RELAP5/MOD3 Code Manual

User's Guide and Input Requirements

Prepared by
The RELAP5 Development Team

Idaho National Engineering Laboratory
Lockheed-Martin Idaho Technologies Company

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

The RELAP5 code has been developed for best estimate transient simulation of light water reactor coolant systems during postulated accidents. The code models the coupled behavior of the reactor coolant system and the core for loss-of-coolant accidents, and operational transients, such as anticipated transient without scram, loss of offsite power, loss of feedwater, and loss of flow. A generic modeling approach is used that permits simulating a variety of thermal hydraulic systems. Control system and secondary system components are included to permit modeling of plant controls, turbines, condensers, and secondary feedwater systems.

RELAP5/MOD3 code documentation is divided into seven volumes: Volume I provides modeling theory and associated numerical schemes; Volume II contains detailed instructions for code application and input data preparation; Volume III provides the results of developmental assessment cases that demonstrate and verify the models used in the code; Volume IV presents a detailed discussion of RELAP5 models and correlations; Volume V contains guidelines that have evolved over the past several years through the use of the RELAP5 code; Volume VI discusses the numerical scheme used in RELAP5; and Volume VII is a collection of independent assessment calculations.

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EXECUTIVE SUMMARY

The light water reactor (LWR) transient analysis code, RELAP5, was developed at the Idaho National Engineering Laboratory (INEL) for the U.S. Nuclear Regulatory Commission (NRC). Code uses include analysis required to support rulemaking, licensing audit calculations, evaluation of accident mitigation strategies, evaluation of operator guidelines, and experiment planning analysis. REl AP5 has also been used as the basis for a nuclear plant analyzer. Specific applications have included simulations of transients in LWR systems such as loss of coolant, anticipated transients without scram (ATWS), and operational transients such as loss of feedwater, loss of offsite power, station blackout, and turbine trip. RELAP5 is a highly generic code that, in addition to calculating the behavior of a reactor coolant system during a transient, can be used for simulation of a wide variety of hydraulic and thermal transients in both nuclear and nonnuclear systems involving mixtures of steam, water, noncondensable, and solute.

The MOD3 version of RELAP5 has been developed jointly by the NRC and a consortium consisting of several countries and domestic organizations that were members of the International Code Assessment and Applications Program (ICAP), and its successor organization, Code Applications and Maintenance Program (CAMP). Credit also needs to be given to various Department of Energy sponsors, including the INEL laboratory-directed discretionary funding program. The mission of the RELAP5/MOD3 development program was to develop a code version suitable for the analysis of all transients and postulated accidents in LWR systems, including both large- and small-break loss-of-coolant accidents (LOCAs) as well as the full range of operational transients.

The RELAP5/MOD3 code is based on a nonhomogeneous and nonequilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients. The objective of the RELAP5 development effort from the outset was to produce a code that included important first-order effects necessary for accurate prediction of system transients but that was sufficiently simple and cost effective so that parametric or sensitivity studies are possible.

The code includes many generic component models from which general systems can be simulated. The component models include pumps, valves, pipes, heat releasing or absorbing structures, reactor point kinetics, electric heaters, jet pumps, turbines, separators, accumulators, and control system components. In addition, special process models are included for effects such as form loss, flow at an abrupt area change, branching, choked flow, boron tracking, and noncondensable gas transport.

The system mathematical models are coupled into an efficient code structure. The code includes extensive input checking capability to help the user discover input errors and inconsistencies. Also included are free-format input, restart, renodalization, and variable output edit features. These user conveniences were developed in recognition that generally the major cost associated with the use of a system transient code is in the engineering labor and time involved in accumulating system data and developing system models, while the computer cost associated with generation of the final result is usually small.

The development of the models and code revisions that constitute RELAP5 has spanned approximately 17 years from the early stages of RELAP5 numerical scheme development to the present. RELAP5 represents the aggregate accumulation of experience in modeling core behavior during accidents, two-phase flow process, and LWR systems. The code development has benefitted from extensive application and comparison to experimental data in the LOFT, PBF, Semiscale, ACRR, NRU, and other experimental programs.

As noted earlier, several new models, improvements to existing models and user conveniences have been added to RELAP5/MOD3. The new models include:

- The Bankoff counter-current flow limiting correlation, that can be activated by the user at each junction in the system model

- The ECCMIX component for modeling of the mixing of subcooled emergency core cooling system (ECCS) liquid and the resulting interfacial condensation

- A zirconium-water reaction model to model the exothermic energy production on the surface of zirconium cladding material at high temperature

- A surface-to-surface radiation heat transfer model with multiple radiation enclosures defined through user input

- A level tracking model

- A thermal stratification model.

Improvements to existing models include:

- New correlations for interfacial friction for all types of geometry in the bubbly-slug flow regime in vertical flow passages

- Use of junction-based interphase drag

- An improved model for vapor pulithrough and liquid entrainment in horizontal pipes to obtain correct computation of the fluid state convected through the break

- A new critical heat flux correlation for rod bundles based on tabular data

- An improved horizontal stratification inception criterion for predicting the flow regime transition between horizontally stratified and dispersed flow

- A modified reflood heat transfer model

- Improved vertical stratification inception logic to avoid excessive activation of the water packing model

- An improved boron transport model

- A mechanistic separator/dryer model

- An improved crossflow model

- An improved form loss model

- The addition of a simple plastic strain model with clad burst criterion to the fuel mechanical model

- The addition of a radiation heat transfer term to the gap conductance model

- Modifications to the noncondensable gas model to eliminate erratic code behavior and failure

- Improvements to the downcomer penetration, ECCS bypass, and upper plenum deentrainment capabilities

Additional user conveniences include:

- Code speedup through vectorization for the CRAY X-MP computer

- Computer portability through the conversion of the FORTRAN coding to adhere to the FORTRAN 77 standard

- Code execution and validation on a variety of systems. The code should be easily installed (i.e., the installation script is supplied with the transmittal) on the CRAY X-MP (UNICOS), DECstation 5000 (ULTRIX), DEC Alpha Workstation (OSF/1), IBM Workstation 6000 (UNIX), SUN Workstation (UNIX), and HP Workstation (UNIX). The code has been installed (although the installation script is not supplied with the transmittal) on the CDC Cyber (NOS/VE), IBM 309 1 (MVS), and IBM-PC (DOS). The code should be able to be installed on all 64-bit machines (integer and floating point) and any 32-bit machine that provides for 64-bit floating point.

The RELAP5/MOD3 code manual consists of seven separate volumes. The modeling theory and associated numerical schemes are described in Volume I, to acquaint the user with the modeling base and thus aid in effective use of the code. Volume II contains more detailed instructions for code application and specific instructions for input data preparation. Both Volumes I and II are expanded and revised versions of the RELAP5/MOD2 code manual[a] and Volumes I and III of the SCDAP/RELAP5/MOD2 code manual.[b]

Volume III[c] provides the results of developmental assessment cases run with RELAP5/MOD3 to demonstrate and verify the models used in the code. The assessment matrix contains phenomenological problems, separate-effects tests, and integral systems tests.

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a. V. H. Ransom et al., *RELAP5/MOD2 Code Manual, Volumes I and II*, NUREG/CR-4312, EGG-2396, August and December, 1985, revised April 1987.

b. C. M. Allison and E. C. Johnson, Eds., *SCDAP/RELAP5/MOD2 Code Manual, Volume I: RELAP5 Code Structure, System Models, and Solution Methods, and Volume III: User's Guide and Input Requirements*, NUREG/CR-5273, EGG-2555, June 1989.

c. To be published in 1996.

Volume IV contains a detailed discussion of the models and correlations used in RELAP5/MOD3. It provides the user with the underlying assumptions and simplifications used to generate and implement the base equations into the code so that an intelligent assessment of the applicability and accuracy of the resulting calculations can be made. Thus, the user can determine whether RELAP5/MOD3 is capable of modeling his or her particular application, whether the calculated results will be directly comparable to measurement or whether they must be interpreted in an average sense, and whether the results can be used to make quantitative decisions.

Volume V provides guidelines for user that have evolved over the past several years from applications of the RELAP5 code at the Idaho National Engineering Laboratory, at other national laboratories, and by users throughout the world.

Volume VI discusses the numerical scheme in RELAP5/MOD3, and Volume VII is a collection of independent assessment calculations.

ACKNOWLEDGMENTS

1 INTRODUCTION

The purpose of this volume is to help educate the code user by documenting the modeling experience accumulated from developmental assessment and application of the RELAP5 code. This information includes a blend of the model developers' recommendations with respect to how the model is intended to be applied and the application experience that indicates what has been found to work or not to work. Where possible, approaches known to work are definitely recommended, and approaches known not to work are pointed out as pitfalls to avoid.

1.1 General

The objective of the user's guide is to reduce the uncertainty associated with user simulation of light water reactor (LWR) systems. However, we do not imply that uncertainty can be eliminated or even quantified in all cases, since the range of possible system configurations and transients that could occur is large and constantly evolving. Hence, the effects of nodalization, time step selection, and modeling approach are not completely quantified. As the assessment proceeds, there will be a continual need to update the user guidelines document to reflect the current state of simulation knowledge.

1.2 Areas of Application

RELAP5 is a generic transient analysis code for thermal-hydraulic systems using a fluid that may be a mixture of steam, water, noncondensables, and a nonvolatile solute.

The fluid and energy flow paths are approximated by one-dimensional stream tube and conduction models. The code contains system component models applicable to LWRs. In particular, a point neutronics model, pumps, turbines, generator, valves, separator, and controls are included. The code also contains a jet pump component.

The LWR applications for which the code is intended include accidents initiated from small break loss-of-coolant accidents, operational transients such as anticipated transients without SCRAM, loss of feed, loss-of-offsite power, and loss of flow transients. The reactor coolant system (RCS) behavior can be simulated up to and slightly beyond the point of fuel damage.

1.3 Modeling Philosophy

RELAP5 is designed for use in analyzing system component interactions; it does not offer detailed simulations of fluid flow within components. As such, it contains limited ability to model multidimensional effects, either for fluid flow, heat transfer, or reactor kinetics. Exceptions are the modeling of cross flow effects in a pressurized water reactor (PWR) core and the reflood modeling that uses a two-dimensional conduction solution in the vicinity of a quench front. To further enhance the overall system modeling capability, a control system model is included. This model provides a way to perform basic mathematical operations, such as addition, multiplication, integration, and control components such as proportional-integral, lag, and lead-lag controllers, for use with the basic fluid, thermal, and component variables calculated by the remainder of the code. This capability can be used to construct models of system controls or components that can be described by algebraic and differential equations. The code numerical solution includes the evaluation and numerical time advancement of the control system coupled to the fluid and thermal system.

The hydrodynamic model and the associated numerical scheme are based on the use of fluid control volumes and junctions to represent the spatial character of the flow. The control volumes can be viewed as stream tubes having inlet and outlet junctions. The control volume has a direction associated with it that is positive from the inlet to the outlet. Velocities are located at the junctions and are associated with mass and energy flow between control volumes. Control volumes are connected in series, using junctions to represent a flow path. All internal flow paths, such as recirculation flows, must be explicitly modeled in this way since only single liquid and vapor velocities are represented at a junction. (In other words, a countercurrent liquid-liquid flow cannot be represented by a single junction.) For flows in pipes, there is little confusion with respect to nodalization. However, in a steam generator having a separator and recirculation flow paths, some experience is needed to select a nodalization that will give correct results under all conditions of interest. Nodalization of branches or tees also requires more guidance.

Heat flow paths are also modeled in a one-dimensional sense, using a finite difference mesh to calculate temperatures and heat flux vectors. The heat conductors can be connected to hydrodynamic volumes to simulate a heat flow path normal to the fluid flow path. The heat conductor or heat structure is thermally connected to the hydrodynamic volume through a heat flux that is calculated using heat transfer correlations. Electrical or nuclear heating of the heat structure can also be modeled as either a surface heat flux or as a volumetric heat source. The heat structures are used to simulate pipe walls, heater elements, nuclear fuel pins, and heat exchanger surfaces.

A special, two-dimensional, heat conduction solution method with an automatic fine mesh rezoning is used for low-pressure reflood. Both axial and radial conduction are modeled, and the axial mesh spacing is refined as needed to resolve the axial thermal gradient. The hydrodynamic volume associated with the heat structure is not rezoned, and a spatial boiling curve is constructed and used to establish the convection heat transfer boundary condition. At present, this capability is specialized to the LWR core reflood process, but the plan is to generalize this model to higher pressure situations so that it can be used to track a quench front anywhere in the system.

The point reactor kinetics model is advanced in a serial and implicit manner after the heat conduction-transfer and hydrodynamic advancements but before the control system advancement. The kinetics model consists of a system of ordinary differential equations integrated using a modified Runge-Kutta technique. The integration time step is regulated by a truncation error control and may be less than the hydrodynamic time step; however, the thermal and fluid boundary conditions are held fixed over each hydrodynamic time interval. The reactivity feedback effects of fuel temperature, moderator temperature, moderator density, and boron concentration in the moderator are evaluated, using averages over the hydrodynamic control volumes and associated heat structures that represent the core. The averages are weighted averages established a priori such that they represent the effect on total core power. Certain nonlinear or multidimensional effects caused by spatial variations of the feedback parameters cannot be accounted for with such a model. Thus, the user must judge whether or not the model is a reasonable approximation of the physical situation being modeled.

The control system model provides a way for simulating any lumped process, such as controls or instrumentation, in which the process can be defined in terms of system variables through logical, algebraic, differentiating, or integrating operations. These models do not have a spatial variable and are integrated with respect to time. The control system is coupled to the thermal and hydrodynamic components serially and implicitly. The control system advancement occurs after the heat conduction transfer, hydrodynamic, and reactor kinetics advancements and uses the same time step as the hydrodynamics so that new time thermal and hydrodynamic information is used in the control model advancement. However, the control variables are fed back to the thermal and hydrodynamic model in the succeeding time step, i.e., they are explicitly coupled.

A system code such as RELAP5 contains numerous approximations to the behavior of a real, continuous system. These approximations are necessitated by the finite storage capability of computers, by the need to obtain a calculated result in a reasonable amount of computer time, and in many cases because of limited knowledge about the physical behavior of the components and processes modeled. For example, knowledge is limited for components such as pumps and separators, processes such as two-phase flow, and heat transfer. Examples of approximations required because of limited computer resources are limited spatial nodalization for hydrodynamics, heat transfer, and kinetics; and density of thermodynamic and property tables. In general, the accuracy effect of each of these factors is of the same order; thus, improving one approximation without a corresponding increase in the others will not necessarily lead to a corresponding increase in physical accuracy. At the present time, very little quantitative information is available regarding the relative accuracies and their interactions. What is known has been established through applications and comparison of simulation results to experimental data. Progress is being made in this area as the code is used; but there is, and will be for some time, a need to continue the effort to quantify the system simulation capabilities.

2 HYDRODYNAMICS

The hydrodynamics simulation is based on a one-dimensional model of the transient flow for a steam-water noncondensable mixture. The numerical solution scheme used results in a system representation using control volumes connected by junctions. A physical system consisting of flow paths, volumes, areas, etc., is simulated by constructing a network of control volumes connected by junctions. The transformation of the physical system to a system of volumes and junctions is an inexact process, and there is no substitute for experience. General guidelines have evolved though application work using RELAP5. The purpose here is to summarize these guidelines.

In selecting a nodalization for hydrodynamics, the following general rules should be followed:

1. The length of volumes should be such that all have similar material Courant limits, i.e., flow length divided by velocity about the same. (Expected velocities during the transient must be considered.)

2. The volumes should have $L/D \geq 1$, except for special cases such as the bottom of a pressurizer where a smaller L/D is desired to sharpen the emptying characteristic.

3. The total system cannot exceed the computer resources. RELAP5 dynamically allocates memory based on the requirements of each problem, and most models require memory based on factors such as the number of volumes, junctions, number of heat structures and the number of meshes, and the number and length of various user input tables. The number of hydrodynamic volumes is a reasonable measure of problem size, and typical LWR systems with over 600 volumes have been run on workstations with 32 Mbytes of memory. The memory should be sufficiently large to avoid paging during transient advancement.

4. If possible, a nodalization sensitivity study should be made in order to estimate the uncertainty owing to nodalization. Volume V provides guidance and examples of appropriate nodalizations for reactor systems.

5. Avoid nodalizations where a sharp density gradient coincides with a junction (a liquid interface, for example) at steady state or during most of the transient. This type of situation can result in time-step reduction and increased computer cost.

6. Eliminate minor flow paths that do not play a role in system behavior or are insignificant compared to the accuracy of the system representation. This can not usually be done until some preliminary trial calculations have been made that include all the flow paths. Care must be used here because in certain situations flow through minor flow paths can have a significant effect on system behavior. An example is the effect of hot-to-cold-leg leakage on core level depression in a PWR under small break loss-of-coolant accident conditions.

7. Establish the flow and pressure boundaries of the system beyond which modeling is not required and specify appropriate boundary conditions at these locations.

2.1 Basic Flow Model

The RELAP5 flow model is a nonhomogeneous, nonequilibrium two-phase flow model. See Section 3 of Volume I for a detailed description of the model and the governing equations. However, options exist for homogeneous, equilibrium, or frictionless models if desired. These options are included to facilitate comparisons with other homogeneous and/or equilibrium codes. Generally, the code will not run faster if these options are selected.

The RELAP5 flow model is a one-dimensional, stream-tube formulation in which the bulk flow properties are assumed to be uniform over the fluid passage cross section. The control volumes are finite increments of the flow passage and may have a junction at the inlet or outlet (normal junctions) or at the side of a volume (crossflow junctions). The stream-wise variation of the fluid passage is specified through the volume cross-sectional area, the junction areas, and through use of the smooth or abrupt area change options at the junctions. The smooth or abrupt area change option affects the way in which the flow is modeled, both through the calculation of loss factors at the junction and through the method used to calculate the volume average velocity. (Volume average velocity enters into momentum flux, boiling heat transfer, and wall friction calculations.) The abrupt area change model should be used to model the effect of reducers, orifices, or any obstruction in which the flow area variation with length is great enough to cause turbulence and flow separation. Only flow passages having a low wall angle (<10 degrees, including angle) should be considered smooth. An exception to this rule is the case where the user specifies the kinetic loss factor at a junction and uses the smooth option. This type of modeling should only be attempted for cases where the actual flow area change is modest (less than a factor of two).

The hydrodynamic boundaries of a system are modeled using time-dependent volumes and junctions. For example, a reservoir condition would normally be modeled as a constant pressure source of mass and energy (a sink in the case of an outflow boundary). The reservoir is connected to the system through a normal junction, and the inflow velocity is determined from the momentum equation solution. For this type of boundary, some caution is required, since the energy boundary condition is in terms of the thermal energy rather than total energy. Thus, as the velocity increases, the total energy inflow increases owing to the increase in kinetic energy. This effect can be minimized for simulation of a reservoir by making the cross-sectional area of the time-dependent volume very large compared to the inlet junction area. This policy should be followed for outflow boundaries as well, or else flow reversals may occur.

A second way of specifying a flow boundary is using the time-dependent junction in addition to a time-dependent volume. This type of boundary condition is analogous to a positive displacement pump where the inflow rate is independent of the system pressure. In this case, the cross-sectional area of the time-dependent volume is not used because the velocity is fixed and the time-dependent volume is only used to specify the properties of the inflow. Thus, the total energy of the inflow is specified. When only time-dependent junctions are used as boundary conditions, the system pressure entirely depends on the system mass, and, in the case of all liquid systems, a very stiff system results. An additional fact that should be considered when using a time-dependent junction as a boundary is that pump work is required for system inflow if the system pressure is greater than the time-dependent volume pressure. In particular, any energy dissipation associated with a real pumping process is not simulated. The flow work done against the system pressure is approximated by work terms in the thermal energy equation.

In RELAP5, any volume that does not have a connecting junction at an inlet or outlet is treated as a closed end. Thus, no special boundary conditions are required to simulate a closed end.

The fluid properties at an outflow boundary are not used unless flow reversal occurs. In this respect, some caution is necessary and is best illustrated by an example. In the modeling of a subatmospheric pressure containment, saturated steam is often specified for the containment volume condition. This will result in the outflow volume containing pure steam at low pressure and temperature. If in the course of calculation a flow reversal occurs, even a very minute one (possibly caused by numerical noise), a cascading result occurs. The low-pressure or low-temperature steam can rush into a volume at higher pressure and rapidly condense. The rapid condensation leads to depressurization of the volume and increased flow. Such a result can be avoided by using air or superheated steam in the containment volume.

A general guide to modeling hydrodynamic boundary conditions is to simulate the actual process as closely as possible. This guideline should be followed unless initial calculations result in unphysical results because of unanticipated numerical idiosyncrasies.

Only the algebraic sign is needed in the one-dimensional hydrodynamic components to indicate the direction of vector quantities, i.e., the volume and junction velocities. Both the volumes and the junctions have coordinate directions that are specified through input. Each hydrodynamic volume has three coordinate directions, named x, y, and z, and each coordinate direction has an associated inlet and outlet face. The coordinate direction is positive from the inlet to the outlet. The normal, one-dimensional flow is along the x-coordinate. Normal volume connections are to the inlet and outlet faces associated with the x-coordinate. Cross flow connections are to the inlet and outlet faces associated with coordinates orthogonal to the x-coordinate, that is, the y- and z-coordinates.

Which faces of a volume are the inlet or outlet faces depend upon the specifications of the volume orientation. For a positive vertical elevation change, the inlet is at the lowest elevation, whereas for a negative vertical elevation change, the inlet is at the highest elevation of the volume. For a horizontal volume, whether the inlet is at the left or right depends upon the azimuthal angle. (A zero value implies an orientation with the inlet at the left.) This orientation of a horizontal volume is not important as far as hydrodynamic calculations are concerned but is important if one tries to construct a three-dimensional picture of the flow path. Several possible volume orientations, depending upon the input values for the azimuthal and inclination angles, are illustrated in **Figure 2.1-1**.

The junction coordinate direction is established through input of the junction connection code (Words W1 and W2 of Cards CCC0101 through CCC0109, Section A-7.4 of Appendix A). The junction connection codes designate a *from* and a *to* component, and the velocity is positive in the direction from the *from* component to the *to* component. The connection codes can be entered in an old or an expanded format. The expanded format is recommended, but the old format is still valid.

A connection code has the format CCCVV000N, where CCC is the component number, VV is the volume number, and N is the face number, where zero indicates the old format and nonzero indicates the expanded format. The old format (N=0) can only specify connections to the faces associated with normal flow, that is, flow along the x-coordinate. In the old format, VV is not a volume number but, instead, VV=00 specifies the inlet face of the component, and VV=01 specifies the outlet face of the component. The volume number is only implied. For components specifying single volumes (currently only a pipe specifies multiple volumes), normal flow (as opposed to crossflow) to either the inlet or outlet face can be specified. For a pipe, however, the old format allows specification of normal flow only to the inlet of the first pipe volume or to the outlet of the last pipe volume. Crossflow meaning connections to faces associated with y or z faces cannot be specified with the old format.

Azimuthal angle = 0 or 360
inclination angle = 0

Azimuthal angle = 180
inclination angle = 0

Azimuthal angle = 0 or 360
inclination angle = 30

Azimuthal angle = 180
inclination angle = 30

Azimuthal angle = 0 or 360
inclination angle = 30

Azimuthal angle = 0 or 360
inclination angle = -30
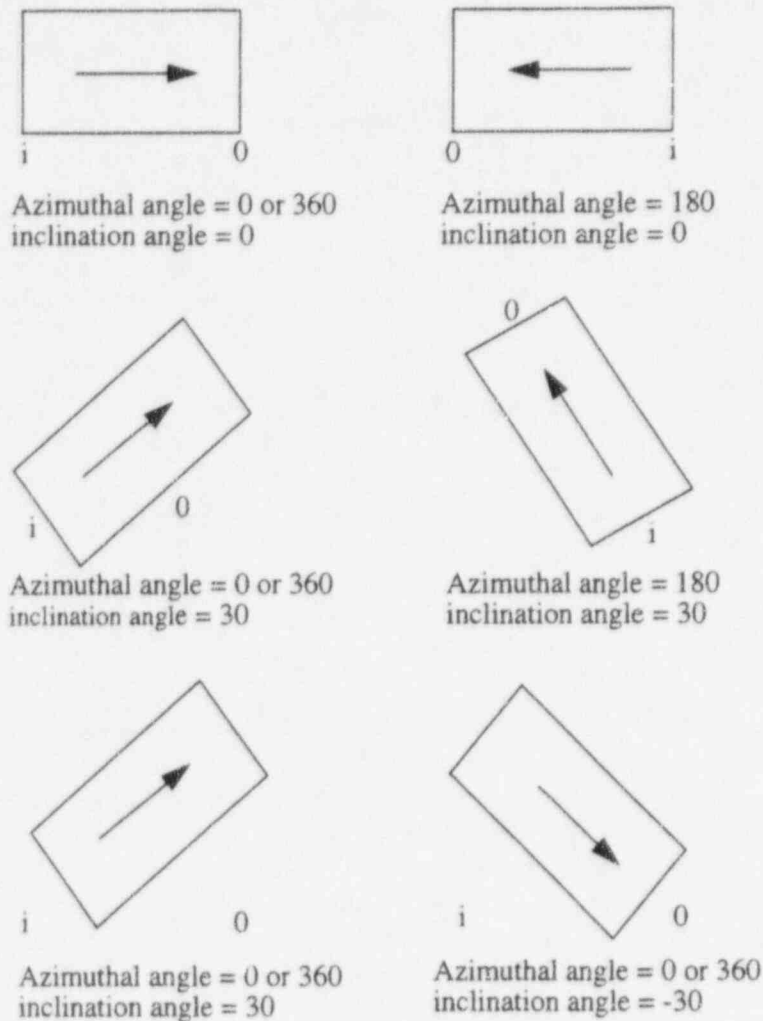
Figure 2.1-1 Possible volume orientation specifications.

The expanded connection code assumes that a volume has six faces, i.e., an inlet and outlet for each of three coordinate directions (see **Figure 2.1-2**). The expanded connection code indicates the volume being connected and through which face it is being connected. In the new format (N nonzero), N is the face number and VV is the volume number. For components specifying single volumes, VV is 01; but for pipes, VV can vary from 01 for the first pipe volume to the last pipe volume number. The quantity N is 1 and 2 for the inlet and outlet faces, respectively, for the volume's normal or x-coordinate direction. The quantity N is 3 and 4 to indicate inlet and outlet faces for the y direction, and N is 5 and 6 to indicate inlet and outlet faces for the z direction. Entering N as 1 or 2 specifies normal connections to a volume; entering N as 3 through 6 specifies a crossflow connection to a volume.

Average volume velocities are computed along each coordinate direction that is active. The x coordinate is assumed active, and a warning message is issued during input processing if no junctions attach to normal faces. A y or z coordinate is active only if a junction attaches to one of the associated faces. The average volume velocity for each coordinate direction involves only junction velocities at the
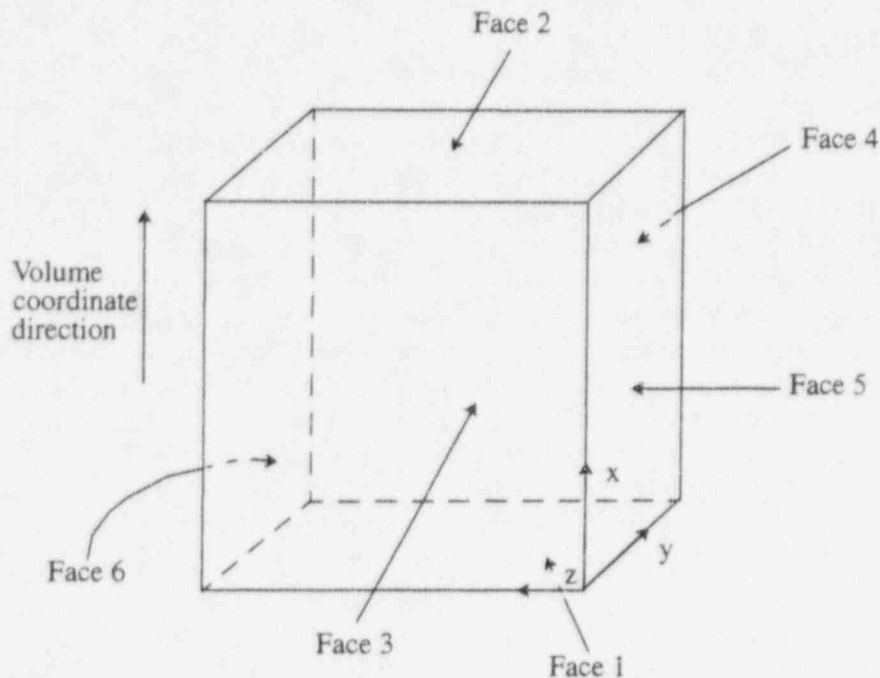
Figure 2.1-2 Volume schematic showing face numbers.

faces associated with that coordinate direction. Thus, a crossflow entering a y face does not contribute to the computation of the volume velocity in the x direction. But that crossflow does contribute to the average velocity in the y direction.

Users of previous versions of RELAP5 will note that the crossflow discussed above is different from older versions. The crossflow capability has been improved, but unfortunately the differing meanings for the term *crossflow* may lead to misunderstanding. The previous use of crossflow implied the following: Flow entered a face orthogonal to the normal flow; crossflows never contributed to any average volume velocity; a limited form of the momentum equation was used; and face numbers 3 through 6 and/or junction flags could specify a crossflow connection. The limited momentum equation ignored momentum flux, wall friction, and gravity terms. Now, crossflow means only that the connection is to a face other than one of the normal faces. Note especially that crossflow does not imply a modified form of the momentum equation. The same momentum equation options are available to both normal flows and crossflows. The standard one-dimensional momentum equations can be applied to both normal and crossflows. Optionally, and only through the use of the momentum flux junctions flags, the momentum flux contribution in the *from* or *to* volume can be ignored for normal and crossflow connections.

In view of the above paragraph, what is the difference between normal and crossflow connections? The answer is there is no difference in the application of the conservation equations to the two types of connections. The only difference is that the term normal is applied to the flow that would occur in a strictly one-dimensional volume; crossflow is an approximation to multidimensional effects consisting of applying the one-dimensional momentum equation to each of the coordinate directions in use. To give some perspective to the approximation, the three-dimensional momentum equation contains nine terms for momentum flux; the momentum in each of the three directions being convected by velocities in the three

directions. In the crossflow model, only three momentum flux terms are used--the momentum in each direction convected by velocity in the same direction.

The code input provides junction flags to ignore momentum flux effects in either the *from* volume, the *to* volume, both volumes, or to include momentum effects in both volumes (the default). Intuitively, including momentum effects is more accurate modeling, and momentum effects should be included in junctions attached to the normal faces. In previous versions of the code, a restricted form of the momentum equation was used that omitted momentum flux, wall friction, and gravity terms. One reason was that the geometric information necessary for computing these terms was not available and average volume velocity terms in the crossflow directions were not computed. The earliest motive for the crossflow model was to treat recirculation flows in the reactor core, and these restrictions were acceptable since velocities were low and there were no elevation changes. The crossflow model was subsequently used for tees since the crossflow model, even with the restrictions, was a better model than previous approaches for tees. The current recommendation is to include the momentum flux terms for crossflows but remove them if computational difficulties involving crossflow junctions are encountered. The crossflow model is currently under developmental assessment. A more definite recommendation is not to have multiple junctions with differing momentum flux options attached to the same coordinate direction. Even though the momentum flux is ignored in one junction, its velocity contributes to the average velocity in that coordinate direction and thus other junctions using momentum flux terms use that average volume velocity.

The current crossflow model requires input information for the y and z coordinates similar to that entered for the x coordinate. Default data for the y and z coordinates are obtained from the x coordinate data by assuming the volume is a section of a right circular pipe. Optional input data may be entered when this assumption is not valid.

In major edits and similar input edits, the junction connection code is edited in the new format. Note that the new logic allows branching and merging flow (i.e., multiple junctions at a face) at any volume, including interior pipe volumes. The primary reason for this change is to permit crossflow to all volumes in a pipe. Now it is possible to use pipe volumes to represent axial levels in a vessel and to use multiple pipe components to represent radial or azimuthal dependence. Single junctions can crosslink any of the pipe volumes at the same axial level.

A simpler method to crosslink volumes is to use the multiple junction component. This component describes one or more junctions, with the limitation that all volumes connected by the junctions must be part of the same hydrodynamic system. Although this component can be considered a collection of single junctions, its common use is to crosslink adjacent volumes of parallel pipes. Because the junctions linking pipe volumes tend to be similar, N junctions crosslinking N volumes per pipe can be entered with the amount of input comparable to one junction.

A sketch showing a series of three horizontal volumes connected by two junctions is shown in **Figure 2.1-3** to illustrate some of the possible coordinate orientations that result from combinations of the connection codes and the volume orientation data. In **Figure 2.1-4**, two possible combinations are illustrated for the connection of two vertical volumes. **Figure 2.1-4**a shows the two volumes unconnected; **Figure 2.1-4**b shows the result when the outlet of Volume 1 is joined to the inlet of Volume 2; and **Figure 2.1-4**c shows the result when the inlet of Volume 1 is connected to the inlet of Volume 2. In particular, note that the geometry can be modified from a straight passage to a manometer configuration by simply reversing the inlet/outlet designator in the junction connection code.
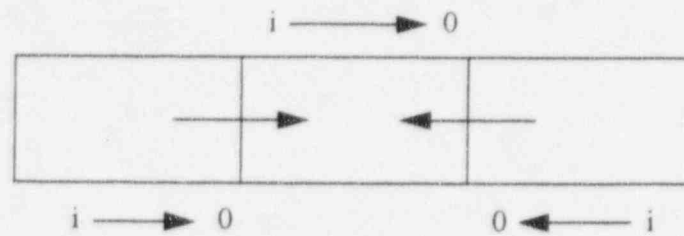
Figure 2.1-3 Sketch of possible coordinate orientation for three volumes and two junctions.
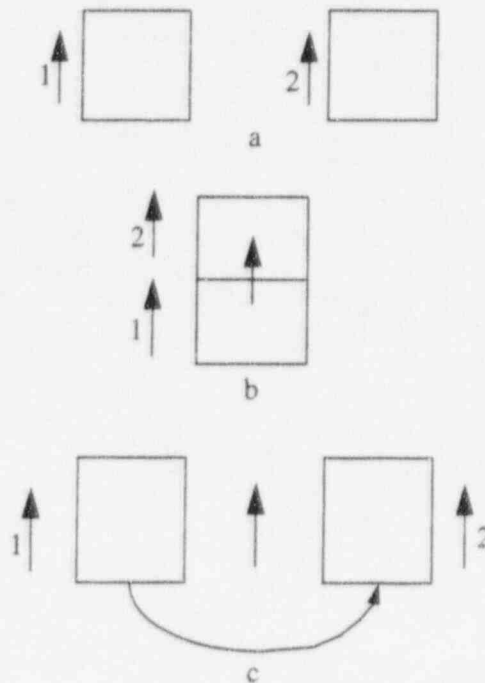
Figure 2.1-4 Sketch of possible vertical volume connections.

When systems of volumes or components are connected in a closed loop, the summation of the volume elevations must close when they are summed according to the junction connection codes and sequence, or an unbalanced gravitational force will result. RELAP5 has an input processing feature that finds all loops or closed systems (which are defined by the input) and checks for elevation closure around each loop. The error criterion is 10^{-4} m. If closure is not obtained, the fail flag is set, and no transient or steady-state calculations will be made. The elevation checker will print out that elevation closure does not occur at a particular junction that formed a closed loop during input processing. The junction at which closure of the loop occurs is somewhat arbitrary and depends on the input order of the components.

The elevation checking with crossflows differs from earlier versions of RELAP5. The elevation checking starts from the center of a volume with the initial volume and its elevation obtained from input data or defaulted. Using *to* and *from* junction information and elevation change information from the connected volumes, the elevation to the common face of the volumes is computed; then, the elevation of the center of the connected volume is computed. This computing of the elevations by tracking the junctions continues until all junctions have been used. Whenever a volume is reentered, the newly obtained elevation is compared to the previously computed elevation, and an error occurs if they do not match. With the previous crossflow model, the elevation from the center to a face was zero for a crossflow connection. This meant that the same elevation would be obtained regardless of which face the crossflow connection used. The face number is now important, both for elevation checking and in computing elevation effects, momentum flux effects, and friction. We recommend that decks prepared for previous versions of the code have all crossflow connections reviewed for use with the newer crossflow model.

The junctions are printed out in the major edits in the hydrodynamic junction information sections (see Section 8.3.2.9 and Section 8.3.2.10). The *from* and *to* volumes are listed for each junction. In addition, the flow regimes for the volumes (floreg) and the junctions (florgj) are also listed using three letters. It is also possible to list the flow regime for the volumes and the junctions in the minor edits and plots, where a number is used. **Table 2.1-1** shows the three-letter code and number used for each flow regime.

Table 2.1-1 Flow regime letters and numbers.

Flow regime	Three-letter code (major edits)	Number (minor edits/plots)
High mixing bubbly	CTB	1
High mixing bubbly/mist transition	CTT	2
High mixing mist	CTM	3
Bubbly	BBY	4
Slug	SLG	5
Annular-mist	ANM	6
Mist-pre-CHF	MPR	7
Inverted annular	IAN	8
Inverted slug	ISL	9
Mist	MST	10
Mist-post-CHF	MPO	11
Horizontal stratified	HST	12
Vertical stratified	VST	13
ECC mixer wavy	MWY	14
ECC mixer wavy/annular-mist	MWA	15
ECC mixer annular-mist	MAM	16

Table 2.1-1 Flow regime letters and numbers. (Continued)

Flow regime	Three-letter code (major edits)	Number (minor edits/plots)
ECC mixer mist	MMS	17
ECC mixer wavy/slug transition	MWS	18
ECC mixer wavy-plug-slug transition	MWP	19
ECC mixer plug	MPL	20
ECC mixer plug-slug transition	MPS	21
ECC mixer slug	MSL	22
ECC mixer plug-bubbly transition	MPB	23
ECC mixer bubbly	MBB	24

Table 2.1-2 Bubbly/slug flow regime numbers for vertical junctions.

Geometry and flow conditions	Correlations used	Numbers (minor edits/plots)
Rod bundles	EPRI	2
High up/down flows in small pipes	EPRI	3
Low up/down countercurrent flows in small pipes	Zuber-Findlay slug	4
Transition regions between 3 and 4	EPRI & Zuber-Findlay slug	5
High up/down flows in intermediate pipes	EPRI	9
Low up/down countercurrent flows in intermediate pipes	Churn-turbulent bubbly	10
Transition regions between 10 and 12	Churn-turbulent bubbly & Kataoka-Ishii	11
Low up/down countercurrent flows in intermediate pipes	Kataoka-Ishii	12
Transition between regions 9 and 10-11-12	EPRI & Churn-turbulent bubbly/Kataoka-Ishii	13
Large pipes	Churn-turbulent bubbly	14
Transition regions between 14 and 16	Churn-turbulent bubbly & Kataoka-Ishii	15
Large pipes	Kataoka-Ishii	16

In the bubbly and slug flow regimes for vertical junctions, it is possible to list an additional flow regime number (iregj) in the minor edits and plots that is associated with a particular geometry/flow and correlation that is used in the interphase drag. If not in bubbly or slug flow and not a vertical function, the number will be zero. **Table 2.1-2** shows the number used for each regime. In the transition regions (11 and 15), a fraction is added to the number (between 0 and 1) that indicates how far the junction conditions are between churn-turbulent bubbly and Kataoka-Ishii, based on the dimensionless vapor superficial velocity (j_g^*).

The interphase friction model for bundles (i.e., core and steam generator) can be activated with a volume control flag (b). The model is based on a correlation from EPRI, as discussed in Volume I of this Manual. When in bubbly or slug flow, the flow regime number is 2, as indicated in **Table 2.1-2**, otherwise it is 0.

The user should be aware that all plant or experimental facility geometries that are not circular should have an input junction hydraulic diameter to specify the necessary information required for the code calculated interphase friction. For bundles and steam generators, the junction hydraulic diameter should match the volume hydraulic diameter (including grid spacers, which should use the volume hydraulic diameter at the junction). In addition for grid spacers, the volume flow area should be used at the junction and the user input loss should be multiplied by ratio of squared areas of the volume and the grid spacer. For area changes, the donor diameter for the normal flow direction is recommended. For orifices, the actual diameter is recommended.

2.2 Process Models

In RELAP5, process models are used for simulation of processes that involve large spatial gradients or which are sufficiently complex that empirical models are required. The flow processes for an abrupt area change, a choked flow, a branch, reflood, noncondensables, water packer, CCFL, level tracking, and thermal stratification are all simulated using specialized modeling. These particular processes are not peculiar to a component and will be discussed as a group. Some components, such as pumps and separators, also involve special process models; these models will be discussed with the component models. The use of the process models is specified through input, and proper application is the responsibility of the user. As a general rule, we recommend that the user not mix process models; e.g., we recommend the user not use the choking model at either the inlet or outlet side of a volume where the abrupt area change is activated and more than one junction is connected. The purpose of this section is to advise the user regarding proper application of the process models.

2.2.1 Abrupt Area Change

The abrupt area change option should generally be used in the following situations:

1. Sharp edged area changes

2. Manifolds and plena connecting parallel flow passages

3. At break locations.

For the abrupt area model, the junction area (upon which the velocities are based) is the minimum area of the two connecting volumes.

In addition to the computed form loss from the abrupt area change model, users have the option of input form loss factors to achieve the desired pressure drop. See Section 2.2.3.3 for discussion for modeling of minor flow paths.

The pressure drop calculated by using form losses is a function of junction velocity.

2.2.2 Choked Flow

The choked flow option is specified in the junction flags on the junction geometry card. In general, the choked flow model should be used at all exit junctions of a system. We recommend that the choked flow model be usually used at the choke plane and that the user not model anything past this plane. (Therefore, just use a time-dependent volume downstream of the choke plane.) Internal choking is allowed but may not be desirable under certain conditions. Some applications of RELAP5 require that volumes downstream of the choke plane be modeled with non-time-dependent volumes. For this case, the user should monitor the mass error in the downstream volumes to ensure that the total mass error is not governed by these volumes. If the mass error in these volumes is large, the user should consider adjusting the size of the volumes.

The current recommendation regarding the choking model is based on circumventing problems that have been observed when specifying the nonhomogeneous choking model at all junctions. Specifically, it has been demonstrated that the nonhomogeneous model produces unrealistically low mass fluxes at low pressure (below 30 bar) and low static upstream quality (below 0.5). This in turn causes choking to remain "on" down to very low pressure ratios (1.1). Consequently, the current recommendation is to invoke choking ($c = 0$) only where it is expected to occur (i.e., breaks, relief valves, etc.) and to select the homogeneous flow option ($h = 2$) for these junctions. All other junctions in the model should be specified as nonhomogeneous ($h = 0$) with choking turned off ($c = 1$). Using the homogeneous junction option produces mass fluxes that closely agree with the homogeneous equilibrium critical flow model. In identifying the junctions where choking should be invoked, the user should not overlook the possibility of choking occurring at locations internal to the system; for example, the upper core support plate in a PWR. The recommendation for such locations is to invoke choking with the nonhomogeneous junction option. This allows slip to occur and does not preclude countercurrent flow. When specifying the choking option at internal junctions, the user should carefully monitor calculated results for nonphysical choking, particularly at low pressure. If this occurs, the user should turn choking off for the remainder of the calculation.

Guidelines for the discharge coefficients (subcooled and two-phase) are as follows. For a break nozzle/venturi geometry, a discharge coefficient of nearly 1.0 should be used. For an orifice geometry, the discharge coefficient depends on the break configuration and may be somewhat less than 1.0.

The throat dA/dx used in subcooled choking, which is denoted by $(dA/dx)_t$ in Volume 1 of this manual, is calculated differently for the normal junction abrupt area option, the normal junction smooth area option, and the crossflow junction (only uses smooth area option). For the recommended abrupt area change option, the following formula is used:

$$\left(\frac{dA}{dx}\right)_{L\,abrupt} = \frac{[A_K - A_t]}{[10.0D_K]} \tag{2.2-1}$$

where

A_K = the upstream volume flow area

A_t = the throat or junction area (minimum physical area)

D_K = the upstream volume diameter.

It is recommended the user input the actual physical values for A_K, A_t, and D_K. This formula is empirical, and the data base is limited. It was developed primarily to obtain the proper subcooled discharge at the break for the LOFT-Wyle Blowdown Test WSB03R,[2.2-1] which is one of the developmental assessment separate-effects test problems. In addition, it has been used successfully in many Semiscale test comparisons for the break flow.[2.2-2] If the user selects the smooth area change option, the code uses the following formula:

$$\left(\frac{dA}{dx}\right)_{L, smooth} = \frac{[A_K - A_t]}{[0.5\Delta x_K]} \tag{2.2-2}$$

where

A_K = the upstream volume flow area

A_t = the throat or junction area (minimum physical area)

Δx_K = is the upstream volume length.

The smooth area option is intended to be used for smoothly varying geometries. The length $0.5\Delta x_K$ would be the actual length of the upstream volume (A_K) to the throat (A_t). Since the smooth area change option is not recommended, this formula has had little assessment. If the user selects the crossflow option for the junction and if the K volume is a crossflow volume, the code uses

$$\left(\frac{dA}{dx}\right)_{L, crossflow} = \frac{[A_K - A_t]}{[0.5D_K]} \tag{2.2-3}$$

The length $0.5D_K$ is the radius of the volume if the default is used, and it is one half the length in the cross-direction if the optional input is used. There has been little assessment of this formula.

Sometimes, it is observed that the choking junction oscillates in time between the inlet and outlet junctions of a control volume. This may induce flow oscillations and should be avoided. The situation most often occurs in modeling a break nozzle. The choking plane is normally located in the neighborhood of the throat. The break can be adequately modeled by putting the break junction at the throat and including only the upstream portion of the nozzle. If the entire nozzle is modeled, the choked flow option should be applied only to the junction at the throat.

The internal choking option must be removed when supersonic flows are anticipated or when its application causes unphysical flow oscillations. Typical cases are propagation of shock waves downstream from a choked junction. Sometimes, it is necessary to remove the choking option at junctions near a known internal choked junction in order to avoid oscillations.

2.2.3 Branching

A fundamental and vital model needed for simulation of fluid networks is the branched flow path. Two types of branches are common, the tee and the plenum. The tee involves a modest change in flow area from branch to branch and a large change in flow direction, while the plenum may involve a very large change in flow area from branch to branch and little or no change in flow direction. In PWR simulations, a tee model would be used at pressurizer surge line connections, hot leg vessel connections, and cold leg connections to the vessel inlet annulus. A plenum model would be used for modeling upper and lower reactor vessel plenums, steam generator models, and low-angle wyes.

Two special modeling options are available for modeling branched flow paths. These are a crossflow junction model and a flow stratification model, in which the smaller pipe at a tee or plenum may be specified as connected to the top, center, or bottom of a larger connecting pipe. When stratified flow is predicted to exist at such a branch, vapor pullthrough and/or liquid entrainment models are used to predict the void fraction of the branched flow. The use of these models for simulating tees, plenums, and leak paths are discussed in greater detail below.

2.2.3.1 Tees. The simplest tee is the 90-degree tee, in which all branches have the same or comparable diameters. The recommended nodalization for this flow process is illustrated in **Figure 2.2-1**. The small volume at the intersection of the side branch with the main flow path should have a length equal to the pipe diameters. Generally, this length will be shorter than most other hydraulic volumes and will have a relatively small material Courant limit. The code, however, has a time step scheme that permits violation of the material Courant for an isolated volume for the semi-implicit scheme. Thus, this modeling practice may not result in a time step restriction. User experience has shown that if the code runs too slowly and is Courant-limited in the small volume, it is possible to increase the length of the volume to allow faster running without adversely affecting the results.

The Junction J3 is specified as a half normal junction and half crossflow junction. The half of Junction J3 associated with Volume V4 is a normal junction, whereas the half associated with Volume V2 is a crossflow junction. The junction specification is made using the junction flag *efvcahs*, which (for a single junction) is Word W6(I) of Cards CCC0101 through CCC0109. As noted in previous crossflow discussions, the same momentum equation options are used available in both normal and crossflow. Both flow types allow ignoring of momentum flux and wall friction terms through the use of volume and junction flags. User experience shows that temperature oscillations may develop in Volume V2. It may be necessary to increase the length of Volume V2 to remove the oscillations. In general, a user loss coefficient will be needed at Junction J3. This coefficient should be determined to obtain the proper pressure drop.

A tee can also be modeled using the branch component, as illustrated in **Figure 2.2-2**. This approach has the advantage that fewer volumes are used. Disadvantages are that the calculated result may be altered, depending on whether Junction J_2 is connected to Volume V_1 or V_2, and that the flow division has less resolution at the tee in the presence of sharp density gradients. In cases where the Volumes V_1 and V_3 are nearly parallel, the model illustrated in **Figure 2.2-2** may be a more accurate representation of the physical process (such as for a wye).
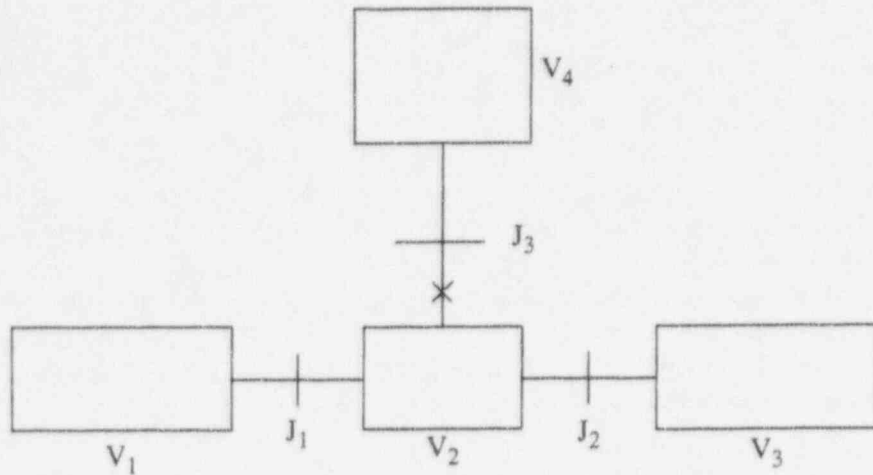
Figure 2.2-1 A 90-degree tee model using a crossflow junction.
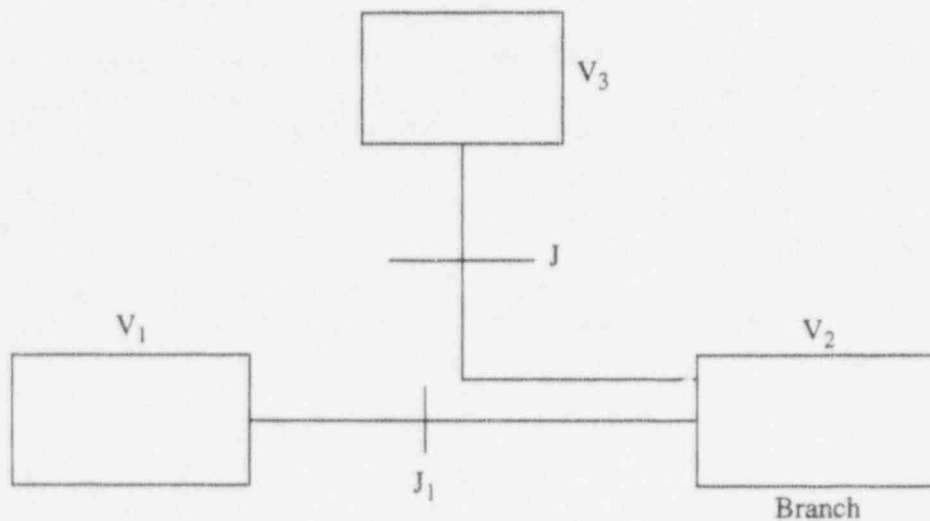
Figure 2.2-2 Tee model using a branch component.

2.2.3.2 Branch. The branch model approximates the flow process that occurs at merging or dividing flows, such as at wyes and plenums. This model does not include momentum transfer caused by mixing and thus is not suited for high-velocity merging flows. A special component, the JETMIXER, is provided for modeling the mixing of high-velocity, parallel streams. Application of this model is discussed in Section 2.3.9.

A branch component consists of one system volume and zero to nine junctions. The limit of nine junctions is due to a card numbering constraint. Junctions from other components, such as single junctions, pumps, other branches, or even time-dependent junction components, may be connected to the branch

component. The results are identical whether junctions are attached to the branch volume as part of the branch component or as part of other components. Use of junctions connected to the branch but defined in other components is required in the case of pump and valve components. Any of these may also be used to attach more than the maximum of nine junctions that can be described in the branch component input.

A typical one-dimensional branch is illustrated in **Figure 2.2-3**. The figure is only one example and implies merging flow. Additional junctions could be attached to both ends, and any of the volume and junction coordinate directions could be changed. The actual flows may be in any direction; thus, flow out of Volume V_3 through Junction J_1 and into Volume V_3 through Junction J_2 is permitted.
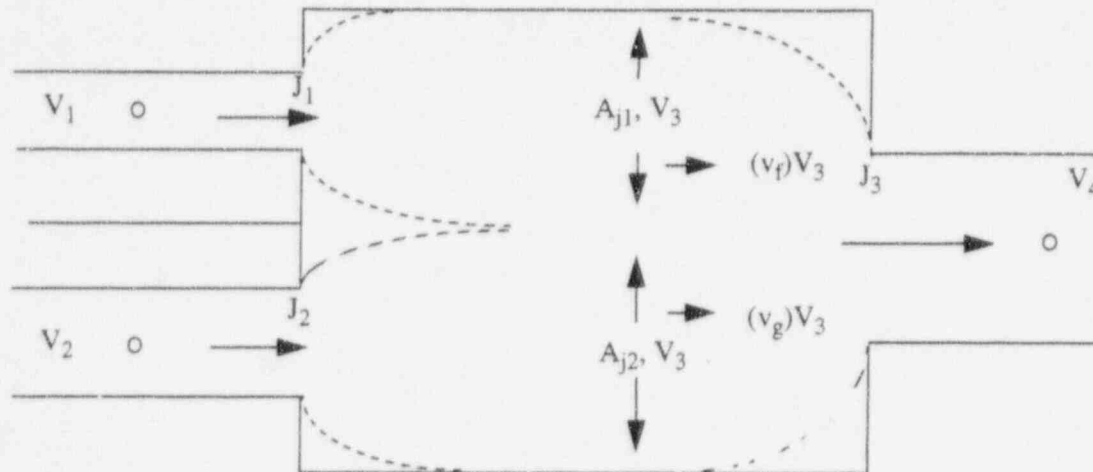
Figure 2.2-3 Typical branching junctions.

The volume velocities are calculated by a method that averages the phasic mass flows over the volume cell inlets and outlets. The volume velocities of Volume V_3 are used to evaluate the momentum flux terms for all junctions connected to Volume V_3. The losses associated with these junctions are calculated using a stream tube formulation based on the assumption that the fraction of volume flow area associated with a junction stream tube is the same as the volumetric flow fraction for the junction within the respective volume. Also, using the junction flow area, the adjacent volume flow areas, and the branch volume stream tube flow area, the stream tube formulation of the momentum equation is applied at each junction. However, if the smooth area change is specified, large changes in flow can lead to nonphysical results. Therefore, it is normally recommended that the abrupt area change option be used at branches.

Plenums are modeled using the branch component. Typical LWR applications of a plenum are the upper and lower reactor vessel regions, steam generator plenums, and steam domes. The use of a branch to model a plenum having four parallel connections is illustrated in **Figure 2.2-4**. The flows in such a configuration can be either inflows or outflows. The junctions connecting the separate flow paths to the plenum are ordinary junctions with the abrupt area change option recommended. It is possible to use crossflow junctions at a branch for some or all of the connections.

A wye is modeled, as illustrated in **Figure 2.2-3**, using the branch component. The flow can either merge or divide. Either the smooth or the abrupt area change option may be used. If the smooth area
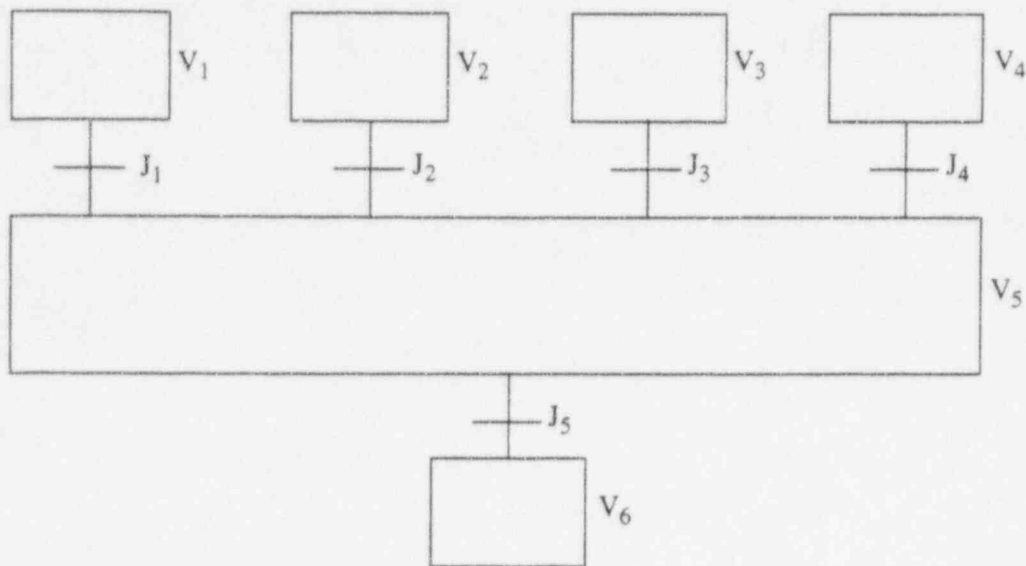
Figure 2.2-4 Plenum model using a branch.

change is specified, large changes in flow can lead to nonphysical results. Therefore, it is normally recommended that the abrupt area change option be used at wyes.

2.2.3.3 Leak Paths. An application, that may or may not involve branching but which is frequently a source of problems, is the modeling of small leak paths. These may be high-resistance paths or may involve extreme variations in flow area. The approximation of the momentum flux terms for such flow paths is highly uncertain and can lead to large forces, resulting in numerical oscillations. Modeling of small leak paths was one of the primary motivations for developing the crossflow connections. As needed, the momentum flux and wall friction can be omitted, and the flow resistance could instead be computed from a user-specified kinetic loss factor.

In applying the crossflow junction to leak path models, the actual area of the leak path is used as the junction area. A kinetic loss factor is input, based on the fluid junction area velocity for the forward and reverse loss factors. The forward and reverse loss factors should be equal unless there is a physical reason why they should be different. In particular, a very large forward and small reverse loss factor should not be used to simulate a check valve. This approach can cause code failure. A typical leak path model between vertical volumes is illustrated in **Figure 2.2-5**.

Minor flow paths having extreme area variations or flow splits, in which the minor flow is a small fraction of the main flow (<0.1), can also be modeled using the standard junction by the following special procedures. The smooth area change option is used for the junction (the *efvcahs* flag with $a = 0$), and the junction area is allowed to default (the minimum area of the adjoining volume areas). It may be necessary for the user to input a more reasonable flow area if the default area is too large. With this specification, it is necessary to enter user input form loss coefficients normalized to the default area in order to give the proper flow rate and pressure drop relationship. The loss factor to be input can be estimated using the following equation:
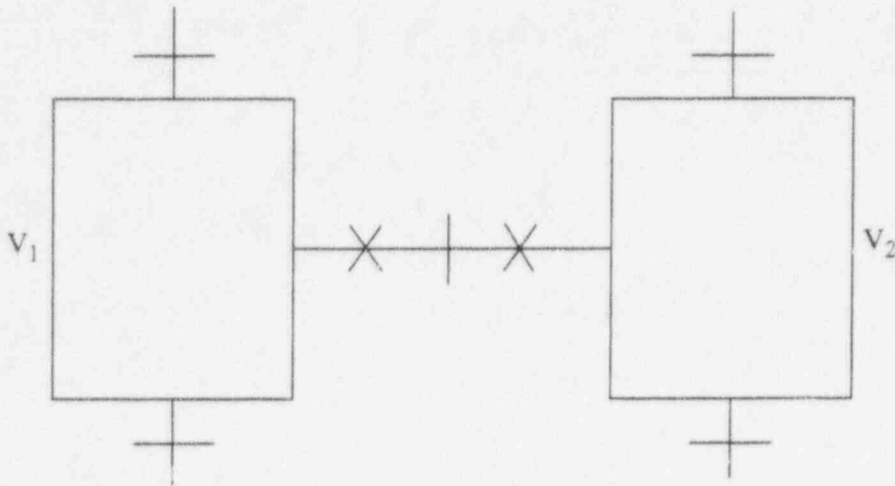
Figure 2.2-5 Leak path model using the crossflow junction.

$$K = 2\Delta P A^2 \frac{\rho}{\dot{m}^2} \tag{2.2-4}$$

where

K	=	loss factor
ΔP	=	nominal pressure drop (Pa)
A	=	junction area (m^2)
ρ	=	fluid density (kg/m^3)
$\dot{m}$	=	nominal mass flow rate (kg/s).

The value computed for K in this way may be very large because the default area is much larger than the actual flow area. Also, critical flow would not be detected with this approach. Both the forward and reverse loss coefficients should be equal unless there is a reason why they are physically different. In this case, Equation (2.2-4) should be used to calculate the effective loss factor for both the forward and reverse flow conditions (i.e., assume ΔP and $\dot{m}$ also correspond to the reverse flow case). The geometric relationship between the actual situation and the model is illustrated schematically in **Figure 2.2-6**.

In the case of minor flow paths that connect at branches having large main flows, a similar approach can be used. In this case, let the junction area default to the minimum of the adjoining volumes (presumably the area of the minor flow path) and use the smooth option (*efvcahs* with $a = 0$). The determination of the loss factor may require some experimentation because of the possible large

Abrupt area change (efvcahs = 0000100)

Throat ratio = $A_{throat}/A_{junction}$

Physical situation with a loss factor K_{actual}

Smooth area change (efvcahs = 0000000)

$$K_{effective} = K_{actual} (A_{junction}/A_{throat})^2$$

Equivalent model with effective loss factor for the same pressure drop-flow relation
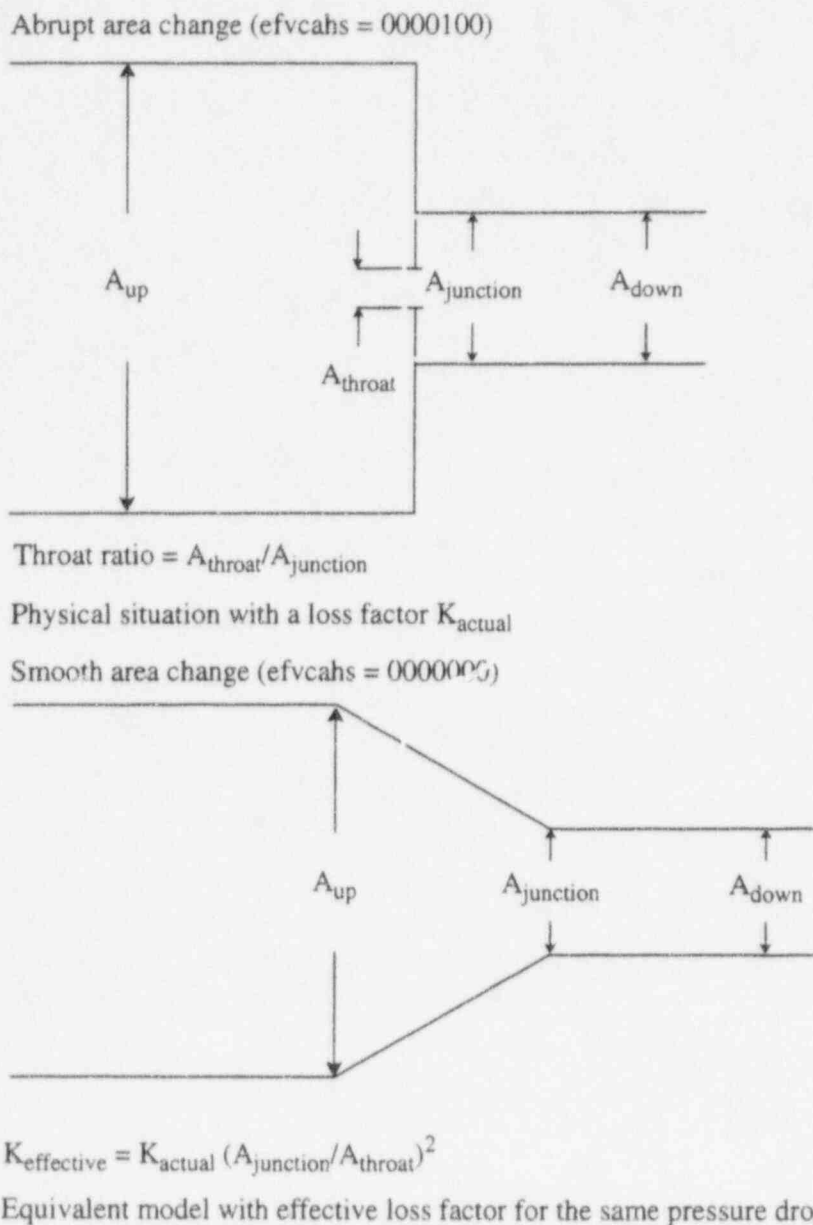
Figure 2.2-6 High-resistance flow path model.

momentum flux effect, which is ignored in the derivation of Equation (2.2-4). If one of the volumes is quite large compared to the other, a modified Bernoulli equation can be used in which the overall loss factor defined by Equation (2.2-4) can be replaced by K+1. [In other words, the user input loss factor is computed by substituting K+1 for K in Equation (2.2-4).]

All of the development herein assumes that known pressure drop flow relations exist for the single-phase case and that compressibility effects are small. If such is not the case, then the effective loss factor values must be determined experimentally by running the code for a series of cases. Some experimentation

may be required, since the actual momentum flux calculation is complicated by several factors and may differ slightly from the simple Bernoulli form.

Another problem relative to a minor leak path can occur when an incorrect flow rate through an orifice for a given ΔP and loss coefficient K is calculated. As noted previously, this problem can be avoided if the user inputs reasonable values for the flow area and the loss coefficient K, rather than allowing the flow area to default and using a very large K.

2.2.4 Reflood Model

The reflood model is designed so that it can be activated at low pressure (less than 1.2×10^6 Pa) with nearly empty conditions (average void fraction in connected stack of hydraulic volumes > 0.9) or dryout beginning (average void fraction >0.1) or by user command through a trip. The model considers a heat-structure geometry composed of 1 to 99 heat structures as a reflood unit. As there is no input specification for the length of a structure (except for the heat structure surface), such length is inferred from the length of the boundary volume connected to the heat structure. It is the user's responsibility to make certain that the length of a heat structure corresponds to the length of its connected volume for reflood calculations.

Additional suggestions concerning the use of the reflood model are listed below:

1. the appropriate user-specified maximum number of axial fine mesh intervals is 8 to 32. No significant differences have been found in using 16 to 128 axial nodes for 0.18-m (0.6 ft) long heat structures

2. the appropriate length of hydrodynamic volumes is 0.15 to 0.61 m (0.5 to 2.0 ft)

3. the maximum user-specified time step size is 0.01 to 0.05 s

4. each reflood unit should have its own flow channel and parallel flow channels should be connected by crossflow junctions.

The number of heat-structure geometries that can be specified for a reflood calculation is limited only by computer storage capacity. Once the reflood model is activated for a particular heat-structure geometry, only the structures where the critical heat flux are located will have a value in the critical heat flux column of the output. The heat transfer modes that appear in the mode column of the major edit are the same as those that appear when reflood is not activated except that 40 is added (see Section 3.2).

2.2.5 Noncondensables

The noncondensable model has the ability to be applied at every hydrodynamic volume in a system model. While in operation, the model affects interface mass and heat transfer, wall heat transfer, and the output of several variables that may cause discontinuities in plotted output. The purpose of this discussion is to clarify the operation of the noncondensable model and its affect on the calculated results and to give guidance for its use in system calculations.

In order to properly understand the operation of the noncondensable model, the fundamental assumptions used in the model need to be discussed. First, the steam/noncondensable mixture is assumed to be in thermal equilibrium. Second, the total pressure is the sum of the partial pressures of the steam and

the noncondensable. Next, the specific vapor internal energy is the mass weighted sum of the steam specific internal energy and the noncondensable specific internal energy. Last, the saturation properties of the liquid and steam are assumed to be a function of the partial pressure of the steam.

One of the effects of these assumptions is to force the phasic temperatures and the saturation temperature to the same value. This causes a reduced driving potential for the interface mass and heat transfer models. The interface heat transfer coefficients are reduced in the presence of noncondensables. Consequently, low interfacial heat transfer regimes, such as the vertical stratification flow regime, may give heat transfer coefficients that are too low for stable calculations (as evidenced by oscillatory behavior). When this occurs, the vertical stratification model should be turned off on a volume basis. The highest probability for this occurrence is under very low flow conditions.

A second problem may occur when noncondensables first appear in a system volume. At times, again depending on the convection of noncondensable into the volume, the noncondensable iteration may fail or water property errors occur at the minimum time step. This problem can usually be overcome by reducing the size of the minimum time step. If this procedure fails, the convection rate or the concentration of the noncondensable convection must be changed. This may be accomplished by modifying the boundary conditions or by renodalizing the problem areas with acceptable thermodynamic conditions.

Last, the output from the code may contain discontinuities as noncondensables appear or disappear. The variables that will have these discontinuities are the partial pressure of steam, phasic temperatures, saturation temperature, vapor specific internal energy, and noncondensable quality. The partial pressure of steam is set to the system pressure if noncondensables are not present, to 1.0 Pa if the volume state is pure noncondensable, or to the calculated value otherwise. When a pure noncondensable is present in a volume, all temperatures are set to equal values and are a function of the gas energy. As a fluid is injected into the volume, the temperatures, the partial pressure of steam, and possibly the vapor energy will abruptly change to new values based on the calculated thermodynamic conditions. Additionally, the liquid and saturation temperature may appear at the fluid triple point value if the partial pressure of the steam is calculated to be lower than the minimum fluid property table value.

As an example, a checkout problem used for development[2.2-3] consisted of 322 K liquid water being injected into 436 K helium. The liquid temperature and saturation temperature both changed from 436 to 273 K in one time step as the volume changed from a pure noncondensable state to a steam/ noncondensable mixture state. As more water was injected, the liquid transitioned to the correct value.

Selecting noncondensable input consists of specifying type and concentration of species on the system cards and by selecting Options 4, 5, and 6 on the volume initial condition cards. Option 4, which consists of pressure, temperature, and equilibrium quality, is the easiest to use. A restriction on the temperature is that it has to be less than the saturation temperature as a function of pressure. Little experience has been obtained in using Option 5, and it has not been checked out. Option 6 is generally used to renode system models from Pygmalian decks.[2.2-4] See Volume I of this manual for the equations and variables used. The equilibrium quality used in option 4 is the static quality (since in equilibrium) and is given by $M_g/(M_g + M_f)$, where $M_g = M_s + M_n$.

The capability for initializing and performing transients with pure noncondensables has been implemented. Input Options 4 and 6 have provisions for initializing a system volume to a pure noncondensable state. This is accomplished in Option 4 by using the equilibrium quality variable as a flag. By setting this quantity to 0, logic specifies an ideal gas equation of state. The variable is reset to 1.0 for transient calculations. To use Option 6 for initializing a pure noncondensable, both void fraction and

noncondensable quality must be set to 1.0 and the vapor energy must be set to a value that gives the desired gas temperature.

The code will not allow a noncondensable to exist as just liquid water and no steam. The code will add a little bit of steam (keeps steam quality $X_s = M_s/(M_s + M_n) \geq 10^{-8}$). Thus, we recommend that users input some steam when noncondensables and liquid water are present.

At the present time, a value of 4 for the control word in the volume initial condition card is recommended. Only a saturated noncondensable state (100% humidity) is obtained by this option. Improvement of input conveniences for initial noncondensable states is under consideration. Users have reported some success with the nonequilibrium, noncondensable state input option (value of 6 for the volume initial conditions control word $\underline{t}$). The users employ the following method. For a given total pressure (P), gas temperature (T_g), liquid temperature (T_f), void fraction (α_g), and noncondensable gas quality ($X_n = M_n/(M_n + M_s)$)], first calculate the steam quality ($X_s = 1 - X_n$). The partial pressure of steam (P_s) is determined from the relation $P_s = X_s \bullet P$, which is true only if both steam and noncondensable are ideal gases, obey Dalton's mixture law, and have similar molecular weight. Using steam tables to get the steam energy (U_s) from the known values of P_s and T_g; then, calculate the noncondensable energy (U_n) from Equations in Volume I of the code manual. The mixture gas energy (U_g) is then calculated from Equations in Volume I of the code manual. Finally, the liquid energy (U_f) is determined using steam tables from the known values of P and T_f.

Option 4 with quality = 1.0 is recommended for containment volumes.

2.2.6 Water Packing

The volume control flag $\underline{p}$ is used to activate the water packing mitigation scheme. The scheme is invoked if the detection criteria are met.

The number of partial time step repeats is shown in the hydrodynamic volume statistics block (time step control information) in the major edit. Both the number of repeats since the last major edit and for the whole calculation are shown.

2.2.7 Countercurrent Flow Limitation Model

The countercurrent flow limitation (CCFL) model (discussed in detail in Section 3 of Volume I) is controlled by the junction control flag. The CCFL flag ($\underline{f}$) can be used with a single junction, pipe, annulus, branch, valve, pump, and multiple junction. It cannot be used with a time-dependent junction, separator, jet mixer, ECC mixer, turbine, or accumulator. Setting $\underline{f} = 1$ will activate the CCFL model if all other conditions are met, and setting $\underline{f} = 0$ will not activate the model. The other conditions are as follows:

1.   the orientation of both the connecting volumes cannot be horizontal (i.e., the elevation angle must be greater than or equal to 15 degrees)

2.   both gas and liquid phases must be present

3.   countercurrent flow must exist, with liquid flowing down and gas flowing up.

As with the choking model, we recommend that if a junction is designated CCFL ($\underline{f} = 1$), then an adjacent junction should not be designated CCFL ($\underline{f} = 0$). It is anticipated that this flag will find use in activating the CCFL model in such internal structures as the upper core tie plate, downcomer annulus, steam generator tube support plates, and entrance to the tube sheet in the steam generator inlet plenum.

Junction data cards can be used to input four quantities (junction hydraulic diameter, correlation form, gas intercept, and slope). For these CCFL junction data cards, all four quantities must be entered (must have five quantities for pipe and multiple junction). If no card is entered but the CCFL flag $\underline{f}$ is set to 1, then default values of the four quantities will be used. Presently, the default values are

$$D_j \quad = \quad 2(A_j/\pi)^{1/2}$$

$$\beta \quad = \quad 0$$

$$c \quad = \quad 1$$

$$m \quad = \quad 1.$$

This corresponds to a Wallis CCFL correlation with a gas intercept of 1 and a slope of 1, which, according to Wallis,[2.2-5] is the case for turbulent flow ($m = 1$) and when end effects are minimized ($c = 1$).

The input was made general so that the user can input CCFL correlations for the particular geometry of interest. Wallis,[2.2-5] Bankoff et al.,[2.2-6] and Tien et al.[2.2-7] discuss numerous examples, and these, along with other references, should be consulted in order to justify the use of a particular correlation for a given geometry. Wallis suggests $m = 1$ for a turbulent flow, $c = 0.725$ for tubes with sharp-edged flanges, and $c = 0.88$ to 1.0 for tubes when end effects are minimized. Bankoff suggests $\beta = \tanh (\gamma k_c D_j)$, where the critical wave number $k_c = 2\pi/t_p$ corresponds to the maximum wavelength that can be sustained on a interface of length t_p (the plate thickness), and γ is the perforation ratio (fraction of plate area occupied by holes). Bankoff suggests $m = 1$ and c of the form

$$c = 1.07 + 4.33 \times 10^{-3} D^* \quad D^* < 200 \tag{2.2-5}$$

$$c = 2 \quad D^* \geq 200$$

where D^* is a Bond number defined as

$$D^* = n\Pi D \ [g(\rho_f - \rho_g)/\sigma]^{1/2}, \tag{2.2-6}$$

and n is the number of holes. Tien uses the Kutateladze form ($\beta = 1$), but the form of c allows the Wallis form also to be invoked for small diameters. He suggests c of the form

$$c = c_7 \ [\tanh c_8 \ (D^*)^{1/4}],$$

where D^* is a Bond number defined differently from Equation (2.2-6) as

$$D^* = D \left[g \left((\rho_f - \rho_g) / \sigma \right) \right]^{\frac{1}{2}} .$$

(2.2-7)

The values of m, c_7, and c_8 Tien found for four different conditions are provided in **Table 2.2-1**. With regard to guidelines for plant-specific geometry (i.e., tie plates, support plates, etc.), flooding data obtained in measurements from the plant geometry should be used to generate an appropriate CCFL model that can be input with CCFL junction data cards.

Table 2.2-1 Values of m, c_7, and c_8 for Tien's CCFL correlation form.

Tests	m	c_7	c_8
Nozzle air supply with tapered inlet	0.8	2.1	0.9
Nozzle air supply with sharp edge inlet	0.8	2.1	0.8
Indirect air supply with tapered inlet and sharp edge output	0.65	1.79	0.9
Indirect air supply with sharp edge inlet and tapered output	0.65	1.79	0.8

Wallis,[2.2-5] Bankoff,[2.2-6] and Tien[2.2-7] discuss the effects of viscosity, surface tension, and subcooling on the correlations. At the present time, these effects have not been directly incorporated into the form of the CCFL correlation used in RELAP5. We anticipate that these, particularly the subcooling effects, will be addressed in future modifications to the code.

2.2.8 Level Tracking Model

The volume control flag 1 in tlpvbfe is used to activate the level tracking model as described in Volume I.

If the volume control flag is set, the major edit will print out parameters associated with the mixture level in the hydrodynamic volume. The parameters are voidla(i), the void above the level; voidlb(i), the void below the level; vollev(i) the location of the level in side the volume; and vlev(i), the velocity of the level movement. The parameters voidla(i), voidlb(i), and vollev(i) can also be written to the restart-plot file if a 2080xxxx card is used. One can use control system cards 205CCCNN or 205CCCCN to construct the level in the component.

2.2.9 Thermal Stratification Model

The volume control flag t in tlpvbfe is used to turn on the subcell resolution scheme in the model. The model is invoked if the detection criteria are satisfied. The model is intended for one-dimensional components only.

The thermal stratification model should be used to improve the accuracy of calculations where there is a warm fluid layer appearing above a cold fluid in a vertical stack of cells. A complete description of the model is presented in Section 3 of Volume I.

2.2.10 Energy Conservation at an Abrupt Change

The junction control flag e in efvcahs is used to activate the modification to the energy flux term described in Volume I. This model is recommended for break junctions that connect to containment volumes that are modeled using regular volumes (not time-dependent volumes).

2.2.11 References

2.2-1.   V. H. Ransom, et al, *RELAP5/MOD2 Code Manual, Volume 3: Development Assessment Problems,* EGG-TFM-7952, December 1987, pp. 14-17.

2.2-2.   *Ibid.,* pp. 61-63.

2.2-3.   K. E. Carlson, *Improvements to the RELAP5/MOD3 Noncondensable Model,* EGG-EAST-8879, January 1990.

2.2-4.   W. H. Grush, *Pygmalion,* INEL software, 1994.

2.2-5.   G. B. Wallis, *One-Dimensional Two-Phase Flow,* New York: McGraw-Hill, 1969, pp. 336-341.

2.2-6.   S. G. Bankoff, R. R. Tankin, M. C. Yuen, and C. L. Hsieh, " untercurrent Flow of Air/Water and Steam/Water Through a Horizontal Perforated Plate," *In   ·ational Journal of Heat and Mass Transfer, 24,* 1981, pp. 1381-1385.

2.2-7.   C. L. Tien, K. S. Chuent, and C. P. Lin, *Flooding in Two-Phase Countercurrent Flow,* EPRI NP-984, February 1979.

2.3 Hydrodynamic Components

The basic two-fluid model is applied uniformly to all volumes and junctions. Thus, the programming design of the hydrodynamic calculation is primarily organized on volumes and junctions. Components are organized collections of volumes and junctions and, to a lesser extent, the program is organized on components. Components are designed for either input convenience or to specify additional specialized processing. A pipe component is an example of a component designed for input convenience, since by taking advantage of typical features of a pipe, several volumes and junctions can be described with little more data than for one volume. Pump and valve components are examples of components requiring additional processing. A pump component includes data defining pump head and torque characteristics for single-phase and two-phase conditions as a function of pump angular velocity. A pump component requires additional processing to advance the differential equation defining pump angular velocity. A valve component requires additional data defining its characteristics and additional processing to calculate the junction flow area as a function of valve position.

Components are numbered with a three-digit number, 001-999. Components need not be in strictly consecutive order so that changes to a model of a hydrodynamic system requiring addition or deletion of

components are easily made. Volumes and junctions within a component are numbered by appending a six digit number to the component number, cccxxyyzz. The ccc is the component number. At present, yyzz are zeros and xx is numbered consecutively starting at 01 for the volumes and junctions in the one-dimensional components presently defined.

2.3.1 Common Features of Components

Each volume's flow area, length, and volume must be supplied as input. As noted above, each one-dimensional volume has a x-coordinate direction along which fluid flows in a positive or negative direction, and may have y- and z-coordinate directions if crossflow connections are made to the volume. The x-volume flow area is the volume cross-sectional area perpendicular to the x-coordinate direction. The x-volume length is the length along the x-coordinate direction and similarly for the y- and z-coordinate directions. The hydrodynamic numerical techniques require that the volume be equal to the volume flow area times the length for each coordinate direction. This requirement is easily satisfied for constant area volumes, but poses difficulties for irregular shaped volumes. Since it is very important that such a systems code as RELAP5 conserves mass and energy, with momentum being an important but lesser consideration, we recommend that an accurate volume be used; that the volume flow area be the cross-sectional area averaged over the actual length of the volume; and the volume length be the quotie of the volume and the flow area. The component input routines permit the volume, flow area, and length of each volume to be entered as three nonzero positive numbers or two nonzero positive numbers and a zero. If three nonzero quantities are entered, the volume must equal the flow area times length within a relative error of 0.000001. If one quantity is zero, that quantity is computed from the other two. The user need not be concerned with x- or y-coordinate data unless crossflow connections are made, and even then only if the default data for those coordinates are not satisfactory.

The volume horizontal angle specifies the orientation of the volume in the horizontal plane. The code numerics have no requirement for this quantity; they were entered so a graphics package could be developed to show isometric views of the system as an aid in model checking. Such a graphics package is not included in the MOD3 version. The horizontal angle is checked to verify that its absolute value is less than or equal to 360 degrees, but no further use is made of the quantity.

The volume vertical angle specifies the vertical orientation of the volume. This quantity would also be used in the graphics package and, in addition, specifies the vertical orientation of the volume coordinate direction. The vertical angle must be within the range 90 to -90 degrees. The angle 0 degrees means the x-coordinate direction is in the horizontal plane; a positive angle means that the coordinate direction is directed upward; a negative angle means it is directed downward. Slanted vertical orientation, such as an angle equal to 45 degrees, is permitted. Note that as the vertical angle changes from zero, the y-coordinate is always in the horizontal plane, and that the x-and z-coordinates, and their associated faces move out of their original horizontal and vertical planes, respectively.

The coordinate direction implies the position of the inlet and outlet ends of the volume. The terms inlet and outlet are convenient mnemonics relative to the coordinate direction but do not necessarily have any relation to the fluid flow. The direction of fluid flow is indicated by the sign of the velocity relative to the coordinate direction. For input convenience or ease in output interpretation, the coordinate direction should be an easily remembered direction, such as the normal flow direction as opposed to the flow in an accident situation.

As noted in the discussion of **Figure 2.1-4**, and described further below, a junction connects a specified end of one volume to the specified end of another volume. This, in turn, establishes relative

positioning of the volumes. Because of gravity heads, the relative position is important to any volume with a nonzero vertical component of a volume coordinate direction. If the coordinate direction in a volume with a vertical component is reversed but no other changes are made, the inlet and outlet ends of the volumes are also reversed. The physical problem is changed since the relative vertical positions of the volumes are changed. If appropriate changes are made to junctions connecting the reversed volume, such that the physical problem remains unchanged, the only change in the problem results would be a reversal in the sign of the vector quantities associated with the volume. Furthermore, given a stack of vertically oriented volumes, the proper gravity head is computed whether the direction coordinates are all upward, all downward, or any random distribution. This assumes that junction connections are such that a vertical stack is specified. As shown in **Figure 2.1-4**, a change in junction specification can change the relative position of two volumes from two, vertically stacked volumes to a U-tube configuration.

Input for a volume includes the elevation change in a volume. For a straight pipe, the elevation change (Δz) is related to the volume length (Δx) and the vertical angle (ϕ) by

$$\Delta z = \Delta x \sin \phi .$$
(2.3-1)

Note that the elevation change associated with the x-coordinate has the same sign as the vertical angle. To allow for irregularly shaped and curved volumes, the input elevation change is used for gravity head calculations. Input checks are limited to the following: the magnitude of the elevation change must be equal to or less than the volume length; and for the x-direction, the elevation change must be zero if the vertical angle is zero; and the elevation change must be nonzero and have the same sign as the vertical angle if the vertical angle is nonzero. The volume input does not need the elevation height of a volume relative to an arbitrary base. The elevation change data performs the same function in determining gravity heads.

If the hydrodynamic system has one or more loops, the user must ensure that the sum of the elevation changes of the volumes in each loop is zero. A loop is any hydrodynamic flow path starting at a volume, passing through one or more other volumes, and returning to the starting volume. If the net elevation change in a loop is not zero, an incorrect gravity head exists; this is comparable to having an undesired pump in the loop. This error is checked by the program. If closure is not within the error criterion of 0.0001 m, an input error will result.

The horizontal flow regime map is used rather than the vertical flow regime map when ϕ is less than or equal to 45 degrees. Horizontal flow calculations include a horizontal stratified flow capability and a horizontal stratified entrainment model.

Wall friction effects are computed from pipe roughness and hydraulic diameter data entered for each volume. If the input hydraulic diameter (D_h) is zero, it is computed from the volume flow area (A_v),

$$D_h = \sqrt{\frac{4A_v}{\pi}} .$$
(2.3-2)

The thermal stratification (t), level model (l), water packer (p), vertical stratification (v), and equilibrium (e) flags can be entered only for the x- coordinate direction. The friction (f) flag can be entered for the x- y-, and z-coordinate directions.

A check is made that the pipe roughness is less than half the hydraulic diameter.

Most volumes allow seven control flags (tlpvbfe): the t flag is the thermal stratification flag the l flag is the level model flag; the p flag is the water packer flag; the v flag is the vertical stratification flag; the b flag is the bundle interphase friction flag, recommended for cores and steam generators; the f flag determines whether wall friction from the volume is to be included or neglected; the e flag controls whether a nonequilibrium (two phases permitted to have unequal temperature) or an equilibrium (two phases forced to have equal temperatures) calculation is used. Generally we recommend that wall friction be computed in the x-direction and usually not in the y-direction, and that the nonequilibrium equation of state be used.

System volumes require initial thermodynamic state conditions, and time-dependent volumes require state conditions as a function of time or a time-advanced quantity. Seven options, numbered 0 through 6, are available to specify state conditions. Options 0 through 3 specify water-only conditions and do not allow a noncondensable gas. Option 0 requires pressure, liquid specific internal energy, vapor specific internal energy, and void fraction. Options 1 and 2 always specify saturation conditions. Option 1 requires saturation temperature and equilibrium quality. Option 2 requires saturation pressure and equilibrium quality. Two phases are present if the quality is neither 0 nor 1. Option 3 always specifies single-phase conditions and requires pressure and temperature. Options 1 through 3 can only specify equilibrium conditions even if the nonequilibrium equation of state is requested. The next three options can specify the presence of a noncondensable gas. Option 4 requires pressure, temperature, and equilibrium quality. Equilibrium conditions are assumed, and the vapor consists of air and water vapor at 100% humidity. Option 5 requires temperature, equilibrium quality, and noncondensable quality. Option 6 requires pressure, liquid specific internal energy, vapor specific internal energy, void fraction, and noncondensable quality.

For Options 0 through 6, the boron concentration is assumed to be zero. If 10 is added to the above option numbers, a boron concentration is required. See Section 3 of Volume I for a complete description of the boron transport model. Boron is assumed to be only present in and to be convected by liquid water. If a volume with liquid and boron has the liquid water removed by convection, the boron is also removed. If the liquid water is evaporated, the boron remains. This is analogous to boron precipitating out as water is evaporated. Infinite solubility of boron in water is assumed and boron remains in solution regardless of its concentration until all of the liquid water disappears. Boron instantly redissolves the instant the quality becomes less than 1. Boron concentrations are computed using only a boron continuity equation for each volume. Boron is assumed to have no momentum, no internal energy, and to have no effect on the equation of state.

Junctions connect two volumes by specifying a connection code for each volume. The connection code specifies both the volume and a specific face of the volume. Except for a pipe component, current components have only one volume, and a component reference is essentially a volume reference. The connection codes for each component type are described in the beginning of the input description for that component, as well as in Section 2.1.

The junction coordinate direction is from one volume end to another volume end and the input description use the words FROM and TO to identify the connections. If a junction is reversed, the sign of the vector quantities associated with the junction are reversed. To maintain the same physical problem, no further changes are needed in other components. The initial velocities in reversed system junctions or time-dependent velocities in time-dependent junctions should also be reversed.

Two quantities, the junction area and the junction area ratio, are defined from the user-supplied junction area. These are printed in the major edit as JUN.AREA and THROAT RATIO. Junctions can connect two volumes with possibly different volume flow areas, and the junction can also have a different flow area. Two options are provided for calculating area change effects as the fluid flows through the upstream volume flow area, the junction flow area, and the downstream volume flow area.

The smooth area change option uses only the stream tube form of the momentum equation that includes spatial acceleration and wall friction terms. This option should be used when there are no area changes or when the area changes are smooth, such as in a venturi. There are no restrictions on the user-supplied junction area for smooth area changes, and the junction area may be smaller than, larger than, or between the adjacent volume flow areas. The junction flow area is set to the user-supplied flow area and the junction area ratio is set to 1.0.

The abrupt area change option provides for additional losses resulting from abrupt expansions, abrupt contractions, orifices, and vena-contracta effects. The user-supplied junction area must be equal to or less than the minimum of the adjacent volume flow areas for an abrupt area change. The junction area is set to the minimum of the adjacent volume flow areas, and the junction area ratio is set to the ratio of the user-supplied junction area to the minimum of the adjacent volume flow areas. When the user-supplied flow area equals the minimum of the adjacent volume flow areas, the junction area ratio is 1.0, and the junction is a contraction/expansion. Program logic checks flow direction, and an expansion with flow in one direction is treated as a contraction when flow reverses, and vice versa. If the user-supplied junction area is less than the minimum of the adjacent volume flow areas, an orifice is indicated, and the junction area ratio is less than one. Specifying the abrupt area change option when there is no area change gives the same result as specifying the smooth area change option, but slightly more computer time is required.

Valve junctions using either area change option vary the junction area ratio as the valve opens and closes.

Junction velocities correspond to the junction flow area. Thus, the flow rate of a phase is the product of the appropriate junction void fraction, the junction density (donored quantities), the junction velocity, and the junction flow area. For orifices and valves, the actual flow velocity is higher at the minimum area, which is the junction area multiplied by the junction area ratio. The junction area ratio is used to compute the velocity at the minimum area when needed, such as in the choked flow model.

For user convenience, if the user-supplied junction area is zero, it is set to the minimum of the adjacent volume flow areas regardless of the area change option. This is the proper default value for most junctions, and only smooth area changes (where there is an area change) and orifices need nonzero user-supplied junction areas.

Junction loss coefficients can be entered when additional losses above the wall friction and area change losses are needed. These losses could arise from pipe bends, irregularly shaped volumes, entrance or exit losses, or internal obstructions. Two coefficients are entered, one for forward (positive) flow, the other for reverse (negative) flow. The coefficients are applied to the junction dynamic pressure. Zero coefficients mean no additional losses are computed.

It is important to note that MOD3 computes interfacial drag at junctions rather than within volumes. This has important implications with respect to modeling reactor core bundles and steam generator bundles. In these instances, the user should invoke the bundle interfacial drag model by specifying b = 1 on the pipe volume control flags data card (see Section A7.6.20 in Appendix A). In addition, in modeling grid

spacers as junctions within the core or steam generator bundle, the user should specify the junction area and hydraulic diameter as equal to that for the bundle, rather than those characteristics of the grid spacer. The reason for this is that the bundle interfacial drag model was formulated on the basis of bundle geometry. In order to achieve the correct pressure drop at each grid spacer junction, the user should input a loss coefficient that is adjusted for the difference between specifying bundle geometry rather than grid geometry. For example, if the loss coefficient associated with the grid spacer is k_j then the adjusted loss coefficient would be computed as:

$$k_j' = k_j \frac{A_b^2}{A_g^2} \qquad (2.3-3)$$

where A_g is the flow area of the grid spacer and A_b is the flow area of the bundle.

Seven control flags are associated with junctions (efvcahs). The e flag is the energy correction flag, recommended at break junctions into a containment. The f flag is the CCFL model flag, recommended for tie plates, downcomer annulus, etc. The v flag is the horizontal entrainment model flag, recommended at break junctions connected to horizontal volumes. The c flag controls applications of the choking model.

The current recommendation regarding the choking model is based on circumventing problems that have been observed when specifying the nonhomogeneous choking model at all junctions. Specifically, it has been demonstrated that the nonhomogeneous model produces unrealistically low mass fluxes at low pressure (below 30 bar) and low static upstream quality (below 0.5). This in turn causes choking to remain "on" down to very low pressure ratios (1.1). Consequently, the current recommendation is to invoke choking ($c = 0$) only where it is expected to occur (i.e., breaks, relief valves, etc.) and to select the homogeneous flow option ($h = 2$) for these junctions. All other junctions in the model should be specified as nonhomogeneous ($h = 0$) with choking turned off ($c = 1$). Using the homogeneous junction option produces mass fluxes that closely agree with the homogeneous equilibrium critical flow model. In identifying the junctions where choking should be invoked, the user should not overlook the possibility of choking occurring at locations internal to the system; for example, the upper core support plate in a PWR. The recommendation for such locations is to invoke choking with the nonhomogeneous junction option. This allows slip to occur and does not preclude countercurrent flow. When specifying the choking option at internal junctions, the user should carefully monitor calculated results for nonphysical choking, particularly at low pressure. If this occurs, the user should turn choking off for the remainder of the calculation.

The a flag is for the area change option, and has already been discussed. The h flag controls the type of momentum treatment; two-velocity, or one-velocity models. The two-velocity model is recommended except as indicated above. The s flag controls whether the momentum flux is to be used.

System junctions require initial velocities, and time-dependent junctions require velocities as a function of time. Two options are available to specify the velocities. One option requires the velocities; the other requires mass flow rates from which the velocities are computed. If the flow is single-phase, the velocity of the missing phase is set to that of the flowing phase. This matches the transient calculation that computes equal phasic velocities when one phase is missing. The velocity conditions also require an interface velocity. This input is for future capability involving moving volume interfaces. For now, the interface velocity must be set to zero.

2.3.2 Time-Dependent Volume

A time-dependent volume must be used wherever fluid can enter or leave the system being simulated. The geometry data required are similar to system volumes, but during input processing the volume's length, elevation change, and volume are set to zero. With the staggered mesh, the pressure boundary would be applied in the center of the time-dependent volume. Setting these quantities to zero moves the boundary to the edge of the system volume.

The state conditions as a function of time or some time advanced quantity are entered as a table, with time or the time advanced quantity as the independent or search variable. The table must be ordered in increasing values of the search variable, and each succeeding value of the search variable must be equal to or greater than the preceding value. Linear interpolation is used if the search argument lies between search variable entries. End point values are used if the search argument lies outside the search variable entries. If constant state values are desired, only one set of data consisting of any search value and the associated constant data needs to be entered. The program recognizes when only one set of data is entered, and computer time is saved since the equation of state is evaluated only once rather than every time advancement. Step changes can be accommodated by entering two adjacent sets of data with the same time or an extremely small time difference.

The default search argument is time. If no trip number is entered, or if the trip number is zero, the current advancement time is used as the search argument. When a nonzero trip number is entered, a unit step function based on the time the trip was last set is applied. If the trip is false, the search argument is -1.0. When the trip is true, the search argument is the current advancement time minus the last time the trip was set. Thus, the search argument is always -1.0 when the trip is false and can range between zero and the problem time when the trip is true. A time-dependent volume would have some constant condition when the trip is false. When the trip is true, it could follow a prescribed function of time where the time origin is the time of the trip not the start of the transient.

Through an input option, nearly any time-advanced quantity can be specified as the search argument. The allowed quantities are listed in the input description. The search variables in the table are assumed to have the same units as the search argument, and the table lookup, interpolation, and treatment of out of range arguments are identical to those described for the default time argument. However, handling of trips is different. If the trip number is zero, the current value of the specified time-advanced variable is used. If the trip number is nonzero, the time delay cannot be applied as for the default time case, since the search argument may not be time. Thus, if the trip is false, the search argument is -1.0E75; if the trip is true, the current value of the specified variable is the search argument.

When time is the search argument, the current value is the value at the end of the time step; for any other variable, the current value is the value at the beginning of the time step. Time is the default search argument, but time can also be specified as the search argument through the input option of naming a time-advanced variable. These two uses of time as the search argument are different if a trip is used, since the default method can apply a time delay and the other cannot.

2.3.3 Time-Dependent Junction

Time-dependent junctions can be used whenever the phasic velocities or phasic mass flow rates are known as a function of time or other time-advanced quantity. Time-dependent junctions can connect any two system volumes, or a system volume and a time-dependent volume. Phasic mass flow rates are converted to phasic velocities using the upstream phasic densities. Examples of their use would be to

model a constant displacement pump in a fill system, a pump or a valve (or both), by using an associated control system or measured experimental data. Time-dependent junctions are also used frequently in test problems to check code operation.

The phasic velocities or mass flows in the time-dependent junction as a function of time or the time-advanced quantity are entered as a table, with time or the time-advanced quantity as the independent or search variable. The requirements, interpolation, and trip logic are identical to that for time-dependent volumes.

The capability of using time-advanced quantities as search arguments can be used to model pressure-dependent water injection systems. If the injection flow is a function of the pressure at the injection point, the volume pressure at that point is used as the search argument. A trip is defined to be true when the injection system is actuated. One entry of table data with a negative pressure and zero flows causes the flow to be zero when the trip is false. The remaining table entries define the injection flow as a function of positive pressures. The source of injection water is a time-dependent volume. The pressure of the water supplied by the time-dependent volume could also be a function of the pressure at the injection volume to represent the work of pumping the water into the system. If the injection flow is a function of a pressure difference, the pressure difference can be defined by a control system variable, and that control variable is then defined as the search argument.

Some uses of time-dependent junctions can cause modeling difficulties. When using a time-dependent junction to specify flow from a time-dependent volume into the system, the incoming phasic densities, void fractions, phasic velocities, phasic mass flow, and phasic energies can be specified. But when using a time-dependent junction to specify flow out of a system, the densities, void fractions, and energies of the fluid leaving the system are not known in advance. Thus, use of time-dependent junctions to control outflow is not recommended. The following is one example of a modeling problem. The user anticipates that a volume will contain only vapor and accordingly sets a time-dependent junction to a nonzero vapor flow and zero liquid flow. If the user anticipated incorrectly and liquid condenses or is carried into the volume, the liquid will accumulate unrealistically since it cannot leave the system.

In a simple pipe modeling application, a time-dependent volume and junction can be used to specify the inlet flow. Likewise, a time-dependent volume and junction can model the feedwater flow into a reactor steam generator. Controlling the fluid flow out of the pipe or controlling the water/steam flow out of the steam generator through a time-dependent junction is not recommended. If a system junction (flows computed by the simulation rather than specified as boundary conditions) connected to a time dependent volume is not sufficient, perhaps a servo valve can provide the required simulation.

2.3.4 Single-Volume Component

A single-volume component is simply one system volume. A single volume can also be described as a pipe component containing only one volume. This single-volume component uses fewer input cards and fewer data items than does a pipe component. However, if the single volume might be divided into several volumes for nodalization studies, we suggest the pipe component, since such changes are quite easy for pipes.

2.3.5 Single-Junction Component

A single-junction component is simply one system junction. It is used to connect other components such as two pipes. Initial junction conditions can be phasic velocities or phasic mass flow rates.

2.3.6 Pipe

A pipe component is a series of volumes and interior junctions, the number of junctions being one less than the number of volumes, and the junctions connect the outlet of one volume to the inlet of the next volume. Pipe components can be used for those portions of the system without branches. Pipe components offer input conveniences, since most characteristics of the volumes and junctions in a pipe are similar or change infrequently along the pipe, and input data requirements can be reduced accordingly. Because of the sequential connection of the volumes, junctions are generated automatically rather than being individually described. Although the input is designed to assume considerable similarity in volume and junction characteristics, any of the volume and junction features (such as flow area, orientation, pipe roughness, or control flags) can be changed at each volume or junction.

2.3.7 Branch

Branch components are provided to model interconnected piping networks. The branching model is based on one-dimensional fluid flow, which is adequate for most cases of branching and merging flow. Such situations include wyes, parallel flow paths from upper and lower plenums, and any branch from a vessel of large cross section. For branching situations where phase separation effects caused by momentum or gravity are important, an approximate mapping technique can be used to map the two-dimensional situation into the one-dimensional space of the fluid model.

A branch component consists of one system volume and zero to nine junctions. The limit of nine junctions is due to a card numbering constraint. Junctions from other components, such as single junction, pump, other branch, or even time-dependent junction components, may be connected to the branch component. The results are identical whether junctions are attached to the branch volume as part of the branch component or are in other components. Use of junctions connected to the branch, but defined in other components, is required in the case of pump and valve components and may also be used to attach more than the maximum of nine junctions that can be described in the branch component input.

2.3.8 Pump

The pump component model can be separated into models for hydrodynamics, pump-fluid interaction, and pump driving torque. The pump component input provides information for the hydrodynamic and pump-fluid interaction models and may optionally include input for an electric motor to drive the pump. A pump may also be connected to a shaft that is a specialized component within the control system. A shaft component is used when the pump is driven by a turbine or by an electric motor with a control system to regulate speed.

2.3.8.1 Pump Model Description. The hydrodynamic model of a pump component consists of one volume and two associated junctions. The coordinate directions of the junctions are aligned with the coordinate direction of the volume. One junction is connected to the inlet and is called the suction junction; the other junction is connected to the outlet and is called the discharge junction. The pump head, torque, and angular velocity are computed using volume densities and velocities. The head developed by the pump is divided equally and treated like a body force in the momentum equations for each junction. With the exception of the head term, the hydrodynamic model for the pump volume and junctions is identical to that for normal volumes and junctions.

2.3.8.1.1 Pump Performance Modeling--Interaction of the pump and the fluid is described by empirically developed curves relating pump head and torque to the volumetric flow and pump angular velocity. Pump characteristic curves, frequently referred to as four-quadrant curves, present the information in terms of actual head (H), torque (τ), volumetric flow (Q), and angular velocity (ω or N). These data are generally available from pump manufacturers. For use in RELAP5, the four-quadrant curves must be converted to a more condensed form, called homologous curves, which use dimensionless quantities. The dimensionless quantities involve the head ratio, torque ratio, volumetric flow ratio, and angular velocity ratio, where the ratios are actual values divided by rated values. The rated values are also required pump component input and correspond to the design point or point of maximum efficiency for the pump.

The homologous curves are entered in tabular form, and the dependent variable is obtained as a function of the independent variable by a table search and linear interpolation scheme. There is a separate set of curves for head and torque, and each set is composed of eight curves. Not all the regimes need be described by the input, but a problem is terminated if an empty table is referenced. Both head and torque data must be entered for the regimes that are described with input.

The homologous curves for pump head and torque are for single-phase operation. These same tables are used by the two-phase pump model, but additional data must be input to model two-phase degradation effects.

Pump head data are always used in the momentum equations. Torque data may or may not be used in computing pump rotational velocity, depending on the pump motor model selected and if it is energized or not. However, both head and torque are used to determine pump energy dissipation, and consistent data must therefore be entered. The pump homologous data should be checked by computing pump efficiency from the homologous data. No such checking is currently included in RELAP5, nor is the operating efficiency edited on major edits.

The sign conventions for various pump quantities are as follows: a pump operating in the normal pump regime has a positive angular velocity; the volumetric flow is positive if it is in the same direction as the volume coordinate direction; the head is positive if it accelerates the flow in the volume coordinate direction; and the torque is that exerted by the fluid on the pump and is negative if it tends to decelerate the pump. In normal pump regimes and in steady state, this torque is negative and is balanced by the positive torque from the pump motor.

2.3.8.1.2 Pump Data Homologous Representation--The use of pump performance data in terms of nondimensional homologous parameters is often confusing. The purpose of this discussion is to briefly outline rules for a procedure to properly use the homologous data.

The homologous parameters for pumps are obtained from dimensional analysis that can only provide the conditions for similarity. Three independent parameters are obtained from application of Buckingham's Pi theorem.[2.3-1] They are

$$\pi_1 = Q / (vD) \tag{2.3-4}$$

$$\pi_2 = NQ^{\frac{1}{2}} / (gH)^{\frac{3}{4}} \tag{2.3-5}$$

$$\pi_3 = Q / (ND^3) \; . \tag{2.3-6}$$

A fourth parameter that is commonly used can be obtained by a combination of π_2 and π_3 to yield

$$\pi_4 = gH / (N^2 D^2) \; . \tag{2.3-7}$$

The first parameter, π_1, is analogous to a Reynolds number and is the only parameter involving the fluid kinematic viscosity, ν. Experience with pump design and scaling has shown that viscous effects caused by skin friction are small, especially for high Reynolds number flows, and, in practice, the requirement to maintain π_1 constant is not used. The use of π_2, π_3, and π_4 to correlate pump performance has proven quite useful. The parameter π_2 is called the specific speed and is often used as a single parameter to characterize the type of pump impeller best suited for a particular application. In practice, the acceleration of gravity, g, is omitted, and the specific speed is simply defined as

$$N_s = NQ^{\frac{1}{2}} / (H)^{\frac{3}{4}} \tag{2.3-8}$$

where the speed N is in rpm, the capacity Q is in gpm, and the head H is in ft. In this form, N_s is not dimensionless but has a history of usage that still persists.

Two performance parameters that are used for pump modeling are the specific nondimensional capacity,

$$Q_s = Q/(ND^3) \tag{2.3-9}$$

and the specific head (dimensional due to omission of the gravitational acceleration constant),

$$H_s = H/(N^2 D^2) \; . \tag{2.3-10}$$

The D that appears in Equations (2.3-9) and (2.3-10) is a characteristic dimension of the pump and is assumed to be the impeller diameter. When scaling pump performance using homologous parameters, the implication is that all pump dimensions are geometrically similar (i.e., changing D implies a proportional change in impeller width, leakage paths, and in all linear dimensions of the pump).

When the pump torque performance is included, one additional dimensionless parameter is obtained from dimensional analysis and is

$$\pi_5 = \tau/(\rho N^2 D^5) \tag{2.3-11}$$

where π_5 is the nondimensional specific torque.

Generally, constant density is assumed, so the dimensional specific torque used in constructing the homologous representation is reduced to

$$\tau_s = \tau/(N^2 D^5) \ .$$

(2.3-12)

Homologous states are states for which specific capacity, head, and torque are all constant. Thus, at any state it is possible, within the limitations of similarity theory, to predict the performance for other combinations of speed, head, and flow that have the same homologous state. It is also possible to scale pump performance with reasonable accuracy to account for changes in physical pump size through the diameter D by keeping the homologous parameters fixed.

Pump performance data are usually displayed by plotting head and torque as functions of speed and volumetric flow. **Figure 2.3-1** is a four-quadrant pump curve for the Semiscale MOD1 pump, and has speed and flow as independent variables with lines of constant head.

Figure 2.3-2 is a comparable four-quadrant plot of the Semiscale MOD1 pump torque data. All possible operating states of the pump are represented on such plots. These data for a particular pump can be approximately collapsed into a single curve by nondimensionalizing specific head and capacity parameters for corresponding homologous operating points using the design point values for head, capacity, and speed.

All points on **Figure 2.3-1** having the same specific capacity are straight lines passing through the origin (lines of constant Q/N). The impeller diameter is omitted from the homologous parameters since it is constant for a particular pump. The design operating point is indicated by the cross. The line of constant Q/N, passing through the design point and its reflection about the ordinate divides each quadrant into two octants. Each of these eight octants is named according to the convention listed in **Table 2.3-1**, for the purpose of constructing the homologous representation.

The four-quadrant pump head and torque maps in **Figure 2.3-1** and **Figure 2.3-2** can be reduced to the homologous representation curves in two steps. First, the maps are made dimensionless by using the rated head, H_R, flow, Q_R, speed, N_R, and torque, τ_R, to form corresponding dimensionless parameters $h = H/H_R$, $v = Q/Q_R$, $\alpha = N/N_R$, and $\beta = \tau/\tau_R$, respectively. Second, the data are plotted in terms of the homologous parameter h/α^2 or h/v^2, v/α or α/v, and β/α^2 or β/v^2. The parameter used depends upon the octant in which the curve is being plotted. The choice is made so that the values are bounded (i.e., the denominators never vanish and, in the case of the capacity parameter, the range of variation is confined between plus and minus 1.0). **Figure 2.3-3** is the homologous head curve that is obtained from the head map in **Figure 2.3-1**. Note that not all points fall on a single curve. This is a result of the inexact nature of the similarity theory. Real pumps do not perform exactly according to the similarity relations due to
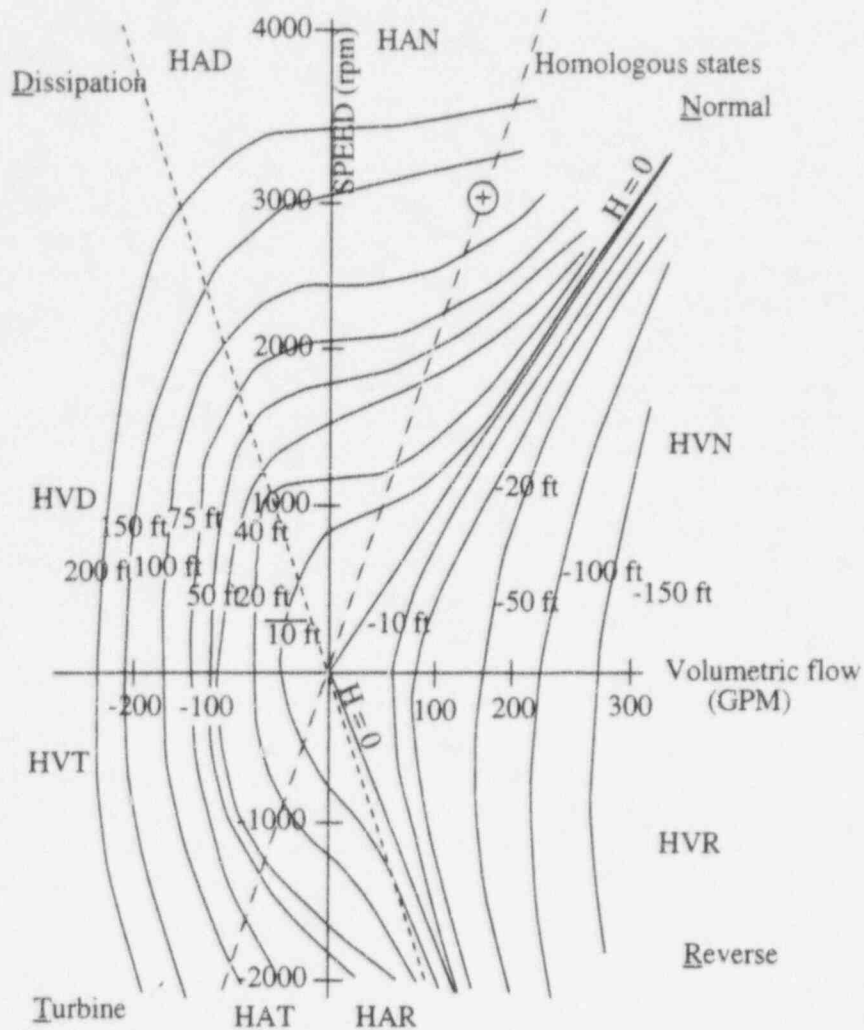
Figure 2.3-1 Four-quadrant head curve for Semiscale MOD1 pump (ANC-A-2083).

leakage, viscous effects, etc.; however, the correspondence is surprisingly close, as evidenced by the tight clustering of points. The homologous curve for the torque data of **Figure 2.3-2** is shown on **Figure 2.3-4**. Since the data do not form a single curve, the design operating usual approach is to use least squares or other smoothing techniques to obtain curves passing through the point (1.0, 1.0). These curves must also be continuous at the point v/α or α/v equal to +1.0. The legends on **Figure 2.3-3** and **Figure 2.3-4** have a key indicating which of the homologous parameters are used in each octant. All combinations of head, flow, speed, and torque can now be located on a corresponding segment of the homologous curve. Note that the impeller diameter parameter that appears in the dimensionless similarity parameters is not used in the homologous reduction of the four-quadrant representation; thus, special considerations are necessary for application of the data to a larger but geometrically similar pump. The advantage of using the homologous pump performance data representation in a computer code is obvious. Two-dimensional data arrays and two-dimensional interpolation are avoided, and, only two parameter tables and one-dimensional interpolation are required.
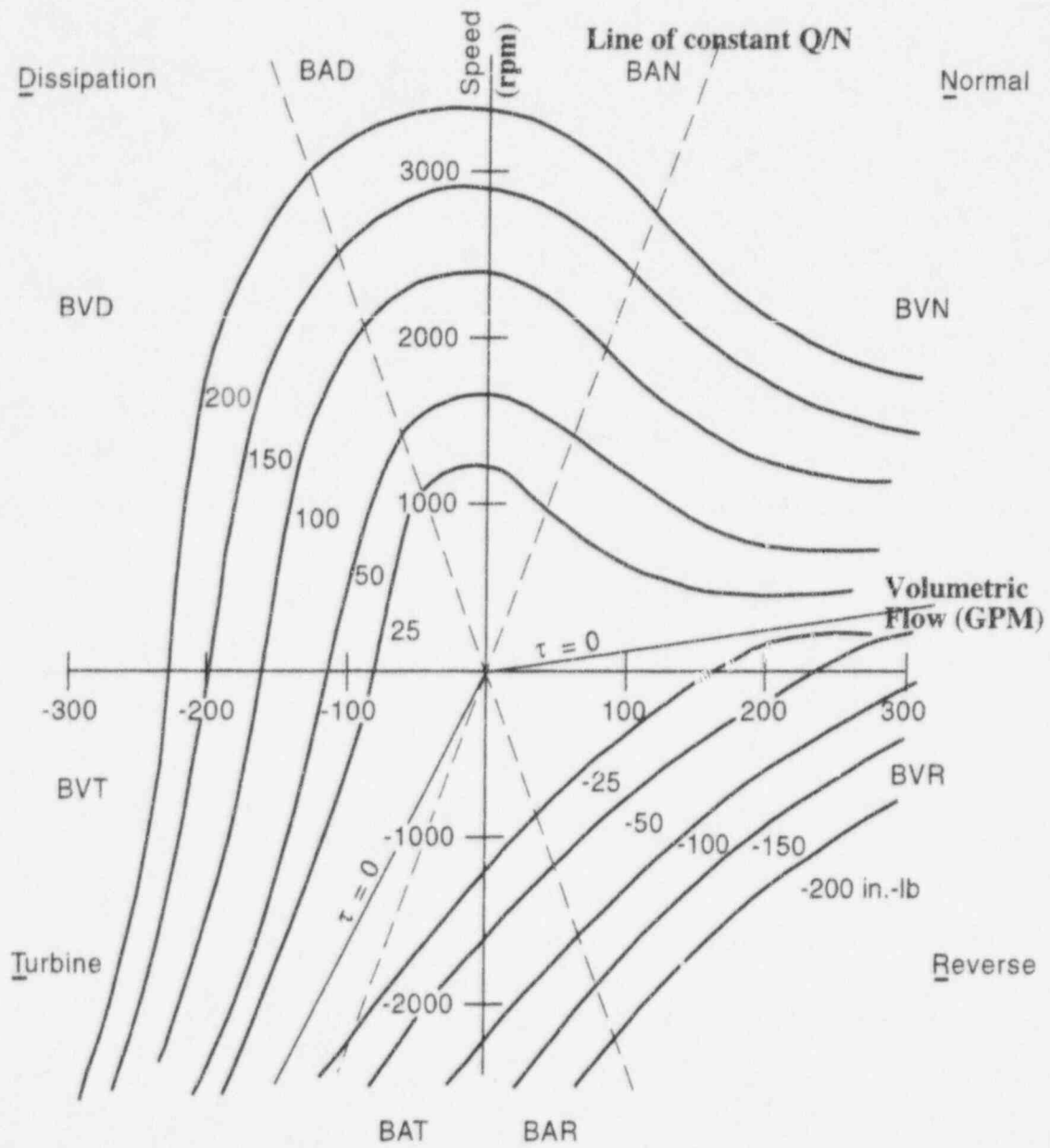
Figure 2.3-2 Four-quadrant torque curve for Semiscale MOD1 pump (ANC-A-3449).

JEN-VII-F211

Table 2.3-1 Pump homologous curve definitions.

Regime number	Regime mode ID name	α	v	v/α	Independent variable[a]	Dependent[a] variable head	Dependent[a] variable torque
1	HAN BAN <u>N</u>ormal	>0	≥0	≤1	v/α	h/α^2	β/α^2
2	HVN BVN Pump	>0	>0	>1	α/v	h/v^2	β/v^2
3	HAD BAD <u>E</u>nergy	>0	<0	≥-1	v/α	h/α^2	β/α^2
4	HVD BVD <u>D</u>issipation	>0	<0	<-1	α/v	h/v^2	β/v^2
5	HAT BAT <u>N</u>ormal	≤0	≤0	≤1	v/α	h/α^2	β/α^2
6	HVT BVT <u>T</u>urbine	≤0	≤0	>1	α/v	h/v^2	β/v^2
7	HAR BAR <u>R</u>everse	≤0	>0	≥-1	v/α	h/α^2	β/α^2
8	HVR BVR Pump	≤0	>0	<-1	α/v	h/v^2	β/v^2

a. α = rotational ratio; v = volumetric flow ratio; h = head ratio; and β = torque ratio.

2.3.8.1.3 Homologous Data and Scaling. In most system simulation tasks, complete pump performance data are not available. Usually, only first-quadrant data are available (normal operation), and sometimes only the design or rated values are known. In the case of full-scale nuclear power plant pumps, it is difficult to test the pumps in all octants of operation or even very far from design conditions. The usual approach to obtain data for such systems is through the use of scaled-down pump tests.

The scaled pump test data can be for the same physical pump operated at reduced speed or for a pump scaled in size such that similarity is preserved. For the case of a pump scaled in size, it is necessary to maintain the similarity in specific head, capacity, speed, and torque parameters. (Note that the diameter was dropped in the development of the homologous performance model since a fixed configuration was considered.) Consideration of the diameter change must be implicitly included in the selection of "rated" parameters to properly account for changes in geometric scale. The homologous parameters, including the impeller diameter, are given in Equations (2.3-9), (2.3-10), and (2.3-12). When a change in scale is considered, an additional degree of freedom is possible, since only two parameters, the rated specific head and capacity, must be held constant. The specific speed is also held fixed whenever both specific head and capacity are kept fixed. There are many combinations of N and D for which this is possible.

The usual situation encountered in applications work is that homologous data exist for a similar pump, and the question arises, "Can we use these data to simulate our pump by adjusting the rated
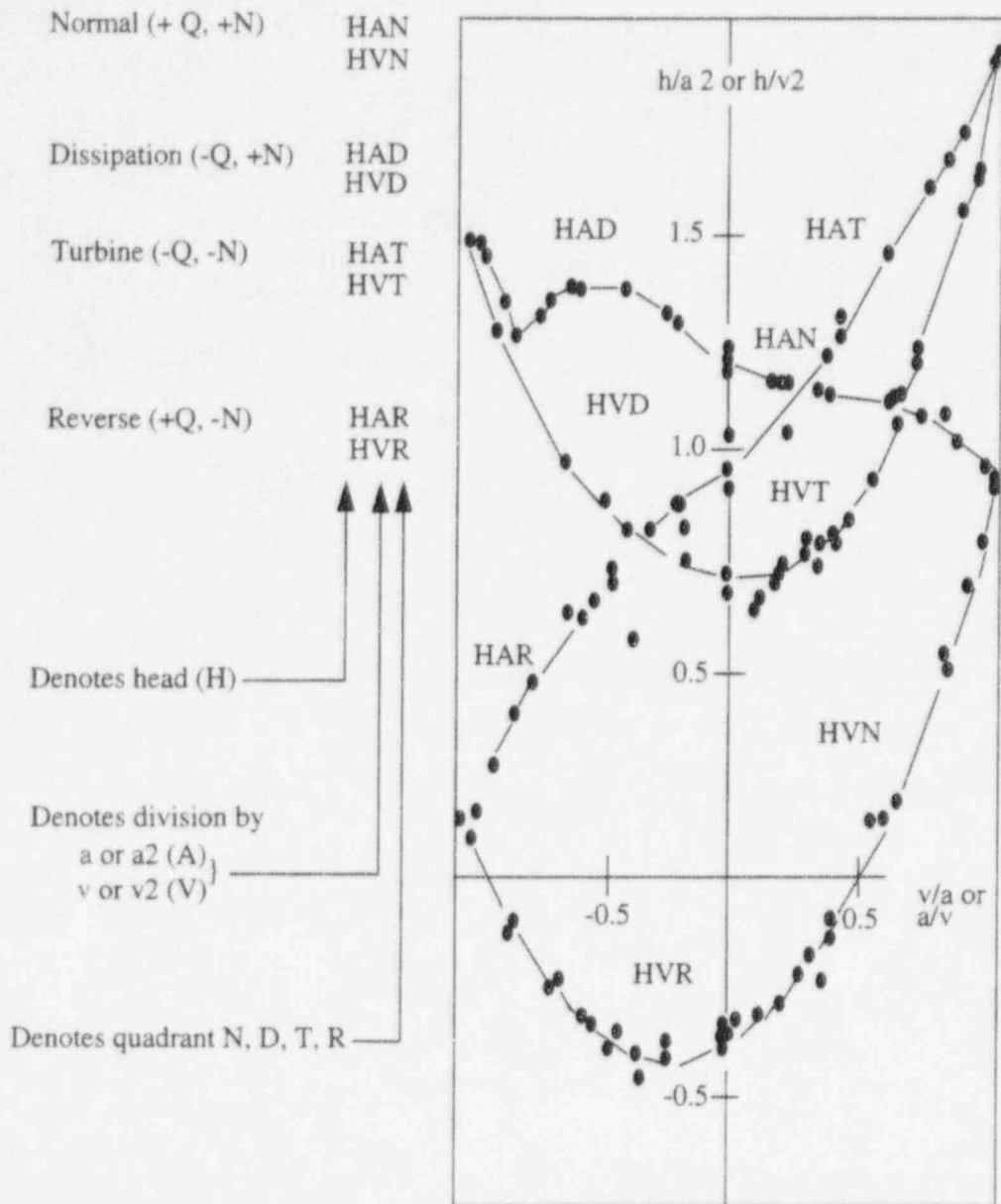
Figure 2.3-3 Homologous head curve.

parameters?" The question can best be answered by the following statements. First, the best approach is to use the rated conditions corresponding to the pump used to generate the data. Second, the rated condition can be changed if the specific head and capacity are kept the same as for the pump used to generate the data. Similarity is assured since the modeled pump will have the same specific speed. The rated conditions by definition locate the region of pump operation on the homologous performance curve, at the design point or point of maximum efficiency. The rated conditions can then be safely adjusted in this way. They can also be adjusted using the impeller diameter as an additional parameter while still maintaining the rated specific speed, head, and capacity constant. However, this type of scaling implies a change in pump geometry and the extrapolation depends more heavily on the validity of the pump similarity relationships,

Normal (+ Q, +N) BAN BVN

Dissipation (-Q, +N) BAD BVD

Turbine (-Q, -N) BAT BVT

Reverse (+Q, -N) BAR BVR

Denotes torque (B)

Denotes division by

α or α^2 (A)
v or v^2 (V)

Denotes quadrant N, D, T, R
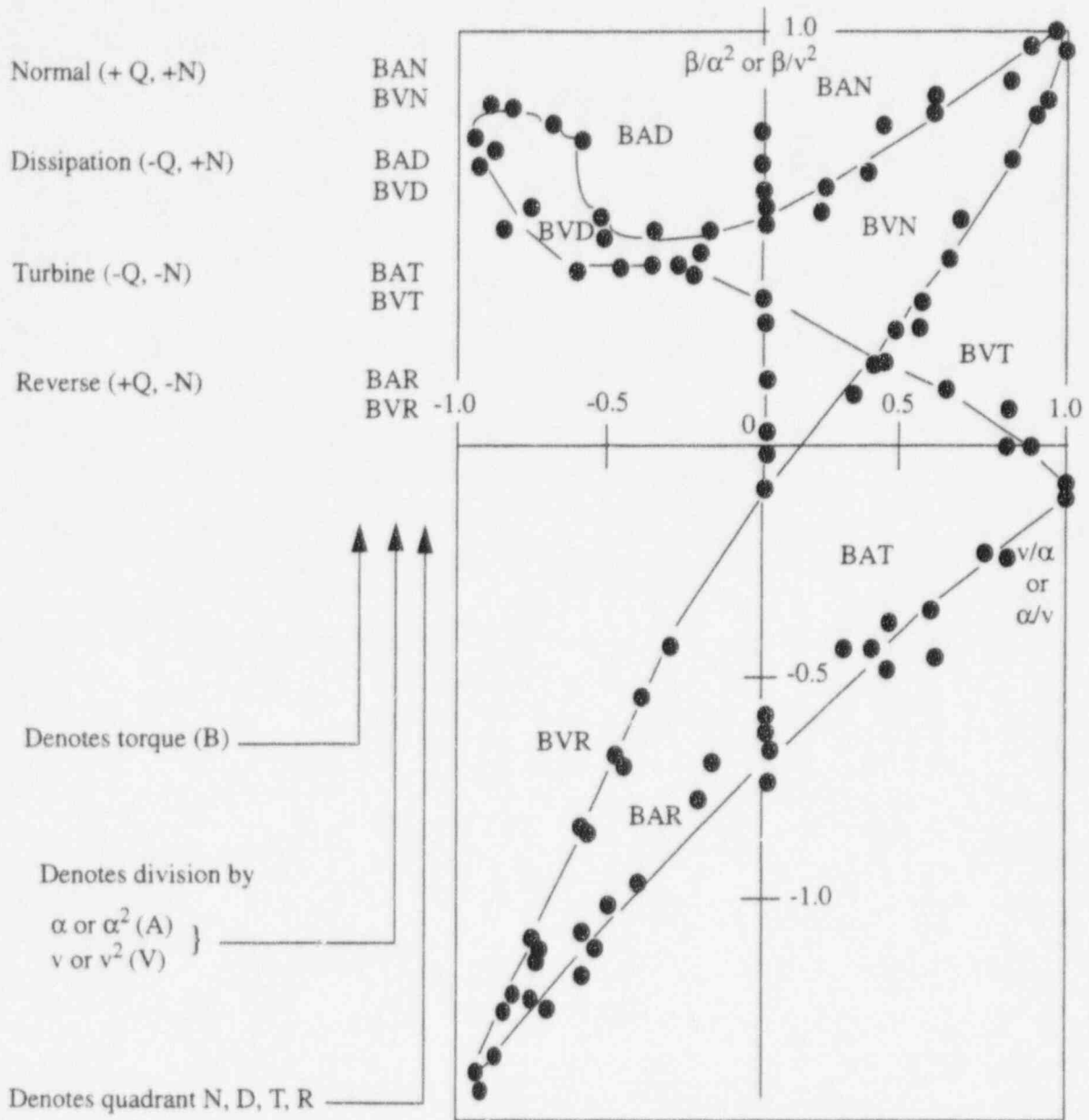
Figure 2.3-4 Homologous torque curve.

which are only approximate. In all cases, the rated conditions must correspond to the same specific speed as the pump used to produce the data. However, the operating point does not have to correspond to the rated conditions. In such a case, the pump will operate at off-design conditions and efficiency will be less than the design value. Such off-design adjustments may be desirable to better match the modeled pump head-flow characteristics at the system operating point.

2.3.8.1.4 Two-Phase Performance Representation--The discussion above applies to a pump operated with a single-phase fluid of constant density. When pump performance operation with a two-phase fluid is considered, the homologous representation of performance data has a less firm basis. An

empirical modification of the homologous approach has therefore been developed. The RELAP5 two-phase pump model is the same as that developed for RELAP4.[2.3-2] The approach is one in which the two-phase performance data are plotted, and a lowest performance envelope is constructed. This curve is called the fully degraded two-phase performance. The fully degraded performance and the single-phase performance data are used to form two-phase difference homologous performance curves for head or torque. The pump performance is then expressed in terms of the single-phase data and the difference data using a two-phase multiplier that is a function of void fraction. The pump head is expressed as

$$H = H_{1\phi} - M_H(\alpha_g) \Delta H \qquad (2.3-13)$$

where ΔH is the head difference obtained from the single-phase to two-phase difference homologous curve. The function $M_H(\alpha_g)$ is the two-phase multiplier, defined such that it is zero for the void fraction, α_g, equal to 0.0 and 1.0. The pump torque is expressed in a similar way. Very little advice can be offered with respect to scaling of the two-phase performance data. Generally, it is assumed that the same similarity principles used for single-phase performance also hold for two-phase performance. A complete set of data was generated for a Semiscale pump, and these data are widely used for predicting two-phase performance of other pumps.

2.3.8.1.5 Pump Velocity Modeling--The pump computation for a time step begins by computing pump head and torque from the homologous data using pump angular velocity and volume conditions at the beginning of the time step. The head is used in the momentum equations. The remaining pump calculation determines the pump angular velocity at the end of the time step. The logic for computing pump angular velocity is complex, since stop logic, friction, an initializing calculation, the presence or absence of two tables, and two trips are involved. Additional capability is provided if the pump is associated with a shaft component. An optional card in the pump component input data specifies whether the pump is associated with a shaft. The remainder of this section defines pump capability when not associated with a shaft. In Section 4.2.3, the available shaft component capabilities are described and user suggestions are given.

Pump frictional torque (τ_{fr}) is modeled as a cubic function of the pump rotational velocity and is given by

$$\tau_{fr} = \pm\left(\tau_{fr0} + \tau_{fr1}\left|\frac{\omega}{\omega_R}\right| + \tau_{fr2}\left|\frac{\omega}{\omega_R}\right|^2 + \tau_{fr3}\left|\frac{\omega}{\omega_R}\right|^3 \right) \qquad (2.3-14)$$

where ω is the pump rotational velocity; ω_R is the rated pump rotational velocity; and τ_{fr0}, τ_{fr1}, τ_{fr2}, and τ_{fr3} are input data. The pump friction torque is negative if $\omega/\omega_R > 0$, and it is positive if $\omega/\omega_R < 0$.

The pump model has special capabilities to accommodate experimental systems. For example; the LOFT system primary pumps use a motor-generator, flywheel, fluid coupling, and an active control system in order to better represent full-size PWR pumps. Allowing a variable pump inertia provides a simple model of the LOFT pump rotational behavior. To facilitate LOFT usage, pump input provides for constant inertia or optionally allows input of variable inertia data. The variable pump inertia (I_p) is given by

$$I_p = I_{pn} \qquad \text{for } \left|\frac{\omega}{\omega_R}\right| < S_L \qquad\qquad\qquad (2.3\text{-}15)$$

$$I_p = I_{p0} + I_{p1}\left|\frac{\omega}{\omega_R}\right| + I_{p2}\left|\frac{\omega}{\omega_R}\right|^2 + I_{p3}\left|\frac{\omega}{\omega_R}\right|^3 \qquad\qquad \text{for } \left|\frac{\omega}{\omega_R}\right| \geq S_L \qquad (2.3\text{-}16)$$

where ω is the pump rotational velocity, ω_R is the rated pump rotational velocity, and I_{pn}, I_{p0}, I_{p1}, I_{p2}, I_{p3}, and S_L are input data.

A pump stop card containing limits on problem time, forward pump angular velocity, and reverse angular velocity may optionally be entered. The pump angular velocity is set to zero and remains zero for the remainder of the problem if any of the limits are exceeded. Selected tests can effectively be disabled by entering a very large number for the limits. If the problem time limit = 0, then the problem time test is ignored.

A time-dependent pump velocity table and an associated trip number may be entered. If the table is entered and the trip number is zero, the pump angular velocity is always determined from this table. If the trip number is nonzero, the table is used only when the trip is true. The default search variable for the time-dependent pump velocity table is time, but time-advanced quantities may be specified as the search variable. When time is the search variable by default, the search argument is time minus the time of the trip. When a time-advanced variable is specified as the search variable (even if it is time), the search argument is just the specified variable. The use of the pump velocity implies a pump motor to drive the pump at the specified velocity.

The following is a possible example of the use of a time-advanced variable as the search argument in the pump velocity table. The motor and its control system that drives a BWR recirculation pump could be modeled using the control system with one of the control variables representing the rotational velocity of the motor. The recirculation pump would be modeled as a hydrodynamic pump component. The torque exerted by the water on the pump would be one of the input variables to the control system model. Motor velocity would be supplied to the pump component by specifying the motor velocity as the search argument of the time-dependent pump velocity table. The table would relate the motor rotational velocity to the pump rotational velocity. If the motor and pump were directly coupled, the search variables and dependent variables would be the same.

Whenever the time-dependent pump angular velocity table is not being used, the pump angular velocity is determined by the advancement in time of the differential equation relating pump moment of inertia, angular acceleration, and net torque. The net torque is the pump motor torque minus the homologous torque value and the frictional torque. If the pump trip is false, electric power is being supplied to the pump motor; if the trip is true, electric power is disconnected from the pump motor and the pump motor torque is zero. If a table of pump motor torque as a function of pump angular velocity is entered, the pump motor is directly specified and motor torque is obtained from the table, interpolating when needed. If the table is missing, the pump motor is implied and torque is assumed to be such that the net torque is zero. This is implemented in the program by simply setting the pump angular velocity at the end of the time step equal to that at the beginning of the time step. This latter option is usually used when the problem starts with the pump at its normal steady-state velocity; the pump is assumed to remain at this velocity until the pump trip, and the trip, once true, remains true for the rest of the problem.

2.3.8.2 Pump Modeling Examples. Two examples are discussed to illustrate pump operation. Consider a pump in a closed loop filled with liquid water. At the start of the transient, all the water in the loop is at zero velocity but the pump is rotating in the positive direction. No pump motor torque table is used, the pump trip is initially false, and thus, the pump angular velocity is constant at the initial value until the pump trip becomes true. With the pump rotating at a constant angular velocity but the water at rest, the head is high and the water is accelerated. As the velocity of the water increases, wall friction and area change losses increase because of the dependence of these losses on wate. velocity. At the same time, the pump head obtained from the homologous data will decrease as the volumetric flow increases. A steady state will be reached when the pump head and the loss effects balance. If no wall friction options are selected for the loop piping and no area losses are present, the water will accelerate until the pump head is zero. When steady state is reached and the pump trip is then set true, the pump will begin to decelerate because the pump friction torque and the torque exerted by the water on the pump are no longer balanced by the pump motor torque. The water also begins to decelerate owing to loss effects. The interaction between the water and pump depends on the relative inertias and friction losses between the two. If the water tends to decelerate more rapidly than the pump, the pump will use its rotational kinetic energy to maintain water velocity. If the pump tends to decelerate more rapidly than the water, the pump, depending on its design as reflected in the homologous data, may continue to act as a pump or the kinetic energy of the water may tend to maintain pump angular velocity.

The second example is similar to the first example except that the initial pump angular rotational velocity is zero and a pump motor torque curve for an induction motor is used. From the curve, the torque is positive at zero angular velocity and increases slowly as the velocity increases to a value slightly below the synchronous speed. Then, the torque decreases sharply to zero at the synchronous speed and continues to negative torque. At the initial conditions, the net torque is positive, the pump angular velocity increases, and the water is accelerated. If the pump torque is sufficiently high, the pump velocity increases to slightly below the synchronous speed where the developed torque matches the frictional torque and the torque imposed by the water. As the water accelerates, the angular velocity decreases slightly to meet the increased torque requirements. The angular velocity decrease is very small owing to the steep slope of the torque versus angular velocity near the synchronous speed. Thus, once the pump approaches the synchronous speed, the transient behavior of the second example is similar to the first example.

2.3.8.3 Built-in Pump Data. RELAP5 contains built-in, single-phase homologous data for a Bingham Pump Company pump with a specific speed of 4200 and a Westinghouse Electric Corporation pump with a specific speed of 5200. Two-phase difference homologous data are also associated with these pumps, but the data curves are identical and were obtained from two-phase tests of the Semiscale pump. (The data curves are stored as data statements in subroutine RPUMP.) No built-in, two-phase multiplier tables are entered. Specification of built-in, single-phase homologous data does not require specification of the built-in, two-phase difference homologous data, or vice versa.

If multiple pump components are used and some tables are common to more than one component, then user effort and computer storage can be saved by entering the data for only one component and specifying that other components use that data. This holds true for built-in data, since built-in data are treated as input data and stored in the pump component data when requested. There are no component ordering restrictions when one pump component references tables in another pump component. Thus, a pump component may reference a pump component numbered higher or lower than itself. Also, a pump component may reference another pump component that references another pump component, as long as a pump component with data entered is eventually reached.

2.3.8.4 Pump Edit Parameters. Major output edits include pump performance information in addition to the quantities common to all volumes and junctions. Pump angular velocity, head, torque, octant number, and motor torque are edited. Pump angular velocity, head, torque, motor torque, and inertia are available as minor edit variables. The pump torque is the sum of torque from homologous data and friction effects. Pump motor torque is zero if the motor is tripped or if no motor is directly specified or implied.

2.3.9 Jet Pump

A jet pump is modeled in RELAP5 using the JETMIXER component. In a jet pump, the pumping action is caused by the momentum mixing of the high-speed drive line flow with the slower suction line flow. **Figure 2.3-5** contains a schematic showing the typical nodalization used for a jet pump mixing section.
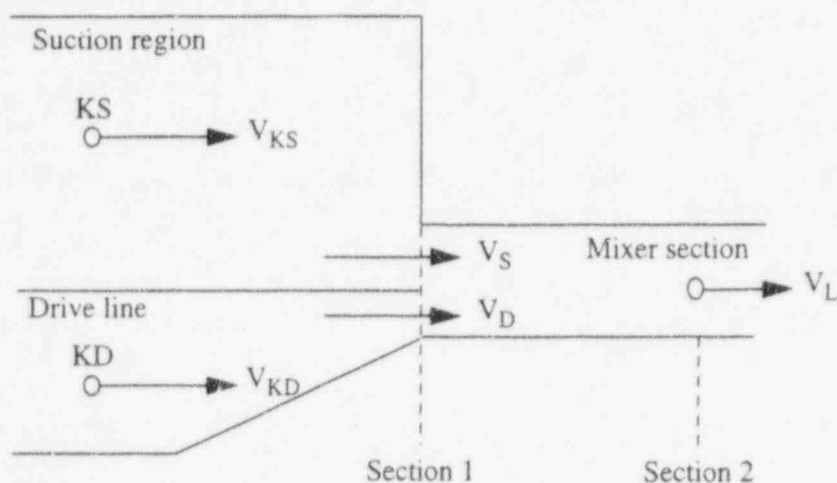
Figure 2.3-5 Schematic of mixing junctions.

2.3.9.1 Input Requirements. The input for a JETMIXER component is the same as that for a BRANCH component, with the following modifications:

1.   for a BRANCH component, the junctions connected to that branch can be input with the branch or as separate components. For a JETMIXER, three (and only three) junctions, representing the drive, suction, and discharge, must be input with the JETMIXER component, i.e., NJ = 3. If NJ is not equal to 3, an input error message is printed

2.   the three junction card sequences must be numbered as follows: Cards CCC1101 and CCC1201 represent the drive junction. Cards CCC2101 and CCC2201 represent the suction junction. Cards CCC3101 and CCC3201 represent the discharge junction in the mixing section

3. The drive and suction junctions must have their TO connection codes referring to the JETMIXER volume, and the discharge junction must have its FROM connection code referring to the JETMIXER volume. If this is not the case, an input error message is printed. The drive and suction junctions must be connected to the inlet side of the JETMIXER volume, and the discharge junction must be connected to the outlet of the JETMIXER volume. If this is not the case, an input error message is printed.

2.3.9.2 Recommendations. Although the junction and volume areas for a JETMIXER are not restricted, the JETMIXER will properly model a jet pump only if the drive and suction junctions flow areas sum to the JETMIXER volume area.

The drive and suction junctions can be modeled with smooth or abrupt area changes. If they are modeled as smooth junctions, then the appropriate forward and reverse loss coefficients must be input by the user. They should be obtained from standard references for configurations similar to those of the jet pump being modeled. The use of smooth junctions gives the user more explicit control over the resistance coefficients. In either case, it should be remembered that the turning losses associated with reverse flow through the suction junction are automatically included in all code calculations.

The JETMIXER component volume is intended to represent the mixing region of the jet pump. The diffuser section of a jet pump normally follows the mixing section. The diffuser section is not an integral part of the JETMIXER component and must be modeled using one or more additional volumes. Several volumes with slowly varying cross sections and the smooth junction option can be used to model the diffuser region.

2.3.9.3 Additional Guidelines. It has been customary to identify jet pump operations in terms of two dimensionless parameters. These are the M and N parameters, defined as follows:

The M ratio (flow ratio) is the suction flow rate, W_S, divided by the drive flow rate, W_D,

$$M = (W_S/W_D) \ . \tag{2.3-17}$$

The N ratio (head ratio) is the increase in dynamic pressure for the suction-discharge path divided by the loss of dynamic pressure for the drive-discharge path,

$$N = \frac{\left(P + \frac{1}{2}\rho v^2 + \rho gH\right)_{Dis} - \left(P + \frac{1}{2}\rho v^2 + \rho gH\right)_{S}}{\left(P + \frac{1}{2}\rho v^2 + \rho gH\right)_{D} - \left(P + \frac{1}{2}\rho v^2 + \rho gH\right)_{Dis}} \ . \tag{2.3-18}$$

Figure 2.3-6 shows an expanded view of the normal operating region (first quadrant) with several curves representing different flow resistances. This figure can be used as a guide for modeling different jet pump geometries. Each curve shows the M-N performance generated with base-case loss coefficients plus a single additional loss coefficient ($K = 0.2$) added to either the drive, suction, or discharge junction. This figure gives an indication of the quantitative change in performance caused by the respective drive, suction, or discharge losses. Using this figure, one can, with a few preliminary runs, design a code model

for a specific jet pump if the performance data are available. If no specific performance data are available, we recommend that standard handbook losses be applied.
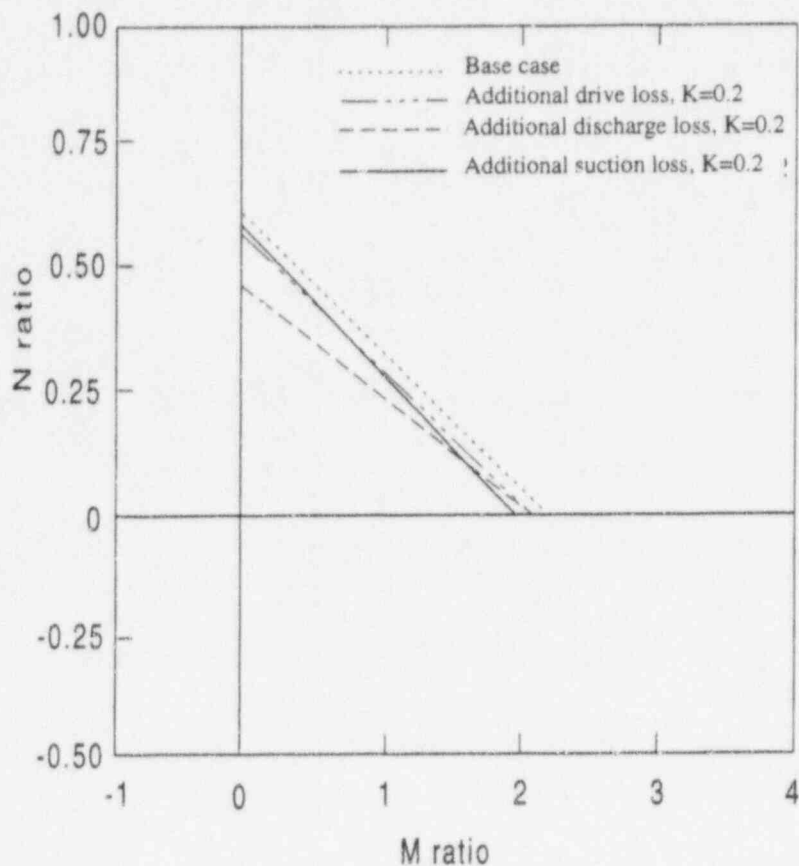
Figure 2.3-6 Jet pump model design.

2.3.9.4 Output. There is no special output printed for the JETMIXER component. We recommend that control variables be used to set up the M and N parameters for minor edit purposes and that these parameters be printed with every edit.

2.3.10 Valves

In RELAP5, eight valves are modeled that are of six types. The types of valves provided are check valves, trip valves, inertial swing check valves, motor valves, servo valves, and relief valves. A single model for each type of valve is provided except for the check valves. For check valves, three models are provided, each of which has different hysteresis effects with respect to the opening/closing forces. Of the six types of valves, the check valves and trip valves are modeled as instantaneous *on/off* switches. That is, if the opening conditions are met, then the valve is instantly and fully opened; if the closing conditions are met, the valve is instantly and fully closed. The remaining four types of valves are more realistic models in that opening/closing rates are considered. In the case of the inertial swing check valve and the relief valve, the dynamic behavior of the valve mechanism is modeled.

Fundamentally, a valve is used to regulate flow by varying the flow area at a specific location in a flow stream. Hence, in the RELAP5 scheme, a valve is modeled as a junction component that gives the

user a means of varying a junction flow area as a function of time and/or hydrodynamic properties. Valve action is modeled explicitly and therefore lags the hydrodynamic calculational results by one time step. In order for the user to more fully use the valve models, some characteristics and recommendations for each valve are discussed in the following subsections.

2.3.10.1 Check Valves. Check valves are on/off switches, and the on/off action is determined by the formulation presented in Volume 1 of this manual. In turn, it is the characteristic of these formulations that determines the kind of behavior modeled by each type of check valve.

2.3.10.1.1 Static Pressure Controlled Check Valve--The check valve logic in Section 3 of Volume I describes the operation of a static pressure controlled check valve. If the equation is positive, the valve is instantaneously and fully opened, and the switch is *on*. If the equation is negative, the valve is instantaneously and fully closed, and the switch is *off*. If the equation is zero, an equilibrium condition exists, and no action is taken to change the existing state of the valve. Hence, in terms of pressure differential, there is no hysteresis. However, because the valve model is evaluated explicitly in the numerical scheme, the actual valve actuation will lag one time step behind the pressure differential. In terms of fluid flowing through the valve in a transient state, it is obvious that if the valve is closed and then opens, the flow rate is zero; but when a pressure differential closes the valve, the flow rate may be either positive, negative, or zero. Hence, with respect to flow, a hysteresis effect will be observed. Also, in the strictest sense, this type of valve is not a check valve, since the model allows reverse flow.

2.3.10.1.2 Flow Controlled Check Valve--Section 3 in Volume 1 shows the model of a check valve in the strictest sense in that flow is allowed only in the positive or forward direction, and the model is again designed to perform as an *on/off* switch. If the valve is closed, it will remain closed until the static pressure differential becomes positive, at which time the valve is instantaneously and fully opened, and the switch is *on*. Once the valve is opened, it will remain open until flow is negative or reversed, regardless of the pressure differential. Hence, with respect to pressure differential, a hysteresis effect may be observed. With respect to flow, it defines a negligible hysteresis effect, since flow is zero when the valve opens, and closes if flow becomes infinitesimally negative. However, since valve actuation lags one time step behind the pressure and flow calculation, a significant flow reversal may be calculated before the valve model completes a closed condition.

2.3.10.1.3 Dynamic Pressure Controlled Check Valve--Section 3 in Volume 1 shows the model of a dynamic pressure-actuated valve also designed to perform as an *on/off* switch. If the valve is closed, there is no flow through the valve, hence the valve must be opened by static pressure differential. For this condition, the valve is opened instantaneously and fully, and the switch is *on*. Once the valve is opened, the fluid is accelerated, flow through the valve begins, and the dynamic pressure aids in holding the valve open. Since the valve cannot close until the closing back pressure, PCV, exceeds the junction static and dynamic pressure, there is a hysteresis effect both with respect to the opening and closing pressure differential and with respect to the fluid flow. These hysteresis effects are also determined by the sign of PCV, as input by the user. If PCV is input as positive, positive or forward flow through the valve will be allowed, and negative or reverse flow will be restricted. In this sense, the valve performs as a check valve. However, if PCV is input as negative, it will aid in opening the valve, and significant negative or reverse flow must occur before the valve will close. In this sense, the valve will not perform as a check valve. In addition, valve actuation lags one time step behind the pressure and flow calculations in the numerical scheme.

2.3.10.1.4 Check Valve Closing Back Pressure Term PCV--In Section 3 in Volume 1, the term PCV is used; in the input requirements, this term is designated as the *closing back pressure*. However, to be precise, PCV is a constant representing an actuation set point. If positive, PCV behaves as a back pressure acting to close the valve. In both the static and dynamic pressure-controlled valves, PCV acts both as an actuation set point for opening a closed valve and as a closing force for closing an open valve. For the flow-controlled valve, the back pressure acts only as an actuation set point for opening a closed valve.

2.3.10.2 Trip Valve. The trip valve is also an on/off switch that is controlled by a trip such that when the trip is *true* (i.e., *on*), the valve is *on* (i.e., instantly and fully open). Conversely, when the trip is *false* (i.e., *off*), the valve is *off* (i.e., instantly and fully closed).

Since trips are highly general functions in RELAP5 and since trips can be *driven* by control systems, the on/off function of a trip valve can be designed in any manner the user desires. The user should remember, however, that trips, control systems, and valves are explicit functions in RELAP5 and hence lag the calculational results by one time step.

2.3.10.3 Inertial Swing Check Valve. The inertial valve model closely approximates the behavior of a real flapper-type check valve. To direct the model to neglect flapper mass and inertial effects, the user simply inputs the flapper mass and moment of inertia as small numbers. Flapper open angles are positive in the positive junction flow direction. The code assumes that gravity always acts in the vertically downward direction, so that gravity can act to either open or close the valve, depending on the implied junction direction. The minimum flapper angle must be greater than or equal to zero.

2.3.10.4 Motor and Servo Valves. The interaction of both motor and servo valves with fluid flow are identical but the means of positioning the valves are different. Both valves use a normalized stem position to position the valve. The normalized stem position ranges between 0.0 for the closed position to 1.0 for the fully open position. The flow area corresponding to a normalized stem position is determined from the normalized flow area, which also ranges from 0.0 for fully closed to 1.0 for fully open. A general table can be used to describe the normalized flow area for a given normalized stem position. If the general table is not used, the normalized flow area is set to equal the normalized stem position. Two models are provided to effect flow changes based on valve flow area. If the abrupt area change flag is set, the abrupt area change model is used to determine flow losses, and the valve flow area is treated as the orifice area in the abrupt area change model. If the abrupt area change flag is not set, a CSUBV table must be entered. This table contains forward and reverse flow coefficients as a function of normalized valve area. The model using CSUBV coefficients should usually be used when the valve is designed for regulating flow.

The motor valve assumes that the valve stem is positioned by a motor. The valve position can be stationary, or the valve can be moving at a constant rate in the opening or closing direction. The rate is a user input quantity in terms of normalized position change per second. The motor is controlled by an open trip and a closed trip. The valve stem position is stationary when both trips are false; when the open trip is true, the valve stem moves in the open position; when the close trip is true, the valve moves in the closing direction. The code terminates if both trips are simultaneously set true. Section 4.1.4 shows trip logic for the open trip that could be used to position a valve to regulate flow such that an upstream pressure is held within a set range.

The servo valve uses the value of a control variable to indicate the normalized valve stem position. A typical application would be regulating steam flow to the turbine to maintain a desired quantity such as primary system temperature or secondary side steam generator pressure. The control system, perhaps using a STEAMCTL (specialized proportional-integral controller), would compare the current value of the primary temperature or steam generator pressure to the desired value, and from the difference of the values compute an appropriate valve position. The servo valve, using the control output, would position the valve and thus regulate the flow.

2.3.10.5 Relief Valve. A scheme was designed to input the terms required to define a typical relief valve geometry and dynamic parameters. This scheme is consistent with the RELAP5 input philosophy in that extensive checking is performed during input processing, and error flags are set to terminate the problem if input errors are encountered. Error messages are also printed to inform the user that the data entered were in error. The specific input description is detailed in Appendix A.

2.3.11 Separator

Figure 2.3-7 contains a schematic showing the typical nodalization used for a separator and the adjoining bypass and downcomer regions. If there is any possibility of recirculation flow through a bypass region, we recommend that this flow path be included. In general, there will be a mixture level at some location in the downcomer volumes.

The RELAP5 separator model can be looked on in the following way. The flux through the liquid outlet is all water when the volume fraction of liquid is above a critical value. Below that critical value, a mixture of steam and water are fluxed out the liquid outlet. A similar thing occurs for the steam outlet. When the volume fraction of steam is above a critical value, only steam is fluxed through the steam outlet. When the volume fraction of steam is below this critical value, a mixture of steam and water is fluxed through the seam outlet. The critical values are given names VUNDER for the water outlet, and VOVER for the steam outlet. This behavior can be shown in **Figure 2.3-8**.

The volume on the bottom furnishes a mixture of steam and water to the separator. For the separator water outlet, notice that if the water level drops below the outlet baffle on the left, steam will also come out the junction. And for the separator steam outlet, notice that if the water level rises above the outlet baffle on the right, that water will also come out the junction. Thus the critical values of VUNDER and VOVER are given by the following formulas,

$$\text{VUNDER} = \frac{A_{fj}}{A_t} \text{ and } \text{VOVER} = \frac{A_{gj}}{A_t} \tag{2.3-19}$$

where

A_{fj} = the area open to the water

A_t = the total area

A_{gj} = the area open to the steam.
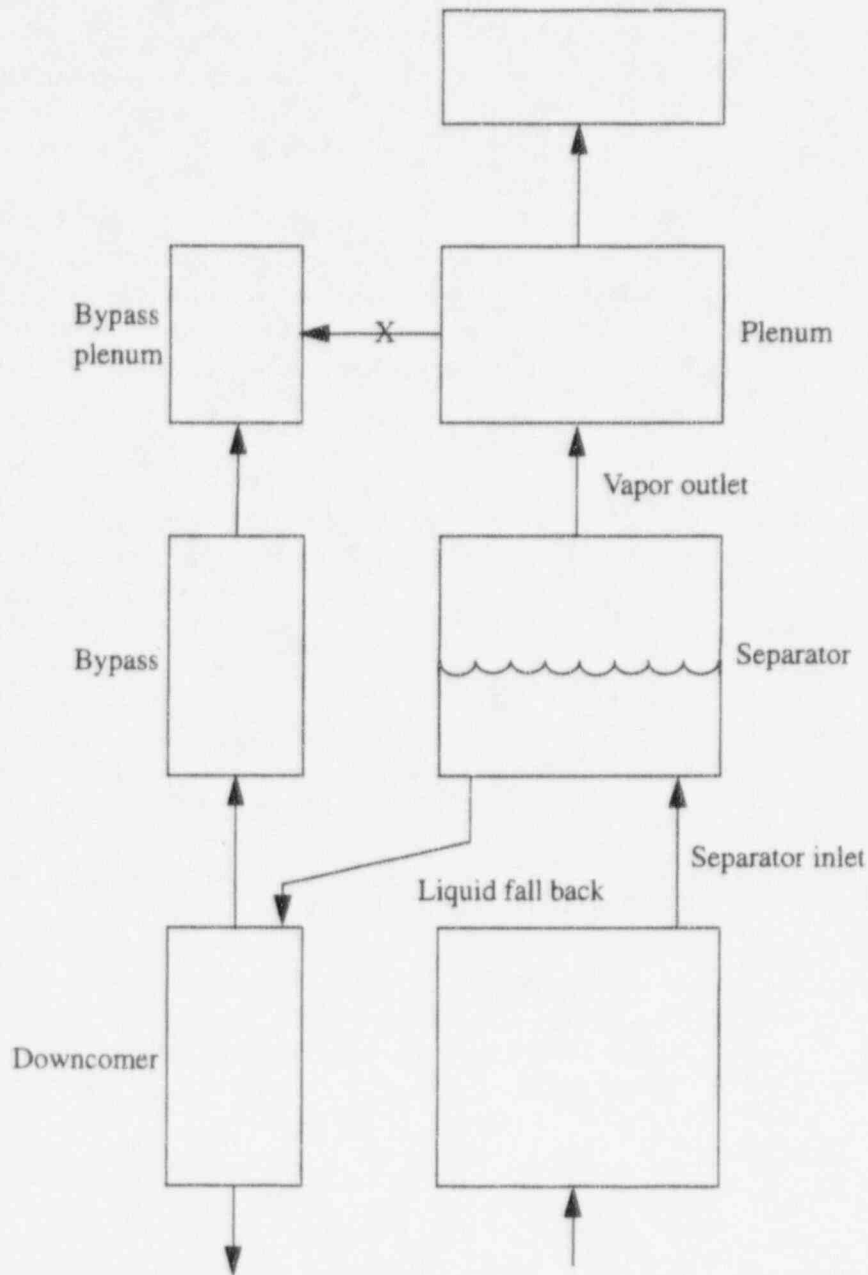
Figure 2.3-7 Schematic of separator.

When the water level drops below the baffle on the left, the volume fraction of steam that is fluxed through the water outlet junction is a linear function of the water level height. A similar relationship is used for the steam outlet when the water level rises above the baffle on the right. These linear relationships are such that if the separator is empty of water, then pure steam comes out the liquid outlet, and conversely, if the separator is full of water, then pure water comes out the steam outlet. The behavior of the separator can now be characterized by **Figure 2.3-9** and **Figure 2.3-10** where the y-axis shows the volume
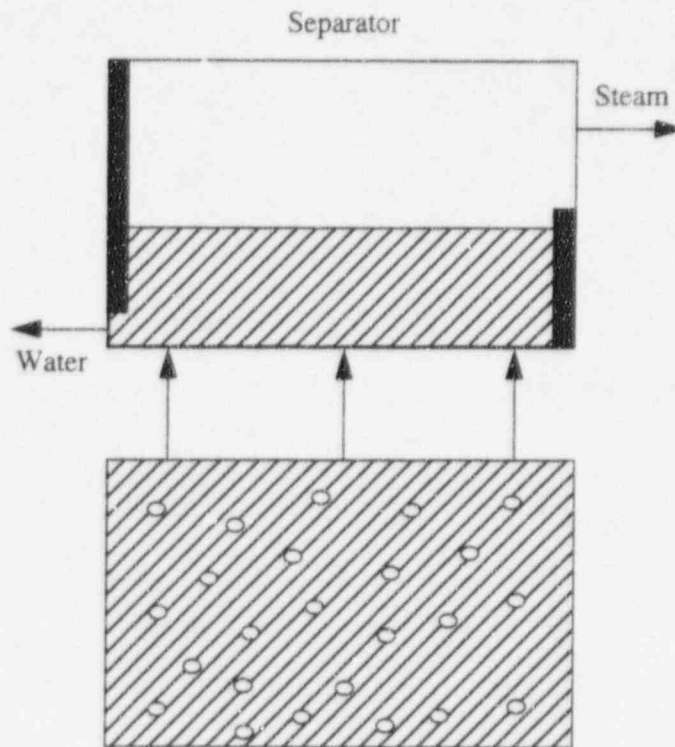
Figure 2.3-8 Physical picture of a separator.

fraction fluxed out the outlet (water or steam) and the x-axis shows the volume fraction (water or steam) in the separator volume.

2.3.11.1 Input Requirements. The input for a SEPARATR component is the same as that for a BRANCH component, with the following modifications:

1. for a BRANCH component, the junctions connected to the branch can be input with the branch or separator components. For a SEPARATR, the three junctions, representing the vapor outlet, liquid fall back, and separator inlet, must be input with the SEPARATR component, i.e., NJ = 3

2. the three junction card sequences must be numbered as follows: Cards CCC1101 and CCC1201 represent the vapor outlet junction, Cards CCC2101 and CCC2201 represent the liquid fall back junction, and Cards CCC3101 and CCC3201 represent the separator inlet junction

3. the FROM connection for the vapor outlet junctions must refer to the outlet of the separator (CCC010000). The FROM connection for the liquid return junction must refer
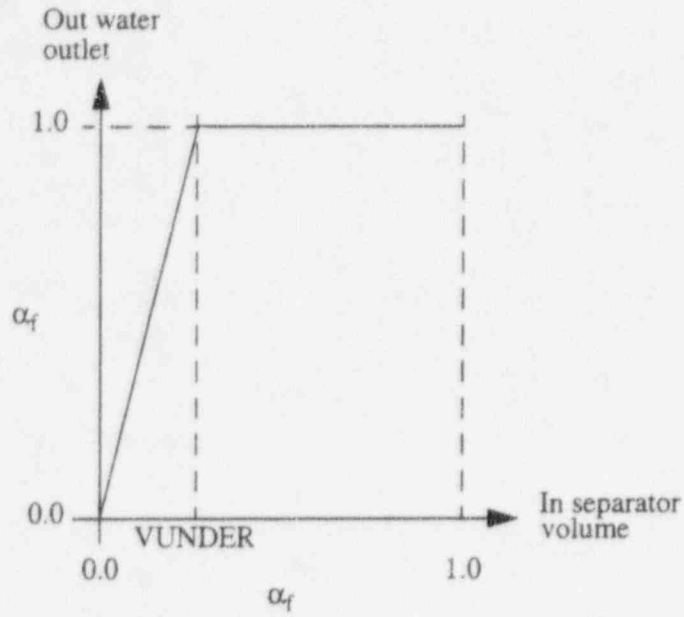
Figure 2.3-9 Separator volume fraction of water fluxed out the water outlet.
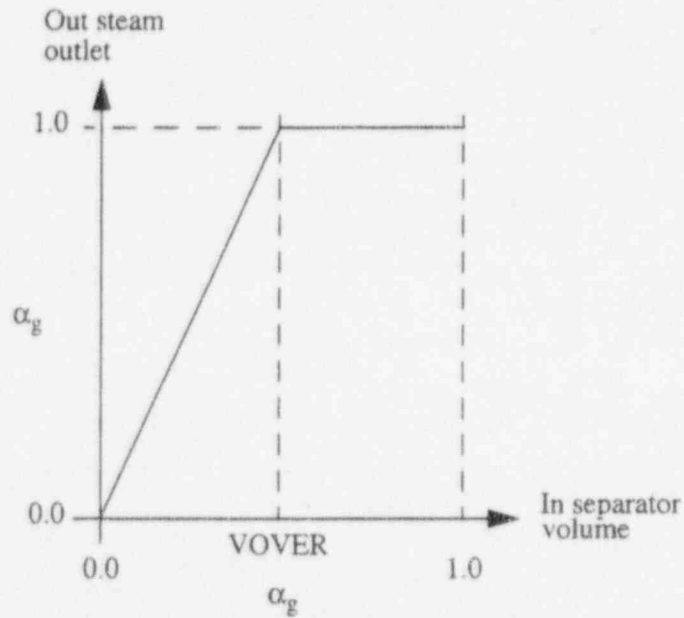
Figure 2.3-10 Separator volume fraction of steam fluxed out the steam outlet.

to the inlet of the separator (CCC000000). The inlet junction should also be connected to the separator inlet side (CCC000000)

4.   the type of separator desired is specified on Card CCC0002. If the mechanistic separator or dryer options are chosen, additional input data may be entered on the CCC050X cards for the mechanistic separator model and on the CCC0600 card for the dryer model. Default data are provided for both the mechanistic separator and dryer models

5.   a word, W7(R), is added to the SEPARATR component junction geometry Cards CCCN101 for the simple separator option. For the vapor outlet, Word W7(R) specifies VOVER. For the liquid fall back junction, Word W7(R) specifies VUNDER. No input should be entered for Word W7(R) on the separator inlet junction.

2.3.11.2 Recommendations for the Simple Separator Option. The smooth or abrupt junction option can be used for the separator. Separators in general have many internal surfaces that lead to flow resistances above that of an open region. For this reason, additional energy loss coefficients may be required at the appropriate separator junctions. These should be obtained from handbook values or adjusted to match a known pressure drop across the separator. In some cases, it is necessary to use large loss coefficients (~100) in order to remove void oscillations in the separator volume. In addition, we recommend that choking be turned off for all three junctions. The nonhomogeneous options should be used for the vapor outlet and liquid fall back junctions.

An important parameter that influences the operation of any heat exchanger/separator combination is the equivalent mixture level in the downcomer region. This level is primarily determined by the rate of flow in the liquid return junction, which in turn is affected by the water level in the separator and the vapor flow out of the separator. The liquid return flow and water level in the separator are affected by the user input void limits VOVER and VUNDER that determine the range of ideal separation. Because of the simple black-box nature of the separator, these limits should be adjusted to obtain the desired operating mixture level in the downcomer region. The default void limits (VOVER = 0.5 and VUNDER = 0.15) for ideal separation are intended to be preliminary.

The black-box nature of the separator, along with the use of VOVER and VUNDER, may result in some changes to the user input initial conditions. If the user inputs a mass flow rate for both the vapor outlet and liquid fall back junctions, the code will in many cases alter the mass flow rates so that they no longer match those inputted. This is due to the use of the piecewise linear donor junction voids used (see Volume 1 of this manual). Depending on the relations of α_{gK} and VOVER as well as α_{fK} and VUNDER, it may be necessary to scale back the mass flow rates to achieve the desired input mass flow rates. Once the transient calculation begins, the mass flow rates and voids will most likely change from the initial value and some adjustment of VOVER and VUNDER may be required.

The final recommendation concerns the use of a bypass volume. If there is any possibility of a recirculation flow through a bypass-like region, we recommend such a flow path be included. The inclusion of such a flow path has generally improved the performance predictions. The use of a crossflow junction between the separator plenum and a bypass plenum instead of a normal junction generally provides a better model for the recirculation flow.

2.3.11.3 Recommendations for the Mechanistic Separator and Dryer Options. The mechanistic separator and dryer models are new in RELAP5/MOD3. They are intended to model the centrifugal separator and chevron dryer components in a BWR reactor. Until a base of user experience is obtained, we recommend default input data for the models be used. The user should explicitly model the separator standpipe as a separate volume or set of volumes because the separator component volume is

intended to model the volume within the separator barrel and discharge passages. Likewise, the dryer volume should encompass the physical volume inside the dryer skirt between the elevations of the dryer inlet and outlet elevations. The separator inlet quality can be adjusted to the desired operating point by modifying the form loss coefficient in the separator liquid discharge junction. The liquid discharge line from a dryer to the downcomer should be modeled as a separate volume or set of volumes so that the liquid removed by the dryer may be injected into the downcomer at the correct elevation below the two-phase mixture level in the downcomer. The void fraction within the dryer component can also be adjusted by use of the liquid discharge junction form loss coefficient. The separator component may represent any number of physical separators. It is required that the geometry (i.e., volume and junction flow areas) of the separator component be the volume and flow areas of all of the physical separators represented by the RELAP5 separator components and that the number of separators represented by the RELAP5 separator component be specified in Word 2 on Card CCC0002 in the separator component input data.

2.3.12 Turbine

A steam turbine is a device that converts thermal energy contained in high-pressure, high-temperature steam to mechanical work. Three different stage group types can be implemented: (a) a two-row impulse stage group, which is normally only used as the first stage of a turbine for governing purposes; (b) a general impulse-reaction stage group with a fixed reaction fraction needed as input; and (c) a constant efficiency stage group to be used for very simple modeling or as a preliminary component during the model design process. A simple efficiency formula for each of the turbine types is given in Volume I, where all the terms are defined.

The mean stage radius needed in the efficiency formulas may not be known from the actual turbine design diagrams. We recommend the mean stage radius, R, be obtained from the efficiency formulas. If the turbine model is used with a constant efficiency factor, the stage radius is not needed (except for startup) and 1.0 can be entered. If the turbine stage is a general impulse-reaction stage, then the maximum efficiency, η_o, is obtained when

$$\frac{v_t}{v} = \frac{0.5}{1-r} \quad . \tag{2.3-20}$$

Using $v_t = R\omega$ and the input values v, r, and ω at the design operating point, Equation (2.3-20) gives for R,

$$R = \frac{0.5v}{\omega(1-r)} \quad . \tag{2.3-21}$$

This is the recommended mean stage radius that is consistent with the assumed efficiency formula. For a two-row impulse stage, the maximum efficiency occurs when

$$\frac{v_t}{v} = 0.25 \quad . \tag{2.3-22}$$

Expressing v_t as $R\omega$ gives

$$R = \frac{0.25v}{\omega} \qquad (2.3\text{-}23)$$

as the mean stage radius consistent with the efficiency formula.

For a TURBINE component, the primary steam inlet junction must be input with the TURBINE component as the first junction. If a steam extraction (bleed) junction is desired, it must be input with the TURBINE component as the second junction. Thus, NJ must be either 1 or 2. Cards CCC1101 and CCC1201 represent the steam inlet junction, and Cards CCC2101 and CCC2201 represent the steam extraction bleed junction (if desired). The TO connection for the steam inlet junction must refer to the inlet of the TURBINE (CCC000000).

Horizontal stratification effects are not modeled in the TURBINE component. Thus, the horizontal stratification flag must be turned off ($v = 0$). If several TURBINE components are in series, the choking flag should be left on ($c = 0$) for the first component but turned off for the other components ($c = 1$). The area changes along the turbine axis are gradual, so the smooth junction option should be used at both the inlet and outlet junctions. No special modeling has been included for slip effects, nor are there any data that could be used as a guide. Thus, the inlet and outlet junctions must be input as homogeneous junctions ($h = 2$). If a steam extraction (bleed) junction is present, it must be a crossflow junction ($s = 1, 2,$ or 3).

The standard wall friction calculation is based upon the wetted perimeter. Because of all the internal blading surfaces, the wall friction based upon the volume geometry will not give a meaningful calculation. The turbine volume must be input using the zero wall friction option.

For some off-design cases, choking can take place at the nozzle and stator throats in a turbine. The junction velocities must represent the maximum nozzle velocities if the critical flow model is to be used. Hence, the junction areas used in the TURBINE component should represent the average nozzle throat or minimum area for the stage group if proper critical flow modeling is desired.

Several of the input parameters needed may not always be easily obtainable from the limited data available to the user. In particular, the stage group nozzle throat area, A_j, and the nozzle velocity, v_j, are not always easily obtained. A steady-state turbine heat balance usually contains the representative stage group pressures, the enthalpies, and the mass flow rates. From the mass flow rate and state properties, the product $v_j A_j$ is easily obtained, but the actual value of v_j or A_j requires more information. If a geometric description of the turbine is available, then A_j is known and v_j can be calculated. This is the proper way to obtain the input data. If no geometric data are available, then the following procedure can be used to crudely estimate the needed input data. A reasonable estimate must be made for one junction area. Then, knowing $v_j A_j$ gives the corresponding v_j. The turbine momentum equation

$$v_j(v_j - v_{j-1}) = -\frac{1-\eta}{\rho}(P_L - P_K) \qquad (2.3\text{-}24)$$

along with the stage pressures, can then be used to estimate the neighboring junction velocity. The mass flow along with this new velocity gives the neighboring junction area. In this way, all the velocities and junction areas can be estimated if any one junction area A_j or junction velocity v_j is known or estimated.

Note that turbines are usually designed to run with large velocities in the nozzles. The turbine may be the component that gives the maximum Courant number in the system. For this reason, the turbine component may limit the time step size. This can be mitigated if the turbine volumes are used with an exaggerated length. This will not affect any steady-state results, but it will give slightly inaccurate storage terms during a transient. The transient storage terms are small, so this should not be a problem.

2.3.13 Accumulator

An accumulator is a *lumped* parameter component modeled by two methods. First, the component is considered to be an accumulator as long as some of the initial liquid remains in the component. In this state, the accumulator is modeled using the special formulations discussed in Volume I of this manual. However, second, when the accumulator empties of liquid, the code automatically converts the component to an equivalent single volume with a single outlet junction and continues calculations using the normal solution algorithms. In performing this conversion, the accumulator wall heat transfer model is retained but the volume flow area (A), hydraulic diameter (D_h), and elevation change (Δz) are reset to

$$A = V/(\Delta x_{TK} + \Delta x_L)$$ (2.3-25)

$$D_h = 4V/\pi (D_{TK}\Delta x_{TK} + D_L\Delta x_L)$$ (2.3-26)

$$\Delta z = \Delta z_{TK} + \Delta z_L$$ (2.3-27)

respectively. In these equations, subscript TK is for the tank, and subscript L is for the surgeline/standpipe. In addition, the accumulator mass transfer model converts to the normal mass transfer model scheme.

In setting up an accumulator component, the user must remember that at the input processing level, the code assumes that the accumulator is initially *off*; that is, flow through the accumulator junction is zero. It is further assumed that the standpipe/surgeline is initially full of liquid and that the tank liquid level is as defined by the user. These assumptions are also true for RESTART runs if the user renodalizes the accumulator. Hence, the user must be careful to define the initial accumulator pressure lower than the injection point pressure, including elevation head effects. The tank geometry may be either cylindrical (see **Figure 2.3-11**) or spherical (see **Figure 2.3-12**). In the input description (Appendix A), the standpipe/ surgeline inlet refers to the end of the pipe inside the tank itself (see **Figure 2.3-13**). Also, the noncondensable (nitrogen) used in the accumulator is that defined for the entire system being modeled. Hence, the user must be sure to input the correct noncondensable name (nitrogen) on Card 110, as discussed in Appendix A.

No other junctions (except the accumulator junction) should be connected to an accumulator volume. There are 4 possible accumulator configurations, as shown in **Figure 2.3-14**. The inclination angle (W5) and elevation change (W6) in Cards CCC0101-CCC0109 can be either positive or negative, but both must have the same sign. The elevation drop of the surgeline and standpipe (W4) in Card CCC2200 is positive
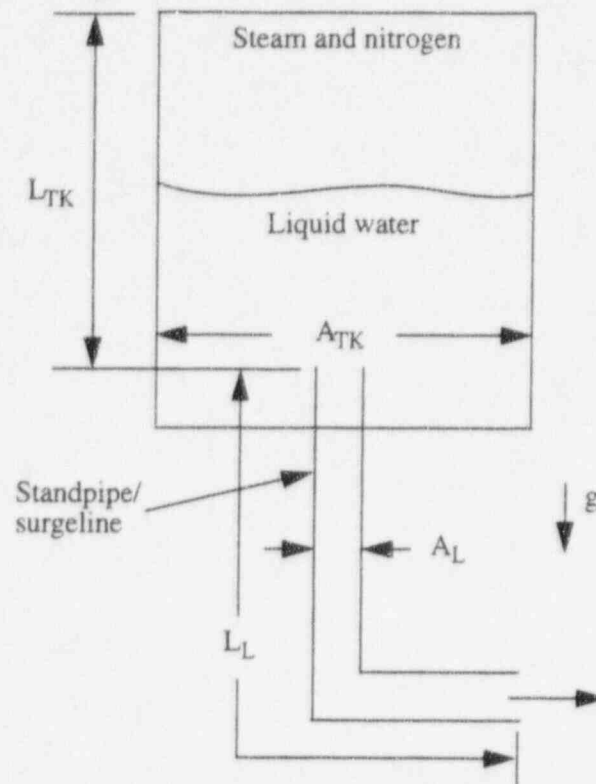
Figure 2.3-11 Schematic of a cylindrical accumulator.

for a decrease in elevation from the standpipe/surgeline inlet to the injection point, and it is negative for an increase in elevation from the standpipe/surgeline inlet to the injection point.

2.3.14 Annulus

The annulus component is identical to a pipe component (Section 2.3.6), except the annulus component must be vertical and the annular mist flow regime is different. If the user specifies this component, all the liquid is in the film and none is in the drops when the flow regime is annular mist. The annulus component should be used to model a vertical annular region (i.e., reactor vessel downcomer or annular downcomer region in a U-tube steam generator).

2.3.15 ECC Mixer

An ECC mixing component is a specialized branch that requires three junctions with a certain numbering order. The physical extent of the ECCMIX is a length of the cold leg pipe centered around the position of the ECC injection location. The length of this segment should be about three times the inside diameter of the cold leg pipe. Junction No. 1 is the ECC connection; junction No. 2 is the cold leg cross section through which flow enters this component in normal reactor operation; and junction No. 3 is the one that leads to the reactor vessel. The geometrical description of the ECCMIX component is very similar to that of the JETMIXER component, except for the specification of an angle for the ECC pipe connection. The modeling details of the ECCMIX component are given in Section A7.7 of the input requirements in
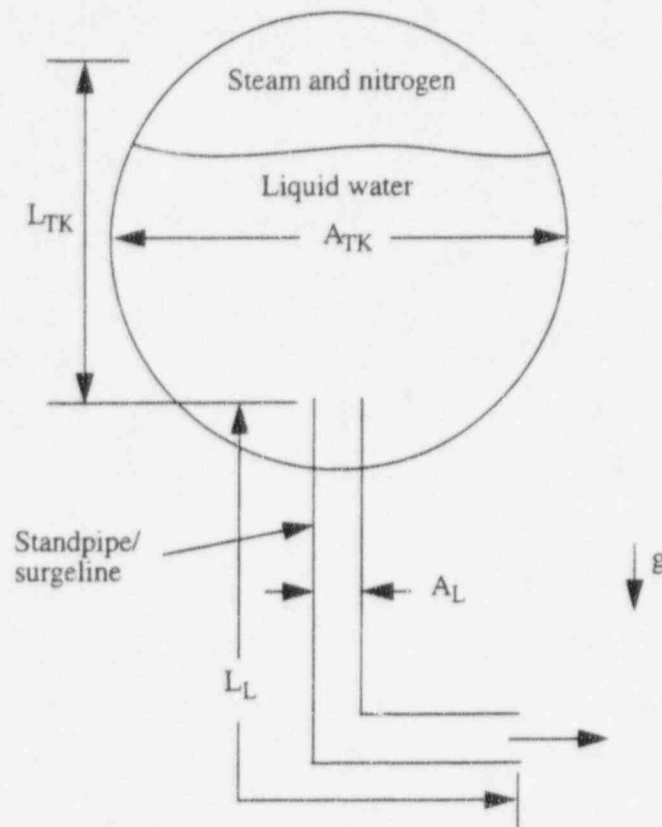
Figure 2.3-12 Schematic of a spherical accumulator.

Appendix A of this volume. The ECCMIX component calculations are evoked only if there is subcooled ECC injection and if there is any steam to be condensed in that component. Otherwise, the ECCMIX component is treated as an ordinary BRANCH component.

2.3.16 References

2.3-1.   E. Buckingham, "Model Experiments and the Forms of Empirical Equations," *Transactions of the ASME, 37,* 1915, p. 263.

2.3-2.   Aerojet Nuclear Company, *RELAP4/MOD5, A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems User's Manual Volume 1, RELAP4/MOD5 Description,* ANCR-NUREG-1335, September 1976.
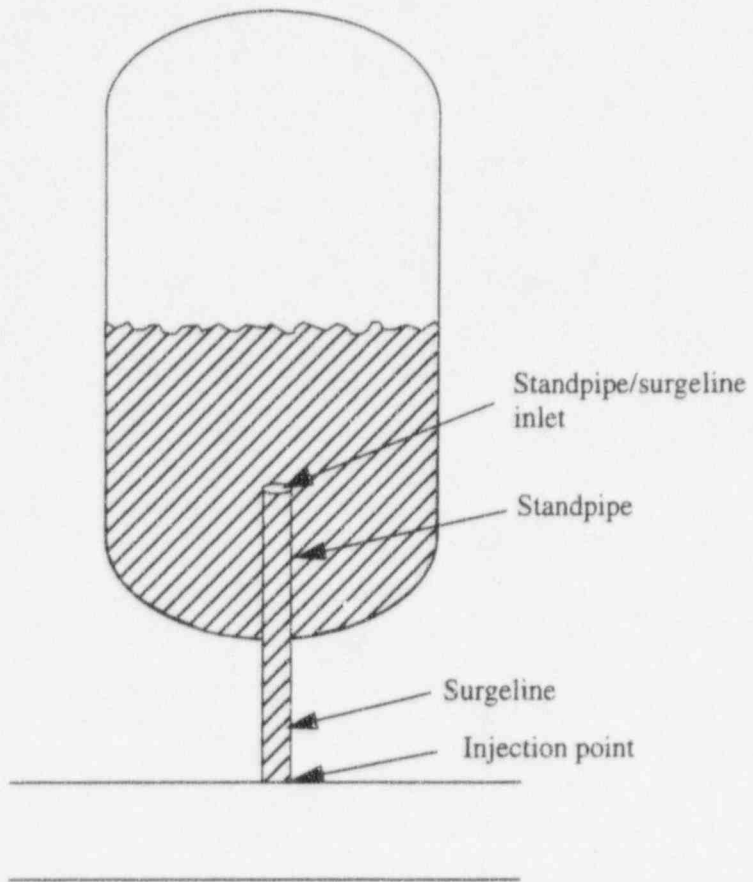
Figure 2.3-13 Schematic of an accumulator showing standpipe/surgeline inlet.
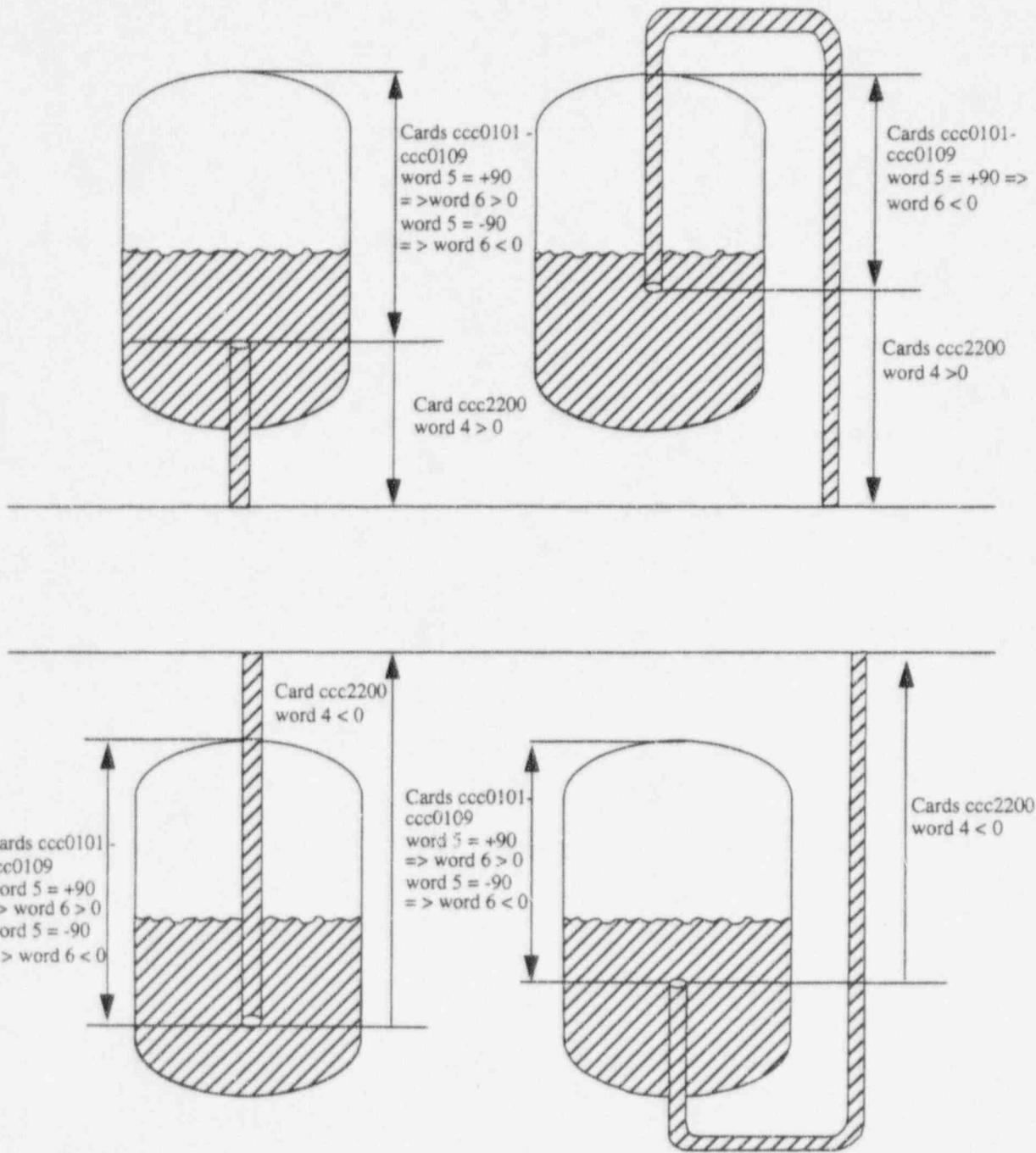
Figure 2.3-14 Possible accumulator configurations.

3 HEAT STRUCTURES

Heat structures represent the selected, solid portions of the thermal-hydrodynamic system. Being solid, there is no flow, but the total system response depends on heat transferred between the structures and the fluid, and the temperature distributions in the structures are often important requirements of the simulation. System components simulated by heat structures include fuel rods, pipe walls, core barrels, pressure vessels, and heat exchanger tubing. In simulations that do not involve core damage, heat structures can represent fuel pins, control rods, and other structural components. In core damage simulations, the SCDAP/RELAP5 code[3.0-1] should be used. Temperatures and heat transfer rates are computed from the one-dimensional form of the transient heat conduction equation.

A heat structure is identified by a number, CCCG0NN. The subfield, CCC, is the heat structure number and is analogous to the hydrodynamic component number. Since heat structures are usually closely associated with a hydrodynamic component, it is suggested that the hydrodynamic component number and the CCC portion of the attached heat structures be the same number. Since different heat structures can be attached to the same hydrodynamic component, such as fuel pins and a core barrel attached to a core volume, the G portion can be used to distinguish the different types of heat structures. The combined field, CCCG, is the heat structure-geometry number, and input data are organized by this heat structure geometry number. Up to 99 individual heat structures may be defined using the geometry described for the heat structure geometry number. The individual heat structures are numbered consecutively starting at 01; this number is the subfield, NN, of the heat structure number. The heat structure input requirements are divided into input common to all heat structures with the heat structure geometry number, Cards 1CCCG000 through 1CCCG499, and input needed to uniquely define each heat structure, 1CCCG501 through 1CCCG999.

3.0.1 Reference

3.0-1.   C. M. Allison and E. C. Johnson (eds.), *SCDAP/RELAP5/MOD3.1 Code Manuals, Volumes I, II, III,* NUREG/CR-6150, EGG-2720, October 1993.

3.1 Heat Structure Geometry

Temperature distributions in heat structures are assumed to be represented adequately by a one-dimensional form of the transient heat conduction equation in rectangular, cylindrical, or spherical coordinates. The spatial dimension of the calculation is along any one of the coordinates in rectangular geometry and is along the radial coordinate in cylindrical or spherical geometry. The one-dimensional form assumes no temperature variations along the other coordinates. **Figure 3.1-1** illustrates placement of mesh points at which temperatures are computed. The mesh point spacing is taken in the positive direction from left to right. A composition is a material with associated thermal conductivity and volumetric heat capacity. Mesh points must be placed such that they lie on the two external boundaries and at any interface between different compositions. Additional mesh points may be placed at desired intervals between the interfaces or boundaries. There is no requirement for equal mesh intervals between interfaces, and compositions may vary at any mesh point.

The heat structure input processing provides a convenient means to enter the mesh point spacing and composition placement. Each composition is assigned a three-digit, nonzero number (these numbers need not be consecutive). For each composition specified, corresponding thermal property data must be entered to define the thermal conductivity and volumetric heat capacity as functions of temperature. The temperature-dependence can be described by tabular data or by a set of functions. Defining thermal
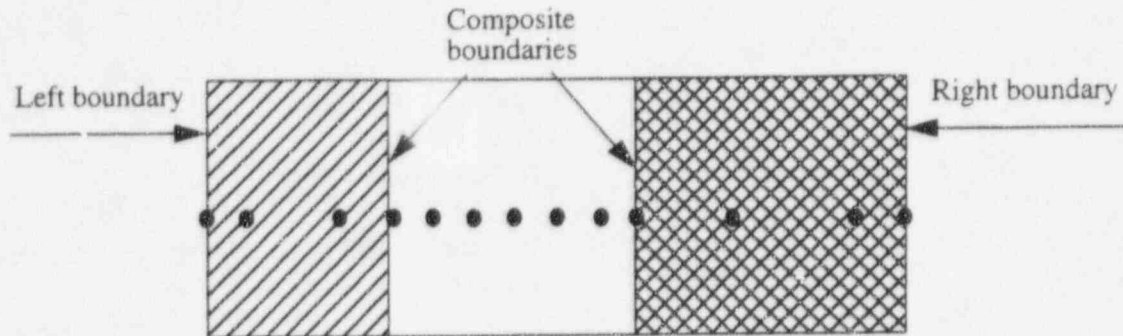
Figure 3.1-1 Mesh point layout.

property data for compositions not specified in any heat structure is not considered an error but does waste storage space. Typical thermal property data for carbon steel, stainless steel, uranium dioxide, and zirconium are stored within the program. The data were entered to demonstrate the capability of the code and as a user convenience, and should not be considered recommended values. Input editing includes the thermal properties, and a list of the built-in data can be obtained by assigning the built-in materials to unused composition numbers in any input-check run. The thermal property data must span the temperature range of the problem. Problem advancement is terminated if temperatures are computed outside the range of the data.

Heat structures can have an internal volumetric heat source that can be used to represent nuclear, gamma, or electrical heating. The source $S(x,t)$ is assumed to be a separable function of space and time.

$$S(x,t) = P_f Q(x) P(t) \tag{3.1-1}$$

where

P_f =   a scaling factor

$Q(x)$ =   a space distribution function

$P(t)$ =   power.

The space function is assumed to be constant over a mesh interval but may vary from mesh interval to mesh interval. Only the relative distribution of the space function is important, and it may be scaled arbitrarily. For example, given a heat structure with two zones, the first zone having twice the internal heat generation of the second, the space distribution factors for the two zones could be 2.0 and 1.0, 200.0 and 100.0, or any numbers with the 2-to-1 ratio. Zeros can be entered for the space distribution if there is no internal heat source.

The mesh point spacings, composition placement, and source space distribution are common to all the heat structures defined with the heat structure geometry number, and only one copy of this information is stored. If a heat structure geometry has this data in common with another heat structure, input

preparation and storage space can be saved by referencing the data in the other component. There are no ordering restrictions as to which heat structure geometry may reference another; one heat structure geometry may reference another, which in turn references a third, etc., as long as a defined heat structure is finally reached.

An initial temperature distribution may be entered for each heat structure geometry. This initial distribution is common to all heat structures defined with the same heat structure geometry number, but storage space for temperatures is assigned to each heat structure. Referencing initial temperature distributions in other heat structure geometries is allowed. Optionally, an initial temperature distribution may be entered for each heat structure.

The input temperature distribution can be used as the initial temperature distribution, or initial temperatures can be obtained from a steady-state heat conduction calculation using initial hydrodynamic conditions and zero-time power values. The input temperature distribution is used as the initial temperature guess for iterations on temperature-dependent thermal properties and boundary conditions. If a good temperature guess is not known, setting the temperature of any surface connected to a hydrodynamic volume equal to the volume temperature assists the convergence of the boundary conditions. The iteration process is not very sophisticated, and convergence to 0.01 K occasionally is not obtained. Input of a better initial distribution, especially surface temperatures, usually resolves the problem.

3.2 Heat Structure Boundary Conditions

Boundary condition input specifies the type of boundary condition, the possible attachment of a heat structure surface to a hydrodynamic volume, and the relating of the one-dimensional heat conduction solution to the actual three-dimensional nature of the structure. Each of the two surfaces of a heat structure may use any of the boundary conditions and may be connected to any hydrodynamic volume. Any number of heat structure surfaces may be connected to a hydrodynamic volume, but only one hydrodynamic volume may connect to a heat structure surface. When a heat structure is connected to a hydrodynamic volume, heat transferred from or to the heat structure is added to or subtracted from the internal energy content of the volume. For both left and right surfaces, a positive heat transfer rate represents heat flow out of the surface.

A symmetry or insulated boundary condition specifies no heat transfer at the surface, that is, a zero temperature gradient at the surface. This condition should be used in cylindrical or spherical coordinates when the radius of the left-most mesh point is zero, though the numerical techniques impose the condition regardless of the boundary condition specified. If a rectangular geometry is modeled with both surfaces attached to the same hydrodynamic volume, with the same boundary conditions, and having symmetry about the structure midpoint, storage space and computer time can be saved by describing only half of the structure. The symmetry boundary condition is used at one of the surfaces, and the heat surface area is doubled. This boundary condition can also be used when a surface is very well insulated.

When a heat structure is connected to a hydrodynamic volume, a set of heat transfer correlations can be used as boundary conditions. The correlations cover the various modes of heat transfer from a surface to fluid, and the reverse heat transfer from fluid to the surface. The heat transfer modes listed in the printed output are:

Mode 0   Convection to noncondensable-water mixture.

Mode 1   Single-phase liquid convection at supercritical pressure with the void fraction equal to zero.

Mode 2   Single-phase liquid convection at subcritical pressure.

Mode 3   Subcooled nucleate boiling.

Mode 4   Saturated nucleate boiling.

Mode 5   Subcooled transition film boiling.

Mode 6   Saturated transition film boiling.

Mode 7   Subcooled film boiling.

Mode 8   Saturated film boiling.

Mode 9   Single-phase vapor convection or supercritical pressure with the void fraction greater than zero.

Mode 10   Condensation when the void is less than one.

Mode 11   Condensation when the void equals one.

If the noncondensable quality is greater than 10^{-9}, 20 is added to the mode number. If the structure is a reflood structure, 40 is added. Thus, the mode number can vary from 0 to 71.

Generally, the hydrodynamic volume will not be a time-dependent volume. Caution should be used in specifying a time-dependent volume, since the elevation and length are set to zero, and the velocities in an isolated time-dependent volume will be zero. Note that the current version of the code does not allow an isolated standard or time-dependent volume.

Users now have the option to be more specific about the type of hydraulic cell a heat slab is next to. Most of the default heat transfer coefficients originate from data taken inside vertical pipes. Users can now specify that the fluid is flowing in a vertical or horizontal rod or tube bundle, or below a flat plate. When modelling a vertical bundle, the rod or tube pitch-to-diameter ratio should be input. This has the effect of increasing the convective part of heat transfer such that users can input the true hydraulic diameter and get reasonable predictions.

Other boundary condition options that can be selected are: setting the surface temperature to a hydrodynamic volume temperature, obtaining the surface temperature from a temperature-versus-time table, obtaining the heat flux from a time-dependent table, or obtaining heat transfer coefficients from either a time or temperature-dependent table. For the last option, the sink temperature can be a hydrodynamic volume temperature or can be obtained from a temperature-versus-time table. These options are generally used to support various efforts to analyze experimental data.

A factor must be entered to relate the one-dimensional heat conduction representation to the actual heat structure. Two options are available for entry: either a heat transfer surface area or a geometry-

dependent factor. For rectangular geometry, the factor is the surface area; there is no difference in the options. In cylindrical geometry, the heat structure is assumed to be a cylinder or a cylindrical shell, and the factor is the cylinder length. For a circular pipe where a hydrodynamic volume represents the flowing part of the pipe and a heat structure represents the pipe walls, the factor equals the hydrodynamic volume length. For a hydrodynamic volume representing a core volume with fuel pins or a heat exchanger volume with tubes, the factor is the product of the hydrodynamic volume length and the number of pins or tubes. In spherical geometry, the heat structure is assumed to be a sphere or a spherical shell, and the factor is the fraction of the sphere or shell. For a hemisphere, the factor would be 0.5. Except for solid cylinders or spheres where the inner surface area is zero, one surface area can be inferred from the other and the mesh point spacing information. Nevertheless, both surface areas must be entered and an input error will exist if the surfaces are not consistent. Consistency is defined to be such that the difference between the calculated left and right factors (or the input left or right factors) must be $\leq 10^{-5}$ times the sum of the calculated left and right factors (or the input left and right factors). This requirement is easily met with the second option of entering a geometry-dependent factor, since the factor is the same for the left and right boundary.

3.3 Heat Structure Sources

Volumetric heat sources for heat structures consist of the product of a scaling factor, a space-dependent function, and a time function. The space-dependent distribution has been discussed. The time function may be total reactor power, fission power, or fission product decay power from the reactor kinetics calculation; a control variable; or may be obtained from a table of power versus time. Input data provide for three factors. The first factor is applied to the power to indicate the internal heat source generated in the structure. This means that in steady state, heat equal to the factor times the power value would be generated in the heat structure and transferred out through its left and right surfaces. If $P(t)$ is the power in Watts and P_f is the factor, then $P_f P(t)$ is the heat generated in Watts. Within the program, this factor is divided by the integral of the space-dependent distribution to allow for the arbitrary scaling of that function. After this scaling, the internal source is in the required units of Watts/m^3. The other two factors provide for the direct heating of the fluid in the hydrodynamic volumes attached to the surfaces. Heat equal to the factor times the power value is added to the internal energy of the fluid in the hydrodynamic volume. If $P(t)$ is the power in Watts and P_f is the factor, then $P_f P(t)$ is the heat added to the fluid. The total direct heating added to a volume is the sum of the direct heating from all structures connected to the volume. Zeros are entered where no heat source or hydrodynamic volumes exist. In a reactor problem, if a power value represents the total reactor power generated and if this power is totally accounted for in the RELAP5 model, then the sum of these three factors over all the heat structures representing that power value should equal one. The summing to one is not required, and no checks are performed by the code. In many instances, the power will not only be applied to the heat structures representing the fuel but also to the heat structures representing such items as the downcomer and pressure vessel walls.

3.4 Heat Structure Changes at Restart

At restart, heat structures may be added, deleted, or replaced. Since heat structure input data are organized with respect to a heat structure geometry, all heat structures with the heat structure geometry number are affected.

Composition and general table data can also be added, deleted, or replaced at restart. A transient or steady-state problem terminated by a heat structure temperature out of range of the thermal property data can be restarted at the restart prior to the termination by replacing the thermal property data.

3.5 Heat Structure Output and Recommended Uses

Up to six sections of heat structure output are printed at major edits. The first section prints one line of heat transfer information for each surface of each heat structure. Each line provides the heat structure number; a left or right surface indicator; the connected hydrodynamic volume or, if none, zero; surface temperature; the heat transfer rate; the heat flux; the critical heat flux; the critical heat flux multiplier; the mode of heat transfer; and the heat transfer coefficient. The first line for each heat structure also includes the heat input to the structure, the net heat loss from the structure, and the volume-average temperature for the structure. The critical heat flux multiplier is the value used to multiply the value from the CHF table.

The second section prints the mesh point temperatures for each heat structure. This section can be suppressed by an input option.

The other optional sections include output on metal-water reaction, rupture, and axial location and temperature of fine mesh nodes.

For the heat structure additional boundary cards (1CCCG801 through 1CCCG899 and 1CCCG901 through 1CCCG999), it is suggested to use zero for the heat transfer hydraulic diameter (D_{he}) (i.e., the heated equivalent diameter). When zero is used, the heat transfer hydraulic diameter is set the same as the hydraulic diameter (D_h) at the boundary volume, which should be determined by the user from

$$D_h = 4 \times \frac{flow\ area}{wetted\ perimeter} \quad . \tag{3.5-1}$$

Because the heat transfer coefficient in RELAP5 is obtained from the correlations developed from tube and parallel channel tests for consistency, the same scaling method used in the hydraulic calculation should be used in the heat transfer calculation. If the heat structure does not represent the pipe walls, the default should not be taken. The heat transfer hydraulic diameter should be determined by the user from

$$D_{he} = 4 \times \frac{flow\ area}{heated\ perimeter} \quad . \tag{3.5-2}$$

4 CONTROLS

4.1 Trips

Extensive trip logic has been implemented in RELAP5. Each trip statement is a single logical statement, but because trip statements can refer to other trip statements, complex logical statements can be constructed.

There are two aspects to trip capability: (a) to determine when a trip has occurred, and (b) to determine what to do when a trip occurs. In the modular design of RELAP5, these two aspects have been separated. The term trip logic refers only to the first aspect and includes the input processing of the trip statements and the transient testing to set trip status. The action to be taken when a trip occurs is considered to be part of a particular model, and that aspect of trip coding is associated with the coding for the model. Examples of the second aspect of trips are the effects of trips on pump models and check valves.

Trip capability provides for variable and logical trips. Both types of trips are logical statements with a false or true result. A trip is false (that is off, not set, or has not occurred) if the result is false. A trip is true (that is on, is set, or has occurred) if the result is true. Trips can be latched or unlatched. A latched trip, once true (set), remains true (set) for the remainder of the problem execution, even if conditions change such that the logical statement is no longer true. An unlatched trip is tested at each time step, and the conditions can be switched at any step.

A TIMEOF quantity is associated with each trip. This quantity is always -1.0 for a trip with the value false. When a trip is switched to true, the time at which it switches replaces the value in TIMEOF. For a latched trip, this quantity once set to other than -1.0 always retains that value. An unlatched trip may have several TIMEOF values other than -1.0 during a simulation. Whenever an unlatched trip switches to false, TIMEOF becomes -1.0; when true again, the new time of switching to true is placed in TIMEOF. The TIMEOF quantities are used to effect delays in general tables, time-dependent volumes, time-dependent junctions, and pump speed tables, and can be referenced in the control system.

Two card formats are available for entering trip data. All trips for a problem must use the same format. At restart, the same format must be used for trip modifications unless all trips are deleted (Card 400) and desired trips are reentered. The default format uses Cards 401 through 599 for variable trips and Cards 601 through 799 for logical trips. The trip number is the same as the card number. Up to 199 variable trips and up to 199 logical trips can be defined. An alternate format is selected by entering Card 20600000. Trip data are entered on Cards 206TTTT0, where TTTT is the trip number. Trip numbers 1 through 1000 are variable trips, and trip numbers 1001 through 2000 are logical trips. The alternate format allows 1000 trips each for variable and logical trips.

As trips are input, the default initial value is false. Optionally, the TIMEOF quantity may be entered. If -1.0 is entered, the trip is false; if 0 or a positive number is entered, the trip is true, and the entered quantity is the time the trip turned true. This quantity must be less than or equal to the time of restart. For a new problem, 0.0 must be entered.

Several options are available on restart. If no trip data are entered, trips are defined at restart with the values at restart. It is possible to delete all trip definitions and enter completely new definitions. Individual trips can be deleted or redefined, and new trips can be inserted. Individual trips can be reset to false. At

restart, a latched trip can be reset. Detailed discussions and examples of the use of trips are presented in Section 4 of Volume V of this code manual.

4.1.1 Variable Trips

A variable trip evaluates a comparison statement relating two variables and a constant using one of the relationships, equal (EQ), not equal (NE), greater than or equal (GE), greater than (GT), less than or equal (LE), or less than (LT). The variables currently allowed are listed in the Input Requirements (Appendix A). Most variables advanced in time are allowed, and any variable that is permanently stored can be added to the list. The only restriction on the two variables is that they have the same units. Thus, a hydrodynamic volume temperature can be compared to a heat structure temperature, but a pressure cannot be compared to a velocity. The variable trip statement is

$$\text{NUM} \quad \text{VAR1} \quad \text{OP} \quad \text{VAR2} + \text{CONSTANT} \quad \begin{bmatrix} L \\ N \end{bmatrix} \quad \text{TIMEOF} \qquad (4.1\text{-}1)$$

where NUM is the card number; VAR1 and VAR2 each consist of two words that identify a variable, the first word being alphanumeric for the variable type, the second word being a number associated with the particular variable; OP is the comparison operation; CONSTANT is a signed number to be added to VAR2 before comparison; and either L or N is used to indicate a latched or unlatched trip. TIMEOF is the optional initialization value. A special form NULL,0 is used to indicate that no variable is to be used. VAR2 must be NULL,0 if VAR1 is to be compared only to the constant. Either VAR1 or VAR2 may also be TIMEOF, trip number. The trip number may refer to either a variable or a logical trip.

Three examples of variable trips are

501	P,3010000	LT	NULL,0	1.5+5	N
502	P,5010000	GT	P,3010000	2.0+5	N
510	TIME,0	GE	NULL,0	100.0	L

Trip 501: Is the pressure in volume 3010000 <1.5 bar (1 bar = 10^5 Pa)?

Trip 502: Is the pressure difference between volumes 5010000 and 3010000 > 2.0 bar?

Trip 510: Is the current advancement time $\geq$ 100 s?

Use of the equal (EQ) or not equal (NE) operator should be avoided because fractions expressed exactly in decimal notation may not be exact in binary notation. As an example, assume a time step of 0.01. After ten advancements, the time should be 0.10, but an equality test of time equal to 0.10 would probably fail. An analogous situation is dividing 1 by 3 on a three-digit decimal calculator, obtaining 0.333. Adding 1/3 three times should give 1.000, but 0.999 is obtained.

4.1.2 Logical Trips

A logical trip evaluates a logical statement relating two trip quantities with the operations AND, OR (inclusive), or XOR (exclusive). **Table 4.1-1** defines the logical operations where 0 indicates false, 1 indicates true. Each trip quantity may be the original value or its complement. (Complement means reversing the true and false values; that is, the complement of true is false.)

Table 4.1-1 Logical operations.

AND	OR	XOR
0 0 1 1	0 0 1 1	0 0 1 1
0 1 0 1	0 1 0 1	0 1 0 1
0 0 0 1	0 1 1 1	0 1 1 0

The logical trip statement is:

$$\text{NUM} \quad \pm\text{TRIP1} \quad \text{OP} \quad \pm\text{TRIP2} \quad \begin{bmatrix} L \\ N \end{bmatrix} \quad \text{TIMEOF} \tag{4.1-2}$$

where NUM is the card number, TRIP1 and TRIP2 are either variable or logical trip numbers, OP is the logical operator, L or N are for latched or unlatched trips, and TIMEOF is the optional initialization value. A positive trip number means the original trip value; a negative number means the complement value. Examples of logical trips are

601	501	OR	502	N

602	601	AND	510	N

620	-510	OR	-510	N

Trip 602 involves a previous logical trip and illustrates the construction of a complex logical statement. With the definitions given in the examples above and using parentheses to indicate the order of logical evaluations, Trip 602 is equivalent to {(Pressure 3010000 < 1.5 bar) OR [Pressure 5010000 > (Pressure 3010000 + 2.0 bar)]} AND (Time $\geq$ 100 s). Trip 620 is the complement of Trip 510, and the AND operation in place of the OR operation would also give the same result. Additional examples of trips are presented in Volume V of this code manual.

4.1.3 Trip Execution

The trip printout for a new problem at time equal to 0 s shows trips as they were entered at input. On restarted problems, the trip printout at the restart time shows input values for new and modified trips and the values from the original problem for the unmodified trips.

Trip computations are the first calculation of a time step. Thus, trip computations use the initial values for the first time step and the results of the previous advancement for all other advancements. Because trips use old values, they are not affected by repeats of the hydrodynamic and heat structure advancements.

Trips are evaluated in order of trip numbers; thus, variable trips are evaluated first, then logical trips (refer to the discussion of trips in Volume I). Results of variable trips involving the TIMEOF quantity and logical trips involving other trips can vary, depending on their position relative to other trips. As an example, consider

6XX -650 OR -650 N

which just complements Trip 650. Also, assume Trip 650 switches to true this time step, and, thus, 650 was false and 6XX was true previous to trip evaluation. At the end of trip evaluation, 6XX is true if 6XX is < 650 and false if 6XX is > 650. If Trip 650 remains true for the following time step, Trip 6XX with 6XX < 650 becomes false one time step late. Similarly, TIMEOF quantities can be one time interval off. This can be minimized by ordering TIMEOF tests last and defining logical trips before they are used in logical statements.

4.1.4 Trip Logic Example

Techniques from Boolean algebra can assist in formulating the logical trip statements. Consider a motor-operated valve that operates such that if the valve stem is stationary, it remains stationary until a specified pressure exceeds 12 bar or drops below 8 bar. The valve starts opening when the pressure exceeds 12 bar and continues opening until the pressure drops below 11 bar. The valve starts closing when the pressure drops below 8 bar and continues closing until the pressure exceeds 9 bar. The motor valve requires two trips, one to be true when the valve should be opening, the other to be true when the valve should be closing.

The following procedure is used to derive the open trip logic. A Boolean variable has one of two possible values, false (0) or true (1). Define as Boolean variables V_0 which is to be true when the valve should be opening; V_1 as the current value of the valve motion; P_1 true when the pressure is > 11 bar; and P_2 true when the pressure is > 12 bar. **Table 4.1-2** is a truth table that has been constructed by listing all possible combinations of the three input variables, V_1, P_2, and P_1, and the desired output, V_o. The number in the rightmost column is the number resulting from assuming the input values form a binary number; this is done to ensure that all combinations are listed. From the truth table, the following expression can be written,

$$V_0 = (\overline{V}_1 \otimes P_2 \otimes P_1) \oplus (V_1 \otimes \overline{P}_2 \otimes P_1) \oplus (V_1 \otimes P_2 \otimes P_1) \qquad (4.1\text{-}3)$$

where $\otimes$ indicates AND, $\oplus$ indicates OR, and the bar indicates the complement. The expression is derived by combining (with OR operations) terms from each line having a true value in the output column. Each term consists of the combining of each input variable with AND operations, using the direct variable if the value is true and the complement if the value is false. **Table 4.1-2** shows that two of the combinations are impossible. This is because if P_2 is true, P_1 must also be true; that is, if the pressure is > 12 bar, it is also > 11 bar. Because of the relationship between P_2 and P_1,

$$P_2 \otimes P_1 = P_2 \qquad P_2 \oplus P_1 = P_1 \qquad (4.1\text{-}4)$$

Using the Boolean identities from **Table 4.1-3**, the logical expression can be reduced to

$$V_0 = (\nabla_1 \otimes P_2) \oplus [\,(V_1 \otimes P_1) \otimes (\bar{P}_2 \oplus P_2)\,] = (\nabla_1 \otimes P_2) \oplus (V_1 \otimes P_1) \tag{4.1-5}$$

Table 4.1-2 Truth table examples.

Output	Input			
V_0	V_1	P_2	P_1	Num
0	0	0	0	0
0	0	0	1	1
impossible	0	1	0	2
1	0	1	1	3
0	1	0	0	4
1	1	0	1	5
impossible	1	1	0	6
1	1	1	1	7

Table 4.1-3 Boolean algebra identities.[a]

$A \otimes A = A$	$A \oplus A = A$	$A \otimes 0 = 0$	$A \oplus 0 = A$
$A \otimes \bar{A} = 0$	$A \oplus \bar{A} = 1$	$A \otimes 1 = A$	$A \oplus 1 = 1$
$A \otimes B = B \otimes A$		$A \oplus B = B \oplus A$	
$A \otimes (B \oplus C) = (A \otimes B) \oplus (A \otimes C)$			
$A \oplus (B \otimes C) = (A \oplus B) \otimes (A \oplus C)$			

   a. $\otimes$ denotes AND; $\oplus$ denotes OR; bar above quantity denotes complement.

The following trip input implements the logic. Trips 601 through 603 implement the rightmost expression in Equation (4.1-5). Trip 603 specifies the open trip in a motor valve. The trip logic is written as follows:

501	P,1010000	GT	NULL,0	11.0+5	N	(P1)
502	P,1010000	GT	NULL,0	12.0+5	N	(P2)
601	-603 AND 502		N			(FIRST TERM OF EQ)

| 602 | 6C3 AND 501 | N | (SECOND TERM OF EQ) |
| 603 | 601 OR 602 | N | (OPEN TRIP) |

The close trip logic can be written similarly.

4.2 Control Components

The control system provides the capability to evaluate simultaneous algebraic and ordinary differential equations. The capability is primarily intended to simulate control systems typically used in hydrodynamic systems, but it can also model other phenomena described by algebraic and ordinary differential equations. Another use is to define auxiliary output quantities (such as differential pressures) so they can be printed in major and minor edits and be plotted.

4.2.1 Basic Control Components

The control system capability consists of several types of control components, each type of component defining a control variable as a specific function of time-advanced quantities. The time-advanced quantities include hydrodynamic volume, junction, pump, valve, heat structure, reactor kinetics, and trip quantities, and the control variables themselves, including the control variable being defined. Permitting control variables to be input to control components allows complex expressions to be developed from components that perform simple, basic operations. The basic control components are listed below, followed by a brief review of the evaluation procedure. Familiarity with the control system numerical techniques documented in Section 6 of Volume I is recommended. In the definitions that follow, Y_i is the control variable defined by the i-th control component; A_j, R, and S are real constants input the by user; I is an integer constant input by the user; V_j is a quantity advanced in time by RELAP5 and can include Y_i; t is time; and s is the Laplace transform variable. Superscripts involving the index n denote time levels. Some components include a definition in Laplace transform notation. The name in parentheses is the name used in the input data to select the type of component.

4.2.1.1 Constant (CONSTANT).

$$Y_i = S \ . \tag{4.2-1}$$

4.2.1.2 Addition-Subtraction (SUM).

$$Y_i = S(A_0 + A_1 V_1 + A_2 V_2 + ...) \ . \tag{4.2-2}$$

4.2.1.3 Multiplication (MULT).

$$Y_i = S V_1 V_2 \ . \tag{4.2-3}$$

4.2.1.4 Division (DIV).

$$Y_i = S/V_1 \text{ or } S_1V_2/V_1 \ldots .$$ (4.2-4)

4.2.1.5 Integer Exponentiation (POWERI).

$$Y_i = SV_1^I .$$ (4.2-5)

4.2.1.6 Real Exponentiation (POWERR).

$$Y_i = SV_1^R .$$ (4.2-6)

4.2.1.7 Variable Exponentiation (POWERX).

$$Y_i = SV_1^{V_2} .$$ (4.2-7)

4.2.1.8 Table Lookup Function (FUNCTION).

$$Y_i = S F(V_1)$$ (4.2-8)

where F is a function defined by table lookup and linear interpolation.

4.2.1.9 Standard Functions (STDFNCTN).

$$Y_i = S F(V_1, V_2, V_3, \ldots)$$ (4.2-9)

where F can be $|V_1|$, $\exp(V_1)$, $\ln(V_1)$, $\sin(V_1)$, $\cos(V_1)$, $\tan(V_1)$, $\tan^{-1}(V_1)$, $(V_1)^{1/2}$, $MAX(V_1, V_2, \ldots)$, and $MIN(V_1, V_2, \ldots)$. Only MAX and MIN may have multiple arguments.

4.2.1.10 Delay (DELAY).

The delay component is defined by

$$Y_i = SV_1(t - t_d)$$ (4.2-10)

where t_d is the delay time. A user input h determines the number of time-function pairs in the table used to store past values of V_1. The maximum number of time-function pairs is h + 2. The delay table time increment is t_d/h. The delayed function is obtained by linear interpolation using the stored past history. As time is advanced, new time values are added to the table. Once the table is filled, new values replace values that are older than the delay time.

4.2.1.11 Unit Trip (TRIPUNIT).

$$Y_i = SU(\pm tr) \ .$$ (4.2-11)

4.2.1.12 Trip Delay (TRIPDLAY).

$$Y_i = ST_r(t_r) \ .$$ (4.2-12)

In the two definitions above, t_r is a trip number and, if negative, indicates that the complement of the trip is to be used; and U is 0.0 or 1.0, depending on trip t_r (or its complement if t_r is negative) being false or true. T_r is -1.0 if the trip is false, and the time the trip was last set true if the trip is true. The trip delay result is -S if the trip is false and can be values between 0 and St (t is time) if the trip is true. The trip delay can be limited to values between 0 and St (instead of -S and St) by use of the optional minimum value for the component.

4.2.1.13 Integration (INTEGRAL).

$$Y_i = S\int_0^t V_1 dt \ ; \ \text{or} \ Y_i(s) = \frac{SV_1(s)}{s} \ .$$ (4.2-13)

4.2.1.14 Differentiation (DIFFERNI or DIFFERND).

$$Y_i = S\frac{dV_1}{dt} \ ; \ \text{or} \ Y_i(s) = SsV_1(s) \ .$$ (4.2-14)

Use of DIFFERNI is *not* recommended, and, if possible, any differentiation should be avoided. See the discussion in Volume I of this manual.

4.2.1.15 Proportional-Integral (PROP-INT).

$$Y_i = S\left(A_1V_1 + A_2\int_0^t V_1 dt\right) \ \text{or} \ Y_i(s) = S\left(A_1 + \frac{A_2}{s}\right)V_1(s) \ .$$ (4.2-15)

4.2.1.16 Lag (LAG).

$$Y_i = \int_0^t \frac{\left(SV_1 - Y_i\right)}{A_1} dt \ ; \ \text{or} \ Y_i(s) = S\left(\frac{1}{1 + A_1 s}\right)V_1(s) \ .$$ (4.2-16)

4.2.1.17 Lead-Lag (LEAD-LAG).

$$Y_i = \frac{A_1 SV_1}{A_2} + \int_0^t \frac{\left(SV_1 - Y_i\right)}{A_2} dt \; ; \; \text{or} \; Y_i(s) = S\left(\frac{1 + A_1 s}{1 + A_2 s}\right) V_1(s) \; . \tag{4.2-17}$$

Each control component generates an equation, and, together, the components generate a system of nonlinear simultaneous equations. The solution of the simultaneous equations is approximated by simply evaluating the equation for each component in order of increasing component numbers and using the currently available information. Evaluation of algebraic control components uses only currently defined values, but evaluation of components involving integration and differentiation use both old (V^n) and new (V^{n+1}) values. For time-advanced variables other than control variables, both the old and new quantities are available. If a control variable is defined (by appearing on the left side of an equation) before it appears on the right side, the correct old and new variables are available. If a control variable appears on the right side before it is defined, or if it appears in the defining equation, the new and old values are off by a time step. That is, V^{m+1} uses V^m and V^m uses V^{m-1}. For good results, the user should try to define a control variable before using it. This is not always possible, as shown in the second example in Section 4.2.2.

Except for a CONSTANT component, each control component may optionally specify a minimum, a maximum, or both. After the component is evaluated by its defining equation, the value is limited by the minimum and maximum values if they are specified.

The control system input provides for an initial value and a flag to indicate that the initial value is to be computed during the initialization phase of input processing. The initialization of all other systems, such as trips, hydrodynamics, heat structures, and reactor kinetics, precedes that for control systems. If one of those systems needs an initial value of a control system variable, the input value is used. Thus, the control variable value used in servo valve initialization, initialization of time-dependent volumes and junctions if control variables are specified as search arguments, initialization of heat structures when a control variable is specified as a heat source, and computation of bias reactivity when control variables contribute to reactivity use input values. However, the input edit and first major edit after introduction of a control variable show the value after initialization.

Except for the SHAFT component, RELAP5 treats control system variables as dimensionless quantities. No unit conversion of the input scaling factors or multiplier constants is done when British input units are specified, and no unit conversion is done on output when British output units are specified. All dimensioned variables are stored within the program in SI units, and the units for variables that can be used in control components are stated in the input description. The user may assume any desired unit for each control variable. It is the user's responsibility to enter appropriate scale factors and multiplier constants to achieve the desired units and to maintain unit consistency.

Two card formats are provided for input of control system data, but only one format may be used in a problem. The default format uses Card 205CCCNN, where CCC is the control component number and NN is a card sequence number. The card format limits the number of control components to 999. The alternate format using Card 205CCCCN can be selected by entering Card 20500000. With the alternate format, only one digit is used for card sequencing, and up to 9999 control components can be used with the

four digit CCCC. Control variables are printed in major edits, can be specified for minor edits, and can be plotted.

4.2.2 Control System Examples

Two examples of control system use are given. (See Section A.14 of Appendix A for input format descriptions.) Input for the examples are shown except that symbols enclosed in parentheses are sometimes used where the actual input would need a number. Also, all examples use control component numbers beginning with one.

The first example is the computation of total flow rate in a volume from

$$W = (\alpha_f \rho_f v_f + \alpha_g \rho_g v_g)A \qquad (4.2\text{-}18)$$

where α is void fraction, ρ is density, v is velocity, A is flow area, the subscript g denotes vapor, and the subscript f denotes liquid. Two multiplication components and one addition-subtraction component are used. The time-advanced quantities, α, ρ, and v, are specified as V_1, V_2, and V_3, respectively, in the two multiplication components, one for each phase. The area A is entered as the scaling factor. An addition-subtraction component adds the results from the multiplication components with $A_0 = 0$, $A_1 = A_2 = S = 1.0$, and V_1 and V_2 are the control variables defined by the multiplication components. For the present numerical scheme, the products should be defined first. This control system is assumed to generate a quantity for plotting only, so initial values are entered as zeros and initialization is selected. For volume number 123010000, input data using the default format would be the following:

```
20500100 FFLOW  MULT  (A)  0.0  1
20500101 VOIDF,123010000  RHOF,123010000
20500102 VELF,123010000
20500200 GFLOW  MULT  (A)  0.0  1
20500201 VOIDG,123010000  RHOG,123010000
20500202 VELG,123010000
20500300 TFLOW  SUM  1.0  0.0  1
20500301 0.0  1.0,CNTRLVAR, 1  1.0, CNTRLVAR, 2
```

The second example is to solve

$$A_2 \ddot{x} + A_1 \dot{x} + A_{10} \dot{x} x + A_0 x + B \int_0^t x\,dt = C \ . \qquad (4.2\text{-}19)$$

Assignment of control variables, Y_i, are made to derivative, integral, and product terms, as listed below. In addition, each line shows equivalent expressions derived from algebraic manipulation and definition of an integral.

$$Y_1 = \dot{x}x = Y_3 Y_4 \tag{4.2-20}$$

$$Y_2 = \ddot{x} = \frac{1}{A_2}\left(C - A_1 Y_3 - A_{10}Y_1 - A_0 Y_4 - BY_5\right) \tag{4.2-21}$$

$$Y_3 = \dot{x} = \int_0^t \ddot{x}\,dt = \int_0^t Y_2\,dt \tag{4.2-22}$$

$$Y_4 = x = \int_0^t \dot{x}\,dt = \int_0^t Y_3\,dt \tag{4.2-23}$$

$$Y_5 = \int_0^t x\,dt = \int_0^t Y_4\,dt \;. \tag{4.2-24}$$

The control components are defined by the rightmost expression. Thus, the third-order, nonlinear equation is defined by a multiplication, an addition-subtraction, and three integration components. Note that the above expressions cannot be rearranged so that all control variables are defined on the left before being used as operands on the right. The above order is recommended for the current numerical scheme. Assuming zero as the initial value for all the quantities, no initialization, and that the integral should be limited between zero and one (no reason except to demonstrate the input), input cards in the alternate format would be the following.

```
20500010  XD1*X  MULT  1.0  0.0  0
20500011  CNTRLVAR,3  CNTRLVAR,4
20500020  XD2  SUM  (1.0/A₂)  0.0  0
20500021  (C)  (-A₁),  CNTRLVAR,3  (-A₁₀),  CNTRLVAR,1
20500022  (-A₀),  CNTRLVAR,4  (-B),  CNTRLVAR,5
20500030  XD1  INTEGRAL  1.0  0.0  0
20500031  CNTRLVAR,2
20500040  X  INTEGRAL  1.0  0.0  0
20500041  CNTRLVAR,3
20500050  "INT OF X"  INTEGRAL  1.0  0.0  0 3,0.0,1.0
20500051  CNTRLVAR,4
```

4.2.3 Shaft Control Component

The shaft component is a specialized control component that computationally couples motor, turbine, pump, and generator components analogously to a shaft mechanically coupling these devices. The primary purpose for the shaft component is to couple multiple turbine hydrodynamic components to represent a multi-stage turbine with steam extraction and liquid drain lines and to allow the turbines to drive a pump or generator. Computations associated with the shaft are advanced in time in the same manner as other control components. The shaft component evaluates the rotational velocity equation as

$$\sum_i I_i \frac{d\omega}{dt} = \sum_i \tau_i - \sum_i f_i \omega + \tau_c \tag{4.2-25}$$

where I_i is the moment of inertial from component i, τ_i is torque from component i, f_i is friction from component i, and τ_c is an optional torque from a control component. The summations are over the pump, generator, motor, or turbine components that might be connected to the shaft and the shaft itself. The rotational velocity is considered positive when rotating in the normal operating direction. A torque is positive when it would accelerate the shaft in the positive direction. In their normal operating modes, motors and turbines would generate positive torque, and pumps and generators would have negative torque.

Each component contains its own model, data, and storage for inertia, friction, and torque and has storage for its rotational velocity. For example, the pump model allows cubic expressions for inertial and friction. The friction expression shown in Equation (4.2-25) is used for the shaft itself and the generator component. Each component also has a disconnect trip number. If zero (no trip), the component is always connected to the shaft. If a trip is specified, the component is connected when false and disconnected when true. Any disconnected component is advanced separately and, thus, can have a different rotational velocity than the shaft. All connected components have the same rotational velocity.

The shaft equation is advanced explicitly by

$$\sum_i I_i^n \frac{(\omega^{n+1} - \omega^n)}{\Delta t} = \sum_i \tau_i^n - \sum_i f_i^n \omega^n + \tau_c \tag{4.2-26}$$

where superscripts indicate time levels. Inertias, torques, and friction are evaluated using old time information. The torque from the control system, τ_c, would be in terms of new time values for quantities other than control variables and would use new or old time values for control variables, depending on their component numbers relative to the shaft component number. Except when a generator component is involved, the shaft component calculations consist of solving Equation (4.2-26) for ω^{n+1} separately for each component disconnected from the shaft (if any) and for the shaft and the connected components as one system. For separated components, the new rotational velocity is stored with the component data, and the summations are only over terms within the component. (Each component has only one term, except the pump/motor component, which has two terms.) For the shaft and the connected components, the new rotational velocity is stored as the rotational velocity of the shaft and each connected component.

The following sections discuss the components that can be connected to a shaft.

4.2.3.1 Motor Component. No separate motor component exists in RELAP5. A motor capability is an optional feature of a pump component, and input describing the motor features are entered as part of the pump input. Specifying a pump as being connected to a shaft includes the motor if it is described in the pump input.

A motor model can also be described though the control system and its torque applied to the shaft through a control variable [τ_c in Equation (4.2-26)].

4.2.3.2 Pump Component. A pump need not be connected to a shaft, since the pump component optionally includes a model for advancing the angular velocity equation. A review of the pump when not associated with a shaft follows, so that the pump with a shaft can be described by their differences.

4.2.3.2.1 Pump Not Associated with Shaft--A pump rotational velocity table and associated trip may be entered. If a rotational velocity table is entered, its use depends on the optional trip. If the trip is not entered, the table is always used; if the trip is entered, the table is used when the trip is true and not used when the trip is false. The dependent variable of the table is rotational velocity. The search variable may be time or any other variable allowed in minor edits, including control variables. This allows a model for pump velocity to be computed by the control system. A motor is implied by the table, since a torque is needed to match the friction and hydrodynamic torque and to accelerate the pump velocity from the previous time-step value. The torque from this implied motor is labeled by MTR.TORQUE in the pump output of major edits.

When the pump speed table is not being used or is not entered, the pump rotational velocity equation is used,

$$I \frac{d\omega}{dt} = \tau_m + \tau_h \qquad (4.2-27)$$

where I is the moment of inertia of the pump, ω is the rotational velocity, τ_m is the pump motor torque, and τ_h is the sum of the frictional and hydrodynamic torques. An operational pump trip may be specified. If not specified (trip number is zero) or if specified and false, electric power is supplied to the pump motor. If the trip is true, the pump breaker has tripped. (This is the origin of the name trips for the Boolean logic in RELAP4, and the name has been continued in RELAP5.) No electric power is supplied to a tripped pump, and, thus, the motor torque, τ_m, is zero.

A pump motor is directly specified when a table of pump motor torque versus rotational velocity is entered. An induction motor can be modeled by entering a function similar to that shown in Volume I. The key features of an induction pump are the negative slope of the torque with respect to velocity near the synchronous velocity, and the fact that the torque is zero at the synchronous velocity. In steady state, the velocity is slightly less than the synchronous speed such that a positive torque balances the negative torque imposed by the pump. Pump transients such as pump startups from rest to operating speeds can be modeled. A simple ac or dc motor could also be modeled by a table that would have only positive torque values and negative slope. The motor torque table is not searched when the pump trip is true, since the motor torque is always zero when the pump is tripped. The motor torque is labeled by MTR.TORQUE in the pump output in major edits.

If a motor torque table is not entered, a pump motor is implied. When the pump trip is true, the torque from the implied pump motor is zero. If the trip is not entered or is false, a motor torque is assumed that is equal to the sum of frictional and hydrodynamic torques, resulting in no change to the rotational velocity over the time step. In this mode, the field labeled MTR.TORQUE has the same magnitude as the pump torque but has opposite sign.

The implied pump motor is normally used in cases where the pump is initially operating at normal velocity and, if tripped, is never restarted. Note that with the implied motor, if the pump trip is set true (pump tripped), the pump is free to change velocity. If the pump trip is reset to false (pump trip reset), the rotational velocity remains at the previous time step velocity; it is not reset to the initial velocity. To return to the initial velocity, the pump rotational velocity table can be used.

Optional input can prevent reverse rotation and stop the pump based on elapsed time and exceeding a maximum rotational speed in either direction.

4.2.3.2.2 Pump Associated With Shaft--Optional pump component input can be entered to associate the pump component with a shaft component. When a pump is associated with a shaft component, the rotational velocity is computed by the shaft component logic and not by the pump logic. The following describes the differences in pump logic when the pump is associated with a shaft.

The pump speed table cannot be entered. The options to prevent reverse velocity and to stop the pump based on time or velocity also cannot be used.

With one exception, the motor torque computation using either the motor torque table or the implied motor with a shaft component is identical to that without a shaft. If no components other than the pump are attached to the shaft, the moment of inertia of the pump-shaft combination is equal to that of the pump alone. Identical results can be obtained with or without using the shaft. The shaft must have a nonzero moment of inertia; to have the inertia of a pump alone equal that of the pump-shaft combination, some of the pump inertia must be apportioned to the shaft.

The one exception noted above is that with an implied pump motor (no motor torque table entered) and no pump trip entered (trip number is zero), the implied motor torque is always zero. This same situation without the shaft generates motor torque sufficient to maintain constant velocity. This option with the shaft forces the pump motor torque always to be zero. It would be used when a turbine is attached to the shaft, or the torque is computed by the control system.

The pump and shaft components offer several options; and, in some cases, the same model can be specified in more than one manner. Some general application recommendations follow. For motor-driven pumps that are either on or off (untripped or tripped), use the pump component without a shaft. For a variable-speed pump where the speed is computed by the control system, use a pump component with a *one-to-one* velocity table. The one-to-one table is a stratagem for forcing pump velocity to be equal to a control variable. Specify the search variable to be the control variable containing the velocity and enter a two-point velocity table. The independent and dependent variable for each point are the same. The first point is for the minimum possible velocity; the second point is for the highest velocity expected. The output from the table lookup and interpolation is just the input search argument. For a motor-driven, variable-speed pump where the torque is computed by the control system, use the shaft component. For a turbine-driven pump, use a shaft with the pump and turbine stages attached.

4.2.3.3 Turbine Component. A turbine component is a hydrodynamic component consisting of one volume and has additional modeling to compute torque based on volume conditions and rotational velocity. One junction may connect to the turbine volume inlet to represent the steam line. Multiple junctions may connect to the outlet to represent steam exit, extraction steam for regenerative heating of feedwater, and drain lines to remove liquid. A small turbine, such as might be used to drive a pump, is usually modeled by one turbine component. The turbine used to drive the electrical generator typically has steam extraction points and drain lines and, thus, is usually modeled by two or more turbine components. The shaft component is the only mechanism for providing the rotational velocity common to each turbine component and summing the torque developed in each turbine component. The shaft is also the only mechanism to couple the turbine to a pump or generator.

4.2.3.4 Generator Component. The generator component consists of the minimum model to load a turbine. Because of the simple model and its small input data requirements, it has been made an option of the shaft component.

The generator model allows two operating modes. One mode is having the generator connected to a large electrical grid; the generator, the shaft, and other connected components are forced to the synchronous speed. The other mode is tripped, and the rotational velocity then responds to the torques applied to the shaft. When the generator is connected to the grid, the torque necessary to maintain synchronous velocity is computed and the generator power is that torque times the synchronous velocity. If the torque is negative, the generator is in its normal mode of generating electricity. If the torque is positive, the generator is acting as a synchronous motor and power is being drawn from the grid to maintain the synchronous velocity. When the generator is tripped, the generator torque is zero.

A generator can be connected to a pump through the shaft component. This allows a synchronous motor-pump combination, which is yet another pump-motor option that can yield results identical to the pump without a shaft using an implied motor.

4.2.3.5 Pump, Generator, and Shaft Sample Problem. Table 4.2-1 shows input data for a sample problem to test pump, generator, and shaft components. The test problem consists of two identical but separate loops. Each loop has a pump and a pipe connecting the pump discharge to the pump suction. The normal wall friction model is used, and an orifice is included for additional dissipation. The loops are filled with subcooled water at zero velocity. The two pumps are driven differently. The first pump uses an implied pump motor operating at normal speed. The water is accelerated to near steady-state velocity within a few seconds. A true steady-state is not possible, since there is no provision for removing dissipation heat. The pump is then tripped, the pump coasts down, and flow velocities diminish. The second pump uses a pump motor torque table representing an induction motor with the rotational velocity initially zero. The pump accelerates to near the synchronous velocity, and, in turn, the water velocity is accelerated similarly to the first loop. The second loop is tripped similarly to the first loop.

In the second problem, the pumps are driven identically but using a different mechanism. The first pump uses a shaft and a generator acting as a motor. The second pump uses a shaft and control system to

develop the torque. A general table duplicates the motor torque table, and a unit trip applies the trip action. Identical results are obtained in the two cases.

Table 4.2-1 Input data for a sample problem to test pump, generator, and shaft.

=two loops with pumps
*

* This problem has two loops, each with friction, an orifice, and a pump. Built-in pump data are used.

* The first loop is similar to the pump problem. The second loop uses pump motor torque data to

* represent an induction motor. The pump is initially at rest. The pump accelerates to near synchronous

* speed, and fluid is accelerated. Reaching near steady state, pump trip and decreasing pump speed and

* fluid velocity are similar to pump. The second problem is identical to the first except that shaft and

* generator (acting as a motor) components are used.

*

100 new transnt

102 british british

104 none

201   1.0 1.0-6 0.010 15001 1 20 1000

202 40.0 1.0-6 0.200 15001 1 20 1000

301 p 1010000

302 p 1040000

303 p 1060000

304 p 1070000

305 p 1100000

306 p 1150000

307 p 1180000

308 p 2010000

309 velfj 1010000

310 velfj 1070000

311 velfj 1180000

312 velfj 2010000

313 velfj 2020000

314 pmpvel 002

315 pmphead 002

316 pmptrq 002

351 p 3010000

352 p 3040000

353 p 3060000

354 p 3070000

Table 4.2-1 Input data for a sample problem to test pump, generator, and shaft. (Continued)

```
355 p 3110000
356 p 3150000
357 p 3180000
358 p 4010000
359 velfj 3010000
360 velfj 3070000
361 velfj 3180000
362 veltj 4010000
363 velfj 4020000
364 pmpvel 004
365 pmphead 004
366 pmptrq 004
501 time 2 q null 0 20.2 1
10000 loop pipe
10001 19
10101 0.0376, 19
10201 0.0376, 6 0.01, 7 0.0376, 18
10301 2.0, 19
10601 0.0, 4 90.0, 9 0.0, 14 -90.0, 19
10801 0, 0, 19
11001 0, 19
11101 0, 6 100, 7 0, 18
11201 3, 2244.780, 540.0, 0, 0, 0, 19
11301 0, 0, 0, 18
20000 loop pump
20101 0.0468 0 0.1660 0 0 0 0
20108 1010000 .0376 0 0 0
20109 1000000 .0376 0 0 0
20200 3 2264.78 540.0 0
20201 0 0 0 0
20202 0 0 0 0
20301 -1 0 -2 -1 -1 501 -1
20302 3560.0 0.66573 180.0 192.0 34.8 38.3 62.3 0 6.7 0 0 0
23000 0
23001 0.0, 0.0 0.1 0.0 0.15, 0.05 0.24, 0.8 0.3, 0.96 0.4, 0.98
```

Table 4.2-1 Input data for a sample problem to test pump, generator, and shaft. (Continued)

```
23002 0.6 0.97 0.8, 0.9 0.9 0.8 0.96, 0.5 1.0, 1.0
23100 0
23101 0.0, -.17 0.0001, -.017 0.0006, 0.0 0.1, 0 0 0.15, 0.05
23102 0.24, 0.56 0.8, 0.56 0.96, 0.45 1.0, 0.0
30000 loop2 pipe
30001 19
30101 0.0376, 19
30201 0.0376, 6 0.01, 7 0.0376, 18
30301 2.0, 19
30601 0.0, 4 90.0, 9 0.0, 14 -90.0, 19
30801 0, 0, 19
31001 0, 19
31101 0, 6 100, 7 0, 18
31202 3, 2265.780, 540.0, 0, 0, 0, 19
31301 0, 0, 0, 18
40000 loop2 pump
40101 0.0468 0 0.1600 0 0 0 0
40108 3010000 .0376 0 0 0
40109 3000000 .0376 0 0 0
40200 3 2244.78 540.0 0
40201 0 0 0 0
40202 0 0 0 0
40301 2 2 2 0 -1 501 1
40302 3560.0 0.0 180.0 192.0 34.8 38.3 62.3 35.0 6.7 0 0 0
46001 1440., 1.00 2160., 1.10 2880., 1.50
46002 3526., 2.80 3672., -2.70 4320., -1.90
46003 5040., -1.20 5760., -1.05 6480., -1.00
46004 7200., -0.98
.end of first case
=two loops with pumps using shaft component
20301 -1 0 -2 -1 -1 0 1
20302 3560.0 0.66573 180.0 192.0 34.8 37.0 62.3 0 6.7 0 0 0
20309 20
40301 2 2 2 -1 -1 0 0
40302 3560.0 0.0 180.0 192.0 34.8 38.0 62.3 0 6.7 0 0 0
```

Table 4.2-1 Input data for a sample problem to test pump, generator, and shaft. (Continued)

```
40309 10
46001
46002
46003
46004
20500100 mtr.trq function 47.4536282 0 0
20500101 cntrlvar, 10 10
20500200 trip tripunit 1.0 1.0 0
20500201 -501
20500300 torque mult 0.7375621495 0 0
20500401 cntrlvar, 3
20501000 shaft4 shaft 1.0 0.0 0
20501001 3 0.3 0.0 pump, 4
20201000 reac-t 0 0.10471975512 1.0
20201001 1440.0, 1.00 2160.0, 1.10 2880.0, 1.50
20201002 3528.0, 2.80 3672.0, -2.70 4120.0, -1.90
20201003 5040.0, -1.20 5760.0, -1.05 6480.0, -1.00
20201004 7200.0, -.098
20502200 shaft2 shaft 1.0 2370.0 1
20502001 0 1.0 0.0 pump, 2 generatr, 20
20502006 1800.0 2370.0 0.3 0.0 501 0
.end of job
```

5 REACTOR KINETICS

The reactor kinetics capability can be used to compute the power behavior in a nuclear reactor. The power is computed using the space-independent or point kinetics approximation, which assumes that power can be separated into the product of space and time functions. This approximation is adequate for those cases in which the space distribution remains nearly constant.

Reactor kinetics data may be entered for new or restart problems. In restart problems, reactor kinetics data completely replaces previous reactor kinetics data if present; thus, all needed data must be entered even if they duplicate existing data.

5.1 Power Computation Options

Data for the six generally accepted delayed neutron groups are built into the code. Optionally, yield ratios and decay constants for up to 50 groups may be entered.

The total reactor power is the sum of immediate fission power and the power from decay of fission fragments. The immediate power is that released at the time of fission and includes power from fission fragment kinetic energy, prompt gammas, and neutron moderation. Decay power is generated as the fission products undergo radioactive decay. The user can specify one of three options for computing reactor power: fission power only; fission and fission product decay product power; or fission, fission product decay, and actinide decay power. Actinide decay power is the power resulting from production of ^{239}U by neutron absorption in ^{238}U and subsequent two-stage beta decay to ^{239}Pu.

Two sets of fission product decay data are built into the code. The default set is the eleven-group ANS standard proposed in 1973.[5.1-1] The other set of data is from the 1979 ANS Standard for Decay Heat Power in Light Water Reactors.[5.1-2] The 1979 standard specifies data for three isotopes, ^{235}U, ^{238}U, and ^{239}Pu, using 23 groups for each isotope. To use the three-isotope data, the user must furnish the fraction of power produced by each isotope. An option exists to use only the ^{235}U isotope data from the 1979 standard. Actinide data are from the 1979 standard. An input fraction is applied to both the fission product and actinide yield data. For fission products, the factor is usually 1.0 for best-estimate calculations; and 1.2 has been used for conservative calculations with the 1973 data. For actinide data, the factor is the ratio of ^{238}U atoms consumed per ^{235}U atoms fissioned; but additional conservative factors can be applied. Fission product and actinide data can also be entered by the user. Earlier versions of the code did not include the G factor, which is part of the 1979 standard. This factor can now be optionally included and should be for long-term transients.

The built-in data for delayed neutrons, fission products, and actinides are recommended and are listed in the reactor kinetic input edit when used. Use of the fission power plus fission product decay power is recommended, as is actinide decay power if an appreciable amount of ^{238}U is present. The new standard is recommended because it is an approved standard and the variance between 1979 data and experimental data is much less than for the 1973 data. The three-isotope option is recommended unless the power fractions for each isotope are not available.

The reactor kinetics output lists total reactor power, fission power, decay power, reactivity, and reciprocal period. Either the total power, fission power, or decay power can be specified as the time-varying part of the heat source in heat structures.

5.1.1 References

5.1-1. American Nuclear Society Proposed Standard, ANS 5.1, *Decay Energy Release Rates Following Shutdown of Uranium-Fueled Thermal Reactors*, October 1971, revised October 1973.

5.1-2. *American National Standard for Decay Heat Power in Light Water Reactors*, ANSI/ANS-5.1-1979.

5.2 Reactivity Feedback Options

Five reactivity feedback options are provided. One assumes separability of feedback effects; the others use three- or four-dimensional table lookup and linear interpolation. The defining equations are given in Volume 1 of this manual. Note that the sign of the feedback terms is positive. Negative quantities must be entered where negative feedback is desired. All options include an input reactivity, r_o, a bias reactivity, r_B, and sums over scram curves and control variables.

The quantity r_o is an input quantity and is the reactivity corresponding to the assumed steady state reactor power at time equal to zero. This quantity must be ≤ 0. A nonzero quantity indicates that a neutron source is present. For most applications, $r_o = 0$ is acceptable.

The bias reactivity, r_B, is calculated during input processing such that $r(0) = r_o$. The purpose of the bias reactivity is to ensure that the initial reactivity is still equal to the input reactivity after including the feedback effects. Without this quantity, the user would have to manually adjust a scram curve or control variable to obtain the input value of initial reactivity or have a step input of reactivity as the transient starts. The bias reactivity, r_B, is printed out during input processing.

The scram curves are obtained from general tables defining reactivity as a function of time. Each table can have an associated trip number. If the trip number is not entered or zero, time is the search argument. If the trip number is nonzero, the search argument is -1.0 if the trip is false. If the trip is true, the search argument is time minus the time at which the trip last turned true. These tables can be used to describe reactivity changes from rod motion.

Control variables can be defined to represent power control systems or to implement alternate feedback models. However, reactor kinetics advancement precedes control system evaluation; thus, feedback from control variables is delayed one time step.

The separable option uses two tables, one defining reactivity as a function of volume density and the other defining reactivity as a function of volumetric average fuel temperatures. The tables allow nonlinear feedback owing to moderator density and fuel temperature changes. A constant temperature coefficient allows for linear moderator temperature feedback, and an additional linear fuel temperature feedback is provided. The separable option is so named because of the assumption that each feedback mechanism is independent and the total reactivity is the sum of the individual effects. The separable option does not directly allow boron feedback, but boron effects can be modeled through the control system.

Data for the separable option can be obtained from reactor operating data, reactor physics calculations, or a combination of the two. The required moderator temperature coefficient is not the usually quoted quantity. Assume the moderator feedback is a function of density and temperature, $r(\rho, T)$,

and density is a function of temperature, $\rho(T)$. The usual temperature coefficient is the total derivative, $\dfrac{dr}{dT}$. The input requires partial derivatives. The moderator density feedback is $\left.\dfrac{\partial r}{\partial \rho}\right|_T$; the temperature coefficient is $\left.\dfrac{\partial r}{\partial T}\right|_\rho$.

The three- and four-dimensional table lookup and interpolation option uses three or four quantities as the independent variables. The four-dimensional table includes the effects of boron; the three-dimensional table does not include boron effects. Two suboptions allow a choice of independent variables. One choice is reactivity as a function of moderator density void weighted moderator temperature, volumetric average fuel temperature, and boron density. This option uses the same variables as the separable option plus boron effects if four variables are used. The other option uses void fraction, liquid moderator temperature, volume averaged fuel temperature, and boron concentration as independent variables. Feedback effects in light water power reactors are usually expressed in terms of these quantities. The multidimensional interpolation allows nonlinearities and interaction of feedback effects but burdens the user with obtaining a larger amount of reactivity data. As with the separable option, required data can be obtained from plant data or reactor physics calculations. As discussed in Volume 1, a data point must be entered for each combination of coordinate values. Accurate reactivity data need only be entered for points near zero reactivity. Once the shutdown reactivity decreases below -2.0 dollars, little change in fission energy release occurs with further decreases in reactivity. Thus, in sections of the multidimensional table where reactivity is known to be very much shut down, data can be determined from extrapolation and need not be accurate. Similarly, some parts of the table may contain large values of reactivity. The user does not expect the transient to use this portion of the table, but the code input requires all tabular points to be entered. Again, accurate data need not be entered; if the transient should enter this area, the large power rises will be evident and the user can investigate the modeling difficulty. In some instances, a coordinate value is introduced to ensure accuracy in one section of a table, but the detail is not needed in other parts of the table. Where the detail is not needed, data could be obtained at a more coarse mesh, and the user can interpolate to meet the input requirements of the code.

Usually, several hydrodynamic volumes are used to represent the coolant channels in a reactor core and several heat structures represent the fuel pins. Weighting factors are input to specify the reactivity contribution of each hydrodynamic volume and heat structure to the total. Reactivity feedback is usually defined such that the weights for volumes and heat structures each should sum to one. The code does not check that the weights sum to one.

The use of the weights is different between the separable and table options. In the separable option, a reactivity effect is first computed for a volume or for a heat structure. Then its contribution to the total reactivity is obtained by multiplying the effect by the weighting factor. This order is reversed for the table option.

Weighted-averaged independent variables for table lookup and interpolation are obtained by using volume or heat structure values and the weighting factors. Table evaluation for total feedback uses the averaged values. It is possible to define a table equivalent to the separable data. However, slightly different transient results would be obtained using the equivalent data owing to the difference in application of the weighting factors.

In steady-state problems, the user usually wishes to specify reactor power. If reactivity feedback data are entered, reactor power will vary as the reactor system moves toward a steady-state condition. To

prevent this, a control system could be defined to adjust reactivity to maintain constant power. A simpler alternative is to omit reactivity feedback in steady state, and the reactor power will remain constant at the input value. At the restart to start the transient, the original reactor kinetics data plus feedback data can be entered.

6 GENERAL TABLES AND COMPONENT TABLES

General tables provide data for several models, including heat structures, valves, reactor kinetics, and control systems. The general table input provides for the following tables: power versus time, temperature versus time, heat flux versus time, heat transfer coefficient versus time, heat transfer coefficient versus temperature, reactivity versus time, and normalized valve area versus normalized stem position. An input item identifies each table so that proper unit conversion and input checking can be done. For example, specifying a temperature table when a power table is required is detected as an error. Because these tables are often experimental data, or scaling may be needed for parametric studies, the input provides for conversion and/or scaling factors for these tables. Input editing of these tables includes both the original and scaled data. General tables can be entered, deleted, or replaced at restart. The tables are linearly interpolated between table values, and the end-point values are used when the search arguments are beyond the range of entered data.

Figure 6.0-1 shows input data for a power-type general table, and the graph shows its time history. The first entry of the first line indicates that it is a power versus time table, the second entry, indicates that the trip number for the table is trip number 605, the third entry indicates that the time values are to be used as entered, i.e., multiplied by 1.0, the last entry indicates that the power values that are input should be scaled by 50.0 + 6, i.e., 50 MW. The search logic is determined by the trip input. A nonzero trip number specifies the following logic: when the trip is false, the table is interpolated using a search argument of - 1.0, resulting in a power of zero up to the trip time t_r; when the trip is true, the table is interpolated with search argument $t-t_r$, effectively shifting the origin of the table to time t_r. This is analytically equivalent to the application of a unit step function and delay. If a zero trip number is specified, current time is always the search argument. The remaining input defines the time history. The data are input as x-y pairs of time and power. The tabular data show two data points having the same time value, zero, but having different power values. This allows entry of step changes, as shown on the graph. The graph also illustrates that when search arguments are beyond the range of entered data, endpoint values are used rather than extrapolation.

Entry of a nonzero trip number in general tables is valid only when time is the independent variable.

Time-dependent volumes, time-dependent junctions, and pump angular velocity tables are examples of component tables. These tables provide for entry of a trip number and in the default mode use time as the independent variable. In this mode, the use of the trip time is identical to that described for time-dependent general tables. But the time-dependent volumes, junctions, and pump velocity tables also permit any time-advanced quantity to be specified as the independent variable. If a trip is specified and is false, the table is interpolated with -1.0×10^{75} as the search argument. If no trip is specified, or the trip is true, the specified time-advanced quantity is the search argument.

A typical use of tables using a quantity other than time as the independent variable is the modeling of a high- or low-pressure reactor safety injection system. Rather than model the valve, pump, and motor for the system, a time-dependent junction is used to approximate the injection system. The pressure at the injection point is specified as the independent variable, and flow rate is the dependent variable. The table would define zero flow for the first zero pressure value, then appropriate flow rates for the second zero pressure and following pressure values. The last pressure value would be the cutoff pressure of the pump and have a corresponding zero flow. In normal reactor operation, the trip would be false, and the table interpolation would return zero flow. When the safety system is actuated, flow may still be zero if the reactor pressure exceeds the cutoff pressure. As the reactor pressure drops, flow would start; and the table could indicate increasing flow with decreasing pressure, possibly up to a maximum flow rate. The source

20201000	Power	605	1.0	50.0+6
20201001	-1.0, 0.0	0.0, 0.0		
20201002	0.0, 0.5	1.0, 1.0		
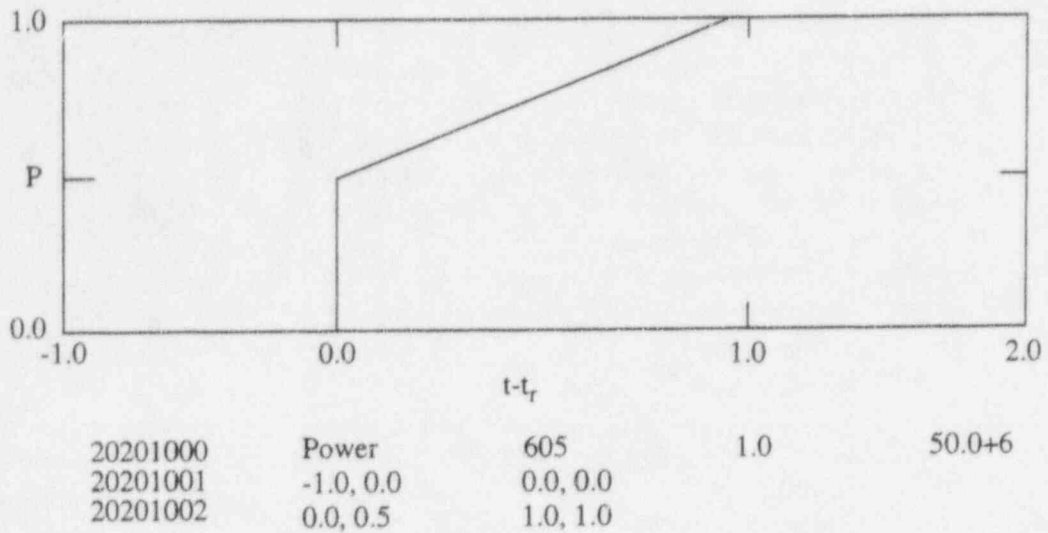
Figure 6.0-1 Input data for a power-type general table and graph.

of injection water is usually a time-dependent volume. This technique would not add pump work to the injected fluid. Some approximation of the pump work could be made by also specifying the injection point pressure as the independent variable of the time-dependent volume and entering appropriate thermodynamic conditions as dependent variables.

7 INITIAL AND BOUNDARY CONDITIONS

All transient analysis problems require initial conditions from which to begin the transient simulation. Usually, the initial conditions will correspond to a steady state, with the transient initiated from a change of some boundary condition. In general, the initial conditions required are a determinate set of the dependent variables of the problem. The hydrodynamic model requires four thermodynamic state variables in each volume and the velocities at each junction. Heat structures require the initial temperature at each node, control systems require the initial value of all control variables, and kinetics calculations require initial power and reactivity. All of these parameters are established through the code input and initialization process for a new problem. For a restart problem, the values are established from the previous calculation. For restart with renodalization or problem changes, the initialization will result from a combination of the two processes, and care must be exercised to ensure that the input values are compatible with those from the restart, especially if an initial steady state is to be simulated.

Boundary conditions may be required for hydrodynamic models, heat structures, or control components if these parameters are governed by conditions outside of the problem boundaries. Examples of these could be mass and energy inflows or an externally specified control parameter.

Obtaining a desired simulation is very dependent upon proper specification of initial and boundary conditions. The purpose of this section is to summarize recommended approaches for these specifications.

7.1 Initial Conditions

All variables of the problem that are established by integration require initial values in order to begin a calculation or simulation. Problem variables related to the integration variables through quasi-steady relationships do not require initial conditions, since they can be established from the initial values required for the integration variables. An example is the pump head, which is related to the pump flow and speed, both of which are obtained by integration. Thus, the initial conditions for pump flow and speed must be specified.

7.1.1 Input Initial Values

Input initial values are required in order to begin a new problem regardless of whether a steady-state or a transient run is specified. These initial values are supplied by the user through input for each component. (Heat structures are an exception and can be initialized either by input or by steady-state initialization using the heat structure boundary conditions at time zero.)

The hydrodynamic volume components have seven options for specifying the volume initial conditions (see Section 2.3.1 for more detail). Four options are provided for pure steam/water systems, and the remaining three options allow noncondensables. Boron concentration can be specified with all seven options by adding 10 to the control word, Word W1(I). Regardless of what option is used, the initialization computes initial values for all primary and secondary dependent variables. The primary variables are pressure, void fraction, two-phasic energies, noncondensable quality, and boron concentration. Secondary variables are quality, density, temperature, and so on.

The most common specification will be an equilibrium condition for the steam/water system. The options 1-3 [control word W1(I) on Card CCC0200, in Appendix A] are equilibrium specifications using temperature and quality, pressure and quality, and pressure and temperature. The first two conditions are valid combinations for single- (at the saturation point) or two-phase conditions. The third combination is

valid only for single-phase nonsaturated conditions. When air is specified, it is best to use conditions of humid or saturated air at the initial pressure and temperature of the system. The specification of dry air can cause numerical difficulties when mixing with water or water vapor occurs. If air is the only system component and mixing with water or water vapor does not occur, the specification of pure air will cause no problems.

Heat structure initial temperatures must be input. Depending upon the initialization option selected, these temperatures are either used as the initial temperatures or as the initial guess for an iterative solution for a steady-state temperature profile. The iteration solution will attempt to satisfy the boundary conditions and heat sources/sinks that have been specified through input. Some care is needed, since an indeterminate solution can result from specification of some boundary conditions (e.g., a two-sided conductor with specified heat fluxes). If the initial temperature of a heat structure is unknown, it is generally safer to use the steady-state option and supply as a first guess a uniform temperature distribution equal to the temperature of a hydrodynamic volume to which it is connected. In the case of a two-sided structure, either side may be selected. The steady-state solution algorithm will rapidly converge to a steady-state temperature distribution.

Initial conditions must be specified for each control component used, even if the option to compute the initial condition is selected. As stated above, only the integral functions should require initial conditions. However, since control components are initialized using a sequential single-pass solution scheme and since some control variables may be specified as arguments for other control variables, it is possible for some to be initially undefined. Hence, the initial value for all control variables must be specified. Also, the code does not check whether initial values are needed nor whether they are reasonable; thus, the user should always supply an accurate initial value.

The reactor kinetics model requires specification of an initial power and reactivity. Previous power history data may also be entered.

7.1.2 Steady-State Initialization

RELAP5 contains an option to perform steady-state calculations. This option uses the transient hydrodynamic, kinetics, and control system algorithms and a modified heat structure thermal transient algorithm to converge to a steady state. The differences between the steady-state and transient options are that a lowered heat structure thermal inertia is used to accelerate the response of the thermal transient, and a testing scheme is used to check if steady state has been achieved. When steady state is achieved, the run is terminated, thus saving computer time. The results of the steady-state calculation are saved so that a restart can be made in the transient mode. In this case, all initial conditions for the transient are supplied from the steady-state calculation. It is also possible to restart in either the transient or steady-state mode from either a prior transient or steady-state run.

The user should be aware that use of the steady-state option provides a more optimum solution than simply running the problem as a transient and monitoring the results. This occurs because the code monitors results for the entire system, including the effects of calculational precision. Also, thermal inertia for the heat structures is generally quite large, so that for the transient option, the heat structure temperature distribution will not achieve steady state in the time that a hydrodynamic steady state can be achieved. Hence, use of the steady-state option will provide the user with a precise steady state, including a precise heat structure steady state.

It is still necessary to supply input specifying initial conditions for a steady-state run. However, the accuracy of the input data is less critical, since they are simply used as a starting point for convergence to a steady state. The values used should be reasonable, however, since the closer they are to the actual steady state, the shorter the calculation will be to achieve steady state.

Once an initial steady state is calculated, the user can save the RESTART/PLOT file and perform subsequent new steady-state runs using the previous steady-state results. This results in reduced calculational times for the subsequent runs and at the same time maintaining a complete set of steady-state initializations.

The steady-state initialization calculation is an open-loop calculation unless control functions are defined such that active control systems are used to obtain desired operating points. Active control is achieved using controlled variables such as pressure, flow rate, etc. The user must design and implement such control functions, and only a limited number of system parameters can be controlled independently. In this regard, the model behaves exactly as a real system, and, if a resistance to flow must be varied to achieve the desired steady state, then a valve must be used with a controller. The use of a controller to achieve a desired steady state can save considerable time compared to the process of open-loop control, in which a resistance or other parameter is varied from run to run until the desired steady state is achieved.

In providing control systems and trips to drive the solution to steady state, two rules of thumb must be considered, both of which revolve around the basic purpose of the steady-state run. The first rule is that if the run is to simulate the real behavior of a plant in achieving steady state, then control systems and trips simulating real plant controls or control procedures should be designed. However, the second rule of thumb is that if the run is simply to achieve a steady-state initialization of the system model, then controls not representative of the actual system may be designed that will drive the solution to steady state in the fastest manner possible. The only restriction is that stability of the calculations must be maintained.

There is also an option, Word 4, digits tt, on the time step control cards, 201 through 299, which allows the user to select part of the steady-state calculation to be used. The thermal inertia of the heat structures is lowered, but the testing scheme to check the derivatives of variables to determine a steady state is not used. This gives a user the advantage of using the artificially accelerated thermal steady state in the heat structures while allowing use of either a set end time or else the user's own choice for a variable to monitor for a steady-state through a simple control system.

7.2 Boundary Conditions

Boundary conditions are required in most transient calculations. In reality, boundary conditions take the form of the containment atmosphere, operator actions, or mass and energy sources that are not explicitly modeled as part of the system. Such boundary conditions are simulated by means of time-dependent volumes for specified sources or sinks of mass, time-dependent junctions for specified flows, or specified heat structure surface heat fluxes and energy sources. Specified variation of parameters in control components to simulate an operator action may also be used. The time variation of the boundary conditions is specified by input tables that can also be varied dynamically by using trips.

7.2.1 Mass Sources or Sinks

Hydrodynamic mass sources or sinks are simulated by the use of a time-dependent volume with a time-dependent junction. The thermodynamic state of the fluid is specified as a function of time by input or by a control variable. The thermodynamic state is needed for inflow because the densities and energies

are needed in the donored flux terms in the density and energy equations. The time-dependent junction flows or velocities are also specified. This approach can be used to model either an inflow or an outflow condition; however, care is required in modeling outflows. A time-dependent junction is analogous to a positive displacement pump in that the flow is independent of the system pressure. In the case of outflow, it is possible to specify a greater outflow than inflow to a volume or even outflow that will exhaust the volume. In this case, a numerical failure will result when the equivalent of a negative density is calculated. For this reason, modeling outflows using a time-dependent junction is not recommended.

7.2.2 Pressure Boundary

A pressure boundary condition is modeled using a time-dependent volume in which the pressure and thermodynamic state variables are specified as a function of time through input by tables or by a control variable. The time-dependent volume is connected to the system through a normal junction; thus, inflow or outflow will result, depending upon the pressure difference. Several precautions are needed when specifying a pressure boundary, since flow invariably accompanies such a boundary. First, the time-dependent volume conditions must represent the state of fluid that would normally enter the system for an inflow condition. Second, there are implied boundary conditions for a time-dependent volume in addition to the specified values. Third, only the static energy of an incoming flow is fixed by a time-dependent volume. The total energy will include the inflow kinetic energy that increases with increasing velocity.

The additional boundary conditions represented by a time-dependent volume concern the virtual viscosity terms inherent in the numerical formulation of the momentum equation (see Section 3 in Volume 1 for a detailed discussion). For this purpose, the derivative of velocity across the time-dependent volume is zero, and the length and volume are assumed to be zero (regardless of the specified input). The fact that the energy of inflow increases with velocity can lead to a nonphysical result, since the stagnation pressure also increases, and for a fixed system pressure, an unmitigated increase in inflow velocity can result. This effect can be avoided by making the cross-sectional area of the time-dependent volume large compared to the junction so that the volume velocity of the time-dependent volume is small, and thus the total energy of the inflow is constant. When a large area ratio exists between the time-dependent volume and the junction connecting it to the system, a reservoir or plenum is simulated. As a general rule, all pressure boundary conditions having either inflow or outflow should be modeled as plenums for stability and realism. In particular, when an outflow is choked, the critical flow model more closely approximates the conditions at a large expansion (i.e., little or no diffusion occurs). Thus, this assumption is consistent with the choked flow model and is, therefore, recommended.

8 PROBLEM CONTROL

8.1 Problem Types and Options

RELAP5 provides for four problem types--NEW, RESTART, PLOT, and STRIP. The first two are concerned with simulating hydrodynamic systems; NEW starts a simulation from input data describing the entire system; RESTART restarts a previously executed NEW or RESTART problem. PLOT and STRIP are output-type runs using the restart-plot file written by NEW or RESTART problems. NEW and RESTART problems require an additional option to be selected, STDY-ST or TRANSNT.

A RESTART problem may restart from any restart record. A note indicating the restart number and record number is printed at the end of the major edit whenever a restart record is written. The restart number is equal to the number of attempted advancements and is the number to be used on Card 103 to identify the desired restart record. The record number is simply a count of the number of restart records written, with the restart record at time equal zero having record number zero. Quantities written in the restart-plot records by default are noted in the input data description. User-specified input can add additional quantities to the restart-plot records.

PLOT and STRIP are output-type runs. PLOT generates plots from data stored on the restart-plot file. The PLOT capability is not now operational but is still documented. The PLOT capability may be dropped from the code since NPA[8.1-1] and XMGR5,[8.1-2] an INEL extension of XMGR,[8.1-3] allow very general and high quality plots of RELAP5 results and associated information. STRIP writes selected information from a restart-plot file onto a new file. The new file consists of records containing time and the user-selected variables in the order selected by the user. Data to be plotted or stripped are limited to that written in the plot records on the restart-plot file.

8.1.1 References

8.1-1   D. M. Snider, K. L. Wagner, W. H. Grush, and K. R. Jones, *Nuclear Plant Analyzer, Volumes 1-4*, NUREG/CR-6291, INEL-94/0123, December 1994.

8.1-2.   K. R. Jones, XMGR5 Extensions (Draft), INEL document, 1995.

8.1-3.   P. J. Turner, *ACE/gr User's Manual*, SDS3, 91-3, 1991-1993, Beaverton, OR.

8.2 Time Step Control

Input data for time step control consist of one or more cards containing a time limit, minimum time step, requested (maximum) time step, control option, minor edit plot/frequency, major edit frequency, and restart frequency. The time limit must increase with increasing card numbers. The information on the first card is used until the problem time exceeds the card limit; then, the next card is used, and so on. In restart problems, these cards may remain or may be totally replaced. Cards are skipped if necessary until the problem time at restart is properly positioned with regard to the time limit values.

The control option is a packed five digit (ssdtt) word containing a major edit select option (ss), a debug output option (d), and the time step control (tt). The major edit select option (ss) allows sections of major edits for the hydrodynamic volumes and junctions, heat structures, and statistics to be skipped. The debug output option (d) forces any combination of plot, minor edits, or major edit output to be written at

each successful advancement rather than at just the completion of advancement over a requested time step. The time step control option (tt) allows the user to change the time step control logic. All options can be changed with each time step control card.

Specifically, digit tt allows the user to select several time step control options. This time step control option is represented by a number between 0 and 31 that can be thought of as a five-bit number. Entering zero (no bits set) attempts to advance both the hydrodynamic and heat conduction advancements at the requested time step. However, the hydrodynamic time step will be reduced if necessary such that the Courant limit is satisfied. If out-of-range thermodynamic property conditions are encountered, the hydrodynamic advancement will be retried with reduced time steps. The problem will be terminated if the time step must be reduced beyond the minimum time step. Each time step reduction halves the previously attempted time step. At the beginning of an advancement for a requested time step, a step counter is set to one. Whenever a reduction occurs, the step counter is doubled. When a successful advancement occurs, the step counter is reduced by one. When the step counter is decremented to 0, the problem has been advanced over one requested time step. Doubling of the time step is allowed only when the step counter is even, and the step counter is halved when the time step is doubled. With no bits set, the time step is doubled whenever possible. At the completion of advancements over a requested time step, the next requested advancement is obtained and may be different from the previous requested time step if data from the next time step control card are used. If necessary, the new requested time step is reduced by halving until the new actual time step is <1.5 times the last successful time step.

Setting bit one (entering 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, or 31) includes the features described for entering zero and, in addition, uses the halving and doubling procedures to maintain an estimate of hydrodynamic truncation error within program-defined limits. The estimate is based on the mass error computed by comparing densities derived from the mass conservation equations and the equations of state. If an acceptable error is not reached and the next reduction would lead to a time step below the minimum time step, the advancement is accepted. The first 100 such occurrences are noted in the output.

If the second bit is set (entering 2, 3, 6, 7, 10, 11, 14, 15, 18, 19, 22, 23, 26, 27, 30, or 31), the heat structure time step will be the same as the hydrodynamic time step. The time step control for the hydrodynamics is determined by the status of the first bit as described above, and both the heat conduction and hydrodynamic advancements are repeated when a time step reduction occurs.

If the third bit is set (entering 4, 5, 6, 7, 12, 13, 14, 15, 20, 21, 22, 23, 28, 29, 30, or 31), the heat conduction-transfer and the hydrodynamics are advanced implicitly. When the third bit is set indicating implicit coupling of heat conduction-transfer, the second bit indicating that the two advancements use the same time step must also be set. (Input checking does not now enforce this, but a future code change will include this checking.) If the third bit is not set, the heat conduction-transfer and hydrodynamic advancements are serially coupled. That is, the heat conduction transfer is advanced first using old hydrodynamic information, and the hydrodynamics is then advanced using new heat transfer information. The time step control for hydrodynamics is determined by the status of the first bit, as described above.

If the fourth bit is set (entering 8, 9, 10, 11, 12, 13, 14, 15, 24, 25, 26, 27, 28, 29, 30, or 31), the hydrodynamics will use the nearly implicit hydrodynamic numerical scheme. The time step can be as large as 20 times the Courant limit for the TRANSNT option and 40 times the Courant limit for the STDY-ST option. The time step control for hydrodynamics is determined by the status of the first bit, as described above.

If the fifth bit is set (entering 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, or 31), control of termination of the steady-state advancement is used. At the end of each advancement in steady state problems, an algorithm measures the approach to steady-state. If this bit is set, advancement will not be terminated by the algorithm; if the bit is not set, steady state can be terminated by the algorithm when it detects steady state has been reached. This control can allow the user to ensure that a steady state run always uses a defined minimum advancement time, then can allow another period of advancement time for the algorithm to determine steady state, and, finally, manually terminate the run if necessary by trip control or exceeding the end time of the last time-step control card.

Note that combinations of the effects of setting of the individual bits are achieved by setting bits in combination. For example, entering three (setting bits two and one) results in the combined effects described above for bits two and one. Older versions of RELAP5 would convert 2 to 3 to maintain compatibility; this is no longer done.

Entering zero is not recommended except for special program testing situations. If bit one is set but not set for 2 and 3, care must be taken in selection of the requested time step. Individually, the hydrodynamic and heat conduction advancements are stable; the hydrodynamic time step is controlled to ensure stability, the heat conduction solution with constant thermal properties is stable for all time steps, and the change of thermal properties with temperature has not been a problem. The serial coupling of the hydrodynamic volumes and heat structures through heat structure boundary conditions can be unstable, and excessive truncation error with large time steps can occur. This has been observed in test problems. Entering three usually eliminates the problem, and nearly all assessment of the code has been done using option three. Using option seven, which includes the implicit coupling of heat conduction and hydrodynamics should lead to an improved advancement. Users are encouraged to use option seven, but with the caution that this is a recent addition to RELAP5 and is still under assessment. Several improvements have been made to the nearly implicit advancement, but use of that option is also still under assessment. Use of option 15 is recommended for steady-state runs and slow transients; and users are encouraged to use option 19, but with the same caution as option 7.

The minor edit, major edit, and restart frequencies are based on the requested time-step size. A frequency n means that the action is taken when a period of time equal to n requested time steps has elapsed. The edits and the restart record are written at time zero and at the specified frequencies up to the time limit on the time step control card. The maximum time step is reduced if needed, and the edits and restart record are forced at the time limit value. Actions at the possibly new specified frequencies begin with the first advancement with a new time step control card. A restart forces a major and minor edit to be written, and a major edit forces a minor edit to be written. Plot information is written to the internal plot and restart-plot files whenever a minor edit is written. Note that minor edits are produced only if minor edit requests are entered; an internal plot file is written only if internal plot requests are entered; and plot and restart data are written on the restart-plot file only if the file is requested.

An option (d) used for program testing can force a plot print, minor edit, major edit, or combinations of these to be written at each advancement. Care should be used, since considerable output can be generated.

Major edits forced by the program testing option or the last major edit of the problem terminated by approach to the job CPU limit may not coincide with the requested time step. When this occurs, a warning message is printed that states that not all quantities are advanced to the same time points.

8.3 Printed Output

A program version identification is printed at the beginning of printed output and the first page following the list of input data.

8.3.1 Input Editing

Printed output for a problem begins with a listing of the input; each line of input is preceded by a sequence number. The sequence number is not the same as the card number. Notification messages are listed when data card replacement or deletion occurs. Punctuation errors, such as an alphabetic character in numeric fields, multiple signs, periods, etc., are noted by an error message, and a ^ (caret) is printed under the card image indicating the column position of the error.

Input processing consists of three phases. The first phase simply reads and stores all the input data for a problem such that the data can later be retrieved by card number. Error checking is limited to punctuation checking, and erroneous data flagged during this phase nearly always causes additional diagnostics in later phases. The second phase does the initial processing of data. Input data are moved and expanded into dynamic arrays sized for the problem being solved, and default options are applied. Processing and error checking is local to the data being processed. That is, when processing a single junction component, no checking is performed regarding the existence of connected volumes. Similarly, hydrodynamic volumes connected to heat structure surfaces are not checked during processing of heat structure boundary data. At the end of this phase, all data cards should have been used. Unused cards are considered errors and are listed. Asterisks following the card number indicate that the card number was bad, that an error was noted in the card image listing, and that the number is the sequence number rather than the card number. The third phase completes input processing and performs requested initialization. Once the second phase has been completed, data specifying linkages between various blocks of data can now be processed and checked. Examples of error checking are junction connections made to nonexisting volumes, heat structure surfaces connected to nonexisting hydrodynamic volumes, specified thermal properties, and power data not entered. Solution of steady-state heat conduction for initial temperature distribution in heat structures is an example of initialization.

The flow map used for a particular volume is printed out during the input editing of the hydrodynamic volumes. **Table 8.3-1** shows the flow map and the corresponding number printed out under the label Flow Map.

Table 8.3-1 Flow map identifiers.

Flow Map	Number (Input Edit)
Vertical	1
Horizontal	2
Annular	3
Pump	4
ECC Mixer	5

Depending on the type of data, input is edited in only one of the last two edits or in both of them. Error diagnostics can be issued during either phase, even if no editing for the erroneous data is done in a phase. When an error is detected, possible corrective actions are disregarding the data, which usually leads to other diagnostics, inserting benign data, or marking data as being entered but useless for further processing. These actions are taken so that input processing continues despite severe errors (other than on problem type and options). Regardless of errors, all data are given preliminary checking. Severe errors can limit cross-checking. Correcting input errors diagnosed in a submittal may lead to other diagnostics in a subsequent submittal, as elimination of errors allow more detailed checking. Except for exceeding requested computer time, disk limits, and printed output limits, any abnormal termination is considered a programming error and even exceeding computer time limits is prevented during transient execution. The final message of input processing indicates successful input processing or that the problem is being terminated as the result of input errors.

8.3.2 Major Edits

Major edits are an editing of most of the key quantities being advanced in time. The amount of output depends on the input deck and output options chosen by the code user. Output includes a time-step summary, trip information, reactor kinetics information, one to four sections of hydrodynamic volume information, hydrodynamic volume time-step control information, one or two sections of hydrodynamic junction information, metal-water reaction information, heat structure/heat transfer information, heat structure temperatures, reflood information, reflood surface temperatures, cladding rupture information, surface radiation information, control variable information, and generator information. Major edits are quite lengthy, and care should be used in selecting print frequencies. Some sections of major edits can be bypassed through input data on time-step control cards. An example of a major edit is shown in **Figure 8.3-1**.

Each section of information is discussed below in the order that each appears in a major edit. In particular, what the abbreviated labels stand for as well as how they relate to variables used in Volume 1 of this manual are indicated.

8.3.2.1 Time Step Summary. As shown in **Figure 8.3-1**, the first section of a major edit prints the problem time and statistics concerning time step control. ATTEMPTED ADV. is the total number of successful and repeated advancements. REPEATED ADV. is the number of advancements that were not accepted and were retried with a halved time step. SUCCESSFUL ADV. is the number of accepted advancements. REQUESTED ADV. is the number of advancements with the specified requested maximum time step. These are presented in two columns. The TOT. column is over the entire problem; the EDIT column contains the number since the previous major edit. MIN. DT, MAX. DT, and AVG. DT are the minimum, maximum, and average time step used since the last major edit. REQ. DT is the requested maximum time step used since the last major edit. This quantity may not be the requested time step entered on the card if the major edit is for the final time value on the card. LAST. DT is the time step used in the last advancement. CRNT. DT is the time step limit based on the Courant stability criterion for the last advancement. ERR. EST is the estimate of the truncation mass error fraction at the last advancement. Entering 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, or 31 for the time step control option will reduce or double the time step to keep this quantity between the limits of 8.0×10^{-4} and 8.0×10^{-3} if the mass error criterion is controlling the time step. In **Figure 8.3-1**, the problem is running at the requested (maximum) time-step, and the ERR. EST is below the lower limit. CPU is the CPU time for the entire problem up to the time of the major edit. TOT. MS is the total mass currently contained in the hydrodynamic systems, and MS. ERR is an estimate of the cumulative error in the total mass owing to truncation error. M. RATO is the

```
RELAP5/3.1#2#2        Reactor Loss of Coolant Analysis Program
edward's pipe problem base case with extras                                          27-Dec-94    17:20:07
MAJOR EDIT !!!time=   0.100000    sec
   attempted adv: tot.=    109    edit=     20    min.dt=   1.000000E-03 sec   last dt=   1.000000E-03 sec   ms.red=  -1.787187E-03 kg
   repeated adv: tot.=      3    edit=      0    max.dt=   1.000000E-03 sec   crnt.dt=   7.025645E-03 sec   tot.ms=   11.1019      kg
 successful adv: tot.=    106    edit=     20    avg.dt=   1.000000E-03 sec   err.est=   3.891584E-06            m.rato=  -1.149045E-04
  requested adv: tot.=    100    edit=     20    req.dt=   1.000000E-03 sec      cpu=   2.00080    sec   time=   0.100000     sec
Trip number, trip time (sec)
    501  -1.000000          502  -1.000000          505  6.0000000E-03
    601  -1.000000          602  -1.000000          603  0.0000000E+00
     Total power        fission power     gamma power        reactivity      rec. period
     (watts)            (watts)           (watts)            (dollars)       (sec-1)
     6.46074E+10        6.45997E+10       7.75141E+06        1.5008          101.02
System 1    *none*   mass=   11.102    kg    mass error= -1.78719E-03 kg     err.est.=  3.89158E-06
     Vol.no.  pressure    voidf          voidg          voidgo         tempf      tempg      sat. temp.      uf           ug          volume
              (pa)                                                     (k)        (k)        (k)             (j/kg)       (j/kg)       flag
edward's pipe
     3-010000  2.58633E+06  0.87323        0.12677        0.12564        500.483    498.867    498.905        9.74638E+05  2.60139E+06  000000
     3-020000  2.58627E+06  0.88929        0.11071        0.10962        500.538    498.872    498.904        9.74892E+05  2.60140E+06  000000
     3-030000  2.58627E+06  0.86369        0.13631        0.13531        500.353    498.870    498.904        9.74035E+05  2.60140E+06  000000
     3-040000  2.58658E+06  0.87074        0.12926        0.12806        500.378    498.894    498.910        9.74150E+05  2.60144E+06  000000
     3-050000  2.58749E+06  0.89085        0.10915        0.10795        500.524    498.939    498.929        9.74826E+05  2.60151E+06  000000
     3-060000  2.58914E+06  0.90717        9.28307E-02    9.18278E-02    500.647    498.997    498.963        9.75398E+05  2.60158E+06  000000
     3-070000  2.59131E+06  0.91570        8.43030E-02    8.34841E-02    500.717    499.055    499.008        9.75723E+05  2.60161E+06  000000
     3-080000  2.59326E+06  0.91516        8.48351E-02    8.41059E-02    500.714    499.091    499.048        9.75708E+05  2.60161E+06  000000
     3-090000  2.59310E+06  0.91185        8.81460E-02    8.72750E-02    500.694    499.033    499.045        9.75614E+05  2.60148E+06  000000
     3-100000  2.58992E+06  0.89705        0.10295        0.10177        500.584    498.885    498.979        9.75102E+05  2.60126E+06  000000
     3-110000  2.58203E+06  0.88244        0.11756        0.11629        500.472    498.674    498.816        9.74589E+05  2.60111E+06  000000
     3-120000  2.56699E+06  0.73794        0.26206        0.23511        498.981    498.471    498.503        9.67675E+05  2.60133E+06  000000
     3-130000  2.46936E+06  0.56045        0.43955        0.43627        496.660    496.433    496.438        9.57014E+05  2.60099E+06  000000
     3-140000  2.40135E+06  0.49097        0.50903        0.50478        495.333    494.953    494.962        9.50972E+05  2.60059E+06  000000
     3-150000  2.36217E+06  0.46318        0.53682        0.53349        494.703    494.063    494.097        9.48107E+05  2.60031E+06  000000
     3-160000  2.33684E+06  0.44284        0.55716        0.55561        494.183    493.443    493.532        9.45740E+05  2.60003E+06  000000
     3-170000  2.31703E+06  0.42559        0.57441        0.57370        493.704    492.949    493.087        9.43550E+05  2.59979E+06  000000
     3-180000  2.30117E+06  0.41320        0.58680        0.58622        493.310    492.561    492.728        9.41752E+05  2.59962E+06  000000
     3-190000  2.28849E+06  0.39956        0.60044        0.59981        492.991    492.248    492.440        9.40295E+05  2.59949E+06  000000
     3-200000  2.28174E+06  0.43684        0.56316        0.56283        492.797    492.163    492.286        9.39410E+05  2.59962E+06  000000
rhtbdy   tmdpvol
     5-010000  1.00000E+05  0.00000E+00    1.0000         1.0000         372.782    372.782    372.782        4.17407E+05  2.50606E+06  011000
     Vol.no.  rhof        rhog           rho-mix        rho-boron      vel-liquid  vel-vapor   sounde         quality      quality      quality
              (kg/m3)     (kg/m3)        (kg/m3)        (kg/m3)        (m/sec)     (m/sec)     (m/sec)        mix-cup      static       non-cond.
     3-010000  830.80     12.945         727.12         0.00000E+00    0.25810     0.12238     26.817         5.163E-03 2.257E-03 0.000E+00
     3-020000  830.73     12.945         740.19         0.00000E+00    0.37923     0.24891     26.638         5.538E-03 1.936E-03 0.000E+00
     3-030000  830.98     12.945         719.47         0.00000E+00    0.61811     0.47123     26.627         5.361E-03 2.452E-03 0.000E+00
     3-040000  830.94     12.945         725.21         0.00000E+00    0.87499     0.68065     26.526         5.582E-03 2.307E-03 0.000E+00
     3-050000  830.75     12.949         741.49         0.00000E+00    1.1313      0.98186     26.488         5.874E-03 1.906E-03 0.000E+00
     3-060000  830.58     12.956         754.68         0.00000E+00    1.3522      1.2668      26.433         5.912E-03 1.594E-03 0.000E+00
```

Vol.no.	rhof	rhog	rho-mix	rho-boron	vel-liquid	vel-vapor	sounde	quality	quality	quality
	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(m/sec)	(m/sec)	(m/sec)	mix-cup	static	non-cond.
3-070000	830.49	12.966	761.57	0.00000E+00	1.5330	1.4546	26.351	5.776E-03	1.435E-03	0.000E+00
3-080000	830.49	12.976	761.14	0.00000E+00	1.6950	1.5898	26.239	5.583E-03	1.446E-03	0.000E+00
3-090000	830.52	12.978	758.46	0.00000E+00	1.8733	1.7781	26.252	5.590E-03	1.508E-03	0.000E+00
3-100000	830.67	12.966	746.48	0.00000E+00	2.1180	2.1369	26.401	5.734E-03	1.788E-03	0.000E+00
3-110000	830.82	12.929	734.67	0.00000E+00	2.4275	2.6664	26.828	6.314E-03	2.069E-03	0.000E+00
3-120000	832.82	12.849	617.94	0.00000E+00	5.9491	9.0256	26.775	6.677E-03	5.449E-03	0.000E+00
3-130000	835.85	12.363	473.88	0.00000E+00	11.926	13.998	32.083	1.000E-02	1.147E-02	0.000E+00
3-140000	837.56	12.027	417.33	0.00000E+00	16.202	17.195	35.657	1.467E-02	1.467E-02	0.000E+00
3-150000	838.36	11.834	394.66	0.00000E+00	19.321	20.204	37.688	1.754E-02	1.610E-02	0.000E+00
3-160000	839.02	11.711	378.08	0.00000E+00	21.396	22.623	38.938	1.919E-02	1.726E-02	0.000E+00
3-170000	839.64	11.615	364.01	0.00000E+00	22.839	24.531	39.881	2.057E-02	1.833E-02	0.000E+00
3-180000	840.14	11.538	353.92	0.00000E+00	23.920	26.099	40.554	2.180E-02	1.913E-02	0.000E+00
3-190000	840.55	11.476	342.74	0.00000E+00	24.935	27.307	41.438	2.276E-02	2.010E-02	0.000E+00
3-200000	840.79	11.440	373.74	0.00000E+00	24.500	29.176	38.238	2.346E-02	1.724E-02	0.000E+00

Vol.no.	rhof	rhog	rho-mix	rho-boron	vel-liquid	vel-vapor	sounde	quality	quality	quality
	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(m/sec)	(m/sec)	(m/sec)	mix-cup	static	non-cond.
5-010000	958.39	0.59041	0.59041	0.00000E+00	23.455	30.878	473.21	2.257E-02	1.00	0.000E+00

Vol.no.	tot.ht.inp	vap.ht.inp	vapor-gen.	wall-flashing	liq.int.htc	vap.int.htc	mass-flux	Reynolds	Reynolds	flow
	(watts)	(watts)	(kg/sec-m3)	(kg/sec-m3)	(watts/m3-k)	(watts/m3-k)	(kg/sec-m2)	liquid	vapor	regi
3-010000	834.80	0.00000E+00	15.228	0.48854	1.70679E+07	1.44099E+06	93.722	60278.	462.43	hst
3-020000	606.63	0.00000E+00	15.638	0.35504	1.70830E+07	1.58281E+06	278.02	1.78759E+05	1761.8	hst
3-030000	595.04	0.00000E+00	14.506	0.34830	1.78500E+07	1.52113E+06	450.88	2.89812E+05	3469.4	hst
3-040000	621.34	0.00000E+00	17.690	0.36378	2.15460E+07	1.82284E+06	631.71	4.05983E+05	5387.5	hst
3-050000	633.11	0.00000E+00	16.963	0.37075	1.89565E+07	2.04745E+06	829.37	5.33072E+05	6977.4	hst
3-060000	635.68	0.00000E+00	13.633	0.37233	1.43152E+07	1.84202E+06	1011.4	6.50298E+05	7628.4	hst
3-070000	644.67	0.00000E+00	10.825	0.37763	1.10888E+07	1.81699E+06	1162.2	7.47516E+05	7686.1	hst
3-080000	671.42	0.00000E+00	10.210	0.39332	1.06929E+07	1.71363E+06	1290.4	8.30236E+05	8027.0	hst
3-090000	704.52	0.00000E+00	11.828	0.41277	1.26306E+07	2.08088E+06	1423.2	9.15610E+05	9187.5	hst
3-100000	791.54	0.00000E+00	17.081	0.46389	1.90636E+07	2.96775E+06	1593.7	1.02475E+06	12194.	hst
3-110000	901.27	0.00000E+00	17.188	0.52830	1.89090E+07	6.49353E+06	1798.1	1.15480E+06	17530.	hst
3-120000	2867.0	0.00000E+00	484.66	1.6981	1.81826E+09	9.10588E+07	4030.9	2.57650E+06	1.01646E+05	bby
3-130000	7513.2	0.00000E+00	265.72	4.4462	2.16831E+09	3.92132E+08	6519.7	4.11257E+06	2.85180E+05	bby
3-140000	9875.7	0.00000E+00	194.69	5.8180	9.46904E+08	3.34815E+08	7225.3	4.50771E+06	4.61445E+05	slg
3-150000	10613.	0.00000E+00	136.36	6.2235	4.02689E+08	9.68110E+07	7850.0	4.86687E+06	5.86370E+05	slg
3-160000	10994.	0.00000E+00	98.479	6.4244	2.65440E+08	2.74888E+07	8274.8	5.10903E+06	6.78599E+05	slg
3-170000	11173.	0.00000E+00	77.516	6.5122	2.16145E+08	1.22905E+07	8485.4	5.22052E+06	7.54779E+05	slg
3-180000	11144.	0.00000E+00	64.022	6.4808	1.85848E+08	7.84995E+06	8601.2	5.27597E+06	8.18613E+05	slg
3-190000	10976.	0.00000E+00	54.341	6.3708	1.63814E+08	5.89453E+06	8701.7	5.32495E+06	8.70984E+05	slg
3-200000	10621.	0.00000E+00	40.610	6.1564	1.27093E+08	7.48087E+06	8783.6	5.36694E+06	9.11898E+05	slg
5-010000	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.00000E+12	0.00000E+00	4406.9	1.17198E+06	6.30557E+05	mpr

vol.no.	voidla	voidlb	vollev	vlev	
			(m)	(m/sec)	

Vol.no.	lrgst.mass err.		reduce-quality		reduce-extrap.		reduce-mass		reduce-propty.		min.courant		reduce-courant	
	edit	total	edit	total	edit	total	edit	total	edit	total	edit	total	edit	total
3-010000	0	6	0	0	0	0	0	0	0	0	0	0	0	0
3-020000	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8.3-1 Example of major edit. (Continued)

Figure 8.3-1 Example of major edit. (Continued)

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3-030000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-040000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-050000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-060000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-070000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-080000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-090000	1	1	0	0	0	0	0	0	0	0	0	0	0	0
3-100000	2	4	0	0	0	0	0	0	0	0	0	0	0	0
3-110000	5	6	0	0	0	0	0	0	0	0	0	0	0	0
3-120000	9	9	0	0	0	0	0	0	0	0	0	0	0	0
3-130000	3	13	0	0	0	0	0	0	0	0	0	0	0	0
3-140000	0	11	0	0	0	0	0	0	0	0	0	0	0	0
3-150000	0	9	0	0	0	0	0	0	0	0	0	0	0	0
3-160000	0	7	0	0	0	0	0	0	0	0	0	0	0	0
3-170000	0	8	0	0	0	0	0	0	0	0	0	0	0	0
3-180000	0	11	0	0	0	0	0	0	0	0	0	0	0	0
3-190000	0	8	0	0	0	0	0	0	0	0	0	0	0	0
3-200000	0	13	0	0	0	2	0	0	0	2	20	105	0	0
5-010000	0	0	0	0	0	0	0	0	0	0	0	0	0	0

System 1   "none"

Jun.no.	from vol.	to vol.	liq.j.vel. (m/sec)	vap.j.vel. (m/sec)	mass flow (kg/sec)	jun.area (m2)	throat ratio	junction flags	flow regi	no. last	advs. edit	choked total
edward's pipe												
3-010000	3-010002	3-020001	0.25810	0.12238	0.85590	4.56037E-03	1.0000	0000000	hst	0	0	0
3-020000	3-020002	3-030001	0.49819	0.39379	1.6830	4.56037E-03	1.0000	0000000	hst	0	0	0
3-030000	3-030002	3-040001	0.74154	0.53413	2.4341	4.56037E-03	1.0000	0000000	hst	0	0	0
3-040000	3-040002	3-050001	1.0074	0.83515	3.3347	4.56037E-03	1.0000	0000000	hst	0	0	0
3-050000	3-050002	3-060001	1.2524	1.1555	4.2397	4.56037E-03	1.0000	0000000	hst	0	0	0
3-060000	3-060002	3-070001	1.4502	1.3975	4.9960	4.56037E-03	1.0000	0000000	hst	0	0	0
3-070000	3-070002	3-080001	1.6152	1.5175	5.6139	4.56037E-03	1.0000	0000000	hst	0	0	0
3-080000	3-080002	3-090001	1.7750	1.6616	6.1653	4.56037E-03	1.0000	0000000	hst	0	0	0
3-090000	3-090002	3-100001	1.9719	1.8903	6.8265	4.56037E-03	1.0000	0000000	hst	0	0	0
3-100000	3-100002	3-110001	2.2664	2.3482	7.7258	4.56037E-03	1.0000	0000000	hst	0	0	0
3-110000	3-110002	3-120001	2.5913	2.9460	8.6965	4.56037E-03	1.0000	0000000	hst	0	0	0
3-120000	3-120002	3-130001	9.9548	11.770	29.068	4.56037E-03	1.0000	0000000	bby	0	0	0
3-130000	3-130002	3-140001	14.513	15.378	31.561	4.56037E-03	1.0000	0000000	bby	0	0	0
3-140000	3-140002	3-150001	18.126	18.809	34.802	4.56037E-03	1.0000	9000000	slg	0	0	0
3-150000	3-150002	3-160001	20.588	21.549	37.336	4.56037E-03	1.0000	0000000	slg	0	0	0
3-160000	3-160002	3-170001	22.242	23.669	38.519	4.56037E-03	1.0000	0000000	slg	0	0	0
3-170000	3-170002	3-180001	23.460	25.374	39.064	4.56037E-03	1.0000	0000000	slg	0	0	0
3-180000	3-180002	3-190001	24.394	26.814	39.499	4.56037E-03	1.0000	0000000	slg	0	0	0
3-190000	3-190002	3-200001	25.494	27.791	39.975	4.56037E-03	1.0000	0000000	slg	0	0	0
rhtbdy sngljun												
4-000000	3-200002	5-010901	26.960	35.493	40.222	3.96752E-03	1.0000	0000000	slg	1	20	98

Figure 8.3-1 Example of major edit. (Continued)

Jun.no.	voidfj	voidgj	fij (n-s2/m5)	fwalfj	fwalgj	fjunf	fjunr	formfj	formgj	no. last	advs edit	ccfl total
3-010000	0.87323	0.12677	12.181	6.057E-02	0.498	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-020000	0.88929	0.11071	44.597	4.627E-02	0.254	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-030000	0.86369	0.13631	18.655	4.403E-02	0.254	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-040000	0.87074	0.12926	31.701	4.077E-02	0.22F	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-050000	0.89085	0.10915	59.239	3.862E-02	0.233	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-060000	0.90717	9.28307E-02	115.43	3.725E-02	0.243	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-070000	0.91570	8.43030E-02	71.569	3.624E-02	0.249	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-080000	0.91516	8.48351E-02	6.0437	3.544E-02	0.236	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-090000	0.91185	8.81460E-02	3.5683	3.483E-02	0.212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-100000	0.89705	0.10295	4.7712	3.378E-02	0.177	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-110000	0.88244	0.11756	18.112	4.765E-02	0.114	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-120000	0.73794	0.26206	51326.	1.966E-02	2.760E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-130000	0.56045	0.43955	2.00582E+05	1.720E-02	2.013E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-140000	0.49097	0.50903	2.00261E+05	1.658E-02	9.475E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-150000	0.46318	0.53682	67008.	1.631E-02	2.725E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-160000	0.44284	0.55716	23980.	1.602E-02	1.223E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-170000	0.42559	0.57441	9935.6	1.581E-02	6.896E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-180000	0.41320	0.58680	4688.7	1.569E-02	4.393E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
3-190000	0.39956	0.60044	2620.7	1.555E-02	8.236E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0	0	0
4-000000	0.43684	0.56316	2944.0	6.521E-03	4.580E-04	0.000E+00	0.000E:00	0.000E+00	0.000E+00	0	0	0

```
RELAP5/3.1#2#2        Reactor Loss Of Coolant Analysis Program
edward's pipe problem base case with extras                              27-Dec 94    17:20:07
HEAT STRUCTURE OUTPUT +++time=    0.100000      sec
```

str.no.	side	bdry.vol. number	surface temp. (k)	heat-trf. convection (watt)	heat-flux convection (watt/m2)	critical heat-flux (watt/m2)	CHF mul	ht mode	heat-trf. coef.conv (watt/m2-k)	int.-heat source (watt)	conv+rad -source (watt)	vol.ave. temp. (k)
30-001	left	3-010000	501.543	834.80	17027.	3.72688E+06	0.72	4	7212.4	0.00000E+00	834.80	502.05
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-002	left	3-020000	501.803	606.63	12373.	5.06775E+06	0.73	4	5916.0	0.00000E+00	606.63	502.11
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-003	left	3-030000	501.849	595.04	12137.	5.20362E+06	0.71	4	6233.7	0.00000E+00	595.04	502.13
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-004	left	3-040000	501.853	621.34	12673.	5.36164E+06	0.72	4	7114.5	0.00000E+00	621.34	502.13
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-005	left	3-050000	501.857	633.11	12913.	5.55411E+06	0.74	4	8225.1	0.00000E+00	633.11	502.13
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-006	left	3-060000	501.856	635.68	12966.	5.70648E+06	0.75	4	9259.3	0.00000E+00	635.68	502.13
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-007	left	3-070000	501.847	644.67	13149.	5.66860E+06	0.76	4	10149.	0.00000E+00	644.67	502.13
	right	0-000000	502.1F3	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			
30-008	left	3-080000	501.829	671.42	13695.	5.59057E+06	0.76	4	10879.	0.00000E+00	671.42	502.13
	right	0-000000	502.183	0.00000E+00	0.00000E+00	0.00000E+00	0.00	0	0.00000E+00			

```
30-009 left   3-090000  501.810  704.52        14370.         5.49912E-06 0.75  4  11586.        0.00000E+00  704.52        0.00000E+00  502.13
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00  502.12
30-010 left   3-100000  501.775  791.54        16145.         5.45335E-06 0.74  4  12478.        0.00000E+00  791.54        0.00000E+00  502.12
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-011 left   3-110000  501.737  901.27        18383.         5.59273E-06 0.73  4  13538.        0.00000E+00  901.27        0.00000E+00  502.12
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-012 left   3-120000  501.611  2867.0        58477.         5.44584E-06 0.83  4  24834.        0.00000E+00  2867.0        0.00000E+00  502.11
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-013 left   3-130000  500.913  7513.2        1.53245E+05    4.27520E-06 0.84  4  36433.        0.00000E+00  7513.2        0.00000E+00  502.06
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-014 left   3-140000  500.003  9875.7        2.01433E+05    4.15672E-06 0.85  4  43779.        0.00000E+00  9875.7        0.00000E+00  501.98
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-015 left   3-150000  499.165  10613.        2.16480E+05    4.10480E-06 0.85  4  49141.        0.00000E+00  10613.        0.00000E+00  501.88
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-016 left   3-160000  498.469  10994.        2.24237E+05    4.10462E-06 0.86  4  52609.        0.00000E+00  10994.        0.00000E+00  501.78
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-017 left   3-170000  497.862  11173.        2.27894E+05    4.10481E-06 0.86  4  54902.        0.00000E+00  11173.        0.00000E+00  501.67
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-018 left   3-180000  497.329  11144.        2.27297E+05    4.10517E-06 0.86  4  56630.        0.00000E+00  11144.        0.00000E+00  501.55
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-019 left   3-190000  496.851  10976.        2.23867E+05    4.10547E-06 0.86  4  58069.        0.00000E+00  10976.        0.00000E+00  501.43
       right  0-000000  502.183  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
30-020 left   3-200000  496.460  10621.        2.16638E+05    4.10587E-06 0.87  4  59203.        0.00000E+00  10621.        0.00000E+00  501.31
       right  0-000000  502.182  0.00000E+00    0.000000E+00   0.00000E+00 0    0  0.000000E+00  0.00000E+00  0.000000E+00
200-001 left  0-000000  9.220    13510.        1.10741E+05    0.00000E+00 0.00  0  0  0.00000E+00  0.00000E+00  13510.        0.00000E+00  5.86
        right 0-000000  0.000    0.00000E+00                                0    0             0.00000E+00
```

Sum of int.-heat source= 0.00000E+00 (watt)

At time= 0.100000 sec

str.no. mesh point temperatures (k)

```
30-001   501.54  501.74  501.90  502.02  502.09  502.14  502.17  502.18  502.18  502.18
         502.18
30-002   501.80  501.94  502.04  502.10  502.14  502.16  502.17  502.18  502.18  502.18
         502.18
30-003   501.85  501.98  502.07  502.12  502.15  502.17  502.17  502.18  502.18  502.18
         502.18
30-004   501.85  501.99  502.07  502.13  502.16  502.17  502.17  502.18  502.18  502.18
         502.18
30-005   501.86  501.99  502.08  502.13  502.16  502.17  502.17  502.18  502.18  502.18
         502.18
30-006   501.86  501.99  502.08  502.13  502.16  502.17  502.17  502.18  502.18  502.18
         502.18
30-007   501.85  501.99  502.08  502.13  502.16  502.17  502.17  502.18  502.18  502.18
         502.18
30-008   501.83  501.98  502.08  502.13  502.15  502.17  502.17  502.18  502.18  502.18
         502.18
30-009   501.81  501.97  502.07  502.13  502.16  502.16  502.17  502.18  502.18  502.18
         502.18
30-010   501.78  501.95  502.06  502.13  502.16  502.16  502.17  502.18  502.18  502.18
         502.18
```

Figure 8.3-1 Example of major edit. (Continued)

Figure 8.3-1 Example of major edit. (Continued)

8-11

```
         502.18
30-011   501.74   501.93   502.05   502.12   502.16   502.17   502.18   502.18   502.18   502.18
         502.18
30-012   501.61   501.91   502.05   502.12   502.16   502.17   502.18   502.18   502.18   502.18
         502.18
30-013   500.91   501.79   502.03   502.12   502.16   502.17   502.18   502.18   502.18   502.18
         502.18
30-014   500.00   501.47   501.95   502.10   502.15   502.17   502.18   502.18   502.18   502.18
         502.18
30-015   499.17   501.04   501.79   502.05   502.14   502.17   502.18   502.18   502.18   502.18
         502.18
30-016   498.47   500.61   501.59   501.98   502.12   502.16   502.18   502.18   502.18   502.18
         502.18
30-017   497.86   500.16   501.35   501.88   502.08   502.15   502.17   502.18   502.18   502.18
         502.18
30-018   497.33   499.72   501.08   501.74   502.02   502.13   502.17   502.18   502.18   502.18
         502.18
30-019   496.85   499.29   500.79   501.58   501.95   502.10   502.16   502.17   502.18   502.18
         502.18
30-020   496.46   498.88   500.48   501.39   501.85   502.05   502.14   502.17   502.18   502.18
         502.18
200-001  9.2198   9.1063   8.7686   8.2149   7.4590   6.5194   5.4193   4.1857   2.8491   1.4423
         0.00000E+00
```

```
              Control variable edit; at time=    0.100000     sec
   1    ctl1       sum       2.586302E+06        4    ctl4       mult       1.140872E+06
   5    ctl5       mult      228.657            10    ctl110     div        4.382614E-07
  11    ctl10      div       1.00296           12    ctl112     diffreni   1.00000
  13    ctl13      integral  5.000000E-03      14    ctl114     integral   0.100000
  15    ctl15      diffreni  1.000000E-01      99    ctl99      diffrend   9.75990
 201    ctl201     function  3.00000          202    ctl202     stdfnctn   0.199667
 203    ctl203     tripunit  0.000000E+00     204    ctl204     tripdlay  -2.00000
 205    ctl205     poweri    0.200000         206    ctl206     powerr     5.000000E-03
 207    ctl207     powerx    0.300000         300    ctl300     delay      0.000000E+00
 301    ctl301     prop-int  2.15000          302    ctl302     lag        0.367876
 303    ctl303     lead-lag  0.683938         304    ctl304     constant   0.387000
 401    con1       constant  0.000000E+00     402    con2       constant   0.100000
 403    pumpctl    pumpctl  -1.000000E-03     404    steamctl   steamctl   2.00167
 405    feedctl    feedctl  -2.500000E-04

---Restart no.    109 written, block no.    2---
```

ratio of the cumulative mass error to the total mass at the start of the transient; M. RATN is the ratio of the cumulative mass error to the current total mass. The output lists the ratio with the largest denominator, thus the smaller of the two ratios. TIME is the simulated time for the entire problem up to the time of the major edits.

8.3.2.2 Trip Information. At major edits, each defined trip number and the current TIMEOF quantity are printed. The TIMEOF quantity is -1.0 when the trip is false, and when ≥ 0, indicates that the trip is true and is the time the trip last switched to true. **Figure 8.3-1** includes an example of a trip edit.

8.3.2.3 Reactor Kinetics Information. At major edits, the total reactor power (labeled TOTAL POWER), fission power (labeled FISSION POWER), decay power (labeled GAMMA POWER), reactivity (labeled REACTIVITY), and reciprocal period (labeled REC. PERIOD) are printed. Either the total power, fission power, or decay power can be specified as the time-varying part of the heat source in heat structures. **Figure 8.3-1** illustrates a reactor kinetics edit; however, it is not intended to be physically realistic.

8.3.2.4 Hydrodynamic Volume Information--First Section. Systems are labeled SYSTEM, followed to the right by the system number (1, 2, 3, etc.) and the name of the system (optional; *none* if no name is input on Cards 120 through 129). To the right of this are the labels MASS, MASS ERROR, and ERR. EST. for this system, followed immediately by the actual value and unit. These three quantities correspond to the TOT. MS, MS. ERR, and ERR. EST listed in the Time Step Summary, except that these are only for the particular system whereas the Time Step Summary quantities are the sum for all the systems. In **Figure 8.3-1**, there is only one system (SYSTEM 1), and, thus, the MASS, MASS ERROR, and ERR. EST. are the same as the corresponding quantities in the Time Step Summary. The largest error estimate (labeled ERR. EST.) for all the systems is used for the error estimate (labeled ERR. EST) of the entire configuration. As **Figure 8.3-1** illustrates, quantities are grouped by component within each system. Each component is first labeled with the component name (supplied by the user) and the component type. Underneath this are the values for each volume within the component.

The first items printed in this section are the abbreviated labels and units for the quantities to be printed out. The first label is VOL. NO., which is the component number (CCC) and the six-digit volume subfield number (XXYYZZ) within the component. These numbers are separated by a hyphen (-). Next is PRESSURE, which is the pressure (P_L^{n+1}) used in the hydrodynamic equation of Volume 1 of this manual. Next are VOIDF, VOIDG, and VOIDGO, which are the new liquid and vapor void fraction and the previous time step vapor void fraction $(\alpha_{f,L}^{n+1}, \alpha_{g,L}^{n+1},$ and $\alpha_{g,L}^{n})$ used in the equations. The previous time step void fraction is significant because it helped determine the wall and interfacial terms on the current edit. Next are TEMPF, TEMPG, and SAT. TEMP., which are the liquid temperature $(T_{f,L}^{n+1})$, the vapor temperature $(T_{g,L}^{n+1})$, and the saturation temperature $(T_L^{s,n+1})$ used in the equations. For single-phase, the temperature of the missing phase is set to the saturation temperature. After this are UF and UG, which are the liquid specific internal energy $(U_{f,L}^{n+1})$ and the vapor specific internal energy $(U_{g,L}^{n+1})$ used in the equations. Finally, the label VOL. FLAG is listed, which is the volume control flag (tlpvbfe) input by the user for hydrodynamic volume components. Following the labels, the title supplied by the user and type of component are given, followed by the actual values of the quantities for each volume.

Additional information is printed in the first hydrodynamic volume section that is unique to certain components. In **Figure 8.3-2**, additional information for a pump, turbine, and accumulator are given. For a pump, five additional quantities are printed. In the normal operating mode, these are the rotational velocity (RPM), pump head (HEAD), torque exerted by the fluid (TORQUE), pump octant number (OCTANT), and torque generated from the pump motor (MTR. TORQUE). These terms are discussed in Volume 1. For an accumulator, four additional quantities are printed. These are the volume of liquid in the tank-standpipe-surge line (LIQ. VOLUME), the mass of liquid in the tank-standpipe-surge line (MASS), the liquid level of water contained in the tank-standpipe-surge line (LEVEL), and the mean tank wall metal temperature (WALL TEMP). These terms are discussed in Volume 1 and in Section 2 of this volume. For a turbine, four additional quantities are printed. In the normal operating mode, these are the power extracted from the turbine (POWER), the torque extracted from the turbine (TORQUE), the turbine rotational speed (SPEED), and the efficiency factor used to represent nonideal internal processes (EFFICIENCY). These terms are also discussed in Volume 1 and in Section 2 of this volume.

```
ipump     pump

rpm = 125.22     (rad/sec)     head = 0.59115E+06 (pa)   torque = -0.10090E+06     (n-m)
octant = 2                                               mtr. torque =  0.10090E+06  (n-m)

snglaccm   accum
liq. volume = 24.404    m3, mass = 24167    kg, level = 19.028    m, wall temp = 322.18 K

stage3    turbine
power = 1.75174E+08 (watt)  torque = 0.30571E+06 (n-m)  speed = 573.00 (rad/sec)
                                                         efficiency = 0.62945
```

Figure 8.3-2 Example of additional output for pumps, turbines, and accumulators.

8.3.2.5 Hydrodynamic Volume Information--Second Section. This information appears in every major edit if noncondensable species were specified in the input. In this section, no system or component label information is printed. The volume number (labeled VOL. NO.) and four to eight other quantities are printed on each line. These are printed out in numerical order within each system. The quantities are PART. PRESS., the partial pressure of steam $(P_{s,L}^{n+1})$; SOLUTE MASS, the mass of soluble species $(M_{B,L}^{n+1})$; NONCOND. VAPOR MASS, noncondensable mass $(M_{n,L}^{n+1})$; and the mass fraction of each of the noncondensable species $(X_{ni,L}^{n+1})$, labeled by the element name and NCOND. QUAL. The noncondensable qualities X_{ni} sum to 1.0 in each volume.

8.3.2.6 Hydrodynamic Volume Information--Third Section. This section of output is optional and can be skipped by setting bit three in the ss digits of Word 4 (W4) on the time step control cards (Cards 201 through 299). This section is printed in **Figure 8.3-1**. In this section, no system information and no component label information is printed. Furthermore, no additional component quantities are printed out. Instead, just the volume number (VOL. NO.) and ten other quantities are printed out on each line. These are printed out in numerical order within each system. The quantities are RHOF, liquid density $(\rho_{f,L}^{n+1})$; RHOG, vapor density $(\rho_{g,L}^{n+1})$; RHO-MIX, void-averaged mixture density (ρ_{L}^{n+1}) ;

RHO-BORON, boron density $(\rho_{B,L}^{n+1})$; VEL-LIQUID, liquid volume-average velocity $(v_{f,L}^{n+1})$; VEL-VAPOR, vapor volume-average velocity $(v_{g,L}^{n+1})$: SOUNDE, isentropic sonic velocity for single-phase or homogeneous equilibrium isentropic sonic velocity for two-phase $(a_{HE,L}^{n+1})$; QUALITY MIX-CUP, mixing cup or equilibrium quality that accounts for slip $(X_{c,L}^{n+1})$; QUALITY STATIC, static quality (X_L^{n+1}) ; and QUALITY NON-COND., noncondensable quality $(X_{n,L}^{n+1})$.

8.3.2.7 Hydrodynamic Volume Information--Fourth Section. This section prints whenever the third section prints. This section is printed in **Figure 8.3-1**. Following the volume number is TOT.HT.INP., the total wall heat transfer rate to the liquid and vapor $(Q_L^n \bullet V_L)$; VAP.HT.INP., wall heat transfer rate to the vapor $(Q_{wg,L}^n \bullet V_L)$; VAPOR-GEN., bulk vapor generation rate per unit volume $(\Gamma_{g,L}^{n+1})$; WALL FLASHING, the direct wall-liquid flashing (positive) mass transfer $(\Gamma_{w,L}^n)$; LIQ.INT.HTC, liquid-to-saturation interfacial heat transfer coefficient times area per unit volume $(H_{if,L}^n)$; VAP.INT.HTC, vapor-to-saturation interfacial heat transfer coefficient times area per unit volume $(H_{ig,L}^n)$; MASS-FLUX, volume average mass flux (G); REYNOLDS LIQUID, liquid Reynolds number; REYNOLDS VAPOR, vapor Reynolds number; and finally, FLOW REGI, flow regime. See Section 2.1 of this volume for the meaning of the flow regime label.

8.3.2.8 Hydrodynamic Volume Time Step Control Information. This section is also optional and can be skipped by setting bit four in the ss digits of Word 4 (W4) on the time step control cards (Cards 201 through 299). This section is printed in **Figure 8.3-1**. As with the previous section, no system or component label information is printed, no additional component quantities are printed, and all quantities are printed in volume numerical order within each system. All quantities are presented in two columns. The EDIT column contains the number since the previous major edit; the TOTAL column is over the entire problem.

The numbers under LRGST. MASS ERR give the number of times a volume had the largest mass error. The numbers under MIN. COURANT give the number of times a volume had the smallest time step based on the Courant stability limit. One volume under each of the headings is incremented by one for each successful advancement. The columns under REDUCE indicate volumes that have caused time step reductions. The MASS and PROPTY columns are for reductions resulting from mass error and out-of-range thermodynamic properties. The MASS column is for time step size reduction resulting from local mass error; it does not include reductions resulting from overall (global) mass error. The QUALITY column is for reductions resulting from problems with void fraction (α_g), noncondensable quality (X_n), and mixture density from the phasic continuity equations (ρ_m). Advancements that result in α_g and X_n being slightly less than 0.0 or slightly greater than 1.0 are allowed, and the variable is reset to 0.0 or 1.0. Advancements that result in values much less than 0.0 or much greater than 1.0 are considered an error, and the time step is repeated. The cutoff points are based on a functional relationship. This relation is tied to the mass error upper limit (8×10^{-3}). Advancements that result in ρ_m being ≤ 0 are also counted in the QUALITY column. The final cause of a QUALITY column reduction relates to the one-phase to two-phase (appearance) case discussed in Volume 1 of this manual. If too much of one phase appears (more than a typical thermal boundary layer thickness), an error is assumed to have occurred, the time step is

halved and repeated, and the QUALITY column counter is incremented. The EXTRAP column is for reductions when extrapolation into a metastable thermodynamic state causes problems (see Section 8 of Volume 1 for a discussion of metastable thermodynamic conditions). These problems are vapor density $(\rho_g) \leq 0.0$, vapor temperature $(T_g) \leq 274$ K, liquid density $(\rho_f) \leq 0.0$, liquid temperature $(T_f) \geq$ saturation temperature $(T^s) + 50$ K, and vapor temperature $(T_g) \leq$ saturation temperature $(T^s) - 50$ K. The COURANT column is for reductions resulting from the material Courant limit check. When the semi-implicit numerical scheme is used, the time step is reduced to the material Courant limit. When the nearly implicit numerical scheme is used, the time step is reduced to 20 times the material Courant limit for the TRANSNT option and to 40 times the material Courant limit for the STDY-ST option.

Columns under the first four REDUCE headings are incremented only after a successful advancement following one or more successive reductions. Quantities are incremented only for those volumes that caused the last reduction. More than one column and row quantity can be incremented in a time step. Because of this characteristic, quantities in the first four REDUCE headings do not necessarily equal the REPEATED ADV quantity in the Time Step Summary at the top of a major edit. Since the REDUCE-COURANT column is for a reduction that occurs before the advancement takes place, it does not cause the time step to be repeated and, thus, does not increase the REPEATED ADV quantity.

New items have been recently added to this section that are not shown in **Figure 8.3-1**. Columns under the REPEAT headings are incremented if an advancement is repeated for several different reasons. If noncondensable gas first appears in a volume during an advancement, the quantity under the REPEAT-AIR APP is incremented and the advancement repeated with the same time step size. If water packing is detected in a volume, the quantity under the heading REPEAT-PACKING is incremented and the time step is repeated with the same time step size. In either of these situations, the time advancement and the time step is repeated with the same time step size. In either of these situations, the time advancement algorithm is modified to accommodate the appearance of noncondensable gas or water packing. The modifications to the hydrodynamic advancement algorithm are described in Volume I in the section entitled Special Techniques. In addition, if in the time step in which noncondensable gas first appears in a volume, the pressure change in that cell is too large, the time step is repeated with a smaller time step size to reduce the pressure change in that cell. The same advancement may be repeated several times with smaller and smaller time steps until the pressure change criterion is satisfied. Like the quantities under the REDUCE headings, the quantity under the REPEAT - DEL PRES heading is incremented only after the pressure change criterion is satisfied.

8.3.2.9 Hydrodynamic Junction Information–First Section. This section of output is not optional and always appears in a major edit. This section is printed in **Figure 8.3-1**. As with the first section of the hydrodynamic volume information, quantities are grouped by system. For each system, the label SYSTEM, the system number (1, 2, 3, etc.), and the system name (optional) are printed on the first line. The first printed quantity for each junction is the junction number. [Labeled JUN. NO., it denotes the component number (CCC) and the six-digit junction subfield number (XXYYZZ) within the component.] These numbers are separated by a hyphen (-). The next two quantities are the volume numbers for the *from* and *to* volumes associated with the junction (labeled FROM VOL. and TO VOL.). A minus sign will be printed in front of the *from* volume number if it is not the outlet end of the volume. Similarly, a minus sign will be printed in front of the *to* volume number if it is not the inlet end of the volume. Next are the liquid junction velocity and vapor junction velocity, LIQ.J.VEL. and VAP.J.VEL. $(v_{f,j}^{n+1}$ and $v_{g,j}^{n+1})$. In single phase, the velocities are equal. This is followed by MASS FLOW, the mass flow rate $\left(\alpha_{f,j}^n \rho_{f,j}^n v_{f,j}^{n+1} + \alpha_{g,j}^n \rho_{g,j}^n v_{g,j}^{n+1} \right) A_j$. The next two quantities are JUN. AREA, junction area (A_j) and

THROAT RATIO, throat ratio (A_T/A_j), where A_T is the junction area at the throat. For the smooth area option, A_j is the physical area (full open area if a valve). For the abrupt area option, A_j is the minimum area of the two connecting volumes. The throat ratio is the ratio of the actual junction area to the defined junction area. This quantity may be less than one for orifices and valves. The velocities are based on the junction area A_j. The next quantity is the junction control flag (JUNCTION FLAGS), which is the seven-digit packed number efvcahs that the user inputs for each junction. The next quantity is the junction flow regime, FLOW REGI; see Section 2.1 of this volume of the manual for the meaning of the flow regime label. The last three columns are a choking summary (NO.ADVS.CHOKED). The subheading LAST indicates whether the choking model was applied on the last time step (set to 1 if it was, set to 0 if it was not). The subheading EDIT lists the number of times the choking model was applied since the last major edit; the subheading TOTAL lists the number of times the choking model was applied for the entire problem. As with the first section of the hydrodynamic volume information, quantities within each system are grouped by component, with the component name and type printed above the quantities.

8.3.2.10 Hydrodynamic Junction Information--Second Section. This section of output is optional and can be skipped by setting bit two in the ss digits of Word 4 (W4) on the time step control cards (Cards 201 through 299). This section is printed in **Figure 8.3-1**. As with the second section of the hydrodynamic volume information, no system information is printed, no component label information is printed, no additional component quantities are printed, and all quantities are printed in numerical order within each system. The junction number (JUN. NO.) and twelve other quantities are next printed out on each line. These are printed out in numerical order within each system. The quantities are VOIDFJ, liquid junction void fraction ($\alpha_{f,j}^{n+1}$) ; VOIDGJ, vapor junction void fraction ($\alpha_{g,j}^{n+1}$) ; FIJ, interphase drag coefficient C_i^n ; FWALFJ and FWALGJ, dimensionless liquid and vapor wall friction [($2 \cdot FWF_f^n \cdot \Delta x_j / |v_{f,j}^n|$) and ($2 \cdot FWG_f^n \cdot \Delta x_j / |v_{g,j}^n|$) in most cases] ; user-specified dimensionless forward and reverse flow energy loss coefficients [FJUNF and FJUNR, corresponds to ($2 \cdot HLOSSF_j^n / |v_{f,j}^n|$) and ($2 \cdot HLOSSG_j^n / |v_{g,j}^n|$)]; and the dimensionless abrupt area change liquid and vapor loss coefficients, FORMFJ and FORMGJ [($2 \cdot HLOSSF_j^n / |v_{f,j}^n|$) and ($2 \cdot HLOSSG_j^n / |v_{g,j}^n|$) in most cases]. The previous six quantities were all made dimensionless so that the relative importance of each in the momentum equations could be determined from the major edits. The last three quantities are a countercurrent flow limitation (CCFL) model summary (NO. ADVS. CCFL). The subheading LAST indicates whether the CCFL model was applied on the last time step (set to 1 if it was or set to 0 if it was not); the subheading EDIT lists the number of times the CCFL model was applied since the last major edit; the subheading TOTAL lists the number of times the CCFL model was applied for the entire problem.

8.3.2.11 Heat Structure-Heat Transfer Information. This section of output is not optional and always appears in a major edit when heat structures are present. Quantities in this section are printed in numerical order. The first printed quantity for each heat structure is the individual heat structure number [STR. NO., denoting the heat structure-geometry number (CCCG) and the three-digit individual heat structure subfield number (0NN)]. These numbers are separated by a hyphen (-). Following this, nine quantities are printed out for both sides of the heat structure. First, the surface indicator is printed for both sides (SIDE, printed as either LEFT or RIGHT). Next, the volume number for the hydrodynamic volume connected on each side is printed (BDRY. VOL. NUMBER, 0-000000 is printed if no volume is present). Then the surface temperature is printed for both sides (SURFACE TEMP.). After this is the heat transfer

rate out of the structure for both sides (HEAT-TRF. CONVECTION). This is followed by two fluxes for both sides, the heat flux and the critical heat flux (HEAT-FLUX CONVECTION and CRITICAL HEAT-FLUX). After these, the critical heat flux multiplier, the mode of heat transfer, and the heat transfer coefficient are printed for both sides (CHF-MUL, HT MODE, and HEAT-TRF. COEF.CONV.). The multiplier is the coefficient multiplied times the critical heat flux found in the CHF table to obtain the final value printed here. Section 3.2 describes the meaning of the modes. Finally, three quantities are printed for the individual heat structure. These are the heat generated within the structure (INT.-HEAT SOURCE), the net heat transfer rate out of the structure, i.e., convection plus radiation minus generation (CONV+RAD-SOURCE), and the volume-average temperature for the structure (VOL. AVE. TEMP.). **Figure 8.3-1** shows an example of this section of the major edit. Following this section, the sum of the sources is given.

8.3.2.12 Heat Structure Temperature. This section of output is optional and can be skipped by setting bit one in the ss digits of Word 4 (W4) on the time step control cards (Cards 201 through 299). As in the first heat structure section, the individual heat structure number (STR. NO) is printed in the first column. Then, all the mesh point temperatures (MESH POINT TEMPERATURES) for the individual heat structure are printed, starting with the left side and proceeding toward the right side (read from left to right across the page). In **Figure 8.3-1**, 11 mesh point temperatures are printed out.

8.3.2.13 Reflood Information. This section of output is not optional and always appears in a major edit when heat structures are present and the reflood model is turned on. Once the model is turned on, it stays on, and this section continues to be printed out. **Figure 8.3-3** shows an example of this section preceded by the normal heat structure printouts. The section begins with the label REFLOOD EDIT and the time. The first quantity printed is the heat structure-geometry number (CCCG, labeled GEOM. NO.). Following this are two columns providing information about the number of axial nodes (AXIAL NODES NUMBER). The first of these columns is the assigned maximum number of axial nodes (MAXIMUM). This number is computed at input time, and it is the theoretical maximum [(number of heat structures with this geometry) • (maximum number of axial intervals) + 1] when the user requests 2, 4, or 8 maximum number of axial intervals. Owing to storage limitations, this number is calculated by a formula that reduces the number below the theoretical maximum for 16, 32, 64, or 128 maximum number of axial intervals. For the example in **Figure 8.3-3**, the user requested 16, so the theoretical maximum is 321, which is larger than the assigned maximum of 153. The next column is the actual number of axial nodes used for the last time advancement (EDIT), and, in this case, it is 59. If the EDIT column is ever larger than the MAXIMUM column, the code will abort. The next four quantities are used in deciding on the number of nodes needed to define the boiling curve. The first three are the wall temperature at incipience of boiling, INC. BOIL. TEMP. (T_{IB}); the wall temperature at critical heat flux, CRITICAL TEMP. (T_{CHF}); and the wall rewetting or quench temperature, REWETTING TEMP. (T_Q). These numbers are set to 5 degrees below and 40 and 250 degrees above the saturation temperature, respectively. The final number is the location of the critical temperature, CRIT. TEMP. POSITION. This location is the distance from the start of the first heat structure. This last output does not appear to be working, but the quench position can be found by examining the next two sections. Next is the axial position of all 59 nodes, followed by the left- and right-side surface temperatures at these axial positions.

This axial section of output is optional, and it is skipped when the heat structure temperatures are skipped. As with the previous section on reflood information, this section is not printed until the reflood model is turned on, and then it continues to be printed out. An example of this section is also shown in

Figure 8.3-3. The temperatures are printed from left to right, beginning with the first heat structure. In this example of 20 heat structures, 59 axial mesh point surface temperatures are printed.

8.3.2.14 Cladding Oxidation and Rupture Information. If the user has activated the metal-water reaction model by using a 1CCCG003 card, the cladding inside and outside oxide penetration depth is printed prior to the heat structure output. **Figure 8.3-4** gives an example where there are two stacks of eight heat structures. The second stack (31) at elevation 5 shows some inside cladding oxidation. This is because this elevation has ruptured, as can be seen in the next section in **Figure 8.3-4**. The pressure shown is the pressure inside the gap.

8.3.2.15 Surface Radiation Model Output. **Figure 8.3-5** shows an example of output from the radiation model. This radiation enclosure of six heat structures was tripped on at 0.25 s and was never tripped off. The heat flux is out of five structures and into number six. In the energy exchange calculation, -0.28 W is unaccounted for.

8.3.2.16 Control Variable Information. This section of output is not optional and always appears in a major edit when control systems are present. **Figure 8.3-1** shows examples of such printout, which begins with the label CONTROL VARIABLE EDIT. Four items are printed for each variable, with two sets of information printed per line. The four items are the control variable number (NNN), the alphanumeric name of the control variable, the control component type, and the value of the control variable at the end of the last advancement.

8.3.2.17 Generator Information. This section of output is not optional and always appears when a generator control component is present. As discussed in Volume 1, the generator component is an optional feature of the shaft component. As a result, the first column under the GENERATOR label in the major edit is the control variable number (NNN) of the corresponding shaft component. To the right of this, under normal operating conditions, is the torque exerted by the generator (TORQUE). Under normal conditions, the torque will be negative, since it is required to turn the generator. The next quantity printed, under normal conditions, is the power applied by the generator (INPUT POWER). Again, under normal conditions, the power will be negative.

8.3.3 Minor Edits

Minor edits are condensed edits of user-specified quantities. The frequency of minor edits is user-specified and may be different from the major edit frequency. **Figure 8.3-6** shows one page of minor edits. The selected quantities are held until 50 time values are stored. The minor edit information is then printed, 50 time values on a page, nine of the selected quantities per page, with time printed in the leftmost column on each page. Minor edits can print selected quantities at frequent intervals using much less paper than major edits. Section 4 of Appendix A of this volume indicates how to request minor edits and what the user-specified quantities represent.

8.3.4 Diagnostic Edit

During a transient (TRANSNT on Card 100) or steady-state (STDY-ST on Card 100) problem, additional tables of variables can be printed out by inputting Words 4 and 5 on Card 105, or the tables often will be printed out when a failure occurs. These tables will be discussed in this section. This printout contains key variables from the hydrodynamic and heat transfer subroutines. The main variable in the code

Figure 8.3-3 Example of reflood major edit.

Reflood edit at time=   6.556816E-02 sec

geom.no.	axial nodes number	inc. boil.	critical	rewetting	crit. temp.
	maximum edit	temp.	temp.	temp.	position
		(k)	(k)	(k)	(m)
61	153 59	510.14	555.14	765.14	0.00000E+00

Present position of axial mesh (0.0 is bottom) (m)

0.00000E+00	1.14300E-02	2.28600E-02	3.42900E-02	4.57200E-02	5.71500E-02	6.85800E-02	8.00100E-02	9.14400E-02	0.10287
0.11430	0.12573	0.13716	0.14859	0.16002	0.17145	0.18288	0.27432	0.36576	0.45720
0.54864	0.64008	0.73152	0.82296	0.91440	1.0058	1.0973	1.1887	1.2802	1.3716
1.4630	1.5545	1.6459	1.7374	1.8288	1.9202	2.0117	2.1031	2.1946	2.2860
2.3774	2.4689	2.5603	2.6518	2.7432	2.8346	2.9261	2.9718	3.0175	3.0632
3.1090	3.1547	3.2004	3.2461	3.2918	3.3833	3.4747	3.5662	3.6576	

geom.no.   surface axial mesh point temperatures (k)
and side

61 left	469.29	473.46	477.65	481.84	486.02	490.21	494.40	498.59	502.78	506.97
	511.16	515.34	519.53	523.72	527.91	532.10	536.29	569.80	613.17	656.55
	694.73	732.92	784.23	835.55	883.84	932.11	946.97	961.83	984.99	1008.2
	1033.0	1057.8	1082.7	1107.6	1108.3	1109.0	1097.2	1085.4	1079.5	1073.6
	1032.9	992.32	952.23	912.13	871.17	830.20	780.18	755.16	730.15	713.58
	697.00	680.43	663.85	650.65	637.46	611.06	601.23	591.40	581.57	
61 right	471.45	475.61	479.78	483.95	488.12	492.29	496.46	500.63	504.80	508.97
	513.14	517.31	521.48	525.65	529.82	533.99	538.05	571.30	614.73	658.07
	696.02	733.91	784.68	835.36	882.87	930.31	944.58	958.83	981.16	1003.5
	1027.2	1050.9	1074.5	1098.1	1098.1	1098.0	1085.5	1073.0	1065.7	1058.4
	1016.3	974.46	942.90	910.13	861.79	815.16	768.24	745.17	721.40	705.53
	690.41	674.96	659.10	646.32	633.89	608.50	598.81	589.07	579.50	

Str.no.	side	penetration depth (m)
21-001	inside	0.00000E+00
21-001	outside	3.85866E-09
21-002	inside	0.00000E+00
21-002	outside	3.65601E-08
21-003	inside	0.00000E+00
21-003	outside	1.52705E-07
21-004	inside	0.00000E+00
21-004	outside	3.07263E-07
21-005	inside	0.00000E+00
21-005	outside	3.36703E-07
21-006	inside	0.00000E+00
21-006	outside	2.10397E-07
21-007	inside	0.00000E+00
21-007	outside	7.34253E-08
21-008	inside	0.00000E+00
21-008	outside	1.35699E-08
31-001	inside	0.00000E+00
31-001	outside	4.44638E-09
31-002	inside	0.00000E+00
31-002	outside	5.52415E-08
31-003	inside	0.00000E+00
31-003	outside	2.15746E-07
31-004	inside	0.00000E+00
31-004	outside	3.91791E-07
31-005	inside	1.83263E-07
31-005	outside	2.52239E-07
31-006	inside	0.00000E+00
31-006	outside	2.89031E-07
31-007	inside	0.00000E+00
31-007	outside	9.74868E-08
31-008	inside	0.00000E+00
31-008	outside	1.49986E-08

Total hydrogen generated 3.82445E-04 (kg)

Str.no.	gas gap m,	clad radius m,	ruptured	pressure (pa)
21-001	1.07668E-04	6.15165E-03	no	1.25221E+07
21-002	1.04248E-04	6.15778E-03	no	
21-003	1.02303E-04	6.16311E-03	no	
21-004	1.01429E-04	6.16637E-03	no	
21-005	1.01504E-04	6.16685E-03	no	
21-006	1.02673E-04	6.16458E-03	no	
21-007	1.05300E-04	6.16027E-03	no	
21-008	1.09669E-04	6.15496E-03	no	
31-001	1.04044E-04	6.14859E-03	no	4.13800E+06
31-002	1.00966E-04	6.15537E-03	no	
31-003	9.81420E-05	6.16033E-03	no	
31-004	9.61598E-05	6.16288E-03	no	
31-005	7.39275E-04	6.80334E-03	yes	
31-006	9.92277E-05	6.16150E-03	no	
31-007	1.01248E-04	6.15719E-03	no	
31-008	1.05442E-04	6.15135E-03	no	

Figure 8.3-4 Example of cladding oxidation and rupture major edit.

```
Radiation set  1.  last time when radiation calculation became active was   0.25000
                   last time when radiation calculation became inactive was  0.00000E+00
 Num   str.no.  side    radiation       radiation
                        heat flux       energy
                        (watt/m2)       (watt)
   1   2111-  1 right    8159.0          1507.2
   1   2222-  1 right    8534.2          2627.5
   1   2333-  1 right    7788.8          1918.4
   1   2444-  1 right    6320.7          1264.9
   1   2555-  1 right    677.39          31.282
   1   2666-  1 left    -34278.         -7349.6
         The sum of the radiation energy=  -0.28
```

Figure 8.3-5 Example of radiation major edit.

that activates this output is the variable HELP. Normally, HELP = 0, and no diagnostic printout occurs. The various ways that this diagnostic edit can occur will be presented, along with the value of the variable HELP. Some examples of the type of printout that occurs in the diagnostic edit will also be presented.

One way a diagnostic edit occurs is when it is forced out for more than one time step. This can be done by inputting Words 4 and 5 on Card 105 which sets HELP = 3, which will force out the hydrodynamic diagnostic edit. This, in turn, will set IWRITE = 1 in the heat transfer subroutines, forcing out the heat transfer diagnostic edit. The diagnostic edit will continue to appear for successive time steps until the count number reaches W5. Then, the calculation will stop. This method is often used by the development staff in debugging the code. An example of a diagnostic edit for one time step when HELP = 3 is presented in Appendix B.

Another way a diagnostic edit can occur is to set HELP = 2 with a debugger in any of the hydrodynamic subroutines. This will force out the diagnostic edit for the remainder of the hydrodynamic subroutines in this time step. Then, the time step will be repeated with HELP set to -2 and IWRITE set to 1 in the heat transfer subroutines. As a result, the entire time step will be repeated with the diagnostic edit obtained for the hydrodynamic and heat transfer subroutines. After this, the code continues the calculation with HELP reset to 0, resulting in no further diagnostic edits.

The final way a diagnostic edit can occur is when a code failure occurs. This does not occur for every code failure, but it does occur for a large number of them. When this occurs, HELP will be set to 1 in most cases. When it is set to 1, the diagnostic edit will be forced out for the remainder of the time step. Then, the time step will be repeated with HELP set to -1 and IWRITE set to 1 in the heat transfer subroutines. As with the previous case, the entire time step will be repeated with diagnostic edit obtained for the hydrodynamic and heat transfer subroutines. For this case, however, the calculation terminates and a final major edit plus a minor edit are printed out.

There are two added printouts for this failure case (HELP = -1) that are an aid in tracing the code failure. Just preceding the diagnostic edit, information concerning the reason why the code failed is printed out. This information begins with eight asterisks (********). An example of this printout for the case of a thermodynamic property failure at the minimum time step is shown in the middle of **Figure 8.3-7**. Following this, the old time STATE diagnostic printout is forced out. The other message often printed out for this case (HELP = -1) can usually be buried somewhere within the diagnostic edit. For the example of a thermodynamic property error, information from the STATEP subroutine concerning the faulty volume is printed out (see middle of **Figure 8.3-8**). The information is the label THERMODYNAMIC PROPERTY FAILURE, the volume number (VOLNO), pressure (P), vapor specific energy (UG), liquid specific energy

time (sec)	p 3010000 (pa)	p 3050000 (pa)	p 3100000 (pa)	p 3150000 (pa)	p 3200000 (pa)	quals 3010000	quals 3200000	velfj 3010000 (m/sec)	velgj 3010000 (m/sec)
0.000000E+00	7.00000E+06	7.00000E+06	7.00000E+06	7.00000E+06	7.00000E+06	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2.000000E-03	6.09595E+06	5.59016E+06	3.90506E+06	2.63640E+06	2.62530E+06	0.00000E+00	3.15487E-03	0.21781	0.21781
4.000000E-03	1.37441E+06	1.49439E+06	2.04011E+06	2.53500E+06	2.51717E+06	0.00000E+00	9.50141E-03	0.35402	0.35402
6.000000E-03	1.96118E+06	2.38019E+06	2.55980E+06	2.64681E+06	2.45216E+06	1.03229E-04	1.24858E-02	0.54599	-0.61598
8.000000E-03	2.61603E+06	2.61606E+06	2.63588E+06	2.65547E+06	2.46592E+06	1.67083E-04	1.21614E-02	0.12627	-1.7106
1.000000E-02	2.67931E+06	2.65608E+06	2.65518E+06	2.65501E+06	2.49875E+06	2.04469E-04	1.06812E-02	0.21780	-1.2075
1.200000E-02	2.67327E+06	2.65938E+06	2.65889E+06	2.65107E+06	2.52564E+06	2.45838E-04	9.28386E-03	0.26593	-0.80086
1.400000E-02	2.66856E+06	2.66000E+06	2.65810E+06	2.64618E+06	2.53806E+06	2.92285E-04	8.53122E-03	0.29181	-0.49368
1.600000E-02	2.66440E+06	2.65952E+06	2.65666E+06	2.64487E+06	2.53504E+06	3.41520E-04	8.47477E-03	0.30592	-0.28538
1.800000E-02	2.66036E+06	2.65806E+06	2.65475E+06	2.64555E+06	2.51880E+06	3.92138E-04	8.98618E-03	0.31254	-0.15440
2.000000E-02	2.65624E+06	2.65578E+06	2.65247E+06	2.64469E+06	2.49330E+06	4.43197E-04	9.91746E-03	0.31422	-7.47591E-02
3.000000E-02	2.63579E+06	2.63869E+06	2.63721E+06	2.62933E+06	2.37695E+06	6.90530E-04	1.53013E-02	0.29283	3.46642E-02
4.000000E-02	2.61627E+06	2.61820E+06	2.61488E+06	2.60294E+06	2.35334E+06	9.15933E-04	1.56999E-02	0.26775	5.00349E-02
5.000000E-02	2.59669E+06	2.59811E+06	2.60207E+06	2.59739E+06	2.32639E+06	1.12553E-03	1.61790E-02	0.25628	7.19093E-02
6.000000E-02	2.58577E+06	2.58423E+06	2.58937E+06	2.60217E+06	2.31729E+06	1.33803E-03	1.63810E-02	0.26613	0.11720
7.000000E-02	2.58946E+06	2.58786E+06	2.57899E+06	2.49350E+06	2.30182E+06	1.57807E-03	1.67368E-02	0.27204	0.14126
8.000000E-02	2.59205E+06	2.59227E+06	2.58084E+06	2.45390E+06	2.29184E+06	1.80915E-03	1.68859E-02	0.25649	0.10747
9.000000E-02	2.58958E+06	2.59177E+06	2.58565E+06	2.39619E+06	2.29192E+06	2.03421E-03	1.70636E-02	0.25519	0.10989
0.100000	2.58633E+06	2.58749E+06	2.58992E+06	2.36217E+06	2.28174E+06	2.25691E-03	1.72378E-02	0.25810	0.12238
0.110000	2.58230E+06	2.58331E+06	2.59420E+06	2.34174E+06	2.27952E+06	2.48113E-03	1.73292E-02	0.25970	0.13130
0.120000	2.59000E+06	2.58786E+06	2.60043E+06	2.32430E+06	2.27297E+06	2.70341E-03	1.75719E-02	0.23041	6.28296E-02
0.130000	2.58640E+06	2.58175E+06	2.48120E+06	2.31092E+06	2.26785E+06	2.91332E-03	1.78266E-02	0.24140	9.40326E-02
0.140000	2.58288E+06	2.57279E+06	2.43458E+06	2.30155E+06	2.26280E+06	3.12678E-03	1.80562E-02	0.23671	8.66769E-02
0.150000	2.57992E+06	2.56282E+06	2.39006E+06	2.29433E+06	2.25817E+06	3.34363E-03	1.82649E-02	0.22555	6.39216E-02
0.160000	2.57310E+06	2.55244E+06	2.35333E+06	2.28703E+06	2.25352E+06	3.56586E-03	1.84566E-02	0.22539	6.82506E-02
0.170000	2.56001E+06	2.53912E+06	2.33132E+06	2.27954E+06	2.24833E+06	3.80216E-03	1.86416E-02	0.22808	8.04724E-02
0.180000	2.55186E+06	2.52416E+06	2.31369E+06	2.27185E+06	2.24236E+06	4.05832E-03	1.88338E-02	0.22644	8.31920E-02
0.190000	2.54663E+06	2.43665E+06	2.29849E+06	2.26364E+06	2.23537E+06	4.33389E-03	1.90561E-02	0.25844	0.16503
0.200000	2.53246E+06	2.37423E+06	2.28615E+06	2.25508E+06	2.22724E+06	4.62236E-03	1.93277E-02	0.42554	0.55780
0.210000	2.51779E+06	2.33807E+06	2.27584E+06	2.24647E+06	2.21826E+06	5.11058E-03	1.96530E-02	0.83404	1.5376
0.220000	2.50015E+06	2.31672E+06	2.26673E+06	2.23758E+06	2.20886E+06	8.93717E-03	2.00231E-02	6.1628	11.401
0.230000	2.30867E+06	2.29389E+06	2.25941E+06	2.22924E+06	2.19934E+06	1.81870E-02	2.04248E-02	7.1194	7.4004
0.240000	2.16806E+06	2.22330E+06	2.24440E+06	2.22077E+06	2.19064E+06	2.65854E-02	2.08391E-02	4.2868	3.3204
0.250000	2.09789E+06	2.14246E+06	2.20520E+06	2.20649E+06	2.18064E+06	3.23567E-02	2.12484E-02	2.5818	1.3673
0.260000	2.06772E+06	2.08623E+06	2.14102E+06	2.17666E+06	2.16348E+06	3.65658E-02	2.17062E-02	1.7801	0.48090
0.270000	2.04889E+06	2.05279E+06	2.08302E+06	2.12231E+06	2.12665E+06	4.00966E-02	2.24343E-02	1.5093	0.35386
0.280000	2.02845E+06	2.02863E+06	2.04013E+06	2.05998E+06	2.05637E+06	4.34078E-02	2.38038E-02	1.4108	0.40779
0.290000	2.00588E+06	2.00501E+06	2.00481E+06	1.99889E+06	1.97047E+06	4.66588E-02	2.57386E-02	1.3539	0.48217
0.300000	1.97803E+06	1.97588E+06	1.96501E+06	1.93955E+06	1.89802E+06	4.98339E-02	2.77759E-02	1.3231	0.65219
0.310000	1.93495E+06	1.93150E+06	1.91683E+06	1.88863E+06	1.84206E+06	5.27627E-02	2.98041E-02	1.3268	1.0511
0.320000	1.87558E+06	1.87523E+06	1.87078E+06	1.84232E+06	1.79862E+06	5.53508E-02	3.19419E-02	1.2971	1.2496
0.330000	1.82688E+06	1.82559E+06	1.81483E+06	1.79327E+06	1.74986E+06	5.80595E-02	3.62839E-02	1.2369	1.2114

Figure 8.3-6 Example of minor edit.

(UF), noncondensable quality (QUALA), liquid void fraction (VOIDF), and vapor void fraction (VOIDG). Further information on the specifics of the thermodynamic property failure such as in which phase the failure occurred is usually printed. This particular printout (using the semi-implicit hydrodynamic scheme) is located between the EQFINL and STATE diagnostic printouts. (No MASS ERROR diagnostic occurs for this failure.)

Failures that result in a diagnostic edit with HELP = -1 can be grouped into two cases. The first case occurs when the user is responsible. The thermodynamic property error mentioned above and shown in **Figure 8.3-7** and **Figure 8.3-8** can occur as a result of this. This can occur when the user inputs state properties that are undetected in input processing and thus get into the transient calculation. Thermodynamic property errors are the same as when either the REDUCE-PROPTY or REDUCE-EXTRAP flags are set in the major edit hydrodynamic volume time step control information block (see Section 8.3.2.8). Another example of a user-caused failure is when material property data are out of range. Two more user-caused failures can occur in the case of valves. If both motor valve trips become true at the same time, a failure will result. In addition, if the control system is set up incorrectly and this results in the servo valve stem position not being between 0 and 1, a failure will result. Another example is when a divide by 0 occurs in a control variable. The second case occurs as the result of a coding failure, which can be caused by a programming error or a model deficiency. Such a failure should be reported to the development staff through the RELAP5 User Services. Such errors often result in negative densities, bad viscosities, bad thermal conductivities, or thermodynamic property errors.

8.4 Plotted Output

The two methods normally used to obtain time plots of computed information are described below.

8.4.1 External Plots

The STRIP option (on Card 100) may be used to obtain ASCII data from the RSTPLT file. **Figure 8.4-1** shows an example of a strip input file. Data for all the parameters listed in the input file will appear on an ASCII file called STRIPF. These data must then be processed to put them into a format that is acceptable to the users' plotting software. XMGR could be used to plot data from the STRIPF file. The INEL usually uses XMGR5, an INEL extension to XMGR that adds features to conveniently plot information from restart-plot files or STRIPF files.

If users plan on using external plots, they should make up their strip input file before generating the RSTPLT file because some parameters they may desire are on the RSTPLT file only if they are specifically requested with 208 cards.

8.4.2 Internal Plots

This code feature, designed at the INEL for the CDC-176, has currently not been made compatible with the CRAY and the workstations. The following discussion of this capability is printed so that it will be available after the capability is restored.

A plot package has been provided in RELAP5 so that the user may produce graphs of calculational results. However, because each user may have a different use for the plots, many options are provided so that the user may design and vary the quality of plots as desired. In addition, since it is often necessary to compare the results to experiments or other calculations, a means to input plot comparison data tables has also been provided.

Figure 8.3-7 Example of printout before the diagnostic edit when a failure occurs.

```
At time=    0.000000E+00 sec        str.no.    mesh point temperatures    (k)
61-001     502.48       502.48       502.48       502.48       502.48       502.48       502.48
61-002     569.54       569.54       569.54       569.54       569.54       569.54       569.54
61-003     656.32       656.32       656.32       656.32       656.32       656.32       656.32
61-004     732.58       732.58       732.58       732.58       732.58       732.58       732.58
61-005     835.17       835.17       835.17       835.17       835.17       835.17       835.17
61-006     931.68       931.68       931.68       931.68       931.68       931.68       931.68
61-007     961.37       961.37       961.37       961.37       961.37       961.37       961.37
61-008     1007.7       1007.7       1007.7       1007.7       1007.7       1007.7       1007.7
61-009     1057.3       1057.3       1057.3       1057.3       1057.3       1057.3       1057.3
61-010     1107.0       1107.0       1107.0       1107.0       1107.0       1107.0       1107.0
61-011     1108.4       1108.4       1108.4       1108.4       1108.4       1108.4       1108.4
61-012     1084.9       1084.9       1084.9       1084.9       1084.9       1084.9       1084.9
61-013     1073.1       1073.1       1073.1       1073.1       1073.1       1073.1       1073.1
61-014     991.89       991.89       991.89       991.89       931.89       991.89       991.89
61-015     911.68       911.68       911.68       911.68       911.68       911.68       911.68
61-016     829.82       829.82       829.82       829.82       829.82       829.82       829.82
61-017     729.82       729.82       729.82       729.82       729.82       729.82       729.82
61-018     663.62       663.62       663.62       663.62       663.62       663.62       663.62
61-019     610.82       610.82       610.82       610.82       610.82       610.82       610.82
61-020     591.15       591.15       591.15       591.15       591.15       591.15       591.15

---Restart no.      0 written, block no.      0---

******** Thermodynamic property error with minimum time step, transient being terminated.

******** Trouble, last advancement being repeated with  debug printout.

############################################################################################################################
     state Diagnostic printout, timehy =  6.5567970E-02, dt =  1.9073486E-07, ncount =       1339, help = -1, lsuces =  2, fail = F

Volume mixture properties
============================================================================================================================
    volno     v            p            voidf        quals        dotm         quala        boron        sounde       rho
              vo           pps          voidg        quale        dotmo        sigma        borono       dsnddp       satt
============================================================================================================================
    005010000 0.00000E+00  2.75790E+05  1.0000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1537.8       987.89
              0.00000E+00  2.75790E+05  0.00000E+00 -0.15544      0.00000E+00  5.26935E-02  0.00000E+00  2.72067E+06  403.84
    006010000 2.83055E-03  1.54960E+06  9.46341E-03  0.20025      146.12       0.00000E+00  0.00000E+00  24.186       11.839
              2.83055E-03  1.54960E+06  0.99054      9.54995E-03  146.12       3.78434E-02  0.00000E+00  4.97445E+06  472.99
    006020000 2.83055E-03  1.34989E+06  7.20929E-05  0.98079      -963.41      0.00000E+00  0.00000E+00  707.12       3.4851
              2.83055E-03  1.34989E+06  0.99993      1.0000       -963.41      3.93030E-02  0.00000E+00  3.67281E+06  466.50
    006030000 2.83055E-03  1.26800E+06  2.67725E-04  0.93243      8.6735       0.00000E+00  0.00000E+00  704.85       3.4673
              2.83055E-03  1.26800E+06  0.99973      1.0000       8.6735       3.99465E-02  0.00000E+00  3.65922E+06  463.62
    006040000 2.83055E-03  1.32421E+06  3.87655E-04  0.91149      14.999       0.00000E+00  0.00000E+00  694.77       3.8216
              2.83055E-03  1.32421E+06  0.99961      1.0000       14.999       3.95017E-02  0.00000E+00  3.60120E+06  465.61
    006050000 2.83055E-03  1.39871E+06  4.81529E-04  0.90059      18.214       0.00000E+00  0.00000E+00  685.13       4.2117
              2.83055E-03  1.39871E+06  0.99952      1.0000       18.214       3.89326E-02  0.00000E+00  3.54662E+06  468.15
    006060000 2.83055E-03  1.48181E+06  6.08762E-04  0.88749      19.338       0.00000E+00  0.00000E+00  673.86       4.6874
              2.83055E-03  1.48181E+06  0.99939      1.0000       19.338       3.83229E-02  0.00000E+00  3.48886E+06  470.86
    006070000 2.83055E-03  1.57004E+06  7.46737E-04  0.87685      22.429       0.00000E+00  0.00000E+00  660.78       5.2366
              2.83055E-03  1.57004E+06  0.99925      1.0000       22.429       3.77018E-02  0.00000E+00  3.42392E+06  473.61
    006080000 2.83055E-03  1.66580E+06  9.06057E-04  0.86712      39.730       0.00000E+00  0.00000E+00  647.34       5.8687
              2.83055E-03  1.66580E+06  0.99909      1.0000       39.730       3.70553E-02  0.00000E+00  3.35791E+06  476.47
    006090000 2.83055E-03  1.77436E+06  1.10754E-03  0.85613      103.33       0.00000E+00  0.00000E+00  634.93       6.5977
```

```
006180000  19  8.23918E-02  2.29640E-07  3.40446E-07  1.82739E+06  2.62915E+06  8.85948E+05  0.99870   0.00000E+00  9.8622
               0.74161      0.00000E+00  0.00000E+00  1.82741E+06  2.62915E+06  8.85958E+05  0.99870   0.00000E+00  35.839
006190000  20  4.48173E-02  7.66357E-08  1.73934E-07  1.41060E+06  2.62187E+06  8.31420E+05  0.99907   0.00000E+00  7.6334
               0.35177      0.00000E+00  0.00000E+00  1.41061E+06  2.62187E+06  8.31422E+05  0.99907   0.00000E+30  87.442
006200000  21  2.18821E-02  6.21175E-08  1.16083E-07  8.49402E+05  2.60382E+06  7.31203E+05  0.99948   0.00000E+00  4.6877
               0.24154      0.00000E+00  0.00000E+00  8.49410E+05  2.60382E+06  7.31204E+05  0.99948   0.00000E+00  143.65
007010000  22  0.82303      9.74341E-06  1.19936E-05  2.75790E+05  2.65715E+06  5.49024E+05  1.0000    0.00000E+00  1.2690
               29.009       0.00000E+00  0.00000E+00  2.75790E+05  2.65715E+06  5.49024E+05  1.0000    0.00000E+00  0.00000E+00

******** Thermodynamic property failure, volno=    6010000, p =   1.550289E+06, ug =   4.326621E+06, uf =   3.459355E+01
                                         quala =   0.000000E+00, voidf =   9.463429E-03, voidg =   9.905366E-01
******** Liquid phase property call had error.

########################################################################################################################
    state Diagnostic printout, timehy =  6.5568161E-02, dt =  1.9073486E-07, ncount =        1340, help = -1, lsuces =  2, fail = F
```

Volume mixture properties

volno	v	p	voidf	quals	dotm	quala	boron	sounde	rho
	vo	pps	voidg	quale	dotmo	sigma	borono	dsnddp	satt
005010000	0.00000E+00	2.75790E+05	1.0000	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1537.8	987.89
	0.00000E+00	2.75790E+05	0.00000E+00	-0.15544	0.00000E+00	5.26935E-02	0.00000E+00	2.72067E+06	403.84
006010000	2.83055E-03	1.55029E+06	9.46343E-03	0.22472	146.08	0.00000E+00	0.00000E+00	86.615	10.557
	2.83055E-03	1.55029E+06	0.99054	7.01770E-02	146.12	3.78386E-02	0.00000E+00	4.97394E+06	473.01
006020000	2.83055E-03	1.35004E+06	7.25842E-05	0.98070	-924.80	0.00000E+00	0.00000E+00	707.13	3.4857
	2.83055E-03	1.35004E+06	0.99993	1.0000	-963.41	3.93019E-02	0.00000E+00	3.67286E+06	466.50
006030000	2.83055E-03	1.26804E+06	2.67783E-04	0.93242	8.6740	0.00000E+00	0.00000E+00	704.84	3.4675
	2.83055E-03	1.26804E+06	0.99973	1.0000	8.6735	3.99462E-02	0.00000E+00	3.65918E+06	463.62
006040000	2.83055E-03	1.32424E+06	3.87707E-04	0.91148	15.000	0.00000E+00	0.00000E+00	694.77	3.8217
	2.83055E-03	1.32424E+06	0.99961	1.0000	14.999	3.95015E-02	0.00000E+00	3.60118E+06	465.61
006050000	2.83055E-03	1.39873E+06	4.81578E-04	0.90059	18.212	0.00000E+00	0.00000E+00	685.12	4.2118
	2.83055E-03	1.39873E+06	0.99952	1.0000	18.214	3.89324E-02	0.00000E+00	3.54660E+06	468.15
006060000	2.83055E-03	1.48183E+06	6.08810E-04	0.88749	19.336	0.00000E+00	0.00000E+00	673.86	4.6875
	2.83055E-03	1.48183E+06	0.99939	1.0000	19.338	3.83228E-02	0.00000E+00	3.48884E+06	470.86
006070000	2.83055E-03	1.57006E+06	7.46785E-04	0.87685	22.424	0.00000E+30	0.00000E+00	660.78	5.2368

Figure 8.3-8 Example of printout buried in the diagnostic edit when a failure occurs.

```
=flecht-seaset separate effects reflood calculation: test 31504
*.
100  strip fmtout.
103  0.
1001 httemp        6100407.
1020 tempg         006040000.
1030 voidg         006040000.
1040 quale         006040000.
1041 gammaw        006040000.
1042 vapgen        006040000.
1043 velg          006040000.
1044 velf          006040000.
1050 floreg        006040000.
1060 htrnr         006040101.
1061 hthtc         006040101.
1062 htmode        006100401.
.end.
```

Figure 8.4-1 Strip input file.

For convenience to the user, a check plot option is p__ __ed that will produce plots of input data, such as for time-dependent volumes and junctions, general tables, plot comparison data tables, valve area and flow coefficients, etc. This option can be used by the input of the *check plot* general plot request cards. The plots are constructed upon completion of the third phase of input data processing so that all information processed by the code will be included. Once the option is activated, it will remain in effect for all subsequent restarts and plot only jobs, including restarts with renodalization, until cancelled by the user with appropriate input.

It is assumed that each plot must be uniquely identified, and, hence, the run time, date, and code version is written in the plot margin oriented to appear on the edge that would be placed in a notebook binder. The plot heading and title are written at the top of the plot, and the axes labels and titles are written parallel to the left-hand and bottom axes. In addition, the curves plotted must lie within the axes' extremities and yet span as much of the axes as possible. The axes labeling subdivisions are also rounded to the first significant digit in order to produce simple labels.

Results can be plotted for any NEW or RESTART run. In addition, a PLOT run can be performed for which plots can be made of any variable stored in the plot record on the restart/plot file.

Plot input is analogous to the component input for NEW and RESTART problems in that once plot requests have been input, the resultant plot records and plot comparison data records are written to the restart/plot file. Hence, only input to delete, replace, insert, or add plot requests is required for successive RESTART or PLOT runs. In addition, undefined results are not plotted for components added or deleted by renodalization.

Some user inconvenience is apparent for input of plot comparison data tables because this input must b_ __ an 80-character card image and must be part of the user input stream. If each data table is reasonably small, the user may manually produce the card images on a terminal. The tables may then be stored for future use with RELAP5 runs or be made part of each problem input stream as desired. To produce plot comparison data tables from other restart/plot files, the RELAP5 STRIP option may be used to retrieve results and build plot comparison data tables. If the data are contained on user tapes or disk files, the user can provide programs to build plot comparison data tables in the format required by RELAP5.

8.5 RELAP5 Control Card Requirements

When run under the Unix operating system, the code includes processing of the command line that initiates RELAP5 execution. This processing permits specification of some options and the names of the files such as input, output, and restart-plot files needed for execution (Unix is an operating system available on Cray computers and most workstations.) The command line for execution under Unix is documented in the last section of the Input Data Requirements, Appendix A.

8.6 Transient Termination

The transient advancement should not abort (terminate by operating system intervention) except for exceeding available disk space. Other program aborts such as floating point errors, illegal address, or segmentation faults are indications of programming errors and should be reported to the RELAP5 development staff.

The user may optionally specify one or two trips to terminate a problem. Normal termination is from one of these trips or the advancement reaching the final time on the last time step control card. Minor and major edits are printed and a restart record is written at termination. Since trips can be redefined and new time step cards can be entered at restart, the problem can be restarted and continued.

Transient termination can also occur based on two tests on the CPU time remaining for the job. One test terminates if the remaining CPU time at the completion of a requested time step is less than an input quantity. The second test is similar, but the comparison is to a second input quantity and is made after every time advancement. The input quantity for the first test is larger than for the second test because the preferred termination is at the completion of a requested time step. In either case, the termination can be restarted.

Failure terminations can occur from several sources, including hydrodynamic solution outside the range of thermodynamic property subroutines, heat structure temperatures outside of thermal property tables or functions, and attempting to access an omitted pump curve. Attempting to restart at the point of failure or at an earlier time without some change in the problem input will only cause another failure. Problem changes at restart may allow the problem to be successfully restarted.

Additional information on terminating calculations is presented in Section 3 of Volume V.

8.7 Problem Changes at Restart

The most common use of the restart option is simply to continue a problem after a normal termination. If the problem terminated because it approached the CPU time limit, the problem can be restarted with no changes to information obtained from the restart file. If the problem stopped because the advancement time reached the time end on the last time step card, new time cards must be entered. If the problem was terminated by a trip, the trip causing the termination must be redefined to allow the problem to continue. Thus, the code must provide for some input changes for even a basic restart capability.

The ability to modify the simulated system at restart is a desirable feature. The primary need for this feature is to provide for a transition from a steady-state condition to a transient condition. In many cases, simple trips can activate valves that initiate the transient. Where trips are not suitable, the capability to redefine the problem at restart can save effort in manually transcribing quantities from the output of one simulation to the input of another. One example of a problem change between steady state and transient is

the use of a liquid-filled, time-dependent volume in place of the vapor region of a pressurizer during steady state. The time-dependent volume provides the pressurizer pressure and supplies or absorbs water from the primary system as needed. The time-dependent volume is replaced by the vapor volumes at initiation of the transient. This technique avoids modeling the control system that maintains liquid level and temperature during steady-state calculations when they are not needed in the transient.

Another reason for a problem change capability is to reduce the cost of simulating different courses of action at some point in the transient. An example is a need to determine the different system responses when a safety system continues to operate or fails late in the simulation. One solution is to run two complete problems. An alternative is to run one problem normally and restart that problem at the appropriate time with a problem change for the second case.

The problem change capability could also be used to renodalize a problem for a certain phase of a transient. This has not been necessary or desirable for problems run at the INEL. For this reason, techniques to automate the redistribution of mass, energy, and momentum when the number of volumes changes have not been provided.

The current status of allowed problem changes at restart in RELAP5 are summarized below. In all instances, the problem definition is that obtained from the restart tape unless input data are entered for deletions, modifications, or additions. The problem defined after input changes must meet the same requirements as a new problem.

Time step control can be changed at restart. If time step cards are entered at restart, all previous time step cards are deleted. New cards need only define time step options from the point of restart to the end of the transient.

Minor edit, internal plot input data, and expanded edit/plot variables (2080xxxx) cards can be changed at restart. If any of the minor edit cards are entered, all previous cards are deleted. New cards must define all desired minor edit quantities. The internal plot request data and expanded edit/plot variables (2080xxxx) cards are handled in the same manner.

Trip cards can be entered at restart. The user can specify that all previous trips be deleted and can then define new trips. The user can also specify that the previously defined trips remain but that specific trips be deleted, be reset to false, be redefined, or that new trips be added.

Existing hydrodynamic components can be deleted or changed, and new components can be added. An especially useful feature is that the tables in time-dependent volumes and junctions can be changed. If a component is changed, all of the cards for the component must be entered.

Control system components can be deleted, changed, or added.

Heat structures, general tables, and material properties can also be deleted, changed, or added. Heat structures can only be changed at the level of heat structure geometry. When the heat structure geometry is changed, all heat structures referencing that heat structure geometry are affected. Individual general tables and material properties can be added, deleted, or changed.

Reactor kinetics can be added or deleted on restart. A complete set of reactor kinetics data must be input, i.e., individual sections of kinetics data may not be specified as replacement data.

In summary, all modeling features in RELAP5 can be added, deleted, or changed at restart.

APPENDIX A

INPUT REQUIREMENTS

CONTENTS

TABLES

A1 INTRODUCTION

This appendix completely describes data deck organization and data card requirements for all problem types allowed in RELAP5/MOD3.2.

A1.1 Control Format

Input is described in terms of input records or cards, where an input record or card is an 80-character record. Punched cards are nearly obsolete and one would be hard-pressed to find a key punch machine at most installations. Now, data are normally entered from interactive terminals, personal computers, or workstations, and the input usually exists only as disk files or is archived on tape. Data are usually viewed as lines on a CRT screen or lines of printed output. Nonetheless, the word card in used extensively in this input description to mean an input record.

RELAP5 attempts to read a 96-character record. If the actual input record is smaller, blank characters are added to the end of the input record to extend it to 96 characters. Each 96-character input record, preceded by a sequential card number starting at one and incrementing by one, is printed as the first part of a problem output. Only the first 80 characters are used for RELAP5 input; the additional 16 columns are for use with editors or utility programs such as UPDATE.

Most interactive editors allow the input of at least 80 character records. With many terminals allowing only 80 characters per line, it is convenient to limit the data record to 72 characters so that the data and editor supplied line numbers fit on one line (eight columns for line number and separator, 72 columns of data). Some editors provide for the optional storing of editor line numbers following the data portion of the record. If the data field is 72 columns, the line numbers might be stored in columns 73 to 80. These line numbers will be processed by RELAP5 as input, since RELAP5 uses the first 80 characters. To avoid this, either request the editor to store line numbers starting at character position 81, put a terminating character before the line number, or don't store the line numbers. The line numbers, if saved, are listed in the output echo of the input data.

If the UPDATE program is used to maintain the input deck, the update command must be used to specify that the card data are 80 columns instead of the default of 72.

A1.2 Data Deck Organization

A RELAP5 problem input deck consists of at least one title card, optional comment cards, data cards, and a terminator card. A list of these input cards is printed at the beginning of each RELAP5 problem. The order of the title, data, and comment cards is not critical except that only the last title card and, in the case of data cards having duplicate data card numbers, only the last data card is used. We recommend that for a base deck, the title card be first, followed by data cards in card number order. Comment cards should be used freely to document the input. For parameter studies and for temporary changes, a new title card with the inserted, modified, and deleted data cards and identifying comment cards should be placed just ahead of the terminating card. In this manner, a base deck is maintained, yet changes are easily made.

When card format punctuation errors, such as an alphanumeric character in numeric fields are detected, a line containing a caret (^) located under the character causing the error and a message giving the card column of the error are printed. An error flag is set such that input processing continues, but the RELAP5 problem is terminated at the end of input processing. A standard RELAP5 error message (error message preceded by ********) is printed if a card error is found. Usually a card error will cause

additional error comments to be printed during further input processing when the program attempts to process the erroneous data.

A1.3 Title Card

A title card must be entered for each RELAP5 problem. A title card is identified by an equal sign (=) as the first nonblank character. The title (remainder of the title card) is printed as the second line of the first page following the list of input data. If more than one title card is entered, the last one entered is used.

A1.4 Comment Cards

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

A1.5 Data Cards

Data cards may contain varying numbers of fields that may be integer, real (floating point), or alphanumeric. Blanks preceding and following fields are ignored.

The first field on a data card is a card identification number that must be an unsigned integer. The value for this number depends upon the data being entered and will be defined for each type. If the first field has an error or is not an integer, an error flag is set. Consequently, data on the card are not used, and the card will be identified by the card sequence number in the list of unused data cards. After each card number and the accompanying data are read, the card number is compared to previously entered card numbers. If a matching card number is found, the data entered on the previous card are replaced by data from the current card. If the card being processed contains only a card number, the card number and data from the last previous card with that card number are deleted. Deleting a nonexistent card is not considered an error. If a card causes replacement or deletion of data, a statement is printed indicating that the card is a replacement card.

Comment information may follow the data fields on any data card by beginning the comment with an asterisk (*) or dollar ($) sign.

A numeric field must begin with either a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or blank (with one exception, subsequently noted) terminates the numeric field. The numeric field has a number part and optionally an exponent part. A numeric field without a decimal point or an exponent is an integer field; a number with either a decimal point, an exponent, or both is a real field. A real number without a decimal point (i.e., with an exponent) is assumed to have a decimal point immediately in front of the first digit. The exponent part denotes the power of ten to be applied to the number part of the field. The exponent part has an E or D, a sign (+ or -), or both followed by a number giving the power of ten. These rules for real numbers are identical to those for entering data in FORTRAN E or F fields except that no blanks (with one exception) are allowed between characters to allow real data written by FORTRAN programs to be read. The exception is that a blank following an E or D denoting an exponent is treated as a plus sign. Acceptable ways of entering real numbers, all corresponding to the quantity 12.45, are illustrated by the following six fields:

12.45, +12.45, 0.1245+2. 1.245+1, 1.245E 1, 1.245D+1 .

Alphanumeric fields have three forms. The most common alphanumeric form is a field that begins with a letter and terminates with a blank, a comma, or the end of the card. After the first alphabetic character, any characters except commas and blanks are allowed. The second form is a series of characters delimited by quotes (") or apostrophes ('). Either a quote or an apostrophe initiates the field, and the same character terminates the field. The delimiters are not part of the alphanumeric word. If the delimiter character is also a desired character within the field, two adjacent delimiting characters are treated as a character in the field. The third alphanumeric form is entered as nHz, where n is the number of characters in the field, and the field starts at the first column to the right of H and extends for n columns. With the exception of the delimiters (even these can be entered if entered in pairs), the last two alphanumeric forms can include any desired characters. In all cases, the maximum number of alphanumeric characters that can be stored in a word is eight. If the number of characters is less than eight, the word is left justified and padded to the right with blanks. If more than eight characters are entered, the field generates as many words as needed to store the field, eight characters per word, and the last word is padded with blanks as needed. Regardless of the alphanumeric type, at least one blank or comma must separate the field from the next field.

Note that the CDC-7600-6600 class of computers stores ten characters per word, while most other computers (e.g., CRAY, Cyber 205, and IBM) hold only eight characters per word. All alphanumeric words required by RELAP5, such as components types, system names, or processing options, have thus been limited to eight characters. We highly recommend that the user limit all other one-word alphanumeric quantities to eight characters so that input decks can be easily used on all computer versions. Examples of such input are alphanumeric names entered to aid identification of components in output edits.

A1.6   Continuation Cards

A continuation card, indicated by a plus sign (+) as the first nonblank character on a card, may follow a data card or another continuation card. Fields on each card must be complete, that is, a field may not start on one card and be continued on the next card. The data card and each continuation card may have a comment field starting with an asterisk (*) or dollar ($) sign. No card number field is entered on the continuation card, since continuation cards merely extend the amount of information that can be entered under one card number. Deleting a card deletes the data card and any associated continuation cards.

A1.7   Terminator Cards

The input data are terminated by a slash or a period card. The slash and period cards have a slash (/) and a period (.), respectively, as the first nonblank character. Comments may follow the slash and period on these cards.

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

When a period card is used as the problem terminator, all previous input is erased before the input to the next problem is processed.

A1.8   Sequential Expansion Format

Several different types of input are specified in sequential expansion format. This format consists of sets of data, each set containing one or more data items followed by an integer. The data items are the parameters to be expanded, and the integer is the termination point for the expansion. The expansion begins at one more than the termination point of the previous set and continues to the termination point of the current set. For the first set, the expansion begins at one. The termination points are generally volume, junction, or mesh point numbers, and always form a strictly increasing sequence. The input description will indicate the number of words per set (always at least two) and the last terminating point. The terminating point of the last expansion set must equal the last terminating point. Two examples are given. For the volume flow areas in a pipe component, the format is two words per set in sequential expansion format for nv sets. Using the number of volumes in the pipe (nv) as 10, the volume flow areas could be entered as

0010101 0.01,10 .

In this case, the volume flow areas for volumes 1 through 10 have the value 0.01.

The second example shows how the pipe volume friction data could be input. The input consists of three words per set for nv sets. The three words designate the wall roughness, hydraulic diameter (input of zero causes the code to calculate it), and volume number. Possible data might be

0010801 1.0-6,0,8 1.0-3,0,9

0010802 1.0-6,0,10 .

Here, volumes 1 through 8 and 10 have the same values, and volume 9 has a different value.

A1.9   Upper/Lower Case Sensitivity

Historically, computer systems allowed only upper case alphabetic characters. Accordingly, the following input descriptions use upper case for required input, e.g., SNGLVOL, 1.25E5. Now, many systems have upper and lower case alphabetic characters, and some applications are case sensitive, others not. At the INEL, required input must be in lower case, and the user should check the requirements at other installations. At installations with both upper and lower case capability, there are utilities and editors that can easily switch alphabetic characters to the desired case.

A1.10   Data Card Requirements

In the following description of the data cards, the card number is given with a descriptive title of the data contained on the card. Next, an explanation is given of any variable data that are included in the card number. Then, the order of the data, the type, and the description of the data item are given. The type is indicated by A for alphanumeric, I for integer, and R for real.

A2 MISCELLANEOUS CONTROL CARDS

A2.1 Card 1, Developmental Model Control

This card has been added to the code for the convenience of developers in testing model improvements or new models. This card is not a standard input feature of the code. The description of this card has been added to the input requirements because several laboratories are receiving test versions to assist in the development and testing of the code. Anyone using this card must realize that they are selecting experimental options still under development. Furthermore, these options may change more frequently that the revision of this input manual. Thus, before using the options, users should obtain the brief listing of current options from the code (described below) and verify those descriptions against this manual.

The purpose of this card is to allow developers and analysts to quickly test new models by activating or deactivating a model through simple input instead of program modification, compilation, and loading. Ninety logical variables having only false or true values are provided and defined at the start of program execution as false. This input sets the logical variables to true or resets them to false at the beginning of a new problem or at any restart. Fortran IF statements added as part of the experimental coding activate or deactivate models based on the values of the logical variables.

As described above, up to 90 options can be defined and the options are identified with a number from 1 through 90. Which options are defined and what they control are very much version dependent. The usual practice is to enter the option capability using a currently unused option number as the new model or improvement is first coded. During further development and testing, the model may change and the effect of the option can change in a manner ranging from large to subtle. When the model has been completed or even abandoned, the production version of the model is coded and the option capability is removed. The option number is then available for reuse with a completely different model. Thus, the options are version dependent as to what option numbers are in use, what models they control, and the particular features of the models. Accordingly, these options should be used only by those in direct contact with the developers.

Each current option is described below. In light of the discussion above, the user should verify that the code version being used corresponds to this description. Programmers using this option feature are asked to include coding that issues error messages when unused options are selected and to issue a brief statement of the purpose of selected options. Remember, however, that all coding associated with these options is experimental and these output conventions may not be thoroughly checked.

Up to 91 numbers consisting of 0 or any of the currently available option numbers may be entered on this card. A positive nonzero number, n, activates Option n by setting the logical variable n to true; a negative nonzero number, -n, deactivates Option n by setting the logical variable n to false. Attempting to activate an unused option is an error, and attempting to deactivate an already inactive option or an unused option is also an error. The status of the options is printed in any NEW or RESTART problem containing this card or a RESTART problem in which the restart point had an option selected. The printout includes a listing of the 90 option numbers and a false (option not selected) or a true (option selected) value plus the brief description of each selected option.

The number 0 is not an option number but may be entered to force the brief descriptions of all available options to be printed regardless of whether they are active. The 0 input should be used only once to observe the available options and then removed so that the list better emphasizes the selected options.

W1-20(I)   Zero or an available option number as described above.

Option 23.   This options selects a boron transport algorithm that greatly reduces the numerical diffusion of boron compared to the standard algorithm.

Option 37.   This option turns off the umbrella model. When the umbrella model is on, an upper limit is placed on the liquid interfacial heat transfer coefficient (H_{if}) when the liquid is subcooled. The limit is umbrella shaped so as to force the coefficient to small values as the void fraction approaches 0.0 or 1.0.

Option 51.   Normally, water packing is activated in all volumes unless specifically disabled by an input volume flag. This option disables water packing for all volumes.

Option 52.   Normally, the choking model is activated for all junctions unless specifically disabled by an input junction flag. This option disables the choking model for all junctions.

A2.2   Card 100, Problem Type and Option

This card is always required.

W1(A)   Problem type. Enter one of the following: NEW, RESTART, PLOT, REEDIT, STRIP, or CMPCOMS.

                NEW specifies a new simulation problem. NEWATH must be used for ATHENA problems. ATHENA provides hydrodynamic fluids in addition to light and heavy water; access to these fluids require the use of NEWATH in place of NEW. RESTART specifies continuation from some point in a previous problem using information from the RSTPLT file. PLOT specifies plotting results from a previous simulation run using the RSTPLT file. REEDIT has not been implemented. STRIP specifies that data are to be extracted (stripped) from the RSTPLT file, and only the data specified are written to the STRIP file. CMPCOMS specifies that a comparison is to be made between dump records on two files written in one or two previous runs.

W2(A)   Problem option. This word is needed if W1 is NEW or RESTART and is optional if W1 is STRIP. If NEW or RESTART is entered, enter either STDY-ST or TRANSNT to specify the type of simulation. Note the cautions discussed in Section A2.5 when the problem option is changed from STDY-ST to TRANSNT or vice versa. When STRIP is entered in W1, W2 may be optionally entered with BINARY or FMTOUT. BINARY is assumed if W2 is not entered. BINARY indicates the unformatted (BUFFER OUT) file. FMTOUT indicates that the same information is to be written as 80-column formatted records. One use of this option is to allow simulation results to be transmitted to a different type of computer. Formats are

                STRIP Record 1. (5A8,10X,A8)

                STRIP Record 2. (A10,3I10)

                STRIP Record 3. (8A10)

STRIP Record 4. (A10,7I10/(8I10))

STRIP Record 5..., N. (A10, 5X,1P,4E15.6/(5E15.6)).

The STRIP record above refers to the data in one record of the unformatted file. Multiple 80-column formatted records may be written for STRIP Records 3 through n.

A2.3   Card 101, Input Check or Run Option

This card is optional for all types.

W1(A)   Option. Enter either INP-CHK or RUN; if this card is omitted, RUN is assumed. If INP-CHK is entered, the problem execution stops at the end of input processing; if RUN is entered, the problem is executed if no input errors are detected. This card has no effect on a CMPCOMS problem.

A2.4   Card 102, Units Selection

This card is optional for all problem types. If the card is omitted, SI units are assumed for both input and output. If the card is used, enter either SI or BRITISH for each word. SI units used are the basic units, kg, m, s, and the basic combined units such as $Pa = kg \bullet m/s^2 \bullet m^2$. British units are a mixture of lb (mass), ft, and s primarily, but pressure is in lb_f/in^2 (lb_f is pounds force), heat energy is in Btu, and power is in MW. Thermal conductivity and heat transfer units use s, not h.

W1(A)   Input units.

W2(A)   Output units. If this word is missing, SI units are assumed for output.

A2.5   Card 103, Restart Input File Control Card

This card is required for all problem types (W1 of Card 100) except NEW and is not allowed for type NEW.

When the problem option (W2 on Card 100) is the same as the problem being restarted, the steady state or transient is continued, and data on the RSTPLT file up to the point of restart are saved. If the restart continues from the point the previous problem terminated, restart and plot information is added to the end of the previous RSTPLT file. If the restart is prior to the termination point of the previous simulation, restart and plot data after the point of restart are overwritten by new results. A copy should be saved if RSTPLT files from each simulation are needed. If the problem options are different, data up to the point of restart are not saved, problem advancement time is reset to zero, and the RSTPLT file will contain information as if this problem type were NEW.

Some cautions should be observed when the problem advancement time is changed by changing the problem option from STDY-ST to TRANSNT, or vice versa, or the problem advancement time is reset through W1 on Card 200. Either or both of these could be specified at restart. When the advancement time is changed, the user is responsible for ensuring that models involving problem time will operate as intended. Affected models include trips using advancement time, control systems using time as an operand (does not include differentiation or integration with respect to time), and table lookup and interpolation

using time as the independent variable. If necessary, trips, control systems, general tables, time-dependent volumes, junctions, and pump speed tables can all be reentered at restart. With normal modeling practices, little use of modeling features involving advancement time is needed for runs to steady state and accordingly little effort should be needed in switching from STDY-ST to TRANSNT. Because of the frequent use of time in logic to initiate failures, as part of safety systems, and used in establishing the delay times allowed in most table lookup and interpolation tables, required changes to a transient run may be extensive.

The program does make a change to delay control components when the advancement time is changed. The delay control component operates by maintaining a tabular past history of the delayed functions and using table lookup and interpolating to evaluate the delayed function. The table consists of pairs of time values and the delayed function. When the problem time is changed, the time values in the history table and the time value to store the next point in the table are modified by adding the difference of the new advancement time and the old advancement time. The modified history table is as if the problem being restarted was run with the new advancement time. This may not be the desired change, and, in that case, the user can reenter the delay component.

W1(I)   Restart number. This must be a number printed in one of the restart print messages and whose associated restart information is stored in the RSTPLT file. If the problem type (W1 on Card 100) is STRIP, this number must be 0.

W2(A)   Compress flag. This optional flag indicates whether the restart-plot file is written in a noncompressed or compressed format. If the word is not entered or if NCMPRESS is entered, the restart plot file is assumed to be in noncompressed format. If CMPRESS is entered, the restart plot file is assumed to be in compressed format.

W3-7(A)   Restart plot file name. This optional alphanumeric entry can be used to enter the file name of the restart plot file. Up to forty characters may be entered as one alphanumeric field. (The code internally treats the field as up to five eight-character words.) The default file name for the restart plot file is rstplt. This may be overridden on Unix machines by using the -r option on the command line. Either the default name, the name from the command field, or the name from this field on a previous case may be overridden by this field.

A2.6   Card 104, Restart-Plot File Control Card

This card can be entered for NEW, RESTART, and STRIP options. For the strip option, this card controls the strip file, and the NONE option is not allowed. If this card is omitted, the restart-plot file is rewound at the end of the problem, but no further action is taken. The user may need to provide system control cards to dispose of the file. To prevent the restart-plot file from being written, a card with NONE must be entered.

W1(A)   Action. This word may not be blank. If the card is NONE, no restart-plot file is written. If this word is NCMPRESS, the restart-plot file is written in noncompressed format. If this word is CMPRESS, the file is written in compressed mode. The NCMPRESS and CMPRESS options may be entered only in NEW problems. In RESTART problems, this information is entered on the 103 card.

W2-6(A)   Restart plot file name. This optional alphanumeric entry can be used to enter the file name of the restart plot file. Up to forty characters may be entered as one alphanumeric field.

(The code internally treats the field as up to five eight-character words.) The default file name for the restart plot file is rstplt. This may be overridden on Unix machines by using the -r option on the command line. Either the default name, the name from the command field, or the name from this field on a previous case may be overridden by this field. This information can be entered only on NEW problems; in RESTART problems, this information may be entered on the 103 card.

A2.7   Card 105, CPU Time Remaining and the Diagnostic Edit Card

Card 105 controls termination of the transient advancement based on the CPU time remaining for the job. Some operating systems allow specification of the CPU time allocated for a job as part of the job control language and also provide a means to determine the CPU time remaining during job execution. As an alternative, Word 3 of this card may be entered as the CPU time allocated. An alternative CPU remaining time is computed by decrementing this quantity by the CPU used as measured by the program. If Word 3 is omitted or zero, the alternative CPU remaining time is assumed infinite. At the end of each time step, the CPU time remaining for the job is determined from the minimum of the system (if available) and alternative CPU remaining times. If the remaining CPU time is less than Word 1, the transient is immediately terminated. The advancement may not be at the end of a requested time step due to time step reduction; the hydrodynamic, heat conduction, and reactor kinetics may not be advanced to the same point; or the advancement may not be successful and the advancement is scheduled to be repeated with reduced time step. Major edits, minor edits, plot edits, and a restart record are forced. The transient can be restarted from this point as if the problem had not been interrupted. The transient is also terminated after successful advancement over a requested time step and the CPU time is less than Word 2. Word 2 should be larger than Word 1. The default values for Words 1 and 2 are 1.0 and 2.0 seconds. The default values are used if the card is not supplied or the entered numbers are less than default values. Word 2 is also forced to be 1.0 seconds larger than Word 1. The time values must include time for the final minor and major edits (very little time required), plotting, and any other processing that is to follow termination of SCDAP execution. This card is optional, but we strongly recommend its use with Word 3 nonzero on systems that do not provide a system CPU limit.

Card 105 also controls the diagnostic edit printout through the use of Words 4 and 5. If these words are missing or zero, no debug options are in effect. If Word 4 is greater than zero, then Word 4 is the attempted advancement count number to start a diagnostic edit, and Word 5 is the attempted advancement count number to stop the diagnostic edit as well as the calculation. If Word 4 is -1, a dump file is written on the file specified by the -A option on the command line at the completion of the advancement given in Word 5. Entering 0 in Word 5 writes the dump file just before the start of transient advancement. The problem is terminated after writing the dump file. If Word 4 is -2, a dump file is written on the file given by the -A option after the advancement given in Word 5; the time advancement is then repeated and a dump file following the repeated advancement is written on the file given by the -B option. The problem is terminated after writing the second dump file. Word 5 must be greater than 0 when Word 4 is -2. The default file names are -A dumpfil1 and -B dumpfil2.

W1(R)   CPU remaining limit 1 (s).

W2(R)   CPU remaining limit 2 (s).

W3(R)   CPU time allocated (s). This quantity is optional.

W4(I)   Debug control word as described above.

W5(I)   Debug control word as described above.

If the program is compiled with compile time option CTSS defined, entering Word 1 as 0.0 will cause no testing for CPU termination and normal CTSS termination at the end of CPU time can occur. In this case, the problem can be restarted.

A2.8   Card 110, Noncondensable Gas Species

This card is required for all calculations that use noncondensable gas. Nitrogen must be included for any problem having accumulators or specifying noncondensables in initial conditions or time-dependent volumes.

W1-WN(A)   Noncondensable gas type. Enter any number of words (maximum 5) of the following noncondensable gas types: argon, helium, hydrogen, nitrogen, xenon, krypton, air, or sf6.

A2.9   Cards 115 , Noncondensable Mass Fractions

Card 115 is related to Card 110. Card 115 is required if Card 110 is entered unless only one species is entered on Card 110, and then the mass fraction is set to 1.0. The number of words on Card 115 must equal the number of words on Card 110. The sum of the mass fractions on each card must sum to one. The mass fractions on these cards are default values and are used for initial conditions of active volumes and for values of time-dependent volumes unless mass fractions are entered in the hydrodynamic component data.

A2.9.1   Card 115, Initial Mass Fraction for Each Noncondensable Gas Type

This card is required if Card 110 is entered, unless only one species is entered on Card 110 and then the mass fraction is set to 1.0. The number of words on Card 115 must equal the number of words on Card 110. This card cannot be entered on a RESTART problem.

W1-WN(R)   Mass fraction for each noncondensable gas type.

A2.10   Cards 120 through 129, Hydrodynamic System Control Cards

Independent hydrodynamic systems can be described by the hydrodynamic component input. The term independent hydrodynamic systems means that there is no possibility of flow between the independent systems. A typical example would be the primary and secondary systems in a reactor where heat flows from the primary system to the secondary system in the steam generator but there is no fluid connection. If a tube rupture were modeled, the two systems would no longer be independent. Input processing lists an elevation for each volume in each independent hydrodynamic system and includes a check on elevation closure for each loop within a system. A reference volume is established for each system through input or default.

The processing for elevation changes and checks on proper loop closure is extended for moving problems. An elevation change in a volume is the component on the fixed z axis of a movement from one face of the volume to the opposite face. In a fixed problem, the only body force is gravity along the negative z axis. With translational and r   'onal movement, additional body forces with components in all three directions are possible. Analogo   elevations changes, the components along each fixed axis due to the face to face movements alon   ch coordinate direction in a volume are required. In moving problems, the loop closure test and associated edited output is done for all three fixed axes.

These cards are optional for each system but these cards will be needed for most moving problems. If not entered for a system, that system contains H_2O as the fluid unless a different fluid is specified in hydrodynamic component data, and the lowest numbered volume in each system is the reference volume. Additionally, the reference volume has a default elevation of zero for fixed problems and position coordinates of zero for a moving problem. These cards should not be entered in a RESTART problem.

In fixed problems, the ability of entering a reference elevation is only a user convenience to perhaps facilitate checking edited elevation data against facility drawings. In moving problems, the information is used in computing rotation effects. The specification of the position coordinates of the reference volume implies an origin, and using volume input information, the position coordinates of each volume in the system. The rotation is assumed to be about the origin implied by the position of the reference volume. The position coordinates of each volume are updated each time step and the position data can be plotted or printed in minor edits. The effects of translation are included when computing forces on the fluid within a volume but are not included in the computation of position coordinates. Thus during rotation and translation, the coordinates may change but the magnitude of the position vector remains constant.

A2.10.1 Hydrodynamic System Card

W1(I)   Reference volume number. This must be a volume in the hydrodynamic system.

W2(R)   Reference elevation of the volume center relative to a fixed z axis (m, ft).

W3(A)   Fluid type. Enter H2O or D2O.

W4(A)   Optional alphanumeric name of system used in output editing. *NONE* is used if this word not entered.

A2.11   Cards 140 through 147, Self-Initialization Option Control Cards

These cards are optional, are not needed, and are only used as a cross-check on the controllers specified in Section A14. Data supplied on these cards are used to invoke the self-initialization option. These data describe which and how many of each controller will be used. To retain generality and flexibility, the self-initialization option does not require that the steady state and nearly implicit solution scheme options be concurrently turned on. However, this is the recommended procedure. These latter options are invoked through input data Cards 100 and 201 through 299. In addition to the data cards described below, the user must furnish data on the controllers to be used. as described in Section A14.

A2.11.1   Card 140, Self-Initialization Control Card

This card specifies the number and type of controllers desired.

W1(I)   Number of pump controllers.

W2(I)   Number of steam flow controllers.

W3(I)   Number of feedwater controllers.

A2.11.2   Cards 141 through 142, Self-Initialization Pump Controller and Identification

Cards

These cards establish the relationship between the pump number and the number of the pump controller. For each pump so referenced, the user *must* use the time-dependent pump velocity option. For pump component Card ccc6100, Words 2 and 3 must be the alphanumeric and numeric parts for the pump controller. The time-dependent pump velocity data (pump component Cards ccc6100 through ccc6199) should be input so that the search variable and pump velocity are related by a straight line through the origin with a slope of 1.

W1(I)   Component number of pump number

W2(I)   Controller identification number for pump number 1

W3(I)   Component number of pump number 2

W4(I)   Controller identification number for pump number 2.

A maximum of six pump/controller pairs may be entered.

A2.11.3   Cards 143 through 144, Self-Initialization Steam Flow Controller Identification Cards

These cards establish the relationship between the steam flow control valve number and the steam flow controller number.

W1(I)   Component number of steam flow control valve number 1

W2(I)   Controller number of steam flow controller for steam flow control valve number 1

W3(I)   Component number of steam flow control valve number 2

W4(I)   Controller number of steam flow controller for steam flow control valve number 2.

A maximum of six control valve/controller pairs may be entered. Note that in the above the valve component is assumed to be the control component. However, the user is not constrained to use a valve and may use a pump or a time-dependent junction. CAUTION: only a servo valve, a time-dependent junction, or a pump may be used, or a diagnostic error will result.

A2.11.4   Cards 145 and 146, Self-Initialization Feedwater Controller Identification Cards

These cards establish the relationship between the feedwater valve number and the feedwater controller number.

W1(I)   Component number of feedwater valve number 1

W2(I)   Controller id number of the feedwater controller for feedwater valve number 1

W3(I)   Component number of feedwater valve number 2

W4(I)   Controller id number of the feedwater controller for feedwater valve number 2.

A maximum of six control valve/controller pairs may be entered. Note that in the above it is assumed that a valve component is the control component. However, the user is not constrained to use a valve and may use a pump or time-dependent junction. CAUTION: only a servo valve, time-dependent junction, or a pump is allowed, or a diagnostic will result, such as a time-dependent junction with the controller output used as the independent variable in place of time.

A2.11.5 Card 147, Pressure and Volume Control Component Identification Card

This card identifies the component number, connection data, and pressure level for the time-dependent volume that is to provide pressure and volume control during the self-initialization null transient.

W1(I)   Component number of time-dependent volume that replaces the pressurizer

W2(I)   Component number to which the above time-dependent volume is connected; CAUTION: only a single junction is allowed or an error will result

W3(R)   Desired steady state pressure.

A3 CARDS 200 THROUGH 299, TIME STEP CONTROL CARDS

A3.1   Card 200, Initial Time Value and User Controlled Time Step

This card is optional. See the description of each word on this card for the default values if this card is not entered.

W1(R)   Initial time. If not entered, the simulation time at the start of the advancements is zero for a NEW problem, the advancement time at the point of restart for a RESTART problem, or zero for a RESTART problem in which the problem option switches from STDY-ST to TRANSNT or vice versa. If this card is entered, the simulation time is set to the entered value, which must be greater than or equal to zero. Setting the simulation time with this entry can be done on any NEW or RESTART problem but with most applications should only be used in NEW or RESTART problems that switch from the STDY-ST or TRANSNT options. See the cautions discussed in Section A2.5 for this capability. When needing to enter W2 but do not wish to enter a new initial time, enter -1.0, which is a flag to ignore this word.

W2(I)   Control variable number for user controlled time step. This word is optional. A nonzero number specifies a control variable whose value is used for user-specified time step control. The time step will be determined from the maximum of the value of the control variable and the current minimum time step entered on Cards 201 through 209. The time step will be equal to or less than this value and depends on the current requested time step, the mass error and other error checks, the Courant limit, and the time-step reduction options.

A3.2   Cards 201 through 299, Time Step Control

At least one card of this series is required for NEW problems. If this series is entered for RESTART problems, it replaces the series from the problem being restarted. This series is not used for other problem types. Card numbers need not be consecutive.

W1(R)   Time end for this set (s). This quantity must increase with increasing card number.

W2(R)   Minimum time step (s). This quantity should be a positive number $\leq$ 1.0E-6. If a larger number is entered, it is reset to 1.0E-6.

W3(R)   Maximum time step (s). This quantity is also called the requested time step. In transient problems (Word 2 = TRANSNT for Card 100), the user should be careful not to make this too large for the first time step.

W4(I)   Control option (see Section 8.2 for a discussion of this input). This word has the packed format ssdtt. It is not necessary to input leading zeros.

      The digits ss, that represent a number from 0 through 15, are used to control the printed content of the major edits. The number is treated as a four-bit binary number. If no bits are set (i.e., the number is 0), all the standard major printed output is given. If the first bit from the right is set (i.e., ss=1 if the other bits are not set), the heat structure temperature block is omitted. If the second bit from the right is set (i.e., ss=2 if the other bits are not set), the

second portion of the junction block is omitted. If the third bit from the right is set (i.e., ss=4 if the other bits are not set), the third and fourth portions of the volume block is omitted. If the fourth bit from the right is set (i.e., ss=8 if the other bits are not set), the statistics block is omitted.

The digit d, which represents a number from 0 through 7, can be used to obtain extra output at every hydrodynamic time step. The number is treated as a three-bit binary number. If no bits are set (i.e., the number is 0), the standard output at the requested frequency using the maximum time step is obtained (see words 5 and 6 of this card). If the number is nonzero, output is obtained at each successful time step; and the bits indicate which output is obtained. If the first bit from the right is set (i.e., d=1 if the other bits are not set), major edits are obtained every successful time step. If the second bit from the right is set (i.e., d=2 if the other bits are not set), minor edits are obtained every successful time step. If the third bit from the right is set (i.e., d=4 if the other bits are not set), plot records are written every successful time step. These options should be used carefully, since considerable output can be generated.

The digits tt, that represent a number from 0 through 31, are used to control the time step. The number is treated as a four-bit binary number. The effect of no bits being set, i.e., 0 being entered, and the effect of each bit are first described followed by the recommended combination of bits

If no bits are set (i.e., the number is 0), no error estimate time step control is used, and the maximum time step is attempted for both hydrodynamic and heat structure advancement. The hydrodynamic time step, however, is reduced to the material Courant limit and further to the minimum time step for causes such as water property failures. If the first bit from the right is set (i.e., tt=1 if no other bits are set), the hydrodynamics advancement, in addition to the time step control when no bits are set, uses a mass error analysis to control the time step between the minimum and maximum time step. If the second bit from the right is set (i.e., tt=2 if the other bits are not set), the heat conduction/transfer time step is the same as the hydrodynamic time step; if the second bit from the right is not set, the heat conduction/transfer time step uses the maximum time step. If the third bit from the right is set (i.e., tt=4 if the other bits are not set), the heat conduction/transfer and hydrodynamics are coupled implicitly; if the third bit from the right is not set, the heat conduction/transfer and hydrodynamic advancements are done separately and the information between the models is coupled explicitly. If the fourth bit from the right is set (i.e., tt=8 if the other bits are not set), the nearly-implicit scheme is used to advance the hydrodynamics; if the fourth bit from the right is not set, the semi-implicit scheme is used to advance the hydrodynamics. If the fifth bit from the right is set (i.e., tt=16 if the other bits are not set), the test for convergence of a steady-state calculation is not made; if the fifth bit from the right is not set, the test for convergence of a steady-state calculation is made.

We recommend not using tt equal to 0 except for special testing situations. The use of tt equal to 1 is possible if the maximum time step is kept sufficiently small to ensure that the explicit connection between the heat conduction/transfer and hydrodynamics calculations remains stable. If there is any doubt, use tt equal to or greater than 3 (sets first bit and second bit). Using tt equal to 3 or 11 specifies the semi-implicit or the nearly implicit advancement scheme, respectively, with both schemes using time step control, the heat conduction and hydrodynamics use the same time step, and the heat conduction/transfer and hydrodynamics are advanced separately. Using tt equal to 7 or 15 specifies the same

features as tt equal to 3 or 11 and, in addition, specifies the implicit advancement of the heat conduction/transfer with the hydrodynamics. We recommend the nearly implicit scheme during a steady-state and/or self-initialization case problem where the time step is limited by the material Courant limit. The nearly implicit scheme can also be used during slower phases of a transient problem, though we advise the user that the answers may change somewhat from the semi-implicit scheme answers (depending on the time step size). (The nearly implicit advancement scheme is still under development; most of the verification and assessment for the code has been done with the semi-implicit advancement scheme.) We did not recommend use of the implicit coupling of the heat conduction/transfer and hydrodynamics in prior versions since the implicit coupling was only partially implemented. With the implicit coupling now complete, we encourage the use of tt equal to 7 or 15. When using the implicit coupling, the heat conduction time step must be the same as the hydrodynamic time step. This requirement is currently not enforced by the coding. In steady-state calculations, setting the fifth bit (adding 16) for the early part of the run can ensure the calculation runs to a user-specified time; then, setting the fifth bit off can allow the steady-state convergence to test control the termination of the problem.

W5(I)   Minor edit and plot frequency. This is the number of maximum or requested time advances per minor edit and write of plot information.

W6(I)   Major edit frequency. This is the number of requested time advances per major edit.

W7(I)   Restart frequency. This is the number of requested time advances per write of restart information.

A4 CARDS 301 THROUGH 399, MINOR EDIT REQUESTS

These cards are optional for NEW and RESTART problems, are required for a REEDIT problem, and are not allowed for PLOT and STRIP problems. If these cards are not present, no minor edits are printed. If these cards are present, minor edits are generated, and the order of the printed quantities is given by the card number of the request card. One request is entered per card, and the card numbers need not be consecutive. For RESTART problems, if these cards are entered, all the cards from the previous problem are deleted.

W1(A)   Variable code (alphanumeric).

W2(I)   Parameter (numeric).

Words 1 and 2 form the variable request code pair. The quantities that can be edited and the input required are listed below. For convenience, quantities that can be used in plotting requests, in trip specifications, as search variables in tables, and as operands in control statements are listed. Units for the quantities are also given. Interactive input variables described in Section A6 can be used in batch or interactive jobs in the same manner as the variables listed below. The parameter for interactive input variables is 1000000000. Quantities compared in variable trips must have the same units, and input to tables specified by variable request codes must have the specified units. The quantities are listed in alphabetical order within each section.

The underlined quantities without an asterisk in Section A4.1 through Section A4.8 are always written to the restart-plot file. Underlined quantities followed by an asterisk have only some of the quantities written to the restart-plot file and the text will indicate which quantities are written. The quantities that are not underlined or some of the quantities underlined and followed with an asterisk are written to the restart-plot file only if requested on a 2080xxxx card as described in Section A4.9.

A4.1 General Quantities

Code	Quantity
COUNT	The current attempted advancement count number. The parameter is 0.
CPUTIME	The current CPU time for this problem (s). The parameter is zero.
DT	The current time step (s). The parameter is 0.
DTCRNT	The current Courant time step (s). The parameter is 0.
EMASS	Estimate of mass error in all the systems (kg, lb). The parameter is zero.
ERRMAX	The current estimate of the truncation mass error fraction. The parameter is 0.
NULL	Specifies null field. Allowed only on trip cards. The parameter is zero.
SYSTMS	Total mass of steam, water, and noncondensable in system n (kg, lb). Parameter is system number n.

STDTRN   Steady state/transient flag. The parameter is 0. For steady state, the value is 0.0. For transient, the value is 1.0.

SYSMER   Estimate of mass error in system n (kg, lb). Parameter is system number n.

TESTDA   An array testda, of twenty quantities, (real testda(20)) has been defined for the convenience of program developers. This entry with a parameter ranging from 1 through 20 selects testda(parameter). The testda array is initially set to zero, and programming must be inserted to set testda values. The usual purpose of this capability is to allow a simple method for debug information to be printed in minor edits or to be plotted.

TIME   Time (s). The parameter is zero. This request cannot be used for minor edit requests.

TIMEOF   Time of trip occurring (s). The parameter is the trip number. This request is allowed only on trip cards.

TMASS   Total mass of water, steam, and noncondensables in all the systems (kg, lb). The parameter is zero.

A4.2 Component Quantities

The quantities listed below are unique to certain components; for example, a pump velocity can only be requested for a pump component. The parameter is the component number, i.e., the three-digit number ccc used in the input cards.

Code	Quantity

ACPGTG   Accumulator vapor specific heat, C_p, at vapor temperature (J/kg·K, Btu/lb·°F).

ACPNIT   Accumulator noncondensable specific heat, C_p, at vapor temperature (J/kg·K, Btu/lb·°F).

ACQTANK   Total energy transport to the gas by heat and mass transfer in the accumulator (W, Btu/s)

ACRHON   Accumulator noncondensable density (kg/m^3, lb/ft^3).

ACTTANK   Mean accumulator tank wall metal temperature (K, °F).

ACVDM   Gas volume in the accumulator tank, standpipe, and surge line (m^3, ft^3).

ACVGTG   Accumulator vapor specific heat, C_v, at vapor temperature (J/kg·K, Btu/lb·°F).

ACVLIQ   Liquid volume in the accumulator tank, standipipe, and surge line (m^3, ft^3).

AHFGTF   Accumulator heat of vaporization at liquid temperature (J/kg, Btu/lb).

AHFGTG   Accumulator heat of vaporization at vapor temperature (m^3/kg, ft^3/lb).

AHFTG   Accumulator liquid enthalpy at vapor temperature (J/kg, Btu/lb).

AHGTF   Accumulator vapor enthalpy at liquid temperature (J/kg, Btu/lb).

AVISCN   Accumulator noncondensable viscosity (kg/m·s, lb/ft·s).

BETAV   Accumulator steam saturation coefficient of expansion (K^{-1}, $°F^{-1}$).

CDIM   GE mechanistic dryer critical inlet moisture quality.

DIM   GE mechanistic dryer inlet moisture quality.

DMGDT   Accumulator/time rate of change in dome vapor mass (kg/s, lb/s).

GDRY   GE mechanistic separator capacity factor.

OMEGA   Inertial valve disk angular velocity (rad/s, rev/min).

PMPHEAD   Pump head in the pump component (Pa, lb_f/in^2).

PMPMT   Pump motor torque (N·m, lb_f·ft).

PMPNRT   Calculated pump inertia (kg·m^2, lb·ft^2).

PMPTRQ   Pump torque in the pump component (N·m, lb_f·ft).

PMPVEL   Pump velocity in the pump component (rad/s, rev/min).

THETA   Inertial valve disk angular position (deg).

TUREFF   The efficiency of the turbine component.

TURPOW   The power developed in the turbine component (W, Btu/s).

TURTRQ   The torque developed in the turbine component (N·m, lb_f·ft).

TURVEL   The rotational velocity of the turbine component (rad/s, rev/min).PMPMTPumpPump
             motor torque (N·m, lb_f·ft).

VLVAREA   This is the ratio of the current valve physical area to the junction area. The junction area is
             the fully open valve physical area for the smooth area option and the minimum of the two
             connecting volumes for the abrupt area change.

VLVSTEM   This is the ratio of the current valve stem position to the fully open valve stem position for
             the motor and servo valves when the normalized stem position option is used. For the
             motor and servo valves when the normalized area option is used and for all the other

valves, this is the ratio of the current valve physical area to the fully open valve physical area.

XCO   GE mechanistic separator liquid carryover quality.

XCU   GE mechanistic separator vapor carryunder quality.

XI   GE mechanistic separator inlet quality.

A4.3 Volume Quantities

For most of the following variable codes, the parameter is the volume number, i.e., the nine-digit number cccnn0000 printed in the major edit. The parameter is ccc010000 for a single volume; ccc010000 for a time-dependent volume; cccnn0000 for a volume in a pipe component (0 < nn < 100); ccc010000 for the volume in a branch, separator, jetmixer, turbine, or ECC mixer component; ccc010000 for the volume in a pump component; and ccc010000 for the volume in an accumulator component. Some of the quantities are associated with the coordinate directions in the volume, and these quantities are computed for each coordinate direction in use. The parameter for the coordinate direction-related quantities is the volume number plus F, where F is described below. The quantities requiring the volume number plus F are so identified.

Every volume has at least one coordinate direction, and some volumes may have up to three orthogonal coordinate directions. Each coordinate has an inlet face and an outlet face. Faces are numbered 1 through 6, where faces 1 and 2 are the inlet and outlet faces associated with coordinate 1 (or x), respectively, faces 3 and 4 are inlet and outlet faces associated with coordinate 2 (or y), and faces 5 and 6 are inlet and outlet faces associated with coordinate 3 (or z). All volumes use coordinate 1. The quantity F to be added to the volume number to form the parameter used with coordinate direction related quantities is 0 or the face number. When F is 0 (i.e., just the volume number), 1, or 2, the volume velocity is for coordinate 1. When F is 3 or 4, the volume velocity is for coordinate 2, and when F is 5 or 6, the volume velocity is for coordinate 3. For the underlined quantities followed by an asterisk in the list below, the coordinate-dependent quantities for coordinate 1 are automatically written to the restart-plot records using the parameter with F equal to 0. The other coordinate-dependent quantities can be written to the plot records using the 208 card series. Input checks are made to ensure the parameter specifies a volume coordinate direction that is in use.

Code	Quantity
AVOL	Area of the volume (m^2, ft^2); the parameter is the volume number plus F.
BETAFF	Liquid isobaric coefficient of the thermal expansion, β_f, bulk conditions (K^{-1}, $°F^{-1}$).
BETAGG	Vapor isobaric coefficient of the thermal expansion, β_g, bulk conditions (K^{-1}, $°F^{-1}$).
BORON	Boron density (kg/m^3, lb/ft^3).
CSUBPF	Liquid specific heat, C_{pf}, bulk conditions ($J/kg·K$, $Btu/lb·°F$).

CSUBPG Vapor specific heat, C_{pg}, bulk conditions (J/kg·K, Btu/lb·°F).

DRFDP Partial derivative of ρ_f with respect to pressure (s^2/m^2, s^2/ft^2).

DRFDUF Partial derivative of ρ_f with respect to U_f (kg·s^2/m^5, lb·s $^2/ft^5$).

DRGDP Partial derivative of ρ_g with respect to pressure (s^2/m^2, s^2/ft^2).

DRGDUG Partial derivative of ρ_g with respect to U_g (kg·s $^2/m^5$, lb· s^2/ft^5).

DRGDXA Partial derivative of ρ_g with respect to X_n (kg/m^3, lb/ft^3).

DSNDDP Steam specific enthalpy at bulk conditions using partial pressure of steam (J/kg, Btu/lb).

DTDP Partial derivative, of T^s with respect to pressure (K/Pa, in^2·°F/lb$_f$).

DTDUG Partial derivative of T^s with respect to U_g (s^2·K/m^2, s^2·°F/ft^2).

DTDXA Partial derivative of T^s with respect to X_n (K, °F).

DTFDP Partial derivative of T_f with respect to pressure (K/Pa, in^2·°F/lb$_f$).

DTFDUF Partial derivative of T_f with respect to U_f (s^2·K/m^2, s^2·°F/ft^2).

DTGDP Partial derivative of T_g with respect to pressure (K/Pa, in^2·°F/lb$_f$).

DTGDUG Partial derivative of T_g with respect to U_g (s^2·K/m^2, s^2·°F/ft^2).

DTGDXA Partial derivative of T_g with respect to X_n (K, °F).

FLOREG* Flow regime number; the parameter is the volume number plus F. A chart showing the meaning of each number is shown in Section 2 of this volume of the manual.

FWALF Liquid wall frictional drag coefficient (kg/m^3·s, lb/ft^3·s); the parameter is the volume number plus F.

FWALG Vapor wall frictional drag coefficient (kg/m^3·s, lb/ft^3· s); the parameter is the volume number plus F.

GAMMAC Condensation rate near the wall per unit volume (kg/m^3·s, lb/ft^3· s).

GAMMAI Vapor generation rate in the bulk per unit volume (kg/m^3·s, lb/ft^3· s).

GAMMAW   Vapor generation rate near the wall per unit volume ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).

HIF   Liquid side interfacial heat transfer coefficient per unit volume ($W/m^3 \cdot K$, $Btu/s \cdot ft^3 \cdot {}^{\circ}F$).

HIG   Vapor side interfacial heat transfer coefficient per unit volume ($W/m^3 \cdot K$, $Btu/s \cdot ft^3 \cdot {}^{\circ}F$).

HVMIX   Enthalpy of the liquid and vapor (J/kg, Btu/lb).

P   Volume pressure (Pa, lb_f/in^2).

PECLTV   Peclet number.

PPS   Steam partial pressure (Pa, lb_f/in^2).

Q   Total volume heat source from the wall and direct moderatorheating to liquid and vapor (W, Btu/s). This variable request is the same as TOT.HT.INP. in the major edits.

QUALA   Volume noncondensable mass fraction.

QUALE   Volume equilibrium quality. The quality uses phasic enthalpies, with the mixture enthalpy calculated using the flow quality.

QUALS   Volume static quality.

QWG   Volume heat source from the wall and direct moderator heating to vapor (W, Btu/s). This variable request is the same as VAP.HT.INP. in the major edits.

RHO   Total density (kg/m^3, lb/ft^3).

RHOF   Liquid density (kg/m^3, lb/ft^3).

RHOG   Vapor density (kg/m^3, lb/ft^3).

RHOM   Total density for the mass error check (kg/m^3, lb/ft^3).

SATHF   Liquid specific enthalpy at saturation conditions using partial pressure of steam (J/kg, Btu/lb).

SATHG   Steam specific enthalpy at saturation conditions using partial pressure of steam (J/kg, Btu/lb).

SATTEMP   Volume saturation temperature based on the partial pressure of steam (K, ${}^{\circ}F$).

SIGMA   Surface tension (J/m^2, Btu/ft^2).

SOUNDE   Volume sonic velocity (m/s, ft/s).

TEMPF   Volume liquid temperature (K, °F).

TEMPG   Volume vapor temperature (K, °F).

THCONF   Liquid thermal conductivity (W/m•K, Btu/s•ft•° F).

THCONG   Vapor thermal conductivity (W/m•K, Btu/s• ft°F).

TIENGV   Total internal energy (of both phases and noncondensables) in volume (J, Btu).

TMASSV   Total mass (includes both phases and noncondensables) in volume (kg, lb).

TSATT   Saturation temperature corresponding to total pressure (K, °F).

UF   Liquid specific internal energy (J/kg, Btu/lb).

UG   Vapor specific internal energy (J/kg, Btu/lb).

VAPGEN   Total volume vapor generation rate per unit volume (kg/m^3·s, lb/ft^3·s).

VELF*   Volume oriented liquid velocity (m/s, ft/s); the parameter is the volume number plus F.

VELG*   Volume oriented vapor velocity (m/s, ft/s); the parameter is the volume number plus F.

VISCF   Liquid viscosity (kg/m•s, lb/ft•s).

VISCG   Vapor viscosity (kg/m•s, lb/ft•s).

VOIDF   Volume liquid fraction.

VOIDG   Volume vapor fraction (void fraction).

VOIDLA   Void above the level.

VOIDLB   Void below the level.

VOLLEV   Location of the level inside the volume (m, ft).

VVOL   Volume of the volume (m^3, ft^3).

A4.4   Junction Quantities

For the following variable request codes, the parameter is the junction number, i.e., the nine-digit number cccnn0000 printed in the major edit. The parameter is ccc000000 for a single junction; ccc000000

for a time-dependent junction; cccmm0000 for a junction in a pipe component (0 < mm < 99); cccmm0000 for a junction in a branch, separator, jetmixer, turbine, or ECC mixer component (0 < mm < 9); ccc000000 for a valve junction; ccc010000 for the inlet junction in a pump component; ccc020000 for the outlet junction in a pump component; ccciinn00 for a junction in the multiple-junction component; and ccc010000 for the junction in an accumulator component.

Code	Quantity
C0J	Junction distribution coefficient. The 0 in C0J is a zero and not an upper case letter O.
FIJ	Interphase friction (N·s^2/m^5, lb_f·s^2/ft^5). This is the variable C_i in Volume I in this manual.
FLENTH	Total enthalpy flow in junction (includes both phases and noncondensables) (J/s, Btu/s).
FLORGJ	Junction flow regime number. A chart showing the meaning of each number is shown in Section 2 of this volume of the manual.
FORMFJ	Liquid form loss factor (dimensionless).
FORMGJ	Vapor form loss factor (dimensionless).
IREGJ	Vertical bubbly/slug flow junction flow regime number. A chart showing the meaning of each number is shown in Section 2 of this volume of the manual.
MFLOWJ	Combined liquid and vapor flow rate (kg/s, lb/s).
QUALAJ	Junction noncondensable mass fraction.
RHOFJ	Junction liquid density (kg/m³, lb/ft³).
RHOGJ	Junction vapor density (kg/m³, lb/ft³).
SONICJ	Junction sound speed (m/s, ft/s).
UFJ	Junction liquid specific internal energy (J/kg, Btu/lb).
UGJ	Junction vapor specific internal energy (J/kg, Btu/lb).
VELFJ	Junction liquid velocity (m/s, ft/s).
VELGJ	Junction vapor velocity (m/s, ft/s).
VGJJ	Vapor drift velocity (m/s, ft/s).
VOIDFJ	Junction liquid fraction.
VOIDGJ	Junction vapor fraction (void fraction).

VOIDJ   Junction vapor fraction (void fraction) used in the interphase drag.

XEJ   Junction equilibrium quality.

A4.5   Heat Structure Quantities

For the request code, HTVAT, the parameter is the seven-digit heat structure number cccg0nn. For the remaining codes, the parameter is the seven-digit heat structure number cccg0nn with a two-digit number appended. For codes other than HTTEMP and HTVAT, the appended number is 00 for the left boundary and 01 for the right boundary. For HTTEMP, the appended number is the mesh point number. For HTVAT, omit the two appended digits and use only the seven digit number. Only the left and right surface temperatures are written by default in plot records on the RSTPLT file, and, thus, plot requests in plot-type problems and strip requests are limited to those temperatures unless the interior temperatures are forced to the RSTPLT file through 2080xxxx cards.

Code	Quantity

HTCHF   Critical heat flux (W/m^2, $Btu/s \cdot ft^2$).

HTGAMW   Wall vapor generation rate per unit volume ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$). The parameter is the heat structure geometry number cccg0nn with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).

HTHTC   Heat transfer coefficient ($W/m^2 \cdot K$, Btu/s-$ft^2 \cdot {}^{\circ}F$).

HTMODE   Boundary heat transfer mode number (unitless). The mode number indicates which heat transfer regime is currently in effect. The parameter is the seven-digit heat structure geometry number, cccg0nn, with a two-digit number appended. The two-digit appended number, 00, specifies the left boundary, and 01 specifies the right boundary. This same quantity is valid for the reflood heat structures. A chart showing the meaning of each number is shown in Section 3.2 of this volume of the manual.

HTRG   Heat flux to vapor phase (W/m^2, $Btu/s \cdot ft^2$). The parameter is the heat structure geometry number, cccg0nn, with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).

HTRNR   Heat flux (W/m^2, $Btu/s \cdot ft^2$).

HTTEMP*   Mesh point temperature (K, ${}^{\circ}F$). The parameter is the heat structure geometry number cccg0nn with a two-digit number appended (mesh point number). The surface temperatures are written to the plot record but interior mesh point temperatures must be requested through the 2080xxxx cards.

HTVAT   Volume averaged temperature in the heat structure (K, ${}^{\circ}F$)

PECL   Liquid Peclet number for the heat structures. The parameter is the heat structure geometry
             number cccg0nn with a two-digit number appended (00 for the left boundary, and 01 for
             the right boundary).

STANT   Stanton number. The parameter is the heat structure geometry number cccg0nn with a
             two-digit number appended (00 for the left boundary, and 01 for the right boundary).

A4.6   Reflood-Related Quantities

For the following variable codes, the parameter is the heat structure geometry number, i.e., the
seven-digit number cccg0nn printed in the major edit.

Code	Quantity
QFCHFN	Critical heat flux (W/m^2, $Btu/s \cdot ft^2$).
QFHTCN	Critical heat transfer coefficient ($W/m^2 \cdot K$, $Btu/s. \ ft^2 \cdot {}^{o}F$).
TCHFQF	Temperature corresponding to QFCHFN (K, ${}^{o}F$).
TREWET	Rewet temperature (K, ${}^{o}F$).
ZTRWT	Position of CHF point (m, ft).

A4.7   Reactor Kinetic Quantities

The parameter is zero for the following reactor kinetic quantities. The following list is for point
kinetics variables.

Code	Quantity
RKFIPOW	Reactor power from fission (W).
RKGAPOW	Reactor power from fission product decay (W).
RKREAC	Reactivity (dollars).
RKRECPER	Reciprocal period (s^{-1}).
RKTPOW	Total reactor power, i.e., sum of fission and fission product decay power (W).

A4.8   Control System Quantities

The parameter is the control component number, i.e., the three-digit number, ccc, or the four-digit
number, cccc, used in the input cards.

<u>CNTRLVAR</u>   Control component number. These quantities are assumed dimensionless except for a SHAFT component.

A4.9   Cards 2080xxxx, Expanded Plot Variables

The underlined variables listed above are always available for plotting. The variables that are not underlined and some of the underlined variables followed by an asterisk are not written to the restart-plot file and are thus unavailable for plotting unless the user enters the desired variables on 2080xxxx cards. The format of these cards is given below. They are only required for the additional variables that the user wants to have written on the restart-plot file. The user can specify that between 1 and 9999 of these variables be written to the restart-plot file.

The field xxxx need not be consecutive.

W1(A)   Variable request code. See the previous sections for valid request codes.

W2(I)   Parameter. Enter the parameter associated with the variable request code.

A5 CARDS 400 THROUGH 799 OR 20600000 THROUGH 20620000, TRIP INPUT DATA

These cards are optional for NEW and RESTART type problems and are not used for other problem types. Two different card series are available for entering trip data, but only one series type may be used in a problem. Card numbers 401 through 799 allow 199 variable trips and 199 logical trips. Card numbers 20600010 through 20620000 allow 1000 variable trips and 1000 logical trips.

A5.1   Card 400, Trips Cancellation Card

This card is allowed only for RESTART problems. The card causes all trips in the problem being restarted to be deleted. Any desired trips must be reentered.

W1(A)   Discard. Any other entry is an error.

A5.2   Card 20600000, Trip Card Series Type

This card, if omitted, selects card numbers 401 through 599 for variable trips and 601 through 799 for logical trips. For this case, the trip numbers are equal to the card numbers.

If this card is entered, card numbers 206nnnn0 are used for entering trip data, and nnnn is the trip number. Trip numbers (nnnn) 1 to 1000 are variable trips, and 1001 to 2000 are logical trips. Trip numbers do not have to be consecutive.

W1(A)   Expanded. Any other entry is an error.

A5.3   Cards 401 through 599 or 20600010 through 20610000, Variable Trip Cards

Each card defines a logical statement or trip condition concerned with the quantities being advanced in time. A trip is false or not set if the trip condition is not met, and true if it is met. On restart, new trips can be introduced, old trips can be deleted, and a new trip with the same number as an old trip replaces the old trip.

The variable codes and parameters are the same as described for minor edits, Section A4 NULL is allowed for the right side when only a comparison to the constant is desired. The variable code TIMEOF, with the parameter set to the trip number, indicates the time at which the trip was last set. If the trip goes false, TIMEOF is set to -1.0.

W1(A)   Variable code. On RESTART problems, this word can also contain DISCARD or RESET. DISCARD deletes the trip; RESET sets the trip to false. If DISCARD or RESET are entered, no further words are entered on the card.

W2(I)   Parameter.

W3(A)   Relationship. This may be either EQ, NE, GT, GE, LT, or LF, where the symbols have the standard FORTRAN meaning. Do not enter periods as part of the designator. For example, use GE rather than .GE. to specify *greater than* or *equal to*.

W4(A)   Variable code.

W5(I)   Parameter.

W6(R)   Additive constant.

W7(A)   Latch indicator. If L, the trip once set true remains true, even if the condition later is not
               met. If N, the trip is tested each time advancement.

W8(R)   Timeof quantity (s). This word is optional. If it is not entered, the trip is initialized as false
               and the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized
               as false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true.
               TIMEOF must not be greater than zero for NEW problems and must not be greater than
               the time of restart for RESTART problems.

The logical statement is "Does the quantity given by Words 1 and 2 have the relationship given by
Word 3 with the quantity given by Words 4 and 5 plus Word 6?" If the relationship is false, the trip is false
or not set. If the relationship is true, the trip is true or set. The TIMEOF variable is -1.0 if the trip is false.
If the trip is true, this variable is the time the trip was last set true. A latched trip is never reset, so the trip
time never changes once it changes from -1.0. For the nonlatched trips, the trip time when set remains
constant until the trip condition becomes false and then the trip time is -1.0 again. If the trip condition
becomes true again, the process is repeated. For trips such as a time test, L should be used to eliminate
repeated testing, although no error or difference in results will occur if N is used.

A5.4   Cards 601 through 799 or 20610010 through 20620000, Logical Trip Cards

If these cards are entered, at least one of the variable trip cards must have been entered. Each card
defines a logical relationship with the trips defined on these cards or on the variable trip cards. (For a more
detailed description of this input, see Section 4.1.4.)

W1(I)   Trip number. The absolute value of this number must be one of the trip numbers defined
               by the variable or logical trip cards. A negative trip number indicates that the complement
               of the trip is to be used in the test.

W2(A)   Operator. The operator may be AND, OR, or XOR. For RESTART problems, this
               quantity may also contain DISCARD or RESET. DISCARD deletes the trip and RESET
               sets the trip to false. If DISCARD or RESET are entered, no further words are entered on
               the card and Word 1 (W1) may be zero.

W3(I)   Trip number. This is similar to Word 1 (W1).

W4(A)   Latch indicator. If L, the trip when set remains set. If N, the trip is tested each time
               advancement.

W5(R)   Timeof quantity (s). This word is optional. If not entered, the trip is initialized as false, and
               the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized as
               false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true.

TIMEOF must not be greater than zero for NEW problems and must not be greater than the time of restart for RESTART problems.

The trip condition is given by the result of the following logical expression:

CONDITION OF TRIP IN W1   OPERATOR   CONDITION OF TRIP IN W3.

A5.5   Card 600, Trip Stop Advancement Card

This card can be entered in NEW and RESTART problems. One or two trip numbers may be entered. If either of the indicated trips are true, the problem advancement is terminated. These trips are tested only at the end of a requested advancement. If the trips can cycle true and false, they should be latched-type trips to ensure being true at the test time.

W1(I)   Trip number.

W2(I)   Trip number. A second trip number need not be entered.

A6 CARDS 801 THROUGH 999, INTERACTIVE INPUT DATA

An interactive and color display capability exists when the code is interfaced with Nuclear Plant Analyzer (NPA) software. This capability allows a user to view selected results on a color graphics terminal and to modify user-defined input quantities. A user can view RELAP5/MOD3.2 output in a format that enhances understanding of the transient phenomena and enter commands during the simulation. This input, coupled with trip and control system capability, allows a user to initiate operator-like actions, such as opening/closing valves, starting/stopping/changing speed on pumps, and changing operating power settings.

These data may be entered for either batch or interactive jobs. These cards may be used in a NEW or RESTART job; in a restart job, they add to or replace data in the restarted problem.

These cards define variables that may be changed during execution by data input from a computer terminal if the job is being run interactively. The card input defines input variable names and initial values. These variables are completely independent from the Fortran variable names used in the RELAP5 coding, even if they are spelled the same. These user-defined variables can appear wherever variables listed in Section A4 can be used. Thus, the user-defined variables can be used in trips, control variable statements, search arguments for some tables, edited in minor edits, and plotted. With appropriate input, an interactive user can effect changes similar to those made by a reactor operator, such as opening/closing/repositioning valves or setting new operating points in controllers. When entering these user-defined variables, the variable name is the alphanumeric part of the variable request code, and 1000000000 is the numeric part.

W1(A)   Variable name. Enter the variable name or DELETE in a RESTART job to delete the variable.

W2(R)   Initial value. This is not needed if DELETE is entered in Word 1.

In interactive execution, the initial value is used until changed by a terminal entry. The value can be changed at any time and as often as needed. One or more variables can be changed by entering the variable name and value pairs on the computer terminal. An example is VLV1=0 VLV2,1 VLV3,0, POWER=3050.+6, where VLV1, VLV2, VLV3, and POWER are user-defined variable names. The format is identical to data input on cards. An equal sign is treated as a terminating comma. The values should be floating-point quantities, but integers are converted to floating point values. The NPA interface also allows other more convenient methods for entering new values during the simulation.

W3(R)   Conversion factor. Word 2 or any terminal-entered replacement value is entered in user-defined units. These quantities should be converted to SI units if they are to be involved in comparisons or computations with quantities advanced in time. User units can be used only if these input interactive variables are used with control variables defined in compatible units. This word, if nonzero, is the conversion factor. If this word is positive, the conversion is V(converted) = V(input)*W3. If negative, V(converted) = V(input)/1.8 - W3. For temperature conversion from °F to K, Word 3 should be -255.3722222. If this word is missing, the conversion factor defaults to 1.0. If this word is zero, the next two words must contain a variable request code, and the conversion factor appropriate for this quantity is supplied by the code. If SI units are in use, the supplied conversion factor is 1.0. If British units are in use, the appropriate conversion factor is supplied.

A7 CARDS CCCXXNN, HYDRODYNAMIC COMPONENTS

These cards are required for NEW type problems and may be entered for RESTART problems. Hydrodynamic systems are described in a NEW problem. In a RESTART problem, the hydrodynamic systems may be modified by deleting, adding, or replacing components. The resultant problem must describe at least two volumes and one junction. The hydrodynamic card numbers are divided into fields, where ccc is the component number (the component numbers need not be consecutive), xx is the card type, and nn is the card number within type. When a range is indicated, the numbers need not be consecutive.

A7.1   Card ccc0000, Component Name and Type

This card is required for each component.

W1(A)   Component name. Use a name descriptive of the component's use in system. A limit of 10 characters is allowed for CDC-7600 computers, and a limit of 8 characters is allowed for most other computers, e.g., CRAY, Cyber-205, and IBM computers.

W2(A)   Component type. Enter one of the following component types, SNGLVOL, TMDPVOL, SNGLJUN, TMDPJUN, PIPE, ANNULUS, BRANCH, SEPARATR, JETMIXER, TURBINE, ECCMIX, VALVE, PUMP, MTPLJUN, ACCUM, or the command DELETE. The command DELETE is allowed only in RESTART problems, and the component number must be an existing component at the time of restart. The DELETE command deletes the component.

The remaining cards for each component depend on the type of component.

A7.2   Single-Volume Component

A single-volume component is indicated by SNGLVOL on Card ccc0000. The junction connection code determines the placement of the volume within the system. More than one junction may be connected to an inlet or outlet. If an end has no junctions, that end is considered a closed end. Normally, only a branch has more than one junction connected to a volume end. For major edits, minor edits, and plot variables, the volume in the single volume component is numbered as ccc010000.

A7.2.1 Cards ccc0101 through ccc0109, Single Volume X-Coordinate Volume Data

This card (or cards) is required for a single volume component. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R)   Volume flow area (m^2, ft^2).

W2(R)   Length of volume (m, ft).

W3(R)   Volume of volume (m^3, ft^3). The program requires that the volume equals the volume flow area times the length (W3=W1*W2). At least two of the three quantities, W1, W2, and W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R)   Azimuthal angle (degrees). The absolute value of this angle must be ≤360 degrees and is defined as a positional quantity. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R)   Inclination angle (degrees). The absolute value of this angle must be ≤90 degrees. The angle 0 degrees is horizontal; and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation.

W6(R)   Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. When the absolute value of the elevation angle determined by the ratio of the elevation change (this word 6) and the volume length (word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used. When the ratio is greater than 45 degrees, the vertical flow regime map is used.

W7(R)   Wall roughness (m, ft).

W8(R)   Hydraulic diameter (m, ft). This should be computed from 4.0*(volume flow area)/(wetted perimeter). If zero, the hydraulic diameter is computed from 2.0*(volume flow area/π)**0.5. A check is made to ensure the pipe roughness is less than half the hydraulic diameter. See word 1 for volume flow area.

W9(I)   Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag.

               The digit t specifies whether the thermal front tracking model is to be used; t=0 specifies that the front tracking model is not to be used for the volume, and t=1 specifies that the front tracking model is to be used for the volume.

               The digit l specifies whether the mixture level tracking model is to be used; l=0 specifies that the level model not be used for the volume, and l=1 specifies that the level model be used for the volume.

               The digit p specifies whether the water packing scheme is to be used. p=0 specifies that the water packing scheme is to be used for the volume, and p=1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer.

               The digit v specifies whether the vertical stratification model is to be used. v=0 specifies that the vertical stratification model is to be used for the volume, and v=1 specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer.

The digit $\underline{b}$ specifies the interphase friction that is used. $\underline{b}=0$ means that the pipe interphase friction model will be applied, $\underline{b}=1$ means that the rod bundle interphase friction model will be applied, and $\underline{b}=2$ means that the narrow channel model will be applied.

The digit $\underline{f}$ specifies whether wall friction is to be computed. $\underline{f}=0$ specifies that wall friction effects are to be computed along the x coordinate of the volume, and $\underline{f}=1$ specifies that wall friction effects are not to be computed along the x coordinate.

The digit $\underline{e}$ specifies if nonequilibrium or equilibrium is to be used. $\underline{e}=0$ specifies that a nonequilibrium (unequal temperature) calculation is to be used, and $\underline{e}=1$ specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison with other codes.

A7.2.2   Cards ccc0181 through ccc0189, Single-Volume Y-Coordinate Volume Data

These cards are optional. These cards are used when the user specifies the y-direction connection with the crossflow model.

W1(R)   Area of the volume (m^2).

W2(R)   Length of the crossflow volume (m).

W3(R)   Roughness.

W4(R)   Hydraulic diameter (m).

W5(I)   Volume control flags. This word has the general packed format $\underline{tlpvbfe}$, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the y direction.

The digit $\underline{f}$ specifies whether wall friction is to be computed. $\underline{f}=0$ specifies that wall friction effects are to be computed along the y coordinate direction in the volume, and $\underline{f}=1$ specifies that wall friction effects are not to be computed along the y coordinate direction.

W6(R)   This word is not used. Enter 0.

W7(R)   This word is not used. Enter 0.

W8(R)   This word is the position change in the z fixed (vertical) direction as the flow passes from the y inlet face to the y outlet face (m, ft). This quantity affects problems if connections are made to the y faces.

A7.2.3   Cards ccc0191 through ccc0199, Single-Volume Z-Coordinate Volume Data

These cards are optional. These cards are used when the user specifies the z-direction connection with the crossflow model.

W1(R)   Area of the volume (m^2).

W2(R)   Length of the crossflow volume (m).

W3(R)   Roughness.

W4(R)   Hydraulic diameter (m).

W5(I)   Volume control flags. This word has the general packed format tlpvbfe, but this word is
               limited to 00000f0 since it only enters the coordinate oriented flags for the z direction.

               The digit f specifies whether wall friction is to be computed. f=0 specifies that wall
               friction effects are to be computed along the z coordinate direction in the volume, and f=1
               specifies that wall friction effects are not to be computed along the z coordinate direction.

W6(R)   This word is not used. Enter 0.

W7(R)   This word is not used. Enter 0.

W8(R)   This word is the position change in the z fixed (vertical) direction as the flow passes from
               the z inlet face to the z outlet face (m, ft). This quantity affects problems if connections are
               made to the z faces.

A7.2.4   Card ccc0131, Additional Laminar Wall Friction Card

This card is optional. If this card is not entered, the default values are 1.0 for the shape factor and 0.0
for the viscosity ratio exponent. Two, four, or six quantities may be entered on the card, and the data not
entered are set to default values. A detailed description of this model is presented in Section 3 of Volume I.

W1(R)   Shape factor for x-coordinate.

W2(R)   Viscosity ratio exponent for x-coordinate.

W3(R)   Shape factor for y-coordinate.

W4(R)   Viscosity ratio exponent for y-coordinate.

W5(R)   Shape factor for z-coordinate.

W6(R)   Viscosity ratio exponent for z-coordinate.

A7.2.5   Card ccc0200, Single-Volume Initial Conditions

This card is required for a single volume.

W1(I)   Control word. This word has the packed format ebt. It is not necessary to input leading
               zeros.

               The digit e specifies the fluid. e =0 is the default fluid, e =1 specifies water, e=2 specifies
               D_2O, and e =3 specifies H_2. The default fluid is that set for the hydrodynamic system by

Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If Cards120 through 129 are not entered and all control words use the default $g = 0$, then H_2O is assumed as the fluid.

The digit b specifies whether boron is present or not. The digit $b=0$ specifies that the volume fluid does not contain boron; $b=1$ specifies that a boron concentration in parts of boron per parts of liquid (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the following words are to be used to determine the initial thermodynamic state. Entering $t=0$ through 3 specifies only one component (steam/water). Entering $t=4$ through 6 allows the specification of two components (steam/water and noncondensable gas).

If $t=0$, the next four words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction; these quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the volume control flag. If equilibrium, the static quality is checked; but only the pressure and internal energies are used to define the thermodynamic state.

If $t=1$, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

If $t=2$, the next two words are interpreted as pressure (Pa, lb_f/in^2) and quality in equilibrium condition.

If $t=3$, the next two words are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium condition.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are

$1.0E-9 \leq$ quality ≤ 0.99999999, two phase conditions, and quality $< 1.0 E-9$ or quality > 0.99999999, single phase. Section 3 of Volume I presents the definitions of quality.

Noncondensable options are as follows:

If $t=4$, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. Using this input option with quality 0.0 and ≤ 1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If $t=5$, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted

to be between 1.0 E-9 and 0.99999999. Little experience has been obtained using this option, and it has not been checked out.

If $t=6$, the next five words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables are present and noncondensable quality is greater than 0.0, then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then the vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy.

W2-W7(R)   Quantities as described under Word1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, boron concentration follows the last required word for thermodynamic conditions.

A7.3   Time-Dependent Volume Component

This component is indicated by TMDPVOL on card ccc0000. For major edits, minor edits, and plot variables, the volume in the time-dependent volume component is numbered as ccc010000.

A7.3.1   Cards ccc0101 through ccc0109, Time-Dependent Volume Geometry Cards

This card (or cards) is required for a time-dependent volume component. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R)   Volume flow area (m^2, ft^2).

W2(R)   Length of volume (m, ft).

W3(R)   Volume of volume (m^3, ft^3). The program requires that the volume equals the volume flow area times the length (W3=W1*W2). At least two of the three quantities, W1, W2, and W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R)   Azimuthal angle (degrees). The absolute value of this angle must be $\leq$ 360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R)   Inclination angle (degrees). The absolute value of this angle must be $\leq$ 90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation.

W6(R)   Elevation change (m, ft). A positive value is an increase in elevation. The absolute value
             of this quantity must be less than or equal to the volume length. If the vertical angle
             orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity
             must also be nonzero and have the same sign. As with the other components, this word 6 is
             compared to the volume length (word 2) to determine if the horizontal or vertical flow
             regime map is used. This is not important for this component, since the correlations that
             depend on the flow regime maps are not needed for this component. The volume
             conditions are prescribed through input cards ccc0201-ccc0299.

W7(R)   Wall roughness (m, ft).

W8(R)   Hydraulic diameter (m, ft). This should be computed fro 4*(volume flow area)/(wetted
             perimeter). If zero, the hydraulic diameter is computed from 2.0*(volume flow area/
             π)**0.5. A check is made to ensure the pipe roughness is less than half the hydraulic
             diameter. See word 1 for the volume flow area.

W9(I)   Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input
             leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented
             flags. Only one value for a scaler oriented flag is entered per volume but up to three
             coordinate oriented flags can be entered for a volume, one for each coordinate direction.
             At present, the f flag is the only coordinate direction oriented flag. This word enters the
             scaler oriented flags and the x coordinate flag. The time dependent component uses only
             the e digit and y and z coordinate data are not read.

             The digit t is not used and must be entered as zero (t=0). The thermal stratification model
             is not used in a time dependent volume.

             The digit l is not used and must be entered as zero (l=0). The level tracking model is not
             used in a time dependent volume.

             The digit p is not used and should be input as zero (p=0). The major edit will show p=1.

             This digit v is not used and should be input as zero (v=0). The major edit will show v=1.

             The digit b specifies the interphase friction that is used. b=0 means that the pipe interphase
             friction model will be applied, and b=1 means that the rod bundle interphase friction
             model will be applied. The interphase friction models are not used for time-dependent
             volumes, so either b=0 or b=1 can be inputted and the output will show the digit entered.

             The digit f specifies whether wall friction is to be computed. f=0 specifies that wall
             friction effects are to be computed for the volume, and f=1 specifies that wall friction
             effects are not to be computed for the volume. The wall friction model is not used for
             time-dependent volumes, so either f=0 or f=1 can be inputted and the output will show the
             digit entered.

             The digit e specifies if nonequilibrium or equilibrium is to be used. e=0 specifies that a
             nonequilibrium (unequal temperature calculation is to be used, and e=1 specifies that an
             equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not
             be connected to nonequilibrium volumes. The equilibrium option is provided only for

comparison to other codes. The nonequilibrium and equilibrium options are not used for time-dependent volumes, so either $\varepsilon=0$ or $\varepsilon=1$ can be used.

A7.3.2   Card ccc0200, Time-Dependent Volume Data Control Word

This card is required for a time-dependent volume.

W1(I)   Control word for time-dependent data on ccc02nn cards. This word has the packed format $\underline{\varepsilon b t}$. It is not necessary to input leading zeros.

The digit $\underline{\varepsilon}$ specifies the fluid. $\varepsilon=0$ is the default fluid, $\varepsilon=1$ specifies H_2O, $\varepsilon=2$ specifies D_2O, and $\varepsilon=3$ specifies H_2. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words within the hydrodynamic system must be consistent (i.e., not specify different fluids). If Cards 120 through 129 are not entered and all control words use the default $\varepsilon=0$, then H_2O is assumed as the fluid.

The digit $\underline{b}$ specifies whether boron is present or not. The digit $\underline{b}=0$ specifies that the volume fluid does not contain boron; $\underline{b}=1$ specifies that a boron concentration in parts of boron per parts of liquid water (which may be zero) is being entered after the other required thermodynamic information.

The digit $\underline{t}$ specifies how the words of the time-dependent volume data in Cards ccc0201 through ccc0299 are to be used to determine the initial thermodynamic state. Entering $\underline{t}$ equal to 0 through 3 specifies one component (steam/water). Entering $\underline{t}$ equal to 4 through 6 allows the specification of two components (steam/water and noncondensable gas).

With options 4 through 6, Card 110 defining components of the noncondensable gas must be entered and mass fractions of the components are entered on Card ccc0301, if entered, or are taken from the default data on Card 115. Entering $\underline{t}=7$ specifies three components, liquid/steam, noncondensable gas, and a molten metal. Option 7 requires Card 110 and Card ccc0301 or Card 115 similarly to options 4 through 6. In addition, option 7 requires Card 111 defining components of the metal. The mass fractions are defined by Card ccc0302 if entered or from Card 116.

If $\underline{t}=0$, the second, third, fourth, and fifth words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction; these quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the volume control flag. If equilibrium, the static quality is checked, but only the pressure and internal energies are used to define the thermodynamic state. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If $\underline{t}=1$, the second and third words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as temperature (K, °F) and quality in equilibrium

condition. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If t=2, the second and third words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb_f/in^2) and quality in equilibrium condition. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If t=3, the second and third words of the time-dependent volume data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium conditions. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are

$1.0E-9 \leq$ quality ≤ 0.99999999, two-phase conditions, and quality $< 1.0E-9$ or quality > 0.99999999, single-phase.

Noncondensable options are as follows:

If t=4, the second, third, and fourth words of the time-dependent data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, $lb_f/in.^2$), temperature (K, °F), and equilibrium quality. Using this input option with quality >0.0 and ≤1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If t=5, the second, third, and fourth words of the time-dependent data on Cards ccc0201 through ccc0299 are interpreted as temperature (K, °F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions. Little experience has been obtained using this option, and it has not been checked out.

If t=6, the second, third, fourth, fifth, and sixth words of the time-dependent data on Cards ccc0201 through ccc0299 are interpreted as pressure (Pa, $lb_f/in.^2$), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present, and the input processing branches to that type of processing. If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure

noncondensable), then the vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If $t=7$, the next seven words are interpreted as pressure (Pa, lb_f/in^2), liquid-specific internal energy (J/kg, Btu/lb), vapor-specific internal energy (J/kg, Btu/lb), vapor void fraction, noncondensable quality, metal internal energy (J/kg, Btu/lb) and metal void fraction. The sum of the vapor void fraction and the metal void fraction must be greater than or equal to zero and less than or equal to one. The noncondensable quality must be greater than or equal to zero and less than or equal to one. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

W2(I)   Table trip number. This word is optional. If missing or zero and Word 3 is missing, no trip is used, and the time argument is the advancement time. If nonzero and Word 3 is missing, this number is the trip number, and the time argument is -1.0 if the trip is false, and the advancement time minus the trip time if the trip is true.

W3(A)   Alphanumeric part of variable request code. This quantity is optional. If not present, time is the search argument. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. If the trip number is zero, the specified argument is used. If the trip number is nonzero, -1.0E+75 is used if the trip is false, and the specified argument is used if the trip is true. TIME can be selected, but note that the trip logic is different than if this word were omitted.

W4(I)   Numeric part of variable request code. This is assumed zero if missing.

A7.3.3   Cards ccc0201 through ccc0299, Time-Dependent Volume Data Cards

These cards are required for time-dependent volume components. A set of data is made up of the search variable (e.g., time) followed by the required data indicated by control word 1 in Card ccc0200. The card numbers need not be consecutive, but the value of the search variable in a succeeding set must be equal to or greater than the value in the previous set. One or more sets of data, up to 5000 sets, are allowed. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions. Linear interpolation is used if the search argument lies between the search variable entries. End-point values are used if the argument lies outside the table values. Only one set is needed if constant values are desired, and computer time is reduced when only one set is entered. Step changes can be accommodated by entering the two adjacent sets with the same search variable values or an extremely small difference between them. Given two identical argument values, the set selected will be the closest to the previous argument value. Sets may be entered one or more per card and may be split across cards. The total number of words must be a multiple of the set size.

Inputting time-dependent volume tables where the search variable is a thermodynamic variable from some other component can run into difficulties if the component numbering is such that the time-dependent volume is initialized before the component providing the needed search variable. A reliab' .x for this is to make the search variable a control system output in the desired units, wh' .. the thermodynamic variable is the control system input in code internal (SI) units. The control system initial

value can be set to the desired initial value of the search variable, and this will be used by the time-dependent table.

W1(R)   Search variable (e.g., time).

W2-W7(R)   Quantities as described under word 1 in Card 200. Depending on the control word, two
                 through five quantities may be required. If entered, boron concentration follows the last
                 required word for thermodynamic conditions.

As described above, sets may be entered one or more per card.

A7.4   Single-Junction Component

A single-junction component is indicated by SNGLJUN on card ccc0000. For major edits, minor edits, and plot variables, the junction in the single junction component is numbered ccc000000.

A7.4.1   Cards ccc0101 through ccc0109, Single-Junction Geometry Cards

This card (or cards) is required for single-junction components.

W1(I)   <u>From</u> connection code to a component. This refers to the component from which the
                 junction coordinate direction originates. For connecting to a time-dependent volume, the
                 connection code is ccc000000, where ccc is the component number of the time-dependent
                 volume. An old or an expanded format can be used to connect all other volumes. In the old
                 format, use ccc000000 if the connection is to the inlet side of the component and use
                 ccc010000 if the connection is to the outlet side of the component. In the expanded
                 format, the connection code is cccvv000n, where cc is the component number, vv is the
                 volume number, and n indicates the face number. A nonzero n specifies the expanded
                 format. The number n equal to 1 and 2 specifies the inlet and outlet faces, respectively, for
                 the volume's coordinate direction (see Section 2.1). The number n equal to 3 through 6
                 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for
                 the second coordinate direction; n equal to 5 and 6 would do the same for the third
                 coordinate direction.

W2(I)   <u>To</u> connection code to a component. This refers to the component at which the junction
                 coordinate direction ends. See the description for W1 above.

W3(R)   Junction area (m^2, ft^2). If zero, the area is set to the minimum volume flow area of the
                 adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller
                 than the minimum of the adjoining volume areas. For smooth area changes, there are no
                 restrictions.

W4(R)   Forward flow energy loss coefficient. This quantity will be used in each of the phasic
                 momentum equations when the junction velocity of that phase is positive or zero. Note: a
                 variable loss coefficient may be specified. See Section A7.4.3.

W5(R)   Reverse flow energy loss coefficient. This quantity will be used in each of the phasic
                 momentum equations when the junction velocity of that phase is negative. Note: a
                 variable loss coefficient may be specified. See Section A7.4.3.

W6(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equations. e=0 means that the modified PV term will not be applied, and e=1 means that it will be applied.

The digit f specifies CCFL options. f=0 means that the CCFL model will not be applied, and f=1 means that it will be applied.

The digit v specifies horizontal stratification entrainment/ pullthrough options. This model is for junctions connected to a horizontal volume. v=0 means the model is not applied; v=1 means an upward-oriented junction; v=2 means a downward-oriented junction; and v=3 means a centrally (side) located junction.

The digit c specifies choking options. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous. h=0 specifies the nonhomogeneous (two velocity momentum equations) option, and h=2 specifies the homogeneous (single velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a 1.

The digit s specifies momentum flux options. s=0 uses momentum flux in both the to volume and the from volume. s=1 uses momentum flux in the from volume, but not in the to volume. s=2 uses momentum flux in the to volume, but not in the from volume; s=3 does not used momentum flux in either the to or the from volume.

W7(R) Subcooled discharge coefficient. This quantity is applied only to subcooled liquid choked flow calculations. The quantity must be >0.0 and ≤2.0. If missing, it is set to 1.0.

W8(R) Two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be >0.0 and ≤2.0. If missing, it is set to1.0.

W9(R) Superheated discharge coefficient. This quantity is applied only to superheated vapor choked flow calculations. The quantity must be >0.0 and ≤2.0. If missing, it is set to 1.0.

A7.4.2   Card ccc0110, Single-Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., f=0 in Word 6 of Cards ccc0101-ccc0109), then, the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., f=1 in Word 6 of Cards ccc0101-ccc0109), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R)   Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥ 0. This number should be computed from 4.0*(junction area)/(wetted perimeter). If zero is entered or if the default is used, the junction diameter is computed from 2.0*(junction area/π)**0.5. See Word 3 of Cards ccc0101-ccc0109 for the junction area.

W2(R)   Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form). See Section 3 of Volume I for details of the model.

W3(R)   Gas intercept, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R)   Slope, m. This quantity is the slope used in the CCFL correlation and must be > 0. The default value is 1.

A7.4.3   Card ccc0111, Single-Junction Form Loss Data Card

This card is optional. The user-specified form loss is given in Words 4 and 5 of Card ccc0101 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) B_f (≥ 0). This quantity must be greater than or equal to zero.

W2(R) c_f (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_r (≥ 0). This quantity must be greater than or equal to zero.

W4(R) c_r (≥ 0). This quantity must be greater than or equal to zero.

A7.4.4   Card ccc0201, Single-Junction Initial Conditions

This card is required for single-junction components.

W1(I)   Control word. If zero, the next two words are velocities; if one, the next two words are mass flows.

W2(R)   Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow
             (kg/s, lb/s), depending on the control word.

W3(R)   Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow
             (kg/s, lb/s), depending on the control word.

W4(R)   Interface velocity (m/s, ft/s). Enter zero.

A7.5 Time-Dependent Junction Component

This component is indicated by TMDPJUN on Card ccc0000. For major edits, minor edits, and plot
variables, the junction in the time-dependent junction component is numbered as ccc000000.

A7.5.1 Card ccc0101, Time-Dependent Junction Geometry Card

This card is required for time-dependent junction components.

W1(I)   From connection code to a component. This refers to the component from which the
             junction coordinate direction originates. For connecting to a time dependent volume, the
             connection code is ccc000000, where ccc is the component number of the time dependent
             volume. An old or an expanded format can be used to connect all other volumes. In the old
             format, use ccc000000 if the connection is to the inlet side of the component and use
             ccc010000 if the connection is to the outlet side of the volume. In the expanded format,
             the connection code is cccvv000n, where ccc is the component number, vv is the volume
             number, and n indicates the face number. A nonzero n specifies the expanded format. The
             number n equal to 1 and 2 specifies the inlet and outlet faces respectively or the volume's
             coordinate direction (see Section 2.1). The number n equal to 3 through 6 specifies
             crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the
             second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate
             direction.

W2(I)   To connection code to a component. This refers to the component at which the junction
             coordinate direction ends. See the description for W1 above.

W3(R)   Junction area (m^2, ft^2). If zero, the area is set to the minimum flow area of the adjoining
             volumes. There are no junction area restrictions for time dependent junctions.

A7.5.2 Card ccc0200, Time-Dependent Junction Data Control Word

This card is optional. If this card is missing, the second and third words of the time-dependent data
are assumed to be velocities.

W1(I)   Control word. If zero, the second and third words of the time-dependent junction data in
             Cards ccc0201 through ccc0299 are velocities. If one, the second and third words of the
             time-dependent junction data in Cards ccc0201 through ccc0299 are mass flows. In both
             cases, the fourth word is interface velocity and should be entered as zero.

W2(I)　　　　　　Table trip number. This word is optional. If missing or zero and Word 3 is missing, no trip is used, and the time argument is the advancement time. If nonzero and Word 3 is missing, this number is the trip number and the time argument is -1.0 if the trip is false, and the advancement time minus the trip time if the trip is true.

W3(A)　　　　　　Alphanumeric part of variable request code. This quantity is optional. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. If the trip number is zero, the specified argument is always used. If the trip number is nonzero, -1.0E75 is used if the trip is false, and the specified argument is used if the trip is true. TIME can be selected, but note that the trip logic is different than if this word is omitted.

W4(I)　　　　　　Numeric part of variable request code. This is assumed zero if missing.

A7.5.3　Cards ccc0201 through ccc0299, Time-Dependent Junction Data Cards

These cards are required for time-dependent junction components. A set of data consists of the search variable (e.g., time) followed by the required data indicated by control word 1 on card ccc0200. The card numbers need not be consecutive, but the value of the search variable in a succeeding set must be equal to or greater than the value in the previous set. One or more sets of data up to 5000 sets may be entered. Zero may be entered for a velocity or flow if the phase or material is not present. The interpolation and card formats for the time-dependent data are identical to that in Section A7.3.3 (Cards ccc0201-ccc0209, Time-Dependent Volume Data Cards).

When doing a single phase problem and entering velocities here, the same value should be entered for both liquid and vapor velocities. If entering mass flows, the correct value should be entered for either liquid or vapor (whichever single phase is being modeled) and the other entry should be zero.

If the user wants to specify the vapor void fraction as a function of time in the time-dependent volume, and the total mass flow as a function of time in the time-dependent junction, then both the phasic (gas and liquid) mass flow rates must be calculated and entered .n these cards.

W1(R)　　　　　　Search variable (e.g., time).

W2(R)　　　　　　Liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control word 1 on card ccc0200.

W3(R)　　　　　　Vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control word 1 on card ccc0200.

W4(R)　　　　　　Interface velocity (m/s, ft/s). Enter zero.

As described above, sets may be entered one or more per card.

A7.6　Pipe, Annulus Component

A pipe component is indicated by PIPE, an annulus component is indicated by ANNULUS on Card ccc0000. The PIPE and ANNULUS components are similar, except that the ANNULUS component must be vertical and all the water is in the film (i.e., no drops) when in the annular-mist flow regime. The

remaining input for both components is identical. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. For major edits, minor edits, and plot variables, the volumes in the pipe component are numbered as cccnn0000, where nn is the volume number (greater than 00 and less than 100). The junctions in the pipe component are numbered as cccmm0000, where mm is the junction number (greater than 00 and less than 99).

The input for a pipe or annulus component assumes that the pipe has at least two volumes with one junction separating the two volumes. It is possible to input a one-volume pipe or annulus. In order to implement this special case, the user must set the number of volumes and the volume number on the volume cards to one. In addition, the user should not input any of the junction cards.

The volumes in a pipe are usually considered one-dimensional components and flow in the volumes is along the x-coordinate. Cross flow junctions can connect the pipe volumes in the y and z-coordinate directions using a form of the momentum equation that does not include momentum flux terms. Optional input may be added that allow the full one-dimensional momentum equations to be used in the y- and z-coordinate directions.

A7.6.1   Card ccc0001, Pipe, Annulus Information Card

This card is required for pipe components.

W1(I)   Number of volumes, nv. nv must be greater than zero and less than 100. The number of associated junctions internal to the pipe is nv-1. The outer junctions are described by other components.

A7.6.2   Cards ccc0101 through ccc0199, Pipe, Annulus X-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are required, and the card numbers need not be consecutive. The words for one set are

W1(R)   Volume flow area (m^2, ft^2).

W2(I)   Volume number.

A7.6.3   Cards ccc1601 through ccc1699, Pipe, Annulus Y-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are optional and if entered activate the y-coordinate for each volume and allow the full one-dimensional momentum equations to be used in connections to the y faces. The card numbers need not be consecutive. The words for one set are:

W1(R)   Volume flow area (m^2, ft^2).

W2(I)   Volume number.

A7.6.4   Cards ccc1701 through ccc1799, Pipe, Annulus Z-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets. These cards are optional and if entered activate the z-coordinate for each volume and allow the full one-dimensional momentum equations to be used in connections to the z faces. The card numbers need not be consecutive. The words for one set are:

W1(R)   Volume flow area (m^2, ft^2).

W2(I)   Volume number.

A7.6.5   Cards ccc0201 through ccc0299, Pipe, Annulus Junction Flow Areas

These cards are optional, and, if entered, the card numbers need not be consecutive. The format is two words per set in sequential expansion format for nv-1 sets.

W1(R)   Internal junction flow area (m^2, ft^2). If cards are missing or a word is zero, the junction flow area is set to the minimum area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or less than the minimum of the adjacent volume areas. There is no restriction for smooth area changes.

W2(I)   Junction number.

A7.6.6   Cards ccc0301 through ccc0399, Pipe, Annulus X-Coordinate Volume Lengths

These cards are required for pipe components. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R)   Pipe volume length (m, ft).

W2(I)   Volume number.

A7.6.7   Cards ccc1801 through ccc1899, Pipe, Annulus Y-Coordinate Volume Lengths

These cards are optional and if entered activate the y-coordinate for each volume and allow the full one-dimensional momentum equation for connections to the y faces. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R)   Pipe volume length (m, ft).

W2(I)   Volume number.

A7.6.8   Cards ccc1901 through ccc1999, Pipe, Annulus Z-Coordinate Volume Lengths

These cards are optional and if entered activate the z-coordinate for each volume and allow the full one-dimensional momentum equation for connections to the z faces. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R)   Pipe volume length (m, ft).

W2(I)   Volume number.

A7.6.9 Cards ccc0401 through ccc0499, Pipe, Annulus Volume Volumes

The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R)   Volume (m^3, ft^3). If these cards are missing, volumes equal to zero are assumed. The code requires that each volume equal the flow area times length. For any volume, at least two of the three quantities, area, length, or volume, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the quantities are zero, the volume must equal the area times the length within a relative error of 0.000001.

W2(I)   Volume number.

A7.6.10 Cards ccc0501 through ccc0599, Pipe, Annulus Volume Azimuthal Angles

These cards are optional, and, if not entered, the angles are set to zero. The format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(R)   Azimuthal angle (degrees). The absolute value of the angle must be ≤ 360 degrees.

W2(I)   Volume number.

A7.6.11 Cards ccc0601 through ccc0699, Pipe, Annulus Volume Vertical Angles

These cards are required for pipe components. The format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(R)   Vertical angle (degrees). The absolute value of the angle must be less than or equal to 90 degrees. This angle is used in the interphase drag calculation.

W2(I)   Volume number.

A7.6.12 Cards ccc0701 through ccc0799, Pipe, Annulus X-Coordinate (Elevation) Changes

These cards are optional. If these cards are missing, the coordinate changes or elevation changes are computed from the x-coordinate volume length and a rotation matrix computed from the angle information. If these cards are entered, the entered data becomes the x-coordinate change or elevation change data. Two formats entering one or three coordinate changes per volume are provided. The card format is two or four words per set in sequential expansion format up to nv sets, and card numbers need not be consecutive.

One Coordinate Change Per Volume Format:

W1(R)   Elevation change. This is the coordinate change along the fixed z-axis due to the traverse from inlet to outlet along the local x-coordinate, Δ_{zx} (m, ft). A positive value is an increase in elevation. The magnitude must be equal to or less than the volume length. When the absolute value of the elevation angle determined by the ratio of the elevation change (this Word 6) and the volume length (Word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used; when the ratio is greater than 45 degrees, the vertical flow regime map is used.

W2(I)   Volume number.

   Three Coordinate Changes Per Volume Format:

W1(R)   Coordinate change along the fixed x-axis due to traverse from inlet to outlet along the local x-coordinate, Δ_{xx}, (m, ft).

W2(R)   Coordinate change along the fixed y-axis due to traverse from inlet to outlet along the local x-coordinate, Δ_{yx}, (m, ft).

W3(R)   Coordinate change along the fixed z-axis due to traverse from inlet to outlet along the local x-coordinate, Δ_{zx}, (m, ft).

W4(I)   Volume number.

A7.6.13 Cards ccc2101 through ccc2199, Pipe, Annulus Y-Coordinate (Elevation) Changes

   These cards are optional. If these cards are missing, the coordinate changes are computed from the y-coordinate volume length and a rotation matrix computed from the angle information. If these cards are entered, the entered data overwrites the previously computed coordinate change data. The card format is four words per set in sequential expansion format up to nv sets, and card numbers need not be consecutive.

W1(R)   Coordinate change along fixed x-axis due to traverse from inlet to outlet along the local y-coordinate, Δ_{xy} (m, ft).

W2(R)   Coordinate change along fixed y-axis due to traverse from inlet to outlet along the local y-coordinate, Δ_{yy} (m, ft).

W3(R)   Coordinate change along fixed z-axis due to traverse from inlet to outlet along the local y-coordinate, Δ_{zy} (m, ft).

W4(I)   Volume number.

A7.6.14 Cards ccc2201 through ccc2299, Pipe, Annulus Z-Coordinate (Elevation) Changes

   These cards are optional. If these cards are missing, the coordinate changes are computed from the z-coordinate volume length and a rotation matrix computed from the angle information. If these cards are

entered, the entered data overwrites the previously computed coordinate change data. The card format is four words per set in sequential expansion format up to nv sets, and card numbers need not be consecutive.

W1(R)   Coordinate change along fixed x-axis due to traverse from inlet to outlet along the local z-coordinate, Δ_{xz} (m, ft).

W2(R)   Coordinate change along fixed y-axis due to traverse from inlet to outlet along the local z-coordinate, Δ_{yz} (m, ft).

W3(R)   Coordinate change along fixed z-axis due to traverse from inlet to outlet along the local z-coordinate, Δ_{zz} (m, ft).

W4(I)   Volume number.

A7.6.15   Cards ccc0801 through ccc0899, Pipe, Annulus Volume X-Coordinate Friction Data

These cards are required for pipe components. The card format is three words per set for nv sets, and card numbers need not be consecutive.

W1(R)   Wall roughness (m, ft).

W2(R)   Hydraulic diameter (m, ft). This should be computed from 4.0*(volume flow area)/(wetted perimeter). If zero, the hydraulic diameter is computed from 2.0*(volume flow area/π)**0.5. A check is made to ensure that the roughness is less than half the hydraulic diameter. See Word 1 on Cards ccc0101-ccc0109 for the volume flow area.

W3(I)   Volume number.

A7.6.16   Cards ccc2301 through ccc2399, Pipe, Annulus Volume Y-Coordinate Friction Data

These cards are optional and may be entered if volume flow area or volume length data was entered for the y-coordinate. If the cards are not entered, the wall roughness defaults to zero and the default hydraulic diameter is computed as if zero was entered in Word 2. The format for these cards is the same as for the friction data for the x-coordinate (Section A7.6.15).

A7.6.17   Cards ccc2401 through ccc2499, Pipe, Annulus Volume Z-Coordinate Friction Data

These cards are optional and may be entered if volume flow area or volume length data was entered for the y-coordinate. If the cards are not entered, the wall roughness defaults to zero and the default hydraulic diameter is computed as if zero was entered in Word 2. The format for these cards is the same as for the friction data for the x-coordinate (Section A7.6.15).

A7.6.18   Cards ccc2501 through ccc2599, Pipe, Annulus Volume Additional Laminar Wall

Friction Data

These cards are optional. If these cards are not entered, the default values are 1.0 for the shape factor and 0.0 for the viscosity ratio exponent. The card format is seven words per set in sequential expansion format for nv sets and card numbers need not be consecutive.

W1(R)   Shape factor for x-coordinate.

W2(R)   Viscosity ratio exponent for x-coordinate.

W3(R)   Shape factor for y-coordinate.

W4(R)   Viscosity ratio exponent for y-coordinate.

W5(R)   Shape factor for z-coordinate.

W6(R)   Viscosity ratio exponent for z-coordinate.

W7(I)   Volume number.

A7.6.19   Cards ccc0901 through ccc0999, Pipe, Annulus Junction Loss Coefficients

These cards are optional and if missing, the energy loss coefficients are set to zero. The card format is three words per set in sequential expansion format for nv-1 sets, and card numbers need not be consecutive.

W1(R)   Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified. See Section A7.6.29.

W2(R)   Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified. See Section A7.6.29.

W3(I)   Junction number.

A7.6.20   Cards ccc1001 through ccc1099, Pipe, Annulus Volume X-Coordinate Control Flags

These cards are required for pipe volumes. The card format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W.(I)   Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. These words enter the scaler oriented flags and the x coordinate flags for each volume in the pipe.

The digit t specifies whether the thermal front tracking model is to be used; t=0 specifies that the front tracking model is not to be used for the volume, and t=1 specifies that the front tracking model is to be used for the volume. The thermal front tracking model can only be applied to vertically-oriented components.

The digit l specifies whether the mixture level tracking model is to be used; l=0 specifies that the level model not be used for the volume, and l=1 specifies that the level model be used for the volume. The mixture level tracking model can only be applied to vertically-oriented components.

The digit p specifies whether the water packing scheme is to be used. p=0 specifies that the water packing scheme is to be used for the volume, and p=1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer.

The digit v specifies whether the vertical stratification model is to be used. v=0 specifies that the vertical stratification model is to be used for the volume, and v=1 specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer.

The digit b specifies the interphase friction that is used. b=0 means that the pipe interphase friction model will be applied, and b=1 means that the rod bundle interphase friction model will be applied.

The digit f specifies whether wall friction is to be computed. f=0 specifies that wall friction effects are to be computed along the x coordinate of the volume, and f=1 specifies that wall friction effects are not to be computed along the x coordinate.

The digit e specifies if nonequilibrium or equilibrium is to be used. e=0 specifies that a nonequilibrium (unequal temperature) calculation is to be used, and e=1 specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison to other codes.

W2(I)   Volume number.

A7.6.21 Cards ccc2701 through ccc2799, Pipe, Annulus Y-Coordinate Control Flags

W1(I)   Volume control flags. This word has the general packed format tlpvbfe, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the y direction.

The digit f specifies whether wall friction is to be computed. f=0 specifies that wall friction effects are to be computed along the y coordinate direction in the volume, and f=1 specifies that wall friction effects are not to be computed along the y coordinate direction.

W2(I)   Volume number.

A7.6.22   Cards ccc2801 through ccc2899, Pipe, Annulus Z-Coordinate Control Flags

W1(I)   Volume control flags. This word has the general packed format tlpvbfe, but this word is limited to 00000f0 since it only enters the coordinate oriented flags for the z direction.

The digit f specifies whether wall friction is to be computed. $f=0$ specifies that wall friction effects are to be computed along the z coordinate direction in the volume, and $f=1$ specifies that wall friction effects are not to be computed along the z coordinate direction.

W2(I)   Volume number.

A7.6.23   Cards ccc1101 through ccc1199, Pipe, Annulus Junction Control Flags

These cards are required for pipe components. The card format is two words per set in sequential expansion format for nv-1 sets, and card numbers need not be consecutive.

W1(I)   Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equations. $e=0$ means that the modified PV term will not be applied, and $e=1$ means that it will be applied.

The digit f specifies CCFL options. $f=0$ means that the CCFL model will not be applied, and $f=1$ means that the CCFL model will be applied.

The digit v is not used and should be input as zero ($v=0$). The horizontal stratification entrainment/pullthrough model cannot be used.

The digit c specifies choking options. $c=0$ means that the choking model will be applied, and $c=1$ means that the choking model will not be applied.

The digit a specifies area change options. $a=0$ means either a smooth area change or no area change, and $a=1$ means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous. $h=0$ specifies the nonhomogeneous (two-velocity momentum equations) option, and $h=2$ specifies the homogeneous (single velocity momentum equation) option. For the homogeneous option ($h=2$), the major edit printout will show a one.

The digit s is not used and should be input as zero ($s=0$).

W2(I)   Junction number.

A7.6.24   Cards ccc1201 through ccc1299, Pipe, Annulus Volume Initial Conditions

These cards are required for pipe components. The card format is seven words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(I)   Control word. This word has the packed format εbt. It is not necessary to input leading
               zeros.

The digit ε specifies the fluid. ε=0 is the default fluid, ε=1 specifies H_2O, ε=2 specifies
D_2O, and ε=3 specifies H_2. The default fluid is that set for the hydrodynamic system by
Cards 120 through 129 or this control word in another volume in this hydrodynamic
system. The fluid type set on Cards 120 through129 or these control words must be
consistent (i.e., not specify different fluids). If Cards120 through129 are not entered and
all control words use the default ε=0, then H_2O is assumed as the fluid.

The digit b specifies whether boron is present or not. b=0 specifies that the volume fluid
does not contain boron; b=1 specifies that a boron concentration in parts of boron per parts
of liquid (which may be zero) is being entered after the other required thermodynamic
information.

The digit t specifies how the following words are to be used to determine the initial
thermodynamic state. Entering t equal to 0 through 3 specifies one component (steam/
water). Entering t equal to 4 through 6 allows the specification of two components (steam/
water and noncondensable gas).

If t=0, the next four words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal
energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void
fraction. These quantities will be interpreted as nonequilibrium or equilibrium conditions,
depending on the volume control flag. If equilibrium, the static quality is checked, but
only the pressure and internal energies are used to define the thermodynamic state. W6
should be 0.0.

If t=1, the next two words are interpreted as temperature (K, °F) and quality in equilibrium
condition. W4, W5, and W6 should be 0.0.

If t=2, the next two words are interpreted as pressure (Pa, lb_f/in^2) and quality in
equilibrium condition. W4, W5, and W6 should be 0.0.

If t=3, the next two words are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F)
in equilibrium condition. W4, W5, and W6 should be 0.0.

The following options are used for input of noncondensable states only. In all cases, the criteria used
for determining the range of values for quality are

1.0E-9 ≤ quality ≤ 0.99999999, two-phase conditions, and quality < 1.0E-9 or quality > 0.99999999,
single phase.

Noncondensable options are as follows:

If t=4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F),
and equilibrium quality. Using this input option with quality >0.0 and ≤1.0, saturated
noncondensables will result. W5 and W6 should be 0.0. Also, the temperature is restricted

to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. W5 and W6 should be 0.0. Little experience has been obtained using this option, and it has not been checked out.

If t=6, the next five words are interpreted as pressure (Pa, lb$_f$/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor-specific internal energy.

W2-W6(R) Quantities as described under Word 1. Five quantities must be entered, and zeros should be entered for unused quantities. If any control word (Word 1) indicates that boron is present, Cards ccc2001 through ccc2099 must be entered to define the initial boron concentrations. Boron concentrations are not entered in Words 2 through 6.

W7(I) Volume number.

A7.6.25 Cards ccc2001 through ccc2099, Pipe, Annulus Initial Boron Concentrations

These cards are required only if boron is specified in one of the control words (Word 1) in Cards ccc1201 through ccc1299. The card format is two words per set in sequential expansion format for nv sets. Boron concentrations must be entered for each volume, and zero should be entered for those volumes whose associated control word did not specify boron.

W1(R) Boron concentration. Parts of boron per parts of liquid.

W2(I) Volume number.

A7.6.26 Card ccc1300, Pipe, Annulus Junction Conditions Control Words

This card is optional, and, if missing, velocities are assumed on Cards ccc1301 through ccc1399.

W1(I) Control word. If zero, the first and second words of each set on Cards ccc1301 through ccc1399 are velocities. If one, the first and second words of each set on Cards ccc1301 through ccc1399 are mass flows.

A7.6.27 Cards cc1301 through ccc1399, Pipe, Annulus Junction Initial Conditions

W1(R)   Initial liquid velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R)   Initial vapor velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W3(R)   Interface velocity (m/s, ft/s). Enter zero.

W4(I)   Junction number.

A7.6.28 Cards ccc1401 through ccc1499, Pipe, Annulus Junction Diameter and CCFL Data Cards

These cards are optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation, (i.e., $f=0$ in Word 1 of Cards ccc1101-ccc1199) then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., $f=1$ in Word 1 of Cards ccc1101-ccc1199), then enter all four words for the appropriate CCFL model if values different from the default value are desired.

W1(R)   Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥ 0. The number should be computed from 4.0*(junction area)/(wetted perimeter). If a zero is entered or if the default is used, the junction diameter is computed from 2.0*(junction area/π)**0.5. See Word 1 of Cards ccc0201-ccc0299 for the junction area.

W2(R)   Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R)   Gas intercept, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R)   Slope, m. This quantity is the slope used in the CCFL correlation and must be >0. The default value is 1.

W5(I)   Junction number.

A7.6.29 Card ccc3001 through ccc3099, Pipe, Annulus Junction Form Loss Data Card

This card is optional. The user specified form loss is given in Words 1 and 2 of Cards ccc0901 through ccc0999 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 1 and 2 of Cards ccc0901 through ccc0999. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all five words for the appropriate expression.

W1(R) B_f (≥ 0). This quantity must be greater than or equal to zero.

W2(R) c_f (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_r (≥ 0). This quantity must be greater than or equal to zero.

W4(R) c_r (≥ 0). This quantity must be greater than or equal to zero.

W5(I)   Junction number.

A7.7   Branch, Separator, Jetmixer, Turbine, or ECC Mixer Component

A branch component is indicated by BRANCH, a steam separator is indicated by SEPARATR, a jetmixer is indicated by JETMIXER, a turbine is indicated by TURBINE, and an ECC mixer is indicated by ECCMIX on Card ccc0000. In junction references using the old format, the code for the component inlet is ccc000000 and the code for the component outlet is ccc010000. In the junction references using the expanded format, the connection code is cccvv00n, where ccc is the component number, vv is the volume number, and n is the face number. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. Normally, only a branch has more than one junction connected to a volume end. Multiple junctions may connect to the ends of pipes and single volumes, except that a warning message is issued even though the connections are handled correctly. Limiting multiple connections to branch components allows the warning message to indicate probable input error. If more than one junction is connected on one end of a branch, each junction should be modeled as an abrupt area change. For major edits, minor edits, and plot variables, the volume in the branch component is numbered as ccc010000. The junctions associated with the branch component are numbered as cccmm0000, where mm is the junction number (greater than 00 and less than 10).

A separator component is a specialized branch component having three junctions. nj defined below must be three, and no junctions in other components may connect to this component. N defined below must have values of 1, 2, and 3. For the junctions, n=1 is the vapor outlet, n=2 is the liquid fall back, and n=3 is the separator inlet. The _from_ part of the vapor outlet junction must refer to outlet of the separator (ccc010000), and the _from_ part of the liquid fall back must refer to the inlet of the separator (ccc000000). To include the direct path from a steam generator downcomer to the steam dome, a bypass volume is recommended. The smooth or abrupt junction option can be used for the three junctions. Appropriate user input energy loss coefficients may be needed to match a known pressure drop across the separator. We recommend that choking be turned off for all three junctions. The vapor outlet and liquid fall back junctions should use the nonhomogeneous option. The CCFL flag must be turned off (f=0) for all three junctions. The horizontal stratification flag is not used for separator junctions and should be set to zero (v=0). The rod bundle interphase friction flag must be turned off (b=0) in the separator volume. The vertical stratification model flag is not used in the separator volume and should be set to zero (v=0). The water packing scheme flag is not used in the separator volume and should be set to zero (p=0).

A jetmixer component is a specialized branch using three junctions numbered in the same manner as the separator. For the junctions, n=1 represents the drive, n=2 represents the suction, and n=3 represents the discharge. The to part of the drive and suction junctions must refer to the inlet end of the jetmixer (ccc000000), and the from part of the discharge junction must refer to the outlet end of the jetmixer (ccc010000). To model a jet pump properly, the junction flow areas of the drive and suction should equal the volume flow area. The CCFL flag must be turned off (f=0) for all three junctions. The horizontal stratification flag is not used for jetmixer junctions and should be set to zero (v=0). The rod bundle interphase friction flag must be turned off (b=0) in the jetmixer volume. The vertical stratification model flag is not used in the jetmixer volume and should be set to zero (v=0). The water packing scheme flag is not used in the jetmixer volume and should be set to zero (p=0).

A turbine component is a specialized branch with additional input to describe the turbine characteristics. A simple turbine might use only one turbine component. A multistage turbine with steam extraction points might require several turbine components. nj must be equal to 1 or 2. For the junctions, n=1 is the turbine junction that models the stages, and n=2 is the steam extraction (bleed) junction that must be crossflow. The primary steam inlet junction (n=1) is a normal junction, and the steam extraction line (n=2) is modeled as a crossflow junction. The turbine junction (n=1) must be the only entrance junction, and there must be only one exit junction (part of another component). The to part of the steam inlet junction (n=1) must refer to the inlet end of the turbine volume (ccc000000). A restriction currently exists such that the volume and junction upstream (usual flow) must be the numerically preceding volume and junction. For the first turbine, there must be an artificial turbine component preceding it (i.e., constant efficiency, with efficiency=0, turbine with h=0). The volume and junction upstream of the artificial turbine need not be the numerically preceding volume and junction. The inertia and the friction of this artificial turbine should be entered somewhat less than that of the normal turbines. The horizontal stratification flag must be turned off (v=0). If several turbine components are in series, the choking flag should be left on (c=0) for the first component but turned off for the other components (c=1). The smooth junction option (a=0) should be used at both inlet and outlet junctions. The inlet and outlet junctions must be input as homogeneous junctions (h=2). If a steam extraction (bleed) junction is present, it must be a crossflow junction (s=1, 2, or 3). The CCFL flag must be turned off (f=0) for both junctions. The rod bundle interphase friction flag must be turned off (b=0) in the turbine volume. The vertical stratification model flag is not used in the turbine volume and should be set to zero (v=0). The water packing scheme flag is not used in the turbine volume and should be set to zero (p=0).

An ECC mixer (ECCMIX) component is a specialized branch that requires three junctions with a certain numbering order. The physical extent of the ECC mixer is a length of the cold leg, or any other horizontal pipe, centered around the position of the ECC injection location. The length of this pipe segment should be equal to three times the inside diameter of the pipe (if the physical arrangement of the system permits). Junction number one (the lowest numbered junction) must be the ECC connection. This is, in some respects, similar to the drive junction of a jetmixer component. Junction number two (the junction with higher number than the first one) should be the one that is the flow inlet to this component in normal operation. The geometrical angle between the axis of junctions one and two is one of the necessary inputs, as will be specified later. The third, or discharge, junction is the normal outlet of flow through this pipe segment. The to part of junctions one and two must refer to the inlet end of the ECC mixer (ccc000000), and the from part of the discharge junction must refer to the outlet end of the ECC mixer (ccc010000).

Two or more ECCMIX components may be considered in modeling some piping. These may be connected in tandem and require at least one normal volume between them.

The component identification word on Card ccc0000 should be ECCMIX for the ECC mixer. Th. word directs the code to use a specific flow regime map and a specific interfacial heat transfer package for steam condensation.

A7.7.1 Card ccc0001, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Information Card

This card is required for branch components.

W1(I)   Number of junctions, nj. nj is the number of junctions described in the input data for this component and must be equal to or greater than zero and less than ten. This number must be 3 for SEPARATR, JETMIXER, and ECCMIX components and must be 1 or 2 for TURBINE components. For BRANCH components, not all junctions connecting to the branch need be described with this component input, and NJ is not necessarily the total number of junctions connecting to the branch. Junctions described in single junctions, time dependent junctions, pumps, separators, jetmixers and other branches can be connected to this branch.

W2(I)   Initial condition control. This word is optional and, if missing, the junction initial velocities in the first and second words on Cards cccn201 are assumed to be velocities. If zero, velocities are assumed; if nonzero, mass flows are assumed.

A7.7.2 Card ccc0002, Separator Component Options Card

This card is an optional card for a separator component. The first word specifies the separator option while the second word specifies the number of actual separator components represented by this RELAP5 SEPARATOR component. The second word is needed if the user uses the General Electric separator options

W1(I)   Separator option, ISEPST. A value of 0 specifies the simple separator contained in previous versions of RELAP5 (default), a value of 1 specifies the General Electric dryer model, a value of 2 specifies a General Electric two stage separator, and a value of 3 specifies a three stage General Electric separator.

W2(I)   Number of separator components represented by this RELAP5 component. The number is needed only if Word 1 has a value of two or three.

A7.7.3 Cards ccc0101 through ccc0109, Branch, Separator, Jetmixer, Turbine, Or ECC Mixer X-Coordinate Volume Data

This card (or cards) is required for branch, separator, jetmixer, turbine, and ECC mixer components. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R)   Volume flow area (m^2, ft^2).

W2(R)   Length of volume (m, ft).

W3(R)   Volume of volume (m^3, ft^3). The code requires that the volume equals the volume flow
                 area times the length (W3=W1*W2). At least two of the three quantities, W1, W2, and
                 W3, must be nonzero. If one of the quantities is zero, it will be computed from the other
                 two. If none of the words are zero, the volume must equal the area times the length within
                 a relative error of 0.000001.

W4(R)   Azimuthal angle (degrees). The absolute value of this angle must be ≤360 degrees. This
                 quantity is not used in the calculation but is specified for possible automated drawing of
                 nodalization diagrams.

W5(R)   Inclination angle (degrees). The absolute value of this angle must be ≤90 degrees. The
                 angle 0 degrees is horizontal, and positive angles have an upward inclination, i.e., the inlet
                 is at the lowest elevation. This angle is used in the interphase drag calculation. For
                 ECCMIX, the allowable inclination angle is less than ±15 degrees. Any other value will
                 be considered an input error.

W6(R)   Elevation change (m, ft). A positive value is an increase in elevation. The absolute value
                 of this quantity must be less than or equal to the volume length. If the vertical angle
                 orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity
                 must also be nonzero and have the same sign. When the absolute value of the elevation
                 angle determined by the ratio of the elevation change (this Word 6) and the volume length
                 (Word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used. When
                 the ratio is greater than 45 degrees, the vertical flow regime map is used. For ECCMIX,
                 the ECC mixer flow regimes are used.

W7(R)   Wall roughness (m, ft).

W8(R)   Hydraulic diameter (m, ft). This should be computed from 4.0*(volume flow area)/(wetted
                 perimeter). If zero, the hydraulic diameter is computed from 2.0*(volume flow area/
                 π)**0.5. A check is made that the pipe roughness is less than half the hydraulic diameter.
                 See Word 1 for the volume flow area.

W9(I)   Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input
                 leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented
                 flags. Only one value for a scaler oriented flag is entered per volume but up to three
                 coordinate oriented flags can be entered for a volume, one for each coordinate direction.
                 At present, the f flag is the only coordinate direction oriented flag. This word enters the
                 scaler oriented flags and the x coordinate flag.

                 The digit t specifies whether the thermal front tracking model is to be used; t=0 specifies
                 that the front tracking model is not to be used for the volume, and t=1 specifies that the
                 front tracking model is to be used for the volume. This model is not used for SEPARATR,
                 JETMIXER, or ECCMIX components and the flag if entered as 1 is reset to 0 and is not
                 considered an input error. This model is also not used for the TURBINE component but
                 entering the digit as 1 is an input error.

                 The digit l specifies whether the mixture level tracking model is to be used; l=0 specifies
                 that the level model not be used for the volume, and l=1 specifies that the level model be
                 used for the volume. This model is not used for SEPARATR, JETMIXER, or ECCMIX

components and the flag if entered as 1 is reset to 0 and is not considered an input error. This model is also not used for the TURBINE component but entering the digit as 1 is an input error.

The digit p specifies whether the water packing scheme is to be used. $p=0$ specifies that the water packing scheme is to be used for the volume, and $p=1$ specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer. This digit is used for the BRANCH and ECCMIX components. For the SEPARATR, JETMIXER, and TURBINE components, the water packer scheme is not allowed, the digit is not used and may be input as 0 or 1. The major edit will show $p=1$.

The digit v specifies whether the vertical stratification model is to be used. $v=0$ specifies that the vertical stratification model is to be used for the volume, and $v=1$ specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer. This digit is used for the BRANCH component. For the SEPARATR, JETMIXER, ECCMIX, and TURBINE components, the vertical stratification model is not allowed, the digit is not used and may be input as 0 or 1. The major edit will show $v=1$.

The digit b specifies the interphase friction that is used. $b=0$ means that the pipe interphase friction model will be applied, $b=1$ means that the rod bundle interphase friction model will be applied, and $b=2$ means that the narrow channel model will be applied. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, ECCMIX, and TURBINE components, the rod bundle interphase friction is not allowed, the digit is not used and should be input as 0. The major edit will show $b=0$. The digit b must be entered as 0 for a TURBINE component.

The digit f specifies whether wall friction is to be computed. $f=0$ specifies that wall friction effects are to be computed along the x coordinate direction in the volume, and $f=1$ specifies that wall friction effects are not to be computed along the x coordinate. For a separator, either 0 or 1 may be entered; the code will set $f=1$ and no wall friction will be calculated. The digit f must be entered as 1 for a TURBINE component.

The digit e specifies if nonequilibrium or equilibrium is to be used. $e=0$ specifies that a nonequilibrium (unequal temperature) calculation is to be used, and $e=1$ specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison to other codes.

A7.7.4 Cards ccc0181 through ccc0189, Branch, Separator, Jetmixer, or ECC Mixer Y-Coordinate Volume Data

These cards are optional for BRANCH, SEPARATR, JETMIXER, and ECCMIX components but are not allowed for TURBINE components. These cards are used when the user specifies the y-direction connection with the crossflow model.

W1(R)   Area of the volume (m^2).

W2(R)   Length of the crossflow volume (m).

W3(R)   Roughness.

W4(R)   Hydraulic diameter (m).

W5(I)   Volume control flags. This word has the general packed format tlpvbfe, but this word is
             limited to 00000f0 since it only enters the coordinate oriented flags for the y direction.

             The digit f specifies whether wall friction is to be computed. f=0 specifies that wall
             friction effects are to be computed along the y coordinate direction in the volume, and f=1
             specifies that wall friction effects are not to be computed along the y coordinate direction.

W6(R)   This word is not used. Enter 0.

W7(R)   This word is not used. Enter 0.

W8(R)   This word is the position change in the z fixed (vertical) direction as the flow passes from
             the y inlet face to the y outlet face (m, ft). This quantity affects problems if connections
             are made to the y faces.

A7.7.5   Cards ccc0191 through ccc0199, Branch, Separator, Jetmixer, or ECC Mixer Z-Coordinate Volume Data

These cards are optional for BRANCH, SEPARATR, JETMIXER, and ECCMIX components but
are not allowed for TURBINE components. These cards are used when the user specifies the z-direction
connection with the crossflow model.

W1(R)   Area of the volume (m^2).

W2(R)   Length of the crossflow volume (m).

W3(R)   Roughness.

W4(R)   Hydraulic diameter (m).

W5(I)   Volume control flags. This word has the general packed format tlpvbfe, but this word is
             limited to 00000f0 since it only enters the coordinate oriented flags for the z direction.

             The digit f specifies whether wall friction is to be computed. f=0 specifies that wall
             friction effects are to be computed along the z coordinate direction in the volume, and f=1
             specifies that wall friction effects are not to be computed along the z coordinate direction.

W6(R)   This word is not used. Enter 0.

W7(R)   This word is not used. Enter 0.

W8(R)   This word is the position change in the z fixed (vertical) direction as the flow passes from the z inlet face to the z outlet face (m, ft). This quantity affects problems if connections are made to the zfaces.

A7.7.6   Card ccc0131, Additional Laminar Wall Friction Card

This card is optional except for a turbine component. If this card is not entered, the default values are 1.0 for the shape factor and 0.0 for the viscosity ratio exponent. Two, four, or six quantities may be entered on the card, and the data not entered are set to default values.

W1(R)   Shape factor for x-coordinate.

W2(R)   Viscosity ratio exponent for x-coordinate.

W3(R)   Shape factor for y-coordinate.

W4(R)   Viscosity ratio exponent for y-coordinate.

W5(R)   Shape factor for z-coordinate.

W6(R)   Viscosity ratio exponent for z-coordinate.

A7.7.7   Card ccc0200, Branch, Separator, Jetmixer, Turbine. or ECC Mixer Volume Initial Conditions

This card is required for branch, separator, jetmixer, turbine, and ECC mixer components.

W1(I)   Control word. This word has the packed format $\underline{ebt}$. It is not necessary to input leading zeros.

The digit $\underline{e}$ specifies the fluid; $\underline{e}$=0 is the default fluid, $\underline{e}$=1 specifies H_2O, $\underline{e}$=2 specifies D_2O, and $\underline{e}$=3 specifies H_2. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If Cards 120 through 129 are not entered and all control words use the default $\underline{e}$=0, then water is assumed to be the fluid.

The digit $\underline{b}$ specifies whether boron is present. $\underline{b}$=0 specifies that the volume fluid does not contain boron, and $\underline{b}$=1 specifies that a boron concentration in parts of boron per parts of liquid (which may be zero) is being entered after the other required thermodynamic information.

The digit $\underline{t}$ specifies how the following words are to be used to determine the initial thermodynamic state. $\underline{t}$=0 through 3 specifies one component (steam/water); $\underline{t}$=4 through 6 allows the specification of two components (steam/water and noncondensable gas).

If $\underline{t}$=0, the next four words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void

fraction. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on volume control flag. If equilibrium, the static quality is checked, but only the pressure and internal energies are used to define the thermodynamic state.

If $t=1$, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

If $t=2$, the next two words are interpreted as pressure (Pa, lb_f/in^2) and quality in equilibrium condition.

If $t=3$, the next two words are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium condition.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are

$1.0E-9 \leq$ quality ≤ 0.99999999, two phase conditions, and quality $< 1.0E-9$ or quality > 0.99999999, single phase.

Noncondensable options are as follows:

If $t=4$, the next three words are interpreted as pressure (Pa, $lb_f/in.^2$), temperature (K, °F), and equilibrium quality. Using this input option with quality greater than 0.0 and less than or equal to 1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If $t=5$, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. Little experience has been obtained using this option, and it has not been checked out.

If $t=6$, the next five words are interpreted as pressure (Pa, $lb_f/in.^2$), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor-specific internal energy.

W2-W7(R) Quantities as described under Word 1. Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, boron concentration follows the last required word for thermodynamic conditions.

A7.7.8 Cards cccn101 through cccn109, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Geometry Card

These cards are required if nj is greater than zero. Cards with n equal to 1 through 9 are entered, one for each junction. N equal to 1, 2, and 3 must be used for SEPARATR, JETMIXER, and ECCMIX components. For a BRANCH component, n need not be consecutive, but nj cards must be entered. The card format for Words 1 through 6 is listed below and is identical to Words1 through 6 on Card ccc0101 of the Single Junction Geometry Card, except that n instead of 0 is used in the fourth digit. Word 7 is not used for BRANCH, JETMIXER, and TURBINE components. Word 7 is defined for SEPARATR and ECCMIX components.

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is ccc000000, where ccc is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connections to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction (see Section 2.1). The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m^2, ft^2). If zero, the area is set to the minimum volume area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.

W4(R) Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero.

W5(R) Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative.

W6(I) Junction control flags. This word has the packed format efvcahs.

The digit e specifies the modified PV term in the energy equations. e=0 means that the modified PV term will not be applied, and e=1 means that it will be applied. This digit is only for the BRANCH component. For the SEPARATR, JETMIXER, ECCMIX, and

TURBINE components, this digit is not used and should be set to 0. The major edit output will show $e=0$.

The digit f specifies CCFL options. $f=0$ means that the CCFL model will not be applied, and $f=1$ means that the CCFL model will be applied. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, ECCMIX, and TURBINE components, the CCFL model is not allowed, this digit is not used and should be set to 0. The major edit output will show $f=0$.

The digit v specifies horizontal stratification entrainment/pullthrough options. This model is for junctions connected to a horizontal volume. $v=0$ means the model is not applied; $v=1$ means an upward oriented junction; $v=2$ means a downward oriented junction; and $v=3$ means a centrally (side) located junction. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, ECCMIX, and TURBINE components, the horizontal stratification entrainment/pullthrough model is not allowed, this digit is not used and should be set to 0.

The digit c specifies choking options. $c=0$ means that the choking model will be applied, and $c=1$ means that the choking model will not be applied.

The digit a specifies area change options. $a=0$ means either a smooth area change or no area change, and $a=1$ means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous. $h=0$ specifies the nonhomogeneous (two-velocity momentum equations) option and $h=2$ specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option ($h=2$), the major edit printout will show $h=1$.

The digit s specifies momentum flux options. This digit is used for the BRANCH, SEPARATR, and TURBINE components. $s=0$ uses momentum flux in both the to and the from volume. $s=1$ uses momentum flux in the from volume, but not in the to volume. $s=2$ uses momentum flux in the to volume, but not in the from volume. $s=3$ does not use momentum flux in either the to volume or the from volume. For the JETMIXER and ECCMIX components, this digit is not used and should be input as 0.

W7(R)   Void fraction limit (for SEPARATR) or ANGLE (for ECCMIX). This word is needed only for a SEPARATR or an ECCMIX component. For SEPARATR, this word is VOID FRACTION LIMIT. For the vapor exit junction (n=1), this quantity (VOVER) is the vapor void fraction above which flow out of the vapor outlet is pure vapor. If the word is missing, a default value of 0.5 is used. For the liquid fall back junction (n=2), this quantity (VUNDER) is the liquid void fraction above which flow out of the liquid fall back is pure liquid. If the word is missing, a default value of 0.15 is used. For the separator inlet, this word is not used.

For ECCMIX, this word is ANGLE and is the angle between the axis of the ECC injection line and the main pipe (or the angle between Junctions 1 and 2). This angle must be between 0 and 180 degrees. If missing, a 90-degree connection for the ECC pipe is assumed.

A7.7.9   Cards cccn110, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Diameter and CCFL Data Cards

These cards are optional. The value n should follow the same approach as used in Cards cccn101-cccn109. The defaults indicated for each word are used if the card is not entered. If these cards are being used to specify only the junction hydraulic diameter for the interphase drag calculations (i.e., $f=0$ in Word 6 of Cards cccn101-cccn109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If these cards are being used for the CCFL model (i.e., $f=1$ in Word 6 of Cards cccn101-cccn109), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R)   Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag. This number must be ≥ 0. This number should be computed from 4.0*(junction area)/wetted perimeter). If a zero is entered or if the default is used, the junction diameter is computed from 2.0*(junction area/π)**0.5 of the respective junction. See Word 3 of Cards cccn101-ccn109 for the junction area.

W2(R)   Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. f between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R)   Gas intercept, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R)   Slope, m. This quantity is the slope used in the CCFL correlation and must be >0. The default value is 1.

A7.7.10   Cards cccn112, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Form Loss Data Card

These cards are optional. The user specified form loss is given in Words 4 and 5 of Cards cccn101-cccn109 if these cards are not entered. If these cards are entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Cards cccn101-cccn109. Re is the Reynolds number based on mixture fluid properties. If these cards are being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) B_f (≥ 0). This quantity must be greater than or equal to zero.

W2(R) c_f (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_r (≥ 0). This quantity must be greater than or equal to zero.

W4(R) c_r (≥ 0). This quantity must be greater than or equal to zero.

A7.7.11   Cards cccn201, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Initial Conditions

These cards are required depending on the value of nj as described for Cards cccn101-cccn109. The values of n should follow the same approach as used in Cards cccn101-cccn109.

W1(R)   Initial liquid or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R)   Initial vapor velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W3(R)   Interface velocity (m/s, ft/s). Enter zero.

A7.7.12   Card ccc0300, Turbine/Shaft Geometry Card

This card is used only for TURBINE components.

W1(R)   Turbine stage shaft speed, w (rad/s, rev/min). This speed should equal the shaft speed used in the SHAFT component.

W2(R)   Inertia of rotating stages in stage group, I_i, (kg•m^2, lb•ft^2).

W3(R)   Shaft friction coefficient, f_i (N•m•s, lb• ft•s). The frictional torque equals $f_i x$. This fractional torque is used by the SHAFT component.

W4(I)   Shaft component number to which the turbine stage is connected.

W5(I)   Disconnect trip number. If zero, the turbine is always connected to the shaft. If nonzero, the turbine is connected to the shaft when the trip is false and disconnected when the trip is true.

W6(I)   Drain flag. At the present time, this is not used and can be neglected or set to zero.

A7.7.13   Card ccc0400, Turbine Performance Data Card

This card is used only for TURBINE components.

W1(I)   Turbine type

               0 = Two-row impulse stage group.

               1 = General impulse-reaction stage group.

2 = Constant efficiency stage group.

W2(R)   Actual efficiency h_o at the maximum efficiency design point.

W3(R)   Design reaction fraction, r. This is the fraction of the enthalpy decrease that takes place in the rotating blade system.

W4(R)   Mean stage radius, r (m, ft).

A7.7.14 Card ccc0500, GE Separator Data

This card is optional for the GE separator. If this card is missing and the GE separator has been specified on Card ccc0002, the default values will be used. If the card is present, all eight values must be specified.

W1(R)   Radius of larger pickoff ring at first stage of a two-stage separator (m, ft). (Default = 0.0857208 m)

W2(R)   Standpipe flow area (m^2, ft^2). (Default = 0.018637 m^2).

W3(R)   Separator nozzle exit area (m^2, ft^2). (Default = 0.01441 m^2).

W4(R)   Radius of separator hub at inlet (m, ft). (Default = 0.0809585 m).

W5(R)   Swirl vane angle relative to the horizontal (deg). (Default = 48 deg).

W6(R)   Liquid carryover coefficient for upper separating stages. (Default = 0.009 for two stage separator and 0.110 for three stage separator.)

W7(R)   Vapor carryunder coefficient for upper separating stages. (Default = 0.0004).

W8(R)   Axial distance between exit of first stage discharge passage and swirl vanes (m, ft). (Default = 0.2127 m for two stage separator and 0.45083 m for three stage separator.)

A7.7.15 Card ccc0501, GE Separator First Stage Data

This card is optional for the GE separator. If this card is missing and the GE separator has been specified on Card ccc0002, the default values will be used. If the card is present, all nine values must be specified.

W1(R)   Liquid film void profile coefficient. (Default = 110.0.)

W2(R)   Vapor core void profile coefficient. (Default = 0.5.)

W3(R)   Separator wall inner radius (m, ft). (Default = 0.10794 m.)

W4(R)   Pickoff ring inner radius (m, ft). (Default = 0.069875 m for two stage separator and 0.0857208 m for three stage separator.)

W5(R)   Discharge passage flow area (m^2, ft^2). (Default = 0.0415776 m^2 for two stage separator and 0.0096265 m^2 for three stage separator.)

W6(R)   Discharge passage hydraulic diameter (m, ft). (Default = 0.045558 m for two stage separator and 0.025399 m for three stage separator.)

W7(R)   Separating barrel length (m, ft). (Default = 0.877845 m for two stage separator and 1.0699 m for three stage separator.)

W8(R)   Discharge passage loss coefficient. (Default = 10.0 for two stage separator and 2.5 for three stage separator.)

W9(R)   Discharge passage effective L/D coefficient. (Default = 450.0 for two stage separator and 53.44 for three stage separator.)

A7.7.16 Card ccc0502, GE Separator Second Stage Data

This card is optional for the GE separator. If this card is missing and the GE separator has been specified on Card ccc0002, the default values will be used. If the card is present, all nine values must be specified.

W1(R)   Liquid film void profile coefficient. (Default = 20.0.)

W2(R)   Vapor core void profile coefficient. (Default = 0.25.)

W3(R)   Separator wall inner radius (m, ft). (Default = 0.06985 m for two-stage separator and 0.10794 m for three-stage separator.)

W4(R)   Pickoff ring inner radius (m, ft). (Default = 0.06032 m for two-stage separator and 0.0952453 m for three-stage separator.)

W5(R)   Discharge passage flow area (m^2, ft^2). (Default = 0.0029133 m^2 for two-stage separator and 0.0096265 m^2 for three-stage separator.)

W6(R)   Discharge passage hydraulic diameter (m, ft). (Default = 0.0121699 m for two-stage separator and 0.025399 m for three-stage separator.)

W7(R)   Separating barrel length (m, ft). (Default = 0.16255 m for two-stage separator and 0.384156 m for three-stage separator.)

W8(R)   Discharge passage loss coefficient. (Default = 0.5 for two-stage separator and 1.429 for three-stage separator.)

W9(R)   Discharge passage effective L/D coefficient. (Default = 95.85 for two-stage separator and 194.64 for three-stage separator.)

A7.7.17   Card ccc0503, GE Separator Third Stage Data

This card is optional for the GE separator. If this card is missing and the GE three-stage separator has been specified on Card ccc0002, the default values will be used. If the card is present, all nine values must be specified.

W1(R)   Liquid film void profile coefficient. (Default = 20.0.)

W2(R)   Vapor core void profile coefficient. (Default = 0.55.)

W3(R)   Separator wall inner radius (m, ft). (Default = 0.10794 m.)

W4(R)   Pickoff ring inner radius (m, ft). (Default = 0.0984201 m.)

W5(R)   Discharge passage flow area (m^2, ft^2). (Default = 0.0096265 m^2.)

W6(R)   Discharge passage hydraulic diameter (m, ft). (Default = 0.025399 m.)

W7(R)   Separating barrel length (m, ft). (Default = 0.384156 m.)

W8(R)   Discharge passage loss coefficient. (Default = 2.563.)

W9(R)   Discharge passage effective L/D coefficient. (Default = 424.96.)

A7.7.18   Card ccc0600, GE Dryer Data

This card is optional for the GE dryer. If this card is missing and the GE dryer has been specified on Card ccc0002, the default values will be used. If the card is present, all three values must be specified.

W1(R)   Vapor velocity at dryer inlet below which there is 0% liquid carryover (m/s, ft/s). (Default = 1.5 m/s.)

W2(R)   Vapor velocity at dryer inlet above which there is 100% liquid carryover (m/s, ft/s). (Default = 6.0 m/s.)

W3(R)   Range of dryer inlet quality where dryer carryover changes from 0 to 100% when dryer inlet vapor velocity is between lower and upper values. (Default = 0.05.)

A7.8   Valve Junction Component

A valve junction component is indicated by VALVE on Card ccc0000. For major edits, minor edits, and plot variables, the junction in the valve junction component is numbered ccc000000.

A7.8.1   Cards ccc0101 through ccc0109, Valve Junction Geometry Cards

This card (or cards) is required for valve junction components.

W1(I)   From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is ccc000000, where ccc is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connection is to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction (see Section 2.1). The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(I)   To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R)   Junction area (m^2, ft^2). This quantity is the full open area of the valve except in the case of a relief valve. For valves other than relief valves, if this area is input as zero, the area is set to the minimum area of adjoining volumes. If nonzero, this area is used. For relief valves, this term is the valve inlet throat area. If this term is input as zero, it will default to the area calculated from the inlet diameter term input on Cards ccc0301 through ccc0309, in which case the inlet diameter term cannot be input as zero. If both this area and the inlet diameter are input as nonzero, this area will be used but must agree with the area calculated from the inlet diameter within 10^{-5} m^2. However, if this area is input as nonzero and the inlet diameter is input as zero, the inlet diameter will default to the diameter calculated from this area. When an abrupt area change model is specified, the area must be less than or equal to the minimum of the adjoining volume areas.

W4(R)   Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero.

W5(R)   Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative.

W6(I)   Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

             The digit e specifies the modified PV term in the energy equations. e=0 means that the modified PV term will not be applied, and e=1 means that it will be applied.

             The digit f specifies CCFL options. f=0 means that the CCFL model will not be applied, and f=1 means that the CCFL model will be applied.

             The digit v is not used and should be input as zero (v=0). The horizontal stratification/ entrainment model is not used.

             The digit c specifies choking options. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change. Either option may be input for a motor or servo valve. If the smooth area change option is input, then a C_v table must be input; or, if no C_v table is input, then the abrupt area change option must be input. For all other valves, the abrupt area change option must be input.

The digit h specifies nonhomogeneous or homogeneous. h=0 specifies the nonhomogeneous (two-velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show h=1.

The digit s is not used and should be input as zero (s=0). The major edit printout will show s=0.

W7(R)   Subcooled discharge coefficient. This quantity is applied only to subcooled choked flow calculations. The quantity must be >0 and ≤2.0. If missing, it is set to 1.0.

W8(R)   Two phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be >0 or ≤2.0. If missing, it is set to 1.0.

W9(R)   Superheated discharge coefficient. This quantity is applied only to superheated choked flow calculations. The quantity must be >0 and ≤2.0. If missing, it is set to 1.0.

A7.8.2   Card ccc0110, Valve Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify the junction hydraulic diameter for the interphase drag calculation (i.e., f=0 in Word 6 of Cards ccc0101-ccc0109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through (will not be used). If this card is being used for the CCFL model (i.e., f=1 in Word 6 of Cards ccc0101-ccc0109), then enter all four words for the appropriate CCFL model if values different from the default values are used.

W1(R)   Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥0. This number should be computed from 4.0*(junction area)/(wetted perimeter). If a zero is entered or if the default is used, the junction diameter is computed from 2.0* (junction area/π)**0.5. See Word 3 of Cards ccc0101-ccc0109 for the junction area.

W2(R)   Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥0 and≤ 1. The default value is 0 (Wallis form).

W3(R)   Gas intercept, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0. The default value is 1.

W4(R)   Slope, m. This is the slope used in the CCFL correlation and must be >0. The default value is 1.

A7.8.3   Card ccc0111, Valve Junction Form Loss Data Card

This card is optional. The user specified form loss is given in Words 4 and 5 of Card ccc0101 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) B_f ($\geq$0). This quantity must be greater than or equal to zero.

W2(R) c_f ($\geq$0). This quantity must be greater than or equal to zero.

W3(R) B_r ($\geq$0). This quantity must be greater than or equal to zero.

W4(R) c_r ($\geq$0). This quantity must be greater than or equal to zero.

A7.8.4   Card ccc0201, Valve Junction Initial Conditions

This card is required for valve junction components.

W1(I)   Control word. If zero, the next two words are velocities; if one, the next two words are mass flows.

W2(R)   Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control word.

W3(R)   Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control word.

W4(R)   Interface velocity (m/s, ft/s). Enter zero.

A7.8.5   Card ccc0300, Valve Type Card

This card is required to specify the valve type.

W1(A)   Valve type. This word must contain one of the following: CHKVLV for a check valve, TRPVLV for a trip valve, INRVLV for an inertial swing check valve, MTRVLV for a motor valve, SRVVLV for a servo valve, or RLFVLV for a relief valve.

A7.8.6   Cards ccc0301 through ccc0399, Valve Data and Initial Conditions

These cards are required for valve junction components. Six different types of valves are allowed. The following words may be placed on one or more cards, and the card numbers need not be consecutive. The card format of these cards depends on the valve type.

A7.8.6.1   Check Valve. This behaves as an <u>on</u>, <u>off</u> switch. If the valve is <u>on</u>, then it is fully open; and if the valve is <u>off</u>, it is fully closed.

W1(I)   Check valve type. Enter +1 for a static pressure-controlled check valve (no hysteresis), 0 for a static pressure/flow-controlled check valve (has hysteresis effect), cr -1 for a static/ dynamic pressure-controlled check valve (has hysteresis effect). It is recommended that 0 be used for most calculations, as it is more stable (i.e., less noisy and less oscillations) than +1 or -1.

W2(I)   Check valve initial position. The valve is initially open if zero, closed if one.

W3(R)   Closing back pressure (Pa, lb_f/in^2).

W4(R)   Leak ratio. This is the fraction of the junction area for the leakage when the valve is nominally closed. If omitted or input as zero, then either the smooth or the abrupt area change model may be specified. If input as nonzero, then the abrupt area change model must be specified.

A7.8.6.2   Trip Valve. This behaves as an <u>on</u>, <u>off</u> switch as described for the check valve.

W1(I)   Trip number. This must be a valid trip number. If the trip is false, the valve is closed; if the trip is true, the valve is open.

A7.8.6.3   Inertial Valve. This behaves realistically in that the valve area varies considering the hydrodynamic forces and the flapper inertia, momentum, and angular acceleration. The abrupt area change model must be specified.

W1(I)   Latch option. The valve can open and close repeatedly if the latch option is zero. The valve either opens or closes only once if the latch option is one.

W2(I)   Valve initial condition. The valve is initially open if zero, initially closed if one.

W3(R)   Cracking pressure (Pa, lb_f/in^2).

W4(R)   Leakage fraction. Fraction of the junction area for leakage when the valve is nominally closed.

W5(R)   Initial flapper angle (degrees). The flapper angle must be within the minimum and maximum angles specified in Words 6 and 7.

W6(R)   Minimum flapper angle (degrees). This must be greater than or equal to zero.

W7(R)   Maximum flapper angle (degrees).

W8(R)   Moment of inertia of valve flapper (kg/ m², lb /ft²).

W9(R)   Initial angular velocity (rad/s).

W10(R)   Moment length of flapper (m, ft).

W11(R)   Radius of flapper (m, ft).

W12(R)   Mass of flapper (kg, lb).

A7.8.6.4   Motor Valve. This behaves realistically in that the valve area varies as a function of time by either of two models specified by the user. The user must also select the model for valve hydrodynamic losses by specifying either the smooth or the abrupt area change model. If the smooth area change model is selected, a table of flow coefficients must also be input as described in Cards ccc0400 through ccc0499, CSUBV Table Section A7.8.7. If the abrupt area change model is selected, a flow coefficient table cannot be input.

W1(I)   Open trip number.

W2(I)   Close trip number. Both the open and close trip numbers must be valid trips. When both trips are false, the valve remains at its current position. When one of the trips is true, the valve opens or closes depending on which trip is true. The transient will be terminated if both trips are true at the same time.

W3(R)   Valve change rate (s^{-1}). If Word 5 is not entered, this quantity is the rate of change of the normalized valve area as the valve opens or closes. If Word 5 is entered, this quantity is the rate of change of the normalized valve stem position. This word must be greater than zero.

W4(R)   Initial position. This number is the initial normalized valve area or the initial normalized stem position depending on Word W5. This quantity must be between 0.0 and 1.0.

W5(I)   Valve table number. If this word is omitted or input as zero, the valve area is determined by the valve change rate and the trips. If this word is input as nonzero, the valve stem position is determined by the valve change rate and the trips; and the valve area is determined from a general table containing normalized valve area versus normalized stem position.

Input for general tables is discussed in Cards 202tttnn, General Table Data, Section A11. For this case, the normalized stem position is input as the *argument value* and the normalized valve area is input as the *function value*.

A7.8.6.5   Servo Valve. This behaves as described for a motor valve except that the valve flow area or stem position is calculated by a control system. Input for control systems is discussed in Section A1. Input specifying the hydrodynamic losses for servo valves is also identical to that for motor valves.

W1(I)   Control variable number. The value of the indicated control variable is either the
               normalized valve area or the normalized stem position, depending on whether Word 2 is
               entered. The control variable is also the search argument for the CSUBV table if it is
               entered.

W2(I)   Valve table number. If this word is not entered, the control variable value is the
               normalized flow area. If it is entered, the control variable value is the normalized stem
               position, and the general table indicated by this word contains a table of normalized area
               versus normalized stem position. Input for the general table is identical to that for a motor
               valve.

   A7.8.6.6   Relief Valve. The valve area varies, considering the hydrodynamic forces and the
valve mass, momentum, and acceleration. The abrupt area change model must be specified. The junction
area input by Card ccc0101 through ccc0199 is the valve inlet area.

W1(I)   Valve initial condition. The valve is initially closed if zero, open if one.

W2(R)   Inlet diameter (m, ft). This is the inside diameter of the valve inlet. If this term is input as
               zero, it will default to the diameter calculated from the junction area input on Card
               ccc0101 through ccc0109. If both this diameter and the junction area are input as nonzero,
               care must be taken that these terms are input with enough significant digits so that the
               areas agree within 10^{-5} m^2. If the junction area is input as zero, then this diameter must be
               input as nonzero.

W3(R)   Valve seat diameter (m, ft). Nonzero input is required. This term is the outside diameter of
               the valve seat, including the minimum diameter of the inner adjustment ring. This term
               must also be greater than or equal to the inlet diameter.

W4(R)   Valve piston diameter (m, ft). If input as zero, the default is to the valve seat diameter.

W5(R)   Valve lift (m, ft). Nonzero input is required. This is the distance the valve piston rises
               above the valve seat at the fully open position.

W6(R)   Maximum outside diameter of the inner adjustment ring (m, ft). If this input is zero, it will
               default to the valve seat diameter; in which case W7(R), following, must be input as zero.
               If this input is nonzero, the value must be greater than or equal to the valve seat diameter.
               If input is greater than the valve seat diameter, a nonzero input of W7(R), is allowed.
               Also refer to the warning stated for W9(R).

W7(R)   Height of outside shoulder relative to the valve seat for inner adjustment ring (m, ft).
               Input of a positive, nonzero value is not allowed. Input of a zero value is required if
               W6(R) preceding is defaulted or input equal to the valve seat diameter. If the shoulder is
               below the seat, this distance is negative. Also refer to the warning stated for W9(R).

W8(R)   Minimum inside diameter of the outer adjustment ring (m, ft). If this input is zero, it will
               default to the valve piston diameter, in which case W9(R) must be input as positive and
               nonzero. If this input is nonzero, the value must be greater than or equal to the valve piston
               diameter. Input of a negative W9(R) is allowed only if this diameter is greater than the
               valve piston diameter. Also refer to the warning stated for W9(R).

W9(R)   Height of inside bottom edge relative to the valve seat for outer adjustment ring (m, ft). This may be input as positive, zero, or negative. If this input is negative, then W8(R) preceding must be greater than the valve piston diameter. If the bottom edge is below the valve seat, this distance is negative. WARNING: Input of this term and terms W6(R), W7(R), and W8(R) preceding must be done with care to ensure that the resultant gap between the adjustment rings is positive and nonzero; otherwise, an input error will result.

W10(R)   Bellows average diameter (m, ft). if this term is input as zero, it will default to the valve piston diameter, resulting in a model not containing a bellows for which the valve bonnet region is vented to the atmosphere.

W11(R)   Valve spring constant (N/m, lb$_f$/ft). Positive, nonzero input is required.

W12(R)   Valve setpoint pressure (Pa, lb$_f$/in^2). Positive input is required.

W13(R)   Valve piston, rod, spring, bellows mass (kg, lb). Nonzero input is required.

W14(R)   Valve damping coefficient (N s/m, lb$_f$ s/ft).

W15(R)   Bellows inside pressure (Pa, lb$_f$/in^2). Defaults to standard atmospheric pressure if omitted or input as zero.

W16(R)   Initial stem position. This is the fraction of total lift and is required if W1(I) is input as one. Total lift is input as W5(R).

W17(R)   Initial valve piston velocity (m/s, ft/s). This must be zero or omitted if W1(I) is input as zero.

A7.8.7   Cards ccc0400 through ccc0499, Valve CSUBV Table

The CSUBV table may be input only for motor and servo valves. If the CSUBV table is input, the smooth area change model must be specified on the valve junction geometry card (Card ccc0101 through ccc0109). If the smooth area change model is specified, a CSUBV table must be input.

The CSUBV table contains forward and reverse flow coefficients as a function of normalized flow area or normalized stem position.

A7.8.7.1   Cards ccc0400, Factors. This card is optional. The factors apply to the flow area or the stem position and the flow coefficient entries in the CSUBV table.

W1(R)   Normalized flow area or normalized stem position.

W2(R)   Flow coefficient factor.

A7.8.7.2   Cards ccc0401 through ccc0499, Table Entries. The table is entered by using three-word sets. W1 is the flow area or stem position and must be normalized. The factor W1 on Card ccc0400 can be used to normalize the flow area or stem position. In either case, the implication is that if the

valve is fully closed, the normalized term is zero. If the valve is fully open, the normalized term is one. Any value may be input that is between zero and one. The forward and reverse flow coefficients are W2 and W3, respectively. The code internally converts flow coefficients to energy loss coefficients by the formula $K = 2*A_j**2/(\rho*CSUBV**2)$, where ρ is density of water at 60 °F (288.71 K), A_j is the full open valve area, and CSUBV is the flow coefficient. On Card ccc0400, W2 may be used to modify the definition of CSUBV. A smooth area change must be specified in W6 on Card ccc0101 to use the CSUBV table. CSUBV is entered in British units only.

W1(R)   Normalized flow area or normalized stem position.

W2(R)   Forward CSUBV {gal/[min $(lb/in^2)**0.5$]}. The CSUBV is input in British units only and is converted to SI units using 7.598055E-7 as the conversion factor.

W3(R)   Reverse CSUBV {gal/[min $(lb/in^2)**0.5$]}.

A7.9   Pump Component

A pump component is indicated by PUMP on Card ccc0000. A pump consists of one volume and two junctions, one attached to each end of the volume. For major edits, minor edits, and plot variables, the volume in the pump component is numbered as ccc010000. The pump junctions are numbered ccc010000 for the inlet junction and ccc020000 for the outlet junction.

A7.9.1   Cards ccc0101 through ccc0107, Pump Volume Geometry Cards

This card (or cards) is required for a pump component. The seven words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R)   Volume flow area (m^2, ft^2).

W2(R)   Length of volume (m, ft).

W3(R)   Volume of volume (m^3, ft^3). The program requires that the volume equals the volume flow area times the length (W3=W1*W2). At least two of the three quantities, W1, W2, W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R)   Azimuthal angle (degrees). The absolute value of this angle must be ≤360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R)   Inclination angle (degrees). The absolute value of this angle must be ≤90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward direction, i.e., the outlet is at a higher elevation than the inlet. This angle is used in the interphase drag calculation.

W6(R)   Elevation change (m, ft). A positive value is an increase in elevation. The absolute value
               of this quantity must be equal to or less than the volume length. If the vertical angle
               orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity
               must also be nonzero and have the same sign. For this component, this Word 6 is not
               compared to the volume length (Word 2) to decide if the horizontal or vertical flow regime
               is used. Rather, the pump flow regime map is used.

W7(I)   Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input
               leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented
               flags. Only one value for a scaler oriented flag is entered per volume but up to three
               coordinate oriented flags can be entered for a volume, one for each coordinate direction.
               At present, the f flag is the only coordinate direction oriented flag. This word enters the
               scaler oriented flags and the x coordinate flag. The pump component forces all volume
               flags except for the e digit, and y and z coordinate flags are not read. The effective format
               is 000000e.

               The digit t is not used and must be input as zero (t=0). Thermal stratification is not used in
               a pump component.

               The digit l is not used and must be entered as zero (l=0). Level tracking is not used in a
               pump component.

               The digit p is not used and must be input as zero (p=0). The major edit output will show
               p=1. The water packing scheme is not used.

               The digit v is not used and must be input as zero (v=0). The major edit output will show
               v=1. The vertical stratification model is not used.

               The digit b is not used and must be input as zero (b=0). The major edit will show b=0. The
               rod bundle interphase friction is not used.

               The digit f that normally specifies whether wall friction is to be computed is not used and
               a 0 must be entered. No wall friction is computed for a pump, since it is included in the
               homologous pump data. The major edit output will show f=1, which indicates that the no
               friction flag is set.

               The digit e specifies if nonequilibrium or equilibrium is to be used; e=0 specifies that a
               nonequilibrium (unequal temperature) calculation is to be used, and e=1 specifies that an
               equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not
               be connected to nonequilibrium volumes. The equilibrium option is provided only for
               comparison to other codes.

A7.9.2   Card ccc0108, Pump Inlet (Suction) Junction Card

This card is required for a pump component.

W1(I)   Volume code of connecting volume on inlet side. This refers to the component from
               which the junction coordinate direction originates. For connecting to a time-dependent
               volume, the connection code is ccc000000, where ccc is the component number of the

time dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connection is to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction (see Section 2.1). The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

With the old format, connections are possible only to the inlet or crossflow faces of the first pipe volume or to the outlet or crossflow faces of the last pipe volume. With the expanded format, connections can be made to any face of any pipe volume. Output edits use the expanded format regardless of the input format.

W2(R)   Junction area (m², ft²). If zero, the area is set to the minimum of the volume areas of adjacent volumes. If an abrupt area change, the area must be equal to or less than the minimum of the adjacent volume areas.   If a smooth area change, no restrictions exist. Note: a variable loss coefficient may be specified. See Section A7.9.6.

W3(R)   Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified. See Section A7.9.6.

W4(R)   Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative.

W5(I)   Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

             The digit e is not used and should be input as zero (e=0).

             The digit f specifies CCFL options. f=0 means that the CCFL model will not be applied, and f=1 means that the CCFL model will be applied.

             The digit v is not used and should be input as zero (v=0). The horizontal stratification entrainment/pullthrough model is not used.

             The digit c specifies choking options. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

             The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

             The digit h specifies nonhomogeneous or homogeneous. h=0 specifies the nonhomogeneous (two-velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a one.

The digit $\underline{s}$ is not used and should be input as zero ($\underline{s}$=0).

A7.9.3 Card ccc0109, Pump Outlet (Discharge) Junction Card

This card is required for a pump component. The format for this card is identical to Card ccc0108 except data are for the outlet junction.

A7.9.4 Card ccc0110, Pump Inlet (Suction) Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., $\underline{f}$=0 in Word 5 of Card ccc0108), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If the card is being used for the CCFL model (i.e., $\underline{f}$=1 in Word 5 of card ccc0108), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R)   Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥ 0. This number should be computed from 4.0*(junction area)/(wetted perimeter). If a zero is entered or the default is used, the junction diameter is computed from 2.0*(junction area/π)**0.5. See Word 2 of Card ccc0108 for the junction area.

W2(R)   Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R)   Gas intercept, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R)   Slope, m. This is the slope used in the CCFL correlation and must be > 0. The default value is 1.

A7.9.5 Card ccc0111, Pump Outlet (Discharge) Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to just specify the junction hydraulic diameter for the interphase drag calculation (i.e., $\underline{f}$=0 in Word 5 of Card ccc0109), then the diameter should be entered in Word 2 and any allowable values should be entered in Words 2 through 4 (will not be used). If the card is being used for the CCFL model (i.e., $\underline{f}$=1 in Word 5 of Card ccc0109), then enter all four words for the appropriate CCFL model if values different from the default values are desired. The format for this card is identical to Card ccc0110 except that data are for the outlet junction.

A7.9.6 Card ccc0112, Pump Inlet (Suction) Junction Form Loss Data Card

This card is optional. The user-specified form loss is given in Words 3 and 4 of Card ccc0108 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 3 and 4 of Card ccc0108. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) B_f (≥ 0). This quantity must be greater than or equal to zero.

W2(R) c_f (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_r (≥ 0). This quantity must be greater than or equal to zero.

W4(R) c_r (≥ 0). This quantity must be greater than or equal to zero.

A7.9.7 Card ccc0113, Pump Outlet (Discharge) Junction Form Loss Data Card

This card is optional. The user-specified form loss is given in Words 3 and 4 of Card ccc0109 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 3 and 4 of Card ccc0109. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression. The format of this card is identical to Card ccc0112 except data are for the outlet junction.

A7.9.8 Card ccc0200, Pump Volume Initial Conditions

This card is required for a pump component.

W1(I)   Control word. This word has the packed format gbt. It is not necessary to input leading zeros.

                 The digit g specifies the fluid; g=0 is the default fluid, g=1 specifies H_2O, g=2 specifies D_2O, and g=3 specifies H_2. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If cards 120 through 129 are not entered and all control words use the default g=0, then H_2O is assumed to be the fluid.

The digit <u>b</u> specifies whether boron is present. <u>b</u>=0 specifies that the volume fluid does not contain boron; <u>b</u>=1 specifies that a boron concentration in parts of boron per parts of liquid (which may be zero) is being entered after the other required thermodynamic information

The digit <u>t</u> specifies how the following words are to be used to determine the initial thermodynamic state. <u>t</u>=0 through 3 specifies one component (steam/water). Entering <u>t</u>=4 through 6 allows the specification of two components (steam/water and noncondensable gas).

If <u>t</u>=0, the next four words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on volume control flag. If equilibrium, the static quality is checked, but only the pressure and internal energies are used to define the thermodynamic state.

If <u>t</u>=1, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

If <u>t</u>=2, the next two words are interpreted as pressure (Pa, lb_f/in^2) and quality in equilibrium condition.

If <u>t</u>=3, the next two words are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium condition.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for quality are

1.0E-9 ≤ quality ≤ 0.99999999, two phase conditions, and quality < 1.0E-9 or quality > 0.99999999, single phase.

Noncondensable options are as follows:

If <u>t</u>=4, the next three words are interpreted as pressure (Pa, $lb_f/in.^2$), temperature (K, °F), and equilibrium quality.

Using this input option with quality >0.0 and ≤1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure.

Setting quality to 0.0 is used as a flag that will initialize the volume to all noncondensables (dry noncondensable) with no temperature restrictions. Quality is reset to 1.0 using this dry noncondensable option.

If <u>t</u>=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. Little experience has been obtained using this option, and it has not been checked out.

If $\underline{t}$=6, the next five words are interpreted as pressure (Pa, lb$_f$/in.^{2}), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, But/lab), vapor void fraction, and noncondensable quality. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing. If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must not be 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor-specific internal energy.

W2-W7(R)   Quantities as described under word 1. Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, boron concentration follows the last required word for thermodynamic conditions.

A7.9.9   Card ccc0201, Pump Inlet (Suction) Junction Initial Conditions

This card is required for a pump component.

W1(I)   Control word. If zero, the next two words are velocities; if one, the next two words are mass flow rates.

W2(R)   Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s).

W3(R)   Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s).

W4(R)   Initial interface velocity (m/s, ft/s). Enter zero.

A7.9.10   Card ccc0202, Pump Outlet (Discharge) Junction Initial Conditions

This card is similar to Card ccc0201 except that data are for the outlet junction.

A7.9.11   Card ccc0301, Pump Index and Option Card

This card is required for a pump component.

W1(I)   Pump table data indicator. If zero, single phase homologous tables are entered with this component. A positive nonzero number indicates that the single phase tables are to be obtained from the pump component with this number. If -1, use built-in data for the Bingham pump. If -2, use built-in data for the Westinghouse pump.

W2(I)   Two phase index. Enter -1 if the two phase option is not to be used. Enter zero if the two phase option is desired and two phase multiplier tables are entered with this component. Enter nonzero if the two phase option is desired and the two phase multiplier table data are

to be obtained from the pump component with the number entered. There are no built-in data for the two phase multiplier table.

W3(I)   Two phase difference table index. Enter -3 if the two phase difference table is not needed (i.e., if W2 is -1). Enter zero if a table is entered with this component. Enter a positive nonzero number if the table is to be obtained from pump component with this number. Enter -1 for built-in data for the Bingham pump. Enter -2 for built-in data for the Westinghouse pump.

W4(I)   Pump motor torque table index. If -1, no table is used. If zero, a table is entered for this component. If nonzero, use the table from the component with this number.

W5(I)   Time dependent pump velocity index. If -1, no time-dependent pump rotational velocity table is used and the pump velocity is always determined by the torque-inertia equation. If zero, a table is entered with this component. If nonzero, the table from the pump component with this number is used. A pump velocity table cannot be used when the pump is connected to a shaft control component.

W6(I)   Pump trip number. When the trip is off, electrical power is supplied to the pump motor; when the trip is on, electrical power is disconnected from the pump motor. The pump velocity depends on the pump velocity table and associated trip, the pump motor torque data, and this trip. If the pump velocity table is being used, the pump velocity is always computed from that table. If the pump velocity table is not being used, the pump velocity depends on the pump motor torque data and this trip. If the trip is off and no pump motor torque data are present, the pump velocity is the same as for the previous time step. This will be the initial pump velocity if the pump trip has never been set. Usually the pump trip is a latched trip, but that is not necessary. If the trip is off and a pump motor torque table is present, the pump velocity is given by the torque-inertia equation where the net torque is given by the pump motor torque data and the homologous torque data. If the trip is on, the torque-inertia equation is used and the pump motor torque is set to zero. If the pump trip number is zero, no trip is tested and the pump trip is assumed to always be off.

W7(I)   Reverse indicator. If zero, no reverse is allowed; if one, reverse is allowed.

A7.9.12   Cards ccc0302 through ccc0304, Pump Description Card

This card (or cards) is required for a pump component.

W1(R)   Rated pump velocity (rad/s, rev/min).

W2(R)   Ratio of initial pump velocity to rated pump velocity. Used for calculating initial pump velocity.

W3(R)   Rated flow (m^3/s, gal/min).

W4(R)   Rated head (m, ft).

W5(R)   Rated torque (N·m, lb$_f$·ft).

W6(R)   Moment of inertia (kg·m^2, lb·ft^2). This includes all direct coupled rotating components, including the master for a motor driven pump.

W7(R)   Rated density (kg/m^3, lb/ft^3). If zero, initial density is used. This is the density used to generate homologous data.

W8(R)   Rated pump motor torque (N·m, lb$_f$·ft). If this word is zero, the rated pump motor torque is computed from the initial pump velocity and the pump torque that is computed from the initial pump velocity, initial volume conditions, and the homologous curves. This quantity must be nonzero if the relative pump motor torque table is entered.

W9(R)   TF2 friction torque coefficient (N·m, lb$_f$·ft). This parameter multiplies the speed ratio (absolute pump speed/rated speed) to the second power. The friction torque factors are summed together.

W10(R)   TF0, friction torque coefficient (N·m, lb$_f$·ft). This is constant frictional torque.

W11(R)   TF1, friction torque coefficient (N·m, lb$_f$·ft). This multiplies the speed ratio to the first power.

W12(R)   TF3, friction torque coefficient. (N·m, lb$_f$·ft). This multiplies the speed ratio to the third power.

A7.9.13   Card ccc0308, Pump Variable Inertia Card

Pump inertia is given by Word 6 of Card ccc0302 if this card is not entered. If this card is entered, pump inertia is computed from

$$I = I_3 S^3 + I_2 S^2 + I_1 S^1 + I_0$$

where S is the relative pump speed defined as the absolute value of the pump rotational velocity divided by the rated rotational velocity.

W1(R)   Relative speed at which to use the cubic expression for inertia. When the relative speed is less than this quantity, the inertia from Word 6 of Card ccc0302 is used.

W2-W5(R) I_3, I_2, I_1, I_0 (kg/m^2, lb·ft^2).

A7.9.14   Card ccc0309, Pump-Shaft Connection Card

If this card is entered, the pump is connected to a SHAFT component. The pump may still be driven by a pump motor that can be described in this component, by a turbine also connected to the SHAFT component, or from torque computed by the control system and applied to the SHAFT component. The pump speed table may not be entered if this card is entered.

W1(I)   Control component number of the shaft component.

W2(I)   Pump disconnect trip. If this quantity is omitted or zero, the pump is always connected to
                    the SHAFT. If nonzero, the pump is connected to the shaft when the trip is false and
                    disconnected when the trip is true.

A7.9.15 Card ccc0310, Pump Stop Data Card

If this card is omitted, the pump will not be stopped by the program.

W1(R)   Elapsed problem time for pump stop (s).

W2(R)   Maximum forward velocity for pump stop (rad/s, rev/min).

W3(R)   Maximum reverse velocity for pump stop (rad/s, rev/min). Reverse velocity is a negative
                    number.

A7.9.16 Cards cccxx00 through cccxx99, Single-Phase Homologous Curves

These cards are needed only if W1 of Card ccc0301 is zero. There are sixteen possible sets of
homologous curve data to completely describe the single phase pump operation, that is, a curve for each
head and torque for each of the eight possible curve types or regimes of operation. Entering all sixteen
curves is not necessary, but an error will occur from an attempt to reference one that has not been entered.

Card numbering is ccc1100 through ccc1199 for the first curve, ccc1200 through ccc1299 for the
second curve, through ccc2600 to ccc2699 for the sixteenth curve. Data for each individual curve are input
on up to 99 cards, which need not be numbered consecutively.

W1(I)   Curve type. Enter one for a head curve; enter two for a torque curve.

W2(I)   Curve regime. See **Table 2.3-1** of this manual for definitions. The possible integer
                    numbers and the corresponding homologous curve octants are: 1 (HAN or BAN), 2 (HVN
                    or BVN), 3 (HAD or BAD), 4 (HVD or BVD), 5 (HAT or BAT), 6 (HVT or BVT), 7
                    (HAR or BAR), and 8 (HVR or BVR).

W3(R)   Independent variable. Values for each curve range from -1.0 to 0.0 or from 0.0 to 1.0
                    inclusive. The variable is v/a for W2(I) = 1, 3, 5, or 7 and a/v for W2(I) = 2, 4, 6, or 8. If
                    the tabular data does not span the entire range of the independent variable, end point
                    values are used for data outside the table. This usually leads to incorrect pump
                    performance data. Thus, entering data to cover the complete range is recommended.

W4(R)   Dependent variable. The variable is h/a^2 or b/a^2 for W2(I) = 1, 3, 5, or 7 and h/v^2 or b/v^2
                    for W2(I) = 2, 4, 6, or 8.

Additional pairs as needed are entered on this or following cards, up to a limit of 100 pairs.

A7.9.17 Cards cccxx00 through cccxx99, Two-Phase Multiplier Tables

These cards are needed only if W2 of Card ccc0301 is zero; xx is 30 and 31 for the pump head
multiplier table and the pump torque multiplier table, respectively.

W1(I)   Extrapolation indicator. This is not used, enter zero.

W2(R)   Void fraction.

W3(R)   Head or torque difference multiplier depending on table type.

Additional pairs of data as needed are entered on this or additional cards as needed, up to a limit of 100 pairs. Void fractions must be in increasing order.

A7.9.18   Cards cccxx00 through cccxx99, Two-Phase Difference Tables

These cards are required only if W3 of Card ccc0301 is zero. The two-phase difference tables are homologous curves entered in a similar manner to the single phase homologous data. Card numbering is ccc4100 through ccc4199 for the first curve, ccc4200 through ccc4299 for the second curve, through ccc5600 to ccc5699 for the sixteenth curve. Data are the same as the data for the single phase data except that the dependent variable is the difference between single phase and fully degraded two-phase data.

A7.9.19   Cards ccc6001 through ccc6099, Relative Pump Motor Torque Data

These cards are required only if W4 of Card ccc0301 is zero. If the pump velocity table is not being used and these cards are present, the torque-inertia equation is used. When the electrical power is supplied to the pump motor (the pump trip is off), the net torque is computed from the rated pump motor torque times the relative pump motor torque from this table and the torque from the homologous data. If the electrical power is disconnected from the pump (the pump trip is on), the pump motor torque is zero.

W1(R)   Pump velocity (rad/s, rev/min).

W2(R)   Relative pump motor torque.

Additional pairs as needed are added on this or additional cards, up to a maximum of 100 pairs.

A7.9.20   Card ccc6100, Time-Dependent Pump Velocity Control Card

This card is required only if W5 of Card ccc0301 is zero. The velocity table, if present, has priority in setting the pump velocity over the pump trip, the pump motor torque data, and the torque-inertia equation.

W1(I)   Trip number. If the trip number is zero, the pump velocity is always computed from this
                 table using time as the search argument. If the trip number is nonzero, the trip determines
                 which table is to be used. If the trip is off, the pump velocity is set from the trip, the pump
                 motor torque data, and the torque-inertia equation. If the trip is on, the pump velocity is
                 computed from this table. If Word 3 is missing, the search variable in the table is time and
                 the search argument is time minus the trip time. If this word is used, it takes precedence
                 over the trip number used in Word 6 of the ccc0301 card.

W2(A)   Alphanumeric part of variable request code. This quantity is optional. If present, this word
                 and the next are a variable request code that specifies the search argument for the table
                 lookup and interpolation. TIME can be selected, but the trip time is not subtracted from
                 the advancement time.

W3(I)   Numeric part of variable request code. This is assumed to be zero if missing.

A7.9.21   Cards ccc6101 through ccc6199, Time-Dependent Pump Velocity

These cards are required only if W5 of Card ccc0301 is zero.

W1(R)   Search variable. Units depend on the quantity selected for the search variable.

W2(R)   Pump velocity (rad/s, rev/min).

Additional pairs as needed are added on this or additional cards, up to a maximum of 100 pairs. Time values must be in increasing order.

A7.10   Multiple Junction Component

A multiple junction component is indicated by MTPLJU. on Card ccc0000.

The one or more junctions specified by this component can connect volumes in the same manner as several single junction components except that all the volumes connected by the junctions in the component must be in the same hydrodynamic system. If this restriction is violated, corrective action is to merge the hydrodynamic systems. For major edits, minor edits, and plot variables, the junctions in the multiple junction component are numbered ccciinn00, where nn is the set number and ii is the junction number within the set. The quantity nn may be 01 through 99; ii is 01 for the first junction described in a set and incremented by one for each additional junction ($1 \leq ii \leq 99$).

A7.10.1   Card ccc0001, Multiple Junction Information Card

W1(I)   Number of junctions, nj. This number must be >0 and <100.

W2(I)   Initial condition control. This word is optional and, if missing, is assumed to be zero. If zero is entered, the initial conditions on Cards ccc1nnm are velocities; if one is entered, the initial conditions are mass flows.

A7.10.2   Cards ccc0nnm, Multiple Junction Geometry Card

Junctions are described by one or more sets of data, nn being the set number and m being the card number within a set. The junctions are numbered as ccciinn00, where ii is 01 for the first junction described in a set and increments by one for each additional junction. The quantity nn may be 01 through 99, and m may be 1 through 9. Cards are processed by increasing set number nn, and cards within a set by increasing m.   Neither nn or m need be strictly consecutive.

W1(I)   From connection code to a component. This refers to the component from which the junction coordinate direction originates. For connecting to a time dependent volume, the connection code is ccc000000, where ccc is the component number of the time dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connection is to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume

number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction (see Section 2.1). The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(I)   To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R)   Junction area (m^2, ft^2). If zero, the area is set to the minimum volume area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.

W4(R)   Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified. See Section A7.10.5.

W5(R)   Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified. See Section A7.10.5.

W6(I)   Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equations. $e=0$ means that the modified PV term will not be applied, and $e=1$ means that it will be applied.

The digit f specifies CCFL options. $f=0$ means that the CCFL model will not be applied, and $f=1$ means that the CCFL model will be applied.

The digit v is not used and should be input as zero ($v=0$). The horizontal stratification entrainment/pullthrough model is not used.

The digit c specifies choking options. $c=0$ means that the choking model will be applied, and $c=1$ means that the choking model will not be applied.

The digit a specifies area change options. $a=0$ means either a smooth area change or no area change, and $a=1$ means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous. $h=0$ specifies the nonhomogeneous (two-velocity momentum equations) option; $h=2$ specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option ($h=2$), the major edit printout will show $h=1$.

The digit s specifies momentum flux options. $s=0$ uses momentum flux in both the to and from volume. $s=1$ uses momentum flux in the from volume, but not in the to volume. $s=2$

uses momentum flux in the to volume, but not in the from volume. s=3 does not use momentum flux in either the to volume or the from volume.

W7(R)   Subcooled discharge coefficient. This quantity is applied only to subcooled liquid choked flow calculations. The quantity must be >0.0 and ≤2.0.

W8(R)   Two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be >0.0 and ≤2.0.

W9(R)   Superheated discharge coefficient. This quantity is applied only to superheated vapor choked flow calculations. The geometry must be > 0.0 and ≤ 2.0.

W10(I)   From volume increment. Words 1 and 2 contain the from and to connection codes respectively for the first junction defined by the set. If the set defines more than one junction, connection codes for the following junctions are given by the connection code of the previous junction plus the increments in Words 10 and 11. The increments may be positive, negative, or zero. Junctions are defined up to the limit in Word 13. Words 3 through 8 apply to all junctions defined by the set. If additional sets are entered, Words 1 and 2 apply to the next junction, and increments are applied as with the first set. Word 13 for the second and following sets must be greater than Word 13 of the preceding set, and Word 13 of the last set must equal nj. A new set is used whenever a new increment is needed, Words 3 through 9 need to be changed, or a change in junction numbering is desired.

W11(I)   To volume increment. See description for Word 10.

W12(I)   Enter zero. This is reserved for future capability.

W13(I)   Junction limit. Described above.

A7.10.3 Cards ccc1nnm, Multiple Junction Initial Condition Cards

Initial velocities are entered using one or more sets of data. The processing of sets of data is identical to that described in Section A7.10.2 except that there need be no relationship in the division of junctions within sets between these cards (ccc1nnm) and the multiple junction geometry cards (ccc0nnm). Likewise, these cards do not affect the numbering of the junctions.

W1(R)   Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control Word 2 of Card CCC0001.

W2(R)   Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control Word 2 of Card CCC0001.

W3(I)   Junction limit number.

A7.10.4 Cards ccc2nnm, Multiple Junction Diameter and CCFL Data Cards

These cards are optional. The defaults indicated for each word are used if the card is not entered. If the card is being used to specify only the junction hydraulic diameter for the interphase drag calculation

(i.e., $\underline{f}=0$ in Word 6 of Cards ccc0nnm), then the diameter should be entered in Word1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., $\underline{f}=1$ in Word 6 of Cards ccc0nnm), then enter all four words for the appropriate CCFL model if values different from the default values are desired. The processing of sets of data is identical to that described in Section A7.10.2 except that there need be no relationship in the division of junctions within sets between these cards (ccc1nnm) and the multiple junction geometry cards (ccc0nnm). Likewise, these cards do not affect the numbering of the junctions.

W1(R)   Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥ 0. This number should be computed from 4.0*(junction area)/(wetted perimeter). If a zero is entered or if the default is used, the junction diameter is computed from 2.0*(JUNCTION AREA/π)**0.5. See Word 3 of Card ccc0nnm for junction area.

W2(R)   Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R)   Gas intercept, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0. The default value f is 1.

W4(R)   Slope, m. This is the slope used in the CCFL correlation and must be >0. The default value is 1.

W5(I)   Junction limit number.

A7.10.5   Card ccc3nnm, Multiple Junction Form Loss Data Card

This card is optional. The user specified form loss is given in Words 4 and 5 of Card ccc0nnm if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 4 and 5 of Card ccc0nnm. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all five words for the appropriate expression.

W1(R) B_f (≥ 0). This quantity must be greater than or equal to zero.

W2(R) c_f (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_r (≥ 0). This quantity must be greater than or equal to zero.

W4(R) c_r (≥ 0). This quantity must be greater than or equal to zero.

W5(I)   Junction limit number.

A7.11   Accumulator Component

An accumulator component is indicated by ACCUM on Card ccc0000. For major edits, minor edits, and plot variables, the volume in the accumulator component is numbered ccc010000, and the junction in the accumulator component is numbered ccc010000.

An accumulator is a <u>lumped</u> parameter component treated by special numerical techniques that model both the tank and surgeline until the accumulator is emptied of liquid. When the last of the liquid leaves the accumulator, the code automatically resets the accumulator to an equivalent single volume with an outlet junction and proceeds with calculations using the normal hydrodynamic solution algorithm.

In the following input requirements, it is assumed that the component is an accumulator in which liquid completely fills the surgeline but may or may not occupy the tank. It is further assumed that the accumulator is not initially in the injection mode. Hence, the initial pressure must be input lower than the injection point pressure, including elevation head effects; and junction initial conditions may not be input (i.e., initial hydrodynamic velocities are set to zero in the code). It is further assumed that the noncondensable gas in the accumulator is nitrogen and that the gas and liquid are initially in equilibrium. No other junctions (except the accumulator junction) should be connected to the accumulator volume. The geometry of the tank may be cylindrical or spherical. The standpipe/surgeline inlet refers to the end of the pipe inside the tank itself (see Section 2.3.13).

A7.11.1   Cards ccc0101 through ccc0109, Accumulator Volume Geometry Cards

W1(R)   Volume flow area (m^2, ft^2). This is the flow area of a cylindrical tank, or the maximum flow area of a spherical tank. In the case of a spherical tank, the flow area and the tank radius are related by the formula $A = \pi R^2$.

W2(R)   Length of volume (m, ft). This is the length of the tank above the standpipe/surgeline inlet, where this inlet refers to the end of the pipe inside the tank itself.

W3(R)   Volume of volume (m^3, ft^3). This is the volume of the tank above the standpipe/surgeline inlet, where this inlet refers to the end of the pipe inside the tank itself. The code requires that the volume, volume flow area, and length are consistent. For a cylindrical tank, W3=W1*W2, and at least two of the three quantities, W1, W2 or W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. For a spherical tank, W1 and W2 must be nonzero. If W3 is zero, it will be computed from the other two. If none of the words are zero, they must satisfy the consistency condition within a relative error ± 0.000001.

W4(R)   Azimuthal angle (degrees). The absolute value of this angle must be ≤ 360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R)   Inclination angle (degrees). Only +90 or -90 degrees is allowed. The accumulator is assumed to be a vertical tank with the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank itself) at the bottom. This angle is used in the interphase drag calculation.

W6(R)   Elevation change (m, ft). This is the elevation change from the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank itself) to the top of the tank. A positive value is an increase in elevation. The absolute value of this quantity must be nonzero, less than or equal to the volume length, and have the same sign as the angle for vertical orientation. As with other components, this Word 6 is compared to the volume length (Word 2) to decide if the horizontal or vertical flow regime map is used. This is not important for this component, since the correlations that depend on the flow regime map are not needed for this component. The volume conditions are determined from the accumulator's special model.

W7(R)   Wall roughness (m, ft).

W8(R)   Hydraulic diameter (m, ft). This should be computed from 4.0*(volume flow area)/(wetted perimeter). If zero, the hydraulic diameter of the tank is computed from 2.0*(volume flow area/π)**0.5. A check is made that the pipe roughness is less than half the hydraulic diameter of the tank. See Word 1 for the volume flow area.

W9(I)   Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x coordinate flag. The accumulator component forces all volume flags except for the f digit, and y and z coordinate flags are not read. The effective format is 00110f0 where 0 and 1 indicate fields as set by the accumulator component. The user must enter 0 in the digits marked with 0 and may enter 0 or 1 in the digits marked with 1.

The t flag is not used and must be set to 0. The thermal stratification model is not used for an accumulator component.

The l flag is not used and must be set to 0. The level tracking model is not used for an accumulator component.

The flag p is not used and may be input as 0 or 1. The major edit will show p=1. The water packing scheme is not used.

The flag v is not used and may be input as 0 or 1. The major edit will show v=1. The vertical stratification model is not used.

The flag b is not used and must be input as zero. The rod bundle interphase friction model is not used.

The flag e must be specified zero, since only a nonequilibrium (unequal temperature) calculation is allowed.

W10(I)   Geometry flag (optional). To specify a cylindrical tank, set the flag equal to 0 (default); to specify a spherical tank, set the flag equal to 1.

A7.11.2   Card ccc0131, Additional Laminar Wall Friction Card

This card is optional. If this card is not entered, the default values are 1.0 for the shape factor and 0.0 for the viscosity ratio exponent.

W1(R)   Shape factor for x-coordinate.

W2(R)   Viscosity ratio exponent for x-coordinate.

A7.11.3   Card ccc0200, Accumulator Tank Initial Thermodynamics Conditions

W1(R)   Pressure (Pa, lb_f/in^2).

W2(R)   Temperature (K, ^oF).

W3(R)   Boron concentration. Parts of boron per parts of liquid water. This word is optional.

A7.11.4   Card ccc1101, Accumulator Junction Geometry Card

W1(I)   To connection code to a component. The from connection is not entered, since it is always from the accumulator. The to connection code refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is ccc000000, where ccc is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use ccc000000 if the connection is to the inlet side of the component and use ccc010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is cccvv000n, where ccc is the component number, vv is the volume number, and n indicates the face number. A nonzero n specifies the expanded format. The number n equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction (see Section 2.1). The number n equal to 3 through 6 specifies crossflow. The number n equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; n equal to 5 and 6 would do the same for the third coordinate direction.

W2(R)   Junction area (m^2, ft). This is the average area of the surgeline and standpipe.

W3(R)   Forward flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified. See Section A7.11.5.

W4(R)   Reverse flow energy loss coefficient. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified. See Section A7.11.5.

W5(I)   Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The accumulator model automatically disables the following terms as long as liquid remains in the accumulator. However, when the accumulator empties of liquid, the model is automatically converted to an active normal volume. The following terms are then enabled and used as defined.

The digit e is not used and should be input as zero (e=0). The modified energy model is not used.

The digit f is not used and should be input as zero (f=0). The major edit output will show f=0. The CCFL model is not used.

The digit v is not used and should be input as zero (v=0). The horizontal stratification entrainment/pullthrough model is not used.

The digit c specifies choking options. c=0 means that the choking model will be applied, and c=1 means the choking model will not be applied.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 is not allowed for an accumulator.

The digit h specifies nonhomogeneous or homogeneous. h=0 specifies the nonhomogeneous (two-velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit will show h=1.

The digit s specifies momentum flux options. s=0 uses momentum flux in both the to volume and the from volume. s=1 uses momentum flux in the from volume, but not in the to volume. s=2 or 3 is not allowed for an accumulator.

A7.11.5 Card ccc1102, Accumulator Junction Form Loss Data Card

This card is optional. The user-specified form loss is given in Words 3 and 4 of Card ccc1101 if this card is not entered. If this card is entered, the form loss coefficient is calculated from

$$K_f = A_f + B_f Re^{-c_f}$$

$$K_r = A_r + B_r Re^{-c_r}$$

where K_f and K_r are the forward and reverse form loss coefficient. A_f and A_r are the Words 3 and 4 of Card ccc1101. Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculation, then enter all four words for the appropriate expression.

W1(R) B_f ($\geq$0). This quantity must be greater than or equal to zero.

W2(R) c_f ($\geq$0). This quantity must be greater than or equal to zero.

W3(R) B_r ($\geq$0). This quantity must be greater than or equal to zero.

W4(R) c_r ($\geq$0). This quantity must be greater than or equal to zero.

A7.11.6 Card ccc2200, Accumulator Tank Initial Fill Conditions, Standpipe/Surgeline Length/Elevation, And Tank Wall Heat Transfer Terms

W1(R)   Liquid volume in tank (m^3, ft^3). This is the volume of water contained in the tank above the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank).

W2(R)   Liquid level in tank (m, ft). This is the liquid level of water contained in the tank above the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank) entrance. For a cylindrical tank, either W1 or W2 must be specified as nonzero. For a spherical tank, W2 must be specified as nonzero. If one of the words is zero, it is computed from the other two.

W3(R)   Length of surgeline and standpipe (m, ft). If input as zero, then the surgeline and standpipe are not modeled.

W4(R)   Elevation drop of surgeline and standpipe (m, ft). This is the elevation drop from the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank) entrance to the injection point. A positive number denotes a decrease in elevation.

W5(R)   Tank wall thickness (m, ft). This is not allowed to be zero.

W6(I)   Heat transfer flag. If zero, heat transfer will be calculated. If one, no heat transfer will be calculated.

W7(R)   Tank density (kg/m^3, lb/ft^3). If zero, the density will default to that for carbon steel.

W8(R)   Tank volumetric heat capacity (J/kg·K, Btu/lb·°F). If zero, the heat capacity will default to that for carbon steel.

W9(I)   Trip number. If zero or if no number is input, then no trip test is performed. If nonzero then this must be a valid trip number, the operations performed are similar to those performed for a trip valve. If the trip is false, then the accumulator is isolated and no flow through the junction can occur. If the trip is true, then the accumulator is not isolated and flow through the junction will occur in the normal manner for an accumulator.

A8 CARDS 1CCCGXNN, HEAT STRUCTURE INPUT

These cards are used in NEW and RESTART type problems and are required only if heat structures are described. The heat structure card numbers are divided into fields, where

> ccc is a heat structure number. The heat structure numbers need not be consecutive. We suggest, but the system does not require, that if heat structures and hydrodynamic volumes are related, they be given the same number.

> g is a geometry number. The combination cccg is a heat structure geometry combination referenced in the heat structure input data. The g digit is provided to differentiate between different types of heat structures (such as fuel pins and core barrel) that might be associated with the same hydrodynamic volume.

> x is the card type.

> nn is the card number within a card type.

A8.1 Card 1cccg000, General Heat Structure Data

This card is required for heat structures. Use eight words for new data input or one word for deleting a heat structure.

A8.1.1 General Heat Structure Data Card

W1(I)   Number of axial heat structures with this geometry, nh. This number must be >0 and <100.

W2(I)   Number of radial mesh points for this geometry, np. This number must be <100. Enter >1 if no reflood is specified, and >2 if reflood is specified.

W3(I)   Geometry type. Enter 1 for rectangular, 2 for cylindrical, and 3 for spherical. Spherical geometry is not allowed if reflood is specified. Cylindrical geometry must be specified when the gap conductance model is used.

W4(I)   Steady state initialization flag. Use zero if the desired initial condition temperatures are entered on input Cards 1cccg401-1cccg499; use one if the steady-state initial condition temperatures are to be calculated by the code. If option one is chosen, the user is still required to enter temperatures on cards 1cccg402-1cccg499. In this case, the temperatures are used as starting points for the steady-state solutions. The user should therefore enter temperatures either below or above the minimum film boiling point to assure the respective pre-DNB or post-DNB steady-state condition is calculated. This is because the boiling curve is multi-valued.

W5(R)   Left boundary coordinate (m, ft).

Warning. The reflood model, activated by the next three words, is not operational in RELAP5/MOD3.2. Work to regain reflood capability is in progress.

W6(I)   Reflood condition flag. This quantity is optional if no reflood calculation is to be performed. This quantity may be 0, 1, 2, or a trip number. If zero, no reflood calculation is to be performed. If nonzero, all the heat structures in this heat structure/geometry are assumed to form a two-dimensional representation of a fuel pin. The radial mesh is defined on Card 1cccg1nn. Each heat structure represents an axial level of the fuel pin, with the first heat structure being the bottom level. Each heat structure should be connected to a hydrodynamic volume representing the same axial section of the coolant channel. The length of the axial mesh in the fuel pin is given by the height of the connected hydrodynamic volume. If the heat structure is fuel pins or heat exchanger tubes, the length factor (Word 5 on Cards 1cccg501-1cccg509) is the product of the hydrodynamic volume length and the number of pins or tubes (see Section 3.2). The heat structures represent the temperatures at the midpoint of the axial mesh. Once the reflood calculation is initiated, additional mesh lines are introduced at each end of the fuel pin and between the heat structures. Once the reflood calculation is initiated, it remains activated, and the two-dimensional heat conduction calculation uses a minimum of 2*nh+1 axial mesh nodes. Additional mesh lines are introduced and later eliminated as needed to follow the quench front. If 1 is entered, the reflood calculation is initiated in this heat structure geometry when the average pressure in the connected hydrodynamic volumes is less than 1.2×10^6 Pa, and the average void fraction in the interconnected hydrodynamic volumes is greater than 0.9 (i.e., nearly empty). If 2 is entered, the reflood calculation is initiated in this heat structure geometry when the average pressure in the connected hydrodynamic volumes is less than 1.2×10^6 Pa and the average void fraction in the interconnected hydrodynamic volumes is greater than 0.1 (i.e., dryout begins). If a trip number is entered, the reflood calculation is initiated when the trip is set true. When using the expanded trip number format, 1 and 2 are possible trip numbers. A 1 or 2 entered in this word is not treated as a trip number.

W7(I)   Boundary volume indicator. Enter zero or one to indicate that reflood heat transfer applies to the left or right boundary, respectively.

W8(!)   Maximum number of axial intervals. Enter 2, 4, 8, 16, 32, 64, or 128 to indicate the maximum number of axial subdivisions a heat structure can have. Storage is allocated for the number indicated, even though a transient may not require that level of subdivision.

A8.1.2   Heat Structure Delete Card

This card is entered only for RESTART problems. If entered, all heat structures associated with the heat structure geometry number cccg are deleted.

W1(A)   Enter DELETE.

A8.2   Card 1cccg001, Gap Conductance Model Initial Gap Pressure Data

This card is needed only if the gap conductance model is to be used. If the card is entered, Word 1 of Card 1cccg100 must be zero, Cards 1cccg011 through 1cccg099, and Cards 1cccg201 through 1cccg299 are required. Word 2 of Card 201mmm00 must be 3, and a table of the gas component name and mole fraction must be specified in the gap material data (Cards 201mmm01 through 201mmm49).

W1(R)   Initial gap internal pressure (Pa, lb$_f$/in^2).

W2(I)   Gap conductance reference volume. This word is required. The pressure of the gas in a
               fuel pin for the gap conductance model is given by $P(t) = P(O)/T(O)*T(t)$, where $P(t)$ is
               the pressure in the fuel pin and $T(t)$ is the temperature in the reference volume. $P(O)$ is
               Word 1 above, and $T(O)$ is the initial value, if the volume is also being defined with these
               input data or the value from the restart block. The reference volume is usually the
               hydrodynamic volume (i.e., the nine-digit number cccnn0000) most closely associated
               with the nonfuel region in a fuel pin at the top of a stack of fuel pellets.

A8.3   Card 1cccg003, Metal-Water Reaction Control Card

Cccg is a heat structure geometry number. If this card is not present, no metal-water reaction will be
calculated.

W1(R)   Initial oxide thickness on cladding's outer surface.

A8.4   Card 1cccg004, Fuel Cladding Deformation Model Control Card

Cccg is a heat structure geometry number. If this card is not present, no deformation calculations will
be done. If this card is present, then Card 1cccg001 must also be present.

W1(I)   Form loss factor flag. Enter 0 if no additional form loss factors are to be calculated after a
               rod ruptures. Enter 1 if additional form loss factors are to be calculated. Either a 0 or a 1
               must be entered.

A8.5   Cards 1cccg011 through 1cccg099, Gap Deformation Data

These cards are required for the gap conductance model only. The card format is sequential format,
five words per set, describing nh heat structures.

W1(R)   Fuel surface roughness (m, ft). This number must be $\geq$0. An appropriate value is 10^{-6} m. A
               negative entry is reset to 10^{-6} m with no errors.

W2(R)   Cladding surface roughness (m, ft). This number must be either positive or zero. An
               appropriate value is 2×10^{-6} m. A negative entry is reset to 2×10^{-6} m with no errors.

W3(R)   Radial displacement due to fission gas-induced fuel swelling and densification (m, ft).
               This number must be $\geq$0. A negative entry is reset to zero. An appropriate value can be
               obtained from calculations using FRAPCON-2 or FRAP-T6.

W4(R)   Radial displacement due to cladding creepdown (m, ft). The value is normally negative. A
               positive entry is reset to zero. An appropriate value can be obtained from calculations
               using FRAPCON-2 or FRAP-T6.

W5(I)   Heat structure number.

A8.6   Card 1cccg100, Heat Structure Mesh Flags

This card is required for heat structure input.

W1(I)   Mesh location flag. If zero, geometry data, including mesh interval data, composition data, and source distribution data, are entered with this heat structure input. If nonzero, that information is taken from the geometry data from the heat structure geometry (cccg) number in this word. If this word is nonzero, the remaining geometry information described in Section A8.6 through Section A8.10 is not entered.

W2(I)   Mesh format flag. This word is needed only if Word 1 is zero, though no error occurs if it is present when Word 1 is nonzero. The mesh interval data are given as a sequence of pairs of numbers in one of two formats to be used in Cards 1cccg101 through 1cccg199. If this word is 1 (format 1 on Cards 1cccg101-1cccg199), the pairs of numbers contain the number of intervals in this region and the right boundary coordinate. For the first pair, the left coordinate of the region is the left boundary coordinate previously entered in Word 5 of Card 1cccg000; for succeeding pairs, the left coordinate is the right coordinate of the previous pair. If this word is 2 (format 2 on Cards 1cccg101-1cccg199), the format is a sequential expansion of mesh intervals; i.e., the distance in Word 1 on Cards 1cccg101 through 1cccg199 is used for each interval starting from the leftmost, as yet unspecified, interval to and including the interval number specified in Word 2.

A8.7   Cards 1cccg101 through 1cccg199, Heat Structure Mesh Interval Data (Radial)

These cards are required if Word 1 of Card 1cccg100 is zero. In Format 1, the sum of the numbers of intervals must be np-1. In Format 2, the sequential expansion must be for np-1 intervals. The card numbers need not be sequential.

A8.7.1   Format 1

W1(I)   Number of intervals. Enter the number of intervals, not the interval number.

W2(R)   Right coordinate (m, ft).

A8.7.2   Format 2

W1(R)   Mesh interval (m, ft.)

W2(I)   Interval number.

A8.8   Cards 1cccg201 through 1cccg299, Heat Structure Composition Data (Radial)

These cards are required if Word 1 of Card 1cccg100 is zero and must not be entered otherwise. The card format is two numbers per set in sequential expansion format for np-1 intervals. The card numbers need not be in sequential order.

W1(I)   Composition number. The absolute value of this quantity is the composition number, and it must be identical to the subfield mmm used in Heat Structure Thermal Property Data, Section A10. The sign indicates whether the region over which this composition is applied is to be included or excluded from the volume averaged temperature computation. If positive, the region is included; if negative, the region is not included. The option to exclude regions from the volume averaged temperature integration is to limit the integration to fuel regions only for use in reactivity feedback calculations. Gap and cladding regions should not be included in this case. If the gap conductance model is used, only one interval can be used for the gap model.

W2(I)   Interval number.

A8.9   Card 1cccg300, Fission Product Decay Heat Flag

This card sets the fission product decay heat flag. The code will then treat Card 1CCCG301 as a gamma attenuation coefficient card. This card is not needed if fission product decay heat is not used on this heat structure.

W1(A)   DKHEAT.

A8.10   Cards 1cccg301 through 1cccg399, Heat Structure Source Distribution Data (Radial)

These cards are required if Word 1 of Card 1cccg100 is zero and must not be entered otherwise. The card format is two numbers per set in sequential expansion format for np-1 intervals. The card numbers need not be in sequential order. Radial power peaking factors are entered here.

W1(R)   Source value. These are relative values only and can be scaled by any factor without changing the results. By entering different values for the various mesh intervals, a characteristic shape of a power curve can be described.

W2(I)   Mesh interval number.

If Card 1cccg300 is entered, then Card 1cccg301 is treated as a gamma attenuation coefficient card.

W1(R)   Gamma attenuation coefficient. These are values dependent on the heat structure material. A value of 50 is recommended for stainless steel.

W2(I)   Mesh interval number.

A8.11   Card 1cccg400, Initial Temperature Flag

This card is optional; if missing, Word 1 is assumed to be zero.

W1(I)   Initial temperature flag. If this word is zero or -1, initial temperatures are entered with the input data for this heat structure geometry. If greater than zero, initial temperatures for this heat structure geometry are taken from the heat structure geometry number in this word.

A8.12   Cards 1cccg401 through 1cccg499, Initial Temperature Data

These cards are required if Word 1 of Card 1cccg400 is zero or -1.

A8.12.1   Format 1 (Word 1 on Card 1cccg400 = 0)

If Word 1 is zero, one temperature distribution is entered; and the same distribution is applied to all of the nh heat structures. The card format is two numbers per set in sequential expansion format for np mesh points.

W1(R)   Temperature (K, $^{\circ}$F).

W2(I)   Mesh point number.

A8.12.2   Format 2 (Word 1 on Card 1cccg400 = -1)

If Word 1 of Card 1cccg400 is -1, a separate temperature distribution must be entered for each of the nh heat structures. The distribution for the first heat structure is entered on Card 1cccg401, the distribution for the second heat structure is entered on Card 1cccg402, and the remaining distributions are entered on consecutive card numbers. Continuation cards can be used if the data do not fit on one card.

W1-WNP(R)   Temperature (K, $^{\circ}$F). Enter the np mesh point temperatures in order from left to right.

A8.13   Cards 1cccg501 through 1cccg599, Left Boundary Condition Cards

These cards are required. The boundary condition data for the heat structures with this geometry are entered in a slightly modified form of sequential expansion using six quantities per set for the number of heat structures with this geometry (nh sets). The modification deals with Words 1 and 2.

W1(I)   Boundary volume number or general table. This word specifies the hydrodynamic volume number (of the form cccnn000f) or general table associated with the left surface of this heat structure. These are used to specify the sink temperature. If zero, no volume or general table is associated with the left surface of this heat structure, and a symmetry or insulated boundary condition is used (i.e., a zero temperature gradient at the boundary), or a temperature of zero is used for a surface temperature or a sink temperature in boundary conditions. A boundary volume number is entered as a positive number. If f is 0 or 4, the volume coordinate associated values such as average volume velocity are taken from the x coordinate; if f is 2 or 1, volume coordinate associated values are taken from the y or z axes, respectively. These numbers define the flow direction parallel with tube bundles. Any flow in other directions is vectorally added to give the cross flow mass flux. Specifying a volume coordinate not in use is an input error. A general table is entered as a negative number (-1 through -999).

W2(I)   Increment. This word and Word 1 of this card are treated differently from the standard sequential expansion. Word 1 of the first set applies to the first heat structure of the heat structure geometry set. The increment (normally 10000) is added to Word 1, which results in the hydraulic cell number associated with heat structure 2; etc. The increment is applied

up to the limit in Word 6 of a set. Word 1 of the next set applies to the next heat structure, and increments are applied as for the first set. The increment may be zero or nonzero, positive or negative. If Word 1 is zero, this word should be zero. Additional examples are shown in Section 4 of Volume V.

W3(I)   Boundary condition type.

If 0, a symmetry or insulated boundary condition is used (i.e., a zero temperature gradient is used at the boundary). The boundary volume must be 0.

If 1 or 1nn, a convective boundary condition where the heat transfer coefficient obtained from Heat Transfer Package 1 is used. The sink temperature is the temperature of the boundary volume. Word 1 must specify a boundary volun,: with this boundary condition type. The boundary volume cannot be a time-dependent volume.

There are several numbers allowed for Word 3 to activate convective boundary conditions for nonstandard geometries. A 1, 100, or 101 give the default values. The default convection and boiling correlations were derived mainly based on data from internal vertical pipe flow. Other possible input values are shown in **Table A8.13-1**. When modelling a vertical bundle, the rod or tube pitch-to-diameter ratio should be input on the 901 card. This has the effect of increasing the convective part of heat transfer such that users can input the true hydraulic diameter and get reasonable predictions.

Table A8.13-1 Card 501 and 601 Word 3 convection boundary type.

Word 3	Geometry Type
1,100,101	Default
110	Vertical bundle without crossflow (set P/D on 801/901 card)
111	Vertical bundle with crossflow (set P/D on 801/901 card)
130	Flat plate above fluid
134	Horizontal bundle

If 1000, the temperature of the boundary volume or the temperature from the general table (as specified in Word 1) is used as the left surface temperature. If Word 1 is zero, the surface temperature is set to zero.

If 1xxx, the temperature in general Table xxx is used as the left surface temperature.

If 2xxx, the heat flux from Table xxx is used as the left boundary condition.

If 3xxx, a convective boundary condition is used where the heat transfer coefficient as a function of time is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume or from the table specified in Word 1. If Word 1 is zero, the sink temperature is set to zero.

If 4xxx, a convective boundary condition is used where the heat transfer coefficient as a function of surface temperature is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume or from the table specified in Word 1. If Word 1 is zero, the sink temperature is set to zero.

If reflood is specified, the left boundary condition type must be same for all nh heat structures and, similarly, for the right boundary condition type. The left and right boundary types need not be the same, but neither can be 1000 or 1xxx.

W4(I)   Surface area code. If zero, Word 5 is the left surface area. If one, Word 5 is (a) the surface area in rectangular geometry, (b) the cylinder height or equivalent in cylindrical geometry, or (c) the fraction of a sphere (0.5 is a hemisphere) in spherical geometry.

W5(R)   Surface area or factor. As indicated in Word 4, this word contains the surface area (m^2, ft^2) or a geometry dependent multiplier (m^2, ft^2) for rectangular; (m, ft) for cylindrical; or dimensionless for spherical geometries). If the symmetry boundary condition is specified (Word 3=0), this word must still be entered nonzero.

W6(I)   Heat structure number.

A8.14 Cards 1cccg601 through 1cccg699, Right Boundary Condition Cards

These cards are required. These cards are the same as Cards 1cccg501 through 1cccg599, except for the right boundary. The left and right surface areas must be compatible with the geometry.

A8.15 Cards 1cccg701 through 1cccg799, Source Data Cards

These cards are required for heat structure data. The card format is sequential expansion format, five words per set, describing nh heat structures.

W1(I)   Source type. If zero, no source is used. If a positive number is less than 1000, power from the general table with this number is used as the source. If 100000 through 199994, the number has the form 1zzzzt, and the source is taken from a reactor kinetics calculation. The field zzzz must be 0000 for point reactor kinetics and is the zone number for nodal reactor kinetics. The zone number specified must be in use in the nodal kinetics model. The field t=0 specifies total reactor power, t=1 specifies total decay power, t=2 specifies fission power, t=3 specifies fission product decay power, and t=4 specifies actinide decay power. If 10001 through 14095, the source is the control variable whose number is this quantity minus 10000.

W2(R)   Internal source multiplier. Axial peaking factors may be entered here. These values are multiplied by the power in the general table number in Word 1 to obtain the total power generated in this heat structure. These factors are not relative factors.

W3(R)   Direct moderator heating multiplier for left boundary volume (see Section 3.3).

W4(R)   Direct moderator heating multiplier for right boundary volume (see Section 3.3).

W5(I)   Heat structure number.

A8.16   Card 1cccg800, Additional Left Boundary Option

W1(I)   If this card is not entered or if this word is zero, the nine word format is used on cards 1cccg801 through 1cccg899. If this word is one, the twelve word format is used on the cards.

A8.17   Cards 1cccg801 through 1cccg899, Additional Left Boundary Cards

These cards are required whenever the left boundary communicates energy with the left hand fluid volume. The cards are in sequential expansion format, nine words per set, describing nh heat structures. Sequential expansion would only be used where the critical heat flux value was not of importance, since the length to all heat structures in the expansion would be the same. Words 2-8 are used for the CHF correlation.

Nine-word format:

W1(R)   Heat transfer hydraulic diameter (i.e., heated equivalent diameter) (m, ft). This is 4*(flow area)/(heated perimeter) and is recommended to be greater than or equal to the volume hydraulic diameter since (heated perimeter) ≤(wetted perimeter). It is possible to input this diameter to be less than the volume hydraulic diameter. If Word 1 equals 0.0, the volume hydraulic diameter is used.

W2(R)   Heated length forward (m, ft). Distance is from the heated inlet to the center of this slab. This quantity will be used when the liquid volume velocity is positive or zero. This is used to get the hydraulic entrance length effect. This is used only for the CHF correlation. It must be >0. To ignore the length effect, put in a large number (i.e., ≥ 10.0).

W3(R)   Heated length reverse (m, ft). Distance is from the heated outlet to the center of this slab. This quantity will be used when the liquid volume velocity is negative. This is used to get the hydraulic entrance length effect. This is used only for the CHF correlation. It must be >0. to ignore the length effect, put in a large number (i.e., ≥ 10.0).

W4(R)   Grid spacer length forward (m, ft). Distance is from the center of this slab to the nearest grid or obstruction upstream. This quantity will be used when the liquid volume velocity is positive or zero. This is used to get the boundary layer disturbance and atomization effect of a grid spacer in rod bundles. This is used only for the CHF correlation. If the grid K loss (Word 6) is zero, Word 4 is not used.

W5(R)   Grid spacer length reverse (m, ft). Distance is from the center of the slab to the nearest grid or obstruction downstream. This quantity will be used when the liquid volume velocity is negative. This is used to get the boundary layer disturbance and atomization affect of a grid space in rod bundles. This is used only for the CHF correlation. If the grid K loss (Word 7) is zero, Word 5 is not used.

W6(R)   Grid loss coefficient forward. Used for forward flow in rod bundles. This quantity is used when the liquid volume velocity is positive or zero. This is used only for CHF calculation.

W7(R)   Grid loss coefficient reverse. Used for reverse flow in rod bundles. This quantity is used when the liquid volume velocity is negative. This is used only for the CHF correlation.

W8(R)   Local boiling factor. Enter 1.0 if there is no power source in the heat structure or if the local equilibrium quality is negative (i.e., liquid is subcooled and void is zero). This is the local heat flux/average heat flux from start of boiling. If the power profile is not flat, a steady state run may help determine this number. This number must be greater than 0.0.

W9(I)   Heat structure number.

Twelve-word format (Word 1 = 1 on Card 1cccg800). The first eight words of this format is identical to the nine-word format.

W9(I)   Natural circulation length (m, ft). This should be the height of a hydraulic natural convection cell. For a heated vertical plate, this is the total height of the plate. For inside a horizontal tube, this should be the inside tube diameter. For the outer surface of vertical or horizontal bundles, it is suggested to use the heated bundle height in the vertical direction. When using the nine word format, this quantity is set to Word 1, the heat transfer hydraulic diameter.

W10(R)   Rod or tube pitch-to-diameter ratio. The default is 1.1. The maximum is 1.6. It is not used unless Word 3 on the 501 card is 110 or 111.

W11(R)   Fouling factor. This factor is applied to the heat transfer correlations and may be used to represent fouling or to run sensitivity studies. This quantity must be a positive nonzero number. When using the nine-word format, this quantity is set to 1.0.

W12(I)   Heat structure number.

A8.18   Card 1cccg900, Additional Right Boundary Option

This card is the same as Card 1cccg800 but applies to the right boundary.

A8.19   Cards 1cccg901 through 1cccg999, Additional Right Boundary Cards

These cards are the same as Cards 1cccg801 through 1cccg899 but applies to the right boundary.

A9 CARD 60000000, RADIATION MODEL CONTROL CARD

Any heat structure may radiate to any other heat structure or set of heat structures in a user-defined enclosure. An enclosure is a set of heat structures that communicate via thermal radiation. The calculation ignores fluid in the enclosure.

W1(I)   Number of sets of radiation enclosures, NSET. This word must be less than 100 and greater than 0 for radiation to be on.

A9.1   Card 6ss00000, Radiation Set Card

SS is the set number. One of these cards must be input for each radiating set. The first word is required; the other three are optional.

W1(I)   Number of radiating heat slabs, NRH. This word is the number of radiating heat slabs (surfaces) that participate in radiation heat transfer in set SS. The maximum is 99.

W2(R)   Minimum temperature, TRMIN (K, °F). This word is the minimum temperature of all surfaces in a radiation enclosure below which radiation will no longer be calculated. The default value is 900 K.

W3(R)   Minimum void fraction, VOIDMN. This word is the minimum void fraction below which radiation will no longer be calculated. The default value is 0.75. Each volume connected to any of the radiating surfaces in the set is checked and if any have a void fraction greater than Word 3, radiation stays on in the enclosure set.

W4(I)   View factor set, REFSET. If input, this is the number of the set (SS) from which view factors are to be obtained. If no number is found here, the view factors must be input for this set.

A9.2   Cards 6ssnn001 through 6ssnn099, Radiation Heat Structure Data

For these cards, ss must take on every value from 1 to NSET (Word 1 in Card 60000000), and nn must take on every value from 1 to NRH (Word 1 on Card 6ss00000) for each ss. Data are entered for each conductor surface that participates in radiation heat transfer.

W1(I)   Heat structure geometry level, JRH. This word is cccg0zz, where cccg is the heat structure geometry combination of NH, and zz is the axial level number participating in radiation.

W2(I)   Surface flag, JLR. For this word, 0=left surface, and 1=right surface of nn.

W3(R)   Emissivity of surface nn.

A9.3 Cards 6ssnn101 through 6ssnn199, Radiation View Factors

There are NRH•NRH values in each set. ss is the set number (from 1 to NSET). nn is the surface number (from 1 to NRH). For a given nn, the sum of the view factors must be 1.0, and the view factor times the surface area must equal the view factor times the area of the receiving surface.

W1(R)   View factor, VFIJ. View factor from surface nn to surface W2(I).

W2(I)   Radiation surface number to which nn radiates. Repeat the above two words until view factors to all NHR surfaces from all surfaces are entered. Sequential expansion is used.

A10 CARDS 201MMMNN, HEAT STRUCTURE THERMAL PROPERTY DATA

These cards are used in NEW or RESTART problems. These cards are required if Cards 1cccgtxnn, Heat Structure Input Cards, are entered. These data, if present, are processed and stored even if no Cards1 cccgxnn are entered.

The subfield mmm is the composition number, and the cards with this subfield describe the thermal properties of composition mmm. The composition numbers entered on Cards 1cccg201 through 1cccg299 correspond to this subfield. A set of Cards 201mmmnn must be entered for each composition number used, but mmm need not be consecutive. During RESTART, thermal property may be deleted, new compositions may be added, or data may be modified by entering new data for an existing composition.

A10.1 Card 201mmm00, Composition Type and Data Format

This card is required.

W1(A)   Material type. Thermal properties for four materials are stored within the program: carbon steel (C-STEEL), stainless steel (S-STEEL), uranium dioxide (UO_2), and zirconium (ZR). These properties are selected by entering the name in parentheses for this word. If a user-supplied table or function is to be used, enter TBL/FCTN for this word. At present, the data are primarily to demonstrate capability. The user should check whether the data are satisfactory. The word DELETE may be entered in RESTART problems to delete a composition.

The next two words are required only if TBL/FCTN is entered for W1.

W2(I)   Thermal conductivity format flag or gap mole fraction flag. Enter 1 if a table containing temperature and thermal conductivity is to be entered; enter 2 if functions are to be entered. Enter 3 if the gap conductance model is used, and thus a table containing gas component names and mole fractions is to be entered.

W3(I)   Volumetric heat capacity flag. Enter 1 if a table containing temperature and volumetric heat capacity is to be entered; enter -1 if a table containing only volumetric heat capacities is to be entered and the temperature values are identical to the thermal conductivity table; enter 2 if functions are to be entered.

A10.2 Cards 201mmm01 through 201mmm49, Thermal Conductivity Data or Gap Mole Fraction Data

These cards are required if W1 of Card 201mmm00 contains TBL/FCTN. For a table, enter pairs of temperatures and thermal conductivities or pairs of gas component names and mole fractions according to the specification of W2 of Card 201mmm00. One to 7 pairs of gas names and their mole fractions can be entered. The gas component names that may be entered are helium, argon, krypton, xenon, nitrogen, hydrogen, and oxygen. No particular order of the pairs is required. Do not enter any gas component with a zero mole fraction. Normalization of the total mole fraction to one is performed if the sum of the mole fractions entered is not one. The table of gas composition data is applicable to any gap and is required if Card 1 cccg001 is present.

A10.2.1 Table Format

If only one word is entered, that word contains the thermal conductivity that is assumed constant. Otherwise, pairs of temperatures and thermal conductivities are entered. The number of pairs or single entries is limited to 100. The temperatures must be in increasing order. The end-point temperatures must bracket the expected temperatures during the transient. That is, if the temperature is outside the bracketed range, a failure will occur, and a diagnostic edit will be printed out.

W1(R)   Temperature (K, °F) or gas name. If only volumetric heat capacities are being entered, this word is not entered.

W2(R)   Thermal conductivity (W/m•K, Btu/s•ft•°F) or mole fraction.

A10.2.2 Functional Format

In the functional format, sets of nine quantities are entered, each set containing one function and its range of application. The function is

$$k = A0 + A1*TX + A2*TX**2 + A3*TX**3 + A4*TX**4 + A5*TX**(-1)$$

where TX = T-C, T is the temperature argument, and C is a constant. Each function has a lower and upper limit of application. The first function entered must be for the lowest temperature range. The lower limit of each following function must equal the upper bound of the previous function.

W1(R)   Lower limit temperature (K, °F).

W2(R)   Upper limit temperature (K, °F).

W3(R)   A0 (W/m•K, Btu/s•ft•°F).

W4(R)   A1 (W/m•K^2, Btu/s•ft•°F^2).

W5(R)   A2 (W/m•K^3, Btu/s•ft•°F^3).

W6(R)   A3 (W/m•K^4, Btu/s•ft•°F^4).

W7(R)   A4 (W/m•K^5, Btu/s•ft•°F^5).

W8(R)   A5 (W/m, Btu/s•ft).

W9(R)   C (K, °F).

A10.3   Cards 201MMM51 through 201MMM99, Volumetric Heat Capacity Data

These cards are required if W1 of Card 201MMM00 contains TB/.FCTN. The card number need not be consecutive.

A10.3.1   Table Format

If only one word is entered, that word contains the volumetric heat capacity that is assumed constant. Pairs of temperature and volumetric heat capacity are entered if the temperatures are different than the thermal conductivity table or if functions are used for thermal conductivity. If the temperature values are identical, only the volumetric heat capacities need be entered. The number of pairs or single entries are limited to one hundred. The temperatures must be in increasing order. The end-point temperatures must bracket the expected temperatures during the transient. That is, if the temperature is outside the bracketed range, a failure will occur, and a diagnostic edit will be printed out.

W1(R)   Temperature (K, °F). If only volumetric heat capacities are being entered, this word is not entered.

W2(R)   Volumetric heat capacity ($J/m^3 K$, Btu/ft^3 °F). This is ρC_p, where ρ is density (kg/m^3, lb/ft^3) and C_p is specific heat capacity ($J/kg\,K$, Btu/lb·°F).

A10.3.2   Functional Format

In the functional format, sets of nine quantities are entered, each set containing one function and its range of application. The function is $c\rho = A0 + A1*TX + A2*TX**2 + A3*TX**3 + A4*TX**4 + A5*TX**(-1)$, where $TX = T - C$, and T is the temperature argument. Each function has a lower and upper limit of application. The first function entered must be for the lowest temperature range. The lower limit of each following function must equal the upper bound of the previous function.

W1(R)   Lower limit temperature (K, °F).

W2(R)   Upper limit temperature (K, °F).

W3(R)   A0 ($J/m^3 K$, Btu/ft^3 °F).

W4(R)   A1 ($J/m^3 K^2$, Btu/ft^3 °F²).

W5(R)   A2 ($J/m^3 K^3$, Btu/ft^3 °F³).

W6(R)   A3 ($J/m^3 K^4$, Btu/ft^3 °F⁴).

W7(R)   A4 ($J/m^3 K^5$, Btu/ft^3 °F⁵).

W8(R)   A5 (J/m^3, Btu/ft^3).

W9(R)   C (K, °F).

A11 CARDS 202TTTNN, GENERAL TABLE DATA

These cards are used only in NEW or RESTART type problems and are required only if any input references general tables. ttt is the table number, and table references such as for power, heat transfer coefficients, and temperatures refer to this number. Data must be entered for each table that is referenced, but ttt need not be consecutive. Tables entered but not referenced are stored, and this is not considered an error. During RESTART, general tables may be added, existing tables may be deleted, or existing tables may be modified by entering new data.

A11.1 Card 202ttt00, Table Type and Multiplier Data

W1(A)   Table type. Enter POWER for power versus time; enter HTRNRATE for heat flux versus time; enter HTC-T for heat transfer coefficient versus time; enter HTC-TEMP for heat transfer coefficient versus temperature; enter TEMP for temperature versus time; enter REAC-T for reactivity versus time; enter NORMAREA for normalized area versus normalized stem position. In RESTART problems, DELETE can be entered to delete general table ttt. When a general table is used to define a FUNCTION type control system variable, table type REAC-T can be used to prevent undesirable units conversion, since no British to SI units conversion is done for REAC-T entries.

The following two, three, or four words are optional and allow trips and factors or units changes to be applied to the table entries. If the factors are omitted, the data are used as entered. One multiplier is used for time, power, heat flux, heat transfer coefficient, normalized stem position, and normalized area; a multiplier and additive constant are used for temperature as $T = M*TX + C$, where M is the multiplier, C is the additive constant, and TX is the temperature entered. The first one or two factors apply to the argument variable, time or temperature; one factor is applied if the argument is time, and two factors are used if the argument is temperature. The remaining one or two factors are used for the function, two factors being used if temperature is the function.

W2(I)   Table trip number. This number is optional unless factors are entered. If missing or zero, no trip is used, and the time argument in the following table is the time supplied to the table for interpolation. If nonzero, the number is the trip number, and the time argument in the following table is -1.0 if the trip is false and the time supplied to the table minus the trip time if the trip is true. This field may be omitted if no factors are entered. This number must be zero or blank for tables that are not a function of time.

W3-W5(R)   Factors. As described above, enter factors such that when applied to the table values entered, the resultant values have the appropriate units. For the NORMAREA table, the resultant values for both the normalized length and area must be ≥ 0 and ≤ 1.0.

A11.2 Cards 202ttt01 through 202ttt99, General Table Data

The card numbers need not be consecutive. The units given are the units required after the factors on Card 202ttt00 have been applied. Pairs of numbers are entered; the limit on the number of pairs is 99.

W1(R)   Argument value (s, if time; K, °F, if temperature; dimensionless, if normalized stem position).

W2(R)   Function value (W, MW, if power; K, °F, if temperature; W/m^2, $Btu/s \cdot ft^2$, if heat flux; W/ $m^2 \cdot K$, $Btu/s \cdot ft^2 \cdot °F$, if heat transfer coefficient; dollars, if reactivity; dimensionless, if normalized area).

The tables use linear interpolation for segments between table search argument values. For search arguments beyond the range of entered data, the end-point values are used.

A12 CARDS 30000000 THROUGH 39999999, REACTOR KINETICS INPUT

These cards are required if a space-independent (point) reactor kinetics or a nodal reactor kinetics calculation is desired. These cards may be entered in a new problem or on a restart. If no reactor kinetics data are present in a restart problem, the data will be added; if reactor kinetics data are already present, the data are deleted and replaced by the new data. A complete set of reactor kinetics data must always be entered. Initial conditions are computed the same for new or restart problems; the initial conditions can be obtained from assuming infinite operating time at the input power or from an input power history.

A12.1 Card 30000000, Reactor Kinetics Type Card

This card is required.

W1(A)   Kinetics type. Enter POINT or DELETE. Enter POINT for the point reactor kinetics option. Enter DELETE in a restart problem if reactor kinetics is to be deleted. No other data are needed if reactor kinetics is being deleted.

W2(A)   Feedback type. Enter SEPARABL, TABLE3, TABLE4, TABLE3A, TABLE4A. If Word 2 is not entered, a default value is assumed. If the kinetics type is POINT, the default is SEPARABL. If SEPARABL is entered, reactor kinetics feedback due to moderator density, void fraction weighted moderator temperature, and fuel temperature is assumed to be separable, and feedback data are entered on Cards 30000501 through 30000899. If TABLE3, TABLE4, TABLE3A, or TABLE4A is entered, reactivity is obtained from a table defining reactivity as a function of three or four variables using Cards 30001001 through 30002999. If TABLE3 or TABLE4 are entered, the variables are moderator density, void fraction weighted moderator temperature, fuel temperature, and boron density. If TABLE3A or TABLE4A is entered, the variables are void fraction, liquid moderator temperature, volume average fuel temperature, and boron concentration. If TABLE3 or TABLE3A is entered, the first three of the variables in one of the sets defined above are used, and if TABLE4 or TABLE4A is entered, all four variables are used.

A12.2 Card 30000001, Reactor Kinetics Information Card

W1(A)   Fission product decay type. Enter NO-GAMMA for no fission product decay calculations, GAMMA for standard fission product decay calculations, or GAMMA-AC for fission product decay plus actinide decay calculations.

W2(R)   Total reactor power (W). This is the sum of fission power, fission product decay power, and actinide decay power. Watts are used for both SI and British units. This must be >0.0.

W3(R)   Initial reactivity (dollars). This quantity must be less than or equal to 0.0.

W4(R)   Delayed neutron fraction over prompt neutron generation time (s^{-1}).

W5(R)   Fission product yield factor. This is usually 1.0 for best-estimate problems, and 1.2 has been used with ANS73 data for conservative mode problems. The factor 1.0 is assumed if this word is not entered.

W6(R) ^{239}U yield factor. This is the number of ^{239}U atoms produced per fission times any conservative facte ..sired. The factor 1.0 is assumed if this word is not entered.

W7(R)   Fissions per initial fissile atom, ψ. Used in

$$factor\ (G(t) = 1.0 + (3.24 \cdot 10^{-6} + 5.23 \cdot 10^{-10}t)\ T^{0.4}\psi)$$

to account for neutron capture in fission products when using ANS79-1 or ANS79-3 option. Entering this quantity as a nonzero includes the G factor as part of the decay heat. The factor is not included if this quantity is not entered or is entered as zero. Entering this word as a positive quantity indicates that the equation is to be used for shutdown time up to 10^4 s, and the table is to be used from that time on. Entering this word as a negative number indicates that the table is to be used for all shutdown times. Note that there is a discontinuity in G(t) when switching between and equation and the table. The standard indicates that the table can be used for all shutdown times and that would result in a higher neutron absorption capture effect. The magnitude of this quantity if nonzero must be greater than or equal to 1.0 and less than or equal to 3.0.

W8(R)   Reactor operating time T. This quantity is the T in the expression given in W7 above. The unit for this quantity is given in the next word. If not entered or entered as zero, this quantity defaults to 52 wk. This quantity is used only if the power history data in Section A12.7 are not entered. When the power history data are entered, the reactor operating time is obtained from that data. When the power history data are not entered, an infinite operating time is assumed in initializing the decay heat variables, and if the equation form of G(T) is being used, the quantity in this word is used with the shutdown period t set to zero to determine the G factor at the start of the simulation. The limit for this quantity is $1.2614 \cdot 10^8$ s.

W9(A)   Units for W8 above. Must be sec, min, hr, day, wk.

A12.3   Card 30000002, Fission Product Decay Information

This card is optionally entered for POINT problems if W1 of Card 30000001 contains GAMMA or GAMMA-AC. If this card is not entered, the Proposed 1973 ANS Standard fission product data are used if default data are used.

W1(A)   Fission product type. Enter ANS73, ANS79-1, or ANS79-3. If default fission product data are used, ANS73 specifies the Proposed 1973 ANS Standard data, ANS79-1 specifies the 1979 Standard data for ^{235}U, and ANS79-3 specifies the 1979 ANS Standard data for the three isotopes, ^{235}U, ^{238}U, and ^{239}Np. ANS79-3 also requires that power fractions for each isotope must be entered. If fission product data are entered, ANS73 and ANS79-1 specify only one isotope and ANS79-3 specifies three isotopes and also requires that the number of decay heat groups for each isotope be entered.

W2(R)   Energy release per fission (MeV/fission). If not entered or zero, the default value of 200 MeV/fission is used.

W3-W5(R)   If ANS79-3 is specified in W1, the fraction of power generated in ^{235}U, ^{238}U, and ^{239}Pu must be entered in these three words. The sum of the fractions must add to one.

W6-W8(I)   Number of groups per isotope. If ANS79-3 is entered in W1 and default data are not being used, the number of decay groups for ^{235}U, ^{238}U, and ^{239}Pu must be entered in these words. The number of groups for each isotope must be less than or equal to 50.

A12.4   Cards 30000101 through 30000199, Delayed Neutron Constants

If these cards are missing, constants for the six generally accepted delayed neutron groups are supplied. Otherwise, two numbers for each delay group are entered, one or more pairs per card. Card numbers need not be consecutive. The number of pairs on these cards defines the number of delay groups. Up to 50 delay groups may be entered.

W1(R)   Delayed neutron precursor yield ratio.

W2(R)   Delayed neutron decay constant (s^{-1}).

A12.5   Cards 30000201 through 30000299, Fission Product Decay Constants

These cards are not needed if W1 of Card 30000001 is NO-GAMMA. If this word is GAMMA or GAMMA-AC, data from these cards or default data are used to define fission product decay. If the cards are missing, data as defined in W1 of Card 30000002 are supplied. Up to 50 fission product groups may be entered. Data are entered on cards similarly to Cards 30000101 through 30000199. The factor in W5 of Card 30000001 is applied to the yield fractions.

W1(R)   Fission product yield fraction (MeV).

W2(R)   Fission product decay constant (s^{-1}).

A12.6   Cards 30000301 through 30000399, Actinide Decay Constants

These cards are not needed unless W1 of Card 30000001 is GAMMA-AC. If GAMMA-AC is entered, data from these cards or default data are used to define actinide decay. If the cards are missing, default data are supplied.

W1(R)   Energy yield from ^{239}U decay (Mev).

W2(R)   Decay constant of ^{239}U (s^{-1}).

W3(R)   Energy yield from ^{239}Np (Mev).

W4(R)   Decay constant of ^{239}Np (s^{-1}).

A12.7   Cards 30000401 through 30000499, Power History Data

If these cards are not present, initial conditions for fission product and actinide groups are for steady-state operation at the power given in W2 of Card 30000001. This is equivalent to operation at that power for an infinite time. If these cards are present, the power history consisting of power and time duration is used to determine the fission product and actinide initial conditions. The power from gamma and actinide decay is assumed to be zero at the beginning of the first time duration. Data are entered in three- or six-word sets, one or more sets per card. Card numbers need not be consecutive.

W1(R)   Reactor power (W). This quantity is the total reactor power, that is, the sum of fission power and decay power, and must be ≥ 0. If a decay power obtained from the power history exceeds this quantity, the fission power is assumed to be zero.

W2(R)   Time duration. Units are as given in next word. This quantity must be greater than or equal to 0.

W3(A)   Time duration units. Must be sec, min, hr, day, or wk.

W4-W6(R)   Power fractions. If ANS79-3 is entered in W1 of Card 30000002, the power fractions for ^{235}U, ^{238}U, and ^{239}Pu must be entered in these words.

A12.8   Feedback Input

Feedback information for point kinetics information are entered on the following cards. For steady state computations in which constant power is desired, these cards can be omitted and the feedback reactivity will be zero.

A12.8.1   Cards 30000011 through 30000020, Reactivity Curve or Control Variable Numbers

Reactivity (or scram) curves from the general tables (Cards 202TTTNN) or control variables that contribute to reactivity feedback are specified on these cards. These cards are not used if there are no references to reactivity contributions from general tables or control variables. Tables and control variables referenced must be defined. No error is indicated if reactivity curves are defined but not referenced on this card, but memory space is wasted. Curve numbers, which are the TTT of the general table card number or control variable number code, are entered one or more per card. Card numbers need not be consecutive.

W1(I)   Table or control variable number. Up to 20 numbers may be entered. Numbers from 1 through 999 indicate general table numbers. Numbers greater than 10000 indicate the control variable whose number is the entered number minus 10000.

A12.8.2   Cards 30000501 through 30000599, Density Reactivity Table

This table is required if the SEPARABL option is being used and if Cards 30000701 through 30000799 are entered. One or more pairs of numbers are entered to define reactivity as a function of moderator density. Data are entered one or more pairs per card, and card numbers need not be consecutive.

Up to 100 pairs may be entered. The table uses linear interpolation for segments between table search argument values. For search arguments beyond the range of entered data, the end-point values are used.

W1(R)   Moderator density (kg/m^3, lb/ft^3).

W2(R)   Reactivity (dollars).

A12.8.3   Cards 30000601 through 30000699, Doppler Reactivity Table

This table is required if the SEPARABL option is being used and if Cards 30000801 through 30000899 are entered. One or more pairs of numbers are entered to define Doppler reactivity as a function of volume-averaged fuel temperature. Heat structure composition data Cards 1cccg201-1cccg209 need to exclude the gap and the cladding for the volume-average fuel temperatures. Data are entered one or more pairs per card, and card numbers need not be consecutive. Up to 100 pairs may be entered. The table uses linear interpolation for segments between table search argument values. For search arguments beyond the range of entered data, the end-point values are used.

W1(R)   Temperature (K, $^\circ$F).

W2(R)   Reactivity (dollars).

A12.8.4   Cards 30000701 through 30000799, Volume Weighting Factors

These cards are used only if the SEPARABL option is being used and are omitted if no reactor kinetics feedback from hydrodynamics is present. Each card contains the input for reactivity feedback due to conditions in one or more hydrodynamic volumes. Words 1 and 2 are a volume number and an increment (see Section A8.13). Words 3 and 4 are the reactivity data for the volume defined by Word1; Words 5 and 6 are the reactivity data for the volume defined by Word 1 plus Word 2; Words 7 and 8 contain data for the volume defined by Word 1 plus two times Word 2; etc. Each card must contain at least four words. Volumes must be defined by hydrodynamic component data cards, and any volume reactivity data must be defined only once on these cards. Card numbers need not be consecutive.

W1(I)   Hydrodynamic volume number.

W2(I)   Increment.

W3(R)   Weighting factor for density feedback, W_{qi}. See Volume 1 of this manual for a discussion of the symbols.

W4(R)   Water temperature coefficient, a_{wi} (dollars/K, dollars/$^\circ$F). As defined in Volume 1, the weighting factor in Word 3 is not applied to this quantity.

A12.8.5   Cards 30000801 through 30000899, Heat Structure or SCDAP Component Weighting Factors

These cards are used only if the SEPARABL option is being used and are omitted if no reactor kinetics feedback from heat structures or SCDAP components are present. Each card contains the input for

reactivity feedback due to conditions in one or more heat structures or SCDAP components representing fueled portions of the reactor. Data are entered in a manner similar to Cards 30000701 through 30000799.

For each heat structure specified on these cards, input on the heat structure data Cards 1CCCG2NN must define the fueled region as the region over which the volume-average temperature is computed.

Usually, either Word 3 or 4 is zero.

W1(I)   Heat structure number, or SCDAP component IIJJ. II equals the axial node, and JJ equals the component number.

W2(I)   Increment.

W3(R)   Weighting factor for doppler feedback, W_{F_i}.

W4(R)   Fuel temperature coefficient, a_{F_i} (dollars/K, dollars/°F). As defined in Volume 1, the weighting factor in Word 3 is not applied to this quantity.

A12.8.6   Cards 30001701 through 30001799, Volume-Weighting Factors

These cards are used only if the TABLE3 or TABLE4 option is not being used. Each card contains the weighting factor for reactivity feedback due to moderator density (void fraction), void weighted moderator temperature (liquid moderator temperature), and boron density (boron concentration) in one or more hydrodynamic volumes. The quantities preceding the quantities within parentheses are used if TABLE3 or TABLE4 has been entered; the quantities within parentheses are used if TABLE3A or TABLE4A has been entered. The same factor is assumed to apply to all three effects, so only one factor is entered for each value. At least three quantities must be entered on each card. The use of the increment field is similar to that in Section A12.8.5.

W1(I)   Hydrodynamic volume number.

W2(I)   Increment.

W3(R)   Weight factor.

A12.8.7   Cards 30001801 through 30001899, Heat Structure or SCDAP Component Weighting Factors

These cards are used only if the TABLE3 or TABLE4 option is not being used. Each card contains the weighting factor for reactivity feedback due to temperature in one or more heat structures or SCDAP components. At least three quantities must be entered on each card. The use of the increment field is similar to that in Section A12.8.5.

W1(I)   Heat structure number or SCDAP component IIJJ. II is the axial node, and JJ is the component number.

W2(I)   Increment.

W3(R)   Weight factor.

A12.8.8   Cards 300019C1 through 300019C9, Feedback Table Coordinate Data

If the TABLE3 option is being used, the feedback table is a function of three variables: moderator density or void fraction (C=1), void weighted moderator temperature or liquid moderator temperature (C=2), and fuel temperature (C=3). If the TABLE4 option is being used, the feedback table is a function of four variables: the three above and boron density or boron concentration (C=4). Which variables are used depend on the feedback option used (see W2 in Section A12.1). These cards define the coordinates of the table, and table values are entered (on another card set) for each point defined by all combinations of the coordinate values. The table size is the product of the number of coordinate values entered for each variable. At least two coordinate points must be entered, and up to twenty points may be entered for each variable. Coordinate values are entered in increasing magnitude, one or more per card on one or more cards as desired. Card numbers need not be consecutive. The C in the parentheses above defines the C to be used in the card number.

W1(R)   Coordinate value (kg/m^3, lb/ft^3 for moderator and boron densities; K, $^\circ$F for moderator and heat structure temperatures; void fractions and boron concentrations are dimensionless).

A12.8.9   Cards 30002001 through 30002999, Feedback Table Data

Values defining the table are entered in pairs. The first is a coded number defining the position of the table entry. The second number is the table entry. One or more pairs may be entered on one or more cards as needed. Card numbers need not be consecutive. There is no required ordering for the coded number, but a coded number may be entered only once.

W1(I)   Coded number. The coded number has the form ddmmffbb, where the letter pairs represent coordinate numbers of the independent variables of the table. The dd pair refers to moderator density, mm refers to moderator temperature, ff refers to heat structure temperature, and bb refers to boron density. The paired numbers range from 00 to one less than the number of coordinate values for that variable. The 00 pair refers to the first coordinate value. If boron dependence is not included, bb is always 00. All table values must be entered. (A future version may allow gaps that are filled in by interpolation.)

W2(R)   Table value.

A13 CARDS 20300000 THROUGH 20499999, PLOT REQUEST INPUT DATA

The plotting capability is not currently active. Besides not being converted to machine-dependent form from the original CDC-7600 version, a proprietary plotting package was required. Most users use the strip option to write an ASCII coded file containing data to be plotted and interface this file to plotting routines available within their organizations.

A14 CARDS 205CCCNN OR 205CCCCN, CONTROL SYSTEM INPUT DATA

These cards are used in NEW and RESTART problems if a control system is desired. They are also used to define the generic control components employed with the self-initialization option. Input can also be used to compute additional quantities from the normally computed quantities. These additional quantities can then be output in major and minor edits and plots.

Two different card types are available for entering control system data, but only one type can be used in a problem. The digits ccc or cccc form the control variable number (i.e., control component number). The card format 205cccnn allows 999 control variables, where ccc ranges from 001 through 999. The card format 205ccccn allows 9999 control variables, where cccc ranges from 1 through 9999.

If the self-initialization option is selected, the data cards described in Section A14.2, Section A14.3.20, and Section A14.3.21 must be included. If loop flow control is to be included, the data cards described in Section A14.3.19 must also be included.

A14.1 Card 20500000, Control Variable Card Type

If this card is omitted, card type 205cccnn is used. If this card is entered, either card format can be selected. This card cannot be entered on RESTART problems if control components exist from the restart problem, in which case the card format from the restart problem must be used.

W1(I)   Enter 999 to select the 205cccnn format or 9999 (4095 also allowed) to select the 205ccccn format.

A14.2 Card 205ccc00 or 205cccc0, Control Component Type Card

One card must be entered for each of the generic control components when using the self-initialization option.

W1(A)   Alphanumeric name. Enter a name descriptive of the component. This name will appear in the printed output along with the component number. A limit of 10 characters is allowed for CDC 7600 computers, and a limit of 8 characters is allowed for most other computers.

W2(A)   Control component type. Enter one of the component names, SUM, MULT, DIV, DIFFRENI, DIFFREND, INTEGRAL, FUNCTION, STDFNCTN, DELAY, TRIPUNIT, TRIPDLAY, POWERI, POWERR, POWERX, PROP-INT, LAG, LEAD-LAG, CONSTANT, SHAFT, PUMPCTL, STEAMCTL, or FEEDCTL, or the command, DELETE. If DELETE is entered, enter any alphanumeric word in Word 1 and zeros in the remaining words. No other cards are needed when deleting a component.

W3(R)   Scaling factor. For a CONSTANT component, this quantity is the constant value. No additional words are entered on this card, and Cards 205ccc01 through 205ccc09 or 205cccc1 through 205cccc9 are not entered. For the PUMPCTL, STEAMCTL, or FEEDCTL components, this is the gain multiplier (G) for the output signal.

W4(R)   Initial value.

W5(I)   Initial value flag. Zero means no initial condition calculation and W4 is used as the initial
                 condition; one means compute initial condition.

W6(I)   Limiter control. Enter zero, or omit this and the following words if no limits on the control
                 variable are to be imposed. Enter 1 if only a minimum limit is to be imposed, 2 if only a
                 maximum limit is to be imposed, and enter 3 if both minimum and maximum limits are to
                 be imposed.

W7(R)   Minimum or maximum value. This word is the minimum or maximum value if only one
                 limit is to be imposed or is the minimum value if both limits are to be imposed.

W8(R)   Maximum value. This word is used if both limits are to be imposed.

A14.3   Cards 205ccc01 through 205ccc98 or 205cccc1 through 205cccc8, Control Component Data Cards

The format of these cards depends on the control component type. An equation is used to describe
the processing by each component. The symbol Y represents the control variable defined by the
component. The symbols A_j, j=1,2,...J, represent constants defined by the control component input data.
The variables V_j, j=1,2,...J, represent any of the variables listed in the minor edit input description. Besides
hydrodynamic component data, heat structure data, reactor kinetic data, etc., any of the control variables
including the variable being defined may be specified. The symbol S is the scale factor (or G, the gain
multiplier, for self-initialization control components) on Card 205ccc00 or 205cccc0. The variables V_j use
the code's internal units (SI). To use British units, the user must convert from SI to British using the scale
factor S (or the gain multiplier G) and the constants A_j.

See Section 8 of volume I for a detailed description of these models.

A14.3.1   Sum-Difference Component

This component is indicated by SUM in Word 2 of Card 205ccc00 or 205cccc0. The sum-difference
component is defined by

$$Y = S(A_0 + A_1V_1 + A_2V_2 + ... + A_jV_j)$$

W1(R)   Constant A_0.

W2(R)   Constant A_1.

W3(A)   Alphanumeric name of variable request code for V_1.

W4(I)   Integer name of the variable request code for V_1. At least four words that define a constant
                 and one product term must be entered. Additional sets of three words corresponding to
                 Words 2 through 4 can be entered for additional product terms up to twenty product terms.
                 One or more cards may be used as desired. Card numbers need not be strictly consecutive.
                 The sign of A_j determines addition or subtraction of the product terms.

A14.3.2   Multiplier Component

This component is indicated by MULT in Word 2 of Card 205ccc00 or 205cccc0. The multiplier component is defined by

$$Y = SV_1 V_2 ... V_j .$$

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1. At least two words must be entered. Additional pairs of words can be entered on this or additional cards to define additional factors. Card numbers need not be strictly consecutive.

A14.3.3   Divide Component

This component is indicated by DIV in Word 2 of Card 205ccc00 or 205cccc0. The divide component is defined by

$$Y = \frac{S}{V_1} \quad \text{or} \quad Y = \frac{V_2}{V_1} .$$

Specifying two words on the card indicates the first form, and specifying four words on the card indicates the second form. Execution will terminate if a divide by zero is attempted.

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

W3(A)   Alphanumeric name of the variable request code for V_2.

W4(I)   Integer name of the variable request code for V_2.

A14.3.4   Differentiating Components

These components are indicated by DIFFRENI or DIFFREND in Word 2 of Card 205ccc00 or 205cccc0. The differentiating component is defined by

$$Y = S\frac{dV_1}{dt} .$$

This is evaluated by

$$Y = S*[2(V_1 - V_{10})/\Delta t] - Y_o \qquad \text{(DIFFERENI)}$$

$$Y = S*(V_1 - V_{10})/\Delta t \qquad\qquad \text{(DIFFREND)}$$

where Δt is the time step, and V_{10} and Y_0 are values at the beginning of the time step. The numerical approximations for the DIFFRENI and INTEGRAL components are exact inverses of each other. However, an exact initial value is required to use the DIFFRENI component, and erroneous results are obtained if an exact initial value is not furnished. The DIFFREND component uses a simple difference approximation that is less accurate and is not consistent with the integration approximation, but does not require an initial value. For these reasons, use of DIFFRENI is not recommended.

Since differentiation, especially numerical differentiation, can introduce noise into the calculation, it should be avoided if possible. When using control components to solve differential equations, the equations can be arranged such that INTEGRAL components can handle all indicated derivatives except possibly those involving noncontrol variables.

W1(A)   Alphanumeric name of variable request code for V_1.

W2(I)   Integer name of variable request code for V_1.

A14.3.5 Integrating Component

This component is indicated by INTEGRAL in Word 2 of Card 205ccc00 or 205cccc0. The integrating component is defined by

$$Y = S \int_0^t V_1 dt$$

or, in Laplace notation,

$$Y(s) = \frac{SV_1(s)}{s} .$$

This is evaluated by

$$Y = Y_o + S*(V_1 + V_{10})*\Delta t/2$$

where Δ is the time step and Y_o and V_{10} are values at the beginning of the time step.

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

A14.3.6 Functional Component

This component is indicated by FUNCTION in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S[FUNCTION (V_1)]$$

where FUNCTION is defined by a general table. This allows the use of any function that is conveniently defined by a table lookup and linear interpolation procedure. The function component can also be used to set limiting values.

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

W3(I)   General table number of the function.

A14.3.7   Standard Function Component

This component is indicated by STDFNCTN in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S[FNCTN (V_1, V_2, ...)]$$

where FNCTN is ABS (absolute value), SQRT (square root), EXP (e raised to power), LOG (natural logarithm), SIN (sine), COS (cosine), TAN (tangent), ATAN (arc tangent), MIN (minimum value), or MAX (maximum value). All function types except MIN and MAX must have only one argument; MIN and MAX function types must have at least two arguments and may have up to twenty arguments. If the control variable being defined also appears in the argument list of MIN or MAX, the old time value is used in the comparison.

W1(A)   FNCTN.

W2(A)   Alphanumeric name of the variable request code for V_1.

W3(I)   Integer name of the variable request code for V_1.

A14.3.8   Delay Component

This component is indicated by DELAY in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = SV_1 (t - t_d)$$

where t is time and t_d is the delay time.

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

W3(R)   Delay time, t_d (s).

W4(I)   Number of hold positions. This quantity, h, must be > 0 and ≤ 100. This quantity
                   determines the length of the table used to store past values of the quantity V_1. The
                   maximum number of time-function pairs that can be stored is h+2. The delay table time
                   increment, d_{TM}, is $d_{TM} = t_d/h$. The delayed function is obtained by linear interpolation for
                   $V_1(t - t_d)$ using the stored past history. As the problem is advanced in time, new time
                   values are added to the table. Once the table is filled, new va   replace values that are
                   older than the delay time. There are no restrictions on $t_d T$ or d_{TM} relative to the time steps
                   on Cards 2nn. When a change in advancement time is made at a restart, the time values in
                   this table are changed to have time values as if the problem in the restart had run to the
                   new advancement time.

A14.3.9   Unit Trip Component

This component is indicated by TRIPUNIT in Word 2 of Card 205ccc00 or 205cccc0. The
component is defined by

$$Y = S*U(\pm T_1)$$

where U is 0.0 if the trip, T_1, is false and is 1.0 if the trip is true. If the complement of T_1 is specified, U is
1.0 if the trip is false and 0.0 if the trip is true.

W1(I)   Trip number. A minus sign may prefix the trip number to indicate that the complement of
                   the trip is to be used.

A14.3.10   Trip Delay Component

This component is indicated by TRIPDLAY in Word 2 of Card 205ccc00 or 205cccc0. The
component is defined by

$$Y = ST_{rptim}(T_1)$$

where T_{rptim} is the time the trip last turned true. If the trip is false, the value is -1.0; if the trip is true, the
value is zero or a positive number.

W1(I)   Trip number, T_1.

A14.3.11   Integer Power Component

This component is indicated by POWERI in Word2 of Card 205ccc00 or 205cccc0. The component
is defined by

$$Y = SV_1^I.$$

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

W3(I)   I.

A14.3.12   Real Power Component

This component is indicated by POWERR in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = SV_1^R.$$

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

W3(R)   R.

A14.3.13   Variable Power Component

This component is indicated by POWERX in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = SV_1^{V_2} .$$

W1(A)   Alphanumeric name of the variable request code for V_1.

W2(I)   Integer name of the variable request code for V_1.

W3(A)   Alphanumeric name of the variable request code for V_2.

W4(I)   Integer name of the variable request code for V_2.

A14.3.14   Proportional-Integral Component

This component is indicated by PROP-INT in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = S\left[A_1 V_1 + A_2 \int_0^t V_1 dt\right]$$

or in Laplace transform notation,

$$Y(s) = S\left[A_1 + \frac{A_2}{s}\right] V_1(s) .$$

If the control variable is initialized,

$$Y(t_o) = SA_1V_1(t_o) .$$

If it is desired that the output quantity Y remain constant as long as the input quantity remains constant, V_1 must initially be zero regardless of the initialization flag.

W1(R) A_1.

W2(R) A_2.

W3(A)   Alphanumeric name of the variable request code for V_1.

W4(I)   Integer name of the variable request code for V_1.

A14.3.15   Lag Component

This component is indicated by LAG in Word 2 of Card 205ccc00 or 205cccc0. This component is defined by

$$Y = \int_0^t \left(\frac{SV_1 - Y}{A_1} \right) dt$$

or, in Laplace transform notation,

$$Y(s) = \frac{S}{1 + A_1 s} V_1(s) .$$

If the control variable is initialized,

$$Y(T_0) = SV_1(t_0).$$

If the initialization flag is set on and if the initial values of Y and V_1 satisfy a specified relationship, Y remains constant as long as V_1 retains its initial value.

W1(R)   Lag time, A_1 (s).

W2(A)   Alphanumeric name of the variable request code for V_1.

W3(I)   Integer name of the variable request code for V_1.

A14.3.16   Lead-Lag Component

This component is indicated by LEAD-LAG in Word 2 of Card 205ccc00 or 205cccc0. The component is defined by

$$Y = \frac{A_1 S V_i}{A_2} + \int_0^t \left(\frac{S V_1 - Y}{A_2} \right) dt$$

or, in Laplace transform notation,

$$Y(s) = S \frac{1 + A_1 s}{1 + A_2 s} V_i(s) .$$

If the control variable is initialized,

$$Y(t_0) = S V_1(t_0).$$

If the initialization flag is set on and if the initial values of Y and V_1 satisfy a specified relationship, Y remains constant as long as V_1 retains its initial value.

W1(R)   Lead time, A_1 (s).

W2(R)   Lag time, A_1 (s).

W3(A)   Alphanumeric name of the variable request code for V_1.

W4(I)   Integer name of the variable request code for V_1.

A14.3.17   Constant Component

Cards 205ccc01 through 205ccc09 or 205cccc1 through 205cccc9 are not entered. The quantity in Word 3 of Card 205ccc00 or 205cccc0 is the constant value used for this component.

A14.3.18   Shaft Component

This component is indicated by SHAFT in Word 2 of Card 205ccc00 or 205cccc0. A GENERATR component may optionally be associated with a SHAFT component. The SHAFT component advances the rotational velocity equation

$$\sum_i I_i \frac{d\omega}{dt} = \sum_i \tau_i - \sum_i f_i \omega + \tau_c$$

where I_i is the moment of inertia of component i, ω is rotational velocity, τ_i is torque of component i, f_i is the friction factor of component i, and τ_c is an optional torque from a control component. The summations include the shaft as well as the pump, turbine, and generator components that are connected to the shaft.

The SHAFT control component differs somewhat from other control components. The scale factor on Card 205ccc00 or 205cccc0 must be 1.0. The initial value and optional minimum and maximum values have units (rad/s, rev/min), and British-SI units conversion are applied to these quantities. The output of the SHAFT in minor and major edits is in the requested units. Card number ranges are restricted so that

both data to complete the SHAFT component description and optional data to describe a generator can be entered. Units conversion is applied to the following cards.

A14.3.18.1   Card 205ccc01 through 205ccc05 or 205cccc1 through 205cccc5, Shaft Description Card.

W1(I)   Torque control variable number. If zero, there is no contribution to torque from the control system. If nonzero, the control variable with this number is assumed to be a torque and is added to the torques from the other components attached to the shaft. The torque must be in SI units.

W2(R)   Shaft moment of inertia, I_i (kg$\cdot$m^2, lb$\cdot$ft^2).

W3(R)   Friction factor for the shaft, f_i (N$\cdot$m$\cdot$s, lb$_f$$\cdot$ft$\cdot$s).

W4(A)   Type of attached component. Enter either TURBINE, PUMP, or GENERATR.

W5(I)   Component number. This is the hydrodynamic component number for a TURBINE or PUMP, or the control variable number for this SHAFT component if GENERATR.

Additional two-word pairs may be entered to attach additional components to the shaft, up to a total of ten components. Only one generator, the one which is defined as part of this SHAFT component, may be attached.

A14.3.18.2   Card 205ccc06 or 205cccc6, Generator Description Card. Each SHAFT component may optionally define an associated GENERATR component.

W1(R)   Initial rotational velocity (rad/s, rev/min).

W2(R)   Synchronous rotational velocity (rad/s, rev/min).

W3(R)   Moment of inertia, I_i (kg$\cdot$m^2, lb$\cdot$ft^2).

W4(R)   Friction factor, f_i (N$\cdot$m$\cdot$s, lb$_f$$\cdot$ft$\cdot$s).

W5(I)   Generator trip number. When the trip is false, the generator is connected to an electrical distribution system and rotational velocity is forced to the synchronous speed. When the trip is true, the generator is not connected to an electrical system and the generator and shaft rotational velocity is computed from the rotational velocity equation.

W6(I)   Generator disconnect trip number. If zero, the generator is always connected to the shaft. If nonzero, the generator is connected to the shaft when the trip is false and disconnected when the trip is true.

A14.3.19 PUMPCTL Component

This component is specified when using the self-initialization option and loop flow control is desired, but it is not limited to that use. For each PUMPCTL component enter:

W1(A)   Alphanumeric name of setpoint variable.

W2(I)   Parameter part of setpoint variable.

W3(A)   Alphanumeric name of sensed variable.

W4(I)   Parameter part of sensed variable.

W5(R)   Scale factor(s) applied to sensed and setpoint values, S_i. Must be nonzero.

W6(R)   Integral name time constant, T_2 (s).

W7(R)   Proportional part time constant, T_1 (s).

Standard use of PUMPCTL controller require the following interpretation of the input data. W1 and W2 contain CNTRLVAR and ccc (or cccc), respectively, where ccc (or cccc) is a CONSTANT type control element containing the desired (setpoint) flow rate. W3 is MFLOWJ, and W4 is the junction number at which the flow is to be sensed and compared to the setpoint. W5 is the S_i value used to divide the difference between the desired (setpoint) and sensed flow rate to produce the error signal E_1. E_1 must be initially zero if it is intended to have the controller output remain constant as long as the input quantities remain constant. W6 and W7 are the T_2 and T_1 values, respectively. All variables having units must be in SI units.

A14.3.20 STEAMCTL Component

This component is specified when using the self-initialization option to control steam flow from one or more steam generators, but it is not limited to that use. For each STEAMCTL component enter:

W1(A)   Alphanumeric name of setpoint variable.

W2(I)   Parameter part of setpoint variable.

W3(A)   Alphanumeric name of sensed variable.

W4(I)   Parameter part of sensed variable.

W5(R)   Scale factor(s) applied to sensed and setpoint values, S_i. Must be nonzero.

W6(R)   Integral name time constant, T_4 (s).

W7(R)   Proportional part time constant, T_4 (s).

Standard use of the STEAMCTL controller requires the following interpretation of the input data. W1 and W2 would contain CNTRLVAR and ccc (or cccc), respectively, where ccc (or cccc) is a CONSTANT type control element. This constant would be the desired (setpoint) cold leg temperature (for suboptions A and B) or secondary pressure (suboptions C and D). W3 would be TEMPF (for suboptions A and B) or P (for suboptions C and D), and W4 would be the volume number where the temperature (suboptions A and B) or pressure (suboptions C and D) is sensed. W5 is the S_j value used to divide the difference between the desired (setpoint) and sensed temperature (suboptions A and B) or pressure (suboptions C and D) to produce the error signal E_2. E_2 must be initially zero if it is intended to have the controller output remain constant as long as the input quantities remain constant. W6 and W7 are the T_4 and T_3 values respectively. All variables having units must be in SI units.

A14.3.21   FEEDCTL Component

This component is specified when using the self-initialization option to control feedwater flow to a steam generator, but it is not limited to that use. For each FEEDCTL component enter:

W1(A)   Alphanumeric name of first setpoint variable.

W2(I)   Parameter part of first setpoint variable.

W3(A)   Alphanumeric name of sensed variable to be compared with first setpoint.

W4(I)   Parameter part of sensed variable to be compared with first setpoint.

W5(R)   Scale factor applied to sensed and setpoint values (first setpoint), S_k. Must be nonzero.

W6(A)   Alphanumeric name of second setpoint variable.

W7(I)   Parameter part of second setpoint variable.

W8(A)   Alphanumeric name of sensed variable to be compared with second setpoint.

W9(I)   Parameter part of sensed variable to be compared with second setpoint.

W10(R)   Scale factor applied to sensed and setpoint values (second setpoint), S_m. Must be nonzero.

W11(R)   Integral name time constant, T_6 (s).

W12(R)   Proportional part time constant, T_5 (s).

Standard use of the FEEDCTL controller requires the following interpretation of the input data. W1 and W2 contain CNTRLVAR and ccc (or cccc), respectively, where ccc (or cccc) is a CONSTANT type control element. This constant would be the desired (setpoint) steam generator secondary side water level. The latter may be expressed alternatively as a desired secondary coolant mass or as a differential pressure measured between two locations in the steam generator downcomer. W3 and W4 would contain CNTRLVAR and ccc (or cccc), respectively, where ccc (or cccc) is the number of the control component that describes the summing algorithm to compute the sensed variable (e.g., collapsed water level may be

computed by summing the product of VOIDF and volume length over the control volumes in the riser section). W5 is the S_k value used to divide the difference between the desired (setpoint) and sensed water level to produce the first portion of the error signal E_3. W6 is MFLOWJ, and W7 is the junction number of the steam exit junction from the steam generator. W8 is MFLOWJ, and W9 is the junction number of the feedwater inlet junction. W10 is the S_m value used to divide the difference between the sensed steam flow and sensed feedwater flow to produce the second portion of the error signal E_3. E_3 must be initially zero if it is intended to have the controller output remain constant as long as the input quantities remain constant. W11 and W12 are the T_6 and T_5 values, respectively. All variables having units must be in SI units.

A15 CARDS 1001 THROUGH 1999, STRIP REQUEST DATA

These cards are required only in STRIP-type problems. One or more cards are entered, each card containing one variable request. Card numbers need not be consecutive. Variables are ordered on the STRIPF file in the order of increasing card numbers. If an incorrect variable request code is entered, the value will be 0.0. It is not flagged as an input error, since at some later time in the transient, a renodalization may result in the variable request code becoming correct.

W1(A)   Alphanumeric part of the variable request code.

W2(I)   Integer part of the variable request code.

A16 CARDS 1001 THROUGH 1999, COMPARE DUMP FILES CONTROL DATA

These cards are required only in CMPCOMS problems. One or more cards are entered, each card containing one request to compare dump blocks on the files specified with the -A and -B options on the command line. Card numbers need not be consecutive.

W1(I)   Dump file number from file specified on -A command line option.

W2(I)   Dump file number from file specified on -B command line option.

The values in Words 1 and 2 on a succeeding card must be greater than the values on the preceding card. The values in Words 1 and 2 are the advancement number when the dump block was written. This information is written as a line in the printed output of the run writing the dump file. The form of the line is, "---Dmpcom no. nnn written, block no. mmm on unit u---," where nnn is the advancement count number, mmm is the count of the number of blocks written, and u is A or B indicating the file specified by the -A or -B option.

A17 RELAP5-BASED CODE OPERATING PROCEDURES

When operating on Unix systems, the RELAP5-based program can interpret a Unix-style command line. The command line below is written with all of the allowed options (prefixed by a minus sign), and each option is followed by its default value.

relap5.x -f ftb1 -i indta -o outdta -p plotfl -r rstplt -s stripf -j jbinfo \

-n null   -c cdffile -a coupfl -X -C 0 -A dumpfil1 -B dumpfil2 \

-w tpfh2o -d tpfd2o

If an option and its parameter are not entered, the default is used. With the exception of the X option, an option character must always be followed with a file name, and an option may not be repeated. The f option specifies a scratch word addressable file used only on CRAY versions. This file is a word addressable file, and the I/O is done by CRAY library subroutines that have successfully resisted external open and close statements. This file is small and can fit in most directories. This file should be removed after execution, but no error occurs in subsequent calculations if it is not removed. The file indta contains input data, outdta contains printed output, plotfl contains plotter information, rstplt is the restart plot file, and stripf is the strip file. The files dumpfil1 and dumpfil2 are files used to dump common and dynamic blocks for debugging purposes. The files beginning with tpf (e.g., tpfh2o) are thermodynamic property files where the characters following the tpf are chemical names of the material. The RELAP5 code uses only the light and heavy water (h_2o and d_2o) materials. The file jbinfo is an optional file created by the user who wishes to place some additional information on his output file (such as a listing of the control cards used to run the job). The indta file must be available and the outdta file must not exist, or else a diagnostic message followed by immediate termination will follow. The rstplt must not exist for a NEW problem and must exist for other type problems. The dumpfil1 and dumpfil2 must not exist for the run that creates them and must exist for the CMPCOMS run. Most of the other options are for operation with the Nuclear Plant Analyzer (NPA).

The command line capability eliminates the need to have all files needed for execution in the same directory or to copy/rename files to match the default names. For example, the command:
relap5.x -i myprob.i -o /usr/tmp/rjw/myprob.o \

-r /usr/tmp/rjw/myprob.r -w /u2/rjw/relap5/tpfh2o

takes the executable file and input file from the current directory, uses a temporary disk for the output and restart-plot files, and uses a water property file from a different directory.

For operating systems other than UNIX, the default file names must be used.

APPENDIX B

EXAMPLE OF A DIAGNOSTIC EDIT

FIGURES

APPENDIX B--EXAMPLE OF A DIAGNOSTIC EDIT

This appendix contains an example (**Figure B0.0-1**) of a diagnostic edit for one time step using the semi-implicit scheme for the case when HELP = 3. As can be seen from the figure, this edit can be quite lengthy. As Section 2 of Volume I of this manual indicates, there are many subroutines called from the main hydrodynamic subroutine HYDRO and the main heat transfer/conduction subroutine HTADV. The diagnostic edit prints out information for most of the subroutines called by these two subroutines In addition, the particular ones printed will vary, depending on whether the time step is repeated, if bad donoring occurs, if the choking model is turned on, whether heat structures are present or not, whether the heat time advancement is different from the hydrodynamic time advancement, etc. For the example presented here, the time step is not a repeated time step, a heat transfer calculation occurs, and a choking diagnostic edit occurs. In order to save space in the appendix, only the first 3 heat structures, the first 3 volumes, and the first 2 junctions are shown.

Each subroutine section of the edit (except heat transfer) begins with a line of pound signs (###...). The next line lists the name of the subroutine, the label DIAGNOSTIC PRINTOUT, the simulated time (TIMEHY), the time step size (DT), the total attempted advancements (NCOUNT), and the value of the variables HLEP, SUCCES, and FAIL. HELP is explained in Section 8 of this manual. SUCCES is a code variable that indicates if a time step is successful (SUCCES=0 means successful, SUCCES=1 or 2 means unsuccessful). FAIL is a code variable that is normally false (F) until the code fails, and then it becomes true (T).

The order of the subroutines in the diagnostic edit printed in **Figure B0.0-1** is as follows:

Heat transfer subroutines (HTRC1 plus appropriate correlation subroutines.)

VOLVEL

PHANTV

PHANTJ

FWDRAG

VEXPLT

JCHOKE

JPROP

PRESEQ

SYSSOL

JPROP

VFINL

EQFINL

STATE

MASS ERR

JPROP

VLVELA

MS ERR T

The particular quantities printed out in each subroutine will not be presented here. Most of the tables are grouped by volumes and junctions, and they usually begin with either the volume number (VOLNO) or the junction number (JUNNO). The definition of many of these volume and junction terms are listed in the comment common blocks VOLDATC and JUNDATC in RELAP5. A copy of these blocks is contained in **Figure B0.0-2** and **Figure B0.0-3** as an aid to understanding this diagnostic edit. Many of the other quantities printed out are calculated only within that particular subroutine, and they are printed because it was felt they were important in debugging that subroutine.

```
o  htrc1 initial :   id =      30001   volno =    3010000   irwt = 0
      tw         htdiam       htsa         p              tsatt          satt          voidg          g              v
      5.016510E+02  7.620002E-02  4.902718E-02  6.405464E+05  4.345595E+02  4.345595E+02  9.451944E-01  2.404556E+01  9.339683E-04
      tempf       tempg
      4.356360E+02  4.341691E+02
  In chfcal
    CHF debug printout, ncount, volno, time       509    3010000 5.00000E-01
    Passed in and calculated quantities, both aqueous and nonaqueous
    p, pm, g, ga, gabs, gab, rf/rg, rfa, rfna
    6.40546E+05 6.40546E-01 2.40456E+01 2.40456E+01 2.40456E+01 2.40456E+01 0.00000E+00 0.00000E+00 0.00000E+00
    rga, rgna, hfga, hfgp, siga, sigma, x, diamv, aqua
    0.00000E+00 0.00000E+00 2.07619E+06 2.07619E+06 4.62893E-02 4.62893E-02 2.27550E-01 7.62000E-02 1.00000E+00
            p,g,x,ip,ig,ix= 0.640546E+06 0.240456E+02 0.227550E+00    6    3   13
            k1,k2,k3,k4,k5,k6,k7,k8= 0.79000    1.0000    1.0000    1.2009    1.0000    0.00000E+00  1.0000    1.0000
      chf =  0.000000E+00    chfmul=  0.000    hfgp,rhf,rhg,sigma,aqua =  0.207619E+07   904.809        3.37673     0.462893E-01  1.00000
      prednb - thconf       viscf       csubpf      sigma          tw-tsatt      rhof        rhog         hfgp
               6.823210E-01  1.674918E-04  4.344334E+03  4.628926E-02  6.709156E+01  9.048091E+02  3.376729E+00  2.076186E+06
      dittus - tf           thcons      viscs       cps
               4.356360E+02  6.823210E-01  1.674918E-04  4.344334E+03
               htcoef       qfluxo      mode        hlam          hnat          hturb
               7.595107E+02  5.013909E+04     2  3.904093E+01  7.595107E+02  2.920891E+02
      prednb   hmac         f           hmic        sf            htcoef        qfluxo        chf
               5.414682E+03  7.129171E+00  8.293794E+04  3.813658E-01  8.835262E-04  5.921886E+06  0.000000E+00
      pstdnb - thcons       viscs       csubpg      rhof          rhog          sigma
               3.372731E-02  1.575588E-05  2.414047E+03  9.048091E+02  3.376729E+00  4.628926E-02
      dittus - tf           thcons      viscs       cps
               4.345595E+02  3.372731E-02  1.575588E-05  2.414047E+03
               htcoef       qfluxo      mode        hlam          hnat          hturb
               3.750358E+01  2.516174E+03     9  1.929804E+00  9.340970E+00  3.750358E+01
      pstdnb -htbf         htbg        qtfbf       qtfbg         hfb           hv           qfbf          qfbg
               0.000000E+00  3.580729E+01  0.000000E+00  2.402367E+03  5.111356E+00  3.750358E+01  3.429289E+02  2.516174E+03
               htcoef       qfluxo      qfb         qtb
               4.261493E+01  2.859102E+03  2.859102E+03  2.402367E+03
    suboil final output :
      gamw         gammul      qffo        peclet        numod         enmin         encrit        sathfp
      8.670467E-03  2.528357E-05  3.429289E+02  1.166607E+04  3.829750E+01  6.817137E+05  6.813481E+05  6.817137E+05
    htrc1 final output :
      mode    chf          htcoef      htcf        htcg          qfluxo        qffo          qfgo
         8    0.000000E+00  4.261493E+01  5.111356E+00  3.750358E+01  2.859102E+03  3.429289E+02  2.516174E+03
              gamw         fstrt       quala       quale         dtsat         sathrp
              8.670467E-03  1.000000E+00  0.000000E+00  2.275499E-01  6.709156E+01  6.817137E+05
o  htrc1 initial :   id =      30002   volno =    3020000   irwt = 0
      tw         htdiam       htsa         p              tsatt          satt          voidg          g              v
      5.011370E+02  7.620002E-02  4.902718E-02  6.404966E+05  4.345564E+02  4.345564E+02  9.317909E-01  7.940285E+01  9.339683E-04
      tempf       tempg
      4.354654E+02  4.342100E+02
  In chfcal
    CHF debug printout, ncount, volno, time       509    3020000 5.00000E-01
    Passed in and calculated quantities, both aqueous and nonaqueous
    p, pm, g, ga, gabs, gab, rf/rg, rfa, rfna
    6.40497E+05 6.40497E-01 7.94029E+01 7.94029E+01 7.94029E+01 7.94029E+01 0.00000E+00 0.00000E+00 0.00000E+00
    rga, rgna, hfga, hfgp, siga, sigma, x, diamv, aqua
    0.00000E+00 0.00000E+00 2.07620E+06 2.07620E+06 4.62899E-02 4.62899E-02 2.18124E-01 7.62000E-02 1.00000E+00
            p,g,x,ip,ig,ix= 0.640497E+06 0.794029E+02 0.218124E+00    6    4   13
            k1,k2,k3,k4,k5,k6,k7,k8= 0.79000    1.0000    1.0000    1.2006    1.0000    0.00000E+00  1.0000    1.0000
```

```
   cht =  0.000000E+00      chfmul=  0.000     htgp,rhf,rhg,sigma,aqua =  0.207620E+07   904.978        3.37604       0.462899E-01  1.00000
     prednb - thconf        viscf         csubpf        sigma          tw-tsatt      rhof          rhog          hfgp
              6.823593E-01  1.674952E-04  4.344325E+03  4.628992E-02  6.658064E+01  9.049778E+02  3.376043E+00  2.076196E+06
     dittus - tf            thcons        viscs         cps
              4.354654E+02  6.823593E-01  1.674952E-04  4.344325E+03
              htcoef        qfluxo        mode          hlam          hnat          hturb
              7.685994E+02  5.047516E+04    2   3.904312E+01  7.586511E+02  7.685994E+02
     prednb   hmac          f             hmic          sf            htcoef        qfluxo        chf
              5.257292E+03  6.840094E+00  3.042331E+04  1.414360E-01  3.568060E+04  2.370858E+06  0.000000E+00
     pstdnb - thcons        viscs         csubpg        rhof          rhog          sigma
              3.370634E-02  1.574475E-05  2.414020E+03  9.049778E+02  3.376043E+00  4.628992E-02
     dittus - tf            thcons        viscs         cps
              4.345564E+02  3.370634E-02  1.574475E-05  2.414020E+03
              htcoef        qfluxo        mode          hlam          hnat          hturb
              9.367075E+01  6.236659E+03    9   1.928604E+00  9.322819E+00  9.367075E+01
     pstdnb -htbf           htbg          qt.fbf        qt.fbg        hfb           hv            qfbf          qfbg
              0.000000E+00  8.553882E+01  0.000000E+00  5.695230E+03  7.895455E+00  9.367075E+01  5.256845E+02  6.236659E+03
              htcoef        qfluxo        qfb           qtb
              1.015662E+02  6.762343E+03  6.762343E+03  5.695230E+03
   suboil final output :
    gamw          gammul        qffo          peclet        numod         enmin         encrit        sathfp
   1.329112E-02  2.528345E-05  5.256845E+02  3.852126E+04  5.870393E+01  6.817004E+05  6.811399E+05  6.817004E+05
   htrcl final output :
    mode    chf           htcoef        htcf          htcg          qfluxo        qffo          qfgo
       8    0.000000E+00  1.015662E+02  7.895455E+00  9.367075E+01  6.762343E+03  5.256845E+02  6.236659E+03
            gamw          fstrt         quala         quale         dtsat         sathfp
            1.329112E-02  1.000000E+00  0.000000E+00  2.181238E-01  6.658064E+01  6.817004E+05
o  htrcl initial :    id =   30003   volno =   3030000   irwt =  0
    tw            htdiam        htsa          p             tsatt         satt          voidg         g             v
    4.859351E+02  7.620002E-02  4.902718E-02  6.403597E+05  4.345479E+02  4.345479E+02  9.312849E-01  1.414440E+02  9.339683E-04
    tempf         tempg
    4.351487E+02  4.342624E+02
In chfcal
   CHF debug printout, ncount, volno, time         509     3030000 5.00000E-01
   Passed in and calculated quantities, both aqueous and nonaqueous
   p, pm, g, ga, gabs, gab, rf/rg, rfa, rfna
   6.40360E+05 6.40360E-01 1.41444E+02 1.41444E+02 1 41444E+02 1.41444E+02 0.00000E+00 0.00000E+00 0.00000E+00
   rga, rgna, hfga, hfgp, siga, sigma, x, diamv, aqua
   0.00000E+00 0.00000E+00 2.07622E+06 2.07622E+06 4.62917E-02 4.62917E-02 2.12822E-01 7.62000E-02 1.00000E+00
        p,g,x,ip,ig,ix= 0.640360E+06 0.141444E+03 0.212822E+00    6    5   13
        k1,k2,k3,k4,k5,k6,k7,k8=  0.79000       1.0000        1.0000        1.2004        1.0000        0.18943       1.0000        1.0000
   chf =    404743.        chfmul=  0.180     hfgp,rhf,rhg,sigma,aqua =  0.207622E+07   905.291        3.37476       0.462917E-01  1.00000
     prednb - thconf        viscf         csubpf        sigma          tw-tsatt      rhof          rhog          hfgp
              6.824303E-01  1.675045E-04  4.344300E+03  4.629173E-02  5.138721E+01  9.052910E+02  3.374755E+00  2.076224E+06
     dittus - tf            thcons        viscs         cps
              4.351487E+02  6.824303E-01  1.675045E-04  4.344300E+03
              htcoef        qfluxo        mode          hlam          hnat          hturb
              1.226662E+03  6.229773E+04    2   3.904718E+01  7.116532E+02  1.226662E+03
     prednb   hmac          f             hmic          sf            htcoef        qfluxo        chf
              8.224450E+03  6.704742E+00  1.422551E+04  9.506101E-02  2.244996E+04  1.148699E+06  4.047429E+05
     pstdnb - thcons        viscs         csubpg        rhof          rhog          sigma
              3.311139E-02  1.541671E-05  2.413948E+03  9.052910E+02  3.374755E+00  4.629173E-02
     dittus - tf            chcons        viscs         cps
              4.345479E+02  3.311139E-02  1.541671E-05  2.413948E+03
              htcoef        qfluxo        mode          hlam          hnat          hturb
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

B-5

```
          1.454092E+02  7.472172E+03     9  1.894562E+00  8.752997E+00  1.454092E+02
 pstdnb -htbf          htbg           qtfbf        qt.fbg        hfb           hv            qfbf          qfbg
          1.583266E+03  1.161797E+02  8.135961E+04  5.970149E+03  8.460500E+00  1.454092E+02  4.347615E+02  7.472172E+03
          htcoef        qfluxo        qfb           qtb
          1.699446E+03  8.732976E+04  7.906933E+03  8.732976E+04
  suboil final output :
     gamw        gammul          qffo          peclet         numod         enmin         encrit        sathfp
 2.057025E+00  2.528312E-05  8.135961E+04  6.861217E+04  9.084597E+03  6.816637E+05  5.949248E+05  6.816637E+05
  htrcl final output :
    mode       chf           htcoef        htcf          htcg          qfluxo        qffo          qfgo
     6     4.047429E+05  1.699446E+03  1.583266E+03  1.161797E+02  8.732976E+04  8.135961E+04  5.970149E+03
          gamw          fstrt         quala         quale         dtsat         sathfp
          2.057025E+00  8.105669E-01  0.000000E+00  2.128222E-01  5.138721E+01  6.816637E+05
0###############################################################################################################################
     volvel Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Volume inlet and outlet terms
 ===============================================================================================================================
        volno(i)          invcnt(i)
        avol(i)     iiflag   loop jx   junno(jx)  ivf ajun(jx)     voidfj(jx)    rhofj(jx)    velfjo*ivf   arat(jx)     cvelf(ivr)
                                                      athrot(jx)   voidgj(jx)    rhogj(jx)    velgjo*ivf   arat(jx+1)   cvelg(ivr)
 ===============================================================================================================================
        003010000            1
        4.56037E-03
 *               outlet   1       003010000   1  4.56037E-03  5.48056E-02   904.81       0.74716      1.0000       0.00000E+00
                                                  1.0000       0.94519       3.3767       3.4585       1.0000       0.00000E+00
        003020000            2
        4.56037E-03
 *               inlet    1       003010000   1  4.56037E-03  5.48056E-02   904.81       0.74716      1.0000       0.00000E+00
                                                  1.0000       0.94519       3.3767       3.4585       1.0000       0.00000E+00
                 outlet   2       003020000   1  4.56037E-03  6.82091E-02   904.98       1.4113       1.0000       0.00000E+00
                                                  1.0000       0.93179       3.3760       7.5009       1.0000       0.00000E+00
        003030000            2
        4.56037E-03
 *               inlet    1       003020000   1  4.56037E-03  6.82091E-02   904.98       1.4113       1.0000       0.00000E+00
                                                  1.0000       0.93179       3.3760       7.5009       1.0000       0.00000E+00
                 outlet   2       003030000   1  4.56037E-03  6.87151E-02   905.29       2.1800       1.0000       0.00000E+00
                                                  1.0000       0.93128       3.3748       11.633       1.0000       0.00000E+00
0Volume average terms
 ===============================================================================================================================
        volno(i)   sumvfx(ix)   difvfx(ix)   vvfx(ix)     vvfx(ix+1)   vfa(ix)      vfa(ix+1)    vrhof(ix)    vrhof(ix+1)  areav(ix)
                   sumvgx(ix)   difvgx(ix)   vvgx(ix)     vvgx(ix+1)   vga(ix)      vga(ix+1)    vrhog(ix)    vrhog(ix+1)  areav(ix+1)
 ===============================================================================================================================
        003010000  0.74716      -0.55825     0.00000E+00  0.74716      0.00000E+00  0.16897      0.00000E+00  0.22614      0.00000E+00
                   3.4585       -11.961      0.00000E+00  3.4585       0.00000E+00  5.03391E-02  0.00000E+00  1.45552E-02  4.56037E-03
        003020000  1.1155       -0.41083     0.74716      1.4113       0.16897      0.39729      0.22614      0.28150      4.56037E-03
                   5.4651       -10.966      3.4585       7.5009       5.03391E-02  0.10761      1.45552E-02  1.43459E-02  4.56037E-03
        003030000  1.7971       -0.69333     1.4113       2.1800       0.39729      0.61843      0.28150      0.28369      4.56037E-03
                   9.5662       -19.757      7.5009       11.633       0.10761      0.16674      1.43459E-02  1.43326E-02  4.56037E-03
0###############################################################################################################################
     phantv Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Volume mass transfer terms
 ===============================================================================================================================
   i    volno(i)   hif(i)       hifo(i)      hifc         hifcl        dtsf         dtsfm        dtsfsp       dtsfsb       xliqh
        vctrl(i)   hig(i)       higo(i)      higc         higcl        dtsg         higsub       dtsgms       dtsgm        xvaph
        nmap       fluxm        avelf        avelfg       rhocpf       hfg          term         term1        rvcrit(ix)   scrach
```

```
========================================================================================================================
    1 003010000  6.31082E+07  6.33475E+07  4.91436E+07  1.0000     -1.0766      328.10       1.0000     0.00000E+00  6.86391E+05
            0  8.86346E+06  8.90658E+06  6.43145E+06  1.0000      0.39032    4.38413E+05  0.00000E+00  1.0000     2.75790E+06
            2    48.089       0.74716      2.7113     3.93079E+06  2.07619E+06  3.11365E-02   24.794     0.19410     0.21604
    2 003020000  9.27300E+07  9.31524E+07  6.86744E+07  1.0000     -0.90903      269.57       1.0000     0.00000E+00  6.85650E+05
            0  9.26113E+06  9.30843E+06  6.61368E+06  1.0000     -0.34639    3.86389E+05  0.00000E+00  1.0000     2.75790E+06
            2    86.047       1.1155       4.3496     3.93152E+06  2.07620E+06  3.91431E-02   30.864     0.33011     0.20411
    3 003030000  1.38855E+08  1.40346E+08  4.73614E+07  1.0000     -0.60080      163.25       1.0000     0.00000E+00  6.84274E+05
            0  1.13352E+07  1.13291E+07  6.08563E+06  1.0000      0.28548    3.15850E+05  0.00000E+00  1.0000     2.75789E+06
            2   0.58148       1.7971       7.7691     3.93286E+06  2.07622E+06  4.07490E-02   31.104     0.59063     0.18786
0Final volume mass transfer terms
========================================================================================================================
 i   volno      tempf        tempg        tempf-satt   tempg-satt   hif          hig          gammaw       qwf          qwg
========================================================================================================================
    1 003010000  435.64       434.17       1.0766      -0.39032    6.31082E+07  8.86346E+06  8.67051E-03   16.813      123.36
                                                                   4.91436E+07  6.43145E+06
    2 003020000  435.47       434.21       0.90903     -0.34639    9.27300E+07  9.26113E+06  1.32914E-02   25.773      305.77
                                                                   6.86744E+07  6.61368E+06
    3 003030000  435.15       434.26       0.60080     -0.28548    1.38855E+08  1.12352E+07  2.0646     .  4003.5      293.77
                                                                   6.85443E+07  6.47971E+06
0Other volume terms
========================================================================================================================
 i   volno(i)   viscf(i)     thconf(i)    voidf(i)     fwalf(i)     diamv(i)     costhe(ix)   fidxup(ix)   flomap(ix)   fwfxaf(ix)
     imap(i)    viscg(i)     thcong(i)    voidg(i)     fwalg(i)     dstar(ix)    rvcrit(ix)                pfinrg(ix)   fwfxag(ix)
========================================================================================================================
    1 003010000  1.67492E-04  0.68232      5.48056E-02  5.48056E-02  7.62000E-02 -0.79283      0.00000E+00              12  0.20861
      3162114    1.43039E-05  3.14723E-02  0.94519      0.94519       33.300      0.19410                  0.00000E+00  0.79139
    2 003020000  1.67495E-04  0.68236      6.82091E-02  6.82091E-02  7.62000E-02 -0.75943      0.00000E+00              12  0.22548
      3162114    1.43038E-05  3.14719E-02  0.93179      0.93179       33.303      0.33011                  0.00000E+00  0.77452
    3 003030000  1.67505E-04  0.68243      6.87151E-02  6.87151E-02  7.62000E-02 -0.75821      0.00000E+00              12  0.27787
      3162114    1.43035E-05  3.14708E-02  0.93128      0.93128       33.308      0.59063                  0.00000E+00  0.72213
0#######################################################################################################################
   phantj Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0junction drag terms
========================================================================================================================
     junno(i)   fij(i)       cOj(i)       fxj(i)       sinbt(ix)    diamj(i)     faaj(i)      ireg(ix)     voidj(i)     avkx(ix)
     jc(i)      fijo(i)      cOjo(i)      fxjo(i)      vgjj(ix)     athrot(i)    jcex(i)      dpstf(ix)    flompj(ix)   avlx(ix)
========================================================================================================================
     003010000  9.90460E-02  1.0000       0.00000E+00  0.00000E+00  7.62000E-02  0.58698               0  0.94519                1.0000
        65536   9.97859E-02  1.0000       0.00000E+00  0.00000E+00  1.0000          1052768 -0.21658               12          1.0000
     003020000  8.99069E-02  1.0000       0.00000E+00  0.00000E+00  7.62000E-02  0.60980               0  0.93179                1.0000
        65536   9.09186E-02  1.0000       0.00000E+00  0.00000E+00  1.0000          1052768 -8.79932E-03            12          1.0000
0#######################################################################################################################
   fwdrag Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Volume terms
========================================================================================================================
     volno(i)   vctrl(i)                  voidf(i)     rhof(i)      viscf(i)     diamv(i)     fwalf(i)
                imap(i)                   voidg(i)     rhog(i)      viscg(i)     roughv(i)    fwalg(i)
                                          fshape(i)    frica(i)     fricb(i)     fricc(i)
========================================================================================================================
     003010000                         0  5.48056E-02  904.81       1.67492E-04  7.62000E-02  2.6663
                               3162114     0.94519      3.3767       1.43039E-05  1.54581E-05  0.17785
                                           1.0000       0.00000E+00  0.00000E+00  0.00000E+00
     003020000                         0  6.82091E-02  904.98       1.67495E-04  7.62000E-02  3.8532
                               3162114     0.93179      3.3760       1.43038E-05  1.54581E-05  0.24982
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

```
                                      1.0000      0.00000E+00  0.00000E+00  0.00000E+00
        003030000              0  6.87151E-02     905.29       1.67505E-04  7.62000E-02  7.2527
                         3162114  0.93128          3.3748       1.43035E-05  1.54581E-05  0.36063
                                      1.0000      0.00000E+00  0.00000E+00  0.00000E+00
0scratch terms, friction factor loop
=====================================================================================================
 nd   volno(i)     sumvfx(l)     fwfafl(l)     reynfl(l)     fwfl(l)      fwfxaf(l)     reynf2(l)     fwf2(l)       pfinrg(l)
              sumvgx(l)     fwfagl(l)     reyngl(l)     fwgl(l)      fwfxag(l)     reyng2(l)     fwy2(l)
              frlmfl(l)     frtrfl(l)     frtbfl(l)     frlmf2(l)    frtrf2(l)     frtbf2(l)
              frlmgl(l)     frtrgl(l)     frtbgl(l)     frlmg2(l)    frtrg2(l)     frtbg2(l)
=====================================================================================================
  0   003010000  0.74716     5.48056E-02  0.00000E+00  0.00000E+00  0.20861       80803.       2.94681E-03  0.00000E+00
              3.4585       0.94519      0.00030E+00  0.00000E+00  0.79139       74304.       5.26698E-02
              0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.0000        1.89062E-02
              0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.0000        1.92434E-02
  0   003020000  1.1155      6.82091E-02  0.00000E+00  0.00000E+00  0.22548       1.38926E+05  4.25777E-03  0.00000E+00
              5.4651       0.93179      0.00000E+00  0.00000E+00  0.77452       1.18247E+05  7.39987E-02
              0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.0000        1.69286E-02
              0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.0000        1.74822E-02
  0   003030000  1.7971      6.87151E-02  0.00000E+00  0.00000E+00  0.27787       1.83026E+05  8.01149E-03  0.00000E+00
              9.5662       0.93128      0.00000E+00  0.00000E+00  0.72213       2.21799E+05  0.10686
              0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.0000        1.60433E-02
              0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.0000        1.54692E-02
0Wall friction terms, phase apportioning loop
=====================================================================================================
 volno(i)    fwalf(i)                   reynfl(l)    dpdxfx(l)    zambda(l)     tpdpdx(l)
             fwalg(i)      gfwabs(l)    reyngl(l)    dpdxgx(l)    ctermx(l)     ratdpf(l)
             frimfl(l)     frtrfl(l)    frtbfl(l)    frlmgi(l)    frtrgl(l)     frtbgl(l)
=====================================================================================================
 003010000   31.946                     16856.       4.10283E-02  0.28565       4.7608
             2.1309        48.089       58804.       0.73011      23.052        11.981
             0.00000E+00   1.0000       2.70425E-02  0.00000E+00  1.0000        2.02335E-02
 003020000   52.061                     31325.       0.12210      0.28548       11.661
             3.3754        86.047       91585.       1.6125       22.372        13.511
             0.00000E+00   1.0000       2.33064E-02  0.00000E+00  1.0000        1.84189E-02
 003030000   83.906                     50857.       0.28835      0.28517       29.063
             4.1721        141.86       1.60168E+05  4.4094       21.608        11.569
             0.00000E+00   1.0000       2.08865E-02  0.00000E+00  1.0000        1.64623E-02
0Wall friction terms, heated wall effect
=====================================================================================================

0*********************************************************************************************************************************
  vexplt Diagnostic printout, timehy =   0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Sum and difference terms
=====================================================================================================
    junno(i)  sumf      sumg      sumold    diff      difg      difold    avrf      avrg
=====================================================================================================
    003010000  11.400   0.65675   10.755    0.34342  -0.34344  -0.93043   55.658    3.1687
    003020000  12.697   0.65277   22.742    0.38092  -0.38094  -2.3173    61.967    3.1443
0volume terms
=====================================================================================================
    volno(i)  dl(i)     voidf(i)  rhof(i)   fwalf(i)  velf(i)   difvfx(ix) sourcf(ix) sourcm(ix) gamas(i)
              hydzc(i)  voidg(i)  rhog(i)   fwalg(i)  velg(i)   difvgx(ix) sourcg(ix) sourca(ix) enths(i)
=====================================================================================================
    003010000  0.20480  5.48056E-02  904.81   31.946   0.74716  -0.55825   -83.415   5.81609E-05  0.00000E+00
               0.00000E+00  0.94519  3.3767   2.1309   3.4585   -11.961    83.556    0.00000E+00  0.00000E+00
```

```
   003020000  0.20480       6.82091E-02    904.98         52.061        1.1155        -0.41083      -103.79        7.31168E-05   0.00000E+00
              0.00000E+00   0.93179        3.3760         3.3754        5.4651        -10.966       104.13         0.00000E+00   0.00000E+00
   003030000  0.20480       6.87151E-02    905.29         83.906        1.7971        -0.69333      -103.95        7.61165E-05   0.00000E+00
              0.00000E+00   0.93128        3.3748         4.1721        9.5662        -19.757       108.25         0.00000E+00   0.00000E+00
0Junction terms
=================================================================================================================================================
   junno(i)   fij(i)        ajun(i)        arat(i)        fjunf(i)      formfj(i)     velfjo(i)     velgjo(i)      fifj(ix)      vfdpk(ix)
              fidxup(ix)    athrot(i)      arat(i+1)      fjunr(i)      formgj(i)     velfj(i)      velgj(i)       figj(ix)      vgdpk(ix)
=================================================================================================================================================
   003010000  9.90460E-02   4.56037E-03    1.0000         0.00000E+00   0.00000E+00   0.74716       3.4585         1.84127E-02   3.61408E-05
              0.00000E+00   1.0000         1.0000         0.00000E+00   0.00000E+00   0.74449       3.4536         1.84127E-02   8.95301E-04
   003020000  8.99069E-02   4.56037E-03    1.0000         0.00000E+00   0.00000E+00   1.4113        7.5009         3.75312E-02   3.70220E-05
              0.00000E+00   1.0000         1.0000         0.00000E+00   0.00000E+00   1.4061        7.4892         3.75312E-02   8.11824E-04
0###############################################################################################################################################
   jprop Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =          509, help =  3, lsuces =  0, fail = F
0Junction donored properties, ivrev =  1
=================================================================================================================================================
   junno(i)   velfj(i)      voidfj(i)      rhofj(i)       qualaj(i)     ufj(i)        jc(i)                        volno(k)      voidgo(k)
              velgj(i)      voidgj(i)      rhogj(i)       voids         ugj(i)        jcex(i)                      volno(l)      voidgo(l)
=================================================================================================================================================
   003010000  0.74449       5.48056E-02    904.81         0.00000E+00   6.85683E+05                  65536        003010000     0.94519
              3.4536        0.94519        3.3767         1.0000        2.56726E+06                  1052768       003020000     0.93179
   003020000  1.4061        6.82091E-02    904.98         0.00000E+00   6.84942E+05                  65536        003020000     0.93179
              7.4892        0.93179        3.3760         1.0000        2.56734E+06                  1052768       003030000     0.93128
0###############################################################################################################################################
   preseq Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =          509, help =  3, lsuces =  0, fail = F
0Volume terms
=================================================================================================================================================
i  volno      po            ufo            ugo            voidgo        qualao        rhof          rhog           sathf         sathg
              drfdp         drfduf         drgdp          drgdug        drgdxa        dtfdp         dtfduf         dtgdp         dtgdug
              dtgdxa        dtdp           dtdug          dtdxa         hif           hig           gammaw         qwf           qwg
=================================================================================================================================================
1  003010000  6.40546E+05   6.85683E+05    2.56726E+06    0.94519       0.00000E+00   904.81        3.2767         6.81714E+05   2.75790E+06
              5.01465E-07  -2.27601E-04    5.24610E-06   -5.37932E-06   0.00000E+00   1.20999E-07   2.30226E-04    3.52149E-05   5.39424E-04
              0.00000E+00   6.18254E-05    0.00000E+00    0.00000E+00   6.31082E+07   8.86346E+06   8.67051E-03    16.813        123.36
2  003020000  6.40497E+05   6.84942E+05    2.56734E+06    0.93179       0.00000E+00   904.98        3.3760         6.81700E+05   2.75790E+06
              5.01690E-07  -2.27682E-04    5.24550E-06   -5.37757E-06   0.00000E+00   1.20950E-07   2.30226E-04    3.52149E-05   5.39430E-04
              0.00000E+00   6.18292E-05    0.00000E+00    0.00000E+00   9.27300E+07   9.26113E+06   1.32914E-02    25.773        305.77
3  003030000  6.40360E+05   6.83566E+05    2.56745E+06    0.93128       0.00000E+00   905.29        3.3748         6.81664E+05   2.75789E+06
              5.02101E-07  -2.27828E-04    5.24469E-06   -5.37466E-06   0.00000E+00   1.20855E-07   2.30228E-04    3.52165E-05   5.39447E-04
              0.00000E+00   6.18397E-05    0.00000E+00    0.00000E+00   1.38855E+08   1.12352E+07   2.0646         4003.5        293.77
0Junction terms
=================================================================================================================================================
   junno(i)   ajun(i)       voidfj(i)      rhofj(i)       ufj(i)        velfjo(i)     velgjo(i)             vfdpk(ix)     vfdpl(ix)
              qualaj(i)     voidgj(i)      rhogj(i)       ugj(i)        velfj(i)      velgj(i)              vgdpk(ix)     vgdpl(ix)
=================================================================================================================================================
   003010000  4.56037E-03   5.48056E-02    904.81         6.85683E+05   0.74716       3.4585                3.61408E-05   3.61408E-05
              0.00000E+00   0.94519        3.3767         2.56726E+06   0.74449       3.4536                8.95301E-04   8.95301E-04
   003020000  4.56037E-03   6.82091E-02    904.98         6.84942E+05   1.4113        7.5009                3.70220E-05   3.70220E-05
              0.00000E+00   0.93179        3.3760         2.56734E+06   1.4061        7.4892                8.11824E-04   8.11824E-04
0Scratch storage volume terms
=================================================================================================================================================
i  volno(i)   coefp         sourcf(ix)     sourcm(ix)     a52(ix)       a54(ix)       resoru(ix)    fracal(ix)     fgrw(ix)      fal(ix)
   sourca     sourcp(is)    sourcg(ix)     a51(ix)        a53(ix)       a55(ix)       resorm(ix)    fracag(ix)     a4(ix)        gal(ix)
=================================================================================================================================================
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

```
1 003010000   3.5213      -83.415     5.81609E-05  0.14896      -1.08748E+05  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00E+00    -5037.1      83.556     0.00000E+00  1.97906E-02  -1.21660E+05  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
1 003020000   5.3498      -103.79     7.31168E-05  0.13383      -95718.       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00E+00    -5037.2      104.13     0.00000E+00  2.04082E-02  -1.09098E+05  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
1 003030000   4.7470      -103.95     7.61165E-05  0.11481      -76670.       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00E+00    -5037.3      108.25     0.00000E+00  2.41167E-02  -92623.       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0############################################################################################################################
    syssol Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Pressure matrix
============================================================================================================================
eq.no. volno    el.no.  coefp    el.no.  coefp    el.no.  coefp    el.no.  coefp    el.no.  coefp    dia.dom.term
============================================================================================================================
  1 003010000    1   3.5213      2  -2.5213
+                                                                                                        1.0000
  2 003020000    1  -2.2958      2   5.3498      3  -2.0540
+                                                                                                        1.00000
  3 003030000    2  -1.8424      3   4.7470      4  -1.9046
+                                                                                                        1.00000
  4 003040000    3  -1.7625      4   4.6387      5  -1.8762
+                                                                                                        1.0000
  5 003050000    4  -1.8671      5   4.8086      6  -1.9415
+                                                                                                        1.00000
  6 003060000    5  -1.9655      6   5.0072      7  -2.0417
+                                                                                                        1.0000
  7 003070000    6  -2.0705      7   5.2225      8  -2.1520
+                                                                                                        1.0000
  8 003080000    7  -2.1856      8   5.4555      9  -2.2699
+                                                                                                        1.0000
  9 003090000    8  -2.3072      9   5.6968     10  -2.3896
+                                                                                                        1.00000
 10 003100000    9  -2.4286     10   5.9334     11  -2.5048
+                                                                                                        1.00000
 11 003110000   10  -2.5434     11   6.1544     12  -2.6110
+                                                                                                        1.0000
 12 003120000   11  -2.6474     12   6.3530     13  -2.7056
+                                                                                                        1.00000
 13 003130000   12  -2.7390     13   6.5272     14  -2.7881
+                                                                                                        1.00000
 14 003140000   13  -2.8182     14   6.6774     15  -2.8592
+                                                                                                        1.0000
 15 003150000   14  -2.8858     15   6.8057     16  -2.9198
+                                                                                                        1.0000
 16 003160000   15  -2.9431     16   6.9144     17  -2.9712
+                                                                                                        1.0000
 17 003170000   16  -2.9912     17   7.0048     18  -3.0136
+                                                                                                        1.0000
 18 003180000   17  -3.0287     18   7.0786     19  -3.0499
+                                                                                                        1.0000
 19 003190000   18  -3.0654     19   7.1417     20  -3.0763
+                                                                                                        1.0000
 20 003200000   19  -3.0709     20   4.1547     21   0.00000E+00
+                                                                                                        1.0838
 21 005010000   21   1.0000
+                                                                                                        1.0000
0Solution array
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

```
===========================================================================================================================
     sourcp(i)     sourcp(i+1)   sourcp(i+2)   sourcp(i+3)   sourcp(i+4)   sourcp(i+5)   sourcp(i+6)   sourcp(i+7)   sourcp(i+8)
===========================================================================================================================
     -5036.2       -5035.9       -5034.8       -5032.5       -5027.1       -5920.9       -5012.3       -5000.5       -4985.0
     -4965.1       -4940.4       -4910.7       -4875.5       -4834.5       -4787.4       -4733.7       -4672.8       -4604.5
     -4529.4       -4443.0        0.00000E+00
OSingularity parameter (if gerr .lt. 0.0, the matrix solution is singular)
gerr =  1.00000E-12
0#########################################################################################################################
     jprop Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
OJunction donored properties, ivrev =  1
===========================================================================================================================
     junno(i)   velfj(i)      voidfj(i)     rhofj(i)      qualaj(i)     ufj(i)        jc(i)                       volno(k)    voidgo(k)
                velgj(i)      voidgj(i)     rhogj(i)      voids         ugj(i)        jcex(i)                     volno(l)    voidgo(l)
===========================================================================================================================
     003010000  0.74448       5.48056E-02   904.81        0.00000E+00   6.85683E+05                   65536        003010000   0.94519
                3.4533        0.94519       3.3767        1.0000        2.56726E+06                  1052768        003020000   0.93179
     003020000  1.4061        6.82091E-02   904.98        0.00000E+00   6.84942E+05                   65536        003020000   0.93179
                7.4883        0.93179       3.3760        1.0000        2.56734E+06                  1052768        003030000   0.93128
0#########################################################################################################################
     vfinl Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
OFinal junction velocities and flows
===========================================================================================================================
     junno(i)   flag        ajun(i)       voidfj(i)     rhofj(i)      velfj(i)      vfdpk(j)      vgdpk(j)      k    p(k)-po(k)
                            mflowj(i)     voidgj(i)     rhogj(i)      velgj(i)      vfdpl(j)      vgdpl(j)      l    p(l)-po(l)
===========================================================================================================================
     003010000              4.56037E-03   5.48056E-02   904.81        0.74448       3.61408E-05   8.95301E-04   1    -5036.2
                            0.21862       0.94519       3.3767        3.4533        3.61408E-05   8.95301E-04   2    -5035.9
     003020000              4.56037E-03   6.82091E-02   904.98        1.4061        3.70220E-05   8.11824E-04   2    -5035.9
                            0.50325       0.93179       3.3760        7.4883        3.70220E-05   8.11824E-04   3    -5034.8
0#########################################################################################################################
     eqfinl Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
OCommon junction data
===========================================================================================================================
     junno      i  ajun(i)       voidfj(i)     rhofj(i)      velfj(i)      ufj(i)        conmf(i)      cond(i)       conm(i)
                   qualaj(i)     voidgj(i)     rhogj(i)      velgj(i)      ugj(i)        conmg(i)
===========================================================================================================================
     003010000  1  4.56037E-03   5.48056E-02   904.81        0.74448       6.85683E+05   1.68358E-04  -1.18094E-04   2.18621E-04
                   0.00000E+00   0.94519       3.3767        3.4533        2.56726E+06   5.02632E-05
     003020000  2  4.56037E-03   6.82091E-02   904.98        1.4061        6.84942E+05   3.95821E-04  -2.88394E-04   5.03247E-04
                   0.00000E+00   0.93179       3.3760        7.4883        2.56734E+06   1.07427E-04
OFrom-to contributions to source terms
===========================================================================================================================
     junno      i        k  scv2(i)       scv3(i)       scv4(i)              l  scv2(i)       scv5(i)       scv6(i)
===========================================================================================================================
     003010000  1        1  0.00000E+00   138.57        115.56               2  0.00000E+00   138.57        115.56
     003020000  2        2  0.00000E+00   296.18        271.39               3  0.00000E+00   296.18        271.39
0#########################################################################################################################
     eqfinl Diagnostic printout, timehy =  0.5000000    , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
OVolume data
===========================================================================================================================
     volno      i  sourcf(i)     sourcm(i)     sorp(i)       po(i)         ugo(i)        ufo(i)        voidgo(i)     qualao(i)     rhom(i)
                   sourcg(i)     sourca(i)     delxa(i)      p(i)          ug(i)         uf(i)         voidg(i)      quala(i)      dotm(i)
===========================================================================================================================
     003010000  1  -198.97       1.76255E-04  -2.18621E-04   6.40546E+05   2.56726E+06   6.85683E+05   0.94519       0.00000E+00   52.546
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

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NUREG/CR-5535-V2

RELAP5/MOD3.2

```
              -55.018   0.00000E+00  0.00000E+00  6.35510E+05  2.56700E+06  6.84312E+05  0.94545   0.00000E+00  30.998
003020000  2  -259.63   2.43416E-04 -2.84626E-04  6.40497E+05  2.56734E+06  6.84942E+05  0.93179   0.00000E+00  64.569
              -53.483   0.00000E+00  0.00000E+00  6.35461E+05  2.56708E+06  6.83576E+05  0.93213   0.00000E+00  39.004
003030000  3  -253.84   2.37021E-04 -2.78766E-04  6.40360E+05  2.56745E+06  6.83566E+05  0.93128   0.00000E+00  65.052
              -54.253   0.00000E+00  0.00000E+00  6.35325E+05  2.56719E+06  6.82223E+05  0.93161   0.00000E+00  38.838
0###################################################################################################################################
```

state Diagnostic printout, timehy = 0.5000000 , dt = 1.0000000E-03, ncount = 509, help = 3, lsuces = 0, fail = F

0Volume mixture properties

volno	v	p	voidf	quals	dotm	quala	boron	sounde	rho
	vo	pps	voidg	quale	dotmo	sigma	borono	dsnddp	satt
003010000	9.33968E-04	6.35510E+05	5.45534E-02	6.03053E-02	30.998	0.00000E+00	0.00000E+00	79.335	52.546
	9.33968E-04	6.35510E+05	0.94545	6.25989E-02	31.269	4.63559E-02	0.00000E+00	2.75661E+06	434.25
003020000	9.33968E-04	6.35461E+05	6.78738E-02	4.83754E-02	39.004	0.00000E+00	0.00000E+00	67.194	64.569
	9.33968E-04	6.35461E+05	0.93213	5.03408E-02	39.358	4.63566E-02	0.00000E+00	2.75673E+06	434.24
003030000	9.33968E-04	6.35325E+05	6.83870E-02	4.79717E-02	38.838	0.00000E+00	0.00000E+00	66.100	65.052
	9.33968E-04	6.35325E+05	0.93161	4.92771E-02	39.178	4.63584E-02	0.00000E+00	2.75685E+06	434.24

0Volume phase properties

volno	rhof	uf	tempf	sathf	betaff	kapaff	csubpf	viscf	thconf
	rhog	ug	tempg	sathg	betagg	kapagg	csubpg	viscg	thcong
003010000	905.12	6.84312E+05	435.32	6.80358E+05	1.09072E-03	6.85176E-10	4343.4	1.67836E-04	0.68239
	3.3517	2.56700E+06	433.86	2.75755E+06	2.95193E-03	1.67015E-06	2411.4	1.42928E-05	3.14311E-02
003020000	905.29	6.83576E+05	435.15	6.80345E+05	1.09090E-03	6.85288E-10	4343.4	1.67840E-04	0.68243
	3.3510	2.56708E+06	433.90	2.75755E+06	2.95154E-03	1.67027E-06	2411.4	1.42927E-05	3.14307E-02
003030000	905.60	6.82223E+05	434.84	6.80308E+05	1.09121E-03	6.85481E-10	4343.4	1.67849E-04	0.68250
	3.3497	2.56719E+06	433.95	2.75754E+06	2.95098E-03	1.67062E-06	2411.3	1.42924E-05	3.14296E-02

0Derivatives

volno	drfdp	drfduf	drgdp	drgdug	drgdxa	dtfdp	dtfduf	dtgdp	dtgdug
	dtgdxa	dtdp	dtdug	dtdxa					
003010000	5.01022E-07	-2.27333E-04	5.24814E-06	-5.34321E-06	0.00000E+00	1.20687E-07	2.30274E-04	3.53392E-05	5.40052E-04
	0.00000E+00	6.22143E-05	0.00000E+00	0.00000E+00					
003020000	5.01245E-07	-2.27413E-04	5.24754E-06	-5.34148E-06	0.00000E+00	1.20637E-07	2.30274E-04	3.53391E-05	5.40058E-04
	0.00000E+00	6.22182E-05	0.00000E+00	0.00000E+00					
003030000	5.01647E-07	-2.27556E-04	5.24675E-06	-5.33861E-06	0.00000E+00	1.20545E-07	2.30276E-04	3.53408E-05	5.40075E-04
	0.00000E+00	6.22287E-05	0.00000E+00	0.00000E+00					

```
0###################################################################################################################################
```

mass err Diagnostic printout, timehy = 0.5000000 , dt = 1.0000000E-03, ncount = 509, help = 3, lsuces = 0, fail = F

0Volume properties

volno	v	rho	rhom	drho/rhof	drho/rho	v*drho
003010000	9.33968E-04	52.546	52.546	1.02192E-07	1.76028E-06	8.63885E-08
003020000	9.33968E-04	64.569	64.569	1.11559E-07	1.56411E-06	9.43242E-08
003030000	9.33968E-04	65.052	65.052	7.06268E-08	9.83209E-07	5.97360E-08

```
System mass error increment for this time step----------------------------------- 1.17019E-07
Mass + flow in - flow out mass error increment----------------------------------- -1.64825E-03
Mean mass error increment-------------------------------------------------------- 6.26460E-06
Rms mass error increment--------------------------------------------------------- 1.73157E-03
Mean mass error fraction--------------------------------------------------------- 1.46810E-07
```

```
Rms mass error fraction------------------------------------------------------ 8.75055E-07
Max. system or overall global mass error tolerance--------------------------- 1.75966E-06
Controlling errmax---------------------------------------------------------- 1.76028E-06
0########################################################################################################
    jprop Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Junction donored properties, ivrev =  0
 =======================================================================================================
    junno(i)   velfj(i)    voidfj(i)   rhofj(i)   qualaj(i)    ufj(i)      jc(i)                           volno(k)   voidg(k)
               velgj(i)    voidgj(i)   rhogj(i)   voids        ugj(i)      jcex'i)                         volno(l)   voidg(l)
 =======================================================================================================
    003010000  0.74448    5.45534E-02  905.12     0.00000E+00  6.84312E+05              65536             003010000  0.94545
               3.4533     0.94545      3.3517     1.0000       2.56700E+06            1052768             003020000  0.93213
    003020000  1.4061     6.78738E-02  905.29     0.00000E+00  6.83576E+05              65536             003020000  0.93213
               7.4883     0.93213      3.3510     1.0000       2.56708E+06            1052768             003030000  0.93161
0########################################################################################################
    vlvela Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =        509, help =  3, lsuces =  0, fail = F
0Volume inlet and outlet terms
 =======================================================================================================
    volno(i)                 invcnt(1)
    avol(i)        iiflag    loop jx    junno(jx)  ivf  ajun(jx)    voidfj(jx)   rhofj(jx)  velfj*ivf   arat(jx)
                                                        athrot(jx)  voidgj(jx)   rhogj(jx)  velgj*ivf   arat(jx+1)
 =======================================================================================================
    003010000                1
    4.56037E-03
*              outlet    1             003010000  1    4.56037E-03 5.45534E-02  905.12     0.74448     1.0000
                                                        1.0000      0.94545      3.3517     3.4533      1.0000
    003020000                2
    4.56037E-03
*              inlet     1             003010000  1    4.56037E-03 5.45534E-02  905.12     0.74448     1.0000
                                                        1.0000      0.94545      3.3517     3.4533      1.0000
               outlet    2             003020000  1    4.56037E-03 6.78738E-02  905.29     1.4061      1.0000
                                                        1.0000      0.93213      3.3510     7.4883      1.0000
    003030000                2
    4.56037E-03
*              inlet     1             003020000  1    4.56037E-03 6.78738E-02  905.29     1.4061      1.0000
                                                        1.0000      0.93213      3.3510     7.4883      1.0000
               outlet    2             003030000  1    4.56037E-03 6.83870E-02  905.60     2.1702      1.0000
                                                        1.0000      0.93161      3.3497     11.607      1.0000
0Volume average terms
 =======================================================================================================
    volno(i)   velf(i)     vvfx(ix)    vvfx(ix+1)  vrhof(ix)    vrhof(ix+1)  areav(ix)
               velg(i)     vvgx(ix)    vvgx(ix+1)  vrhog(ix)    vrhog(ix+1)  areav(ix+1)
 =======================================================================================================
    003010000  0.74448     0.00000E+00  0.16764    0.00000E+00  0.22518      0.00000E+00
               3.4533      0.00000E+00  4.99035E-02 0.00000E+00 1.44510E-02  4.56037E-03
    003020000  1.1113      0.16764      0.39401    0.22518      0.28021      4.56037E-03
               5.4563      4.99035E-02  0.10667    1.44510E-02  1.42445E-02  4.56037E-03
    003030000  1.7897      0.39401      0.61292    0.28021      0.28243      4.56037E-03
               9.5467      0.10667      0.16518    1.42445E-02  1.42313E-02  4.56037E-03
0########################################################################################################
    ms err t Diagnostic printout, timehy =  0.5000000     , dt =  1.0000000E-03, ncount =        509, help =  3, succes =  0, fail = F
 -------------------------------------------------------------------------------------------------------
Total mass error increment for this time step------------------------------- 1.17019E-07
Mass + flow in - flow out mass error increment------------------------------ -1.17019E-07
Mean mass error increment-------------------------------------------------- 6.26460E-06
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

```
Rms mass error increment------------------------------------------------------------  1.73157E-03
Mean mass error fraction-------------------------------------------------------------  1.46810E-07
Rms mass error fraction--------------------------------------------------------------  8.75055E-07
Max. system or overall global mass error tolerance----------------------------------  1.75966E-06
Controlling errmax-------------------------------------------------------------------  1.76028E-06
```

Figure B0.0-1 Diagnostic edit from Edwards pipe problem with extras. (Continued)

```
*comdeck jundatc
c
c  ijskp    junction skip factor.
c  njuns    number of junctions
c  ij1      from volume input code.
c  ij2      to volume input code.
c  jc       choking flag (1 bit); time dependent junction flag (2 bit);
c           reversed from volume connection flag (4 bit); reversed to
c           volume connection flag (8 bit); no choking flag (16 bit);
c           old time choking flag (32 bit); choking test flag for
c           accumulator junction (64 bit); input flag (128 bit); abrupt
c           area change flag (256 bit); two velocity-one velocity flag
c           (512 bit); separator flag (1024 bit); stratified flow flag
c           (2048 bit); from cross flow option (4096 bit); to cross flow
c           option (8192 bit); cross flow flag (16384 bit); accumulator
c           active flag (32768 bit); stratification flag (65536 bit);
c           stratification input data (bit pos. 18-19); jet mixer flags
c           (bit pos. 20-22); separator flags (bit pos. 23-25);
c           unused (bit pos. 26); horiz-vert junction flag (bit pos.27);
c           up-down junction flag (bit pos. 28); valve flag (bit
c           pos. 29); second turbine junction flag (bit pos. 30).
c  ij1vn    from volume ordinal number.
c  ij2vn    to volume ordinal number.
c  junftl(1)  from pointer in output form without sign.
c  junftl(2)  to pointer in output form without sign.
c  ajun     area of junction
c  athrot   ratio of orifice area to junction area
c  arat(1)  mixture volumetric flow rate for the junction divided by
c           the total mixture volumetric flow rate on that end of the
c           volume.  mixture is obtained by using sum of absolute value
c           of phasic volumetric flow rates. 1 is for "from" volume.
c  arat(2)  same as arat(1), except 2 is for "to" volume.
c  diamj    diameter of junction
c  ******   warning: the ordering of velfj, velfjo, velgj, velgjo, ufj,
c  ******   ugj, voidfj, voidgj, qualaj, rhofj, and rhogj must be
c  ******   maintained since vfinl assumes this order.
c  velfj    liquid velocity
c  velfjo   liquid velocity previous time step
c  velgj    vapor velocity
c  velgjo   vapor velocity previous time step
c  ufj      junction liquid specific internal energy
c  ugj      junction vapor specific internal energy
c  voidfj   junction liquid void fraction
c  voidgj   junction vapor void fraction
c  qualaj   junction noncondensible quality
c  rhofj    junction liquid density
c  rhogj    junction vapor density
c  velfjs   intermediate liquid velocity used when have bad donoring
c  velgjs   intermediate vapor velocity used when have bad donoring
c  fjunf    Constant term for form loss coefficient for irreversible
c           losses, foward.
c  fjunr    Constant term for form loss coefficient for irreversible
c           losses, reverse.
c  fjunfb   Multipler term for form loss coefficient for irreversible
c           losses, foward.
```

Figure B0.0-2 Listing of common block JUNDATC from program RELAP5.

```
c  fjunfc  Exponent term for form loss coefficient for irreversible
c          losses, foward.
c  fjunrb  Multipler term for form loss coefficient for irreversible
c          losses, reverse.
c  fjunrc  Exponent term for form loss coefficient for irreversible
c          losses, reverse.
c  formfj  liquid form loss term
c  formgj  vapor form loss term
c  mflowj  mass flow rate
c  faaj    virtual mass
c  fij     interphase friction
c  fijo    interphase friction previous time step
c  jcatn   density correction factor (sqrt of rhot/rhoj) applied to
c          the junction convective term in choking
c  jacto   density correction factor applied to the junction convective
c          term in choking previous time step
c  qualnj(1)  first noncondensible junction mass fraction
c  qualnj(2)  second noncondensible junction mass fraction
c  qualnj(3)  third noncondensible junction mass fraction
c  qualnj(4)  fourth noncondensible junction mass fraction
c  qualnj(5)  fifth noncondensible junction mass fraction
c  ij1nx   from volume index.
c  ij2nx   to volume index.
c  jcnx1   index to scratch space for "from" volume. next word is
c          same for "to" volume.
c  jcnx2   index to diagonal matrix element for "from" volume. next
c          word is same for "to" volume.
c  jcnx3   index to off-diagonal matrix element for "from" volume. next
c          word is same for "to" volume.
c  jcnxd(1)  diagonal index for sum momentum equation
c  jcnxd(2)  diagonal index for difference momentum equation
c  jcnxs   index to scratch space for junction.
c  junno   junction number for output editing
c  jdissc  subcooled discharge coefficient.
c  jdistp  two phase discharge coefficient.
c  jcex    unused (bit pos. 1); ccfl flag (bit pos. 2);
c          input ccfl flag (bit pos. 3); junction flow regime number
c          (bit pos. 4-9); to face-1 bits (bit pos. 10-12); from face-1
c          bits (bit pos. 13-15); input donor pressure flag
c          (bit pos. 16); water packer junction flag (bit pos. 17);
c          stretch junction flag (bit pos. 18); eccmix flags (bit
c          pos. 19-20); debug print flag (bit pos. 21),
c          water packing flag (bit pos. 22).
c  betacc  form of ccfl correlation (0 = wallis, 1 = kutateladze)
c  constc  gas intercept for ccfl correlation
c  constm  slope for ccfl correlation
c  c0j     junction distribution coefficient
c  c0jo    junction distribution coefficient previous time step
c  xej     junction equilibrium quality
c          based on extrapolated pressure & internal energy from jchoke
c  sonicj  junction sound speed
c          divided by the junction density ratio (jcatn)
c  vodfjo  junction liquid void fraction previous timestep
c  vodgjo  junction vapour void fraction previous timestep
c  vdfjoo  junction liquid void fraction previous timestep but one
```

Figure B0.0-2 Listing of common block JUNDATC from program RELAP5. (Continued)

```
c  vdgjoo  junction vapour void fraction previous timestep but one
c  fxj     wall friction interpolating factor
c  fxjo    wall f.iotion interpolation factor previous time step
c  vgjj    vapor 1rif. velocity
c  florgj  junctic \ flow regime number in real format
c  iregj   vertical oubbly/slug flow junction flow regime number in
c          real format
c  voidj   junction vapor void fraction used in the interphase drag
c  jdissh  superheated discharge coefficient
c  ijflg   Junction direction flag (0 = 1D/1D or 1D/3D or 3D/1D,
c          1 = 3D/3D direction 1, 2 = 3D/3D direction 2, 3 = 3D/3D
c          direction 3).
c  flenth  Total enthalpy flow in junction (includes both phases and
c          noncondensibles).
$if def.selap,2
c  ajuno   Old ajun.
c  diamjo  Old diamj.
```

Figure B0.0-2 Listing of common block JUNDATC from program RELAP5. (Continued)

```
*comdeck voldatc
c
c  ivskp    volume skip factor.
c  nvols    number of volumes.
c  vctrl    time dependent volume flag (bit pos. 1); equilibrium flag
c           (bit pos. 2); thermal front flag (bit pos. 3); input flag
c           (bit pos. 4); vapor disappearance flag (bit pos. 5);
c           accumulator flag (bit pos. 6); pump flag (bit pos. 7);
c           input water packer flag (bit pos. 8); new status flags,
c           initialization type during input (bit pos. 9-19);
c           old status flags (bit pos. 20-30); input bundle flag
c           (bit pos. 31).
c           Status flags: negative pressure (bits 9, 20); mass error
c           (bits 10, 21); extrapolation error (bits 11, 22); quality
c           overrun (bits 12, 23); largest mass error (bits 13, 24);
c           error in vapor phase (bits 14, 25); error in liquid phase
c           (bits 15, 26); error in two phase call (bits 16, 27); non-
c           convergence in iterations (bits 17, 28); negative sonic
c           velocity (bits 18, 29); negative derived quantities (bits 19,
c           30).
c  vctrlx   Status flags; debug print flag (bit pos. 1), air appearance
c           repeat(bit pos. 2), pressure change repeat on air appearance
c           (bit pos. 3 ), water packing statistics flag( bit pos. 4).
c  volmat   Fluid type in volume.
c  volno    Volume number for editing.
c  imap     Map, regime, and flags.  Three quantities, one per
c           coordinate.  Flow regime map infomation (bit pos. 1-6);
c           non-condensable gas appearance flag (bit pos. 7);
c           horizontal stratification flag (bit pos. 8);
c           (bit pos. 8)      etch flag (bit pos. 9); input vertical
c           stratificat     lag (bit pos. 10); vertical stratification
c           flags (bit :     11-12); experimental friction being used
c           (bit pos. 13);  wall friction input flag (bit pos. 14); flag
c           that coordinate direction is being used (bit pos. 15); water
c           packer input flag (bit pos. 16); bundle input flag
c           (bit pos. 17); volume in multid component (bit pos. 18);
c           flow  regime number (bit pos. 19-24); metal appearance flags
c           (bit pos. 25-26); laminar friction factor, 64 if 0, 96 if 1
c           (bit pos. 27); ans input flag (bit pos. 28); level tracking
c           input flag (bit pos. 29);  reflood flag (bit pos. 30);
c           water packer  volume flag (bit pos. 31).
c  v        Volume.
c  recipv   Reciprocal of volume (v), zero if v is zero.
c  avol     Area of volume, three quantities, one per coordinate.
c  dl       Volume length, three quantities, one per coordinate.
c  diamv    Equivalent flow diameter, three quantities, one per
c           coordinate.
c  roughv   Wall roughness factor for direction 1.  As input
c           reset in icmpn1 to colebrook full turb friction fac.
c  recrit   Critical reynolds number, three quantities, one per
c           coordinate.  Fric fac = const; see roughv.
c  p        Average pressure.
c  po       Average pressure previous time step.
c  uf       Liquid specific internal energy.
c  ufo      Liquid specific internal energy previous time step.
```

Figure B0.0-3 Listing of common block VOLDATC from program RELAP5.

```
c  ug      vapor specific internal energy.
c  ugo     vapor specific internal energy previous time step.
c  voidf   liquid void fraction.
c  voidg   vapor void fraction.
c  voidgo  vapor void fraction previous time step (n).
c  vodgoo  vapor void fraction at old old time step (n-1).
c  quala   noncondensible quality..
c  qualao  noncondensible quality previous time step.
c  boron   boron density (mass of boron per cell volume).
c  borono  boron density previous time step.
c  quals   static quality.
c  quale   equilibrium quality.
c  rho     total density.
c  rhom    total density for mass error check.
c  rhoo    total density previous time step.
c  ******  warning: the ordering of rhof and rhog must be maintained
c  ******  since fidis assumes this order.
c  rhof    liquid density.
c  rhog    vapor density.
c  satt    saturation temperature based on the steam partial pressure.
c  temp    used in r level subroutines and is usually the same as satt.
c  tempf   liquid temperature.
c  tempg   vapor temperature.
c  velf(1) Average liquid velocity in a volume, three quantities, one
c          per coordinate.
c  velg    Average vapor velocity in a volume, three quantities, one per
c          coordinate.
c  sounde  homogeneous equilibrium sound speed. also, used for scratch
c          in hydro.
c  dsnddp  partial derivative of sounde w/r to pressure. also, used for
c          scratch in hydro.
c  sathf   liquid specific enthalpy at saturation conditions.
c  sathg   vapor specific enthalpy at saturation conditions.
c  betaff  Liquid isobaric coefficient of thermal expansion at bulk
c          conditions.
c  betagg  Vapor isobaric coefficient of thermal expansion at bulk
c          conditions.
c  csubpf  Liquid specific heat capacity at constant pressure at bulk
c          conditions.
c  csubpg  Vapor specific heat capacity at constant pressure at bulk
c          conditions.
c  viscf   Liquid viscosity.
c  viscg   Vapor viscosity.
c  sigma   Surface tension.
c  thconf  Liquid thermal conductivity.
c  thcong  Vapor thermal conductivity.
c  pps     Vapor partial pressure.
c  dotm    Vapor generation rate per unit volume.
c  dotmo   Vapor generation rate per unit volume previous time step.
c  hif     Liquid side interfacial heat transfer coefficient per unit
c          volume.
c  hig     Vapor side interfacial heat transfer coefficient per unit
c          volume.
c  gammaw  Vapor generation rate at the wall per unit volume.
c  q       total heat transfer rate from wall to fluid.
```

Figure B0.0-3 Listing of common block VOLDATC from program RELAP5. (Continued)

```
c   qwg     heat transfer rate from wall to vapor.
c   drfdp   partial derivative of rhof w/r to pressure.
c   drfduf  partial derivative of rhof w/r to liquid specific internal
c           energy.
c   drgdp   partial derivative of rhog w/r to pressure.
c   drgdug  partial derivative of rhog w/r to vapor specific internal
c           energy.
c   drgdxa  partial derivative of rhog w/r to noncondensible quality.
c   dtfdp   partial derivative of tempf w/r to pressure.
c   dtfduf  partial derivative of tempf w/r to liquid specific internal
c           energy.
c   dtgdp   partial derivative of tempg w/r to pressure.
c   dtgdug  partial derivative of tempg w/r to vapor specific internal
c           energy.
c   dtgdxa  partial derivative of tempg w/r to noncondensible quality.
c   dtdp    partial derivative of satt w/r to pressure.
c   dtdug   partial derivative of satt w/r to vapor specific internal
c           energy.
c   dtdxa   partial derivative of satt w/r to noncondensible quality.
c   floreg  flow regime number in real format, three quantities, one per
c           coordinate.
c   hifo    liquid side interfacial heat transfer coefficient per unit
c           volume previous timestep.
c   higo    vapor side interfacial heat transfer coefficient per unit
c           volume previous timestep.
c   qualan  Noncondensible mass fraction, five quantities, one per
c           species.
c   gaman   Noncondensible generation rate per unit volume,
c           five quantities, one per species.
c   enthn   Enthalpy of noncondensible source, five quantities, one per
c           species.
c   gamas   solute generation rate per unit volume.
c   enths   enthalpy of the solute source.
c   vo      volume previous time step.
c   qualno  Noncondensible mass fraction previous time step, five
c           quantities, one per species.
c   rhogo   vapor density previous time step.
c   ppso    vapor partial pressure (old-time).
c   ustm    vapor specific internal energy at pps and tempg with non-
c           condensable present.
c   ustmo   vapor specific internal energy at pps and tempg with non-
c           condensable present (old-time).
c   ggas    Cell centered gas mass flux, three quantities, one per
c           coordinate.
c   gliq    Cell centered liquid mass flux, three quantities, one per
c           coordinate.
c   velfo   Volume average liquid velocity previous timestep, three
c           quantities, one per coordinate.
c   velgo   Volume average vapor velocity previous timestep, three
c           quantities, one per coordinate.
c   fstrt   horizontal stratification interpolating factor, three
c           quantities, one per coordinate.
c   fwalf   liquid wall friction coefficient, three quantities, one per
c           coordinate.
c   fwalg   vapor wall friction coefficient, three quantities, one per
```

Figure B0.0-3 Listing of common block VOLDATC from program RELAP5. (Continued)

```
c         coordinate.
c  vctrln position of volume in volume block.
c  vctrld index to diagonal matrix element.
c  vctrls index to volume scratch space.
c  sth2xv index data for sth2x water property subroutines.
c  invfnd index to inverted junction table.
c  sinb   sine function of volume vertical angle, three quantities, one
c         per coordinate.
c  hvmix  volume mixture enthalpy.
c  ptans  pitch between fuel plates (an`).
c  span   length of fuel plates  (ans.
c  pecltv Volume Peclet number, three quantities, one per coordinate.
c  tsatt  saturation temperature based on the total pressure.
c  fshape Wall friction shape factor (one per coordinate).
c  fmurex Viscosity ratio for wall friction (one per coordinate).
c  hgf    Direct heating heat transfer coefficient per unit volume.
c  frica  Constant term in experimental friction correlation (one per
c         coordinate).
c  fricb  Multiplier term in experimental friction correlation (one per
c         coordinate).
c  fricc  Power term in experimental friction correlation (one per
c         coordinate).
c  invhtf index to inverted heat structure table.
c  hydxc(1) Change along inertial x axis due to moving from face 1
c           to center of volume along local x coordinate.
c  hydxc(2) Change along inertial x axis due to moving from center of
c           volume to face 2 along local x coordinate.
c  hydxc(3) Change along inertial x axis due to moving from face 3
c           to center of volume along local y coordinate.
c  hydxc(4) Change along inertial x axis due to moving from center of
c           volume to face 4 along local y coordinate.
c  hydxc(5) Change along inertial x axis due to moving from face 5
c           to center of volume along local z coordinate.
c  hydxc(6) Change along inertial x axis due to moving from center of
c           volume to face 6 along local z coordinate.
c  hydyc(1) Change along inertial y axis due to moving from face 1
c           to center of volume along local x coordinate.
c  hydyc(2) Change along inertial y axis due to moving from center of
c           volume to face 2 along local x coordinate.
c  hydyc(3) Change along inertial y axis due to moving from face 3
c           to center of volume along local y coordinate.
c  hydyc(4) Change along inertial y axis due to moving from center of
c           volume to face 4 along local y coordinate.
c  hydyc(5) Change along inertial y axis due to moving from face 5
c           to center of volume along local z coordinate.
c  hydyc(6) Change along inertial y axis due to moving from center of
c           volume to face 6 along local z coordinate.
c  hydzc(1) Change along inertial z axis due to moving from face 1
c           to center of volume along local x coordinate.
c  hydzc(2) Change along inertial z axis due to moving from center of
c           volume to face 2 along local x coordinate.
c  hydzc(3) Change along inertial z axis due to moving from face 3
c           to center of volume along local y coordinate.
c  hydzc(4) Change along inertial z axis due to moving from center of
c           volume to face 4 along local y coordinate.
```

Figure B0.0-3 Listing of common block VOLDATC from program RELAP5. (Continued)

```
c  hydzc(5)  Change along inertial z axis due to moving from face 5
c               to center of volume along local z coordinate.
c  hydzc(6)  Change along inertial z axis due to moving from center of
c               volume to face 6 along local z coordinate.
c  hyposv(1) Coordinate along x inertial axis of vector from center
c               of rotation to center of volume.
c  hyposv(2) Coordinate along y inertial axis of vector from center
c               of rotation to center of volume.
c  hyposv(3) Coordinate along z inertial axis of vector from center
c               of rotation to center of volume.
c  gravv(1)  Coordinate of gravity along inertial x coordinate.
c  gravv(2)  Coordinate of gravity along inertial y coordinate.
c  gravv(3)  Coordinate of gravity along inertial z coordinate.
c  tintf     Interface temperature when noncondensible is presentR,
c               saturation temperature at total pressure otherwise.
c  htsens    Heat transfer coefficient for sensible heat transfer
c               between vapor/gas mixture and liquid.
c  tmassv    Total mass (includes both phases and noncondensibles) in
c               volume.
c  tiengv    Total internal energy (of both phases and noncondensibles)
c               in volume.
$if def,selap
c  idbvol    indicator of whether l-th index of relap5 volume contains
c               debris region; 0 = no, 1 = yes.
c  mdbvol    value for l-th relap5 volume index of index m for
c               referencing arrays in common block debcom.
c  ndbvol    value for l-th relap5 volume index of index n for
c               referencing arrays in common block debcom.
$if def,athena
c  bfield    strength of magnetic field acting on volume.
c  econdw    electrical conductivity of duct wall.
c  fwfmhd    equivalent wall friction coefficient due to mhd effects.
c  hwidth    duct half-width.
c  wthick    thickness of duct wall.
c  igmhd     duct geometry type; 1=circular, 2=rectangular.
$endif
c  avolo     Old value of avol.
c  diamvo    Old value of diamv.
$endif
c  dlev      location of two-phase mixture level
c  dlevo     location of two-phase mixture level (old time)
c  vlev      velocity of two-phase level movement
c  vollev    Position of level within volume.
c  voidla    void fraction above the mixture level
c  voidao    void fraction above the mixture level (old time)
c  voidlb    void fraction below the mixture level
c  voidbo    void fraction below the mixture level (old time)
c  dfront    location of thermal front
c  dfrnto    location of thermal front (old time)
c  vfront    velocity of thermal front
c  ufla      liquid internal energy above the thermal front
c  ufao      liquid internal energy aaove the thermal front (old time)
c  uflb      liquid internal energy below the thermal front
c  ufbo      liquid internal energy below the thermal front (old time)
```

Figure B0.0-3 Listing of common block VOLDATC from program RELAP5. (Continued)

2. TITLE AND SUBTITLE

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User's Guide and Input Requirements

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less) The RELAP5/MOD3 computer code has been developed for best-estimate simulation of light water reactor coolant systems during postulated accidents. The code models the coupled behavior of the reactor coolant system and the core for loss-of-coolant accidents and operational transients such as anticipated transient without scram, loss of offsite power, loss of feedwater, and loss of flow. A generic modeling approach is used that permits simulating a variety of thermal-hydraulic systems. Control system and secondary system components are included to permit modeling of plant controls, turbines, condensers, and secondary feedwater systems.

RELAP5/MOD3 code documentation is divided into seven volumes: Volume I presents modeling theory and associated numerical solution schemes; Volume II details instructions for code application and input data preparation; Volume III presents the results of developmental assessment cases that demonstrate and verify the models used in the code; Volume IV discusses in detail RELAP5 models and correlations; Volume V presents guidelines that have evolved over the past several years through the use of the RELAP5 code; Volume VI discusses the numerical scheme used in RELAP5; and Volume VII presents a collection of independent assessment calculations.

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