Any value of FWALL(k) may be entered to give the correct wetted perimeter for the physical flow path. Both a form loss and wall friction factor can be specified for a gap, or one or the other can be set to zero, depending on the geometry of the problem. Both can be set to zero if the gap is in an open fluid region where the fluid-fluid shear within the continuous phase adequately models the transverse drag forces. This should be done only for three-dimensional meshes.

The input required to describe transverse convection of vertical momentum between gaps across section boundaries employs the same sort of reasoning as does the input in group 2 to describe the vertical convection of transverse momentum across section boundaries. The user must specify which transverse gap velocities can transport vertical momentum into or out of the channels associated with gap K at the top and bottom of the section. The transverse velocity of gap IGAPB(K) (at node NONODE+1 in the section below) can convect vertical momentum into or out of the bottom cell of the channels associated

with gap K. The transverse velocity of IGAPA(K) (at node 2 in the section above) can convect vertical momentum into or out of the top cell of the channels associated with gap K.

Transverse convection of vertical momentum at a section boundary is illustrated for a specific case in Figure 15. In this example, vertical momentum is convected between the two vertical mesh cells by the transverse velocity of gap 1 below the section boundary, and by the transverse velocity of gap 2 above the section boundary. The input for IGAPA(K) identifies the gap in the section above gap K that convects vertical momentum between the vertical momentum mesh cells associated with the top of gap K; in the example shown in Figure 11, IGAPA(1) = 2. IGAPB(K) identifies the gap in the section below gap K that convects vertical momentum between the vertical momentum mesh cells associated with the bottom of gap K.

The remainder of the input on CARD3.2 is required only for the three-dimensional form of the transverse momentum equation. It is used to define consistent transverse flow directions for the global coordinate system and to setup connections for orthogonal transport of momentum. If the lumped parameter or one-dimensional formulation is desired for a particular problem, this input is omitted.

The normal crossflow sign convention is not always congruent with a global coordinate system. The user can convert the local transverse flow sign convention to an appropriate global system by specifying the variable FACTOR(K) (the tenth variable on CARD3.2) to indicate the orientation of gap K in the

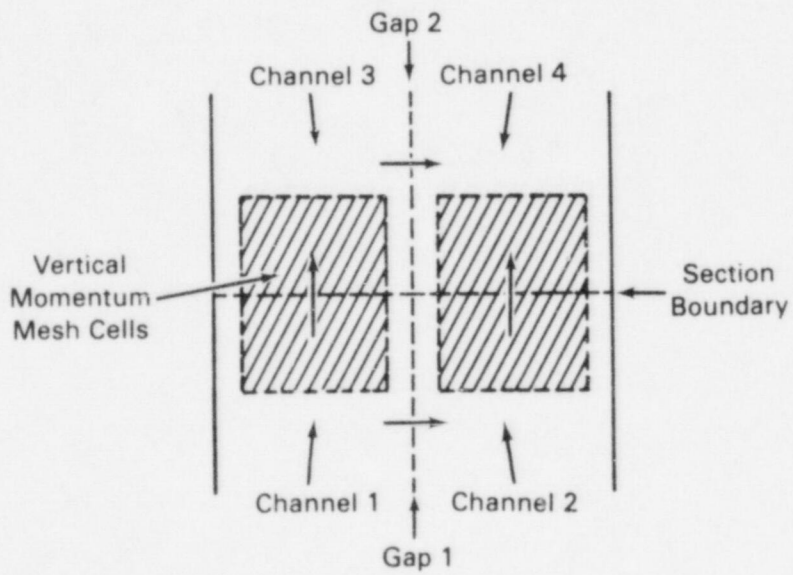


Figure 15 Vertical momentum mesh cell at section boundary

global coordinate system. Figure 16 gives two examples of how FACTOR can be used. Example (a) shows an annular channel arrangement. The annular flow channels are in effect two dimensional, so it is only necessary to define a transverse direction that is consistently positive. The normal convention for defining positive crossflow results in crossflow from channel 1 to 2 and from channel 1 to 4 both being positive. Assuming that the clockwise direction is chosen as positive for the global coordinate system, if flow from IK(K) to JK(K) is clockwise, then FACTOR(K) is set to 1.0. If flow from IK(K) to JK(K) is counterclockwise, the sign convention must be reversed by setting FACTOR(K) to -1.0. (Of course, the user may choose counterclockwise as the positive direction, if he wishes. The important thing is to be consistent.) In this example, FACTOR(2) is set to -1.0.

A three-dimensional channel array is shown in example (b) in Figure 16. For this case, the values for FACTOR(K) must correspond to the actual orientation of the velocity vector in the gap on the global coordinate system. The arrows in the gaps indicate the positive crossflow direction defined by the normal convention. For gaps 1, 3, 6, and 7, this is the same as the global coordinates, so FACTOR(1), FACTOR(3), FACTOR(6), and FACTOR(7) are 1.0 for this case. But the positive flow direction in gaps 2, 4, and 5 is exactly opposite of the global convention, so FACTOR(2), FACTOR(4), and FACTOR(5) must be specified as -1.0 to reverse the sign on the crossflow velocity. For the two-dimensional or three-dimensional form of the transverse momentum equation, the user must identify the gaps facing a given gap K. This information is required in the code to calculate the normal components of transverse momentum. The arrays IGAP(K,N) and JGAP(K,N) on CARD3.2 are used to supply this data. The IGAP array holds the identification numbers of up to three gaps on the IK (or lower-numbered channel) side of gap K, and the

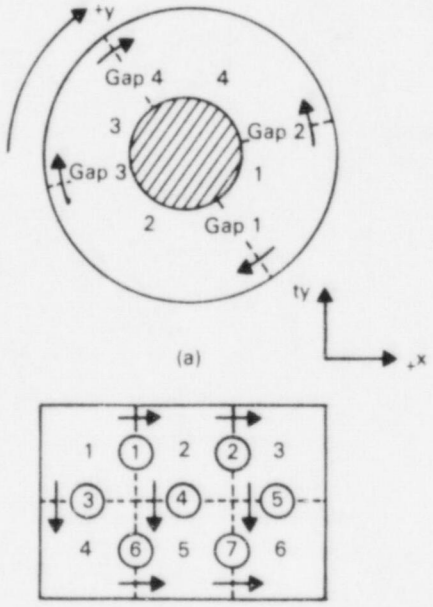


Figure 16 Global coordinate systems

array JGAP holds the identification numbers of up to three gaps on the JK (or higher-numbered channel) side of gap K. This is illustrated in Figure 17. In this example, gap 4 connects channel 1 to channel 2, with the conventional positive flow direction shown by the arrow. Gaps 1 and 3 face the IK side of gap 4, and gaps 5 and 7 face the JK side. In the example, IGAP(4,1) = 1, IGAP(4,2) = 3, JGAP(4,1) = 5, and JGAP(4,2) = 7.

CARD3.3 must be read for each gap following CARD3.2. This input is designed to model gaps between channels that contain large amounts of structure. The nominal gap width, GAPN(K) (supplied on CARD3.2), is the total width for crossflow between the two channels. The characteristic width for two-phase flow through the gap, however, is the distance between the physical structures and not necessarily the total width of the connection between mesh cells. The parameter GMULT(K), input on CARD3.3, is the number of uniform spaces between structures in the region modeled by the gap. The characteristic dimension for two-phase flow is given by

$$S' = \frac{GAPN(K)}{GMULT(K)} \tag{1}$$

The dimensions determines the maximum bubble size that can pass between structures. If GAPN(K) is the actual width available for flow, GMULT(K) is one.

ETANR(K), which is also read on CARD3.3, is the fraction of transverse droplet flow de-entrained on structures within the mesh cell. The correlation suggested by Dallman and Kirchner for the de-entrainment fraction for flow across tube

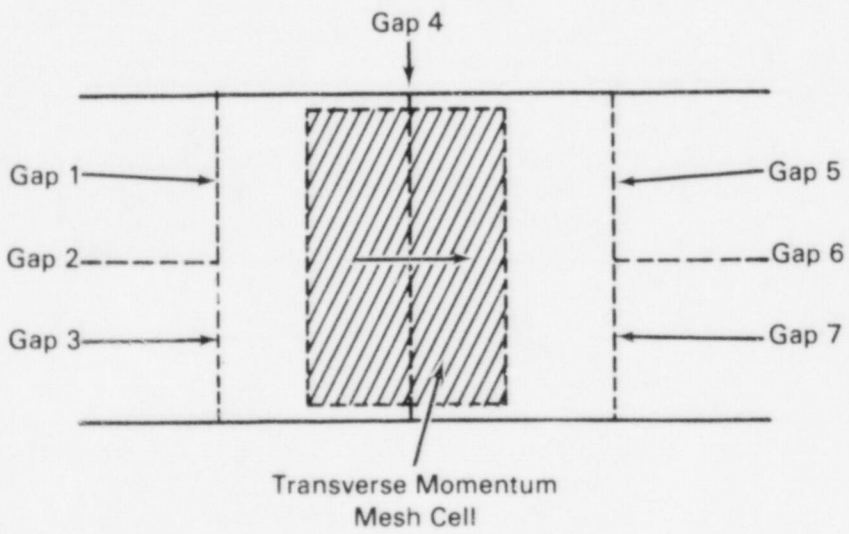


Figure 17 Normal component of transverse momentum

banks is recommended (Ref. 3) unless the user has an experimentally determined value for his particular geometry. The de-entrainment fraction, ETANR(K), for a gap modeling an array of tubes is

$$ETAN(K) = 1 - (1 - \eta_R)^N \quad (2)$$

where η_R = de-entrainment fraction of a single row of tubes

N = number of rows of tubes.

The de-entrainment fraction of a single row of tubes is

$$\eta_R = E_I \ (1 + 4.5 \ \beta^2) \quad (3)$$

where η_R = 0.19 for cylindrical tubes
= 0.27 for square tubes
β = pitch-to- diameter ratio of the array.

(Volume 1 of this manual contains a complete discussion of the model.)

ETANR(K) can be used to model the crossflow de-entrainment rate for geometries other than tube banks, but the user must determine the appropriate value for each particular application. The ratio of vent flow area to surrounding wall area is a reasonable value for ETANR(K) to model de-entrainment fractions between rooms in a containment.

The final input lines for group 3 (CARD3.4, and CARD3.5) are required only for the three-dimensional form of the transverse momentum equation. The total number of gaps that convect orthogonal transverse momentum is specified as the NLMGAP parameter on CARD3.4. The velocity of the gap identified in KGAP1(N) convects transverse momentum from KGAP3(N) to KGAP2(N) if the velocity is positive and from KGAP2(N) to KGAP3(N) if negative. This is illustrated in Figure 18. In this example the velocity of gap 1 convects momentum from the left half of the momentum mesh cell for gap 4 to the left half for gap 2. The velocity of gap 3 convects momentum from the right half of the cell for gap 4 to the right half of gap 2. (Gaps 2 and 4 also convect momentum from gap 1 to gap 2.) In this example, KGAP1(1) = 1, KGAP2(1) = 2, KGAP3(1) = 4, KGAP1(2) = 3, KGAP2(2) = 2, and KGAP3(2) = 4. (Also KGAP1(3) = 2, KGAP2(3) = 3, KGAP3(3) = 1, KGAP1(4) = 4, KGAP2(4) = 3, and KGAP3(4) = 1).

Examples of transverse flow connections typically encountered in the mesh for a containment application are shown in Figure 9, 10, and 11. The gap between the fine mesh for the blowdown room and the surrounding coarse mesh as shown in Figure 10 is a special case and merits some additional discussion. Such relatively small meshes are used to obtain local detail of important flow processes while still maintaining the larger, more economical global mesh size for the containment as a whole. Fine meshes within a relatively larger global mesh represent a compromise in that some of the local details

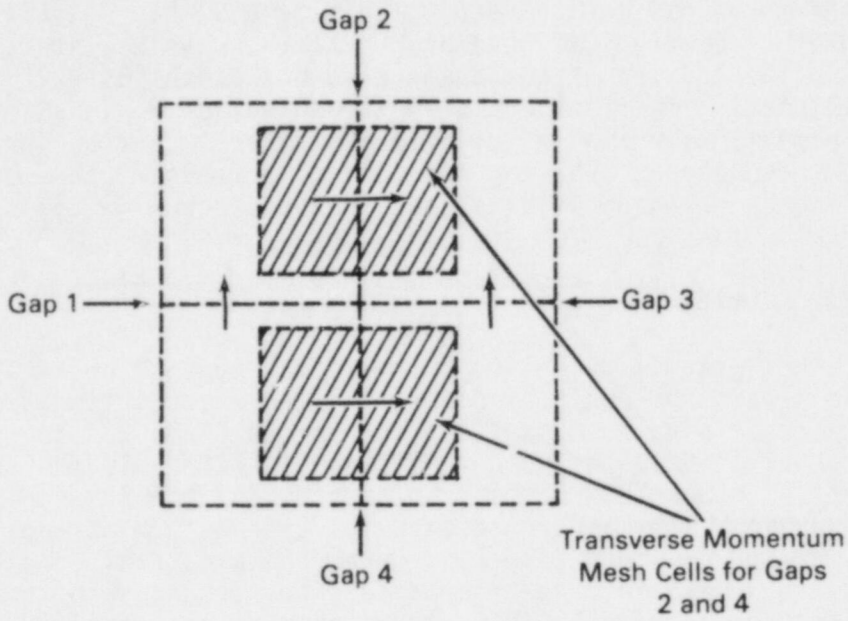


Figure 18 Convection of transverse momentum by orthogonal transverse velocity

of the flow and some of the accuracy (relative to that obtainable with a global mesh size on the order of the fine mesh) is lost. But in most cases a global mesh small enough to resolve flow details is prohibitive in both computation time and storage requirements. A reasonable prediction of local flow phenomena can be achieved using the large global mesh with a local mesh specified within it.

In general, the convection of transverse momentum by transverse velocities in the gap between the local and coarse mesh cells is neglected. The shape of the larger transverse momentum mesh cell is idealized and requires the user's judgement in selecting values for the gap width and length. The gap width should be chosen such that the product of the gap width and the vertical mesh length increment is equal to the physical area for the flow path between the connecting mesh cells. The shape of the momentum mesh cell is assumed rectangular, and its length should be chosen to give a physically meaningful time constant for accelerating flow through the gap. A distance equal to the distance between the center of mass of the two cells is recommended for the centroid distance (LENGTH(K)). The gap flow area may represent several flow paths between the two channels that have been lumped together into a single equivalent area.

Setting up the gap geometry data is relatively simple, even for peculiar geometries, if the user bears in mind that GAPN(K) and LENGTH(K) define the transverse control volume for the gap. The size and shape of this control volume should bear some logical resemblance to the physical structure being modeled, within the constraints of the noding philosophy used in the code. The control volume is important not only for defining the location and magnitude of the transverse flow, but also for determining vertical transport of transverse momentum through the top and bottom surfaces of the control volume. Both aspects of the momentum solution must be considered in defining the gap width and centroid length.

3.2.3 Group 4: Section Data

The input data for group 4 describes the vertical channel connections between sections and defines the rebalancing and simultaneous solution group options. The input data describing each section, is read on CARD4.2. It consists of the section number (ISEC), the number of channels (ICHN) in the section, the number of vertical nodes (NONODE) in the section and the vertical node length (DXS) in the section. The section boundaries are uniform at a given vertical level, so all channels within a section have the same total length. The vertical node length DXS in a section defines the length of both the continuity and momentum control volumes. DXS is constant within a section, so the total vertical height of a section is DXS*NONODE. DXS can vary between sections, and each section may have one or many vertical nodes. The only constraint on the DXS values chosen for different sections is that the change in DXS between adjacent sections should not be greater than a factor of two, unless the momentum flux terms have been zeroed for the section containing the larger cells.

The vertical connections for each channel in a section are specified by the input for CARD4.3 with the identification numbers of the channels it connects to in the section above and the section below. A channel may connect to up to six channels in the section above and six channels in the section below. The array KCHANA contains the index numbers of channels connected to the top of the channel, and KCHANB contains the index numbers of channels connected to the bottom. If a channel does not have a connection above or below, KCHANA or KCHANB is specified with the channel's own identification number. The code will not accept a channel with only zeros in the KCHANA or KCHANB arrays.

There are three basic patterns possible for vertical connections between channels: a) one channel below connected to one channel above, b) one channel below connected to many channels above, and c) multiple channels below connecting to a single channel above. The momentum equation for the vertical velocity at the section boundary is solved at the top node of the bottom channel for case (a), in the bottom node of each of the upper channels in case (b), and in the top node of each of the lower channels in case (c). The momentum mesh cells at the section boundary for these three cases are shown in Figure 19.

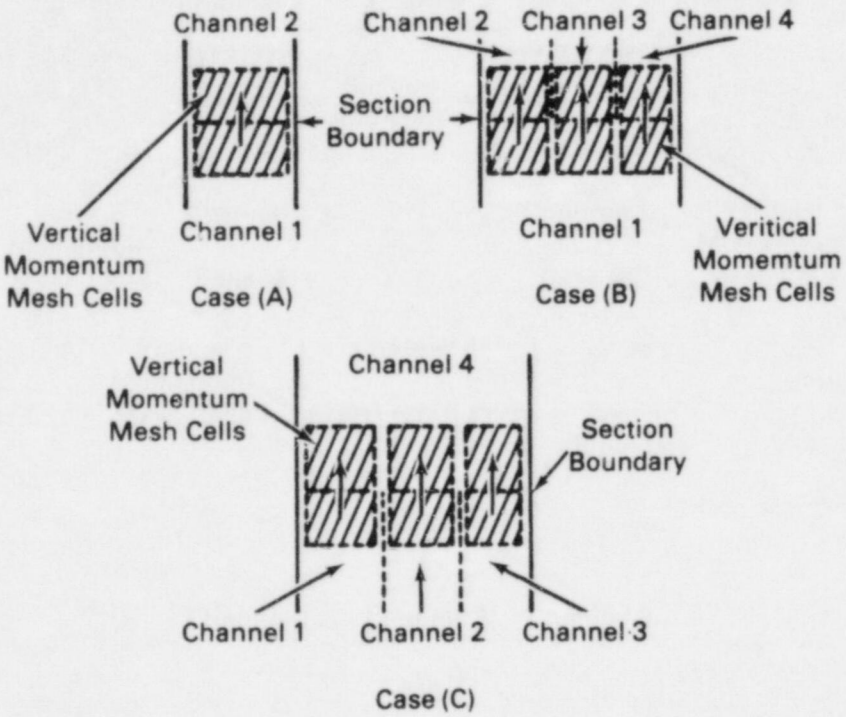


Figure 19 Allowable vertical connections between channels at section boundaries

Velocities are solved for in the momentum cells at the top of channel 1 for case (a), at the bottom of channels 2, 3 and 4 for case (b) and at the top of channels 1, 2 and 3 for case (c).

Velocities at the momentum cell faces, which are used to calculate the momentum flux terms, are obtained by averaging the velocities at the cell centers of adjacent momentum cells. At section boundaries where the connections are like those shown in cases (a) and (c) in Figure 19, the velocity at the top face of the momentum cell is obtained by averaging the velocities at the centers of the momentum mesh cells on the boundary with the velocity at the center of the first momentum mesh cell in the channel above. For case (a), the velocity of channel 2, node 2, is averaged with the velocity calculated in channel 1 at the boundary. For case (c) the velocity of channel 4, node 2, is averaged with the velocities calculated in channels 1, 2, and 3 at the boundary. For case (b) the velocity calculated in the last cell of channel 1 is averaged with velocities calculated in channels 2, 3, and 4 at the boundary. A channel

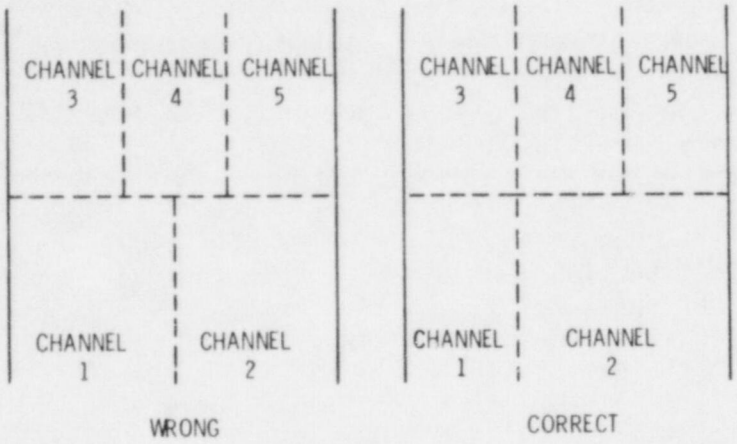
with multiple connections to both the bottom and top must contain at least two mesh cells. If the channel had only one cell, the code would not be able to determine which velocities to use when obtaining average velocities at the cell face for momentum cells at the bottom of the channel or at the top of the channel.

Figure 20 shows two samples of channel connections that are not permitted by the channel-splitting logic in the code. These examples are given because they represent two of the easiest mistakes to make in setting up the channel-splitting input. The user should bear in mind that any other connections he might think of that are not in one of the patterns shown in Figure 19 will not work either. In (a) in Figure 20, the channels below overlap in their connections to the channels above. Trying to draw the momentum control volume at the inlet boundary to channel 4 is the simplest way to see why that configuration is not allowed. (The mirror image of this configuration, i.e., with channels above overlapping channels below, is not permitted either, for the same reasons.) A correct way to connect the channels in this example is also shown in Figure 20. Example (b) in Figure 20 shows a channel with multiple connections above and below. The only thing wrong with this configuration is that channel 3 is only one cell long. If momentum fluxes are to be calculated, this configuration can be corrected by giving the section containing channel 3 one more node.

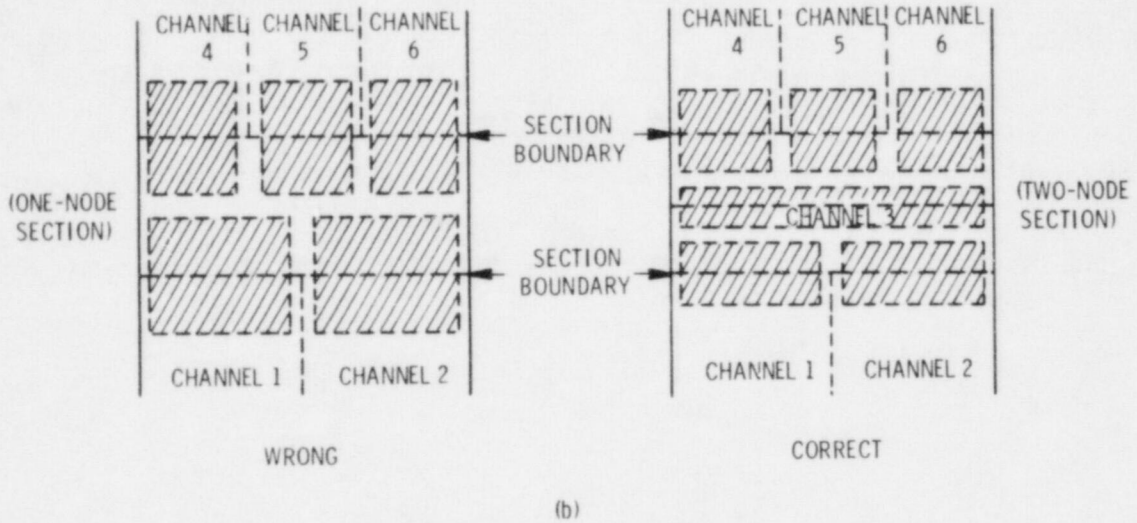
The logic in the code's input subroutine contains some error checks on the channel vertical connections, primarily to determine consistency, but also to check for the erroneous one-node section pattern illustrated in part (b) of Figure 20. Appropriate error messages are printed if inconsistent connections above and below are detected. There is no possible generalized check, however, for the most common error in channel splitting input, i.e., connecting the wrong channels in a logically correct pattern. The only defense against this is for the user to have a clear picture of the channel connection pattern for his problem to check against the output data COBRA-NC provides.

The remainder of the input in card group 4 specifies the numerical solution procedure to be used for solving the linearized continuity and energy equations when using the semi-implicit solution scheme. The equations may be solved by a direct inversion of the system pressure matrix or a combination of direct inversion and iteration. In the combination solution, the pressure matrix for groups of cells is solved by direct inversion while the pressure in cells surrounding each group is held constant. A Gauss-Siedel iteration is then performed over the groups of cells to obtain a converged solution for the entire system pressure matrix.

The matrix solution procedure used is determined by the parameter NSIM input on CARD4.1. NSIM is the number of simultaneous solution groups. If NSIM is set to one (1) the solution is obtained by direct inversion. If NSIM is set to N (where N is an integer greater than one) the solution is obtained with a combination of direct inversion and iteration with N simultaneous solution groups.



(a)



(b)

Figure 20 Common channel splitting errors

A direct inversion is recommended for relatively small problems with fewer than 40 or 50 mesh cells. The group-by-group iteration is recommended for larger problems since the computer time required to invert the large system matrix usually exceeds that required to reach a suitably well- converged solution using the iterative procedure.

The convergence rate for the iterative solution can be greatly enhanced by specifying the rebalancing option, IREBAL = 1. When rebalancing is done, a one-dimensional solution for the linear pressure variation at each level in the mesh is obtained by direct inversion. This value is used as an initial estimate for the linear pressure variation in each cell in the group-by-group iterations. The rebalancing is repeated every third iteration.

This maximum difference, IWIDE, is calculated by the code from the group 4 input and the maximum bandwidth of the pressure matrix is calculated as (2*IWIDE+1). The code must be dimensioned such that dimension parameter NE is greater than or equal to 2*IWIDE+1 (see Section 2.5). The cell numbers used to define IWIDE are not channel node numbers. Channel node numbers are unique only within a channel, while cell numbers are unique throughout the mesh. Cell numbers are assigned in the following manner: beginning at the first channel in the first section, the first node in the channel (node J = 2) is assigned cell number one (1). The cells of all the channels in that section are numbered sequentially at the same level (J = 2). The cell numbering is continued on the next level, starting in the same first channel. This process continues until all cells for all sections have been assigned unique cell numbers. An example illustrating this numbering convention is shown in Figure 21.

In the example in Figure 21, IWIDE is equal to 2 in simultaneous solutions groups 1 and 5. In groups 3 and 4, IWIDE is only 1. In group 2 IWIDE is 3. The value for IWIDE entered on CARD4.4 for this example is 3. (The matrix must accommodate the largest bandwidth in all groups.) The user should construct a similar diagram for his problem, to determine the appropriate value for IWIDE, and also to provide the input for the MSIM array (the number of the last cell in each simultaneous solution group--CARD4.5).

Simultaneous solution groups are based on the geometry of the given problem and should consist of cells that strongly influence each other's behavior, or are influenced by nearly the same external conditions.

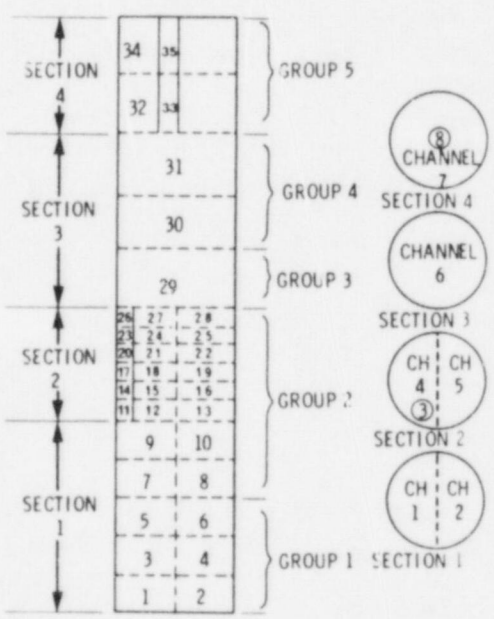


Figure 21 Example of cell numbering scheme for simultaneous solution groups

3.2.4 Group 5 and Group 6: Variations in Channels and Gaps

The geometry of a channel or gap is assumed to remain constant along the entire vertical length at the nominal values specified by input. But the input for groups 5 and 6 permits the user to specify vertical variations in the geometry of channels or gaps. The input for these two groups is optional. If vertical variation data is not needed, groups 5 and 6 are omitted.

The input data for groups 5 and 6 is extremely general. The user provides tables of variation factors in group 5 and identifies in group 6 the channels or gaps that use the tables. Variation tables can be supplied to model variations in the continuity flow area, momentum flow area, wetted perimeter of channels, and the width of gaps. Variation tables are read on CARD5.3 as tables of node number, JAXL(I,N), versus variation factor, AFACT(I,N). The node number JAXL(I,N) refers to the continuity cell for continuity area and gap width variations, and to the momentum cell for momentum area and wetted perimeter variations. The variation factor is defined as

$$\text{AFACT}(I,N) = \frac{\text{local value}}{\text{nominal value}}$$

The value of AFACT(I,N) is applied in the code as a multiplier on the nominal value of the quantity being varied at the corresponding JAXL(I,N) node--continuity area, momentum area, wetted perimeter, or gap width. Figure 22 shows two examples of channels with area variations that can be modeled with variation tables. For example (a), variations of the continuity area occur at nodes 6, 7, and 8. Variations in the momentum area occur at nodes 6, 7, and 8 also, but, because the geometry of the channel is tapered and the continuity and momentum nodes are staggered, the areas vary by different amounts. The tapered region in the channel is approximated by a stack of cells that have a uniform cross section along their individual lengths. The continuity areas of the cells should be defined so that the volumes of the cells are equal to the volumes of the regions they are intended to model. In the continuity solution, cells 6 and 7 model the tapered region. The momentum cells use the actual area at the location of the momentum cell center. In this example, the momentum area variation is modeled in cell 6.

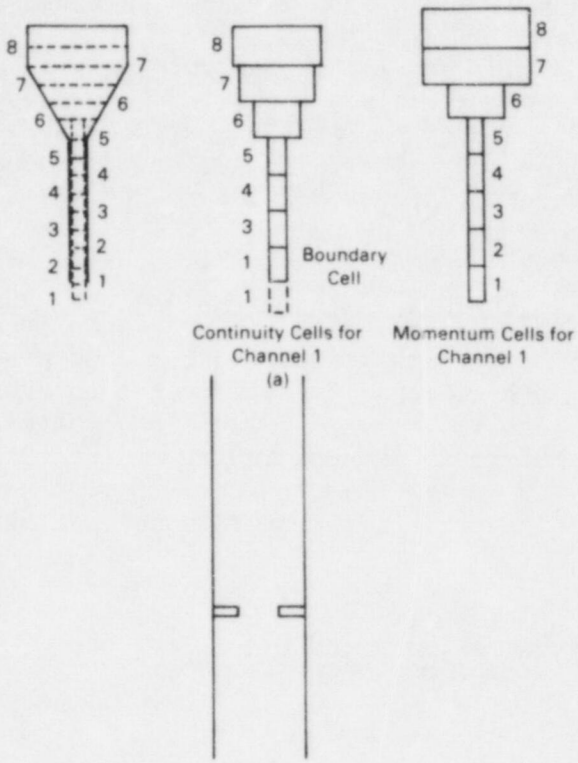


Figure 22 Examples of vertical variations in continuity and momentum area and wetted perimeter of a channel

The wetted perimeter is defined in the momentum cell, so variations in wetted perimeter must be located relative to the momentum cells. In example (a) in Figure 22, the gradually changing wetted perimeter must be approximated by step changes, as is the gradually changing flow area in the taper. For the circular cross section of this example, the simplest approach is to define the wetted perimeter as the perimeter of the momentum cell:

$$PW = \Pi D' \tag{4}$$

where

$$D' = \left[\frac{4A_{\text{momentum cell}}}{\Pi}\right]^{1/2}$$

The input for group 5 to model the variations in example (a) of Figure 22 consists of three variation tables (NAFACT = 3, read on CARD5.1). The tables themselves are read on CARD5.2 (specifying the number of entries in a table)

and on CARD 5.3 (filling the arrays for the node indices, JAXL, and variation factors, AFACT). The tables are numbered sequentially in the order they are read in.

Example (b) in Figure 22 shows a different sort of area variation. The orifice plate in the straight pipe affects the momentum solution, but because it occurs over a relatively short distance compared to the node length, the continuity solution is largely unaffected. This could be modeled with a momentum area variation alone without any variation in the continuity cell area. Gap width variations are specified in the same manner as vertical variations in area or wetted perimeter. The nodes that differ from nominal are identified in the JAXL array, and the corresponding variation factors in the AFACT array.

Variations encountered in most problems for COBRA-NC may not be as neat, generally, as the two examples shown in Figure 22. The user will have to make approximations appropriate for the particular geometry involved and the noding selected. Some general guidelines in setting up vertical variations are:

- In complex geometries, the user should preserve the same fluid volume as in the actual system. (Volume is calculated as A*ΔXin a cell.)

- The momentum area should approximate the actual flow area in the system at sudden changes. (This helps the code calculate the correct pressure losses due to momentum changes.)

- The code interpolates linearly in the table to obtain variation factors for cells within the range of the table but not named explicitly. (Cells with identification numbers lower than the first element of a variation table or greater than the last element in the table remain at nominal values.)

- The area in either the continuity cells or the momentum cells should not change by more than a factor of two between adjacent cells, even if the area in the system actually changes more abruptly, if momentum fluxes are to be computed. In this case the code must be led gradually through a large change in a series of steps.

The input for group 6 specifies the channels or gaps to which the variation tables described in the group 5 input apply. Variation table assignments are read on CARD6.2 for either channels or gaps. The variation tables are identified by sequence number; i.e., the first table read in group 5 is table 1, the second table read in group 5 is table 2, etc. The index number of the table to be used for continuity area variations is specified by IACT. The index number of the table to be used for momentum area variations is specified by IAMT. The index number of the table to be used for wetted perimeter variations is specified by IPWT. The numbers of the channels using the variation tables named by IACT, IAMT, and IPWT are listed in array ICRG(M). Vertical variation in gap width is specified by setting IACT to the negative of the variation table number, and naming the indices of the gaps using the

table in array ICRG(M). When gap variations are specified, IAMT and IPWT are not used.

The input for CARD6.2 is repeated until all channels and gaps having variations have been identified. It is not necessary to specify variations in continuity area, momentum area, and wetted perimeter in a channel simultaneously. Any or all can be used, as appropriate for a given problem. It is possible to specify a continuity variation only, momentum area variation only, perimeter variation only, or any combination of the three.

3.2.5 Group 7: Vertical Loss Coefficients

The input for group 7 is designed to model local pressure losses in the vertical flow due to pipe penetration holes, orifice plates, doorways, stairwells, and other local obstructions in the flow field. The pressure loss is modeled in the code as a velocity head loss

$$\Delta P = C_D \rho \frac{V^2}{2g_c} \qquad (5)$$

The input for group 7 defines values for C_D and specifies where they should be applied.

The total number of loss coefficients to be specified in group 7 is the value assigned to variable NCD on CARD7.1. The loss coefficient values, CDL(N), are specified on CARD7.2 along with the index number of the momentum cell corresponding to the vertical location of the loss. The indices of channels that contain that particular pressure loss are specified in the array ICDUM(I). Figure 23 shows an example of a typical flow path with local pressure losses that can be modeled by using group 7 input. Figure 23 is a sketch of some of the flow paths between rooms 23, 24, and 27 of our example containment problem (Figure 11). Openings U0143 connect room 23 to room 24 and opening U0140 connects room 24 to room 27. Each of these flow paths contain flow resistances that can be modeled by card group 7 input. In our example (Figure 11), room 23 is modeled with channels 30, 31, and 32. Room 24 is modeled with channel 37 and room 27 is modeled with channel 41. Room 23 is modeled with three vertical levels or nodes. Flow path U0143 is modeled by the connection at the top of channel 30. Flow path U0140 is modeled by the gap connecting channel 41 to channel 37 in the next section. The vertical connection diagram for channel 30 and channel 37 is shown in Figure 24.

This diagram corresponds to pattern (c) of Figure 19 so the momentum equations will be solved at the top of channels 28 and 30 rather than at the bottom of

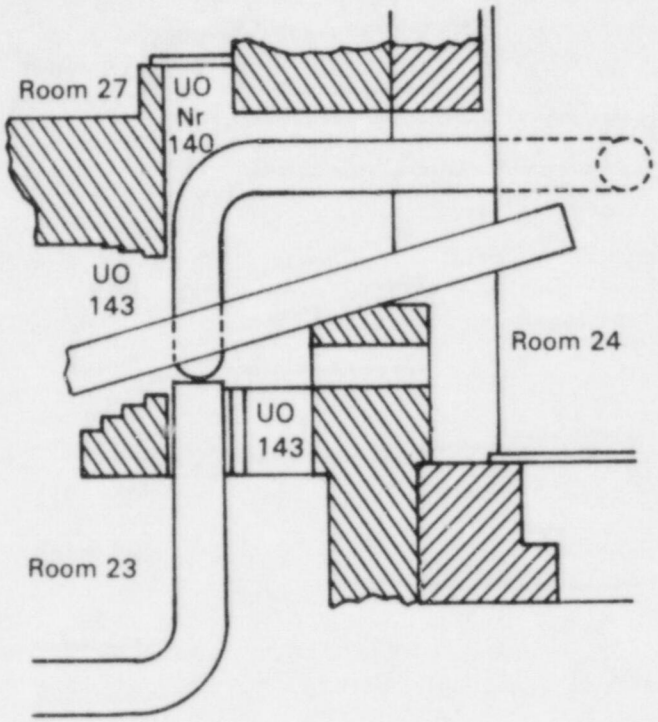


Figure 23 Typical flow path with local flow resistances

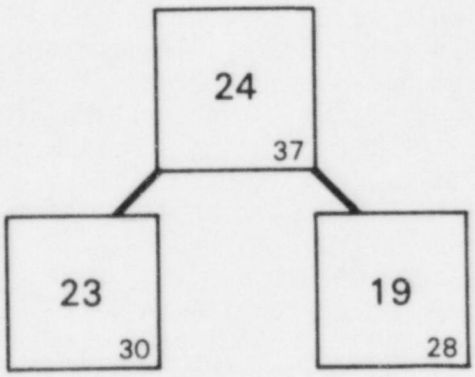


Figure 24 Vertical connections between sections 5 and 6 involving channels 30 and 37

channel 37. Therefore, the loss coefficient for flow path U0143 should be specified at the top of channel 30. The loss coefficient should be specified at node j = 4 since section 5 is divided into 3 nodes (see Figure 12).

If the loss coefficient for U0143 is 5.34, then the card group 7 input for opening U0143 would then be:

	Loss Coefficient (CDL(N)	Vertical Node(j)	Channels (ICDUM(I))
CARD7.1	5.34	4	30

The loss coefficient for opening U0140 is associated with GAP 70 and would be specified on the CARD3.2 input with the WKR(K) parameter.

Often the flow resistance and flow area between compartments is dependent on the differential pressure between the two connecting rooms. This is the case for closed doors, concrete block walls, manhole covers, floor and wall panels, etc., that will be forced open or displaced when a sufficiently large differential pressure acts across them. These conditions can be modeled with the second group of input for card group 7, the loss coefficients that are functions of pressure drop. The total number of loss coefficients that are a function of pressure drop is specified by the parameter NCDDP on CARD7.1. The information required to characterize each pressure dependent loss coefficient is specified on CARD7.3. The IDIT(L) parameter is a flag to indicate if the pressure-dependent loss coefficient is that of a vertical connection or that of a horizontal connection (gap). IDIT(L) should be specified as 1 for a vertical connection and as 2 for a gap. The channel (or gap) number that contains the pressure-dependent loss coefficient is entered in the ICD(L) array and the vertical node number (j for vertical connections and J for horizontal connections) is entered in the JCD(L) array on CARD7.3. The next four arrays, ICD1(L), JCD1(L), ICD2(L) and JCD2(L) are used to enter the channel and node numbers of the two mesh cells between which the differential pressure will be calculated. These will generally be the two mesh cells associated with the flow path under consideration. The differential pressure is calculated by subtracting the absolute pressure of channel (ICD2(L) node JCD2(L) from the absolute pressure of channel ICD1(L) node JCD1(L). If this pressure difference is greater than the values specified for the DPCDP(L) parameter, the code will assume that the flow path is open and that the drag coefficient input on CARD7.2 for this particular flow path should be multiplied by the factor specified for the CDFAA(L) parameter. If the pressure difference is less than the value specified for DPCDM(L) the code will again assume that the flow path is open and will apply the factor CDFAA(L) to the loss coefficient specified on CARD7.2. If the computed pressure difference has never exceeded the value of DPCDP(L) and has never been less than DPCDM(L), then the factor CDFAB(L) will be applied to the drag coefficient specified on CARD7.2.

Once the differential pressure has exceeded either of these limits, a flag is set in the code and the factor CDFAA(L) will be applied to the loss coefficient for the remainder of the calculation, even though the differential pressure may return within the above described limits later in the calculation. This is tantamount to saying that, once a door is blown open during a transient, it remains open, once a block wall is blown down, it stays down; or once a floor panel or cover has been blown away from an opening, it remains away.

Pressure-dependent openings are generally modeled by specifying the flow area as if the flow path were totally open and the loss coefficient on CARD7.2 for the totally open value. The parameter CDFAB(L) on CARD7.3 is then specified to be a large value (on the order of 1.0 E8) so that no flow will be calculated through the opening until the specified differential pressure limits have been exceeded. A value of 1.0 is usually specified for CDFAA(L) so that the loss coefficient specified on CARD7.2 will be used once either of the differential pressure limits have been exceeded.

The pressure-dependent loss coefficient input option can be illustrated by using opening U0140 in Figure 23. This flow opening is covered by a steel plate. The weight and structure of this plate is such that a pressure differential of +0.2 psi is sufficient to lift the plate off of the opening. A pressure differential of a minus-0.5 psi is sufficient to cause the plate to buckle and collapse through the flow opening. The input for CARD7.3 for this example would be as follows:

IDIT(L)	ICD(L)	JCD(L)	ICD1(L)	JCD1(L)	ICD2(L)	JDC2(L)
2	70	2	37	2	41	2

DPCDP(L)	DPCDM(L)	CDFAB(L)	CDFAA(L)
0.2	-0.5	1.0 E8	1.0

IDIT(L) is set to 2 because U0140 is modeled with a gap. ICD(L) is the gap number, 70, and JCD(L) is 2 since the section containing gap 70 only has one vertical level. The pressure difference is computed between channels 37 and 41 which represent rooms 24 and 27, respectively. ICD1(L) is set to 37 and ICD2(L) is set to 41. Both JCD1(L) and JCD2(L) are set to 2 since these are the levels that are connected by U0140. The pressure differential limits for opening the flow path are specified with the DPCDP(L) parameter equal to 0.2 and the DPCDM(L) parameter equal to -0.5. The user is cautioned not to forget the minus sign for the negative pressure differential. Since the flow path is closed as long as the differential pressure remains within the limits set by DPCDP(L) and DPCDM(L) a value of 1.0 E8 is used for CDFAB(L). A larger value (i.e., 1.0 E13) should not be used as it may cause numerical difficulties due to truncation errors in the matrix reduction operations. CDFAA(L) is set to 1.0, so that the value specified for WKR(70) in card group 3 will be used once the flow path is calculated to be open.

The input for group 7 is relatively simple and easy to construct. There are two main points to remember:

- The location of a loss coefficient is determined by node and channel number. The node refers to the momentum cell, not the continuity cell. This must be kept in mind when determining the node that corresponds to the location of the local loss in the system being modeled. Care must be used when placing a loss coefficient in a momentum cell at a section boundary. The loss must be defined in the channel where the momentum equation is solved.(a)

- The loss coefficients are defined assuming positive upflow in the channel. If the loss coefficient of a particular structure changes significantly when flow reverses through it, the code does not see the change. If reverse flow is the dominating pattern for such a situation, the user should specify the loss coefficient corresponding to reverse flow rather than the value for positive flow.

3.2.6 Group 12: Turbulent and Viscous Stress Data

Viscous and turbulent shear stresses and heat transfer may be modeled through the input provided in card group 12. This input is optional and should be used only for problems where these shear stresses have a significant effect on the behavior of the system. Turbulent and viscous shear stresses may be specified for the entire mesh, or for only specific sections of the mesh as the user requires. These terms should be neglected when performing a lumped parameter calculation, as the coarseness of the mesh does not allow for an adequate resolution of the velocity profiles that are required to determine the viscous or turbulent shear stresses.

The user may wish to perform a separate detailed three-dimensional simulation of some region of the containment where turbulent and viscous shear stresses are important, such as in a jet impingement calculation. The viscous and turbulent shear stress calculations are activated in each section of the mesh by specifying the appropriate value for IVIS(ISEC) and ITURB(ISEC). If ITURB(ISEC) is set to a value of one (1), then turbulence properties are assumed constant over the section. If ITURB(ISEC) is set to a value of two (2), then turbulence properties are assumed to vary from channel to channel. A mixing length turbulence model is used in the code. (This model is described in detail in Volume 1.) The user must specify the mixing length, the anisotropy factor, and the turbulent Prandtl numbers for each phase, in each section (if ITURB(ISEC) = 1), or in each channel of a section (if ITURB(ISEC) = 2). The mixing length for a problem is dependent on the geometry of the flow path. The user should consult a turbulent flow text to determine the appropriate

---

(a) To determine for which channel the momentum equation is solved, refer to Section 3.2.1

mixing length for the problem under consideration. A half jet diameter is recommended for jet impingement problems.

While the input allows the user to specify the degree of anisotropy, this is not usually known, and isotropic flow is usually assumed when computing the normal component of the turbulent shear stress. Thus, the anisotropy factors should generally be set to one, as are the turbulent Prandtl numbers, unless the user has, in hand, convincing data to the contrary.

3.3 Thermal Conductor Model

The conduction heat transfer model for COBRA-NC is designed to model the various walls, vessels, structures, and pipes contained in a reactor containment building. The numerical procedure used in the conduction solution is based on a finite-difference resistance network approach. It is discussed in detail in Volume 1 of this manual, Equations and Constitutive Models. Basically, the conduction solution calculates the heat flow in one dimension in a solid structure, with heat transfer to the fluid as a boundary condition on the heat transfer surface. Heat flow in the solid is calculated in the radial, or through wall direction.

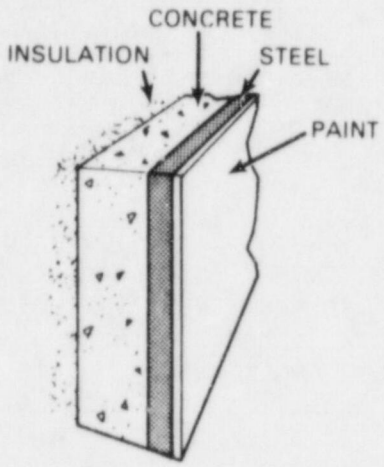
The input data for the conduction model is specified in groups 8, 9, and 10. The input for group 8 identifies the thermal conductors for a specific problem and initializes the surface temperatures. The geometries of the various thermal conductors are described in group 9. The thermal properties of the materials modeled in the thermal conductors are specified in the input data for group 10. The input for each of these groups is discussed in detail, with illustrative examples, in the following subsections.

3.3.1 Group 8: Description of Thermal Conductors

The input data for group 8 identifies the thermal conductors modeling the solid structures that interact significantly with the fluid in a particular problem. Thermal conductors are used to model solid conducting structures in the containment building.

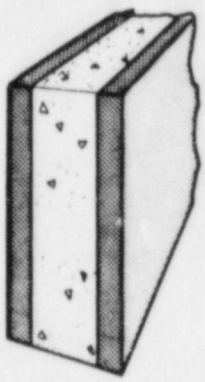
Figure 25 shows examples of containment structures that can be modeled with thermal conductors. Example (a) is a concrete containment wall with a steel inner liner covered with paint. The outer surface is insulated. The inner painted surface faces and exchanges heat with the containment atmosphere. This type structure can have any number of materials through its thickness. Example (b) is similar to example (a) except that both faces exchange heat with the containment atmosphere. Examples (c) and (d) allow modeling of cylindrical structures that may be within the building such as vessels, pipes, conduits, etc. They, too, may consist of several different materials through their thickness.

The first line of input in group 8, CARD8.1, identifies the number of thermal conductors (NSROD). The conduction solution flag NC must be set to select



(a)

INSULATED CONCRETE WALL WITH STEEL LINER AND PAINT COATING FACING CONTAINMENT ATMOSPHERE ON ONE SIDE

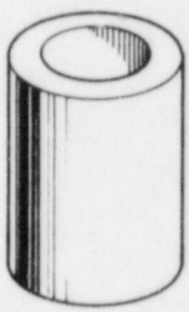


(b)

COMPOSITE WALL FACING CONTAINMENT ATMOSPHERE ON BOTH SIDES

(c)

SOLID ROD MADE OF ANY NUMBER OF MATERIALS



(d)

HOLLOW TUBE MADE OF ANY NUMBER OF MATERIALS. MAY HAVE FLUID ON BOTH INSIDE AND OUTSIDE SURFACE

Figure 25 Typical containment structures

radial conduction only (NC = 1). NROD should be set equal to zero (0), as this parameter is not required for containment applications.

The thermal conductor identification parameters are read on CARD8.2 and CARD8.3. If NSROD is zero, card group 8 is omitted. The thermal conductors are numbered sequentially from 1 to NSROD. Each thermal conductor is uniquely identified by its index number and geometry type number ISTYP(N). The geometry type number corresponds to a set of descriptive geometry data specified in input group 9. An individual thermal conductor may have a unique geometry type, or several conductors may be of the same geometry type.

The thermal conductors do not generate heat but can transfer heat to and from the fluid and store thermal energy during a transient. The user must specify the wetted perimeter of the surface, HPERIM(N), for each thermal conductor. If the conductor is a tube or wall that has contact with the fluid on its inner surface, then the wetted perimeter of the inner surface, HPERIMI(N), must be specified as well. The parameter RMULS(N) is the fraction (or multiple) of the total geometry type surface area that is represented by the thermal conductor, N. For example, the containment shell wall can be described using a single geometry type even though the wall is in contact with several different fluid channels. A separate thermal conductor must be specified for each channel. The fraction of the total wall in contact with a single channel is specified by RMULS(N). Likewise, if there are several identical heat transfer surfaces within a single channel, the geometry of only a single surface need be described and only one thermal conductor need be used to model the heat transfer to or from these surfaces. RMULS(N) in this case is simply the total number of identical heat transfer surfaces.

The remainder of the input in group 8 sets up the initial temperatures of the thermal conductors. The temperatures are specified in tables of initial temperature, TRINIT(I,L), versus vertical distance, AXIALT(I,L), relative to the bottom of the mesh. The code interpolates linearly in the table along the vertical height of the thermal conductor it is applied to, so the first element of the AXIALT(I,L) array for a given table I must be at or below the bottom of the conductor, and the last element must be at or above the top of the conductor. A total of NRTAB tables (the value of NRTAB is specified on CARD8.1) must be supplied, but table I can be applied to more than one thermal conductor. On CARD8.4 the user must specify the number of thermal conductors NST(I) that use table I. The user must also identify on this card how many pairs of TRINIT(I,L) and AXIALT(I,L) elements make up this particular table. The NRAX(I) pairs of entries for table I, TRINIT(I,L) and AXIALT(I,L), are read on CARD8.7.

CARD8.6 is read to fill array ISTAB(I,L) with the identification numbers of the thermal conductors that use temperature table I. The code assumes an initially flat temperature profile in thermal conductors, so it is not necessary to specify whether the temperature applies to the inner or outer surface.

3.3.2 Group 9: Geometry Description for Conduction Model

The input for group 9 describes the characteristics of the geometry types identified in the ISTYP(N) array for the thermal conductors in group 8. The conductors can be characterized as solid cylinders, hollow tubes, or flat plates.

On the first line of input for group 9, the user must specify NFUELT, the number of geometry types. This must be equal to the number of unique entries in the ISTYP(N) arrays.

Data for conductor geometry types is read on CARD9.6 and CARD9.7. The geometry types are classified as solid cylinders, hollow tubes, or flat walls. The physical elements of a nuclear containment building can be modeled with these geometries, even if they do not conform exactly to the ideal shape. In modeling a solid element with a conductor, the important aspects to preserve are:

- the surface area in contact with the fluid
- the mass available for thermal storage
- the thickness of any element (wall or tube) that has fluid contact on both surfaces.

The physical dimensions of the geometry types should be defined so that these three characteristics of the solid elements of the system are modeled with reasonable accuracy.

The geometry types are defined on CARD9.6 by index number I, and an alphanumeric value for FTYPE(I): HROD for a solid cylinder, TUBE for a hollow tube, and WALL for a flat plate. The dimensions of the conductors modeled by a geometry type I are defined by DROD and DIN. For a solid cylinder geometry, DROD is the outside diameter, and DIN is zero. For a tube geometry, DROD is the outside diameter and DIN the inside diameter. For a flat plate geometry, DROD is the perimeter of the plate surface that is in contact with the fluid and DIN is the plate thickness. In many problems, DROD and DIN will correspond exactly to the physical dimensions of the elements being modeled by the geometry type. The surface area of the conductor is given by the product of the conductor perimeter times the height of the channel it is connected to.

The number of different material regions modeled in the conductors of geometry type I is specified by the value of NFUEL on CARD9.6. The number of heat transfer nodes in a given region is specified by input on the subsequent CARD9.7. A region defines a radial ring (or layer, for wall geometries) of uniform material properties for the conduction solution. The wall shown in Figure 25(a), for example, consists of three different materials: concrete, steel, and paint. Three separate regions of materials are formed by the wall geometry, shown in Figure 25(b). NFUEL should be set equal to three (3) for these two examples.

The remaining input for CARD9.6 is not required for containment analysis. The parameter IMATDX(I) and IMATIX(I) should be set equal to the material property table for the material in region NFUEL and region 1, respectively. The material composition and radial noding in the NFUEL regions identified for a geometry type I are read on CARD9.7. The user must specify a material property table index for the region MATR(L), corresponding to a properties table supplied in group 10. The physical thickness of each region must be specified in the variable TREG(L), with the number of radial nodes in that region, NODER(L). The code automatically calculates the size of each node within the region by dividing the region into NODER(L) nodes of equal thickness.

The material temperature is calculated at the center of mass of each node. The only exception to this node placement occurs for a region where one edge forms a heat transfer surface in contact with the fluid. In this case, the node closest to the surface is given only one half the nominal thickness. The node temperature is calculated at the surface rather than the center of the half-width node.

A sample radial noding for a containment wall is shown in Figure 26. This wall is entirely concrete, but it has been divided into seven regions to allow a variable node length through the thickness. This is done to provide a finer node distribution near the wall surface in contact with the containment

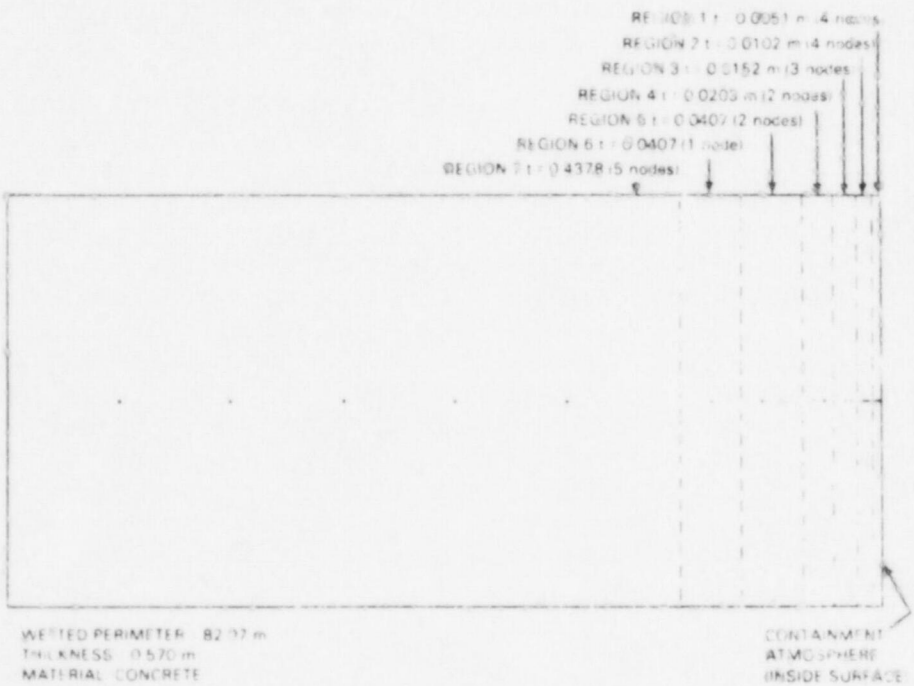


Figure 26 Typical radial noding for containment

atmosphere to resolve the steep temperature gradients near the surface due to the condensation of steam. Temperature profiles deep in the wall are reasonably flat and can be resolved with much larger node sizes without sacrificing computational accuracy. Note that the change in node size between any two regions does not change by more than a factor of 2. Nodes are equally spaced within a region. Each region could consist of a different material if necessary. The input for this example is shown in Table 4.

The number of radial nodes used within a region of a geometry type is governed by two factors: 1) the temperature gradient expected in the structure, and 2) the calculational cost for a large number of heat transfer nodes. The user must specify enough nodes to adequately resolve the heat transfer conditions being modeled. Beyond a certain limit, however, doubling the number of nodes does not double the accuracy of the solution, but it nearly quadruples the computation time required for elements with that geometry type. The user must exercise some judgement as to what constitutes an adequate but not excessive number of radial nodes for the heat transfer solution in a particular problem.

3.3.3 Group 10: Material Properties Table

The input for group 10 supplies the material properties selected by numerical indices in the geometry type input of group 9. Properties tables must be supplied for NMAT materials, where NMAT is the number of unique indices specified in group 9 input for the variables MATR(L), IMATOX(I) and IMATIX(I). The user must keep track of which material he wishes to specify with a given index number. The code cannot check this input internally.

The material properties tables are entered on CARD10.2 and CARD10.3. Both cards are read for each table. CARD10.2 identifies the table by its numerical index and specifies the number of entries, NNTDP, in the table. The cold-state density of the material, RCOLD(N), is also entered on this card. RCOLD(N) is the density at normal (as-built) conditions, and is used to calculate the mass of the nodes. This approach eliminates the tedious process of calculating the relocation of the radial nodes due to thermal expansion during the transient.

The properties table itself is read on CARD10.3. The material properties included in the table are specific heat, CPF(I,N), and thermal conductivity, THCF(I,N), as a function of temperature, TPROP(I,N). The temperature range of the table must be great enough to encompass the temperature extremes expected in the calculation, otherwise the run will abort due to property table lock up failure. The user may specify constant properties for a material type. This is done by entering only one element in the table, i.e, setting NNTDP to 1, and reading CARD10.3 for only one set of TPROP(I,N), CPFF(I,N), and THCF(I,N). The value specified in TPROP(I,1) is in this case superfluous. The values specified in CPFF(I,1) and THCF(I,1) will be used for material type I regardless of the material temperature.

Table 4 Input for thermal conducting wall example

CARD9.6: I	FTYPE(I)	DROD	DIN	NFUEL	IMATOX(I)	IMATIX(I)
1	WALL	82.07	0.570	7	1	1

CARD9.7:

NODER(1)	MATR(1)	TREG(1)	QREG(1)	NODER(2)	MATR(2)	TREG(2)	QREG(2)
4	1	0.0051	0	4	1	0.0102	0
NODER(3)	MATR(3)	TREG(3)	QREG(3)	NODER(4)	MATR(4)	TREG(4)	QREG(4)
3	1	0.0152	0	2	1	0.0203	0
NODER(5)	MATR(5)	TREG(5)	QREG(5)	NODER(6)	MATR(6)	TREG(6)	QREG(6)
2	1	0.0407	0	1	1	0.0407	0
NODER(7)	MATR(7)	TREG(7)	QREG(7)				
5	1	0.4378	0				

3.4 Boundary and Initial Conditions

Boundary and initial conditions for the mesh consist of the initial system operating conditions, and boundary conditions on individual computational cells within the mesh. The initial system operating conditions define the state of the fluid in the containment atmosphere at the beginning of the transient. This data is supplied in input group 1, which is discussed in Section 3.4.1.

Within the mesh itself the user may specify a variety of boundary conditions on individual computational cells. These include pressure boundaries, mass flow boundaries, mass sources, and pressure sinks. In addition, the user may selectively shut off crossflow in specific nodes, a useful aid in modeling transverse flow paths. The data for these boundary condition options are specified in group 13, and the input requirements are discussed in detail in Section 3.4.2.

3.4.1 Group 1: Initial Conditions

The input for group 1 consists of nine cards required to define the initial state of the fluid in the computational mesh.

The number of noncondensable gas species present in the containment atmosphere or that will be introduced via the boundary conditions is input in the parameter

NGAS on CARD1.1. The parameter IREF is a flag used to specify if a uniform initial gas partial pressure or a uniform initial steam pressure is to be assumed. A uniform initial steam pressure is assumed if IREF is entered as zero and a uniform initial gas pressure is assumed if IREF is entered as one. This input is necessary because the local pressure is initialized to be equal to the system pressure plus the gravitational head. If a constant steam partial pressure is specified then the partial pressure of the gas is the difference between the local total pressure and the nominal steam pressure. Therefore the partial pressure of gas will be highest at the lowest elevations of the containment. The opposite will be true if a constant air pressure is specified. Generally, a constant initial steam pressure is desired in containment applications. Also input on this card is the number of gas temperature initialization tables, NTGAS, the number of liquid volume fraction initialization tables, NAL, the number of fluid heat flux tables, NHF, the number of liquid enthalpy tables, NLE, and the number of slab zero heat flux tables, NZS.

The nominal state of the containment atmosphere is defined using CARD1.3. PREF is the system pressure, HIN is the water/vapor enthalpy, HGIN is the noncondensable gas mixture enthalpy, VFRAC(1) is the initial liquid water volume fraction, and VFRAC(2) is the initial volume fraction of steam in the steam/gas mixture. The nominal partial pressure of steam is equal to VFRAC(2)*PREF. Nominal values are input for each of these parameters. Local pressures and enthalpies will be computed for each computational cell based on the local gravitational head computed by the code and on the temperature specified on CARD1.5. If no temperature is specified for a given cell, then the nominal enthalpies specified on CARD1.3 are used for both the steam and the noncondensable gas mixture. If local temperatures are specified for a cell, new enthalpies are computed for the steam and gas mixture using the relationship:

$$h = h_{nom} + C_{p_{nom}} (T - T_{nom}) \qquad (6)$$

where h is the local enthalpy
h_{nom} is the nominal system enthalpy (for either the steam or gas mixture)
C_{pnom} is the specific heat at constant pressure computed at the nominal conditions
T is the local temperature specified on CARD1.1
T_{nom} is the nominal temperature computed by the code from PREF and HIN.

The initial liquid water fraction may also be specified locally by specifying the value for ALIQ on CARD1.6. This is useful when it is necessary to model local concentrations of liquid water such as in suppression pools. If a value is not specified on CARD1.6, then the nominal liquid fraction value is assigned to that cell.

Only a nominal value is allowed for the initial volume fraction of steam in the steam gas mixture. The value entered for the steam volume fraction depends on the amount of water vapor present in the atmosphere. It is possible to have the atmosphere consist almost entirely of steam or almost entirely of noncondensable gases. Generally, the initial containment atmosphere will consist of air at some relative humidity. The initial volume fraction of steam in the atmosphere may be calculated from the relative humidity and nominal temperature of the atmosphere as follows.

If the steam and the air are considered to be ideal gases, then the relative humidity is defined as the ratio of the partial pressure of the vapor as it exists in the atmosphere, Pv, to the saturation pressure of the vapor at the same temperature, Pg. The saturation pressure of the vapor at the atmosphere temperature can be obtained from the saturated steam tables. The partial pressure of the steam in the atmosphere can then readily be calculated as;

$$P_v = \phi P_g$$

where P_v is the partial pressure of steam in the atmosphere, P_g is the saturation pressure of the steam at the atmosphere temperature, and ϕ is the relative humidity.

The partial pressure ratio of steam in the atmosphere is then simply, from Dalton's Law, Pv/PREF. Using the ideal gas assumption that the steam volume fraction is equal to the partial pressure ratio;

$$V_{fv} = \frac{P_v}{PREF}$$

the steam volume fraction is determined.

The NGAS components of the noncondensable gas mixture are input on CARD1.4. An alphanumeric field is first specified to identify the gas species. This is followed by a numerical value for the volume fraction (or mole fraction) of the specified gas component in the noncondensable gas mixture. Any number of gas species may be specified; however, only eight are currently coded. These are air, argon, helium, hydrogen, krypton, nitrogen, oxygen, and xenon. Air is included as a option, so that each component of air does not necessarily have to be modeled as a separate species. The species expected to have the lowest concentration should be specified first.

Local initial gas temperatures are specified on CARD1.5. The temperature is entered via the parameter TGL. Next the vertical node number, J, at which the temperature is specified, is entered. Finally, up to 12 channels may be

specified to have temperature TGL at node J by entering their identification numbers into the IZDUM(M) array.

This input allows the user to specify a different gas temperature in each mesh cell, if he desires, or to specify only some or none of them. CARD1.5 must be repeated NTGAS times. If a temperature is not specified for a cell then it is set to the nominal temperature. The nominal temperature is computed by the code's equation of state based on the values input for PREF, HIN, and VFRAC(2).

Local initial liquid water fractions are specified on CARD1.6. The liquid volume fraction is entered via the parameter ALIQL. The vertical node number at which the local liquid volume fraction is applied is entered as parameter J. Up to 12 channels may be specified to have liquid fraction ALIQL at node J by entering their identification numbers into the IZDUM(M) array.

A constant heat rate to the fluid may be specified on CARD1.7. The constant heat rate is entered as the parameter QMIXL. The units of QMIXL are BTU/sec. This heat is applied to the vapor/gas mixture if the void fraction is greater than 0.995 and to the liquid if the void fraction is less than 0.99. The heat is linearly ramped between the two phases between these two limits. The vertical node number at which the heat rate is applied is entered as parameter J. Up to 12 channels may be specified to have heat rate QMIXL applied to node J by entering their identification numbers into the IZDUM(M) array. This option is useful for modeling known heat sources or sinks, such as coolers or heaters.

The local liquid enthalpy (i.e., temperature) may be specified on CARD1.8. The liquid enthalpy is entered as the HLS. The vertical node number and channels that are to have liquid enthalpy HLS are entered via the parameters J and IZDUM(M), respectively. Up to 12 channels may have enthalpy HLS specified at node J. The user may repeat CARD1.8 as many times as he needs to specify the liquid enthalpies in the mesh. Cells not specified on CARD1.8 will be assigned a liquid enthalpy based on the nominal pressure, PREF, and mixture enthalpy, HIN, specified on CARD1.3.

If HIN is less than the saturation enthalpy of water then the water enthalpy is set to HIN and the vapor enthalpy is set to the vapor saturation enthalpy. If HIN is greater than the saturation enthalpy of water then the liquid enthalpy is set to the saturation enthalpy. The vapor enthalpy is set to the vapor saturation enthalpy or HIN, whichever is greater. The local vapor enthalpies and temperatures can then be specified via CARD1.5.

The input on CARD1.9 is used to control the heat flux from structure within each section of the mesh. When a heat slab is specified within a section the assumption is made in the code that the heat slab extends from the bottom to the top of the section. Often it is desirable to model a heat transfer surface that is only in a part of the section, such as at the very top or bottom. These situations can be handled by shutting off heat transfer calculations

between the fluid and structure and within the structure where they are not desired. The vertical level at which heat transfer calculations are not desired is entered via the parameter J. Up to 12 slabs may be specified to have no heat transfer at node J by entering the slab identification numbers into the IZDUM(M) array.

Initially, stagnant conditions are assumed to exist in the vessel. Initial convection patterns may be important for some slow transients in the containment. If initial flow patterns are deemed important, it will be necessary to run a transient calculation based on the initial conditions to obtain a steady-state solution. This pseudo-transient must be run until the flow pattern has achieved a steady state, as indicated by the steadiness of the computed variables such as pressure, enthalpy, gas concentration, and fluid velocities. These initial flow patterns are generally not of interest and the transient can, for most cases, be run directly from the specified initial conditions.

Also included in the card group 1 input are four parameters that must be specified to place an upper limit on the magnitude of the product of the interfacial heat transfer coefficient and the interfacial area. These four parameters are SCVL, SHVL, SCLL, and SHLL. SCVL is the upper limit of the product when the vapor is subcooled, SHVL is for superheated vapor, SCLL is for subcooled liquid, and SHLL is for superheated liquid. These parameters may be set to the values suggested in the input instructions for most problems. These values are large enough to prevent numerical convergence problems without interfering with the two-phase physics. Lower values can be specified for these variables if excessive phase change rates are driving the solution unstable. A value of zero for any of these parameters will cause the interfacial heat transfer and phase change to be zero for the nonequilibrium condition that the parameter represents.

3.4.2 Group 13: Mesh Cell Boundary Conditions

Two main types of boundary conditions can be specified by input in Group 13. These are 1) inlet or outlet boundary conditions on channels, and 2) specific boundary conditions on particular cells within the mesh for both the vertical and transverse control volumes. Inlet or outlet boundary conditions must be specified for channels that do not have vertical connections to other channels in the system at their inlet or outlet. (This, obviously, must include the inlet to channels in Section 1, and the outlet of channels in the last section NSEC. Other channels within the stack of sections can also be unconnected at the top or bottom to other channels.) Mesh cell boundary conditions may be applied wherever needed, on any face of any cell within the vessel mesh, but only one boundary condition can be applied to any one node. If more than one vertical boundary condition is specified on one node, then only the last one specified will be used.

The total number of channel mesh cell boundary conditions--including inlet, outlet and internal mesh cells--in a given problem is specified by the value of NIBND on CARD13.1. The NIBND boundary conditions are set by reading CARD13.4 for each boundary, specifying the channel number (IBOUND(1,M)), axial node number (IBOUND(2,M)), boundary type number (ISPEC(M)), the first boundary value (PVALUE), the second boundary value (HVALUE), and the third boundary value (XVALUE). The boundary conditions that can be specified for channel mesh cells are listed in Table 5. The specified boundary values are pressure and enthalpy or flow rate, enthalpy, and pressure, and any of them can be modified by forcing function tables. The forcing functions to be applied to boundary condition (M) are identified by table number in parameters NPFN(M), NHFN(M), and NXFN(M) for the first, second, and third boundary values, respectively. If liquid at the boundary is to enter the mesh as drops, then the drop diameter, DROPS(M), must also be entered in units of feet. If no value is entered for DROPS then the liquid is assumed to enter as the continuous liquid rather than as the dispersed liquid field.

Table 5 Channel boundary condition types

Boundary Type Number	Boundary condition
1	pressure and enthalpy
2	flow rate, enthalpy, and pressure
3	flow rate only (enthalpy taken as that of the cell the flow rate convects from)
4	mass source, enthalpy, and pressure
5	pressure sink and enthalpy

If a type 1 boundary condition is specified, the pressure in channel I = IBOUND(1,M) at node J = IBOUND(2,M)y is set to PVALUE, and the steam/water enthalpy of any flow into the system across that boundary is set to HVALUE (XVALUE is not used). For a type 2 boundary condition, the flow at the top face of node IBOUND(2,M) in channel IBOUND(1,M) is set to PVALUE, the steam/

water enthalpy to HVALUE, and the pressure to XVALUE. The flow may be either positive or negative. For a type 3 boundary condition, the flow is set to PVALUE. HVALUE and XVALUE are not used. This boundary condition is used to shut off vertical flows within the mesh or to specify flow into or out of a channel where it is not desirable to specify the node enthalpy, as is done for a type 2 boundary. A type 4 boundary is used to specify a mass source in any cell. PVALUE is the source mass flow rate, HVALUE is the source steam/water enthalpy, and XVALUE is the source pressure. A type 5 boundary is used to specify a pressure sink connected to any mesh cell. PVALUE is the sink pressure and HVALUE the enthalpy of the fluid in the sink (XVALUE is not used). Only one boundary condition may be specified for a given channel I node J. Caution, a type 2 boundary condition specifies the enthalpy and pressure in the continuity cell J = IBOUND(2,M) and the flow at the top of cell J = IBOUND(2,M) (i.e., at j = IBOUND(2,M)). Therefore, a type 2 boundary condition should not be used at the top of a channel or on the interior of the mesh unless the user really wants these parameters to be specified. If a flow boundary condition is desired at the top of the channel, a type 3 boundary condition should be specified at j = NONODE+1 (Figure 12) and, if the specified flow is into the mesh (negative flow), a type 1 boundary condition should be specified at J = NONODE+2 (Figure 12) to provide the desired fluid properties to be convected into the mesh by the type 3 boundary condition. A type 3 boundary condition may be specified anywhere in the mesh. This is a useful feature for modeling zero flow boundaries within the mesh or modeling constant flow pumps or fans.

CARD13.5 and 13.6 are read immediately following CARD13.4 for each boundary condition that is not a type 3 boundary condition. Values for the noncondensable gas mixture steam/water enthalpy and volume fractions of steam and each of the gas species for the boundary condition are specified on CARD13.5. HMGAS(M) is the noncondensable gas mixture enthalpy for boundary condition (M). GVALUE(2,M) is the steam fraction in the steam/gas mixture and GVALUE(3,M) through GVALUE(NGAS+2,M) are the volume fractions for each of the gas species in the problem in the same order that the gas species were specified on CARD1.4. The steam volume fraction can be calculated for boundary conditions in the same manner as was explained earlier for the initial conditions.

The identification numbers of the forcing function to be applied to each of the parameters specified on CARD13.5 are input on CARD13.6. The identification number of the forcing function to be applied to the gas mixture enthalpy for boundary condition M is entered in the NHMFN(M) array. Likewise, forcing function numbers for each of the volume fractions (steam and gas species) are entered in the NGFN(NG,M) array.

In addition to the vertical boundary conditions, the transverse flow between channels connected by a gap can be shut off at any elevation within the mesh by specifying input for CARD13.9. This input is read if NKBND is greater than zero. NKBND is the total number of transverse mesh cells with crossflow set to zero. The input for CARD13.9 consists simply of the gap identification

number, K, and the contiguous vertical levels JSTART to JEND where the crossflow will be set to zero. This format makes it very easy to zero out a sequence of crossflows, from J = 2 to J = 10, for example. If flow is to be shut off in more than one segment of a gap, CARD13.9 input can be specified for gap K more than once until all of the axial levels to be zeroed have been specified.

The general application of the boundary conditions is summarized on Table 6:

Table 6 Application of Boundary Conditions

Boundary Condition	Internal Mesh Cells	Boundary Cells
pressure and enthalpy (type 1)	no	yes
mass flow rate and enthalpy (type 2)	no	yes
mass flow rate (enthalpy unspecified) (type 3)	yes	yes
mass source (flow rate and enthalpy) (type 4)	yes	no
pressure sink (pressure and enthalpy) (type 5)	yes	no
transverse flow set to zero	yes	no

Unless otherwise indicated, the special boundary conditions applied to cells as specified in group 13 are constant in time. The user may, however, specify forcing functions for any or all of the special boundary conditions. The number of forcing functions is specified by the value of NFUNCT on CARD13.1.

The forcing functions on the special boundary conditions are specified as tables of forcing function factors versus time. The number of elements in a given table is read on CARD13.2 as NPTS; then NPTS pairs of (ABSCIS(K,I), ORDINT(K,I)) are read on CARD13.3. The ABSCIS array contains the transient time, in seconds, when the corresponding forcing function factor ORDINT is to be applied. ORDINT is defined as the ratio of the value at time ABSCIS(K,I) of the parameter being forced and its initial value. The factor is determined at any given time step by linear interpolation in the forcing function table.

The forcing function tables are numbered sequentially from 1 to NFUNCT in the order they are read in.

If a pressure sink boundary condition (i.e., type 5 boundary condition) or a mass source boundary condition (i.e., type 4 boundary condition) has been specified for a cell on CARD13.4, additional information describing the sink or source geometry must be supplied on CARD13.7 or CARD13.8. Flow in or out of a sink is defined for a special control volume, as shown in Figure 27. The flow area of the control volume is ASINK and the length of the cell is DXSINK.

The sink boundary condition usually models a real hole in the system, such as a pipe penetration. In such cases, ASINK is the flow area of the hole. The control volume length, DXSINK, should be on the order of the centroid length of the channel in which the sink lies. The flow in and out of the sink generally encounters some unrecoverable pressure loss due to expansion at the orifice, and the loss coefficient associated with the sink flow is defined by SINKK on CARD13.7. Card13.8 is read for the flow area of mass sources in the same manner. The type 4 and 5 boundary conditions are numbered sequentially within the code in the order they are read in on CARD13.4. CARD13.7 or CARD13.8 should be read for the sinks and sources in the same sequential order.

For example, suppose 5 boundary conditions were specified for a problem. The first is a type 3 boundary, the second is a type 4 boundary, the third is a type 5 boundary, the fourth a type 4, and the fifth a type 1 boundary. The boundary condition cards would be read in the following order:

CARD13.4 for the type 3 boundary
CARD13.4 for the type 4 boundary
CARD13.5 for the type 4 boundary
CARD13.6 for the type 4 boundary
CARD13.4 for the type 5 boundary
CARD13.5 for the type 5 boundary
CARD13.6 for the type 5 boundary
CARD13.4 for the second type 4 boundary
CARD13.5 for the second type 4 boundary
CARD13.6 for the second type 4 boundary
CARD13.4 for the type 1 boundary
CARD13.5 for the type 1 boundary
CARD13.6 for the type 1 boundary
CARD13.8 for the first type 4 boundary
CARD13.7 for the type 5 boundary
CARD13.8 for the second type 4 boundary

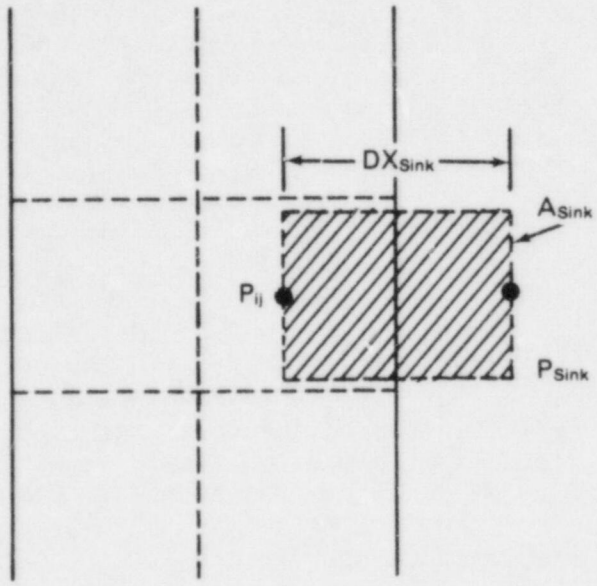


Figure 27 Control volume for pressure sink boundary condition

3.5 Specification of Output of Results

The output that can be generated from the computational results is quite general. The user has options to limit the output to only those mesh elements of special interest or to expand the output to include information not ordinarily specified. The input to specify the form of the output desired is supplied in group 14, which is discussed in Section 3.5.1.

Data for graphical presentation of the calculational results can also be generated. Graphical output provides a comprehensible and accurate picture of what the calculation is doing. The capabilities of the GRAFIX program that processes the results from the calculation are discussed in the Programmers' Manual (Volume 9). The input instructions for GRAFIX are listed in Section 2.5 of Volume 4. Before this feature can be used the graphics dump tape must be created during the calculation. The input to set up the graphics dump is discussed in Section 3.5.2.

3.5.1 Group 14: Line-Printer Output Options

Group 14 offers the user five separate choices for the format of the printed output. These are specified by the value of N1, read on CARD14.1, as

1 - channel data only
2 - channel and gap data only
3 - thermal conductor data only
4 - thermal conductor and channel data only
5 - thermal conductor, channel and gap data.

In addition, the user may specify by index number the channels, gaps, or thermal conductors the printout should include, if he does not want to see all of them. This is done by setting NOUT1, NOUT3, and NOUT4 on CARD14.1 to the number of channels, gaps, and thermal conductors, respectively, to be printed out. For most cases, the user will select N1 = 5, and set NOUT1, NOUT3, and NOUT4 to zero, so that all channels, gaps, and thermal conductors will be printed. The option to limit the output is useful mainly for very large problems.

Two additional printout options specified on CARD14.1 are IPROPP and IOPT. If IPROPP is specified as a positive integer, the fluid properties table used in the code to calculate local fluid properties will be printed out. If the user does not need this information, he can suppress the printout by setting IPROPP to zero. The variable IOPT lets the user request additional channel output information, which includes the vapor and liquid interfacial drag forces, vapor and entrained droplet interfacial drag forces, and interfacial heat transfer coefficients. These are generally only used for code debugging purposes.

If the user specifies nonzero values for NOUT1, NOUT3, or NOUT4 on CARD14.2, he must identify the index numbers of the specific channels, rods, gaps, or thermal conductors he wants to see printed out. The NOUT1 channel numbers are specified in array PRINTC(I) on CARD14.2, the NOUT3 gap numbers are specified in array PRINTG(I) on CARD14.3, and the NOUT4 thermal conductor numbers are specified in array PRINTS(I) on CARD14.5.

3.5.2 Graphics Options

The graphics input options are used to create special data files, one for computer-generated movies and one for input to the graphics program GRAFIX. It is recommended that the movie option be ignored for the time being. Particle-tracker movies are neither simple nor inexpensive to make, and generating the data is but the first step in a long process. The particle-tracker movie software is still under development and will be documented separately at a later date. The graphics option, however, is indispensible for analyzing long and complicated simulations.

The user needs to spend some time thinking about the plots ultimately needed for the simulation. The question "How often should data be saved for the plots?" needs to be answered before the simulation is begun. Properly used, the graphics options will allow the user to save data at any reasonable interval throughout the transient.

The user has the option of specifying a normal graphics dump or a very short dump. For each cell of each channel, the normal graphics dump saves the pressure, liquid fraction, vapor fraction, entrainment fraction, temperature, phase densities, liquid flow rate, vapor flow rate, heat deposited to the liquid, heat deposited to the vapor, entrainment rate, de-entrainment rate, hydraulic diameter, and interfacial heat transfer coefficients, steam and gas volume fractions, plus several useful variable flags. For every transverse momentum cell (i.e., every cell of every gap), the normal graphics dump saves the liquid crossflow, vapor crossflow, and entrained crossflow. For each axial level of each thermal conductor the normal graphics dump saves liquid and vapor temperatures of the fluid seen by the thermal conductor, heat transfer coefficients to the liquid and vapor, thermal conductor temperature, and local heat transfer mode. This amount of data, even for a moderately-sized mesh, can result in a data file too large to manage.

If the normal graphics dump is too big or is not needed, the short dump option can be used. The user specifies (by channel, or gap number and axial level index) precisely which variables to save. This is often the only feasible way to save graphics data for large meshes. The normal dump is flagged by setting IGRFOP to zero on GRAF.2. If the short dump is required, IGRFOP is equal to the number of variables saved. The thermal conductor variables and noncondensable gas variables are not currently available for the short graphics dump.

The maximum number of graphics dumps to be made is specified in MXGDMP. This is constrained by a dimension parameter. MXGDMP must be no greater than MI (see Section 2.4, Table 1 for a complete definition of MI). It should be noted that MXGDMP cannot be changed in the course of a transient. The initial input value of MXGDMP is used to determine the size of file TAPE11, the graphics dump file, and is used subsequently in calculating locations of dumps for the various time steps. If it were changed in the course of the transient on a restart, the code would not be able to locate the correct place to read or write data in the TAPE11 file.

The short graphics dump includes an option to save data for liquid level calculations. (The normal dump automatically saves enough data for such calculations.) This option reduces the amount of data that must be written to file TAPE11 for the calculations by performing part of the calculation in COBRA-NC. Instead of saving the area, void fraction, and cell length for every cell in every channel included in the liquid level calculation, the code performs the liquid level calculation and saves only the height of each liquid level specified. But to do this, the user must tell the code the channels and vertical levels for which the calculation is to be performed.

An example of the geometry for a liquid level calculation that crosses section boundaries is given in Figure 28. The corresponding input for card GRAF.3 is shown in Table 7. This input yields a liquid level calculation over the vertical height length from node 2 in section 8, through section 9, to node 3 in section 10, in this example.

Table 7 Example Input Data for Liquid Level Calculation

NCHLL(N)	JSLL(N)	JELL(N)	ICLL(I,N)
17	2	2	211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227
25	-2	3	237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261
21	-2	3	262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282

3.6 Using the Dump/Restart Option

The DUMP/RESTART option in COBRA-NC makes it possible to run long transient calculations efficiently. Long transients modeling large systems can require many hours of computer time to execute. The DUMP/RESTART capability allows the user to run the transient as a series of shorter runs, each restarting at the point the previous run left off. The user can then monitor the calculation as it progresses and minimize wasted computer time resulting from input errors and computer system failures. The DUMP/RESTART option is relatively easy to implement.

Data to be used for the restart run are written to a dump file named TAPE9. (If the graphics option is being used, a file named TAPE11 is generated also. This has nothing to do with the restart, per se, but TAPE11 must also be accessible for restarts if the graphics output option is being used.) These files, TAPE9 and TAPE11, are local files, and the user must do whatever is appropriate on his system to save them permanently for later access.

The dump file (TAPE9) contains data describing the state of the computation at specific time steps. The line-printer output for the calculation contains, for each time step written to the dump file, the following message:

SAVED ARE START DUMP AT NNNNXX.XXX

where NNNN is an integer number identifying the time step, and XX.XXX is a real number identifying the corresponding simulation time. Dumps are saved at the time intervals specified by input on the time domain cards (see Section 2.4)

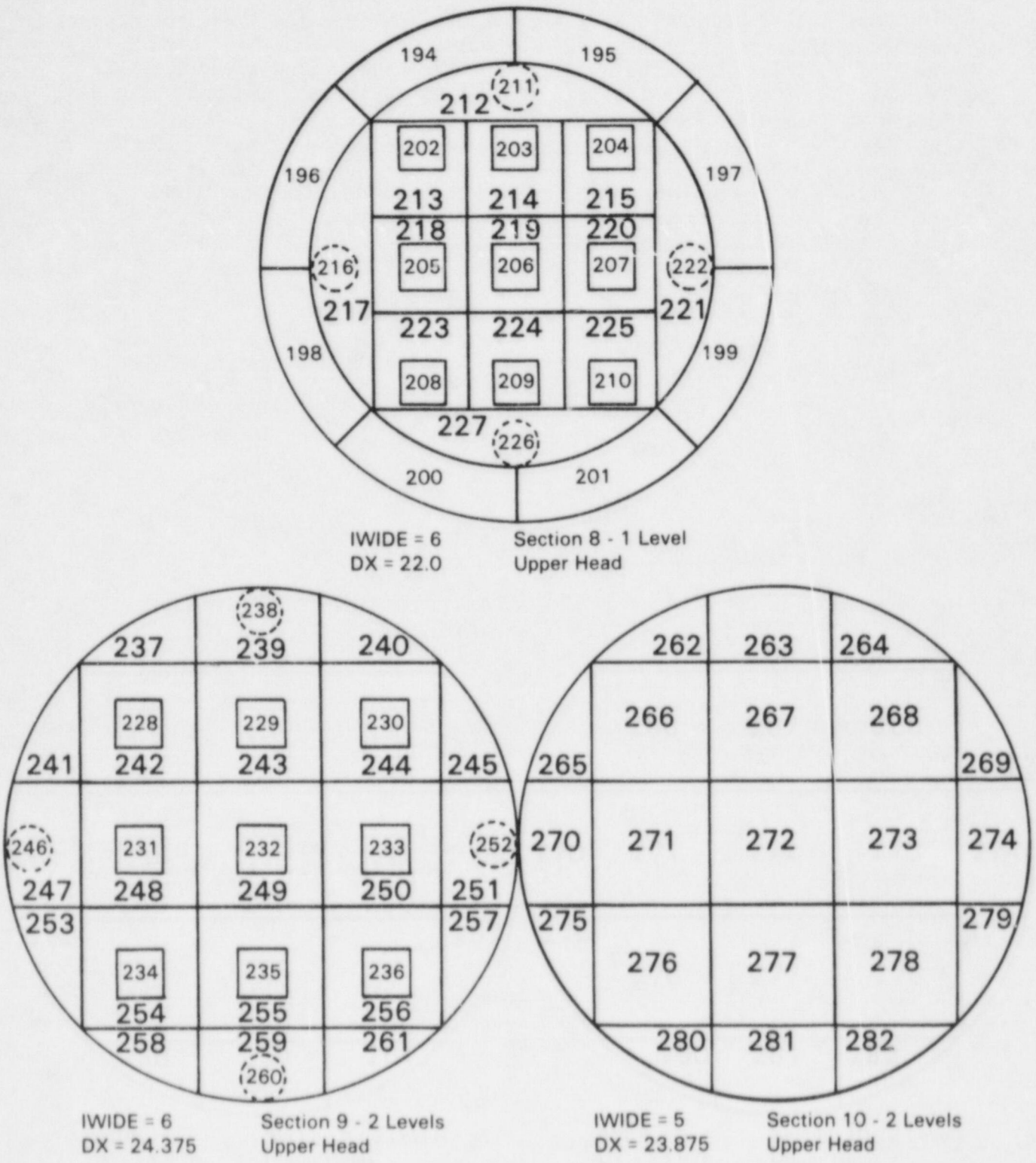


Figure 28 Liquid level calculation example geometry

every 3600 CPU seconds and at the end of each run. The user may specify any interval he deems appropriate for his problem, but since these files can become quite large, excessive dumps should be avoided. The calculation may be restarted from any time step written to the dump file, but in most cases the last time step on the file will be the one used to restart the simulation. The input file for a restart run is much simpler than the initial run input file since most of the required information is stored on the dump file. Cards INPUT.1, INPUT.2, INPUT.3, COBRA.1, and COBRA.2 must be specified for a restart. None of the CARD group cards need be entered. Cards GRAF.1, GRAF.2, GRAF.3, GRAF.4, and GRAF.5 must be specified as must the time domain cards. The time step number, DSTEP, and the transient time, TIMET, for the restart dump to be used are entered on card INPUT.2. The value for INIT on card COBRA.1 must be set to 4 on a restart run. All other parameters on the restart input deck remain the same as for the initial run, with the exception of the time domain cards, which may be respecified on each restart as the user desires. The dump TAPE9 from the previous run must be available to the restart run as TAPE8, since the code reads the restart data from logical unit 8 and writes new restart dump data to a new TAPE9.

4.0 CONTAINMENT SAMPLE PROBLEMS

The input requirements for COBRA-TF will undoubtedly be confusing to the new user. Two example problems are presented in this section to serve as a guide to help the user understand the input requirements and how they are used to model a physical system. The physical system to be modeled is first described in sufficient detail to give a clear picture of the system for these examples. The mesh to be used for the simulation is then described, and the geometrical values for the mesh are presented. Finally, a listing of the actual input deck used to perform the simulation is provided. These examples should allow the user to trace each of the values used in the input deck back to the original system data.

The first example is the input model for the HDR containment that has been used throughout this manual as an example to explain the various input variables and conventions used in the code. This is an example of using the lumped parameter modeling option of the code.

The second sample problem is of a three-dimensional mesh used to model hydrogen distribution in the test compartment of the Hanford Engineering Development Laboratory's Containment Systems Test Facility (CSTF). This problem provides insight into setting up multidimensional meshes. Both of these sample problems will now be described.

4.1 HDR Containment Sample Problem

The HDR containment is a West German large-scale test facility (Ref. 2). Several tests have been run in this facility to examine the response of the facility to steam/water blowdown transients. The steam blowdown test V44 is used for this example problem.

Test V44 is intended to simulate the rupture of a steam pipeline within a nuclear containment. The large mass flow following a loss-of-coolant accident leads to severe mechanical and thermodynamical stresses on the containment structures. The experiments carried out at the HDR facility measured these stresses for a large-scale plant. They are a good extension of the data base obtained from the small-scale facility at Battelle Institute's Frankfurt facility and throw more light on the quality of extrapolating results to a real plant.

4.1.1 Description of the Experiment

The main components of the test facility are the reactor pressure vessel (RPV) with its associated flow circuit and break nozzle, the containment building, and the measurement facility. A drawing of the reactor pressure vessel is shown in Figure 29. It has a total volume of 75 m^3 and was filled with saturated water and steam at a pressure of 110 bar. The liquid level in the vessel was 9.2 m for test V44. The remainder of the vessel was filled with steam. In addition to the fluid volume contained within the vessel there

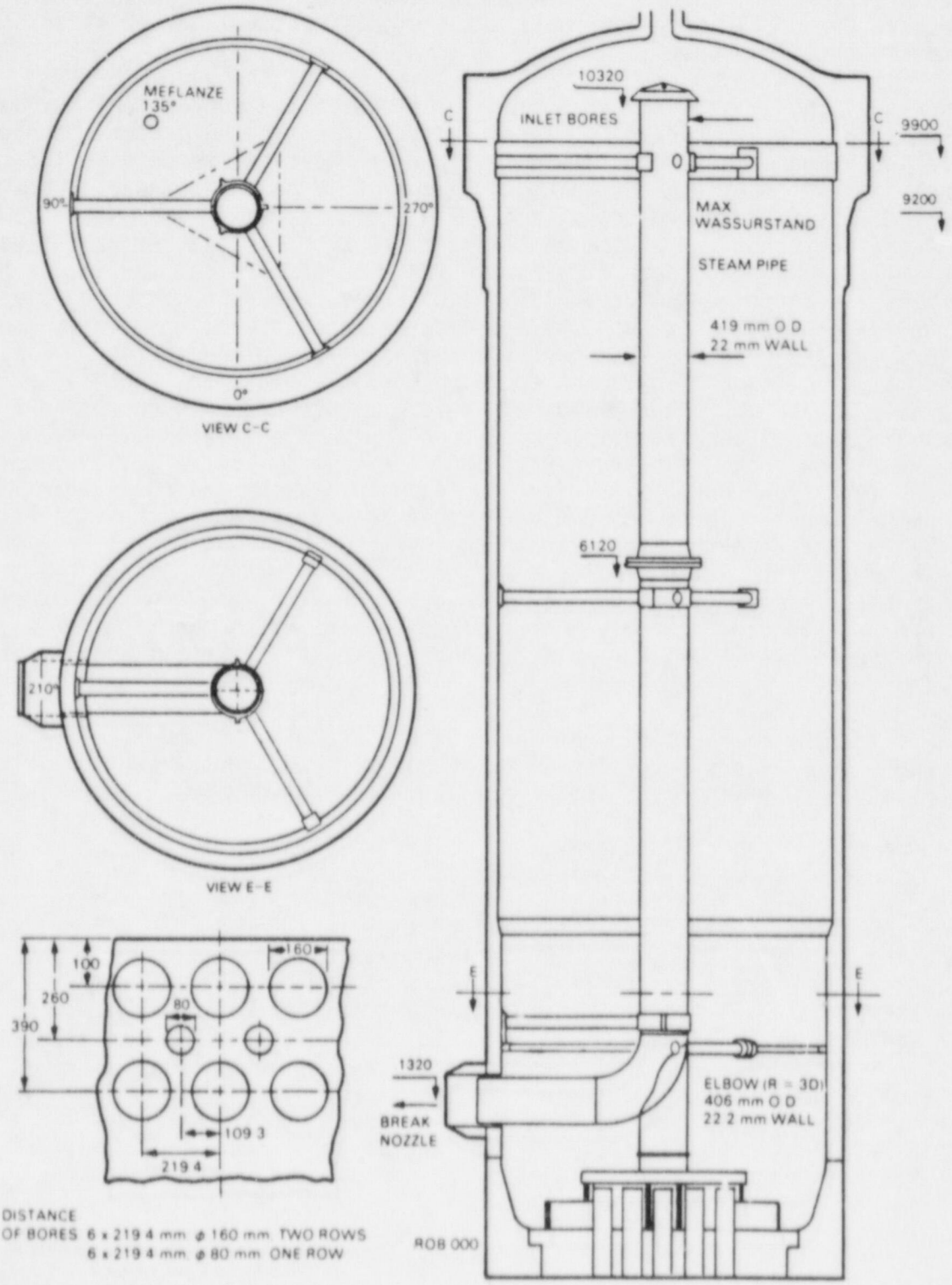


Figure 29 Cutaway views of the reactor pressure vessel used in the experiment

were several pipes hooked to the top and bottom of the vessel that were not isolated during blowdown and contributed significant volumes of steam and water to the blowdown.

Figures 30 and 31 show vertical cross sections of the containment building taken along the 90° to 270° diameter and the 0° to 180° diameter, respectively. Some individual rooms were lumped together by the experimenters to form 34 zones. These zones are designated by number in Figures 30 and 31. Most of the facility data is presented in terms of these zones. Horizontal cross sections BB through kk of the containment are shown in Figures 32 through 40. The small numbers in these figures are the room numbers and the larger bold numbers are the zone numbers. The shaded areas represent concrete walls between rooms. Some of the various openings between rooms are also shown in these figures as are some of the structural components within each room. A brief description of each containment room and the 34 containment zones is provided in Tables 8 and 9. The room numbers that are included in each zone are given in Table 8 as is the fluid volume of each zone. A schematic of the compartments and vent flow openings between each zone is shown in Figure 41. A compilation of the vent flow openings is given in Table 10. Each opening is identified with a unique number. The rooms and zones that are connected by the vent are given in Table 10 as are the flow area of the opening in square meters, the GRS estimate for the vent discharge coefficient, the pressure difference at which the vent will open if the vent is pressure dependent, and a brief description of the flow opening. Some vents remained closed during the experiment. These vents are identified by the word "closed" in the differential pressure column of Table 10.

The solid structures within each zone of the containment have been tabulated by the experimenters according to the material type and thickness. This compilation is given in Tables 11 and 12. The zone number that the solid structure is located in is given in Table 11 along with its material type, coating thickness, surface area, and volume. If the surface is in contact with the atmosphere on both sides, it is referred to as an inner wall. The outer walls have fluid contact only on one surface. The inner walls have been modeled as symmetrical with half of their thickness put into each of the zones separated by the surface. The thickness of the surfaces can be calculated from $d = V/A$ where d is the half thickness of inner slabs and the full thickness of outer slabs, V is the material volume and A is the surface area. All of the heat transfer surfaces are assumed to be insulated on the outer surface and in contact with the zone atmosphere on the inside surface. The metal internals and equipment of the HDR facility are given in Table 12. These structures have been divided into four thickness classes because of the larger varieties of structure present within each zone. The material type and coating thickness on each surface are given. The metal surface area and volume is also given for each thickness class.

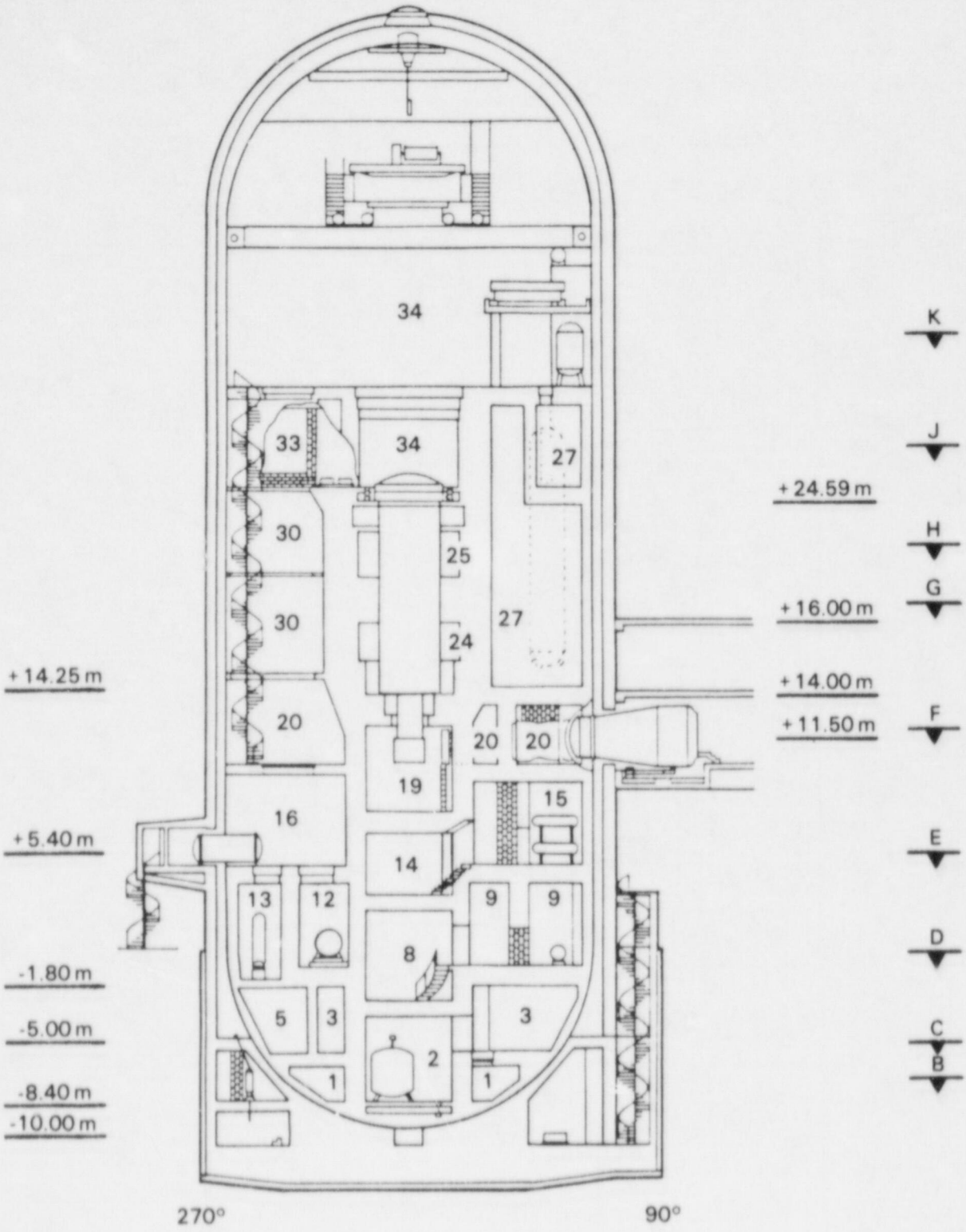


Figure 30 Vertical cross section of containment building along 90° to 270° diameter

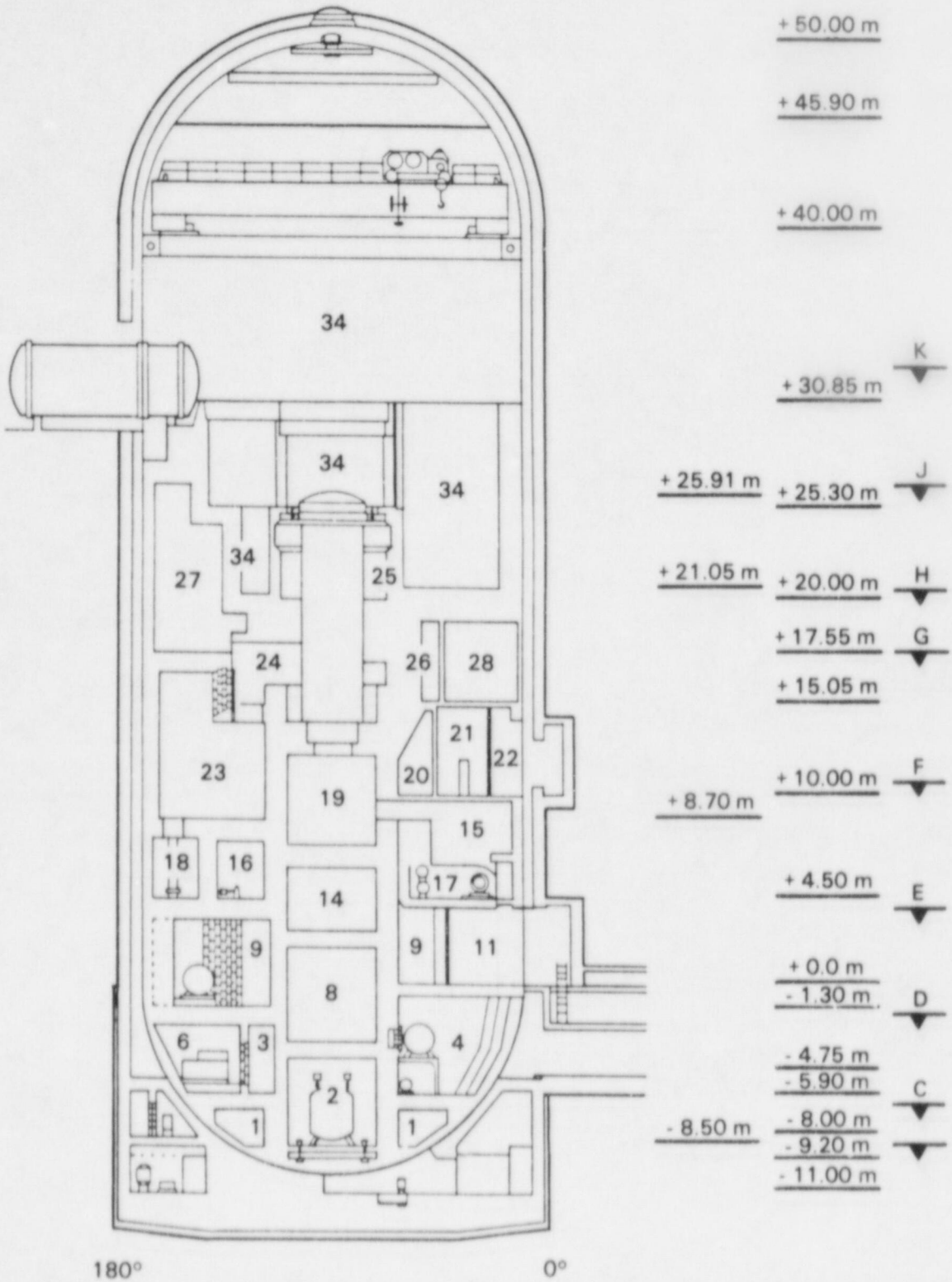


Figure 31 Vertical cross section of containment building along 0° to 180° diameter

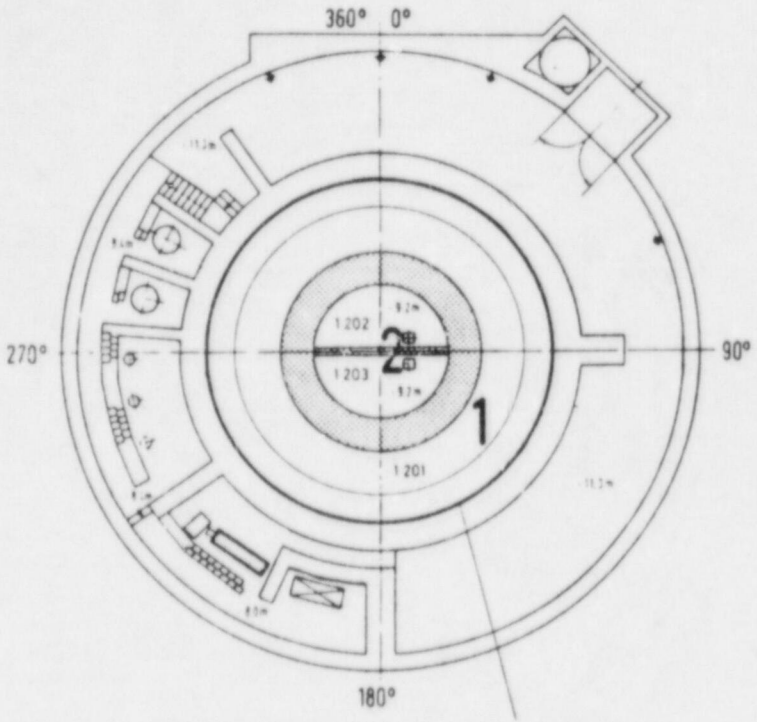


Figure 32 Plan of HDR containment at level B-B (-0.8m) (34-zones model)

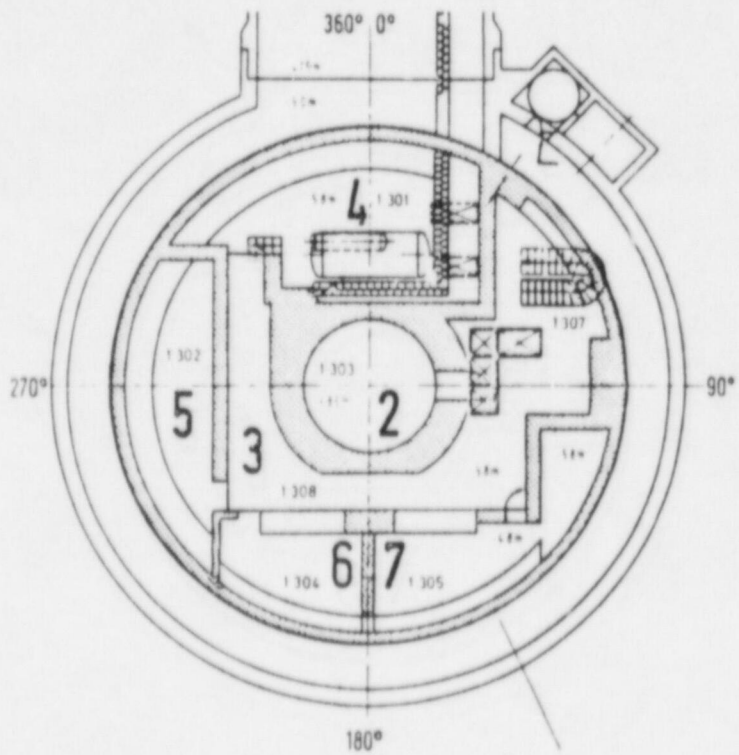


Figure 33 Plan of HDR containment at level C-C (-5.0m) (34 zones model)

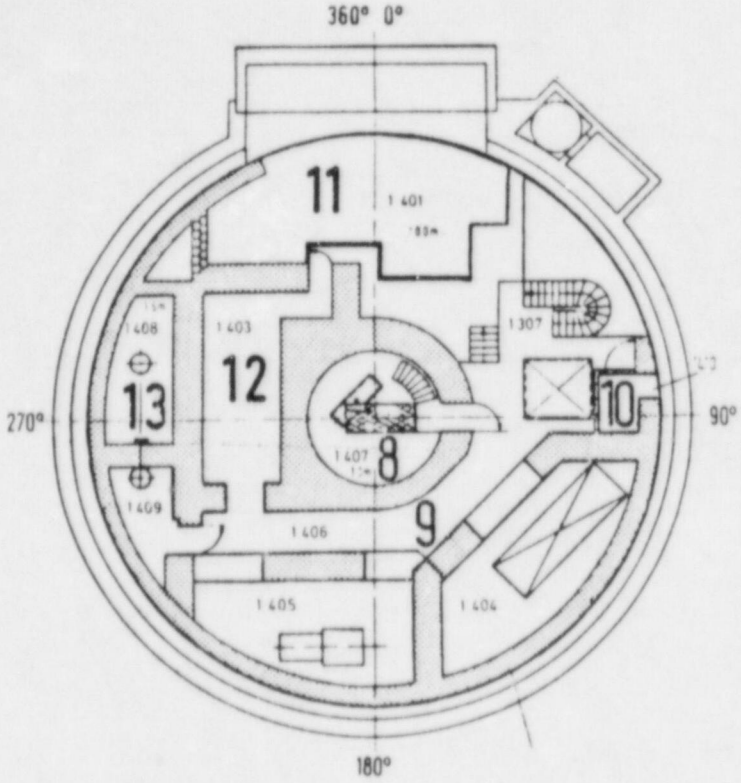


Figure 34 Plan of HDR containment at level D-D (+0m) (34-zones model)

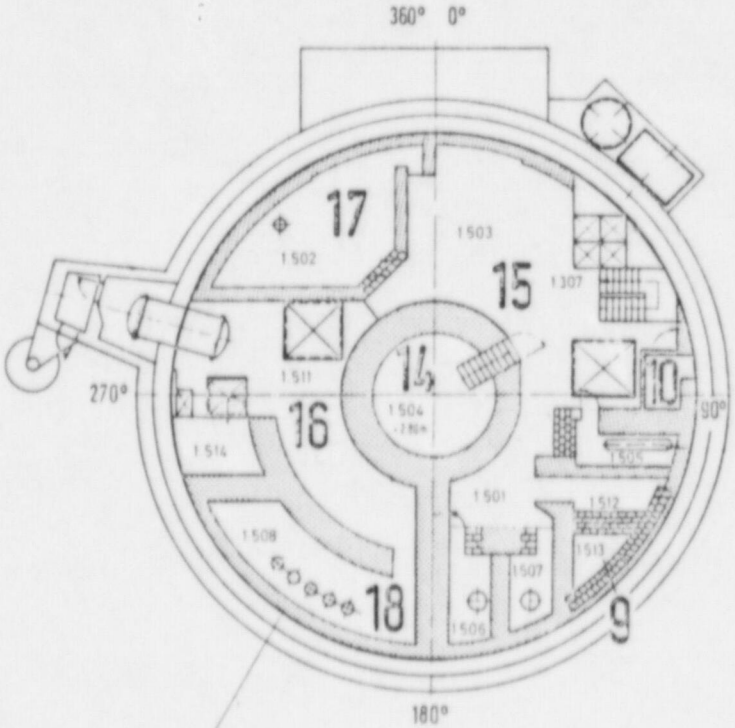


Figure 35 Plan of HDR containment at level E-E (+5.4m) (34 zones model)

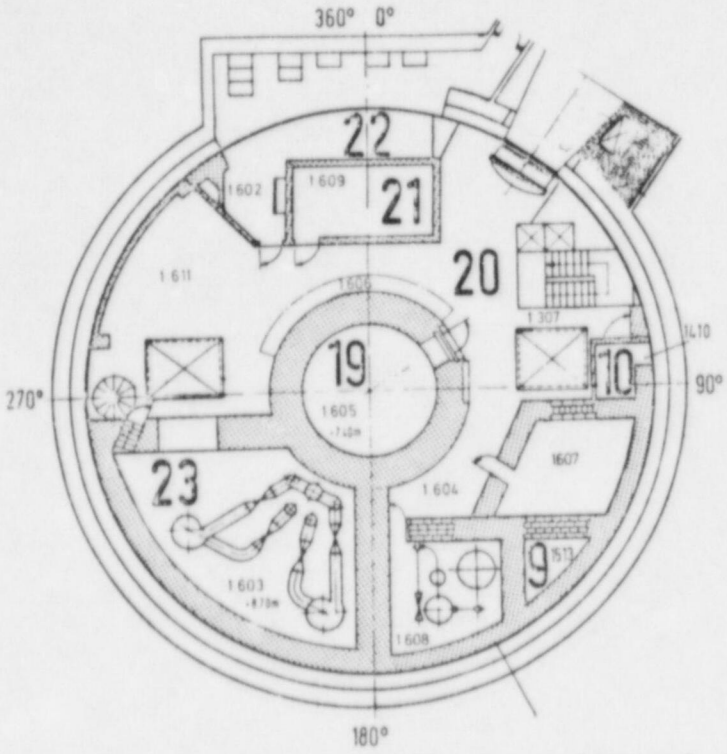


Figure 36 Plan of HDR containment at level F-F (+11.5m) (34-zones model)

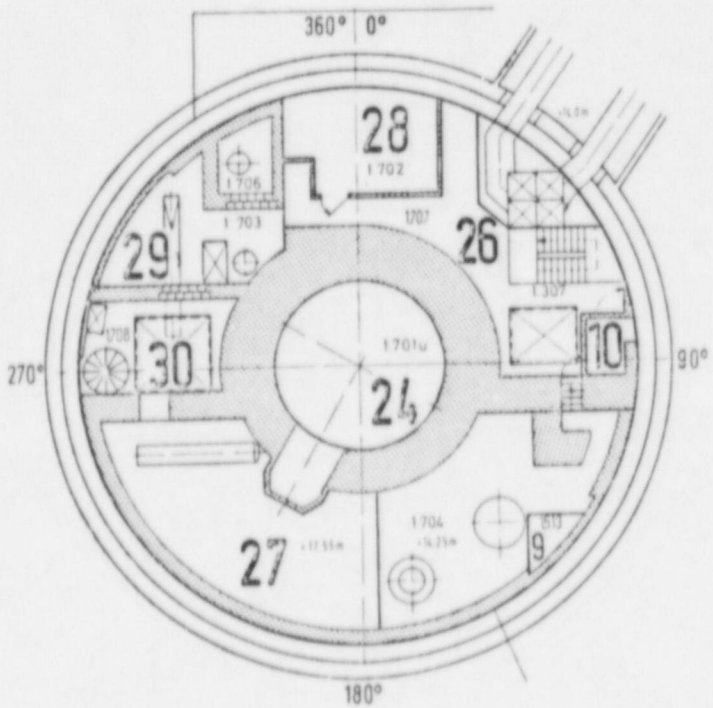


Figure 37 Plan of HDR containment at level G-G (+18.0m) (34 zones model)

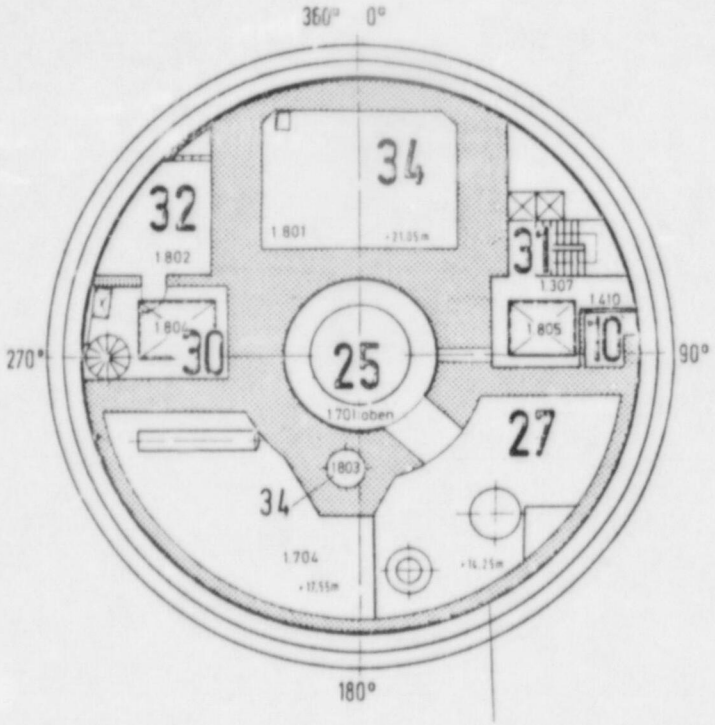


Figure 38 Plan of HDR containment at level H-H (+20.6m) (34-zones model)

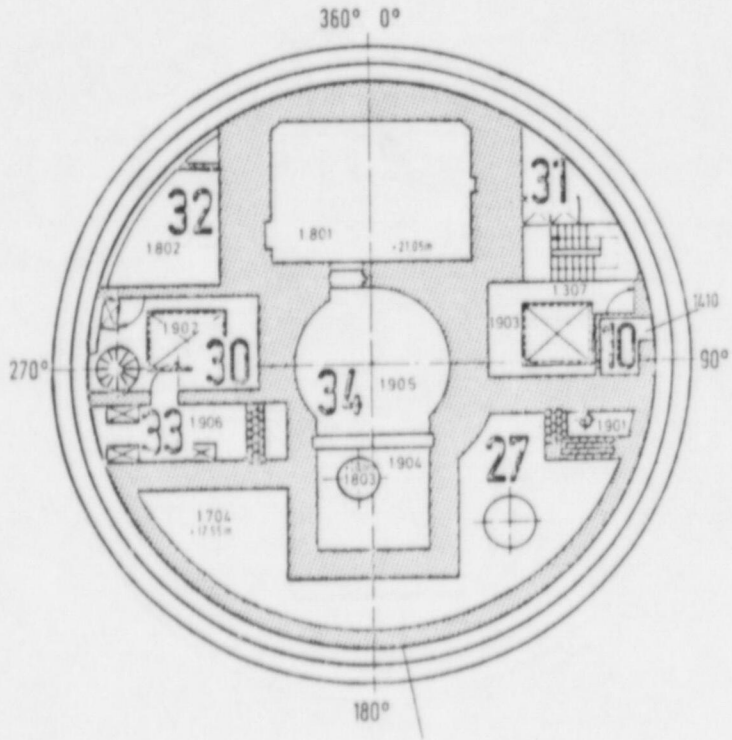


Figure 39 Plan of HDR containment at level J-J (+25.3m) (34 zones model)

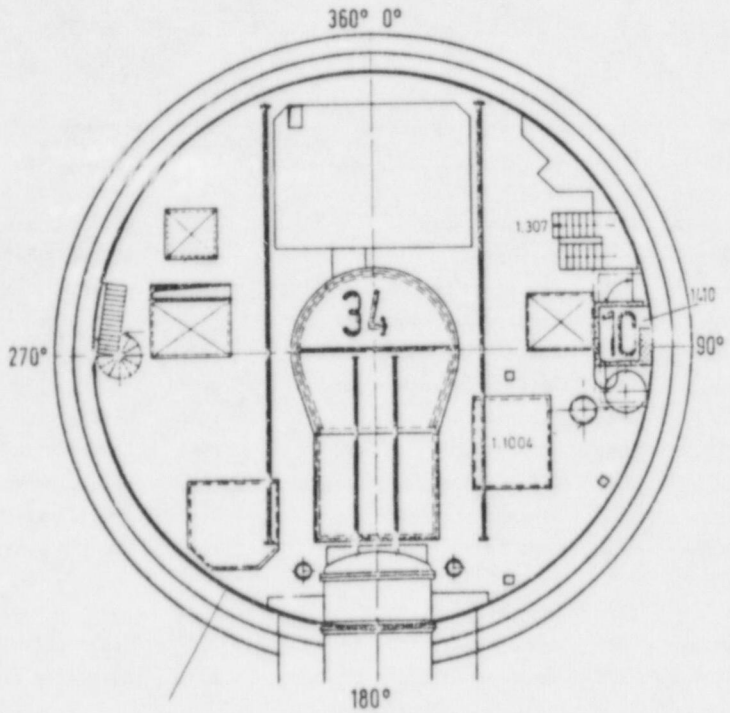


Figure 40 Plan of HDR containment at level K-K (+31.0m) (34-zones model)

Table 8 List of original HDR compartments and their function

Room No.	Purpose During Reactor Operation	Room No.	Purpose During Reactor Operation	Room No.	Purpose During Reactor Operation
1201	Reactor annulus	1202	Building sump I	1203	Building sump II
1301	Overflow facility	1302	Valve room	1303	Active water vessel
1304	Primary water pump	1305	Primary water pump	1307	Stair well
1308	Service room	1311	Water level regulator		
1401	Cable spreading room	1403	Primary loop pump	1404	Primary loop pump
1405	Primary loop pump	1406	Service, assembly room	1407	Neutron flux measurement
1408	Main mixed-bed filter	1409	Precoat tank	1410	Elevator
1501	Service room	1502	Standby cooling	1503	Control rod drives
1504	Neutron flux meas.	1505	After cooler, condensator I	1506	Main cleanup pump
1507	Main cleanup pump	1508	Cleanup preheater	1511	Remote valve drives
1512	Aftercooler, condensator II	1513	Pipe tunnel	1514	Cooling water distribution
1602	Meas. cable dist.	1603	Circ pump 103 room	1604	Service room
1605	Control rods radiator	1606	Reactor measurement	1607	Steam radiator
1608	Steam radiator II, recombiner	1609	Measurement cable boxes	1611	Auxiliary cooling
1701	Reactor (upper)	1701	Reactor (lower)	1702	HVAC
1703	Spent fuel pool cooling	1704	Steam generator	1706	Spent fuel pool filter
1707	Service room	1708	Service room		
1801	Spent fuel pool	1802	New fuel storage	1803	Transfer pool
1804	Service room	1805	Service room		
1901	Superheated steam fill	1902	Service room	1903	Service room
1904	Fuel transfer pool	1905	Flood room	1906	Cladding tube surveillance
11004	Compartment above +30.85 m				

Table 9 List of 34 containment zones

Zone No.	Room Description	Containment Room Number	Volume
1	Annulus at -8.5 m	1201	152
2	Sump	1202,1203,1303	78
3	Stairs and landing at -5.8 m	1307,1308	160
4	Overflow facility	1301	206
5	Valve room	1302	93
6	Primary water pump	1304	39
7	Neutron flux measurement	1305,1311	63
8	Neutron flux measurement	1407	84
9	Stairs, compart., land. at -1.1 m	1307,1404-1406,1409,1513	585
10	Elevator	1410	113
11	Cable spreading	1401	296
12	Primary loop pump	1403	76
13	Primary filter	1408	59
14	Neutron flux measurement	1504	57
15	Stairs, comp, and landing at +4.5 m	1307,1501,1503,1505-1507,1512	543
16	Portion of landing at + 4.5 m	1511,1514	235
17	Standby cooling	1502	107
18	Transfer pool	1508	57
19	Control rod compartment	1605	93
20	Stairs, comp., and landing at +10 m	1307,1604,606-1608,1611	507
21	Condensate discharge	1609	59
22	Measurement cable distribution	1602	61
23	Circulation pumps	1603	280
24	Lower RPV annulus	1701 u	44
25	Upper RPV annulus	1701 o	64
26	Stairs and landing at +15 m	1307,1707	131
27	Superheated steam gen. and filter	1704,1901	848
28	HVAC facility	1702	54
29	Spent fuel cooling and filter	1703,1706	169
30	Assembly tunnel and circular stairs	1708,1804,1902	289
31	Stairs/landing at 20 m and 25.3 m	1307,1805,1903	279
32	New fuel storage	1802	125
33	Cladding tube surveillance	1906	62
34	Dome and transfer pool	1801,1803,1904,1905,11004	5293

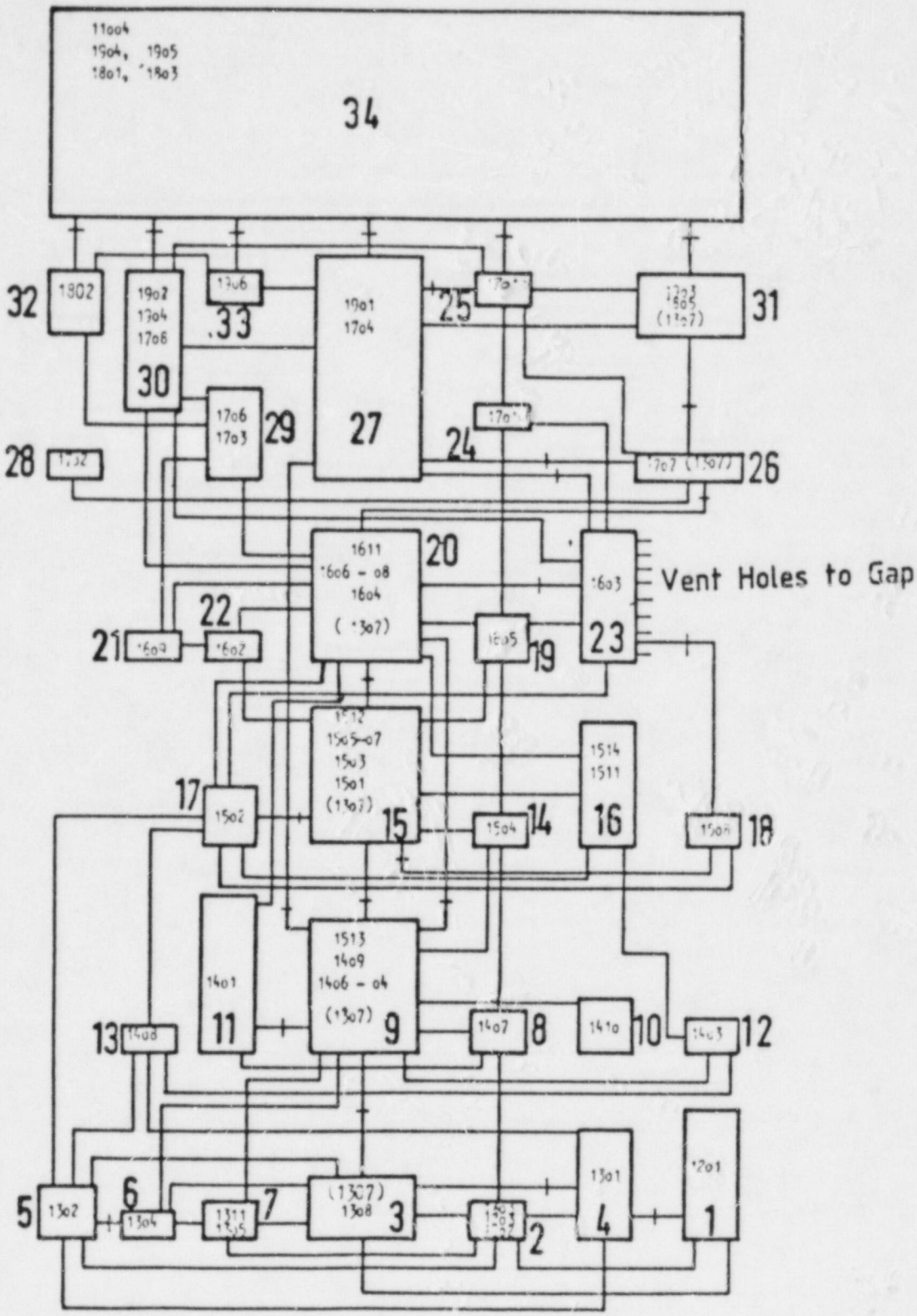


Figure 41 Schematic of compartments and vent flow openings

Table 10 Compilation on the vent flow openings of the 34 zones model

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ GRS	Delta p bar	Description
1	1201	1202	01	02	0.04	0.65		opening in wall to compartment No. R 1202
2	1201	1203	01	02	0.028	0.65		opening in wall to compartment No. R 1203
3	1202	1302	02	05	0.12	0.6		pipe channel with bending, leading from side wall in R 1202 to floor in R 1302
4	1203	1305	02	07	0.149	0.6		pipe channel with bending, leading from side wall in R 1202 to floor in R 1205
5	1303	1308	02	03	0.164	0.7		21 bores in wall of R 1308
6	1303	1308	02	03	0.007	0.7		bore choked by rock wool and with longitudinal cable
7	1301	1303	04	02	0.214	0.6		pipe channel with oblique inlet in ceiling of R 1301
8	1301	1303	04	02	0.09	0.6		pipe channel with vertical inlet in side wall of R 1301
9	1303	1407	02	08	0.042	0.6		pipe channel
10	1303	1407	02	08	0.224	0.6		pipe channel in floor, covered by grating
11.1	1303	1407	02	08	0.071	0.7		ventilation duct No. 3 (see Fig. 32-40)
11.2	1401	1407	11	08	0.03	0.7		ventilation duct No. 3 (see Fig. 32-40)
11.3	1401	1406	11	09	0.24	0.75		ventilation duct No. 3 (see Fig. 32-40)
12.1	1303	1308	02	03	0.2	0.7		ventilation duct No. 6 (see Fig. 32-40)
12.2	1203	1303	02	02	0.017	0.7		ventilation duct No. 6 (see Fig. 32-40)
13	1303	1308	02	03	1.824	0.8		open steel door
14	1201	1308	01	03	0.178	0.6		pipe channel in floor, covered by grating
15	1201	1308	01	03	0.1	0.6		pipe channel (with ledge in its interior) in floor
16	1201	1301	01	04	0.089	0.7		cylindrical pipe channel, oblique in floor
17	1201	1301	01	04	0.09	0.65		oblique opening in floor near opening No. 51
18	1201	1301	01	04	0.051	0.7		cylindrical pipe channel
19	1304	1305	08	07	0.149	0.7		pipe channel
20	1304	1305	06	07	5.775	0.85		large opening covering the total height of the compartments
21	1301	1308	04	03	1.991	0.8		opening (passage)
22	1302	1308	05	03	0.157	0.7		20 bores
23	1302	1308	05	03	0.013	0.7		two bores
24	1301	1302	04	05	0.015	0.7		two openings
25	1302	1308	05	03	1.3	0.8		open door
26.1	1302	1308	05	03	0.081	0.7		ventilation duct No. 3 (see Fig. 32-40)
26.2	1303	1308	02	03	0.07	0.7		ventilation duct No. 3 (see Fig. 32-40)
27	1304	1308	06	03	1.064	0.8		open steel door
28	1301	1302	04	05	0.246	0.5		pipe channel with bending
29	1301	1302	04	05	0.3367	0.6		pipe channel
30.1	1201	1301	01	04	0.063	0.7		ventilation duct No. 1 (see Fig. 32-40)
30.2	1301	1308	04	03	0.16	0.75		ventilation duct No. 1 (see Fig. 32-40)
31	1304	1308	06	03	2.4	0.85		opening in equipment concrete block wall
32	1305	1308	07	03	3.04	0.85		opening in equipment concrete block wall
33	1305	1308	07	03	1.129	0.85		open steel door (closed in V44)
34	1301	1408	04	13	1.199	0.65		hole leading to the lower end of pipe channel (opening No. 151)

(Table 10, continued)

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ GRS	Delta p bar	Description
35	1302	1408	05	13	0.626	0.7		opening in floor
36	1302	1408	05	13	0.487	0.65		opening in floor
37	1302	1408	05	13	0.194	0.65		cable shaft in floor
38	1302	1408	05	13	0.636	0.6		pipe channel in floor
39	1304	1405	06	09	0.03	0.65		ventilation duct No. 5 (see Fig. 32-40)
40.1	1304	1405	06	09	0.06	0.75		ventilation duct No. 4 (see Fig. 32-40)
40.2	1305	1405	07	09	0.06	0.75		ventilation duct No. 4 (see Fig. 32-40)
40.3	1404	1405	09	09	6.1	0.75		ventilation duct No. 4 (see Fig. 32-40)
41.1	1305	1404	07	09	0.02	0.75		ventilation duct No. 5 (see Fig. 32-40)
41.2	1404	1405	09	09	0.12	0.75		ventilation duct No. 5 (see Fig. 32-40)
42	1304	1405	06	09	0.17	0.55		pipe channel
43	1304	1405	06	09	0.017	0.65		bore in ceiling
44	1311	1404	07	09	0.03	0.75		ventilation duct No. 4 (see Fig. 32-40)
45	1305	1404	07	09	1.535	0.6		pipe channel
46	1302	1409	05	09	0.023	0.7		two bores in floor, plated with zinc sheeting
47	1308	1406	03	09	0.01	0.6		cable duct in floor
48	1201	1301	01	04	0.732	0.6	+0.02 - 0.5	oblique floor opening, covered by iron slab
49	1201	1301	01	04	0.034	0.6	+0.02 - 0.5	oblique floor opening, covered by iron slab
50	1201	1301	01	04	0.231	0.6	+0.02 - 0.5	oblique floor opening, covered by iron slab
51	1201	1301	01	04	0.4515	0.6	+0.02 - 0.5	oblique floor opening, covered by iron slab
52	1308	1406	03	09	4.39	0.85	+0.2 - 0.6	transport hatch in floor, covered by iron slabs
53	1406	1410	09	10	1.36	0.8		open elevator door at level -1.1 m
54	1406	1407	09	08	0.921	0.75		open steel door
55	1403	1406	12	09	0.623	0.65		pipe channel, crossed by ventilation duct
56	1401	1406	11	09	2.965	0.85	+-0.05	cable shaft, partially covered with zinc plate
57	1403	1406	12	09	0.442	0.8		passage through concrete block wall
58.1	1308	1409	03	09	0.02	0.7		ventilation duct No. 6 (see Fig. 32-40)
58.2	1408	1409	13	09	0.02	0.7		ventilation duct No. 6 (see Fig. 32-40)
59	1403	1408	12	13	0.099	0.7		cable duct in wall
60	1403	1406	12	09	0.637	0.8		open steel door with L-bended passage
61.1	1403	1406	12	09	0.48	0.75		ventilation duct No. 5 (see Fig. 32-40)
61.2	1403	1404	12	09	6.36	0.75		ventilation duct No. 5 (see Fig. 32-40)
62.1	1308	1406	03	09	2.49	0.8		stair case (compartment No. 1307) at level -1.1 m
62.2	1308	1406	03	09	1.8	0.8		stair case (compartment No. 1307) at level -1.1 m
62.3	1308	1406	03	09	1.627	0.8		stair case (compartment No. 1307) at level -1.1 m
63.1	1501	1511	15	16	0.06	0.75		ventilation duct No. 7 (see Fig. 32-40)
63.2	1406	1501	09	15	0.06	0.75		ventilation duct No. 7 (see Fig. 32-40)
63.3	1501	1503	15	15	0.16	0.75		ventilation duct No. 7 (see Fig. 32-40)
64	1501	1511	15	16	0.0028	0.7		bore

(Table 10, continued)

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ GRS	Delta p bar	Description
65	1406	1504	09	14	0.048	0.7		opening
66	1406	1504	09	14	0.04	0.7		opening with cable duct
67	1503	1504	15	14	1.913	0.8		open steel door leading to stair case
68	1502	1503	17	15	0.0028	0.7		bore
69	1502	1503	17	15	0.00975	0.7		two bores
70	1502	1503	17	15	0.975	0.7		open door and adjacent passage
71	1502	1503	17	15	0.0038	0.7		bore
72	1502	1503	17	15	0.0007	0.7		steel pipe in wall
73	1502	1511	17	16	0.033	0.6		seven bores, plated with zinc sheeting
74	1502	1511	17	16	0.1	0.6		channel, crossed by ventilation duct
75	1502	1511	17	16	0.0012	0.7		bore, plated with zinc sheeting
76	1502	1511	17	16	0.013	0.5		channel with cables
77	1503	1511	15	16	3.648	0.85		passage, covering the total compartments height
78	1301	1306	04	03	0.1	0.75		ventilation duct No. 2 (see Fig. 32-40)
79	1302	1304	05	06	3.068	0.85	+-0.05	opening covered by zinc plate
80	1606	1609	20	21	0.0057	0.7		bore
81	1606	1609	20	21	0.00933	0.65		bore
82.1	1403	1404	12	09	0.4	0.75		ventilation duct No. 4 (see Fig. 32-40)
82.2	1403	1406	12	09	0.1	0.75		ventilation duct No. 4 (see Fig. 32-40)
83.1	1308	1406	03	09	0.18	0.7		ventilation duct No. 6 (see Fig. 32-40)
83.2	1401	1406	11	09	0.08	0.7		ventilation duct No. 6 (see Fig. 32-40)
84.1	1401	1606	11	20	0.08	0.6		ventilation duct No. 6 (see Fig. 32-40)
84.2	1401	1606	11	20	0.14	0.6		ventilation duct No. 6 (see Fig. 32-40)
85	1301	1302	04	05	2.826	0.85	+-0.05	opening covered by zinc plate
86	1602	1606	22	20	1.43	0.8		open steel door
87	1606	1609	20	21	1.43	0.8		open steel door
88.1	1602	1609	22	21	0.044	0.75		ventilation duct No. 12 (see Fig. 32-40)
88.2	1604	1609	20	21	0.15	0.75		ventilation duct No. 12 (see Fig. 32-40)
89	1401	1406	11	09	2.09	0.8		open steel door
90	1702	1707	28	26	1.44	0.8		open steel door
91	1703	1707	29	26	1.69	0.8		open lead-shielded door
92	1704	1707	27	26	1.3	0.7	+- 0.1 closed	zigzag passage with stairs (lateral edges rounded) and instrumented door (initially closed)
93.1	1404	1704	09	27	1.5	0.6		vertical pipe channel leading from R 1704 (level +14,25 m) to R1404 (+3.5 m)separated from R 1607 and R 1512 by concrete block walls
93.2	1513	1607	09	20	0.5	0.65	+-0.4	concrete block wall
93.3	1512	1513	15	09	0.5	0.65	+-0.4	concrete block wall
94	1606	1704	20	27	0.05	0.7		ventilation duct in concrete block wall leading from R 1606 (ceiling) to main ventilation duct
95	1704	11004	27	34	8.0	0.85	+1 closed	opening covered by heavy concrete slab (20 to 30,000 kg)
96	1704	1804	27	30	0.43	0.9		instrumented (DK) channel with rounded inlet
97	1701 o	1704	25	27	0.15	0.65		pipe channel close to opening No. 96
98	1704	1504	27	30	0.02	0.6		bore with measured cables

(Table 10, continued)

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ GRS	Delta p bar	Description
99	1607	1704	20	27	0.21	0.6		pipe channel covered by grating
100	1704	1904	27	34	0.0148			bore
101	1704	1904	27	34	0.0676	0.6		bore
102	1701 o	1704	25	27	1.62	0.75		opening in biological shield
103	1704	1805	27	31	0.088	0.6		two bores close to opening No. 102
104	1701 o	1704	25	27	0.07	0.65		two bores close to opening No. 102
105	1701 o	1704	25	27	0.11	0.6		two bores close to opening No. 102
106.1	1701 o	1704	25	27	0.35	0.65		opening close to opening No. 102
106.2	1701 o	1704	25	27	0.0314	0.65		pipe below opening No. 106.1
107	1704	11004	27	34	0.18	0.6		opening
108	1701 o	1704	25	27	0.25	0.7		opening below opening No. 106
109	1704	1903	27	31	0.31	0.7		ventilation duct leading from compartment R 1704 via two elbows to R 1903 and to main ventilation duct
110	1603	1704	23	27	0.37	0.55		pipe channel with weir sill in R 1704
111	1704	1903	27	31	0.04	0.7		two steel pipes
112	1704	1906	27	33	0.19	0.7		channel adjacent to opening No. 96
113.1	1704	1906	27	33	0.206	0.65		branched cable duct in ceiling of R 1704
113.2	1701 o	1704	25	27	0.206	0.65		branched cable duct in ceiling of R 1704
114.1	1704	1901	27	27	0.48	0.7		opening
114.2	1704	1901	27	27	0.038	0.7		ventilation duct
115	1906	11004	33	34	0.03	0.65	+0.02 - 1 closed	service channel, covered by metal slab
116	1903	11004	31	34	0.03	0.65	+0.02 -1 closed	service channel, covered by metal slab
117.1	1903	11004	31	34	2.06	0.8		ventilation channel (see Fig. 3.7-4)
117.2	1903	11004	31	34	2.72	0.8		stair case (see Fig. 3.7- 4)
117.3	1903	11004	31	34	4.54	0.85	+0.2 -0.6 closed	transport hatch (see Fig. 3.7- 5)
117.4	1903	11004	31	34	0.3	0.8		opening
118.1	1707	1805	26	31	4.99	0.85		main ventilation channel, like opening No. 121.1
118.2	1707	1805	26	31	2.98	0.85		stair case, like opening No. 121.2
118.3	1707	1805	26	31	4.54	0.85	+0.2 - 0.6 closed	close transport hatch, like opening No. 121.3
119.1	1606	1707	20	26	3.58	0.85		main ventilation channel, like No. 121.1
119.2	1606	1707	20	26	3.39	0.85		stair case, like No. 121.2
119.3	1606	1707	20	26	4.54	0.85	+0.2 - 0.6 closed	closed transport hatch, like No. 121.3
120.1	1501	1606	15	20	2.55	0.8		main ventilation channel, like No. 121.1
120.2	1501	1606	15	20	3.2	0.8		stair case, like No. 121.2

(Table 10, continued)

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ QRS	Delta p bar	Description
120.3	1501	1606	15	20	4.54	0.85	+0.2 - 0.6 closed	closed transport hatch, like No. 121.3
121.1	1406	1501	09	15	4.0	0.85		main ventilation channel, see Fig. 32-40
121.2	1408	1501	09	15	3.38	0.85		stair case, see Fig. 32-40
121.3	1406	1501	09	15	4.54	0.85	- 0.2 +0.6 closed	closed transport hatch, see Fig. 32-40
122.1	1902	11004	30	34	4.81	0.85		open transport hatch
122.2	1902	11004	30	34	0.6	0.8		opening
122.3	1902	11004	30	34	2.06	0.8		spiral staircase
123	1902	1906	30	33	0.083	0.65		opening to spiral staircase
123.1	1902	1906	30	33	0.114	0.65		opening to spiral staircase
124	1902	1906	30	33	1.47	0.8		door partially (40%) opened
125	1802	1906	32	33	0.064	0.7		ventilation duct No. 9 (see Fig. 32-40)
126	1701 o	1804	25	30	0.24	0.65		zigzag ventilation duct
127	1802	11004	32	34	1.824	0.85	+0.3 - 0.6 closed	closed transport hatch
128.1	1703	1708	29	30	0.06	0.7		ventilation duct No. 10 (see Fig. 32-40)
128.2	1703	1706	29	29	0.03	0.7		ventilation duct No. 10 (see Fig. 32-40)
128.3	1609	1703	21	29	0.06	0.7		ventilation duct No. 10 (see Fig. 32-40)
129	1902	11004	30	34	0.235	0.7	+0.02 -0.6 closed	openings covered by steel plates, adjacent to opening No.
130	1606	1708	20	30	0.22	0.7		pipe and cable duct
131.1	1606	1708	20	30	3.77	0.85		open transport hatch
131.2	1606	1708	20	30	1.77	0.85		openings parallel to 131.1
132	1606	1708	20	30	1.22	0.75		spiral stair case
133	1603	1708	23	30	0.43	0.85		upper part of opening No. 162
134	1701 o	1701 u	25	24	1.7	0.7		gap between RPV and biological shield
135	1701 o	1805	25	31	0.0806	0.65		three bores of different diameters
136	1701 o	1707	25	26	0.0327	0.65		bores for measuring cable protection tube
137.1	1802	1902	32	30	1.26	0.85		open steel door to compartment No. R 1802
137.2	1802	1902	32	30	1.76	0.85		open steel door to compartment No. R 1802
138	1605	1701 u	19	24	1.374	0.6		17 bores and three grooves in the floor
139	1701 o	1704	25	27	0.3	0.55	+-0.5	choked pipe channel
140	1603	1704	23	27	1.64	0.8	-0.5 +0.2 closed	opening situated in opening No. 143 and covered by steel slab (open for test V44)
141	1802	1902	32	30	0.09	0.7		opening and ventilation duct
142	1405	1506	09	15	0.14	0.65		pipe channel

(Table 10, continued)

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ GRS	Delta p bar	Description
143	1603	1701 u	23	24	3.02	0.7		opening in the upper part of break compartment R 1603, crossed by break pipe
144.1	1506	1508	15	18	1.42	0.65	+-0.2	ventilation duct No. 8 (see Fig. 32-40)
144.2	1506	1508	15	18	0.17	0.65		ventilation duct No. 8 (see Fig. 32-40)
144.3	1506	1508	15	18	0.056	0.7		ventilation duct No. 8 (see Fig. 32-40)
145	1603	1701 u	23	24	0.17	0.65		channel parallel to opening No. 143
146.1	1502	1508	17	18	0.18	0.7		ventilation duct No. 8 (see Fig. 32-40)
146.2	1508	1514	18	16	0.18	0.65		ventilation duct No. 8 (see Fig. 32-40)
147	1508	1511	18	16	1.056	0.8		open lead-shielded door
148	1403	1511	12	16	3.5	0.8		floor opening covered by grating
149	1502	1611	17	20	1.4	0.75		pipe channel
150	1502	1603	17	23	0.28	0.55		pipe channel with weir sill in R 1603
151.1	1302	1502	05	17	0.93	0.7		pipe channel
151.2	1408	1502	13	17	0.276	0.7		pipe channel
152	1511	1611	16	20	0.14	0.7		cable duct and openings in ceiling
153.1	1407	1504	08	14	0.209	0.65		rectangular opening and bores
153.2	1503	1504	15	14	0.08	0.7		zigzag opening in R 1503 leading to ventilation duct
153.3	1407	1504	08	14	0.17	0.65		six cylindrical U- channels
154.1	1504	1605	14	19	0.078	0.65		rectangular openings and bores in ceiling
154.2	1503	1605	15	19	0.229	0.65		four cylindrical U-channels, like No. 153.3
155.1	1505	1607	15	20	0.77	0.7		two openings in ceiling of R 1505
155.2	1512	1607	15	20	0.052	0.65		opening in ceiling of R 1512
156	1503	1602	15	22	0.1	0.7		cable duct and gap by the side of ventilation duct
157.1	1802	1904	32	34	0.06	0.6		ventilation duct No. 11 (see Fig. 32-40)
157.2	1904	1906	34	33	0.075	0.6		ventilation duct No. 11 (see Fig. 32-40)
157.3	1801	1903	34	31	0.42	0.7		ventilation duct No. 11 (see Fig. 32-40)
158.1	1404	1512	09	15	0.072	0.65		circular gap
158.2	1512	1513	15	09	0.11	0.65		gap
159	1507	1608	15	20	0.041	0.65		pipe channel, almost completely covered by ventilation duct
160	1404	1507	09	15	0.085	0.65		trapezoidal pipe channel
161	1406	1501	09	15	0.133	0.65		pipe channels and circular gap
162	1603	1606	23	20	0.90	0.85		opening (upper part see No. 133) (closed in V44)
163	1603	1606	23	20	1.10	0.7		zigzag passage with stairs and open lead-shielded door
164.1	1603	1608	23	20	0.58	0.65	+-0.2 closed	opening covered by sheeting
164.2	1603	1608	23	20	0.072	0.7	closed	ventilation duct
164.3	1603	1604	23	20	0.018	0.65	closed	ventilation duct
165	1603	1605	23	19	0.19	0.7		wall opening and steel pipe
166.1	1603	1608	23	20	0.282	0.7		rectangular wall opening (closed in V44)
166.2	1603	1608	23	20	0.03	0.7	closed	rectangular wall opening
167	1605	1606	19	20	1.99	0.85		open lead-shielded door
168	1605	1606	19	20	0.23	0.6		four cylindrical S- channels
169	1605	1606	19	20	0.05	0.55		oblique bore, see Fig. 32-40

(Table 10, continued)

Open No.	From Comp.	To Comp.	From Zone	To Zone	F min in m**2	DC @ GRS	Delta p bar	Description
170	1503	1605	15	19	0.163	0.65		ventilation duct, covered by grating and leading through compartment R 1503 to ventilation duct No. 8
171.1	1608	1704	20	27	0.036	0.6		opening in ceiling of R 1608
171.2	1513	1608	09	20	0.066	0.7		opening in ceiling of R 1608
172.1	1606	1609	20	21	0.06	0.7		ventilation duct No. 10 (see Fig. 32-40)
172.2	1602	1609	22	21	0.06	0.7		ventilation duct No. 10 (see Fig. 32-40)
172.3	1606	1606	20	20	0.14	0.7		ventilation duct No. 10 (see Fig. 32-40)
173	1606	1707	20	26	0.18	0.7		vertical ventilation duct in ceiling of R 1606, leading without protection via R 1703 and R 1707 to main ventilation duct
174	1611	1703	20	29	0.304	0.65		pipe channel
175.1	1706	1802	29	32	0.032	0.7		ventilation duct No. 9 (see Fig. 32-40)
175.2	1703	1802	29	32	0.04	0.7		ventilation duct No. 9 (see Fig. 32-40)
175.3	1706	1707	29	26	0.15	0.75		ventilation duct No. 9 (see Fig. 32-40)
176	1603	1704	23	27	0.24	0.9		instrumented (DK) channel with rounded inlet
177	1508	1603	18	23	1.145	0.8	closed	floor opening
178	1508	1603	18	23	2.78	0.85	+-1 closed	floor opening
179	1508	1603	18	23	0.98	0.8	+-1 closed	floor opening
180.1	1603	1704	23	27	0.0	0.7	closed	zigzag channel in ceiling of R 1603, closed by PD-transfer
180.2	1603	1704	23	27	0.15	0.7		zigzag channel in ceiling of R 1603, open
180.3	1608	1704	20	27	0.0	0.7		zigzag channel in ceiling of R 1603, closed
181	Spalt	1603	Spalt	23	0.51	0.65		rectangular opening (with weir sill in R 1603) and 13 bores leading to gap between concrete wall and steel shell
182	1701 o	11004	25	34	3.0	0.8	+- 4	membrane seal (2.5 mm thick) at the upper end of RPV
183.1	1603	1704	23	27	0.183	0.7		rectangular opening
183.2	1603	1704	23	27	0.0	0.7		closed bores
183.3	1603	1704	23	27	0.01	0.65		five bores
184.1	1506	1508	15	18	0.033	0.6		open sheet metal sleeve, filled with rock wool
184.2	1506	1508	15	18	0.006	0.7		channel with crushed edges
185	1508	1511	18	16	0.0056	0.6		two pipes

Table 11 Compilation of structural elements of the HDR-containment (34 zones)

Zone Number	Material Type	Coating Thickness in mm	Inner-/INTERWALL Area in m**2	Inner-/INTERWALL Volume in m**3	Outer Wall Area in m**2	Outer Wall Volume in m**3
01	B	0.15	28.09	11.24		
01	B	0.15	94.61	45.16	98.90	69.91
02	B	0.15	130.06	50.08	25.00	20.55
03	B	0.15	342.52	112.82	52.56	38.39
03	S	0.15			4.00	0.07
03	T	0.15	23.30	4.22		
04	B	0.15	214.10	71.20	66.30	33.15
04	S	0.15			4.30	0.17
04	T	0.15	34.30	2.11		
05	B	0.15	80.00	16.05	60.10	36.86
06	B	0.15	42.20	14.39	32.10	19.26
06	B	0.00	10.49	3.33		
06	T	0.15	7.61	1.52		
07	B	0.15	65.13	20.60	51.07	31.08
07	B	0.00	11.74	5.98		
07	T	0.15	7.61	1.52		
08	B	0.15	127.30	55.10		
09	B	0.15	544.55	177.72	109.11	58.10
09	B	1.50	54.51	22.63		
09	B	0.00	11.56	5.78		
09	S	0.15			39.25	1.18
09	T	0.15	57.77	19.61	57.36	29.33
10	B	0.00	245.95	40.58	48.92	32.94
10	S	0.00			35.29	1.05
11	B	0.15	141.55	69.33	17.96	11.67
11	B	1.50	2.10			
11	S	0.15			44.21	1.33
11	T	0.15	7.11	1.78		
11	Z	0.15	90.26	6.56		
12	B	0.15	149.65	75.00		
12	B	1.50	2.24	1.68		

(Table 11, continued)

Zone Number	Material Type	Coating Thickness in mm	Inner-/INTERWALL Area in m**2	Inner-/INTERWALL Volume in m**3	Outer Wall Area in m**2	Outer Wall Volume in m**3
12	B	0.00	2.76			
12	T	0.15	1.62	0.41		
13	B	0.15	86.39	28.00	42.49	22.73
13	S	0.15			0.25	0.01
13	T	0.15	11.20	2.30		
14	B	0.15	118.75	41.04		
15	B	0.15	485.80	145.28	52.58	24.27
15	B	1.50	78.58	14.23		
15	B	0.00	13.03	2.65	2.94	1.18
15	S	0.15			38.52	1.16
15	T	0.15	40.67	12.85	2.60	1.82
16	B	0.15	149.92	69.36	4.62	1.85
16	B	1.50	39.40	19.70		
16	B	0.00	42.77	11.50	1.15	0.46
16	S	0.15			33.78	1.14
16	Z	0.15	15.64	1.68		
17	B	0.15	94.98	15.52	50.71	26.29
17	B	1.50	19.47	4.87		
17	B	0.00	9.83	2.46	4.51	1.80
17	T	0.15	13.75	2.61		
18	B	0.15	111.61	40.75	33.10	13.24
18	T	0.15	2.95	0.44		
19	B	0.15	132.05	59.74		
20	B	0.15	417.19	158.65	62.19	25.53
20	B	1.50	92.49	15.64		
20	B	0.00	54.91	17.01	3.41	2.05
20	S	0.15			67.05	2.49
20	T	0.15	32.12	9.34		
20	T+B	0.15	7.41	2.96		
21	B	0.15	54.24	7.07		
21	B	0.00	5.54	0.55		
21	T+Z	0.15	25.46	5.98		
21	Z	0.15	10.82	0.73		

(Table 11, continued)

Zone Number	Material Type	Coating Thickness in mm	Inner-/INTERWALL Area in m**2	Inner-/INTERWALL Volume in m**3	Outer Wall Area in m**2	Outer Wall Volume in m**3
22	B	0.15	67.03	11.00		
22	B	0.00	1.89	0.19		
22	S	0.15			22.81	1.13
22	T+Z	0.15	29.81	6.71		
22	Z	0.15	8.34	0.71		
23	B	0.15	236.40	93.82	93.99	67.75
24	B	0.15	100.53	65.61		
24	S+B	0.15	46.12	20.34		
25	B	0.15	95.27	75.52		
25	S+B	0.15	16.07	24.11		
26	B	0.15	125.49	58.08	8.15	5.34
26	B	1.50	33.93	7.26		
26	B	0.00	25.78	15.41	3.42	2.22
26	S	0.15			32.11	1.11
26	Z	0.15	24.98	2.12		
27	B	0.00	7.30			
27	B	0.15	493.41	253.41	297.58	178.55
27	B	0.00	45.12	23.48		
27	B	0.15	15.10	9.06		
27	S	0.15			6.20	0.37
27	S+T	0.15	6.00	2.40		
27	S+T	0.00	8.10	2.32		
27	T	0.15	24.16	8.43		
28	B	0.15	109.40	22.01		
28	P+B	0.00	3.99	0.70		
28	S	0.15			22.38	0.67
28	Z	0.15	25.22	2.14		
29	B	0.15	127.66	49.62	54.37	16.09
29	T	0.15	32.42	5.68		
29	Z+B	0.15	1.60			
30	B	0.15	175.50	63.43		
30	B	0.00	91.67	39.30		
30	S	0.15			57.68	1.73
30	T	0.15	10.14	2.54		

(Table 11, continued)

Zone Number	Material Type	Coating Thickness in mm	Inner-/INTERWALL Area in m**2	Inner-/INTERWALL Volume in m**3	Outer Wall Area in m**2	Outer Wall Volume in m**3
31	B	0.15	253.78	91.69	12.03	7.66
31	B	1.50	42.00	7.18		
31	B	0.00	30.07	18.05		
31	S	0.15			74.31	2.23
31	S+B	0.15	11.34	1.13		
32	B	0.15	115.73	21.84		
32	B	0.00	10.35	2.38		
32	S	0.15	48.50	1.46		
32	T	0.15	17.55	1.76		
33	B	0.15	72.81	35.13		
33	S	0.15			9.05	0.27
33	T	0.15	20.28	7.75		
34	B	0.15	345.18	122.83	4.40	1.76
34	B	1.50	243.36	86.23		
34	B	0.00	26.22	2.62		
34	S	0.15		12.46	31.88	
34	S+B	0.15	3.50	3.15		
34	S+B	0.00	513.98	274.96	71.04	74.59
34	T	0.15	5.04	0.50		
Totals			8,397.24	3,071.85	3,234.70	905.84

Abbreviations:

SH	Steel Shell Cont.
B	Concrete
T	Concrete Blocks
S	Steel
Z	Brick work plastered
Sn+B	Concrete with Steelplate Plate thickness: n in mm
P+B	Lead with concrete behind lead thickness: 240 mm

Table 12 Compilation of metal internals and equipment of HDR containment

Zone Number	Material Type	Coating Thickness in mm	Material Thickness d in mm: Class 1. 0<d≤3 Area in mm**2	Volume in m**3	Class 2. 3<d≤20 Area in mm**2	Volume in m**3	Class 3. 20<d≤40 Area in mm**2	Volume in m**3	Class 4. 40<d≤999 Area in mm**2	Volume in m**3
01	SA	0.00			0.60	2.40				
01	SS	0.15	0.69	2.00	84.01	505.77				
01	SZ	0.00	26.16	14.64						
01	SZ	0.15			0.24	1.70				
02	AL	0.00	0.09	0.18	0.14	0.58				
02	SA	0.00	1.54	2.75	2.17	10.00	0.10	1.25		
02	SS	0.00	0.99	2.51	0.49	3.66	0.09	2.31		
02	SS	0.15	5.57	9.65	114.86	596.98				
02	SZ	0.00	13.26	7.43						
03	AL	0.00	0.26	0.53	0.72	2.89				
03	CU	0.00	1.39	2.78						
03	SA	0.00	2.38	5.35	3.06	22.28				
03	SS	0.00	0.67	1.32	2.32	9.28				
03	SS	0.15	60.56	90.40	84.37	638.40			0.57	6.41
03	SZ	0.00	212.30	154.81						
04	AL	0.00	0.09	0.18	0.77	4.68				
04	CU	0.00	0.66	0.99						
04	SA	0.00	7.37	18.26	51.00	254.04				
04	SS	0.00			3.90	11.70				
04	SS	0.15	110.02	135.84	53.05	284.25	0.15	0.90		
04	SZ	0.00	100.59	62.97						
05	AL	0.00	3.33	6.01	0.14	0.58				
05	SA	0.00	1.10	2.20	28.21	175.47				
05	SS	0.15	12.39	29.91	27.76	119.98	5.74	162.73		
05	SZ	0.00	71.93	39.27						
06	AL	0.00	6.57	6.01	0.06	0.23				
06	CU	0.00	0.10	0.15						
06	SA	0.00	0.58	1.16	15.10	72.75	0.17	2.79		
06	SS	0.00			29.09	168.36	1.87	32.73	0.28	3.15
06	SS	0.15	9.77	22.77	26.26	153.37	1.19	34.89		
06	SZ	0.00	22.48	15.76						
07	AL	0.00	0.59	0.48	0.06	0.23				
07	CU	0.00	0.60	0.90						
07	SA	0.00	1.64	4.02	16.02	76.95				
07	SS	0.00	0.77	2.00	1.30	4.91	0.10	0.58		

(Table 12, continued)

Zone Number	Material Type	Coating Thickness in mm	Material Thickness d in mm: Class 1. 0<d<3 Area in mm**2	Volume in m**3	Class 2. 3<d<20 Area in mm**2	Volume in m**3	Class 3. 20<d<40 Area in mm**2	Volume in m**3	Class 4. 40<d<999 Area in mm**2	Volume in m**3
07	SS	0.15	24.22	66.27	20.18	132.40	0.38	11.40	1.40	140.00
07	SZ	0.00	52.92	30.42						
08	AL	0.00	0.21	0.24	0.14	0.58				
08	GG	0.15			1.06	5.30				
08	SA	0.00	4.73	11.98	1.68	16.69				
08	SS	0.00			0.76	3.04				
08	SS	0.15	10.75	14.65	49.24	283.17				
08	SZ	0.00	60.69	38.36						
09	AL	0.00	4.31	4.27	0.53	2.16				
09	CU	0.00	2.17	3.67						
09	MS	0.00			0.11	0.34				
09	PB	0.00			1.83	21.96			0.07	2.33
09	SA	0.00	9.14	21.18	132.01	962.16	4.65	130.98	0.36	13.15
09	SS	0.00			43.03	337.66	1.50	14.31	0.69	9.59
09	SS	0.15	95.99	196.60	173.22	1,249.14	2.89	64.89		
09	SZ	0.00	536.13	367.03	5.57	16.76				
10	AL	0.00			3.03	12.14				
10	SS	0.00	15.16	17.09	38.09	197.82			0.08	4.00
10	SS	0.10			3.80	19.00				
10	SS	0.15	55.96	50.57	40.70	298.16	0.11	3.30		
10	SZ	0.00	3.58	2.69						
11	AL	0.00	12.81	10.28	0.80	3.51				
11	GG	0.15			1.28	6.40				
11	SA	0.00			0.65	3.25				
11	SS	0.15	93.11	95.29	58.17	183.47				
11	SZ	0.00	308.64	340.65	0.76	1.71	7.17	153.64		
12	AL	0.00	1.07	0.91	0.14	0.58				
12	CU	0.00	0.21	0.33						
12	SA	0.00	1.16	1.32	180.82	1,682.66	0.17	2.83	2.85	101.01
12	SS	0.00			0.68	1.70				
12	SS	0.15	3.71	7.04	45.95	324.87	0.71	6.19		
12	SZ	0.00	52.76	36.17	0.02	0.11				
13	AL	0.00	2.30	1.96						
13	SA	0.00	0.68	0.68	0.68	3.35	0.55	11.79		
13	SS	0.00			2.17	21.70				

(Table 12, continued)

Zone Number	Material Type	Coating Thickness in mm	Material Thickness d in mm: Class 1. 0<d≤3 Area in mm**2	Volume in m**3	Class 2. 23<d≤20 Area in mm**2	Volume in m**3	Class 3. 20<d≤40 Area in mm**2	Volume in m**3	Class 4. 40<d≤999 Area in mm**2	Volume in m**3
13	SS	0.15	3.80	8.88	17.38	62.18			1.80	42.67
13	SZ	0.00	93.24	62.83	5.30	12.86				
14	AL	0.00	0.09	0.18	0.41	2.20				
14	SA	0.00			1.99	16.93				
14	SS	0.00			0.78	2.99	0.85	7.12	0.14	2.03
14	SS	0.15	2.54	5.69	21.49	143.90	0.05	0.69		
14	SZ	0.00	15.73	9.02	0.08	0.38				
15	AL	0.00	13.02	12.40	1.26	7.24				
15	CU	0.00	2.36	3.18						
15	GG	0.15			0.21	1.03				
15	PB	0.00							0.55	15.13
15	SA	0.00	5.57	14.02	31.12	111.44			0.06	0.95
15	SS	0.00	1.64	2.88	15.41	77.85	1.43	22.98	0.57	7.84
15	SS	0.15	89.97	144.77	215.56	1,233.63	1.02	16.44		
15	SZ	0.00	526.58	431.45	15.84	81.28				
16	AL	0.00	0.69	0.54	8.30	21.88				
16	CU	0.00	1.04	2.08						
16	SA	0.00	4.52	9.94	18.01	69.57				
16	SS	0.00			2.25	7.24				
16	SS	0.15	46.25	89.64	74.08	557.47	2.27	48.26	0.06	0.71
16	SZ	0.00	122.10	104.06	18.57	55.71				
17	AL	0.00	10.41	6.61	0.14	0.58				
17	SA	0.00	0.72	1.80	32.48	232.13				
17	SS	0.15	32.83	74.04	71.11	442.58	4.61	108.72	0.61	7.39
17	SZ	0.00	104.06	18.57	2.29	4.58				
18	AL	0.00	5.83	4.48	0.14	0.58				
18	PB	0.00							1.05	47.05
18	SA	0.00	0.21	0.42	23.46	124.58	1.30	26.70		
18	SS	0.15	14.15	31.70	36.50	159.30	1.56	36.96	0.39	4.71
18	SZ	0.00	106.02	61.57	1.47	3.68				
19	AL	0.00	9.95	10.53	0.94	3.86				
19	SA	0.00	8.17	11.61	53.54	318.60	0.15	2.25		
19	SS	0.00	0.36	0.72	9.67	28.26	0.33	2.30		
19	SS	0.15	3.93	8.01	32.09	287.79	0.56	3.50		
19	SZ	0.00	55.89	39.98						

(Table 12, continued)

Zone Number	Material Type	Coating Thickness in mm	Material Thickness d in mm: Class 1. 0<d≤3 Area in mm**2	Volume in m**3	Class 2. 3<d≤20 Area in mm**2	Volume in m**3	Class 3. 20<d≤40 Area in mm**2	Volume in m**3	Class 4. 40<d≤999 Area in mm**2	Volume in m**3
20	AL	0.00	1.42	1.68	1.73	10.18				
20	AL	0.15	0.44	0.44	2.11	0.55				
20	CU	0.00	1.25	1.49						
20	PB	0.00							1.97	139.20
20	SA	0.00	6.74	11.12	25.53	150.49	3.82	79.84	0.22	7.70
20	SS	0.00	7.44	17.26	125.35	738.92	8.04	71.88	1.45	76.85
20	SS	0.10			31.53	149.45				
20	SS	0.15	82.59	164.17	176.44	1,411.00	1.82	18.65	5.16	817.39
20	SZ	0.00	478.39	267.39	12 92	82.03				
21	AL	0.00	0.09	0.18	0.06	0.23				
21	SA	0.00	0.66	1.33	5.53	35.52	1.35	33.75		
21	SS	0.00			0.33	2.36				
21	SS	0.15	6.46	13.86	12.87	44.71				
21	SZ	0.00	77.25	58.83						
22	AL	0.00	0.21	0.36	1.36	5.46				
22	SA	0.00	0.83	1.66	0.41	1.31				
22	SS	0.15	18.21	17.36	7.60	34.72				
22	SZ	0.00	42.85	38.88	13.70	34.18				
23	AL	0.00	5.40	4.05	2.70	54.00				
23	CU	0.00	2.14	3.29						
23	MS	0.00			0.73	2.54				
23	PB	0.00			1.36	20.40				
23	SA	0.00	10.62	19.75	67.21	469.08	0.68	15.36	0.37	9.25
23	SS	0.00	4.01	10.76	10.13	56.52				
23	SS	0.15	60.38	125.35	204.88	1,153.44	143.48	3,181.68	1.13	21.19
23	SZ	0.00	114.21	102.62						
24	AL	0.00	0.36	0.72	0.47	2.23				
24	SA	0.00	0.33	0.86	5.91	99.86	3.25	81.25	0.80	33.77
24	SS	0.00	0.90	2.21	15.44	82.00			21.45	3,003.00
24	SS	0.15	39.23	109.69	34.37	216.63	17.65	353.00	6.07	351.70
24	SZ	0.00	52.13	22.69	7.61	29.67				
25	AL	0.00	0.36	0.72	0.56	2.59				
25	SA	0.00	20.11	50.14	31.07	276.59	6.08	171.81		
25	SS	0.00	3.84	5.27	11.07	73.99	0.70	7.00	3.96	316.80
25	SS	0.15	57.54	142.79	27.63	163.86				
25	SZ	0.00	52.42	40.47						

(Table 12, continued)

Zone Number	Material Type	Coating Thickness in mm	Material Thickness d in mm: Class 1. 0<d≤3 Area in mm**2	Volume in mm**3	Class 2. 3<d≤20 Area in mm**2	Volume in mm**3	Class 3. 20<d≤40 Area in mm**2	Volume in mm**3	Class 4. 40<d≤999 Area in mm**2	Volume in mm**3
26	AL	0.00	0.19	0.28	0.67	2.70			0.19	2.38
26	CU	0.00	0.29	0.45						
26	MS	0.00	0.06	0.06						
26	SA	0.00	1.74	4.60	15.90	80.80				
26	SS	0.00	0.38	0.53	3.08	26.30	0.04	0.30		
26	SS	0.15	56.20	90.54	63.88	375.46	6.91	164.88		
26	SZ	0.00	231.22	174.98						
27	AL	0.00	0.18	0.35	17.41	88.09				
27	CU	0.00	1.40	2.01	12.75	110.04				
27	MS	0.00			0.25	0.92				
27	PB	0.00			61.88	33.76				
27	SA	0.00	32.08	69.71	158.26	948.29	2.09	37.12	0.06	0.90
27	SS	0.00	29.12	68.16	74.31	486.01	10.49	217.08	8.35	297.98
27	SS	0.15	102.80	178.96	531.85	2,935.31	9.07	135.13		
27	SZ	0.00	759.82	675.26	0.27	0.68				
28	AL	0.00	0.63	0.72	0.14	0.58				
28	PB	0.00							4.43	354.40
28	SS	0.00	1.12	1.68	0.87	3.05				
28	SS	0.15	11.52	20.33	23.49	111.41				
28	SZ	0.00	183.38	130.28						
29	AL	0.00	1.36	2.04						
29	CU	0.00	2.59	5.18						
29	MS	0.00			0.12	0.37				
29	PB	0.00							1.46	65.70
29	SA	0.00	3.39	6.63	75.46	452.70	4.84	95.07		
29	SS	0.00					0.58	10.63		
29	SS	0.15	28.55	58.21	64.60	389.08	0.73	14.97		
29	SZ	0.00	90.05	75.38	2.69	6.58				
30	AL	0.00	6.89	5.26	3.83	20.53				
30	AL	0.15			0.36	1.26				
30	CU	0.00	0.26	0.26						
30	MS	0.00	0.03	0.06	0.35	1.31				
30	PB	0.00			1.51	9.06				
30	SA	0.00	26.74	14.44	8.43	36.76				
30	SS	0.00	1.17	3.04	4.96	32.29	0.24	9.60		
30	SS	0.15	112.65	176.00	174.89	893.07				
30	SZ	0.00	91.51	87.15	18.76					

(Table 12, continued)

Zone Number	Material Type	Coating Thickness in mm	Material Thickness d in mm: Class 1. 0<d≤3 Area in mm**2	Volume in m**3	Class 2. 3<d≤20 Area in mm**2	Volume in m**3	Class 3. 20<d≤40 Area in mm**2	Volume in m**3	Class 4. 40<d≤999 Area in mm**2	Volume in m**3
31	AL	0.00	0.46	0.73	5.79	48.19				
31	SA	0.00	9.39	19.59	19.23	143.95				
31	SS	0.00	15.31	31.78	25.73	187.71	0.11	0.91		
31	SS	0.15	77.70	147.24	82.50	427.45	0.59	8.85	0.61	11.53
31	SZ	0.00	256.07	214.28	13.33	33.33				
32	AL	0.00	0.09	0.18	6.04	30.08				
32	SA	0.00	27.92	19.74	17.92	84.62				
32	SS	0.15	16.92	19.39	116.55	526.06	4.03	50.38		
32	SZ	0.00	135.32	72.37						
33	AL	0.00	0.09	0.18	2.00	9.88				
33	MS	0.00			0.12	0.42				
33	PB	0.00					12.51	225.18		
33	SA	0.00	21.90	42.29	10.51	106.93				
33	SS	0.00			2.49	9.96				
33	SS	0.15	44.25	66.72	70.87	317.28	1.94	38.70		
33	SZ	0.00	67.22	58.06						
34	AL	0.00	30.19	32.54	18.95	89.39				
34	CU	0.00	0.41	0.58						
34	SA	0.00	64.40	54.89	161.51	852.75	134.19	1,649.42	41.95	3,678.89
34	SS	0.00	31.66	46.62	69.21	541.96	38.11	611.67	59.30	2,029.32
34	SS	0.10			78.82	388.17	69.15	927.30	0.84	18.90
34	SS	0.15	262.39	410.67	1,939.61	11,848.52	114.50	1,690.89	72.67	2,683.51
34	SZ	0.00	450.07	371.76	41.29	187.33	0.09		0.56	
Totals:			7,767.32	7,887.15	6,860.73	41,307.13	638.75	10,816.25	243.76	14,328.64

The blowdown nozzle was located in room 1603 (zone 23). The vent flow openings between room 1603 and other rooms are tabulated in Table 13. The number of each opening along with the room numbers connected by the opening, the location of the opening in room 1603 and the flow area for test V44 are given in this table.

Instrumentation to measure the transient pressure, temperature, differential pressure, water carryover, same/air composition, and heat transfer coefficients were located in several rooms in the containment. A more detailed description of the facility may be found in the experimenter's report (Ref. 2).

Table 13 Specification of flow openings in break compartment R 1603

Opening No.	Comp. 1	Comp. 2	Location in R 1603 *	Open Vent Areas V44 F_{min} (m^2)
110	1603	1704	O	0.37
133	1603	1708	S(O)	0.43
140	1603	1704	O	1.64
143	1603	1701 u	O	3.02
145	1603	1701 u	O	0.17
150	1502	1603		0.28
162	1603	1606	S(U)	0
163	1603	1606	S	1.1
164	1603	1608	S	0
165	1603	1605	S	0.19
166.1	1603	1608	S	0
166.2	1603	1608	S	0
176	1603	1704	O	0.24
177	1508	1603	U	0
178	1508	16 03	U	0
179	1508	1603	U	0
180.1	1603	1704	O	0
180.2	1603	1704	O	0.15
181	1603	Spalt	S	0.51
183.1-3	1603	1704	O	0.19

* Abbreviations: O ceiling
U floor
S side wall

4.1.2 COBRA-NC Model Description

The input model for HDR steam blowdown test V44 is based on the 34-zone model developed by the HDR staff. A diagram of the COBRA-NC lumped-parameter nodalization is shown in Figure 42. Each box in this figure represents a computational node. The lines connecting the nodes represent flow paths between

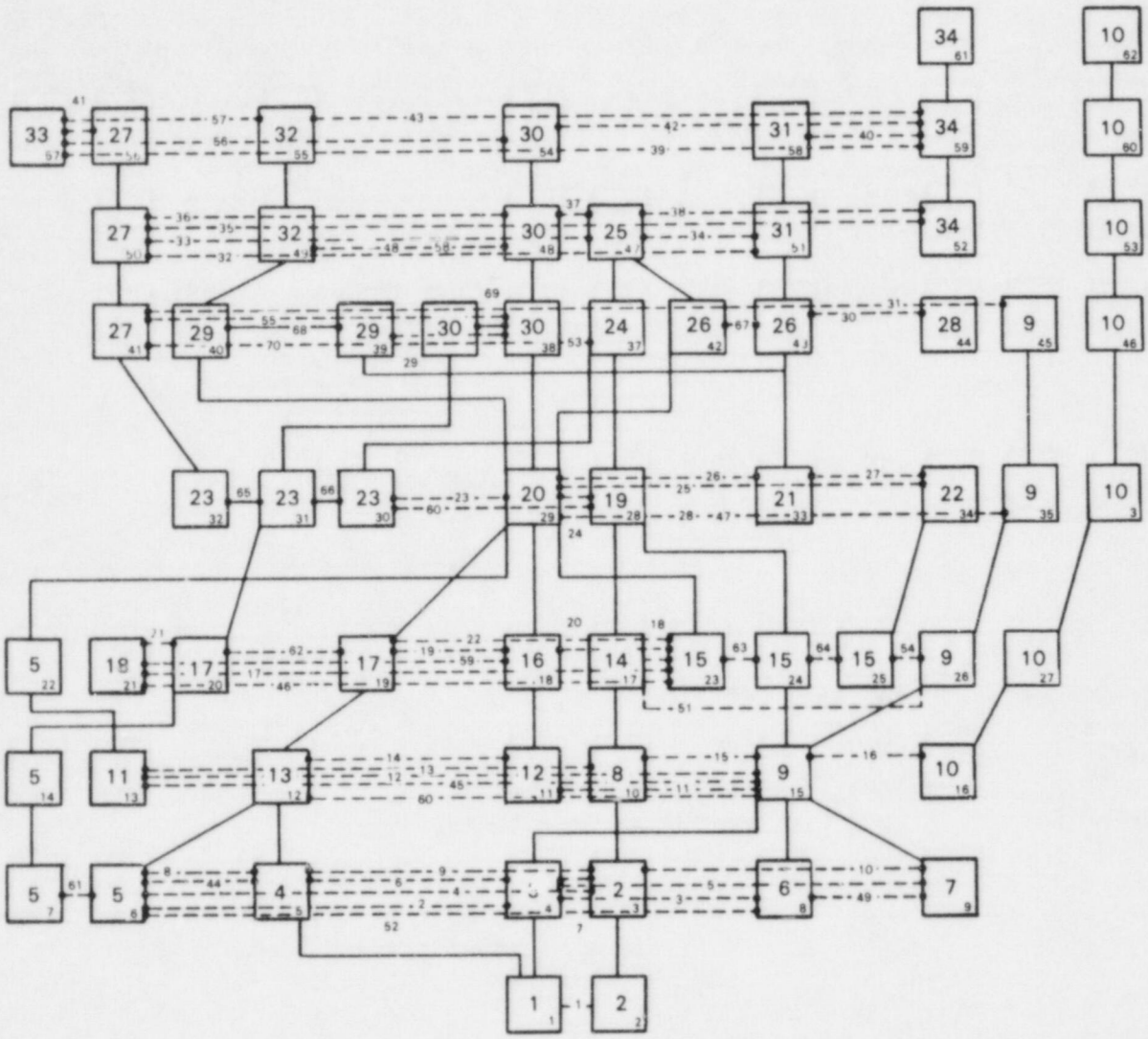


Figure 42 COBRA-TF nodalization of the HDR facility

the nodes. The solid lines represent vertical flow paths, and the dashed lines represent horizontal flow paths. The large number in the center of each box refers to the zone number that node represents. Some zones were divided up into two or more nodes to accommodate the node connection logic of the code. The number in the lower-right-hand corner of each box is the channel number. A channel is a vertical stack of computational cells one or more nodes high. The channels are arranged in nine wall 106 rows or levels. These represent nine elevations into which the containment was divided. Gravity will cause water to flow downward from one elevation to another provided that the vapor-gas updraft is not sufficient to prevent it. The horizontal connections between channels are referred to as gaps. The gaps are each numbered. All of the levels are composed of channels one node high except for the fifth level from the bottom. This level is three nodes high to accommodate the elevation of the vent holes in the blowdown compartment. The input data for each channel is given in Table 14. The height of each level of channels was estimated from the elevations given in Figures 30 and 31. The channel area was calculated by dividing the zone volume (given in Table 9) by the estimated height of the level.

The flow area for connections at the top and bottom of each channel were obtained from Table 10 and are specified by ATOP and ABOT in Table 14. The data for each horizontal flow connection are given in Table 15. The flow area is the sum of the flow paths between the two zones. The width of the vent opening is obtained by dividing the vent flow area by the height of the node. The vents modeled by each channel connection are identified in Tables 14 and 15.

The GRS estimate for the vent flow coefficient was used in these calculations. When several vent holes were lumped together an area-weighted average flow coefficient was used. The total flow area of pressure-dependent openings was used and the loss coefficient specified as a function of pressure drop across the opening to give the correct flow resistance.

At least one heat transfer slab was modeled for each of the 34 zones. All of the concrete surfaces in a zone were lumped together into a single slab. The surface area of this slab was set equal to the total concrete surface area for the zone, and the thickness was calculated by dividing the total volume of concrete in the zone by the surface area for the zone. The metal surfaces were lumped into two slabs per zone. All of the metal was assumed to be steel. The slabs were divided into two groups, one with thicknesses less than 3 mm and the other for thicknesses greater than 3 mm but less than 20 mm. The material beyond 20 mm in depth was ignored. This corresponds to lumping all of the materials listed in Table 12, class 2, 3 and 4 into a single slab of steel.

Table 14 Channel Input Data

Channel Number	Zone Number	Volume (m^3)	Height (m)	Area (m^2)	Top Connection Area (m^2)	Top Connection CD	Bottom Connection Area (m^2)	Bottom Connection CD	Opening Numbers Modeled by Top Connection	Opening Numbers Modeled by Bottom Connection
1	1	152.000	2.7	56.300						
2	2	28.460	2.7	10.541						
3	2	49.540	4.7	10.541	0.337	0.621			9,10,11.1	
4	3	160.000	4.7	34.040	10.520	DP*	0.278	0.6	47,52,58.1,62.1,62.2,62.3,83.1	14,15
5	4	206.000	4.7	43.830	1.199	0.650	1.742	DP**	34	16,17,18,30.1,48,49,50,51
6	5	46.500	4.7	9.894	1.943	0.650			35,36,37,38	
7	5	46.560	4.7	9.894	0.930	0.700			151.1	
8	5	39.000	4.7	8.298	0.277	0.610			39,40.1,42,43	
9	7	63.000	4.7	13.404	1.645	0.610			40.2,41.1,44,45	
10	8	84.000	5.6	15.000	0.379	0.650			153.1,153.3	
11	12	76.000	5.6	13.570	3.500	0.800			148	
12	13	59.000	5.6	10.536	0.276	0.700			151.2	
13	11	296.000	5.6	52.860	0.220	0.600			84.1,84.2	
14	5'	5.200	5.6	0.930						
15	9	577.920	5.6	103.200						
16	10	1.390	5.6	2.749						
17	14	57.000	4.2	13.571	0.078	0.650			154.1	
18	16	235.000	4.2	55.950	0.140	0.700			152	
					(0.33)*					
19	17	53.500	4.2	12.740	1.400	0.750			149	
20	17	53.500	4.2	12.740	0.280	0.550			150	
21	18	57.000	4.2	13.570						
22	5"	0.368	4.2	0.088						
23	15	181.000	4.2	43.090	6.613	0.786			159,120.1,120.2,155.1,155.2	
24	15	181.000	4.2	43.090	0.392	0.650	0.5	DP**	154.2,170	93.3
25	15	181.000	4.2	43.090	0.100	0.700			156	
26	9	1.848	4.2	0.440						
27	10	11.550	4.2	2.749						
28	19	93.000	6.35	14.650	1.374	0.600			138	
29	20	507.000	6.35	79.840						
30	23	93.300	6.35	14.690	3.190	0.350			143,145	
31	23	93.300	6.35	14.690	0.430	0.850			133	

* Value used for test V44

** Pressure dependent

(Table 14 Continued)

Channel Number	Zone Number	Volume (m^3)	Height (m)	Area (m^2)	Top Connection Area (m^2)	Top Connection CD	Bottom Connection Area (m^2)	Bottom Connection CD	Opening Numbers Modeled by Top Connection	Opening Numbers Modeled by Bottom Connection
32	23	93.300	6.35	14.690	0.953 (2.593)*	0.692			110,176,180.2,183.1,183.2,183.3	
33	21	59.000	6.35	9.290	0.060	0.700			128.3	
34	22	61.000	6.35	9.610						
35	9	2.794	6.35	0.440						
36	10	17.460	6.35	2.749						
37	24	44.000	5.55	7.930	1.700	0.700			134	
38	30	45.660	5.55	10.030			8.02	0.831		130,131.1,131.2,132
39	29	84.500	5.55	15.230						
40	29	84.500	5.55	15.230	0.072		0.304	0.7	175.1,175.2	174
41	27	297.900	5.55	53.670						
42	26	65.500	5.55	11.800	0.0327	0.650	6.97	0.85	136119.1,119.2,173	
43	26	65.500	5.55	11.800	7.97	0.85			118.1,118.2	
44	28	54.000	5.55	9.730						
45	9	2.442	5.55	0.440						
46	10	15.260	5.55	2.749						
47	25	64.000	4.7	13.620	3.00				182	
48	30	80.040	4.7	17.030						
49	32	57.340	4.7	12.200						
50	27	252.200	4.7	53.670						
51	31	127.900	4.7	27.220						
52	34	707.930	4.7	150.620						
53	10	12.920	4.7	2.749						
54	30	94.520	5.55	17.030	7.47				122.1,122.2,122.3	
55	32	67.710	5.55	12.200	0.060				157.1	
56	27	297.900	5.55	53.670						
57	33	62.000	5.55	11.170	0.075				157.2	
58	31	151.100	5.55	27.220	5.50				117.1,117.2,117.4,157.3	
59	34	1415.800	5.55	255.100						
60	10	15.260	5.55	2.749						
61	34	3196.000	9.15	348.400						
62	10	25.150	9.15	2.749						
63	30	39.020	5.55	7.030						

* Value used for test V44

** Pressure dependent

Table 15 Gap input data

Gap No.	Channels Connected by Gap	Area (m^2)	Flow Coefficient	Gap Width (m)	Opening Numbers Modeled by Gap
1	1 & 2	0.068	0.650	0.0257	1,2
2	4 & 6	1.551	0.784	0.3300	22,23,25,26.1
3	4 & 8	3.464	0.835	0.7370	27,31
4	3 & 6	0.120	0.600	0.0255	3
5	4 & 9	4.169	0.850	0.8870	32,33
6	4 & 5	2.251	0.706	0.4789	21,30.2,78
7	3 & 4	2.265	0.700	0.4819	5,6,12.1,13,26.2
8	5 & 6	0.298	0.522	0.0634	24,28,29
9	3 & 5	0.304	0.600	0.0647	7,8
10	3 & 9	0.149	0.600	0.0317	4
11	11 & 15	3.042	0.747	0.5432	55,57,60,61.1,61.2,82.1,82.2
12	13 & 15	2.410	0.792	0.4304	11.3,83.2,89
13	10 & 13	0.030	0.700	0.0054	11.2
14	11 & 12	0.099	0.700	0.0177	59
15	10 & 15	0.921	0.750	0.1645	54
16	15 & 16	1.360	0.800	0.2429	53
17	21 & 23	0.316	0.654	0.0752 (0.063)*	144.2,144.3,184.1,184.2
18	17 & 23	1.993	0.0796	0.4745	67,153.3
19	18 & 19	0.147	0.592	0.035	73,74,75,76
20	18 & 23	3.709	0.848	0.8831	63.1,64,77
21	20 & 21	0.180	0.700	0.0429	146.1
22	19 & 23	0.992	0.700	0.2362	68,69,70,71,72
23	29 & 30	2.372	0.752	0.5603 (0.2598)*	162,163,164.2,164.3,166.1
24	28 & 29	2.270	0.818	0.3575	167,168,169
25	29 & 34	1.430	0.800	0.2252	86
26	29 & 33	1.655	0.791	0.2602	80,81,87,88.2,172.1
27	33 & 34	0.104	0.721	0.0164	88.1,172.2
28	29 & 35	0.500	0.650**	0.0787	93.2
29	38 & 39	0.060	0.700	0.0108	128.1
30	43 & 44	1.440	0.800	0.2595	90
31	41 & 45	1.500	0.600	0.2703	93.1
32	50 & 51	0.438	0.680	0.0932	103,109,111
33	47 & 50	2.787	0.711	0.593	97,102,104,105,106.1.106.2, 108,113.2
34	47 & 51	0.0806	0.650	0.0171	135
35	50 & 52	0.262	0.600	0.0557	100,101,107
36	48 & 50	0.450	0.887	0.0957	96,98

* Value used for test V44
** Opening is pressure dependent

(Table 15, continued)

Gap No.	Channels Connected by Gap	Area (m^2)	Flow Coefficient	Gap Width (m)	Opening Numbers Modeled by Gap
37	47 & 48	0.240	0.650	0.0511	126
38	47 & 52	3.000	0.8**	0.6383	182
39	57 & 59	0.075	0.6	0.0135	157.2
40	58 & 59	5.500	0.792	0.9910	117.1,117.2,117.4,157.3
41	56 & 57	0.396	0.674	0.0714	112,113.1
42	54 & 59	7.470	0.832	1.3459	122.1,122.2,122.3
43	55 & 59	0.060	0.6	0.0108	157.1
44	5 & 6	2.826	0.85**	0.6013	44
45	13 & 15	2.965	0.85**	0.5292	56
46	21 & 23	1.420	0.65**	0.3381	144.1
47	29 & 35	0.066	0.70	0.0104	171.2
48	25 & 27	0.300	0.55**	0.0638	139
49	8 & 9	5.924	0.846	1.2604	19,20
50	12 & 15	0.020	0.17	0.0036	58.2
51	17 & 26	0.088	0.7	0.021	65,66
52	6 & 8	3.068	0.85**	0.528	79
53	39 & 42	1.840	0.8	0.3315	91,175.3
54	25 & 26	7.980	0.832	1.9	63.2,121.1,121.2,142,158.1, 158.2,160,161
55	38 & 41	0.296	0.61	0.0533	94,99,171.1
56	54 & 57	1.667	0.782	0.3004	123,123.1,124
57	55 & 57	0.064	0.7	0.0115	125
58	48 & 49	3.110	0.85	0.6617	137.1,137.2,141
59	18 & 21	1.242	0.79	0.2957	146.2,147,185
60	28 & 30	0.190	0.7	0.0449	165
61	6 & 7			9.32***	
62	19 & 20			5.71***	
63	23 & 24			10.23***	
64	24 & 25			10.23***	
65	31 & 32			6.94***	
66	30 & 31			6.94***	
67	42 & 43			4.11***	
68	39 & 40			5.48***	
69	38 & 63			3.00***	

*** Gap used to model connection between two channels modeling the same zone. These gaps do not model flow openings between zones.

The data for the concrete slab conduction models are given in Table 16 and those for the steel slabs are given in Table 17. Each of the concrete slabs were divided into seven regions through its thickness. The region nearest the surface was 0.0051 m thick and was divided into four nodes, one on the surface. The second region was 0.0102 m thick and was divided into four nodes. The third region was 0.0152 m thick and was divided into three nodes, the fourth was 0.0203 m and divided into two nodes; the fifth 0.0407 m and divided into two nodes, the sixth 0.0407 m and one node thick; and the thickness of the seventh region varied depending on the slab and was divided into from two to five nodes. The thin metal slabs were divided into three nodes. The thicker metal slabs were divided into 10 uniformly spaced nodes with one of the 10 nodes on the slab surface. The surface coating was not modeled.

In addition to the structural conduction slabs, 10 more conductors were used to model the alpha blocks. The data for the alpha block conductor input is given in Table 18. The material properties used for each of the conductors is given in Table 19. The initial conditions for each of the tests are given in Table 20.

The boundary conditions for test V44 were obtained from experimental data and are tabulated in Table 21. A complete listing of the input data for test V44 is given in Table 22.

4.2 CSTF Three-Dimensional Mesh Sample Problem

Tests were conducted in the Hanford Engineering Laboratories Containment Systems Test Facility to study the distribution of hydrogen within a containment during severe core damage accidents (Ref. 4). The tests were performed in an annular compartment constructed within a 850 m^3 vessel. A recirculation system provided forced flow between the annular test compartment and a large vessel volume above the test compartment. A horizontal, high velocity jet of steam and hydrogen was released into the test section. COBRA-TF was used to predict the noncondensable gas concentrations and temperatures at five circumferential measurement stations around the test section. A three-dimensional mesh of the test section was used in the calculation. This problem is a good example of how a three-dimensional mesh is set up.

4.2.1 Description of the Experiment

The CSTF contains a large coded vessel 20.4 m high and 7.6 m in diameter having a volume of 850 m^3. The test compartment, which simulated a simplified lower compartment area of an ice condenser plant, was fabricated in the lower area of the vessel and contained no major geometrical objects such as pipes, tanks, or structural elements. Figure 43 shows a schematic of the annular test compartment whose outer diameter was 7.62 m. The inside wall of the annulus was 3 m in diameter by 4.7 m high and was fabricated from corrugated steel sheet. A lower deck was provided inside the test vessel to act as the floor of the annular compartment and an upper deck represented the ceiling. The test compartment volume occupied a 300° section of the annulus leaving a 60° sector

Table 15 Concrete conduction model input

Zone Number	Conductor Number	Channel Number	Surface Area (m^3)	Material Volume (m^3)	Material Thickness (m)	Wetted Perimeter (m)
1	1	1	221.60	126.30	0.5700	82.07
2	2	2	150.00	70.60	0.4710	20.28
3	3	4	418.40	155.50	0.3715	89.01
4	4	5	314.70	106.50	0.3383	66.96
5	5	6	140.10	52.91	0.3777	29.81
6	6	8	92.40	38.50	0.4167	19.66
7	7	9	135.55	59.18	0.4366	28.84
8	8	10	127.30	55.10	0.4328	22.73
9	9	15	834.86	313.20	0.3751	149.08
10	10	16	294.86	73.52	0.2493	52.65
11	11	13	258.98	89.34	0.3450	46.25
12	12	11	156.27	77.09	0.4933	27.91
13	13	12	140.08	53.03	0.3786	25.01
14	14	17	118.75	41.04	0.3456	28.27
15	15	23	676.20	202.28	0.2291	161.00
16	16	18	253.50	104.55	0.4124	60.36
17	17	19	193.25	53.55	0.2743	46.01
18	18	21	147.66	54.43	0.3686	35.16
19	19	28	132.05	59.74	0.4524	20.80
20	20	29	669.72	231.18	0.3452	105.47
21	21	33	96.06	14.33	0.1492	15.13
22	22	34	107.07	18.61	0.1738	16.86
23	23	30	330.39	161.57	0.4890	52.03
24	24	37	146.65	85.95	0.5861	26.42
25	25	47	111.34	99.63	0.8948	23.69
26	26	43	221.75	90.43	0.4078	39.95
27	27	41	896.77	477.65	0.5326	161.58
28	28	44	134.62	24.15	0.1794	24.26
29	29	39	216.05	71.39	0.3304	38.93
30	30	38	277.31	105.27	0.3796	49.97
31	31	51	349.22	125.71	0.5044	74.30
32	32	49	143.63	25.98	0.1809	30.56
33	33	57	93.09	42.88	0.4606	19.81
34	34	52	1212.72	566.64	0.4672	258.00

Table 17 Steel conduction model input

Zone Number	Thickness Class*	Channel Conductor Number	Surface Number	Material Area (m^2)	Material Volume (m^3)	Thickness (m)	Wetted Perimeter
1	1	35	1	26.85	0.0166	0.0006	9.94
1	2	36	1	84.85	0.5099	0.0060	31.43
2	1	37	2	21.45	0.0225	0.0010	7.94
2	2	38	2	117.85	0.6143	0.0052	43.65
3	1	39	4	277.56	0.2552	0.0009	59.06
3	2	40	4	95.34	0.8492	0.0089	20.29
4	1	41	5	218.73	0.2182	0.0010	46.54
4	2	42	5	113.17	0.7275	0.0064	24.08
5	1	43	6	88.75	0.0774	0.0009	18.88
5	2	44	6	61.85	0.4108	0.0066	13.16
6	1	45	8	39.50	0.0459	0.0012	8.40
6	2	46	8	73.02	0.4572	0.0063	15.54
7	1	47	9	80.74	0.1041	0.0013	17.18
7	2	48	9	39.44	0.2507	0.0064	8.39
8	1	49	10	76.38	0.0652	0.0009	13.64
8	2	50	10	52.88	0.3088	0.0058	9.44
9	1	51	15	647.74	0.5928	0.0009	115.67
9	2	52	15	405.71	3.6234	0.0089	72.45
10	1	53	16	74.70	0.0703	0.0009	13.34
10	2	54	16	121.10	1.2367	0.0102	21.63
11	2	55	13	113.04	1.2259	0.0108	20.19
11	1	56	13	414.56	0.4462	0.0011	74.03
12	1	57	11	58.91	0.0458	0.0008	10.52
12	2	58	11	231.34	2.0759	0.0090	41.31
13	1	59	12	100.02	0.0744	0.0007	17.86
13	2	60	12	27.93	0.1531	0.0055	4.99
14	1	61	17	18.36	0.0149	0.0008	4.37
14	2	62	17	25.79	0.1762	0.0068	6.14
15	1	63	23	639.14	0.6087	0.0010	152.18
15	2	64	23	321.55	2.3421	0.0073	76.56
16	1	65	18	174.60	0.2063	0.0012	41.57
16	2	66	18	157.30	1.4336	0.0091	37.45
17	1	67	19	168.98	0.1547	0.0009	40.23
17	2	68	19	111.24	0.7795	0.0070	26.49
18	1	69	21	126.21	0.0982	0.0008	30.05
18	2	70	21	65.87	0.4347	0.0066	15.68
19	1	71	28	76.30	0.0709	0.0009	12.02
19	2	72	28	97.28	0.6466	0.0066	15.32

* Class 1 has a thickness less than 3 mm. Class 2 has a thickness between 3 mm and 20 mm and includes HDR classes 2, 3 and 4 of Table A.5 and all metal structural elements from Table A.4.

(Table 17, continued).

Zone Number	Thickness* Class	Channel Conductor Number	Surface Number (m^2)	Material Area (m^3)	Material Volume (m)	Thickness (m)	Wetted Perimeter
20	1	73	29	578.30	0.4636	0.0008	91.07
20	2	74	29	465.10	4.2355	0.0091	73.25
21	1	75	33	84.46	0.0742	0.0009	13.30
21	2	76	33	20.14	0.1098	0.0055	3.17
22	1	77	34	62.10	0.0583	0.0009	9.78
22	2	78	34	45.88	1.2057	0.0263	7.23
23	1	79	30	196.76	0.2658	0.0014	30.99
23	2	80	30	432.67	4.6672	0.0108	68.14
24	1	81	37	92.95	0.1358	0.0015	16.75
24	2	82	37	113.02	1.4140	0.0125	20.36
25	1	83	47	134.27	0.2394	0.0018	28.57
25	2	84	47	81.07	0.7240	0.0089	17.25
26	1	85	43	290.08	0.2714	0.0009	52.27
26	2	86	43	122.78	1.2681	0.0103	22.12
27	1	87	41	925.42	0.9945	0.0011	166.74
27	2	88	41	848.24	5.1520	0.0061	152.84
28	1	89	44	196.65	0.1530	0.0008	35.43
28	2	90	44	55.30	1.2736	0.0230	9.96
29	1	91	39	125.94	0.1474	0.0012	22.69
29	2	92	39	150.48	0.9986	0.0066	27.11
30	1	93	38	239.25	0.2862	0.0012	43.11
30	2	94	38	271.01	2.1961	0.0081	48.83
31	1	95	51	358.93	0.4136	0.0012	76.37
31	2	96	51	222.20	3.0919	0.0139	47.28
32	1	97	49	180.25	0.1117	0.0006	38.35
32	2	98	49	193.00	1.6411	0.0085	41.06
33	1	99	57	133.46	0.1673	0.0013	24.05
33	2	100	57	109.49	0.8884	0.0081	19.73
34	1	101	52	839.12	0.9171	0.0011	178.54
34	2	102	52	4111.00	47.700	0.0116	874.70

Table 18 Alpha block conduction model input

Zone Number	Conductor Number	Channel Number	Material	Node Locations Surface (m)						
7	103	9	Stainless Steel	0.0	.00033	.00114	.00241	.00369	.00496	.00688
				.00943	.01198	.01453	.01956	.02706	.03593	.04619
				.06419	.08185	.11238	.18522	.29019	.39516	.5
20	104	29	Stainless Steel	0.0	.00013	.00087	.00223	.00357	.00493	.00688
				.00943	.01198	.01453	.01956	.02706	.03593	.04619
				.06419	.08185	.11238	.18522	.29019	.39516	.5
34	105	52	Stainless Steel	0.0	.0014	.00298	.00473	.00688	.00943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		
3	106	4	Lead	0.0	00027	.0017	.00430	.00688	.00943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		
9	107	15	Lead	0.0	00027	.0017	.00430	.00688	.00943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		
16	108	18	Lead	0.0	00027	.0017	.00430	.00688	.0 0943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		
19	109	28	Lead	0.0	00027	.0017	.00430	.00688	.00943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		
23	110	30	Lead	0.0	00027	.0017	.00430	.00688	.00943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522					
24	111	37	Lead	0.0	00027	.0017	.00430	.00688	.00943	.01198
				.01453	.01956	.0 2706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		
27	112	41	Lead	0.0	00027	.0 017	.00430	.00688	.00943	.01198
				.01453	.01956	.02706	.03593	.04619	.06419	.08185
				.11238	.18522	.29019	.39516	.5		

Table 19 Material properties

Material	Density kg/m**3	Specific Heat J/kg°C	Conductivity W/m°C
Concrete	2225.0	879.0	2.1
Carbon Steel	7805.9	473.2	51.93
Stainless Steel	7900.0	520.0	20.0
Lead	11388.0	129.4	34.6

Table 20 Initial conditions for test V44

Pressure	1 Bar
Atmospheric Temperature (all rooms)	20°C
Relative Humidity (all rooms)	35%

Table 21 Flow and energy boundary conditions for test V44

Time (sec)	Mass Flow (kg/sec)	Enthalpy (Joules/kg)
0.0	0.0	2.7089 E6
0.1	1097.5	2.6578 E6
0.2	1182.2	2.6214 E6
0.2	1182.2	2.6214 E6
0.3	1153.8	2.6186 E6
0.4	1088.5	1.8844 E6
0.5	1617.0	1.6350 E6
0.6	1878.7	1.5546 E6
0.7	2038.8	1.5181 E6
0.8	2151.9	1.4955 E6
0.9	2227.4	1.4817 E6
1.0	2282.1	1.4723 E6
1.1	2323.8	1.4653 E6
1.2	2351.5	1.4606 E6
1.3	2375.4	1.4565 E6
1.4	2388.3	1.4542 E6
1.5	2401.2	1.4516 E6
1.6	2406.1	1.4499 E6
1.7	2408.7	1.4486 E6
1.8	2404.4	1.4480 E6
1.9	2399.7	1.4474 E6
2.0	2395.2	1.4468 E6
3.0	2283.1	1.4487 E6
4.0	2148.6	1.4560 E6
5.0	2016.5	1.4667 E6
6.0	1883.8	1.4801 E6
7.0	1750.8	1.4974 E6
8.0	1622.7	1.5174 E6
9.0	1460.0	1.5550 E6
10.0	1365.0	1.5649 E6
11.0	1262.9	1.5841 E6
12.0	1159.0	1.6087 E6
13.0	1055.7	1.6370 E6
14.0	957.6	1.6685 E6
15.0	864.3	1.7033 E6
16.0	774.3	1.7429 E6
17.0	691.9	1.7854 E6
18.0	617.1	1.8319 E6
19.0	547.4	1.8842 E6
20.0	479.2	1.9499 E6
21.0	416.6	2.0283 E6
22.0	363.8	2.1101 E6

(Table 21, continued).

Time (sec)	Mass Flow (kg/sec)	Enthalpy (Joules/kg)
23.0	319.4	2.1993 E6
24.0	287.9	2.2666 E6
25.0	259.3	2.3399 E6
26.0	236.0	2.4044 E6
28.0	196.8	2.5268 E6
30.0	167.0	2.6309 E6
32.0	147.8	2.6657 E6
34.0	130.5	2.7004 E6
36.0	103.5	2.7100 E6
38.0	82.6	2.7102 E6
40.0	67.8	2.7091 E6
42.0	57.0	2.7090 E6
44.0	48.6	2.7103 E6
46.0	41.8	2.7124 E6
48.0	35.4	2.7143 E6
50.0	30.7	2.7164 E6
62.5	0.0	2.7164 E6
1000.0	0.0	2.7164 E6

Table 22 COBRA-TF input listing for test V44

```
             1

          .001              5            40
        1 HDR TEST V44 - STEAM LINE BREAK
    1    1    1                         1
      278.      278.      27.8     2780.
      1.E5  2536947.       0.0       0.0   293347.     1.E-6     .0234
AIR             .9766
    2   63   34
    156.3030.01
    210.5412.98
    310.5412.98       .337
    434.0423.34 .27810.52
    543.8326.481.7421.199
    69.89412.58     1.943
    79.89412.58       .93
    88.29811.52      .277
    913.4014.64     1.645
   1015.0015.49 .337 .379
   1113.5714.74       3.5
   1210.5412.99      .276
   1352.8629.08       .22
   14  .933.858
   15103.240.63
   162.7496.632
   1713.5714.73      .078
   1855.9529.92       .33
   1912.7414.28       1.4
   2012.7414.28       .28
   2113.5714.74
   22  .221.131
   2343.1026.26     6.613
   2443.1026.26   .5 .392
   2543.1026.25        .1
   26  .442.653
   272.7496.632
   2814.6515.31     1.374
   2979.8435.74
   3014.6915.33      3.19
   3114.6915.33       .43
   3214.6915.33     2.593
   33 9.2912.19       .06
   34 9.6112.40
   35  .442.653
   362.7496.632
   37 7.9311.26       1.7
   3810.0316.51 6.98
```

```
3915.2315.61
4015.2315.61 .304 .072
4153.6729.30
4211.8013.74 6.97.0327
43 11.813.74      7.97
449.73012.48
45  .442.653
462.7496.632
4713.6214.76
4817.0316.51
4912.2013.97
5053.6729.30
5127.2220.87
52150.649.09
532.7496.632
5417.0316.51
55 12.213.97
5653.6729.30
5711.1713.37
5827.2220.87
59255.163.89
602.7496.632
61346.474.45
622.7496.632
63 7.0316.51
```

1	-1	-35	-36	
2	-2	-37	-38	
4	-3	-39	-40	-106
5	-4	-41	-42	
6	-5	-43	-44	
8	-6	-45	-46	
9	-7	-47	-48	-103
10	-8	-49	-50	
15	-9	-51	-52	-107
16	-10	-53	-54	
13	-11	-55	-56	
11	-12	-57	-58	
12	-13	-59	-60	
17	-14	-61	-62	
23	-15	-63	-64	
18	-16	-65	-66	-108
19	-17	-67	-68	
21	-18	-69	-70	
28	-19	-71	-72	-109
29	-20	-73	-74	-104
33	-21	-75	-76	
34	-22	-77	-78	
30	-23	-79	-80	-110
37	-24	-81	-82	-111

```
47                                          -25  -83  -84
43                                          -26  -85  -86
41                                          -27  -87  -88 -112
44                                          -28  -89  -90
39                                          -29  -91  -92
38                                          -30  -93  -94
51                                          -31  -95  -96
49                                          -32  -97  -98
57                                          -33  -99 -100
52                                          -34 -101 -102 -105
 3   69
 1    1    2.0257   6. 2.37
1.   .8
 2    4    6  .33   6. 1.63
1.   .8
 3    4    8 .737   6. 1.43
1.   .8
 4    3    6 .025   6. 2.78
1.   .8
 5    4    9 .887   6. 1.38
1.   .8
 6    4    5.4789   6.  2.0
1.   .8
 7    3    4.4819   6. 2.04
1.   .8
 8    5    6.0634   6. 3.67
1.   .8
 9    3    5.0647   6. 2.47
1.   .8
10    3    9.0317   6. 2.78
1.   .8
11   11   15.5432   6. 1.79
1.   .8
12   13   15.4304   6. 1.59
1.   .8
13   10   13.0054   6. 2.04
1.   .8
14   11   12.0177   6. 2.04
1.   .8
15   10   15.1645   6. 1.78
1.   .8
16   15   16.2429   6. 1.56
1.   .8
17   21   23.0630   6. 2.34
1.   .8
18   17   23.4745   6. 1.58
1.   .8
19   18   19 .035   6. 2.85
1.   .8
```

```
20    18    23.8831    6. 1.39
1.    .8
21    20    21.0429    6. 2.04
1.    .8
22    19    23.2362    6. 2.04
1.    .8
23    29    30.2598    6.1.768
1.    .8
24    28    29.3575    6. 1.49
1.    .8
25    29    34.2252    6. 1.56
1.    .8
26    29    33.2606    6. 1.60
1.    .8
27    33    34.0164    6. 1.92
1.    .8
28    29    35.0787    6. 2.37
1.    .8
29    38    39.0108    6. 2.04
1.    .8
30    43    44.2595    6.1.562
1.    .8
31    41    45 .270    6. 2.78
1.    .8
32    50    51.0932    6. 2.16
1.    .8
33    47    50 .593    6. 1.98
1.    .8
34    47    51.0171    6. 2.37
1.    .8
35    50    52.0557    6. 2.78
1.    .8
36    48    50.0957    6. 1.27
1.    .8
37    47    48.0511    6. 2.37
1.    .8
38    47    52.6383    6. 1.56
1.    .8
39    57    59.0135    6. 2.78
1.    .8
40    58    59.9910    6. 1.59
1.    .8
41    56    57.0714    6. 2.20
1.    .8
42    54    591.346    6. 1.44
1.    .8
43    55    59.0108    6. 2.78
1.    .8
44     5     6.6013    6. 1.38
```

```
1.   .8
45   13   15.5295   6. 1.38
1.   .8
46   21   23.3381   6. 2.37
1.   .8
47   29   35.0104   6. 2.04
1.   .8
48   47   50.0638   6.  3.3
1.   .8
49    8    91.260   6.  1.4
1.   .8
50   12   15.0036   6. 2.04
1.   .8
51   17   26.0210   6. 2.04
1.   .8
52    6    8.6528   6. 1.38
1.   .8
53   39   42.3315   6. 1.56
1.   .8
54   25   26  1.9   6. 1.44
1.   .8
55   38   41.0533   6. 2.68
1.   .8
56   54   57.3004   6. 1.64
1.   .8
57   55   57.0115   6. 2.04
1.   .8
58   48   49.6617   6. 1.38
1.   .8
59   18   21.2957   6. 1.60
1.   .8
60   28   30.0299   6. 2.04
1.   .8
61    6    7 9.32   6.        1.
1.   0.
62   19   20 5.71   6.        1.
1.   0.
63   23   2410.23   6.        1.
1.   0.
64   24   2510.23   6.        1.
1.   0.
65   31   32 6.94   6.        1.
1.   0.
66   30   31 6.94   6.        1.
1.   0.
67   42   43 4.11   6.        1.
1.   0.
68   39   40 5.48   6.        1.
1.   0.
```

```
69   38   63 3.06   6.        1.
1.   0.

 4    9    1
 1    2    1       2.7    1
 1    4    5                      1
 2    3                           2
 2    7    1       4.7    1
 3   10                           2
 4   15                           1
 5   12                           1
 6   12                           6
 7   14                           7
 8   15                           8
 9   15                           9
 3    7    1       5.6    1
10   17                           3
11   18                          11
12   19                           5    6
13   22                          13
14   20                           7
15   24   26                      4    8    9
16   27                          16
 4   11    1       4.2    1
17   28                          10
18   29                          11
19   29                          12
20   31                          14
21   21                          21
22   29                          13
23   29                          23
24   28                          15
25   34                          25
26   35                          15
27   36                          16
 5    9    3     2.117    1
28   37                          17   24
29   38   40   42                18   19   22   23
30   37                          30
31   63                          20
32   41                          32
33   39                          33
34   34                          25
35   45                          26
36   46                          27
 6   11    1       5.55    1
37   47                          28   30
38   48                          29
63   63                          31
```

```
   39   39                                    33
   40   49                                    29
   41   50                                    32
   42   47                                    29
   43   51                                    43
   44   44                                    44
   45   45                                    35
   46   53                                    36
    7    7    1        4.7     1
   47   47                                    37    42
   48   54                                    38
   49   55                                    40
   50   56                                    41
   51   58                                    43
   52   59                                    52
   53   60                                    46
    8    7    1       5.55     1
   54   54                                    48
   55   55                                    49
   56   56                                    50
   57   57                                    57
   58   58                                    51
   59   61                                    52
   60   62                                    53
    9    2    1       9.15     1
   61   61                                    59
   62   62                                    60
   14
   81
    7   18   10
2.59    2    3
1.56    2    4
2.37    2    5    6   10   17   24   40   42
2.04    2    7   12   18   25   37
2.69    2    8    9   13
1.56    2   11   23
1.78    2   19
 3.3    2   20
1.38    2   43
2.78    4   28
8.00    4   30
8.00    4   32
2.04    4   33
1.38    4   31
2.36    1    5   24
2.78    1    4
1.38    1   38   42
2.04    1   40
   1    5    1    1    2    4    2 2.E3-5.E432.99  .94
```

```
 1    4    2    4    2   15    2 2.E4-6.E4 2.95  .95
 1   24    1   24    2   15    2 4.E4-4.E4 1.E8  1.0
 2   28    2   35    2   29    2 4.E4-4.E4 1.E8  1.0
 2   38    2   47    2   52    2 4.E5-4.E5 1.E8  1.0
 2   44    2    5    2    6    2 5.E3-5.E3 1.E8  1.0
 2   45    2   13    2   15    2 5.E3-5.E3 1.E8  1.0
 2   46    2   23    2   21    2 2.E4-2.E4 1.E8  1.0
 2   48    2   47    2   50    2 5.E4-5.E4 1.E8  1.0
 2   52    2    6    2    8    2 5.E3-5.E3 1.E8  1.0
 8    0  112    1    8
  1590.       100.
 1    1              82.07          1.
 2    2              26.15          1.
 3    3              89.01          1.
 4    4              66.96          1.
 5    5              29.81          1.
 6    6              19.66          1.
 7    7              28.84          1.
 8    8              22.73          1.
 9    9              149.1          1.
10   10              52.65          1.
11   11              46.25          1.
12   12              27.91          1.
13   13              25.01          1.
14   14              28.27          1.
15   15               161.          1.
16   16              60.36          1.
17   17              46.01          1.
18   18              35.16          1.
19   19              20.80          1.
20   20              105.5          1.
21   21              15.13          1.
22   22              16.83          1.
23   23              52.03          1.
24   24              26.42          1.
25   25              23.69          1.
26   26              39.95          1.
27   27              161.6          1.
28   28              24.26          1.
29   29              38.93          1.
30   30              49.97          1.
31   31              74.30          1.
32   32              30.56          1.
33   33              19.81          1.
34   34               258.          1.
35   35               9.94          1.
36   36              31.43          1.
37   37               7.94          1.
38   38              43.65          1.
```

39	39	59.06	1.
40	40	20.29	1.
41	41	46.54	1.
42	42	24.08	1.
43	43	18.88	1.
44	44	13.16	1.
45	45	8.4	1.
46	46	15.54	1.
47	47	17.18	1.
48	48	8.39	1.
49	49	13.64	1.
50	50	9.44	1.
51	51	115.7	1.
52	52	72.45	1.
53	53	13.34	1.
54	54	21.63	1.
55	55	20.19	1.
56	56	74.03	1.
57	57	10.52	1.
58	58	41.31	1.
59	59	17.86	1.
60	60	4.99	1.
61	61	4.37	1.
62	62	6.14	1.
63	63	152.2	1.
64	64	76.56	1.
65	65	41.57	1.
66	66	37.46	1.
67	67	40.23	1.
68	68	26.49	1.
69	69	30.05	1.
70	70	15.68	1.
71	71	12.02	1.
72	72	15.32	1.
73	73	91.07	1.
74	74	73.25	1.
75	75	13.30	1.
76	76	3.17	1.
77	77	9.78	1.
78	78	7.23	1.
79	79	30.99	1.
80	80	68.14	1.
81	81	16.75	1.
82	82	20.36	1.
83	83	28.57	1.
84	84	17.25	1.
85	85	52.27	1.
86	86	22.12	1.
87	87	166.7	1.

```
 88   88                152.8          1.
 89   89                35.43          1.
 90   90                 9.96          1.
 91   91                22.69          1.
 92   92                27.11          1.
 93   93                43.11          1.
 94   94                48.83          1.
 95   95                76.37          1.
 96   96                47.28          1.
 97   97                38.35          1.
 98   98                41.06          1.
 99   99                24.05          1.
100  100                19.73          1.
101  101                178.5          1.
102  102                874.7          1.
103  103                  .01          1.
104  104                  .01          1.
105  105                  .01          1.
106  106                  .01          1.
107  106                  .01          1.
108  106                  .01          1.
109  106                  .01          1.
110  106                  .01          1.
111  106                  .01          1.
112  106                  .01          1.
  1    0  105    2
  1    2    3    4    5    6    7    8    9   10   11   12
 13   14   15   16   17   18   19   20   21   22   23   24
 25   26   27   28   29   30   31   32   33   34   35   36
 37   38   39   40   41   42   43   44   45   46   47   48
 49   50   51   52   53   54   55   56   57   58   59   60
 61   62   63   64   65   66   67   68   69   70   71   72
 73   74   75   76   77   78   79   80   81   82   83   84
 85   86   87   88   89   90   91   92   93   94   95   96
 97   98   99  100  101  102  104  107  109
     0.0      293.      2000.      293.
  2    0    1    2
103
     0.0      285.      2000.      285.
  3    0    1    2
106
     0.0      295.5     2000.      295.5
  4    0    1    2
108
     0.0      292.5     2000.      292.5
  5    0    1    2
110
     0.0      296.      2000.      296.0
  6    0    1    2
```

```
111
     0.0       310.      2000.       310.
  7    0    1    2
112
     0.0       299.      2000.       299.
  8    0    1    2
105
     0.0       288.      2000.       288.
  9  106
  1 WALL      82.07        .57    7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          5    1.4378
  2 WALL      20.28       .471    7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          4    1.3388
  3 WALL      89.01       .3715   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          3    1.2393
  4 WALL      66.96       .3383   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          3    1.2061
  5 WALL      29.81       .3777   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          3    1.2455
  6 WALL      19.66       .4167   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          4    1.2845
  7 WALL      28.84       .4366   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          4    1.3044
  8 WALL      22.73       .4328   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          4    1.3006
  9 WALL      149.1       .3751   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          3    1.2429
 10 WALL      52.65       .2493   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          2    1.1171
 11 WALL      46.25       .3450   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          3    1.2128
 12 WALL      27.91       .4933   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          5    1.3611
 13 WALL      25.01       .3786   7          1
  4    1.0051          4    1.0102          3    1.0152          2    1.0203
  2    1.0407          1    1.0407          3    1.2464
 14 WALL      28.27       .3456   7          1
```

```
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          3    1.2134
15 WALL     161.0      .2291    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          2    1.0969
16 WALL     60.36      .4124    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          4    1.2802
17 WALL     46.01      .2743    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          2    1.1421
18 WALL     35.16      .3686    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          3    1.2364
19 WALL     20.80      .4524    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          4    1.3202
20 WALL     105.5      .3452    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          3    1.2130
21 WALL     15.13      .1492    6          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0577
22 WALL     10.86      .1738    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          1    1.0416
23 WALL     52.03      .4890    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          4    1.3568
24 WALL     26.42      .5861    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          5    1.4539
25 WALL     23.69      .8948    8          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          1    1.0814          4    1.6812
26 WALL     39.95      .4078    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          4    1.2756
27 WALL     161.6      .5326    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          5    1.4004
28 WALL     24.26      .1794    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          1    1.0472
29 WALL     38.93      .3304    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          3    1.1982
30 WALL     49.97      .3796    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
```

```
 2    1.0407          1    1.0407          3    1.2474
31 WALL     74.30      .5044    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          5    1.3722
32 WALL     30.56      .1809    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          1    1.0487
33 WALL     19.81      .4606    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          4    1.3284
34 WALL     258.0      .4672    7          1
 4    1.0051          4    1.0102          3    1.0152          2    1.0203
 2    1.0407          1    1.0407          4    1.3350
35 WALL      9.94      .0006    1          2
 3    2.0006
36 WALL     31.43       .006    1          2
10    2 .006
37 WALL      7.94       .001    1          2
 3    2 .001
38 WALL     43.65      .0052    1          2
10    2.0052
39 WALL     59.06      .0009    1          2
 3    2.0009
40 WALL     20.29      .0089    1          2
10    2.0089
41 WALL     46.54       .001    1          2
 3    2 .001
42 WALL     24.08      .0064    1          2
10    2.0064
43 WALL     18.88      .0009    1          2
 3    2.0009
44 WALL     13.16      .0066    1          2
10    2.0066
45 WALL       8.4      .0012    1          2
 3    2.0012
46 WALL     15.54      .0063    1          2
10    2.0063
47 WALL     17.18      .0013    1          2
 3    2.0013
48 WALL      8.39      .0064    1          2
10    2.0064
49 WALL     13.64      .0009    1          2
 3    2.0009
50 WALL      9.44      .0058    1          2
10    2.0058
51 WALL     115.7      .0009    1          2
 3    2.0009
52 WALL     72.45      .0089    1          2
10    2.0089
```

```
53 WALL      13.34      .0009     1          2
 3    2.0009
54 WALL      21.63      .0102     1          2
10    2.0102
55 WALL      20.19      .0108     1          2
10    2.0108
56 WALL      74.03      .0011     1          2
 3    2.0011
57 WALL      10.52      .0008     1          2
 3    2.0008
58 WALL      41.31      .0090     1          2
10    2.0090
59 WALL      17.86      .0007     1          2
 3    2.0007
60 WALL      4.990      .0055     1          2
10    2.0055
61 WALL       4.37      .0008     1          2
 3    2.0008
62 WALL      6.140      .0068     1          2
10    2.0068
63 WALL      152.2       .001     1          2
 3    2 .001
64 WALL      76.56      .0073     1          2
10    2.0073
65 WALL      41.57      .0012     1          2
 3    2.0012
66 WALL      37.46      .0091     1          2
10    2.0091
67 WALL      40.23      .0009     1          2
 3    2.0009
68 WALL      26.49      .0070     1          2
10    2.0070
69 WALL      30.05      .0008     1          2
 3    2.0008
70 WALL      15.68      .0066     1          2
10    2.0066
71 WALL      12.02      .0009     1          2
 3    2.0009
72 WALL      15.32      .0066     1          2
10    2.0066
73 WALL      91.07      .0008     1          2
 3    2.0008
74 WALL      73.25      .0091     1          2
10    2.0091
75 WALL      13.30      .0009     1          2
 3    2.0009
76 WALL       3.17      .0055     1          2
10    2.0055
77 WALL       9.78      .0009     1          2
```

```
  3    2.0009
 78 WALL      7.23      .0263    1         2
 10    2.0263
 79 WALL     30.99      .0014    1         2
  3    2.0014
 80 WALL     68.14      .0108    1         2
 10    2.0108
 81 WALL     16.75      .0015    1         2
  3    2.0015
 82 WALL     20.36      .0125    1         2
 10    2.0125
 83 WALL     28.57      .0018    1         2
  3    2.0018
 84 WALL     17.25      .0089    1         2
 10    2.0089
 85 WALL     52.27      .0009    1         2
  3    2.0009
 86 WALL     22.12      .0103    1         2
 10    2.0103
 87 WALL     166.7      .0011    1         2
  3    2.0011
 88 WALL     152.8      .0061    1         2
 10    2.0061
 89 WALL     35.43      .0008    1         2
  3    2.0008
 90 WALL      9.96      .0230    1         2
 10    2.0230
 91 WALL     22.69      .0012    1         2
  3    2.0012
 92 WALL     27.11      .0066    1         2
 10    2.0066
 93 WALL     43.11      .0012    1         2
  3    2.0012
 94 WALL     48.83      .0081    1         2
 10    2.0081
 95 WALL     76.37      .0012    1         2
  3    2.0012
 96 WALL     47.28      .0139    1         2
 10    2.0139
 97 WALL     38.35      .0006    1         2
  3    2.0006
 98 WALL     41.06      .0085    1         2
 10    2.0085
 99 WALL     24.05      .0013    1         2
  3    2.0013
100 WALL     19.73      .0081    1         2
 10    2.0081
101 WALL     178.5      .0011    1         2
  3    2.0011
102 WALL     874.7      .0116    1         2
```

```
 10    2.0116
103 WALL        .01          .5    8          3
  2    3.0005              4    3.0051        4    3.0102          2    3.0150
  2    3.0205              2    3.0407        1    3.0407          4    3.3673
104 WALL        .01          .5    8          3
  2    3.0002              4    3.0054        4    3.0102          2    3.0150
  2    3.0205              2    3.0407        1    3.0407          4    3.3673
105 WALL        .01          .5    8          3
  2    3.0021              2    3.0035        4    3.0102          2    3.0150
  2    3.0205              2    3.0407        1    3.0407          4    3.3673
106 WALL        .01          .5    8          4
  2    4.0004              2    4.0052        4    4.0102          2    4.0150
  2    4.0205              2    4.0407        1    4.0407          4    4.3673
 10    4
  1    2    2225.0
     283.     879.0       2.1       811.     879.0       2.1
  2    2    7805.9
     283.     473.2      51.93      811.     473.2      51.93
  3    2    7900.
     283.     520.0       20.       811.     520.0       20.
  4    2    11388.
     283.     129.4       34.6      811.     129.4       34.6
 13   34    1    3    1
 59   58    6
 0.0     1391.  0.1    1355.0   .2    1281.0   .3    1268.0   .4    1497.0
  .5     1688.0  .6    1878.7   .7    2038.8   .8    2151.9   .9    2227.4
  1.     2282.1 1.1    2323.8  1.2    2351.5  1.3    2375.4  1.4    2388.3
 1.5     2401.2 1.6    2406.1  1.7    2408.7  1.8    2404.4  1.9    2399.7
 2.0     2395.2 3.0    2283.1  4.0    2148.6  5.0    2016.5  6.0    1883.8
 7.0     1750.8 8.0    1622.7  9.0    1460.0  10.    1365.0  11.    1262.9
 12.     1159.0 13.    1055.7  14.     957.6  15.     864.3  16.    774.3
 17.      691.9 18.     617.1  19.     547.4  20.     479.2  21.     416.6
 22.      363.8 23.     319.4  24.     287.9  25.     259.3  26.     236.0
 28.      196.8 30.     167.0  32.     147.8  34.     130.5  36.     103.5
 38.       82.6 40.      67.8  42.      57.0  44.      48.6  46.      41.8
 48.       35.4 50.      30.7 62.5       0.01000.      0.0
 0.0  .27070E7   .1  .27070E7  .26  .27070E7   .3 .258900E7   .4  .22660E7
  .5  .20310E7   .6  .18520E7   .7  .17260E7   .8  .16450E7   .9  .15940E7
  1.  .15560E7  1.1  .15280E7  1.2  .15090E7  1.3  .14930E7  1.4  .14820E7
 1.5  .14730E7  1.6  .14660E7  1.7  .14610E7  1.8  .14590E7  1.9  .14560E7
 2.0  .14530E7  3.0  .14487E7  4.0  .14560E7  5.0  .14667E7  6.0  .14801E7
 7.0  .14974E7  8.0  .15174E7  9.0  .15550E7  10.  .15649E7  11.  .15841E7
 12.  .16087E7  13.  .16370E7  14.  .16685E7  15.  .17033E7  16.  .17429E7
 17.  .17854E7  18.  .18319E7  19.  .18842E7  20.  .19499E7  21.  .20283E7
 22.  .21101E7  23.  .21993E7  24.  .22666E7  25.  .23399E7  26.  .24044E7
 28.  .25268E7  30.  .26309E7  32.  .26657E7  34.  .27004E7  36.  .27100E7
 38.  .27102E7  40.  .27091E7  42.  .27090E7  44.  .27103E7  46.  .27124E7
 48.  .27143E7  50.  .27164E71000.  .27164E7
 0.0       0.0 600.       0.0 605.       1.04200.       1.04205.       0.0
2.E4       0.0
```

```
  30    1    2    1    2        .50        1.0       11.E6          6.56E-4
3.0E5.9999.9999.0001

  32    1    2    1    2        .50        1.0       11.E6          6.56E-4
3.0E5.9999.9999.0001

   1    1    3
   2    1    3
   6    1    3
   7    1    3
   8    1    3
   9    1    3
  11    1    3
  13    1    3
  16    1    3
  21    1    3
  23    1    3
  25    1    3
  21    2    3
  33    1    3
  34    4    3
  39    2    3
  63    2    3
  43    1    3
  44    1    3
  44    2    3
  45    2    3
  47    2    3
  52    1    3
  54    2    3
  55    2    3
  56    2    3
  57    1    3
  57    2    3
  58    2    3
  61    2    3    3    0     -27.8
  62    2    3
  61    3    1    0    0      1.E5    92377.                          .01459
3.E5.9999.9999.0001

  23    2    2
  14    5



  50
         .001          0.05          2.0           1.          200.
        500.            .05        10000.        10000.
       -.001
```

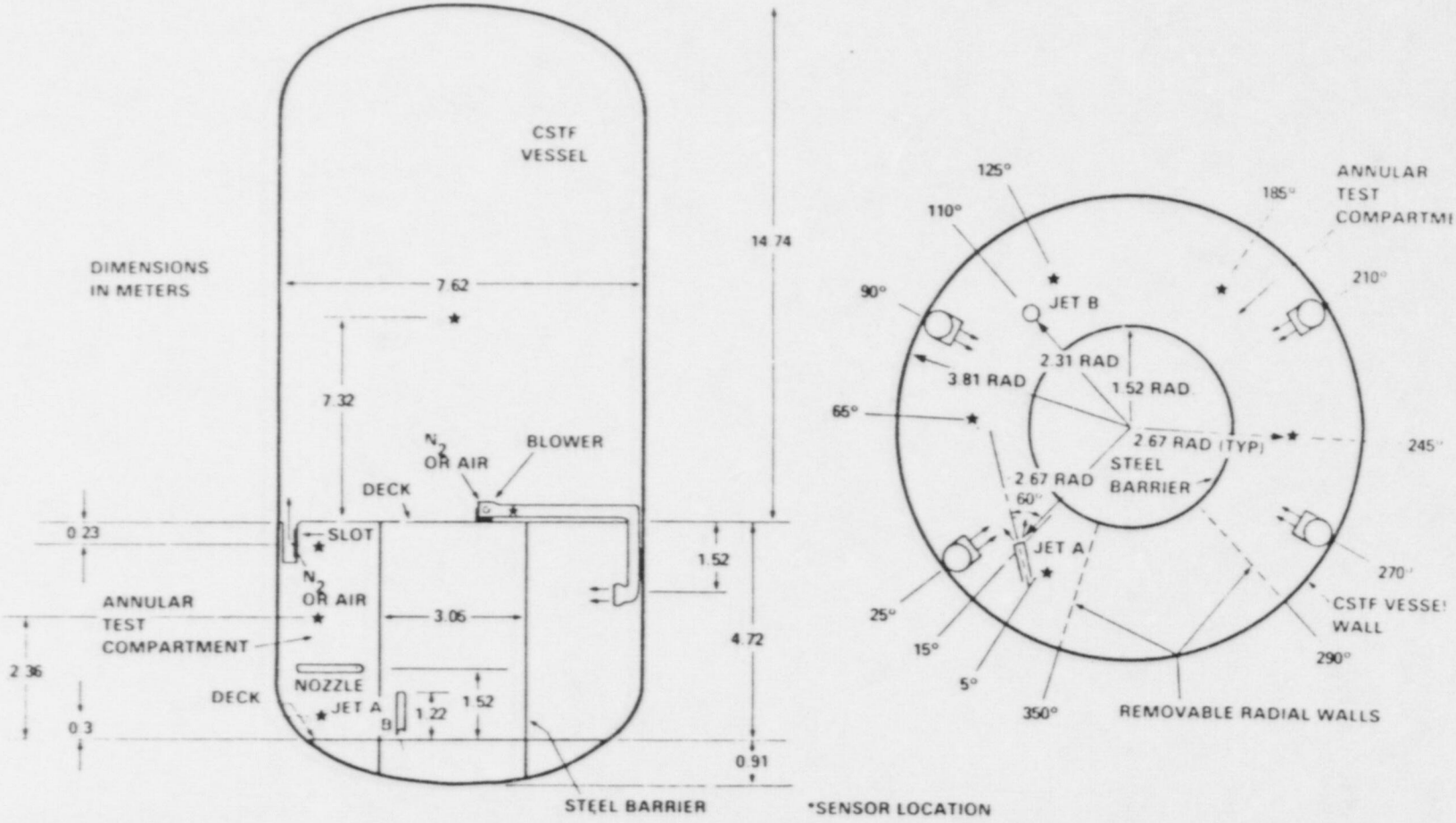


Figure 43 Test Compartment Geometry

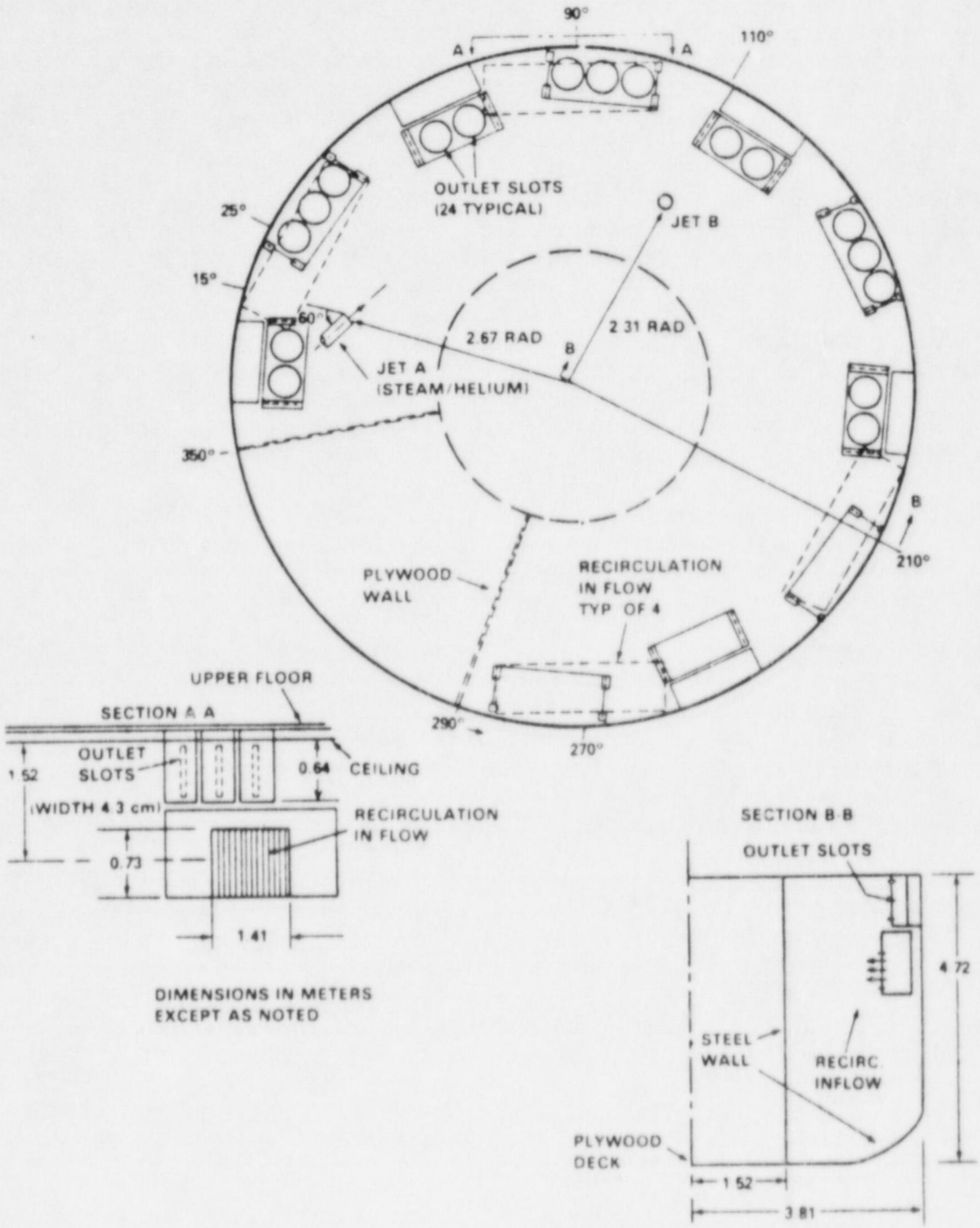


Figure 44 Test compartment air recirculation details

to represent the refueling area of the referenced plant. The containment vessel walls were constructed of steel approximately 1.65 cm thick and the heads were standard elliptical heads 1.9 cm thick. The outside of the vessel was insulated with 2.54 cm of glass fiber; aluminum foil covered insulating board with the following physical properties; (density = 96 Kg/m^3 and k = 0.0467 watt/m-°C at 100°C).

The horizontal, Jet A, nozzle was located 25° from one radial wall of the annulus and was centered at a height of 1.52 m from the floor. The nozzle inside diameter was 7.77 cm and was directed 60° to the radius as shown in Figure 43.

A blower at the vessel axis on the upper containment deck provided air recirculation from the upper to lower compartment atmosphere. The lower compartment inlet ducts were arranged, as shown in Figure 43, at 25°, 90°, 210°, and 270°. The air-flow rate with the blower operating was 109 m^3/min distributed through four openings each 0.73 m in height by 1.41 m wide.

The outlet air-flow passages were 24 vertical slots 0.64 m high by 4.3 cm wide. The slots were made in the wall of circular duct segments suspended from the ceiling of the compartment. The slots were spaced along the periphery of the compartment, over the 300° segment, as shown in Figure 44.

Fifteen instrumentation locations for the lower containment test compartment are illustrated schematically in Figure 45. There were three height locations for each of the five annular locations (5°, 65°, 125°, 185°, and 245°) (see Table 23 and Table 24) all at a radius of 2.7 m. The instrumentation for each measurement station are listed in Table 24. Additional gas sample points and thermocouples were located at 7.32 m above the upper deck at the vessel axis and at the blower discharge.

The test vessel was vented through a 25-cm diameter pipe located at 290° and 7.9 m above the test compartment ceiling. The hydrogen-steam-nitrogen gas mixture was vented through a water bubbler to the building exhaust system during test HM-5. A nitrogen purge was provided upstream of the water bubbler during test HM-5 to dilute the hydrogen-nitrogen mixture and to prevent any possibility of air inleakage. The exhaust system included a scrubber system, HEPA filters, building exhaust tunnel, sand filter, blower, and 61 m stack.

Containment vessel pressure relative to atmospheric was measured with a differential pressure transducer. The vessel pressure was measured at a point 6.4 m above the test compartment ceiling.

The test sequence for the experiment includes the following steps.

1. Place temporary seals over the test compartment outlet vents.

2. purge with N_2

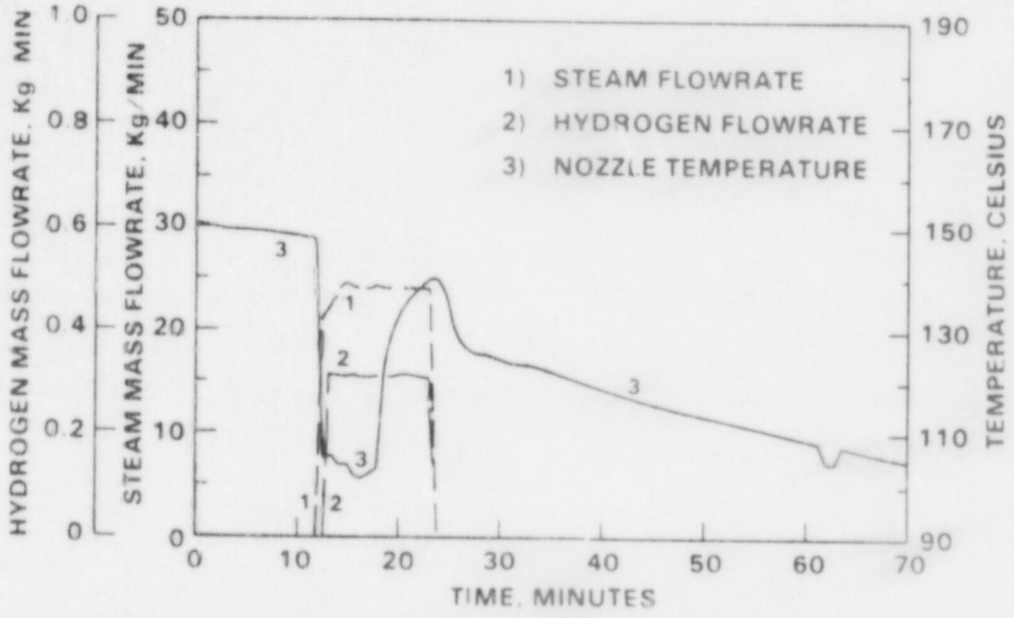


Figure 45 HM-5 nozzle flow rates and temperatures

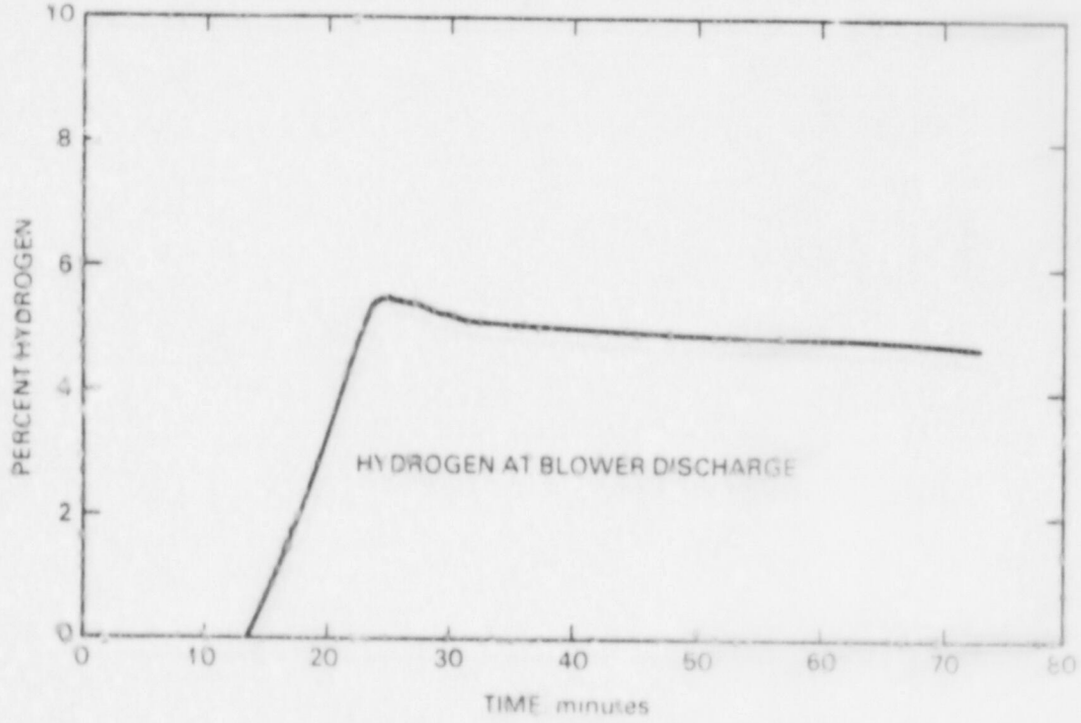


Figure 46 Hydrogen concentration at blower discharge for test HM- 5

Table 23 Lower test compartment height locations

Designation	Location
Top	0.23 m below the ceiling
Midplane	2.36 m up from the lower deck
Bottom	0.3 m up from the lower deck

Table 24 Instrumentation lower containment test compartment

Sensor Location	Point No	Gas Velocity Probe	Gas Sample
5°, Top	1	Yes	Yes
65°, Top	2	No	Yes
125°, Top	3	No	Yes
185°, Top	4	No	Yes
245°, Top	5	No	Yes
5°, Midplane	15	No	No
65°, Midplane	16	No	No
125°, Midplane	8	Yes	Yes
185°, Midplane	17	No	No
245°, Midplane	18	No	No
5°, Bottom	6	Yes	Yes
65°, Bottom	14	No	No
125°, Bottom	7	Yes	Yes
185°, Bottom	9	Yes	Yes
245°, Bottom	10	Yes	Yes
Total sensors		6	10

3. heat test compartment volume to near 66°C while maintaining upper containment near 35°C until steady state reached

4. start data acquisition system

5. remove temporary seals

6. start recirculation blower

7. start steam injection

8. start H_2 flow and continue for approximately 10 minutes

9. stop H_2

10. stop steam flow

11. continue data logging until one hour after start of H_2 or He flow.

Test HM-5 consisted of a horizontal high-velocity hydrogen-steam jet into a nitrogen atmosphere. The panel seal was removed at 11 min. The blower was turned on at 11.8 min. The hydrogen-steam source jet time dependent parameters are plotted in Figure 44. Test compartment initial air and wall temperatures prior to testing are shown in Table 25.

Table 25 Initial temperatures

Test Number	Location	Temperature, C
HM-5		
Gas Temperature:		
	upper level	64.0
	middle level	62.0
	lower level	60.0
Inner Wall Temperature:		
	upper level	65.2
	middle level	65.0
	lower level	61.2
Outer Wall Temperatures:(a)		
	upper level	58.0 - 86.2
	middle level	47.6 - 65.0
	lower level	58.7 - 77.1

The gas recirculation system provided 108 m^3/min of upper containment nitrogen to the lower compartment region during the test. The time-dependent H_2 concentration at the blower discharge is plotted in Figure 46. It was assumed that the recirculation nitrogen is saturated with water vapor once steam release has started. The H_2 concentrations provided for the blower discharge location are on a dry basis with all water vapor removed. The recirculation nitrogen temperature is shown in Figure 47.

(a) Temperature range given because of wide variation in measured wall temperatures

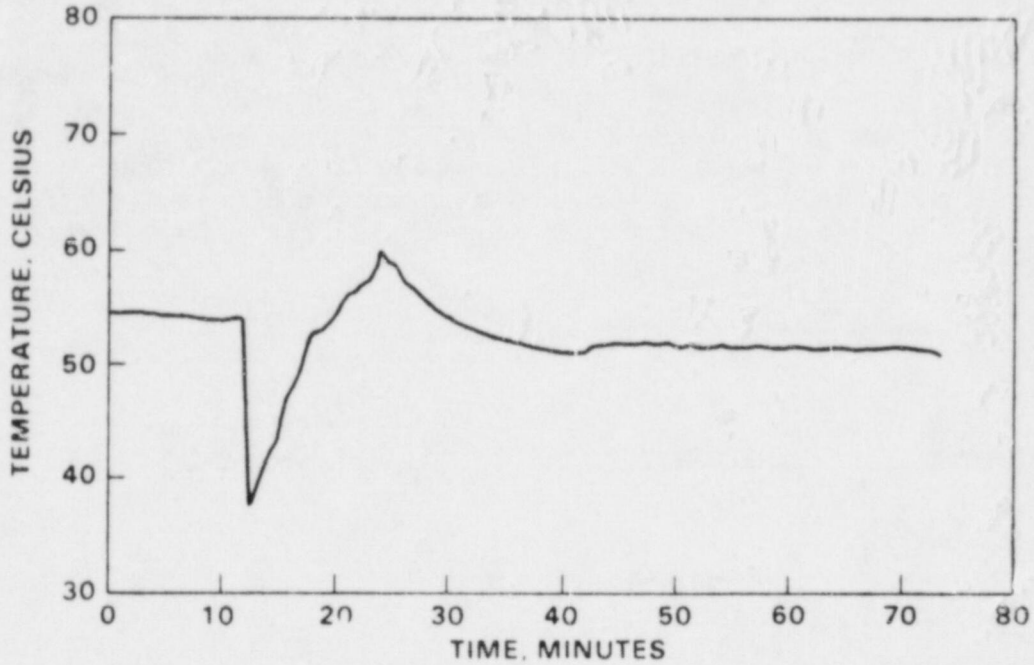


Figure 47 Nitrogen temperature at blower discharge for test HM- 5

4.2.2 COBRA-TF MODEL DESCRIPTION

The mesh used to model the CSTF is shown in Figures 48 through 50. Part (a) of Figure 48 shows a cross-sectional view of the mesh and part (b) shows the vertical height of the mesh. The annular test section was divided into five vertical sections. This was done to accommodate the location of the horizontal jet, the locations of the blower discharge vents, and the locations of the outlet slots. The five sections permitted the use of a different vertical length increment for the mesh at each level. Future versions of COBRA-TF will permit a variable mesh within a section, so that it will not be necessary to divide the mesh into several sections for the sole reason of obtaining a variable mesh length increment. Each section was divided into 51 mesh cells (or channels 1 node high) as shown in Figure 48. Additional channels were added to sections 4 and 5 (Figures 49 and 50) to model the blower inlet vents and outflow slots at the top of the test section. A finer mesh was used in the vicinity of the horizontal jet, so that the momentum of the jet would be conserved in the calculation. This was done because it was believed that the momentum of the jet would be a predominant factor in the mixing behavior of the test section. A total of 266 mesh cells were used to model the test section. Each mesh cell was modeled with a single channel, one node high.

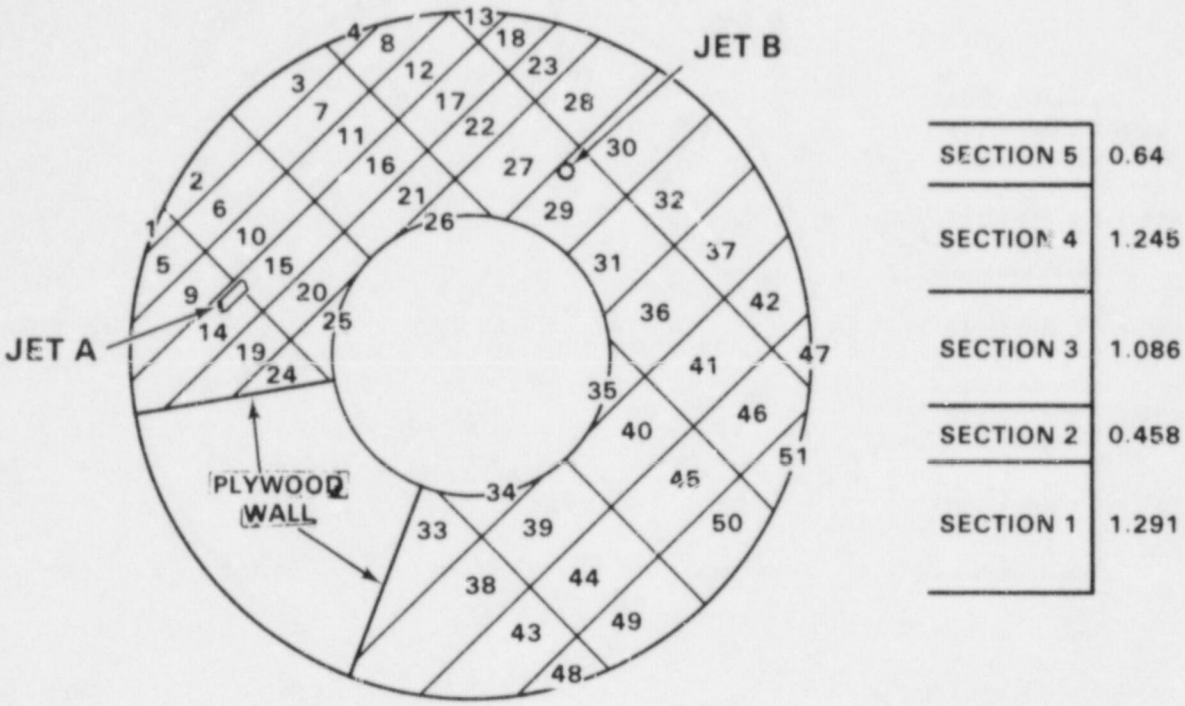


Figure 48 COBRA-TF mesh for CSTF pretest predictions

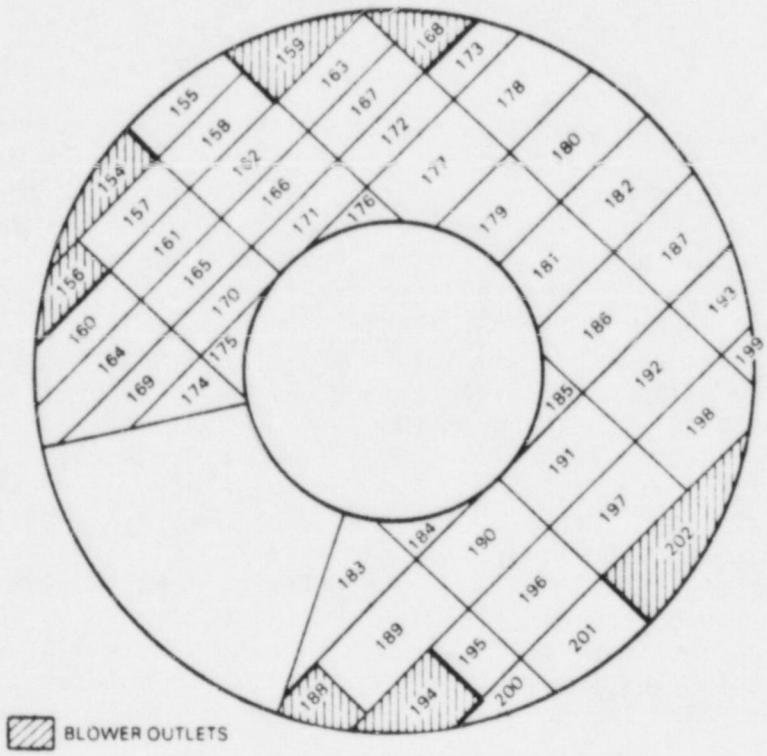


Figure 49 Mesh for section 4

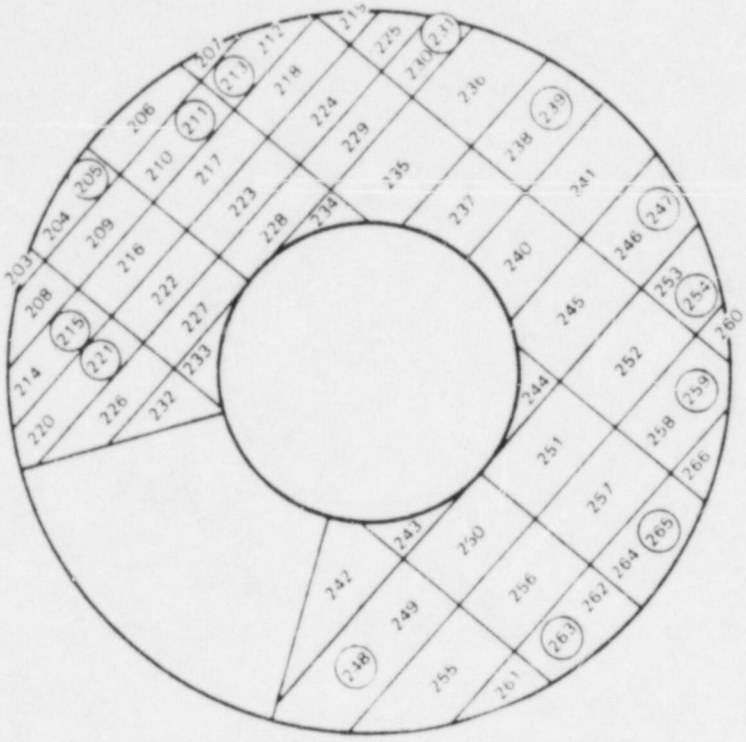


Figure 50 Mesh for section 5

The area for each channel was calculated from the dimensions provided in Figures 43 and 44 using the assumption that the mesh lines shown in Figure 48 were perpendicular to the horizontal nozzle in the one direction and parallel to the nozzle in the other. The channel input data are given in Table 26. Channels in the second and third sections have the same flow area and wetted perimeter as channels occupying the same location in the first section. Sections 4 and 5 contain additional channels to model blower inlet or outlet ducts. Channels with the same flow areas are listed separately. The first section was modeled with channels 1 through 51, the second with channels 52 through 102, the third with channels 103 through 153, the fourth with channels 154 through 202, and the fifth with channels 203 through 266. The input data for the gaps are given in Table 27. The thermal conductor geometry type locations are shown in Figure 51. There are 18 geometry types. The input data for each geometry type is provide in Table 28. The thickness of the inner wall was assumed to be 0.2 in. The outer wall was modeled as a composite wall consisting of 0.65 in. of steel in the inside covered by 1.0 in. of glass fiber insulation. The inner wall was modeled with two regions each 0.1 in. thick and each containing 5 heat transfer nodes. The outer wall was modeled with three regions each having 5 heat transfer nodes through the thickness.

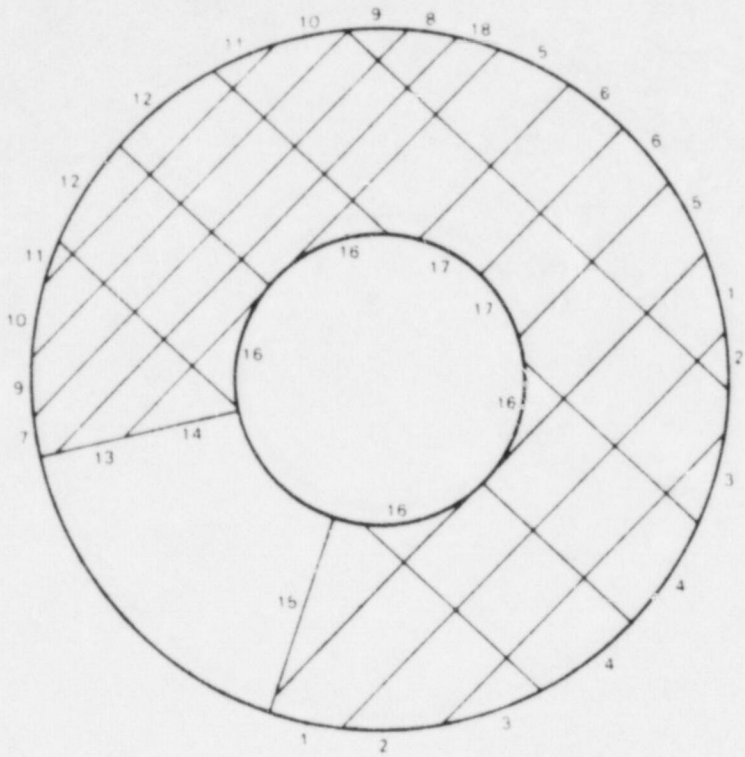


Figure 51 Location of thermal conductor geometry types

The inner region was 0.1 in. thick, the second 0.55 in. thick and the last 1.0 in. thick. The steel wall was modeled with the first two regions and the insulation with the third region. The boundary conditions at the jet nozzle for test HM-5 are given in Table 29. Since the nozzle flows were reported separately for each species of the gas/vapor jet, (Figure 44), these had to be converted into the total mass flow rate, and the volume fraction and enthalpy of each species had to be 128 calculated for input to the code. The jet was injected into channel 66 in the horizontal direction.

The boundary conditions for the blower discharge vent are given in Table 30. The volume fractions given in Table 30 are slightly lower than the measured volume fractions since the measured volume fractions were reported on a dry basis. The volume fraction given in Table 30 are based on the assumption that the recirculated nitrogen and hydrogen are saturated with water vapor.

A listing of the input deck for this sample problem is given in Table 31.

Table 26 Channel input data

Channel Numbers	Area ($in.^2$)	Wetted P (in.)	Comments
1, 52, 103, 203	107.7	23.32	
2, 53, 104	760.3	50.95	
3, 54, 105, 206	760.3	50.95	
4, 55, 106, 207	107.7	23.32	
5, 56, 107, 156, 208	838.9	31.90	
6, 57, 108, 157, 209	901.1	0.001	18.027 x 49.987 = 901.1 $in.^2$
7, 58, 101	901.1	0.001	
8, 59, 110	838.9	31.90	
9, 60, 111, 160	1027.0	25.33	
10, 61, 112, 161, 216	901.1	0.001	
11, 62, 113, 162, 217	901.1	0.001	
12, 63, 114, 163, 218	899.0	3.24	
13, 64, 115, 219	127.9	22.10	
14, 65, 116, 164	1257.0	26.63	
15, 66, 117, 165, 222	901.1	0.001	
16, 67, 118, 166, 223	901.1	0.001	
17, 68, 119, 167, 224	901.1	0.001	
18, 69, 120, 225	396.4	19.159	
19, 70, 121, 168, 226	871.6	31.43	
20, 71, 122, 169, 227	901.1	0.001	
21, 72, 123, 171, 228	901.1	0.001	
22, 73, 124, 172, 229	901.1	0.001	
23, 74, 125, 173	598.1	20.32	
24, 75, 126, 174, 232	440.3	43.26	
25, 76, 127, 175, 233	397.9	57.43	
26, 77, 128, 176, 234	399.1	59.17	
27, 78, 129, 177, 235	1493.0	3.47	
28, 79, 130, 178, 236	1282.0	31.41	
29, 80, 131, 179, 237	1279.0	31.32	
30, 81, 132, 180	1466.0	30.11	
31, 82, 133, 181, 240	1283.0	31.41	
32, 83, 134, 182, 241	1470.0	30.19	
33, 84, 135, 183, 242	1422.0	90.80	
34, 85, 136, 184, 243	407.0	59.17	
35, 86, 137, 185, 244	407.0	59.17	
36, 87, 138, 186, 245	1497.0	3.385	
37, 88, 139, 187	1284.0	31.52	
38, 89, 140	2370.0	31.06	
39, 90, 141, 190, 250	1499.0	0.001	29.992 x 49.987 = 1499.0 $in.^2$
40, 91, 142, 191, 251	1499.0	0.001	
41, 92, 143, 192, 252	1499.0	0.001	
42, 93, 144, 193	885.5	34.79	
43, 94, 145, 255	1693.0	42.56	
44, 95, 146, 196, 256	1499.0	0.001	

(Table 26, continued).

Channel Numbers	Area ($in.^2$)	Wetted P (in.)	Comments
45, 96, 147, 197, 257	1499.0	0.001	
46, 97, 148, 198	1464.0	20.57	
47, 98, 149, 199, 260	450.5	29.63	
48, 99, 150, 200, 261	480.7	45.53	
49, 100,151, 201	1359.0	50.96	
50, 101,152	1359.0	50.96	
51, 102,153, 266	480.7	45.53	
154,	868.0	74.27	Blower outlet at 25°
155	868.0	74.27	
158	1320.5	0.001	
159	419.5	31.9	Blower outlet at 90°
168	524.3	41.3	Blower outlet at 90°
188	1185.0	31.06	Blower outlet at 270°
189	1185.0	0.001	
194	1129.0	42.56	Blower outlet at 270°
195	564.0	0.001	
205	397.51	122.4	Outlet slots at 25°
204	362.8	173.4	
211	132.5	40.8	Outlet slot at 70°
210	768.6	40.8	
212	706.4	72.7	
213	132.5	40.8	Outlet slot at 70° 215 132.5
40.8	Outlet slot at 5°		
214	894.5	66.13	
221	132.5	40.8	Outlet slot at 5°
220	1124.5	67.4	
231	132.5	40.8	Outlet slot at 90°
230	465.6	61.1	
239	265.0	81.6	Outlet slot at 115°
238	1201.0	111.7	
247	265.0	81.6	Outlet slot at 160°
246	1019.0	113.0	
248	397.5	122.4	Outlet slot at 275°
249	1972.5	153.5	
258	1199.0	102.2	
263	265.0	81.6	Outlet slot at 250°
262	1094.0	132.6	
265	265.0	81.6	Outlet slot at 220°
264	1094.0	132.6	
259	265.0	81.6	Outlet slot at 190°
258	1199.0	102.2	
254	132.5	40.8	Outlet slot at 160°
253	753.0	75.6	
202	1839.7	96.49	Blower outlet at 210°

Table 27 Gap Input Data

Gap No.	Channels Connected by Gap		Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
1	1	2	9.45	39.19	0.0	0.25		81			
2	1	5	21.30	15.31	0.0	0.25		82			
3	2	3	18.03	49.99	0.0	0.5		83			
4	2	6	49.99	18.03	0.0	0.0		84			
5	3	4	9.45	39.19	0.0	0.25		85			
6	3	7	49.99	18.03	0.0	0.0		86			
7	4	8	21.30	15.31	0.0	0.25		87			
8	5	6	18.03	46.29	0.0	0.0		88			
9	5	9	47.55	18.03	0.0	0.5		89			
10	6	7	18.03	49.99	0.0	0.0		90			
11	6	10	49.99	18.03	0.0	0.0		91			
12	6	10	18.03	46.29	0.0	0.0		92			
13	7	11	49.99	18.03	0.0	0.0		93			
14	8	12	47.55	18.03	0.0	0.0		94			
15	9	10	18.03	53.21	0.0	0.0		95			
16	9	14	65.31	18.03	0.0	0.5		96			
17	10	11	18.03	49.99	0.0	0.0		97			
18	10	15	49.99	18.03	0.0	0.0		98			
19	11	12	18.03	49.99	0.0	0.0		99			
20	11	16	49.99	18.03	0.0	0.0		100			
21	12	13	15.89	32.65	0.0	0.25		101			
22	12	17	49.99	18.03	0.0	0.0		102			
23	13	18	15.33	18.03	0.0	0.25		103			
24	14	15	18.03	58.22	0.0	0.0		104			
25	14	19	61.2	18.03	0.0	0.5		105			
26	15	16	18.03	49.99	0.0	0.0		106			
27	15	20	49.99	18.03	0.0	0.0		107			
28	16	17	18.03	49.99	0.0	0.0		108			
29	16	21	49.99	18.03	0.0	0.0		109			
30	17	18	18.03	35.87	0.0	0.0		110			
31	17	22	49.99	18.03	0.0	0.0		111			
32	18	23	28.19	18.03	0.0	0.5		112			
33	19	20	18.03	49.15	0.0	0.0		113			
34	19	24	35.45	18.03	0.0	0.5		114			
35	20	21	18.03	49.99	0.0	0.5		115			
36	20	25	49.99	18.03	0.0	0.0		116			
37	21	22	18.03	49.99	0.0	0.0		117			
38	21	26	49.99	18.03	0.0	0.0		118			
39	22	23	18.03	41.43	0.0	0.0		119			

(Table 27, continued).

Gap No.	Channels Connected by Gap		Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
40	22	27	49.99	18.03	0.0	0.0		121			
41	23	28	37.54	18.03	0.0	0.5		121			
42	24	25	24.82	30.22	0.0	0.5		122			
43	26	27	26.95	27.49	0.0	0.0		123			
44	27	28	29.91	46.87	0.0	0.0		124			
45	27	29	48.16	29.91	0.0	0.5		125			
46	28	30	46.97	29.91	0.0	0.5		126			
47	29	30	29.91	46.31	0.0	0.0		127			
48	29	31	40.15	29.95	0.0	0.5		128			
49	30	32	49.99	29.95	0.0	0.5		129			
50	31	32	29.99	46.31	0.0	0.0		130			
51	31	36	48.21	29.99	0.0	0.5		131			
52	32	37	46.96	29.99	0.0	0.5		132			
53	33	34	26.96	51.82	0.0	0.5		133			
54	33	38	76.65	29.99	0.0	0.5		134			
55	34	39	49.99	24.16	0.0	0.0		135			
56	35	36	26.96	34.49	0.0	0.0		136			
57	35	40	49.99	24.16	0.0	0.0		137			
58	36	37	29.99	46.10	0.0	0.0		138			
59	36	41	49.99	29.97	0.0	0.0		139			
60	37	42	37.47	29.99	0.0	0.5		140			
61	38	39	29.99	64.08	0.0	0.0		141			
62	38	43	69.98	29.99	0.0	0.5		142			
63	39	40	29.99	49.99	0.0	0.0		143			
64	39	40	49.99	29.99	0.0	0.0		144			
65	40	41	29.99	49.99	0.0	0.0		145			
66	40	45	49.99	29.99	0.0	0.0		146			
67	41	42	29.99	39.36	0.0	0.0		147			
68	41	46	49.99	29.99	0.0	0.0		148			
69	42	47	29.99	25.89	0.0	0.25		149			
70	43	44	29.99	52.49	0.0	0.0		150			
72	44	45	29.99	49.99	0.0	0.0		152			
73	44	49	49.99	27.85	0.0	0.0		153			
74	45	46	29.99	49.99	0.0	0.0		154			
75	45	50	29.99	27.85	0.0	0.0		155			
76	46	47	21.80	34.99	0.0	0.25		156			
77	46	51	39.99	25.70	0.0	0.25		157			
77	46	51	39.99	25.70	0.0	0.25		157			
78	48	49	21.42	49.99	0.0	0.25		158			

(Table 27, continued)

Gap No.	Channels Connected by Gap		Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
79	49	50	29.99	49.99	0.0	0.5		159			
80	50	51	21.42	49.99	0.0	0.25		160			
81	50	51	9.45	39.19	0.0	0.25		161			
82	52	53	21.30	15.31	0.0	0.25		162			
83	52	56	18.03	49.99	0.0	0.5		163			
84	53	54	49.99	18.03	0.0	0.0		164			
85	53	57	9.45	39.19	0.0	0.25		165			
86	54	55	49.99	18.03	0.0	0.0		166			
87	54	58	21.30	15.31	0.0	0.25		167			
88	55	59	18.03	46.29	0.0	0.0		168			
89	56	57	47.55	18.03	0.0	0.5		169			
90	56	60	18.03	49.99	0.0	0.0		170			
91	57	58	49.99	18.03	0.0	0.0		171			
92	58	59	18.03	46.29	0.0	0.0		172			
93	58	62	49.99	18.03	0.0	0.0		173			
94	59	63	47.55	18.03	0.0	0.0		174			
95	60	61	18.03	53.21	0.0	0.0		175			
96	60	65	65.31	18.03	0.0	0.5		176			
97	61	62	18.03	49.99	0.0	0.0		177			
98	61	66	49.99	18.03	0.0	0.0		178			
99	62	63	18.03	49.99	0.0	0.0		179			
100	62	67	49.99	18.03	0.0	0.0		180			
101	63	64	15.89	32.65	0.0	0.25		181			
102	63	68	49.99	18.03	0.0	0.0		182			
103	64	69	15.33	18.03	0.0	0.25		183			
104	65	66	18.03	58.22	0.0	0.0		184			
105	65	70	61.2	18.03	0.0	0.5		185			
106	66	67	18.03	49.99	0.0	0.0		186			
107	66	71	49.99	18.03	0.0	0.0		187			
108	67	68	18.03	49.99	0.0	0.0		188			
109	67	72	49.99	18.03	0.0	0.0		189			
110	68	69	18.03	35.87	0.0	0.0		190			
111	68	73	49.99	18.03	0.0	0.0		191			
112	69	74	28.19	18.03	0.0	0.5		192			
113	70	71	18.03	49.15	0.0	0.0		193			
114	70	75	35.45	18.03	0.0	0.5		194			
115	71	72	18.03	49.99	0.0	0.5		195			
116	71	76	49.99	18.03	0.0	0.0		196			

(Table 27, continued).

Gap No.	Channels Connected by Gap		Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
117	72	73	18.03	49.99	0.0	0.0		197			
118	72	77	49.99	18.03	0.0	0.0		198			
119	73	74	18.03	41.43	0.0	0.0		199			
120	73	78	49.99	18.03	0.0	0.0		200			
121	74	79	37.54	18.03	0.0	0.5		201			
122	75	76	24.82	30.22	0.0	0.5		202			
123	78	79	26.95	27.49	0.0	0.0		203			
124	78	79	29.91	46.87	0.0	0.0		204			
125	78	80	48.16	29.91	0.0	0.5		205			
126	79	81	46.97	29.91	0.0	0.5		206			
127	80	81	29.91	46.31	0.0	0.0		207			
128	80	82	40.15	29.95	0.0	0.5		208			
129	81	83	49.99	29.95	0.0	0.5		209			
130	82	83	29.99	46.31	0.0	0.0		210			
131	82	87	48.21	29.99	0.0	0.5		211			
132	83	88	46.96	29.99	0.0	0.5		212			
133	84	85	26.96	51.82	0.0	0.5		213			
134	84	89	76.65	29.99	0.0	0.5		214			
135	85	90	49.99	24.16	0.0	0.0		215			
136	86	87	26.96	34.49	0.0	0.0		216			
137	86	91	49.99	24.16	0.0	0.0		217			
138	87	88	29.99	46.10	0.0	0.0		218			
139	87	92	49.99	29.97	0.0	0.0		219			
140	88	93	37.47	29.99	0.0	0.5		220			
141	89	90	29.99	64.08	0.0	0.0		221			
142	89	94	69.98	29.99	0.0	0.5		222			
143	90	91	29.99	49.99	0.0	0.0		223			
144	90	95	49.99	29.99	0.0	0.0		224			
145	91	92	29.99	49.99	0.0	0.0		225			
146	91	96	49.99	29.99	0.0	0.0		226			
147	92	93	29.99	39.36	0.0	0.0		227			
148	92	97	49.99	29.99	0.0	0.0		228			
149	93	98	29.99	25.89	0.0	0.25		229			
150	94	95	29.99	52.49	0.0	0.0		230			
151	94	99	39.99	25.70	0.0	0.25		231			
152	95	96	29.99	49.99	0.0	0.0		232			
153	95	100	49.99	27.85	0.0	0.0		233			

(Table 27, continued).

Gap No.	Channels Connected by Gap		Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
154	96	97	29.99	49.99	0.0	0.0		234			
155	96	101	29.99	27.85	0.0	0.0		235			
156	97	98	21.80	34.99	0.0	0.25		236			
157	97	102	39.99	25.70	0.0	0.25		237			
158	99	100	39.99	25.70	0.0	0.25		238			
159	100	101	21.42	49.99	0.0	0.25		239			
160	101	102	9.45	39.19	0.0	0.25		240			
161	103	104	9.45	39.19	0.0	0.25		0			
162	103	107	21.30	15.31	0.0	0.25		0			
163	104	105	18.03	49.99	0.0	0.5		0			
164	104	108	49.99	18.03	0.0	0.0		0			
165	105	106	9.45	39.19	0.0	0.25		0			
166	105	109	49.99	18.03	0.0	0.0		242			
167	106	110	21.30	15.31	0.0	0.25		0			
168	107	108	18.03	46.29	0.0	0.0		0			
169	107	111	47.55	18.03	0.0	0.5		0			
170	108	109	18.03	49.99	0.0	0.0		244			
171	108	112	49.99	18.03	0.0	0.0		245			
172	109	110	18.03	46.29	0.0	0.0		0			
173	109	113	49.99	18.03	0.0	0.0		246			
174	110	114	47.55	18.03	0.0	0.0		0			
175	111	112	18.03	53.21	0.0	0.0		248			
176	111	116	65.31	18.03	0.0	0.5		249			
177	112	113	18.03	49.99	0.0	0.0		250			
178	112	117	49.99	18.03	0.0	0.0		251			
179	113	114	18.03	49.99	0.0	0.0		252			
180	113	118	49.99	18.03	0.0	0.0		253			
181	114	115	15.89	32.65	0.0	0.25		0			
182	114	119	49.99	18.03	0.0	0.0		255			
183	115	120	15.33	18.03	0.0	0.25		0			
184	116	117	18.03	58.22	0.0	0.0		256			
185	116	121	61.2	18.03	0.0	0.5		257			
186	117	118	18.03	49.99	0.0	0.0		258			
187	117	122	49.99	18.03	0.0	0.0		259			
188	118	119	18.03	49.99	0.0	0.0		260			
189	118	123	49.99	18.03	0.0	0.0		261			
190	119	120	18.03	35.87	0.0	0.0		0			
191	119	124	49.99	18.03	0.0	0.0		263			
192	120	125	28.19	18.03	0.0	0.5		0			
193	121	122	18.03	49.15	0.0	0.0		264			
194	121	126	35.45	18.03	0.0	0.5		265			
195	122	123	18.03	49.99	0.0	0.5		266			

(Table 27, continued).

Gap No.	Channels Connected by Gap	Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
196	122 127	49.99	18.03	0.0	0.0		267			
197	123 124	18.03	49.99	0.0	0.0		268			
198	123 128	49.99	18.03	0.0	0.0		269			
199	124 125	18.03	41.43	0.0	0.0		270			
200	124 129	49.99	18.03	0.0	0.0		271			
201	125 130	37.54	18.03	0.0	0.5		272			
202	126 127	24.82	30.22	0.0	0.5		273			
203	128 129	26.95	27.49	0.0	0.0		274			
204	129 130	29.91	46.87	0.0	0.0		275			
205	129 131	48.16	29.91	0.0	0.5		276			
206	130 132	46.97	29.91	0.0	0.5		277			
207	131 132	29.91	46.31	0.0	0.0		278			
208	131 133	40.15	29.95	0.0	0.5		279			
209	132 134	49.99	29.95	0.0	0.5		280			
210	133 134	29.99	46.31	0.0	0.0		281			
211	133 138	48.21	29.99	0.0	0.5		282			
212	134 139	46.96	29.99	0.0	0.5		283			
213	135 136	26.96	51.82	0.0	0.5		284			
214	135 140	76.65	29.99	0.0	0.5		285			
215	136 141	49.99	24.16	0.0	0.0		286			
216	137 138	26.96	34.49	0.0	0.0		287			
217	138 142	49.99	24.16	0.0	0.0		288			
218	138 139	29.99	46.10	0.0	0.0		289			
219	138 143	49.99	29.97	0.0	0.0		290			
220	139 144	37.47	29.99	0.0	0.5		291			
221	140 141	29.99	64.08	0.0	0.0		293			
222	140 145	69.98	29.99	0.0	0.5		294			
223	141 142	29.99	49.99	0.0	0.0		295			
224	141 146	49.99	29.99	0.0	0.0		296			
225	142 143	29.99	49.99	0.0	0.0		297			
226	142 147	49.99	29.99	0.0	0.0		298			
227	143 144	29.99	39.36	0.0	0.0		299			
228	143 148	49.99	29.99	0.0	0.0		300			
229	144 149	29.99	25.89	0.0	0.25		301			
230	145 146	29.99	52.49	0.0	0.0		303			
231	145 150	25.99	25.70	0.0	0.25		304			
232	146 147	29.99	49.99	0.0	0.0		305			
233	146 151	49.99	27.85	0.0	0.0		306			
234	147 148	29.99	49.99	0.0	0.0		307			
235	147 152	29.99	27.85	0.0	0.0		0			
236	148 149	21.80	34.99	0.0	0.25		309			
237	148 153	39.99	25.70	0.0	0.25		0			

(Table 27, continued).

Gap No.	Channels Connected by Gap	Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
238	150 151	39.99	25.70	0.0	0.25		312			
239	151 152	21.42	49.99	0.0	0.25		0			
240	152 153	29.99	49.99	0.0	0.5		0			
241	154 157	21.69	18.03	0.0	0.5		0			
242	155 158	49.99	18.03	0.0	0.5		319			
243	156 157	10.84	46.29	0.0	0.0		0			
244	157 158	18.03	49.99	0.0	0.5		323			
245	159 161	49.99	18.03	0.0	0.0		324			
246	158 162	49.99	18.03	0.0	0.0		327			
247	159 163	46.27	18.03	0.0	0.0		0			
248	160 161	18.03	53.21	0.0	0.0		331			
249	160 164	65.31	18.03	0.0	0.5		33			
250	161 162	18.03	49.99	0.0	0.0		333			
251	161 165	49.99	18.03	0.0	0.0		334			
252	162 163	18.03	49.99	0.0	0.0		335			
253	162 166	49.99	18.03	0.0	0.0		336			
254	163 168	8.14	32.65	0.0	0.5		0			
255	163 167	49.99	18.03	0.0	0.5		338			
256	164 165	18.03	58.22	0.0	0.0		341			
257	164 169	61.20	18.03	0.0	0.5		342			
258	165 166	18.03	49.99	0.0	0.0		343			
259	165 170	49.99	18.03	0.0	0.0		344			
260	166 167	18.03	49.99	0.0	0.0		345			
261	166 171	49.99	18.03	0.0	0.0		346			
262	167 168	8.14	35.87	0.0	0.0		0			
263	167 172	49.99	18.03	0.0	0.0		347			
264	169 170	18.03	49.15	0.0	0.0		348			
265	169 174	35.45	18.03	0.0	0.5		349			
266	170 171	18.03	49.99	0.0	0.5		350			
267	170 175	49.99	18.03	0.0	0.0		351			
268	171 172	18.03	49.99	0.0	0.0		352			
269	171 176	49.99	18.03	0.0	0.0		353			
270	172 173	18.03	41.43	0.0	0.0		354			
271	172 177	49.99	18.03	0.0	0.0		355			
272	173 178	37.54	18.03	0.0	0.5		357			
273	174 175	24.82	30.22	0.0	0.5		358			
274	176 177	26.95	37.49	0.0	0.0		359			
275	177 178	29.91	46.87	0.0	0.0		360			
276	177 179	48.16	29.91	0.0	0.5		361			
277	178 180	46.97	29.91	0.0	0.5		362			
278	179 180	29.91	46.31	0.0	0.0		363			
279	179 181	40.15	29.95	0.0	0.5		364			

(Table 27, continued).

Gap No.	Channels Connected by Gap	Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
280	180 182	49.99	29.95	0.0	0.5		366			
281	181 182	29.99	46.31	0.0	0.0		367			
282	181 186	48.21	29.99	0.0	0.5		368			
283	182 187	46.96	29.99	0.0	0.5		369			
284	183 184	26.96	51.82	0.0	0.5		370			
285	183 189	57.56	29.99	0.0	0.5		371			
286	184 190	49.99	24.16	0.0	0.0		372			
287	185 186	26.96	34.49	0.0	0.0		373			
288	185 191	49.99	24.16	0.0	0.0		374			
289	186 187	29.99	46.10	0.0	0.0		375			
290	186 192	49.99	29.99	0.0	0.0		376			
291	187 193	37.47	29.99	0.0	0.5		378			
292	188 189	8.14	29.99	0.0	0.25		0			
293	189 190	49.99	29.99	0.0	0.0		380			
294	189 195	19.18	29.99	0.0	0.5		381			
295	190 191	29.99	49.99	0.0	0.5		382			
296	190 196	49.99	29.99	0.0	0.0		383			
297	191 192	29.99	49.99	0.0	0.0		384			
298	191 197	49.99	29.99	0.0	0.0		385			
299	192 193	29.99	39.36	0.0	0.0		386			
300	192 198	49.99	29.99	0.0	0.0		387			
301	193 199	19.99	25.89	0.0	0.25		389			
302	194 195	18.14	19.19	0.0	0.0		0			
303	195 196	29.99	34.58	0.0	0.0		390			
304	195 200	19.18	25.70	0.0	0.25		391			
305	196 197	29.99	49.99	0.0	0.0		392			
306	196 201	49.99	27.85	0.0	0.0		393			
307	197 198	29.99	49.99	0.0	0.0		394			
308	197 202	49.99	27.85	0.0	0.0		0			
309	198 199	21.80	34.99	0.0	0.5		397			
310	198 202	39.99	25.70	0.0	0.25		0			
311	118 194	16.27	29.99	0.0	0.25		0			
312	200 201	21.42	44.99	0.0	0.25		399			
313	203 204	9.45	39.19	0.0	0.25		0			
314	203 208	21.30	15.31	0.0	0.25		0			
315	204 205	5.08	12.98	1.5	0.0		0			
316	204 206	18.03	49.99	0.0	0.0		0			
317	204 208	49.99	18.03	0.0	0.0		0			
318	206 207	9.45	39.19	0.0	0.25		0			
319	206 210	49.99	18.03	0.0	0.0		0			
320	207 212	21.30	15.31	0.0	0.25		0			
321	208 209	18.03	46.29	0.0	0.0		0			

(Table 27, continued).

Gap No.	Channels Connected by Gap	Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
322	208 214	47.55	18.03	0.0	0.5		0			
323	209 210	18.03	49.99	0.0	0.0		0			
324	209 216	49.99	18.03	0.0	0.0		0			
325	210 211	1.693	12.98	1.5	0.0		0			
326	210 212	18.03	46.29	0.0	0.0		0			
327	210 217	49.99	18.03	0.0	0.0		0			
328	212 213	1.693	12.98	1.5	1.5		0			
329	212 218	47.55	18.03	0.0	0.5		0			
330	214 215	1.693	12.98	1.5	1.5		0			
331	214 216	18.03	53.21	0.0	0.0		0			
332	214 220	65.31	18.03	0.0	0.5		0			
333	216 217	18.03	49.99	0.0	0.0		0			
334	216 222	49.99	18.03	0.0	0.0		0			
335	217 218	18.03	49.99	0.0	0.0		0			
336	217 223	49.99	18.03	0.0	0.0		0			
337	218 219	15.89	32.65	0.0	0.25		0			
338	218 224	49.99	18.03	0.0	0.0		0			
339	219 225	3.386	12.98	1.5	0.0		0			
340	220 221	1.693	12.98	1.5	0.0		0			
341	220 222	18.03	58.22	0.0	0.0		0			
342	220 226	61.20	18.03	0.0	0.5		0			
343	222 223	18.03	49.99	0.0	0.0		0			
344	222 227	49.99	18.03	0.0	0.0		0			
345	223 224	18.03	49.99	0.0	0.0		0			
346	223 228	49.99	18.03	0.0	0.0		0			
347	224 229	49.99	18.03	0.0	0.0		0			
348	226 227	18.03	49.15	0.0	0.0		0			
349	226 232	35.45	18.03	0.0	0.5		0			
350	227 228	18.03	49.99	0.0	0.5		0			
351	227 233	49.99	18.03	0.0	0.0		0			
352	228 229	18.03	49.99	0.0	0.0		0			
353	228 234	49.99	18.03	0.0	0.0		0			
354	229 230	18.03	41.43	0.0	0.0		0			
355	229 235	49.99	18.03	0.0	0.0		0			
356	230 231	1.693	12.98	1.5	0.0		0			
357	230 236	37.54	18.03	0.0	0.5		0			
358	232	24.82	30.22	0.0	0.5		0			
359	234 235	26.95	37.49	0.0	0.0		0			
360	235 236	29.91	46.87	0.0	0.0		0			
361	235 237	48.16	29.91	0.0	0.5		0			
362	236 238	46.97	29.91	0.0	0.5		0			
363	237 238	29.91	46.31	0.0	0.0		0			

(Table 27, continued).

Gap No.	Channels Connected by Gap	Width (in.)	Length (in.)	Loss Coefficients	FWALL	IGAPB	IGAPA	FACTOR	IGAP	JGAP
364	237 240	40.15	29.95	0.0	0.5		0			
365	238 239	3.386	12.98	1.5	0.0		0			
366	238 241	49.99	29.95	0.0	0.5		0			
367	240 241	29.99	46.31	0.0	0.0		0			
368	240 245	48.21	29.99	0.0	0.5		0			
369	241 246	46.96	29.99	0.0	0.5		0			
370	242 243	26.96	51.82	0.0	0.5		0			
371	242 249	76.65	29.99	0.0	0.5		0			
372	243 250	49.99	24.16	0.0	0.0		0			
373	244 245	26.96	34.49	0.0	0.0		0			
374	244 151	49.99	24.16	0.0	0.0		0			
375	245 246	29.99	46.10	0.0	0.0		0			
376	245 152	49.99	29.99	0.0	0.0		0			
377	246 247	3.386	12.98	1.5	0.0		0			
378	246 253	37.47	29.99	0.0	0.5		0			
379	248 249	5.079	12.98	1.5	0.0		0			
380	249 150	29.99	64.08	0.0	0.0		0			
381	249 155	69.98	29.99	0.0	0.5		0			
381	250 151	29.99	49.99	0.0	0.5		0			
383	250 156	49.99	29.99	0.0	0.0		0			
384	251 252	29.99	49.99	0.0	0.0		0			
385	251 257	49.99	29.99	0.0	0.0		0			
386	252 253	29.99	39.36	0.0	0.0		0			
387	252 258	49.99	29.99	0.0	0.0		0			
388	253 254	1.693	12.98	1.5	0.0		0			
389	253 260	19.99	25.89	0.0	0.25		0			
390	255 256	29.99	52.49	0.0	0.0		0			
391	255 261	39.99	25.70	0.0	0.25		0			
392	256 257	29.99	49.99	0.0	0.0		0			
393	256 262	49.99	27.85	0.0	0.0		0			
394	257 258	29.99	49.99	0.0	0.0		0			
395	257 264	49.99	27.85	0.0	0.0		0			
396	158 259	3.386	12.98	1.5	0.0		0			
397	258 260	21.80	34.99	0.0	0.25		0			
398	258 266	39.99	25.70	0.0	0.25		0			
399	261 262	21.42	44.99	0.0	0.25		0			
400	262 263	3.386	12.98	1.5	0.0		0			
401	262 264	29.99	49.99	0.0	0.5		0			
402	264 265	3.386	12.98	1.5	0.0		0			
403	264 266	21.42	49.99	0.0	0.25		0			

Table 28 Input data for thermal conductor geometry types

Geometry Type	Heated Perimeter (inches)	Total Thickness (inches)	Number of Nodes and thickness of each region (inches)		
1	34.79	1.65	5(.1)	5(.55)	5(1.0)
2	29.63	1.65	5(.1)	5(.55)	5(1.0)
3	45.54	1.65	5(.1)	5(.55)	5(1.0)
4	50.96	1.65	5(.1)	5(.55)	5(1.0)
5	31.42	1.65	5(.1)	5(.55)	5(1.0)
6	30.11	1.65	5(.1)	5(.55)	5(1.0)
7	26.65	1.65	5(.1)	5(.55)	5(1.0)
8	19.16	1.65	5(.1)	5(.55)	5(1.0)
9	25.34	1.65	5(.1)	5(.55)	5(1.0)
10	31.90	1.65	5(.1)	5(.55)	5(1.0)
11	23.32	1.65	5(.1)	5(.55)	5(1.0)
12	50.96	1.65	5(.1)	5(.55)	5(1.0)
13	31.43	1.65	5(.1)	5(.55)	5(1.0)
14	43.28	1.65	5(.1)	5(.55)	5(1.0)
15	90.13	1.65	5(.1)	5(.55)	5(1.0)
16	59.17	0.2	5(.1)	5(.1)	
17	31.41	0.2	5(.1)	5(.1)	
18	20.32	1.65	5(.1)	5(.55)	5(1.0)

Table 29 Nozzle boundary condition input for test HM-5

Time (sec)	Total Flow (lbm/sec)	Volume Fraction H_2	Volume Fraction H_2O	Time (sec)	Enthalpy (Btu/lbm) H_2	Enthalpy (Btu/lbm) H_2O
703.0	0.0	0.0	1.0	741.8	2297	1155.0
722.2	0.4012	0.0	1.0	967.2	2280	1150.5
743.2	0.7194	0.0	1.0	1060.0	2284	1151.1
746.6	0.7719	0.0115	0.9885	1123.0	2435	1173.5
780.9	0.8180	0.1082	0.8918	1183.0	2465	1178.3
840.2	0.8878	0.1053	0.8947	1243.0	2495	1181.0
880.3	0.9110	0.1024	0.8976	1303.0	2504	1183.5
927.4	0.8962	0.1038	0.8962	1375.0	2519	1185.0
1018.7	0.8927	0.1046	0.8954	2400.0	2519	1185.0
1066.4	0.9022	0.1031	0.8969			
1126.3	0.8920	0.1046	0.8954			
1369.9	0.8925	0.1046	0.8954			
1375.2	0.8917	0.0942	0.9058			
1417.0	0.0	0.0942	0.9058			

Table 30 Blower discharge boundary condition input for test HM-5

Time (sec)	Volume Fractions N_2	H_2	Steam	Enthalpy (Btu/lbm) $N_2 + H_2$	Steam
0.0	0.9438	0.0	0.0562	132.66	1102.9
750.0	0.9438	0.0	0.0562	132.66	1102.9
803.4	0.9438	0.0	0.0562	134.81	1100.1
1080.0	0.8557	0.0180	0.1254	143.14	1116.8
1440.0	0.7883	0.0441	0.1660	147.61	1122.0
1698.0	0.8181	0.472	0.1364	147.63	1118.2
2040.0	0.8322	0.0449	0.1215	147.15	1116.3
2400.0	0.8401	0.0451	0.1140	147.12	1115.3

Table 31 COBRA-TF input listing for CSTF

```
                    703.
       .001              5              40
      1 HEDL SP ON HYDROGEN MIXING AND DISTRIBUTION-JET A
    1    2
      278.      278.      27.8      278.
   14.5038    1123.1       0.0       0.0      143.2     1.E-08     .05998
HYDROGEN     .000001AIR             .940019
    2  266  160
    1107.723.32                 2
    2    1   81    2    2   82
    2760.350.95                 3
    2    1   81    2    3   83    2    4   84
    3760.350.95                 3
    2    3   83    2    5   85    2    6   86
    4107.723.32                 2
    2    5   85    2    7   87
    5838.9 31.9                 3
    2    2   82    2    8   88    2    9   89
    6901.1 .001                 4
    2    4   84    2    8   88    2   10   90    2   11   91
    7901.1 .001                 4
    2    6   86    2   10   90    2   12   92    2   13   93
    8838.9 31.9                 3
    2    7   87    2   12   92    2   14   94
    91027.25.33                 3
    2    9   89    2   15   95    2   16   96
   10901.1 .001                 4
    2   11   91    2   15   95    2   17   97    2   18   98
   11901.1 .001                 4
    2   13   93    2   17   97    2   19   99    2   20  100
```

```
12 899. 3.24                                  4
 2   14   84    2   19   99    2   21  101    2   22  102
13127.9 22.1                                  2
 2   21  101    2   23  103
141257.26.63                                  3
 2   16   96    2   24  104    2   25  105
15901.1 .001                                  4
 2   18   98    2   24  104    2   26  106    2   27  107
16901.1 .001                                  4
 2   20  100    2   26  106    2   28  108    2   29  109
17901.1 .001                                  4
 2   22  102    2   28  108    2   30  110    2   31  111
18396.419.16                                  3
 2   23  103    2   30  110    2   32  112
19871.631.43                                  3
 2   25  105    2   33  113    2   34  114
20901.1 .001                                  4
 2   27  107    2   33  113    2   35  115    2   36  116
21901.1 .001                                  4
 2   29  109    2   35  115    2   37  117    2   38  118
22901.1 .001                                  4
 2   31  111    2   37  117    2   39  119    2   40  120
23598.120.32                                  3
 2   32  112    2   39  119    2   41  121
24440.343.26                                  2
 2   34  114    2   42  122
25397.957.43                                  2
 2   36  116    2   42  122
26399.159.17                                  2
 2   38  118    2   43  123
271493. 3.47                                  4
 2   40  120    2   43  123    2   44  124    2   45  125
281282.31.41                                  3
 2   41  121    2   44  124    2   46  126
291279.31.32                                  3
 2   45  125    2   47  127    2   48  128
301466.30.11                                  3
 2   46  126    2   47  127    2   49  129
311283.31.41                                  3
 2   48  128    2   50  130    2   51  131
321470.30.19                                  3
 2   49  129    2   50  130    2   52  132
331422.90.80                                  2
 2   53  133    2   54  134
34 407.59.17                                  2
 2   53  133    2   55  135
35 407.59.17                                  2
 2   56  136    2   57  137
361497.3.385                                  4
```

```
 2   51  131    2   56  136    2   58  138    2   59  139
371284.31.52                3
 2   52  132    2   58  138    2   60  140
382370.31.06                3
 2   54  134    2   61  141    2   62  142
391499. .001                4
 2   55  135    2   61  141    2   63  143    2   64  134
401499. .001                4
 2   57  137    2   63  143    2   65  145    2   66  146
411499. .001                4
 2   59  139    2   65  145    2   67  147    2   68  148
42885.534.79                3
 2   60  140    2   67  147    2   69  149
431693.42.56                3
 2   62  142    2   70  150    2   71  151
441499. .001                4
 2   64  144    2   70  150    2   72  152    2   73  153
451499. .001                4
 2   66  146    2   72  152    2   74  154    2   75  155
461464.20.57                4
 2   68  148    2   74  154    2   76  156    2   77  157
47450.529.63                2
 2   69  149    2   76  156
48480.745.53                2
 2   71  151    2   78  158
491359.50.96                3
 2   73  153    2   78  158    2   79  159
501359.50.96                3
 2   75  155    2   79  159    2   80  160
51480.745.53                2
 2   77  157    2   80  160
52107.723.32                2
 2   81  161    2   82  162
53760.350.95                3
 2   81  161    2   83  163    2   84  164
54760.350.95                3
 2   83  163    2   85  165    2   86  166
55107.723.32                2
 2   85  165    2   87  167
56838.9 31.9                3
 2   82  162    2   88  168    2   89  169
57901.1 .001                4
 2   84  164    2   88  168    2   90  170    2   91  171
58901.1 .001                4
 2   86  166    2   90  170    2   92  172    2   93  173
59838.9 31.9                3
 2   87  167    2   92  172    2   94  174
601027.25.33                3
 2   89  169    2   95  175    2   96  176
```

```
61901.1 .001                4
 2   91  171    2   95  175    2   97  177    2   98  178
62901.1 .001                4
 2   93  173    2   97  177    2   99  179    2  100  180
63 899. 3.24                4
 2   94  174    2   99  179    2  101  181    2  102  182
64127.9 22.1                2
 2  101  181    2  103  183
651257.26.63                3
 2   96  176    2  104  184    2  105  185
66901.1 .001                4
 2   98  178    2  104  184    2  106  186    2  107  187
67901.1 .001                4
 2  100  180    2  106  186    2  108  188    2  109  189
68901.1 .001                4
 2  102  182    2  108  188    2  110  190    2  111  191
69396.419.16                3
 2  103  183    2  110  190    2  112  192
70871.631.43                3
 2  105  185    2  113  193    2  114  194
71901.1 .001                4
 2  107  187    2  113  193    2  115  195    2  116  196
72901.1 .001                4
 2  109  189    2  115  195    2  117  197    2  118  198
73901.1 .001                4
 2  111  191    2  117  197    2  119  199    2  120  200
74598.120.32                3
 2  112  192    2  119  199    2  121  201
75440.343.26                2
 2  114  194    2  122  202
76397.957.43                2
 2  116  196    2  122  202
77399.159.17                2
 2  118  198    2  123  203
781493. 3.47                4
 2  120  200    2  123  203    2  124  204    2  125  205
791282.31.41                3
 2  121  201    2  124  204    2  126  206
801279.31.32                3
 2  125  205    2  127  207    2  128  208
811466.30.11                3
 2  126  206    2  127  207    2  129  209
821283.31.41                3
 2  128  208    2  130  210    2  131  211
831470.30.19                3
 2  129  209    2  130  210    2  132  212
841422.90.80                2
 2  133  213    2  134  214
85 407.59.17                2
```

```
 2  133  213    2  135  215
86 407.59.17                2
 2  136  216    2  137  217
871497.3.385                4
 2  131  211    2  136  216    2  138  218    2  139  219
881284.31.52                3
 2  132  212    2  138  218    2  140  220
892370.31.06                3
 2  134  214    2  141  221    2  142  222
901499. .001                4
 2  135  215    2  141  221    2  143  223    2  144  224
911499. .001                4
 2  137  217    2  143  223    2  145  225    2  146  226
921499. .001                4
 2  139  219    2  145  225    2  147  227    2  148  228
93885.534.79                3
 2  140  220    2  147  227    2  149  229
941693.42.56                3
 2  142  222    2  150  230    2  151  231
951499. .001                4
 2  144  224    2  150  230    2  152  232    2  153  233
961499. .001                4
 2  146  226    2  152  232    2  154  234    2  155  235
971464.20.57                4
 2  148  228    2  154  234    2  156  236    2  157  237
98450.529.63                2
 2  149  229  a 2  156  236
99480.745.53                2
 2  151  231    2  158  238
1001359.50.96               3
 2  153  233    2  158  238    2  159  239
1011359.50.96               3
 2  155  235    2  159  239    2  160  240
102480.745.53               2
 2  157  237    2  160  240
103107.723.32
104760.350.95
105760.350.95               3
 2  163    0    2  165    0    2  166  242
106107.723.32
107838.9 31.9
108901.1 .001               4
 2  164  241    2  168  243    2  170  244    2  171  245
109901.1 .001               4
 2  166  242    2  170  244    2  172    0    2  173  246
110838.9 31.9
1111027.25.33               3
 2  169    0    2  175  248    2  176  249
112901.1 .001               4
```

```
  2  171  245    2  175  248    2  177  250    2  178  251
113901.1 .001                4
  2  173  246    2  177  250    2  179  252    2  180  253
114 899. 3.24                4
  2  174  247    2  179  252    2  181  254    2  182  255
115127.9 22.1
1161257.26.63                3
  2  176  249    2  184  256    2  185  257
117901.1 .001                4
  2  178  251    2  184  256    2  186  258    2  187  259
118901.1 .001                4
  2  180  253    2  186  258    2  188  260    2  189  261
119901.1 .001                4
  2  182  255    2  188  260    2  190  262    2  191  263
120396.419.16
121871.631.43                3
  2  185  257    2  193  264    2  194  265
122901.1 .001                4
  2  187  259    2  193  264    2  195  266    2  196  267
123901.1 .001                4
  2  189  261    2  195  266    2  197  268    2  198  269
124901.1 .001                4
  2  191  263    2  197  268    2  199  270    2  200  271
125598.120.32                3
  2  192    0    2  199  270    2  201  272
126440.343.26                2
  2  194  265    2  202  273
127397.957.43                2
  2  196  267    2  202  273
128399.159.17                2
  2  198  269    2  203  274
1291493. 3.47                4
  2  200  271    2  203  274    2  204  275    2  205  276
1301282.31.41                3
  2  201  272    2  204  275    2  206  277
1311279.31.32                3
  2  205  276    2  207  278    2  208  279
1321466.30.11                3
  2  206  277    2  207  278    2  209  280
1331283.31.41                3
  2  208  279    2  210  281    2  211  282
1341470.30.19                3
  2  209  280    2  210  281    2  212  283
1351422.90.80                2
  2  213  284    2  214  285
136 407.59.17                2
  2  213  284    2  215  286
137 407.59.17                2
  2  216  287    2  217  288
```

```
1381497.3.385                    4
  2  211  282    2  216  287    2  218  289    2  219  290
1391284.31.52                    3
  2  212  283    2  218  289    2  220  291
1402370.31.06     1185.          5
  2  214  285    2  221  293    2    0  292    2  222  294    2  222  311
1411499. .001                    4
  2  215  286    2  221  293    2  223  295    2  224  296
1421499. .001                    4
  2  217  288    2  223  295    2  225  297    2  226  298
1431499. .001                    4
  2  219  290    2  225  297    2  227  299    2  228  300
144885.534.79                    3
  2  220  291    2  227  299    2  229  301
1451693.42.56      564.          4
  2  222  294    2  230  303    2  231  304    2    0  302
1461499. .001                    4
  2  224  296    2  230  303    2  232  305    2  233  306
1471499. .001                    4
  2  226  298    2  232  305    2  234  307    2  235  308
1481464.20.57                    4
  2  228  300    2  234  307    2  236  309    2  237  310
149450.529.63                    2
  2  229  301    2  236  309
150480.745.53                    2
  2  231  304    2  238  312
1511359.50.96                    3
  2  233  306    2  238  312    2  239    0
1521359.50.96
153480.745.53
154 868.74.27
155 868.74.27                    4
  2  242  319    2  242  320    2    0  316    2    0  318
156838.9 31.9
157901.1 .001                    4
  2  241  317    2  243  321    2  244  323    2  245  324
1581320. .001                    4
  2  242  319    2  244  323    2    0  326    2  246  327
159419.531.9
1601027.25.33                    3
  2    0  322    2  248  331    2  249  332
161901.1 .001                    4
  2  245  324    2  248  331    2  250  333    2  251  334
162901.1 .001                    4
  2  246  327    2  250  333    2  252  335    2  253  336
163 899. 3.24                    4
  2  247  329    2  252  335    2  254  337    2  255  338
1641257.26.63                    3
  2  249  332    2  256  341    2  257  342
```

```
165901.1 .001                                   4
  2  251  334    2  256  341    2  258  343    2  259  344
166901.1 .001                                   4
  2  253  336    2  258  343    2  260  345    2  261  346
167901.1 .001                                   4
  2  255  338    2  260  345    2  262    0    2  263  347
168524.3 41.3
169871.631.43                                   3
  2  257  342    2  264  348    2  265  349
170901.1 .001                                   4
  2  259  344    2  264  348    2  266  350    2  267  351
171901.1 .001                                   4
  2  261  346    2  266  350    2  268  352    2  269  353
172901.1 .001                                   4
  2  263  347    2  268  352    2  270  354    2  271  355
173598.120.32                                   2
  2  270  354    2  272  357
174440.343.26                                   2
  2  265  349    2  273  358
175397.957.43                                   2
  2  267  351    2  273  358
176399.159.17                                   2
  2  269  353    2  274  359
1771493. 3.47                                   4
  2  271  355    2  274  359    2  275  360    2  276  361
1781282.31.41                                   3
  2  272  357    2  275  360    2  277  362
1791279.31.32                                   3
  2  276  361    2  278  363    2  279  364
1801466.30.11                                   3
  2  277  362    2  278  363    2  280  366
1811283.31.41                                   3
  2  279  364    2  281  367    2  282  368
1821470.30.19                                   3
  2  280  366    2  281  367    2  283  369
1831422.90.80                                   2
  2  284  370    2  285  371
184 407.59.17                                   2
  2  284  370    2  286  372
185 407.59.17                                   2
  2  287  373    2  288  374
1861497.3.385                                   4
  2  282  368    2  287  373    2  289  375    2  290  376
1871284.31.52                                   3
  2  283  369    2  289  375    2  291  378
1881185.31.06
1891185. .001                                   5
  2  285  371    2  292    0    2  293  380    2  294  381    2  311  381
1901499. .001                                   4
```

```
  2  286  372    2  293  380    2  295  382    2  296  383
1911499. .001                4
  2  288  374    2  295  382    2  297  384    2  298  385
1921499. .001                4
  2  290  376    2  297  384    2  299  386    2  300  337
193885.534.79                3
  2  291  378    2  299  386    2  301  389
1941129.42.56
195 564. .001                4
  2  294  381    2  302    0    2  303  390    2  304  391
1961499. .001                4
  2  296  383    2  303  390    2  305  392    2  306  393
1971499. .001                4
  2  298  385    2  305  392    2  307  394    2  308  395
1981464.20.57                4
  2  300  387    2  307  394    2  309  397    2  310  398
199450.529.63                2
  2  301  389    2  309  397
200480.745.53                2
  2  304  391    2  312  399
2011359.50.96                3
  2  306  393    2  312  399    2    0  401
2021839.96.49
203107.723.32
204362.8173.4
205397.5122.4
206760.350.95
207107.723.32
208838.9 31.9
209901.1 .001
210768.6 40.8
211132.5 40.8
212706.4 72.7
213132.5 40.8
214894.566.13
215132.5 40.8
216901.1 .001
217901.1 .001
218899.0 3.24
219127.9 22.1
2201124. 67.4
221132.5 40.8
222901.1 .001
223901.1 .001
224901.1 .001
225396.419.16
226871.631.43
227901.1 .001
228901.1 .001
```

```
229901.1 .001
230465.6 61.1
231132.5 40.8
232440.343.26
233397.957.43
234399.159.17
2351493.3.47
2361282.31.41
2371279.31.32
2381201.111.7
239 265. 81.6
2401283.31.41
2411470.30.19
2421422.90.80
243 407.59.17
244 407.59.17
2451497.3.385
2461019. 113.
247 265. 81.6
248397.5122.4
2491972.153.5
2501499. .001
2511499. .001
2521499. .001
253 753. 75.6
254132.540.80
2551693.42.56
2561499. .001
2571499. .001
2581199.102.2
259 265. 81.6
260450.529.63
261480.745.53
2621094.132.6
263 265. 81.6
2641094.132.6
265 265. 81.6
266480.745.53
 24                    -1
 19                    -2
 14                    -3
  9                    -4
  5                    -5
  1                    -6
  2                    -7
  3                    -8
  4                    -9
  8                   -10
 13                   -11
```

18	-12
23	-13
28	-14
30	-15
32	-16
37	-17
42	-18
47	-19
51	-20
50	-21
49	-22
48	-23
43	-24
38	-25
33	-26
34	-27
35	-28
31	-29
29	-30
26	-31
25	-32
75	-33
70	-34
65	-35
60	-36
56	-37
52	-38
53	-39
54	-40
55	-41
59	-42
64	-43
69	-44
74	-45
79	-46
81	-47
83	-48
88	-49
93	-50
98	-51
102	-52
101	-53
100	-54
99	-55
94	-56
89	-57
84	-58
85	-59
86	-60

82	-61
80	-62
78	-63
76	-64
126	-65
121	-66
116	-67
111	-68
107	-69
103	-70
104	-71
105	-72
106	-73
110	-74
115	-75
120	-76
125	-77
130	-78
132	-79
134	-80
139	-81
144	-82
149	-83
153	-84
152	-85
151	-86
150	-87
145	-88
140	-89
135	-90
136	-91
137	-92
133	-93
131	-94
128	-95
127	-96
174	-97
169	-98
164	-99
160	-100
156	-101
154	-102
157	-103
155	-104
158	-105
159	-106
163	-107
168	-108
173	-109

178	-110
180	-111
182	-112
187	-113
193	-114
199	-115
198	-116
202	-117
201	-118
200	-119
194	-120
188	-121
183	-122
184	-123
185	-124
181	-125
179	-126
176	-127
175	-128
232	-129
226	-130
220	-131
214	-132
208	-133
203	-134
204	-135
206	-136
207	-137
212	-138
219	-139
224	-140
230	-141
236	-142
238	-143
241	-144
246	-145
253	-146
260	-147
266	-148
264	-149
262	-150
261	-151
255	-152
249	-153
242	-154
243	-155
244	-156
240	-157
237	-158

```
234                                          -159
233                                          -160
  3  403
  1    1    2 9.4539.19   0.0   .25          81   1.   -1    3
1.
  2    1     521.3015.31  0.0   .25          82   1.   -1    9
1.
  3    2     318.0349.99  0.0    .5          83   1.    1    5
1.
  4    2     649.9918.03  0.0   0.0          84   1.   -1   11
1.
  5    3    4 9.4539.19   0.0   .25          85   1.    3   -1
1.
  6    3     749.9918.03  0.0   0.0          86   1.   -1   13
1.
  7    4     821.3015.31  0.0   .25          87   1.   -1   14
1.
  8    5     618.0346.29  0.0   0.0          88   1.   -1   10
1.
  9    5     947.5518.03  0.0   0.5          89   1.    2   16
1.
 10    6     718.0349.99  0.0   0.0          90   1.    8   12
1.
 11    6    1049.9918.03  0.0   0.0          91   1.    4   18
1.
 12    7     818.0346.29  0.0   0.0          92   1.   10   -1
1.
 13    7    1149.1118.03  0.0   0.0          93   1.    6   20
1.
 14    8    1247.5518.03  0.0    .5          94   1.    7   22
1.
 15    9    1018.0353.21  0.0   0.0          95   1.   -1   17
1.
 16    9    1465.3118.03  0.0    .5          96   1.    9   25
1.
 17   10    1118.0349.99  0.0   0.0          97   1.   15   19
1.
 18   10    1549.9918.03  0.0   0.0          98   1.   11   27
1.
 19   11    1218.0349.99  0.0   0.0          99   1.   17   21
1.
 20   11    1649.9918.03  0.0   0.0         100   1.   13   29
1.
 21   12    1315.8932.65  0.0   .25         101   1.   19   -1
1.
 22   12    1749.9918.03  0.0   0.0         102   1.   14   31
1.
 23   13    1815.3318.03  0.0   .25         103   1.   -1   32
1.
```

```
24   14   1518.0358.22  0.0  0.0      104  1.   -1   26
1.
25   14   1961.2018.03  0.0   .5      105  1.   16   34
1.
26   15   1618.0349.99  0.0  0.0      106  1.   24   28
1.
27   15   2049.9918.03  0.0  0.0      107  1.   18   36
1.
28   16   1718.0349.99  0.0  0.0      108  1.   26   30
1.
29   16   2149.9918.03  0.0  0.0      109  1.   20   38
1.
30   17   1818.0335.87  0.0  0.0      110  1.   28   -1
1.
31   17   2249.9918.03  0.0  0.0      111  1.   22   40
1.
32   18   2328.1918.03  0.0  0.5      112  1.   23   41
1.
33   19   2018.0349.15  0.0  0.0      113  1.   -1   35
1.
34   19   2435.4518.03  0.0  0.5      114  1.   25   -1
1.
35   20   2118.0349.99  0.0  0.5      115  1.   33   37
1.
36   20   2549.9918.03  0.0  0.0      116  1.   27   -1
1.
37   21   2218.0349.99  0.0  0.0      117  1.   35   39
1.
38   21   2649.9918.03  0.0  0.0      118  1.   29   -1
1.
39   22   2318.0341.43  0.0  0.0      119  1.   37   -1
1.
40   22   2749.9918.03  0.0  0.0      120  1.   31   45
1.
41   23   2837.5418.03  0.0  0.5      121  1.   32   46
1.
42   24   2524.8230.22  0.0  0.5      122  1.
1.
43   26   2726.9537.49  0.0  0.0      123  1.   -1   44
1.
44   27   2829.9146.87  0.0  0.0      124  1.   43   -1
1.
45   27   2948.1629.91  0.0  0.5      125  1.   40   48
1.
46   28   3046.9729.91  0.0  0.5      126  1.   41   49
1.
47   29   3029.9146.31  0.0  0.0      127  1.
1.
48   29   3140.1529.95  0.0  0.5      128  1.   45   51
```

```
1.
49   30   3249.9929.95  0.0  0.5      129  1.   46   52
1.
50   31   3229.9946.31  0.0  0.0      130  1.
1.
51   31   3648.2129.99  0.0  0.5      131  1.   48   59
1.
52   32   3746.9629.99  0.0  0.5      132  1.   49   60
1.
53   33   3426.9651.82  0.0  0.5      133  1.
1.
54   33   3876.6529.99  0.0  0.5      134  1.   -1   62
1.
55   34   3949.9924.16  0.0  0.0      135  1.   -1   64
1.
56   35   3626.9634.49  0.0  0.0      136  1.   -1   58
1.
57   35   4049.9924.16  0.0  0.0      137  1.   -1   66
1.
58   36   3729.9946.10  0.0  0.0      138  1.   56   -1
1.
59   36   4149.9929.99  0.0  0.0      139  1.   51   68
1.
60   37   4237.4729.99  0.0  0.5      140  1.   52   69
1.
61   38   3929.9964.08  0.0  0.0      141  1.   -1   63
1.
62   38   4369.9829.99  0.0  0.5      142  1.   54   71
1.
63   39   4029.9949.99  0.0  0.5      143  1.   61   65
1.
64   39   4449.9929.99  0.0  0.0      144  1.   55   73
1.
65   40   4129.9949.99  0.0  0.0      145  1.   63   67
1.
66   40   4549.9929.99  0.0  0.0      146  1.   57   75
1.
67   41   4229.9939.36  0.0  0.0      147  1.   65   -1
1.
68   41   4649.9929.99  0.0  0.0      148  1.   59   77
1.
69   42   4719.9925.89  0.0  .25      149  1.   60   -1
1.
70   43   4429.9952.49  0.0  0.0      150  1.   -1   72
1.
71   43   4839.9925.70  0.0  .25      151  1.   62   -1
1.
72   44   4529.9949.99  0.0  0.0      152  1.   70   74
1.
```

```
73   44   4949.9927.85  0.0  0.0      153  1.  64   -1
1.
74   45   4629.9949.99  0.0  0.0      154  1.  72   76
1.
75   45   5049.9927.85  0.0  0.0      155  1.  66   -1
1.
76   46   4721.8034.99  0.0  .25      156  1.  74   -1
1.
77   46   5139.9925.70  0.0  .25      157  1.  68   -1
1.
78   48   4921.4244.99  0.0  .25      158  1.  -1   79
1.
79   49   5029.9949.99  0.0   .5      159  1.  78   80
1.
80   50   5121.4244.99  0.0  .25      160  1.  79   -1
1.
81   52   53 9.4539.19  0.0  .25      161  1.  -1   83
1.
82   52   5621.3015.31  0.0  .25      162  1.  -1   89
1.
83   53   5418.0349.99  0.0   .5      163  1.  81   85
1.
84   53   5749.9918.03  0.0  0.0      164  1.  -1   91
1.
85   54   55 9.4539.19  0.0  .25      165  1.  83   -1
1.
86   54   5849.9918.03  0.0  0.0      166  1.  -1   93
1.
87   55   5921.3015.31  0.0  .25      167  1.  -1   94
1.
88   56   5718.0346.29  0.0  0.0      168  1.  -1   90
1.
89   56   6047.5518.03  0.0   .5      169  1.  82   96
1.
90   57   5818.0349.99  0.0  0.0      170  1.  88   92
1.
91   57   6149.9918.03  0.0  0.0      171  1.  84   98
1.
92   58   5918.0346.26  0.0  0.0      172  1.  90   -1
1.
93   58   6249.9918.03  0.0  0.0      173  1.  86   100
1.
94   59   6347.5518.03  0.0  0.5      174  1.  87   102
1.
95   60   6118.0353.21  0.0  0.0      175  1.  -1   97
1.
96   60   6565.3118.03  0.0   .5      176  1.  89   105
1.
97   61   6218.0349.99  0.0  0.0      177  1.  95   99
```

```
1.
98   61   6649.9918.03  0.0  0.0      178  1.   91  107
1.
99   62   6318.0349.99  0.0  0.0      179  1.   97  101
1.
100  62   6749.9918.03  0.0  0.0      180  1.   93  109
1.
101  63   6415.8932.65  0.0  .25      181  1.   99   -1
1.
102  63   6849.9918.03  0.0  0.0      182  1.   94  111
1.
103  64   6915.3318.03  0.0  .25      183  1.   -1  112
1.
104  65   6618.0358.22  0.0  0.0      184  1.   -1  106
1.
105  65   70 61.218.03  0.0   .5      185  1.   96  114
1.
106  66   6718.0349.99  0.0  0.0      186  1.  104  108  -41
1.
107  66   7149.9918.03  0.0  0.0      187  1.   98  116
1.
108  67   6818.0349.99  0.0  0.0      188  1.  106  110
1.
109  67   7249.9918.03  0.0  0.0      189  1.  100  118
1.
110  68   6918.0335.87  0.0  0.0      190  1.  108   -1
1.
111  68   7349.9918.03  0.0  0.0      191  1.  102  120
1.
112  69   7428.1918.03  0.0  0.5      192  1.  103  121
1.
113  70   7118.0349.15  0.0  0.0      193  1.   -1  115
1.
114  70   7535.4518.03  0.0  0.5      194  1.  105   -1
1.
115  71   7218.0349.99  0.0  0.5      195  1.  113  117
1.
116  71   7649.9918.03  0.0  0.0      196  1.  107   -1
1.
117  72   7318.0349.99  0.0  0.0      197  1.  115  119
1.
118  72   7749.9918.03  0.0  0.0      198  1.  109   -1
1.
119  73   7418.0341.43  0.0  0.0      199  1.  117   -1
1.
120  73   7849.9918.03  0.0  0.0      200  1.  111  125
1.
121  74   7937.5418.03  0.0  0.5      201  1.  112  126
1.
```

```
122   75   7624.8230.22  0.0  0.5      202   1.
 1.
123   77   7826.9537.49  0.0  0.0      203   1.   -1   124
 1.
124   78   7929.9146.87  0.0  0.0      204   1.   123   -1
 1.
125   78   8048.1629.91  0.0  0.5      205   1.   120   128
 1.
126   79   8146.9729.91  0.0  0.5      206   1.   121   129
 1.
127   80   8129.9146.31  0.0  0.0      207   1.
 1.
128   80   8240.1529.95  0.0  0.5      208   1.   125   131
 1.
129   81   8349.9929.95  0.0  0.5      209   1.   126   132
 1.
130   82   8329.9946.31  0.0  0.0      210   1.
 1.
131   82   8748.2129.99  0.0  0.5      211   1.   128   139
 1.
132   83   8846.9629.99  0.0  0.5      212   1.   129   140
 1.
133   84   8526.9651.82  0.0  0.5      213   1.
 1.
134   84   8976.6529.99  0.0  0.5      214   1.   -1   142
 1.
135   85   9049.9924.16  0.0  0.0      215   1.   -1   144
 1.
136   86   8726.9634.49  0.0  0.0      216   1.   -1   138
 1.
137   86   9149.9924.16  0.0  0.0      217   1.   -1   146
 1.
138   87   8829.9946.10  0.0  0.0      218   1.   136   -1
 1.
139   87   9249.9929.99  0.0  0.0      219   1.   131   148
 1.
140   88   9337.4729.99  0.0  0.5      220   1.   132   149
 1.
141   89   9029.9964.08  0.0  0.0      221   1.   -1   143
 1.
142   89   9469.9829.99  0.0  0.5      222   1.   134   151
 1.
143   90   9129.9949.99  0.0  0.5      223   1.   141   145
 1.
144   90   9549.9929.99  0.0  0.0      224   1.   135   153
 1.
145   91   9229.9949.99  0.0  0.0      225   1.   143   147
 1.
146   91   9649.9929.99  0.0  0.0      226   1.   137   155
```

```
 1.
147   92    9329.9939.96  0.0   0.0        227   1.   145   -1
 1.
148   92    9749.9929.99  0.0   0.0        228   1.   139   157
 1.
149   93    9819.9925.89  0.0   .25        229   1.   140   -1
 1.
150   94    9529.9952.49  0.0   0.0        230   1.    -1   152
 1.
151   94    9939.9925.70  0.0   .25        231   1.   142   -1
 1.
152   95    9629.9949.99  0.0   0.0        232   1.   150   154
 1.
153   95   10049.9927.85  0.0   0.0        233   1.   144   -1
 1.
154   96    9729.9949.99  0.0   0.0        234   1.   152   156
 1.
155   96   10149.9927.85  0.0   0.0        235   1.   146   -1
 1.
156   97    9821.8034.99  0.0   .25        236   1.   154   -1
 1.
157   97   10239.9925.70  0.0   .25        237   1.   148   -1
 1.
158   99   10021.4244.99  0.0   .25        238   1.    -1   159
 1.
159  100   10129.9949.99  0.0   0.5        239   1.   158   160
 1.
160  101   10221.4244.99  0.0   .25        240   1.   159   -1
 1.
161  103   104 9.4539.19  0.0   .25              1.    -1   163
 1.
162  103   10721.3015.31  0.0   .25              1.    -1   169
 1.
163  104   10518.0349.99  0.0    .5              1.   161   165
 1.
164  104   10849.9918.03  0.0   0.0              1.    -1   171
 1.
165  105   106 ? 4539.19  0.0   .25              1.   163   -1
 1.
166  105   10949.9918.03  0.0   0.0        242   1.    -1   173
 1.
167  106   11021.3015.31  0.0   .25              1.    -1   174
 1.
168  107   10818.0346.29  0.0   0.0              1.    -1   170
 1.
169  107   11147.5518.03  0.0   0.5              1.   162   176
 1.
170  108   10918.0349.99  0.0   0.0        244   1.   168   172
 1.
```

```
171  108  11249.9918.03  0.0  0.0      245  1.  164  178
 1.
172  109  11018.0346.29  0.0  0.0           1.  170   -1
 1.
173  109  11349.9918.03  0.0  0.0      246  1.  166  180
 1.
174  110  11447.5518.03  0.0  0.5           1.  167  182
 1.
175  111  11218.0353.21  0.0  0.0      248  1.   -1  177
 1.
176  111  11665.3118.03  0.0  0.5      249  1.  169  185
 1.
177  112  11318.0349.99  0.0  0.0      250  1.  175  179
 1.
178  112  11749.9918.03  0.0  0.0      251  1.  171  187
 1.
179  113  11418.0349.99  0.0  0.0      252  1.  177  181
 1.
180  113  11849.9918.03  0.0  0.0      253  1.  173  189
 1.
181  114  11515.8932.65  0.0  .25           1.  179   -1
 1.
182  114  11949.9918.03  0.0  0.0      255  1.  174  191
 1.
183  115  12015.3318.03  0.0  .25           1.   -1  192
 1.
184  116  11718.0358.22  0.0  0.0      256  1.   -1  186
 1.
185  116  121 61.218.03  0.0   .5      257  1.  176  194
 1.
186  117  11818.0349.99  0.0  0.0      258  1.  184  188
 1.
187  117  12249.9918.03  0.0  0.0      259  1.  178  196
 1.
188  118  11918.0349.99  0.0  0.0      260  1.  186  190
 1.
189  118  12349.9918.03  0.0  0.0      261  1.  180  198
 1.
190  119  12018.0335.87  0.0  0.0           1.  188   -1
 1.
191  119  12449.9918.03  0.0  0.0      263  1.  182  200
 1.
192  120  12528.1918.03  0.0  0.5           1.  183  201
 1.
193  121  12218.0349.15  0.0  0.0      264  1.   -1  195
 1.
194  121  12635.4518.03  0.0  0.5      265  1.  185   -1
 1.
195  122  12318.0349.99  0.0  0.5      266  1.  193  197
```

```
 1.
196  122  12749.9918.03  0.0  0.0      267  1.  187  -1
 1.
197  123  12418.0349.00  0.0  0.0      268  1.  195  199
 1.
198  123  12849.9918.03  0.0  0.0      269  1.  189  -1
 1.
199  124  12518.0341.43  0.0  0.0      270  1.  197  -1
 1.
200  124  12949.9918.03  0.0  0.0      271  1.  191  205
 1.
201  125  13037.5418.03  0.0  0.5      272  1.  192  206
 1.
202  126  12724.8230.22  0.0  0.5      273  1.
 1.
203  128  12926.9537.49  0.0  0.0      274  1.   -1  204
 1.
204  129  13029.9146.87  0.0  0.0      275  1.  203  -1
 1.
205  129  13148.1629.91  0.0  0.5      276  1.  200  208
 1.
206  130  13246.9729.91  0.0  0.5      277  1.  201  209
 1.
207  131  13229.9146.31  0.0  0.0      278  1.
 1.
208  131  13340.1529.95  0.0  0.5      279  1.  205  211
 1.
209  132  13449.9929.95  0.0  0.5      280  1.  206  212
 1.
210  133  13429.9946.31  0.0  0.0      281  1.
 1.
211  133  13848.2129.99  0.0  0.5      282  1.  208  219
 1.
212  134  13946.9629.99  0.0  0.5      283  1.  209  220
 1.
213  135  13626.9651.82  0.0  0.5      284  1.
 1.
214  135  14076.6529.99  0.0  0.5      285  1.   -1  222
 1.
215  136  14149.9924.16  0.0  0.0      286  1.   -1  224
 1.
216  137  13826.9634.49  0.0  0.0      287  1.   -1  218
 1.
217  137  14249.9924.16  0.0  0.0      288  1.   -1  226
 1.
218  138  13929.9946.10  0.0  0.0      289  1.  216  -1
 1.
219  138  14349.9929.99  0.0  0.0      290  1.  211  228
 1.
```

```
220  139  14437.4729.99  0.0  0.5        291  1.  212  229
 1.
221  140  14129.9964.08  0.0  0.0        293  1.   -1  223
 1.
222  140  14569.9829.99  0.0  0.5        294  1.  214  231
 1.
223  141  14229.9949.99  0.0  0.5        295  1.  221  225
 1.
224  141  14649.9929.99  0.0  0.0        296  1.  215  233
 1.
225  142  14329.9949.99  0.0  0.0        297  1.  223  227
 1.
226  142  14749.9929.99  0.0  0.0        298  1.  217  235
 1.
227  143  14429.9939.36  0.0  0.0        299  1.  225   -1
 1.
228  143  14849.9929.99  0.0  0.0        300  1.  219  237
 1.
229  144  14919.9925.89  0.0  .25        301  1.  220   -1
 1.
230  145  14629.9952.49  0.0  0.0        303  1.   -1  232
 1.
231  145  15039.9925.70  0.0  .25        304  1.  222   -1
 1.
232  146  14729.9949.99  0.0  0.0        305  1.  230  234
 1.
233  146  15149.9927.85  0.0  0.0        306  1.  224   -1
 1.
234  147  14829.9949.99  0.0  0.0        307  1.  232  236
 1.
235  147  15249.9927.85  0.0  0.0             1.  226   -1
 1.
236  148  14921.8034.99  0.0  .25        309  1.  234   -1
 1.
237  148  15339.9925.70  0.0  .25             1.  228   -1
 1.
238  150  15121.4244.99  0.0  .25        312  1.   -1  239
 1.
239  151  15229.9949.99  0.0  0.5             1.  238  240
 1.
240  152  15321.4244.99  0.0  .25             1.  239   -1
 1.
241  154  15721.6918.03  0.0  0.0             1.   -1  245
 1.
242  155  15849.9918.03  0.0  0.5        319  1.   -1  246
 1.
243  156  15710.8446.29  0.0  0.0             1.   -1  244
 1.
244  157  15818.0349.99  0.0  0.5        323  1.  243   -1
```

```
 1.
245  157  16149.9918.03  0.0  0.0        324   1.  241  251
 1.
246  158  16249.9918.03  0.0  0.0        327   1.  242  253
 1.
247  159  16316.2718.03  0.0  0.0              1.   -1  255
 1.
248  160  16118.0353.21  0.0  0.0        331   1.   -1  250
 1.
249  160  16465.3118.03  0.0  0.5        332   1.   -1  257
 1.
250  161  16218.0349.99  0.0  0.0        333   1.  248  252
 1.
251  161  16549.9918.03  0.0  0.0        334   1.  245  259
 1.
252  162  16318.0349.99  0.0  0.0        335   1.  250  254
 1.
253  162  16649.9918.03  0.0  0.0        336   1.  246  261
 1.
254  163  168 8.1432.65  0.0  0.5              1.  252   -1
 1.
255  163  16749.9918.03  0.0  0.5        338   1.  247  263
 1.
256  164  16518.0358.22  0.0  0.0        341   1.   -1  258
 1.
257  164  169 61.218.03  0.0  0.5        342   1.  249  265
 1.
258  165  16618.0349.99  0.0  0.0        343   1.  256  260
 1.
259  165  17049.9918.03  0.0  0.0        344   1.  251  267
 1.
260  166  16718.0349.99  0.0  0.0        345   1.  258  262
 1.
261  166  17149.9918.03  0.0  0.0        346   1.  253  269
 1.
262  167  168 8.1435.87  0.0  0.0              1.  260   -1
 1.
263  167  17249.9918.03  0.0  0.0        347   1.  255  271
 1.
264  169  17018.0349.15  0.0  0.0        348   1.   -1  266
 1.
265  169  17435.4518.03  0.0  0.5        349   1.  257   -1
 1.
266  170  17118.0349.99  0.0  0.5        350   1.  264  268
 1.
267  170  17549.9918.03  0.0  0.0        351   1.  259   -1
 1.
268  171  17218.0349.99  0.0  0.0        352   1.  266  270
 1.
```

```
269  171  17649.9918.03  0.0  0.0        353   1.  261   -1
 1.
270  172  17318.0341.43  0.0  0.0        354   1.  268   -1
 1.
271  172  17749.9918.03  0.0  0.0        355   1.  263  276
 1.
272  173  17837.5418.03  0.0  0.5        357   1.   -1  277
 1.
273  174  17524.8230.22  0.0  0.5        358   1.
 1.
274  176  17726.9537.49  0.0  0.0        359   1.   -1  275
 1.
275  177  17829.9146.87  0.0  0.0        360   1.  274   -1
 1.
276  177  17948.1629.91  0.0  0.5        361       271  279
 1.
277  178  18046.9729.91  0.0  0.5        362       272  280
 1.
278  179  18029.9146.31  0.0  0.0        363
 1.
279  179  18140.1529.95  0.0  0.5        364       276  282
 1.
280  180  18249.9929.95  0.0  0.5        366       277  283
 1.
281  181  18229.9946.31  0.0  0.0        367
 1.
282  181  18648.2129.99  0.0  0.5        368       279  290
 1.
283  182  18746.9629.99  0.0  0.5        369       280  291
 1.
284  183  18426.9651.82  0.0  0.5        370
 1.
285  183  18957.5629.99  0.0  0.5        371        -1  311   0  294
 1.
286  184  19049.9924.16  0.0  0.0        372        -1  296
 1.
287  185  18626.9634.49  0.0  0.0        373        -1  289
 1.
288  185  19149.9924.16  0.0  0.0        374   1.   -1  298
 1.
289  186  18729.9946.10  0.0  0.0        375   1.  287   -1
 1.
290  186  19249.9929.99  0.0  0.0        376   1.  282  300
 1.
291  187  19337.4729.99  0.0  0.5        378   1.  283  301
 1.
292  188  189 8.1429.99  0.0  .25             1.   -1  293
 1.
293  189  19049.9929.99  0.0  0.0        380   1.  292  295
```

```
 1.
294  189  19519.1829.99  0.0  0.5      381  1.  285  304
 1.
295  190  19129.9949.99  0.0  0.5      382  1.  293  297
 1.
296  190  19649.9929.99  0.0  0.0      383  1.  286  306
 1.
297  191  19229.9949.99  0.0  0.0      384  1.  295  299
 1.
298  191  19749.9929.99  0.0  0.0      385  1.  288  308
 1.
299  192  19329.9939.36  0.0  0.0      386  1.  297   -1
 1.
300  192  19849.9929.99  0.0  0.0      387  1.  290  310
 1.
301  193  19919.9925.89  0.0  .25      389  1.  291   -1
 1.
302  194  195 8.1419.19  0.0  0.0           1.   -1  303
 1.
303  195  19629.9934.58  0.0  0.0      390  1.  302  305
 1.
304  195  20019.1825.70  0.0 0.25      391  1.  294   -1
 1.
305  196  19729.9949.99  0.0  0.0      392  1.  303  307
 1.
306  196  20149.9927.85  0.0  0.0      393  1.  296   -1
 1.
307  197  19829.9949.99  0.0  0.0      394  1.  305  309
 1.
308  197  20249.9927.85  0.0  0.0           1.  298   -1
 1.
309  198  19921.8034.99  0.0  .25      397  1.  307   -1
 1.
310  198  20239.9925.70  0.0  .25           1.  300   -1
 1.
311  189  19416.2729.99  0.0  .25           1.  285   -1
 1.
312  200  20121.4244.99  0.0  .25           1.
 1.
313  203  204 9.4539.19  0.0  .25           1.   -1  316
 1.
314  203  208 21.315.31  0.0  .25           1.   -1  322
 1.
315  204  205 5.0812.98  1.5  0.0           1.
1.
316  204  20618.0349.99  0.0  0.5           1.  313  318
1.
317  204  20949.9918.03  0.0  0.0           1.   -1  324
 1.
```

```
318  206  207 9.4539.19  0.0  .25            1.  316   -1
1.
319  206  21049.9918.03  0.0  0.0            1.   -1  327
1.
320  207  21221.3015.31  0.0  .25            1.
1.
321  208  20918.0346.29  0.0  0.0            1.   -1  323
 1.
322  208  21447.5518.03  0.0   .5            1.  314  332
1.
323  209  21018.0349.99  0.0  0.0            1.  321  326
 1.
324  209  21649.9918.03  0.0  0.0            1.  317  334
1.
325  210  2111.69312.98  1.5  0.0            1.
 1.
326  210  21218.0346.29  0.0  0.0            1.  323   -1
 1.
327  210  21749.9918.02  0.0  0.0            1.  319  336
 1.
328  212  2131.69312.98  1.5  1.5            1.
 1.
329  212  21847.5518.03  0.0   .5            1.   -1  338
 1.
330  214  2151.69312.98  1.5  1.5            1.
 1.
331  214  21618.0353.21  0.0  0.0            1.   -1  333
 1.
332  214  22065.3118.03  0.0  0.5            1.  322  342
 1.
333  216  21718.0349.99  0.0  0.0            1.  331  335
 1.
334  216  22249.9918.03  0.0  0.0            1.  324  344
1.
335  217  21818.0349.99  0.0  0.0            1.  333  337
 1.
336  217  22349.9918.03  0.0  0.0            1.  327  346
 1.
337  218  21915.8932.65  0.0  .25            1.  335   -1
1.
338  218  22449.9918.03  0.0  0.0            1.  329  347
 1.
339  219  2253.38912.98  1.5  0.0            1.
 1.
340  220  2211.69312.98  1.5  0.0            1.
 1.
341  220  22218.0358.22  0.0  0.0            1.   -1  343
 1.
342  220  22661.2018.03  0.0   .5            1.  332  349
```

```
 1.
343  222  22318.0349.99  0.0  0.0          1.  341  345
 1.
344  222  22749.9918.03  0.0  0.0          1.  334  351
 1.
345  223  22418.0349.99  0.0  0.0          1.  343   -1
 1.
346  223  22849.9918.03  0.0  0.0          1.  336  353
 1.
347  224  22949.9918.03  0.0  0.0          1.  338  355
 1.
348  226  22718.0349.15  0.0  0.0          1.   -1  350
 1.
349  226  23235.4518.03  0.0  0.5          1.  342   -1
 1.
350  227  22818.0349.99  0.0  0.5          1.  348  352
 1.
351  227  23349.9918.03  0.0  0.0          1.  344   -1
 1.
352  228  22918.0349.99  0.0  0.0          1.  350  354
 1.
353  228  23449.9918.03  0.0  0.0          1.  346   -1
 1.
354  229  23018.0341.43  0.0  0.0          1.  352   -1
 1.
355  229  23549.9918.03  0.0  0.0          1.  347  361
 1.
356  230  2311.69312.98  1.5  0.0          1.
 1.
357  230  23637.5418.03  0.0  0.5          1.   -1  362
 1.
358  232  23324.8230.22  0.0  0.5          1.
 1.
359  234  23526.9537.49  0.0  0.0          1.   -1  360
 1.
360  235  23629.914.987  0.0  0.0          1.  359   -1
 1.
361  235  23748.1629.91  0.0  0.5          1.  355  364
 1.
362  236  23846.9729.91  0.0  0.5          1.  357  366
 1.
363  237  23829.9146.31  0.0  0.0          1.
 1.
364  237  24040.1529.95  0.0  0.5          1.  361  368
 1.
365  238  2393.38612.98  1.5  0.0          1.
 1.
366  238  24149.9929.95  0.0  0.5          1.  362  369
 1.
```

```
367  240  24129.9946.31  0.0  0.0          1.
 1.
368  240  24548.2129.99  0.0  0.5          1.  364  376
 1.
369  241  24646.9629.99  0.0  0.5          1.  366  378
 1.
370  242  24326.9651.82  0.0  0.5          1.
 1.
371  242  24976.6529.99  0.0  0.5          1.   -1  381
 1.
372  243  25049.9924.16  0.0  0.0          1.   -1  383
 1.
373  244  24526.9634.49  0.0  0.0          1.   -1  375
 1.
374  244  25149.9924.16  0.0  0.0          1.   -1  385
 1.
375  245  24629.9946.10  0.0  0.0          1.  373   -1
 1.
376  245  25249.9929.99  0.0  0.0          1.  368  387
 1.
377  246  2473.38612.98  1.5  0.0          1.
 1.
378  246  25337.4729.99  0.0  0.5          1.  369  389
 1.
379  248  2495.07912.98  1.5  0.0          1.
 1.
380  249  25029.9964.08  0.0  0.0          1.   -1  382
 1.
381  249  25569.9829.99  0.0  0.5          1.  371  391
 1.
382  250  25129.9949.99  0.0  0.5          1.  380  384
 1.
383  250  25649.9929.99  0.0  0.0          1.  372  393
 1.
384  251  25229.9949.99  0.0  0.0          1.  382  386
 1.
385  251  25749.9929.99  0.0  0.0          1.  374  395
 1.
386  252  25329.9939.36  0.0  0.0          1.  384   -1
 1.
387  252  25849.9929.99  0.0  0.0          1.  376  398
 1.
388  253  2541.69312.98  1.5  0.0          1.
 1.
389  253  26019.9925.89  0.0  .25          1.  378   -1
 1.
390  255  25629.9952.49  0.0  0.0          1.   -1  392
 1.
391  255  26139.9925.70  0.0  .25          1.  381   -1
```

```
 1.
392  256  25729.9949.99  0.0  0.0            1.  390  394
 1.
393  256  26249.9927.85  0.0  0.0            1.  383   -1
 1.
394  257  25829.9949.99  0.0  0.0            1.  392  397
 1.
395  257  26449.9927.85  0.0  0.0            1.  385   -1
 1.
396  258  2593.38612.98  1.5  0.0            1.
 1.
397  258  26021.8034.99  0.0  .25            1.  394   -1
 1.
398  258  26639.9925.70  0.0  .25            1.  387   -1
 1.
399  261  26221.4244.99  0.0  .25            1.   -1  401
 1.
400  262  2633.38612.98  1.5  0.0            1.
 1.
401  262  26429.9949.99  0.0  0.5            1.  399  403
 1.
402  264  2653.38612.98  1.5  0.0            1.
 1.
403  264  26621.4244.99  0.0  .25            1.  401   -1
 1.
572
  1    4    2    3    6    4    5    7    6    2    8    1
  4    8    1    4   10    3    6   10    3    6   12    5
  7   12    5    8    4    2   10    6    4   12    7    6
  8   11    9   10   13   11   12   14   13    9   15    8
 11   15    8   11   17   10   13   17   10   13   19   12
 14   19   12   15   11    9   17   13   11   19   14   13
 15   18   16   17   20   18   19   22   20   21   23   22
 16   24   15   18   24   15   18   26   17   20   26   17
 20   28   19   22   28   19   22   30   21   23   30   21
 24   18   16   26   20   18   28   22   20   30   23   22
 24   27   25   26   29   27   28   31   29   30   32   31
 25   33   24   27   33   24   27   35   26   29   35   26
 29   37   28   31   37   28   31   39   30   32   39   30
 33   27   25   35   29   27   37   31   29   39   32   31
 33   36   34   35   38   36   37   40   38   39   41   40
 34   42   33   36   42   33   38   43   37   40   44   39
 41   44   39   42   36   34   43   40   38   44   41   40
 44   46   45   45   47   44   46   47   44   47   46   45
 47   49   48   48   50   47   49   50   47   50   49   48
 50   52   51   51   58   50   52   58   50   53   55   54
 56   59   57   58   52   51   58   60   59   54   61   53
 55   61   53   57   65   56   59   65   56   59   67   58
 60   67   58   61   55   54   63   57   55   65   59   57
```

67	60	59	61	64	62	63	66	64	65	68	66
67	69	68	62	70	61	64	70	61	64	72	63
66	72	63	66	74	65	68	74	65	68	76	67
69	76	67	70	64	62	72	66	64	74	68	66
76	69	68	70	73	71	72	75	73	74	77	75
71	78	70	73	78	70	73	79	72	75	79	72
75	80	74	77	80	74	78	73	71	79	75	73
80	77	75	81	84	82	83	86	84	85	87	86
82	88	81	84	88	81	84	90	83	86	90	83
86	92	85	87	92	85	88	84	82	90	86	84
92	87	86	88	91	89	90	93	91	92	94	93
89	95	88	91	95	88	91	97	90	93	97	90
93	99	92	94	99	92	95	91	89	97	93	91
99	94	93	95	98	96	97	100	98	99	102	100
101	103	102	96	104	95	98	104	95	98	106	97
100	106	97	100	108	99	102	110	101	103	110	101
104	98	96	106	100	98	108	102	100	110	103	102
104	107	105	106	109	107	108	111	109	110	112	111
105	113	104	107	113	104	107	115	106	109	115	106
109	117	108	111	117	108	111	119	110	112	119	110
113	107	105	115	109	107	117	111	109	119	112	111
113	116	114	115	118	116	117	120	118	119	121	120
114	122	113	116	122	113	118	123	117	120	123	117
120	124	119	121	124	119	122	116	114	123	120	118
124	121	120	124	126	125	125	127	124	126	127	124
127	126	125	127	129	128	128	130	127	129	130	127
130	129	128	130	132	131	131	138	130	132	138	130
133	135	134	136	139	137	138	132	131	138	140	139
134	141	133	135	141	133	137	145	136	139	145	136
139	147	138	140	147	138	141	135	134	143	137	135
145	139	137	147	140	139	141	144	142	143	146	144
145	148	146	147	149	148	142	150	141	144	150	141
144	152	143	146	152	143	146	154	145	148	154	145
148	156	147	149	156	147	150	144	142	152	146	144
154	148	146	156	149	148	150	153	151	152	155	153
154	157	155	151	158	150	153	158	150	153	159	152
155	159	152	155	160	154	157	160	154	40	43	37
161	164	162	163	166	164	165	167	166	162	168	161
164	168	161	164	170	163	166	170	163	166	172	165
167	172	165	168	164	162	170	166	164	172	167	166
168	171	169	170	173	171	172	174	173	169	175	168
171	175	168	171	177	170	173	177	170	173	179	172
174	179	172	175	171	169	177	173	171	179	174	173
175	178	176	177	180	178	179	182	180	181	183	182
176	184	175	178	184	175	178	186	177	180	186	177
180	188	179	182	188	179	182	190	181	183	190	181
184	178	176	186	180	178	188	182	180	190	183	182
184	187	185	186	189	187	188	191	189	190	192	191
185	193	184	187	193	184	187	195	186	189	195	186

189	197	188	191	197	188	191	199	190	192	199	190
193	187	185	195	189	187	197	191	189	199	192	191
193	196	194	195	198	196	197	200	198	199	201	200
194	202	193	196	202	193	198	203	197	200	203	197
200	204	199	201	204	199	202	196	194	203	200	198
204	201	200	204	206	205	205	207	204	206	207	204
207	206	205	207	209	208	208	210	207	209	210	207
210	209	208	210	212	211	211	218	210	212	218	210
213	215	214	216	219	217	218	212	211	218	220	219
214	221	213	215	221	213	217	225	216	219	225	216
219	227	218	220	227	218	221	215	214	223	217	215
225	219	217	227	220	219	221	224	222	223	226	224
225	228	226	227	229	228	222	230	221	224	230	221
240	237	235	224	232	223	226	232	223	226	234	225
228	234	225	228	236	227	229	236	227	230	224	222
232	226	224	234	228	226	236	229	228	230	233	231
232	235	233	234	237	235	231	238	230	233	238	230
233	239	232	235	239	232	235	240	234	237	240	234
238	233	231	239	235	233	102	108	99	158	153	151
159	155	153	160	157	155	244	242	241	244	246	245
245	248	243	245	250	244	246	250	244	250	246	245
252	247	246	248	251	249	250	253	251	252	255	253
249	256	248	251	256	248	251	258	250	253	258	250
253	260	252	255	260	252	255	262	254	256	251	249
258	253	251	260	255	253	256	259	257	258	261	259
260	263	261	257	264	256	259	264	256	261	266	258
261	268	260	263	268	260	263	270	262	264	259	257
266	261	259	268	263	261	264	267	265	266	269	267
268	271	269	270	272	271	265	273	264	267	273	264
269	274	268	271	274	268	271	275	270	272	275	270
273	267	265	274	271	269	275	272	271	276	278	275
277	278	275	278	277	276	278	280	279	279	281	278
280	281	278	281	280	279	281	283	282	282	289	281
283	289	281	284	286	285	287	290	288	289	291	290
289	283	282	285	293	284	286	293	284	288	297	287
290	297	287	290	299	289	291	299	289	293	286	285
295	288	286	297	290	288	299	291	290	293	296	294
295	298	296	297	300	298	299	301	300	294	303	293
296	303	293	296	305	295	298	305	295	298	307	297
300	307	297	300	309	299	301	309	299	303	296	294
305	298	296	307	300	298	309	301	300	303	306	304
305	308	306	307	310	308	304	312	303	306	312	303
313	317	314	316	319	317	318	320	319	314	321	313
317	321	313	317	323	316	319	323	316	319	326	318
320	326	318	321	317	314	323	319	317	326	320	319
321	324	322	323	327	324	326	329	327	322	331	321
324	331	321	324	333	323	327	333	323	327	335	326
329	335	326	331	324	322	333	327	324	335	329	327
331	334	332	333	336	334	335	338	336	332	341	331

```
334  341  331  334  343  333  336  343  333  336  345  335
338  345  335  341  334  332  343  336  334  345  338  336
341  344  342  343  346  344  345  347  346  342  348  341
344  348  341  344  350  343  346  350  343  346  352  345
347  352  345  348  344  342  350  346  344  352  347  346
348  351  349  350  353  351  352  355  353  354  357  355
349  358  348  351  358  348  353  359  352  355  359  352
355  360  354  357  360  354  358  351  349  359  355  353
360  357  355  360  362  361  361  363  360  362  363  360
363  362  361  363  366  364  364  367  363  366  367  363
367  366  364  367  369  368  368  375  367  369  375  367
370  372  371  373  376  374  375  369  368  375  378  376
371  380  370  372  380  370  374  384  373  376  384  373
376  386  375  378  386  375  380  372  371  382  374  372
384  376  374  386  378  376  380  383  381  382  385  383
384  387  385  386  389  387  381  390  380  383  390  380
383  392  382  385  392  382  385  394  384  387  294  384
387  397  386  389  397  386  390  383  381  392  385  383
394  387  385  397  389  387  390  393  391  392  395  393
394  398  395  391  399  390  393  399  390  393  401  392
395  401  392  395  403  394  398  403  394  399  393  391
401  395  393  403  398  395  312  306  304  259  266  258
  4    5    5    1
  1   51    1      50.81
  1   52                                   1
  2   53                                   2
  3   54                                   3
  4   55                                   4
  5   56                                   5
  6   57                                   6
  7   58                                   7
  8   59                                   8
  9   60                                   9
 10   61                                  10
 11   62                                  11
 12   63                                  12
 13   64                                  13
 14   65                                  14
 15   66                                  15
 16   67                                  16
 17   68                                  17
 18   69                                  18
 19   70                                  19
 20   71                                  20
 21   72                                  21
 22   73                                  22
 23   74                                  23
 24   75                                  24
 25   76                                  25
```

26	77			26
27	78			27
28	79			28
29	80			29
30	81			30
31	82			31
32	83			32
33	84			33
34	85			34
35	86			35
36	87			36
37	88			37
38	89			38
39	90			39
40	91			40
41	92			41
42	93			42
43	94			43
44	95			44
45	96			45
46	97			46
47	98			47
48	99			48
49	100			49
50	101			50
51	102			51
2	51	1	18.027	
52	103			1
53	104			2
54	105			3
55	106			4
56	107			5
57	108			6
58	109			7
59	110			8
60	111			9
61	112			10
62	113			11
63	114			12
64	115			13
65	116			14
66	117			15
67	118			16
68	119			17
69	120			18
70	121			19
71	122			20
72	123			21
73	124			22

74	125			23
75	126			24
76	127			25
77	128			26
78	129			27
79	130			28
80	131			29
81	132			30
82	133			31
83	134			32
84	135			33
85	136			34
86	137			35
87	138			36
88	139			37
89	140			38
90	141			39
91	142			40
92	143			41
93	144			42
94	145			43
95	146			44
96	147			45
97	148			46
98	149			47
99	150			48
100	151			49
101	152			50
102	153			51
3	51	1	42.74	
103	103			52
104	104			53
105	155			54
106	106			55
107	107			56
108	157			57
109	158			58
110	110			59
111	160			60
112	161			61
113	162			62
114	163			63
115	115			64
116	164			65
117	165			66
118	166			67
119	167			68
120	120			69
121	169			70

122	170			71
123	171			72
124	172			73
125	173			74
126	174			75
127	175			76
128	176			77
129	177			78
130	178			79
131	179			80
132	180			81
133	181			82
134	182			83
135	183			84
136	184			85
137	185			86
138	186			87
139	187			88
140	189			89
141	190			90
142	191			91
143	192			92
144	193			93
145	195			94
146	196			95
147	197			96
148	198			97
149	199			98
150	200			99
151	201			100
152	152			101
153	153			102
4	49	1	49.	
154	154			154
155	206			105
156	156			156
157	209			108
158	210			109
159	159			159
160	214			111
161	216			112
162	217			113
163	218			114
164	220			116
165	222			117
166	223			118
167	224			119
168	168			168
169	226			121

170	227			122
171	228			123
172	229			124
173	230			125
174	232			126
175	233			127
176	234			128
177	235			129
178	236			130
179	237			131
180	238			132
181	240			133
182	241			134
183	242			135
184	243			136
185	244			137
186	245			138
187	246			139
188	188			188
189	249			140
190	250			141
191	251			142
192	252			143
193	253			144
194	194			194
195	255			145
196	256			146
197	257			147
198	258			148
199	260			149
200	261			150
201	262			151
202	202			202
5	64	1	25.19	
203	203			203
204	204			204
205	205			205
206	206			155
207	207			207
208	208			208
209	209			157
210	210			158
211	211			211
212	212			212
213	213			213
214	214			160
215	215			215
216	216			161
217	217			162

218	218
219	219
220	220
221	221
222	222
223	223
224	224
225	225
226	226
227	227
228	228
229	229
230	230
231	231
232	232
233	233
234	234
235	235
236	236
237	237
238	238
239	239
240	240
241	241
242	242
243	243
244	244
245	245
246	246
247	247
248	248
249	249
250	250
251	251
252	252
253	253
254	254
255	255
256	256
257	257
258	258
259	259
260	260
261	261
262	262
263	263
264	264
265	265
266	266

163
219
164
221
165
166
167
225
169
170
171
172
173
231
174
175
176
177
178
179
180
239
181
182
183
184
185
186
187
247
248
189
190
191
192
193
254
195
196
197
198
259
199
200
201
263
264
265
266

```
 7
51  102  153  202  266
 8    0  160    1    2
   270.       20.
 1   14              43.28          1.
 2   13              31.43          1.
 3    7              26.65          1.
 4    9              25.34          1.
 5   10              31.90          1.
 6   11              23.32          1.
 7   12              50.96          1.
 8   12              50.96          1.
 9   11              23.32          1.
10   10              31.90          1.
11    9              25.34          1.
12    8              19.16          1.
13   18              20.32          1.
14    5              31.42          1.
15    6              30.11          1.
16    6              30.11          1.
17    5              31.42          1.
18    1              34.79          1.
19    2              29.63          1.
20    3              45.54          1.
21    4              50.96          1.
22    4              50.96          1.
23    3              45.54          1.
24    2              29.63          1.
25    1              34.79          1.
26   15              90.13          1.
27   16              59.17          1.
28   16              59.17          1.
29   17              31.41          1.
30   17              31.41          1.
31   16              59.17          1.
32   16              59.17          1.
33   14              43.28          1.
34   13              31.43          1.
35    7              26.65          1.
36    9              25.34          1.
37   10              31.90          1.
38   11              23.32          1.
39   12              50.96          1.
40   12              50.96          1.
41   11              23.32          1.
42   10              31.90          1.
43    9              25.30          1.
44    8              19.16          1.
45   18              20.32          1.
```

46	5	31.42	1.
47	6	30.11	1.
48	6	30.11	1.
49	5	31.42	1.
50	1	34.79	1.
51	2	29.63	1.
52	3	45.54	1.
53	4	50.96	1.
54	4	50.96	1.
55	3	45.54	1.
56	2	29.63	1.
57	1	34.79	1.
58	15	90.13	1.
59	16	59.17	1.
60	16	59.17	1.
61	17	31.41	1.
62	17	31.41	1.
63	16	59.17	1.
64	16	59.17	1.
65	14	43.28	1.
66	13	31.43	1.
67	7	26.65	1.
68	9	25.34	1.
69	10	31.90	1.
70	11	23.32	1.
71	12	50.96	1.
72	12	50.96	1.
73	11	23.32	1.
74	10	31.90	1.
75	9	25.30	1.
76	8	19.16	1.
77	18	20.32	1.
78	5	31.42	1.
79	6	30.11	1.
80	6	30.11	1.
81	5	31.42	1.
82	1	34.79	1.
83	2	29.63	1.
84	3	45.54	1.
85	4	50.96	1.
86	4	50.96	1.
87	3	45.54	1.
88	2	29.63	1.
89	1	34.79	1.
90	15	90.13	1.
91	16	59.17	1.
92	16	59.17	1.
93	17	31.41	1.
94	17	31.41	1.

95	16	59.17	1.
96	16	59.17	1.
97	14	43.28	1.
98	13	31.43	1.
99	7	26.65	1.
100	9	25.34	1.
101	10	31.90	1.
102	11	23.32	1.
103	12	50.96	1.
104	12	50.96	1.
105	11	23.32	1.
106	10	31.90	1.
107	9	25.30	1.
108	8	19.16	1.
109	18	20.32	1.
110	5	31.42	1.
111	6	30.11	1.
112	6	30.11	1.
113	5	31.42	1.
114	1	34.79	1.
115	2	29.63	1.
116	3	45.54	1.
117	4	50.96	1.
118	4	50.96	1.
119	3	45.54	1.
120	2	29.63	1.
121	1	34.79	1.
122	15	90.13	1.
123	16	59.17	1.
124	16	59.17	1.
125	17	31.41	1.
126	17	31.41	1.
127	16	59.17	1.
128	16	59.17	1.
129	14	43.28	1.
130	13	31.43	1.
131	7	26.65	1.
132	9	25.34	1.
133	10	31.90	1.
134	11	23.32	1.
135	12	50.96	1.
136	12	50.96	1.
137	11	23.32	1.
138	10	31.90	1.
139	9	25.30	1.
140	8	19.16	1.
141	18	20.32	1.
142	5	31.42	1.
143	6	30.11	1.

```
144    6                30.11          1.
145    5                31.42          1.
146    1                34.79          1.
147    2                29.63          1.
148    3                45.54          1.
149    4                50.96          1.
150    4                 50.96          1.
151    3                 45.54          1.
152    2                 29.63          1.
153    1                 34.79          1.
154   15                 90.13          1.
155   16                 59.17          1.
156   16                 59.17          1.
157   17                 31.41          1.
158   17                 31.41          1.
159   16                 59.17          1.
160   16                 59.17          1.
  1    0   32    2
  1    2    3    4    5    6    7    8    9   10   11   12
 13   14   15   16   17   18   19   20   21   22   23   24
 25   26   27   28   29   30   31   32
      0.0      141.8      200.      141.8
  2    0  128    2
 33   34   35   36   37   38   39   40   41   42   43   44
 45   46   47   48   49   50   51   52   53   54   55   56
 57   58   59   60   61   62   63   64   65   66   67   68
 69   70   71   72   73   74   75   76   77   78   79   80
 81   82   83   84   85   86   87   88   89   90   91   92
 93   94   95   96   97   98   99  100  101  102  103  104
105  106  107  108  109  110  111  112  113  114  115  116
117  118  119  120  121  122  123  124  125  126  127  128
129  130  131  132  133  134  135  136  137  138  139  140
141  142  143  144  145  146  147  148  149  150  151  152
153  154  155  156  157  158  159  160
      0.0      149.4      200.      149.4
  9   18
  1 WALL      34.79       1.65    3          1
  5    1   .1          5    1   .55          5    2   1.
  2 WALL      29.63       1.65    3          1
  5    1   .1          5    1   .55          5    2   1.
  3 WALL      45.54       1.65    3          1
  5    1   .1          5    1   .55          5    2   1.
  4 WALL      50.96       1.65    3          1
  5    1   .1          5    1   .55          5    2   1.
  5 WALL      31.42       1.65    3          1
  5    1   .1          5    1   .55          5    2   1.
  6 WALL      30.11       1.65    3          1
  5    1   .1          5    1   .55          5    2   1.
  7 WALL      26.65       1.65    3          1
```

```
  5    1   .1          5    1  .55          5    2   1.
  8 WALL     19.16       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
  9 WALL     25.34       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 10 WALL     31.90       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 11 WALL     23.32       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 12 WALL     50.96       1.65    3
  5    1   .1          5    1  .55          5    2   1.
 13 WALL     31.43       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 14 WALL     43.28       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 15 WALL     90.13       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 16 WALL     59.17         .2    2          1
  5    1   .1          5    1  .1
 17 WALL     31.41         .2    2          1
  5    1   .1          5    1  .1
 18 WALL     20.32       1.65    3          1
  5    1   .1          5    1  .55          5    2   1.
 10    2
  1    2   487.32
     50.      .113       30.     1000.       .113       30.
  2    2     5.99
     50.      .24        .027    1000.       .24        .027
 12    5
  1    1    1
1.52 1.52   1.   1.   1.   1.
  2    1    1
1.52 1.52   1.   1.   1.   1.
  3    1    1
1.52 1.52   1.   1.   1.   1.
  4    1    1
1.52 1.52   1.   1.   1.   1.
  5    1    1
1.52 1.52   1.   1.   1.   1.
 13  161    0   11    0
 16   10   10   13   13    8    8    8    8    8    4
 0.0       0.0 703.       0.0722.2     .4012743.2     .71938746.6     .77189
780.9      .8180840.2     .8878880.3     .9110927.4     .896201019.     .8927
1066.      .90221126.     .89201370.     .89251375.     .89171417.      0.0
2400.       0.0
 0.0      1155.741.8     1155.967.2     1150.51060.     1151.1123.     1173.5
1183.     1178.31243.     1181.1303.     1183.51375.     1185.2400.     1185.0
 0.0      2297.741.8     2297.967.2     2280.1060.     2284.1123.      2435.
1183.     2465.1243.     2495.1303.     2504.1375.     2519.2400.      2519.
```

```
  0.0     1.E-8743.2     1.E-8746.6     .0115780.9     .1082840.2     .1053
880.3     .1024927.4     .10381019.     .10461066.     .10311126.     .1046
1370.     .10461375.     .09422400.     .0942
  0.0       1.0743.2       1.0746.6     .9885780.9     .8918840.2     .8947
880.3     .8976927.4     .89621019.     .89541066.     .89691126.     .8954
1370.     .89541375.     .90582400.     .9058
  0.0     132.69 750.    132.66803.4    134.81080.     143.141440.    147.61
1698.     147.632040.    147.152400.    147.12
  0.0     1102.9 750.    1102.9803.4     1107.1080.    1116.81440.    1122.
1698.     1118.22040.    1116.32400.    1115.3
  0.0      .0562 750.     .0562803.4     .05621080.     .12541440.     .1660
1698.      .13642040.     .12152400.     .1140
  0.0      .9438 750.     .9438803.4     .94381080.     .85571440.     .7883
1698.      .81812040.     .83222400.     .8401
  0.0      1.E-8 750.     1.E-8803.4     1.E-81080.      .0181440.     .0441
1698.      .04722040.     .04492400.     .0451
  0.0        0.0 702.       0.0 703.       1.02400.       1.0
    1    1     3
    2    1     3
    3    1     3
    4    1     3
    5    1     3
    6    1     3
    7    1     3
    8    1     3
    9    1     3
   10    1     3
   11    1     3
   12    1     3
   13    1     3
   14    1     3
   15    1     3
   16    1     3
   17    1     3
   18    1     3
   19    1     3
   20    1     3
   21    1     3
   22    1     3
   23    1     3
   24    1     3
   25    1     3
   26    1     3
   27    1     3
   28    1     3
   29    1     3
   30    1     3
   31    1     3
   32    1     3
```

```
 33     1     3
 34     1     3
 35     1     3
 36     1     3
 37     1     3
 38     1     3
 39     1     3
 40     1     3
 41     1     3
 42     1     3
 43     1     3
 44     1     3
 45     1     3
 46     1     3
 47     1     3
 48     1     3
 49     1     3
 50     1     3
 51     1     3
103     2     3
104     2     3
106     2     3
107     2     3
110     2     3
115     2     3
120     2     3
152     2     3
153     2     3
154     1     2    11     7      .8484        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
156     1     2    11     7      .2828        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
159     1     2    11     7      .5656        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
168     1     2    11     7      .5656        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
188     1     2    11     7      .5656        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
194     1     2    11     7      .5656        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
202     1     2    11     7     1.1312        1.0    14.5038
 1.1.E-8  1.0   1.0   1.0
  6     0     8    10     9
```

154	2	3
156	2	3
159	2	3
168	2	3
188	2	3
194	2	3
202	2	3
203	1	3
204	1	3
205	1	3
207	1	3
208	1	3
211	1	3
212	1	3
213	1	3
215	1	3
219	1	3
221	1	3
225	1	3
231	1	3
239	1	3
247	1	3
248	1	3
254	1	3
259	1	3
263	1	3
264	1	3
265	1	3
266	1	3
203	2	3
204	2	3
206	2	3
207	2	3
208	2	3
209	2	3
210	2	3
212	2	3
214	2	3
216	2	3
217	2	3
218	2	3
219	2	3
220	2	3
222	2	3
223	2	3
224	2	3
226	2	3
227	2	3
228	2	3

```
229     2     3
230     2     3
232     2     3
233     2     3
234     2     3
235     2     3
236     2     3
237     2     3
238     2     3
240     2     3
241     2     3
242     2     3
243     2     3
244     2     3
245     2     3
246     2     3
249     2     3
250     2     3
251     2     3
252     2     3
253     2     3
255     2     3
256     2     3
257     2     3
258     2     3
260     2     3
261     2     3
262     2     3
264     2     3
266     2     3
205     3     1                    14.5038     1102.6
 1.1.E-8  1.0  1.0  1.0
  6     0     8    10     9
211     3     1                    14.5038     1102.6
 1.1.E-8  1.0  1.0  1.0
  6     0     8    10     9
213     3     1                    14.5038     1102.6
 1.1.E-8  1.0  1.0  1.0
  6     0     8    10     9
215     3     1                    14.5038     1102.6
 1.1.E-8  1.0  1.0  1.0
  6     0     8    10     9
221     3     1                    14.5038     1102.6
 1.1.E-8  1.0  1.0  1.0
  6     0     8    10     9
225     3     1                    14.5038     1102.6
 1.1.E-8  1.0  1.0  1.0
  6     0     8    10     9
231     3     1                    14.5038     1102.6
```

```
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  239    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  247    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  248    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  254    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  259    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  263    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
  265    3    1              14.5038     1102.6
  1.1.E-8  1.0  1.0  1.0
    6    0    8   10    9
   66    2    4    1    2        .94        1.0   14.5038
  1.1.E-8  1.0  1.01.E-8
    3    0    5    4    0
7.349
   14    5



 2100    0
          .001            60.          2100.            1.          14000.
          200.            60.         10000.       100000.
         -.001
```

REFERENCES

1. Thurgood, M. J. et al., "COBRA/TRAC - A Thermal-Hydraulics Code for Transient Analysis of Nuclear Reactor Vessels and Primary Coolant Systems," NUREG/CR-3046, March 1983. Available for purchase from National Technical Information Services, Springfield, Virginia.

2. Schall, M., and L. Valencia, "Data Compilation on the HDR Containment for Input Data Processing for Pretest Calculations," HDR Safety Program Report No. 3.279/82, January 1982.

3. Dallman, J. C., and W. L. Kirchner, NUREG/CR-1421, April 1980. Available for purchase from National Technical Information Services, Springfield, Virginia.

4. Bloom, G. R., et al., "Hydrogen Mixing and Distribution in Containment Atmospheres," EPRI NP-2669, March 1983.

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-3262
PNL-5515
Vol. 4

2. TITLE AND SUBTITLE
COBRA-NC: A Thermal Hydraulics Code for Transient Analysis of Nuclear Reactor Components
Vol. 4: Users' Manual for Containment Analysis

3. LEAVE BLANK

4. DATE REPORT COMPLETED
MONTH: March
YEAR: 1986

5. AUTHOR(S)
C.L. Wheeler, M.J. Thurgood, T.E. Guidotti, D.E. DeBellis

6. DATE REPORT ISSUED
MONTH: August
YEAR: 1986

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Pacific Northwest Laboratory
Richland, WA 99352

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
B2466

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Reactor System Safety
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT
Technical

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

COBRA-NC is a digital computer program written in FORTRAN IV that simulates the response of nuclear reactor components and systems to thermal-hydraulic transients. The code solves the multicomponent, compressible, three-dimensional, two-fluid, three-field equations for two-phase flow. The three velocity fields are the vapor/gas field, the continuous liquid field, and the liquid drop field. This volume of the manual provides the user with an explanation of the input required to simulate the response of multicompartment nuclear containment systems to postulated loss-of-coolant accidents that result in the release of steam, water, and/or noncondensable gases into the containment.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS
COBRA-NC
3-D
finite difference
thermal hydraulic transient code
multicomponent
compressible
3-field
containment analysis

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT
Unlimited

16. SECURITY CLASSIFICATION
(This page) Unclassified
(This report) Unclassified

17. NUMBER OF PAGES

18. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
USNRC
WASH. D.C.
PERMIT No. G-67

120555078877 1 1AN1R4
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555