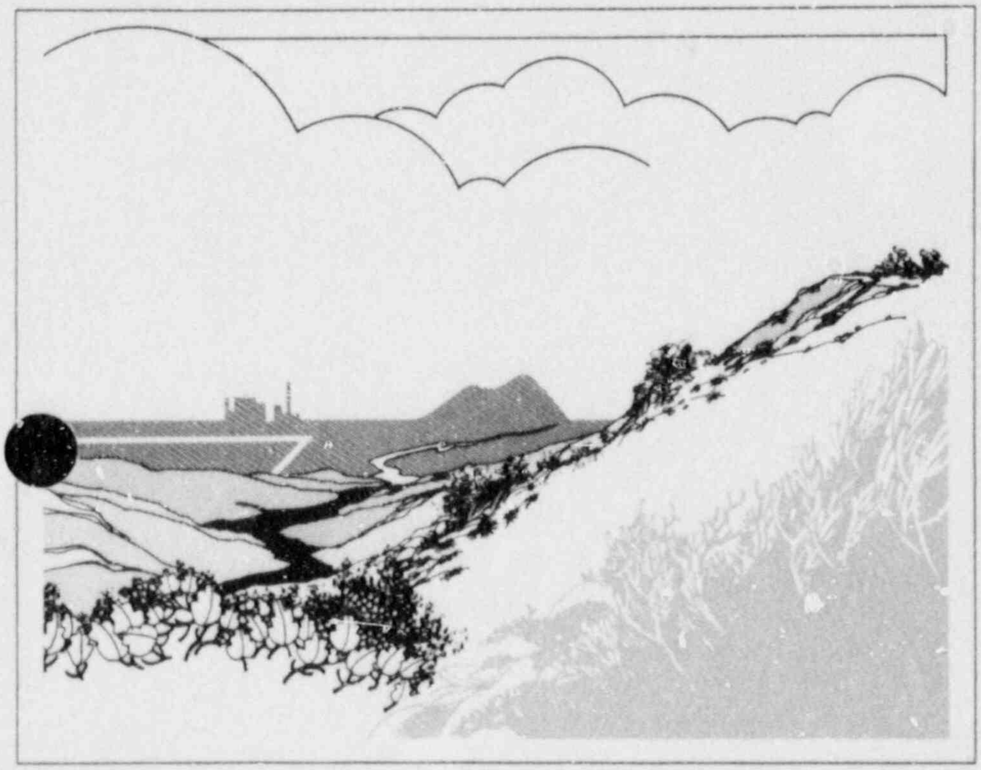
NUREG/CR-4312
EGG-2396
Rev. 1

RELAP5/MOD2 Code Manual
Volume 2: Users Guide and Input Requirements

Victor H. Ransom, et al.

FORMAL REPORT



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Work performed under
DOE Contract No. DE-AC07-76ID01570
for the **U.S. Nuclear Regulatory Commission**

Idaho National Engineering Laboratory

Managed by the U.S. Department of Energy

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RELAP5/MOD2 CODE MANUAL VOLUME 2: USERS GUIDE AND INPUT REQUIREMENTS

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Published March 1987

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Prepared for the
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under DOE Contract No. DE-AC07-76ID01570
FIN No. A6052

ABSTRACT

The RELAP5/MOD2 code has been developed for best estimate transient simulation of pressurized water reactors and associated systems. The code modeling capability includes simulation of large and small break loss-of-coolant accidents as well as operational transients such as anticipated transient without SCRAM, loss-of-offsite power, loss of feedwater, and loss of flow. A generic modeling approach is utilized, which permits as much of a particular system to be modeled as necessary. Control system and secondary system components are included to permit modeling of plant controls, turbines, condensers, and secondary feedwater conditioning systems.

The modeling theory and associated numerical schemes are documented in Volume 1 to acquaint the user with the modeling base and thus aid in effective use of the code. Volume 2 contains detailed instructions for code application and input data preparation. In addition, Volume 2 contains user guidelines that have evolved over the past several years from application of the code at the Idaho National Engineering Laboratory, at other national laboratories, and by industry users from throughout the world.

FIN No. A6052--Thermal-Hydraulic
Code Improvement and Maintenance

ACKNOWLEDGMENT

Development of a complex computer code such as RELAP5/MOD2 is the result of a team effort. Acknowledgment is made of those who made significant contributions to the current version, in particular, Drs. J. C. Lin, H. Chow, C. C. Tsai, W. M. Bryce, and Mr. L. R. Feinauer. Acknowledgment is made to those who made significant contributions to earlier versions, in particular, Mr. K. E. Carlson, and Dr. H. H. Kuo. Acknowledgment is also made to Ms. E. C. Johnson for her work in RELAP5 configuration control and user services.

The RELAP5 Program is indebted to the technical monitors responsible for directing the overall program; Mr. W. Lyon, Drs. R. Landry, R. Lee and Y. Chen of the United States Nuclear Regulatory Commission and Dr. D. Majumdar and Mr. N. Bonicelli of the Department of Energy-Idaho Operations Office. Finally, acknowledgment is made of all the code users who have been very helpful in stimulating timely correction of code deficiencies.

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RELAP5/MOD2 CODE MANUAL

VOLUME 2: USERS GUIDE AND INPUT REQUIREMENTS

1. INTRODUCTION

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

Information relating to the actual construction of a RELAP5/MOD2 input model is presented in the appendices. Appendix A provides a complete description of input deck organization and data card requirements for all problem types. An example of a diagnostic edit is presented in Appendix B. Appendix C discusses general guidelines for the process of developing a RELAP5/MOD2 input model.

1.1 General

The objective of the users guide is to reduce the uncertainty associated with transient modeling of light water reactor 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 the range of transients that possibly occur are large and constantly evolving. Hence, the effect of nodalization, time step selection, and modeling approach are not completely quantified. The purpose of the independent assessment programs is to explore such effects in the situations of interest in light water reactor safety. As these programs proceed, there will be a continual need to update the user guidelines document to reflect the current state of modeling knowledge.

1.2 Areas of Application

RELAP5/MOD2 is a generic transient analysis code for thermal-hydraulic systems using a fluid that may be a mixture of steam, water, one noncondensible specie, 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 peculiar to pressurized water reactors. In particular a point neutronics model, pumps, turbines, generator, valves, separator, and controls are included. The code also contains a jet pump component and has been used for modeling boiling water reactor systems.

The PWR applications for which the code is intended include large and small break loss-of-coolant accidents, operational transients such as anticipated transients without SCRAM, loss of feed, loss-of-offsite power, loss of flow, and over cooling transients. The system behavior can be simulated up to the point of fuel damage. Fuel cladding ballooning and/or rupture with metal-water reaction are not modeled.

RELAP5/MOD2 can also be used for analysis of the transient behavior of piping systems containing steam/water such as for estimating hydraulic loads on relief valve discharge lines.

1.3 Modeling Philosophy

RELAP5/MOD2 is designed for use in analyzing system component interactions as opposed to 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 crossflow effects in a PWR core using an approximate crossflow momentum equation and the reflood model 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 of performing basic mathematical operations such as addition, multiplication, and integration, 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. The fluid scalar properties such as pressure, energy, density, and void fraction are represented by the average fluid conditions and are viewed as being located at the control volume center. The fluid vector properties, i.e., 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 (i.e., 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 some guidance.

Heat flow paths are also modeled in a one-dimensional sense using a staggered 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 a boiling heat transfer formulation. 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 specialized two-dimensional heat conduction solution method with an automatic fine mesh rezoning is used for low pressure reflood. Axial as well as radial conduction is 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 it is planned to generalize this model to higher pressure situations so that it could be used to track a quench front anywhere in the system.

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 algebraic or logical 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 in a serially implicit fashion. The control system advancement occurs after the hydrodynamic advancement 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 on the succeeding time step, i.e., explicitly coupled.

The reactor kinetics model is also advanced in a serially implicit manner after the control system advancement. The kinetics model consists of a system of ordinary differential equations that are 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 feedback effects of fuel temperature, moderator temperature, moderator density, and boron concentration in the moderator (cooling center) are evaluated using averages over the hydrodynamic control volumes and associated heat structures that represent the core. The averages are weighted averages that are established a priori such that they are representative of the effect on total core power. Certain nonlinear or multidimensional effects due to 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 to the physical situation being modeled.

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, 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 that are modeled. Examples where knowledge is limited are components such as pumps, separators, processes such as two-phase flow, and heat transfer. Examples of approximations required due to limited computer resources are limited spatial nodalization for hydrodynamics, heat transfer, kinetics, use of numerical schemes of low order of accuracy, and density of thermodynamic and property tables. In general, the accuracy effect of each of these factors is of the same order; and 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 of a steam-water-noncondensible mixture. The numerical solution scheme that is used results in a system representation using control volumes that are joined 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 through application work with RELAP5 and the purpose here will be to summarize these guidelines.

In selecting a nodalization for the 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., $\Delta x/v$ about the same.

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. This establishes the upper limit on the number of volumes. The exact limit will depend upon the computer being used, but for the CDC Cyber-176 it is possible to use 300 to 400 volumes if no heat structures or other components are used. For LWR systems the upper limit is $\sim$250 volumes when a variety of components are used.

4. If possible, a nodalization sensitivity study should be made in order to estimate the uncertainty due to nodalization.

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. 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 the core level depression in a PWR under small break loss-of-coolant accidents.

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/MOD2 flow model is a nonhomogenous nonequilibrium two-phase flow model. However, options exist for homogenous 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 included 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 due 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, otherwise 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 becomes entirely dependent 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 best illustrated by an example. In the modeling of sub-atmospheric 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 due to 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 inflow. 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 it is anticipated that such a procedure could lead to an unphysical result because of 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 a coordinate direction that is specified through input. The hydrodynamic volumes have a coordinate direction that is positive from the inlet to the outlet. Which end of a volume is the inlet or outlet depends upon the specifications of the volume orientation, i.e , for a positive vertical elevation change the inlet is at the lowest elevation while 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 1.

The junction coordinate direction is established through input of the junction connection code (Words W1 and W2 of card CCC0101-CCC0199, see Subsection 7.4.1 of Appendix A). The junction connection code designates a <u>from</u> and <u>to</u> component, and the velocity is positive in the direction from the <u>from</u> component to the <u>to</u> component. The connection code also has a flag that designates whether the connection is from/to the inlet or the outlet side of the particular component (see Subsection 7.2 of Appendix A).

A sketch showing a series of three horizontal volumes connected by two junctions is shown in Figure 2 to illustrate some of the possible coordinate orientations that result from combinations of the connection codes and the volume orientation data. In Figure 3 two possible combinations are illustrated for the connection of two vertical volumes. Part a of Figure 3 shows the two volumes unconnected. Part b shows the result when the outlet of Volume 1 is joined to the inlet of Volume 2. Part 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.

When systems of volumes or components are connected in a closed loop it is necessary that the summation of the volume elevations close when they are summed according to the junction connection codes and sequence. Otherwise an unbalanced gravitational force will result. RELAP5 has an input processing feature which finds all loops or closed systems (which are defined by the input) and checks for elevation closure around each loop. 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

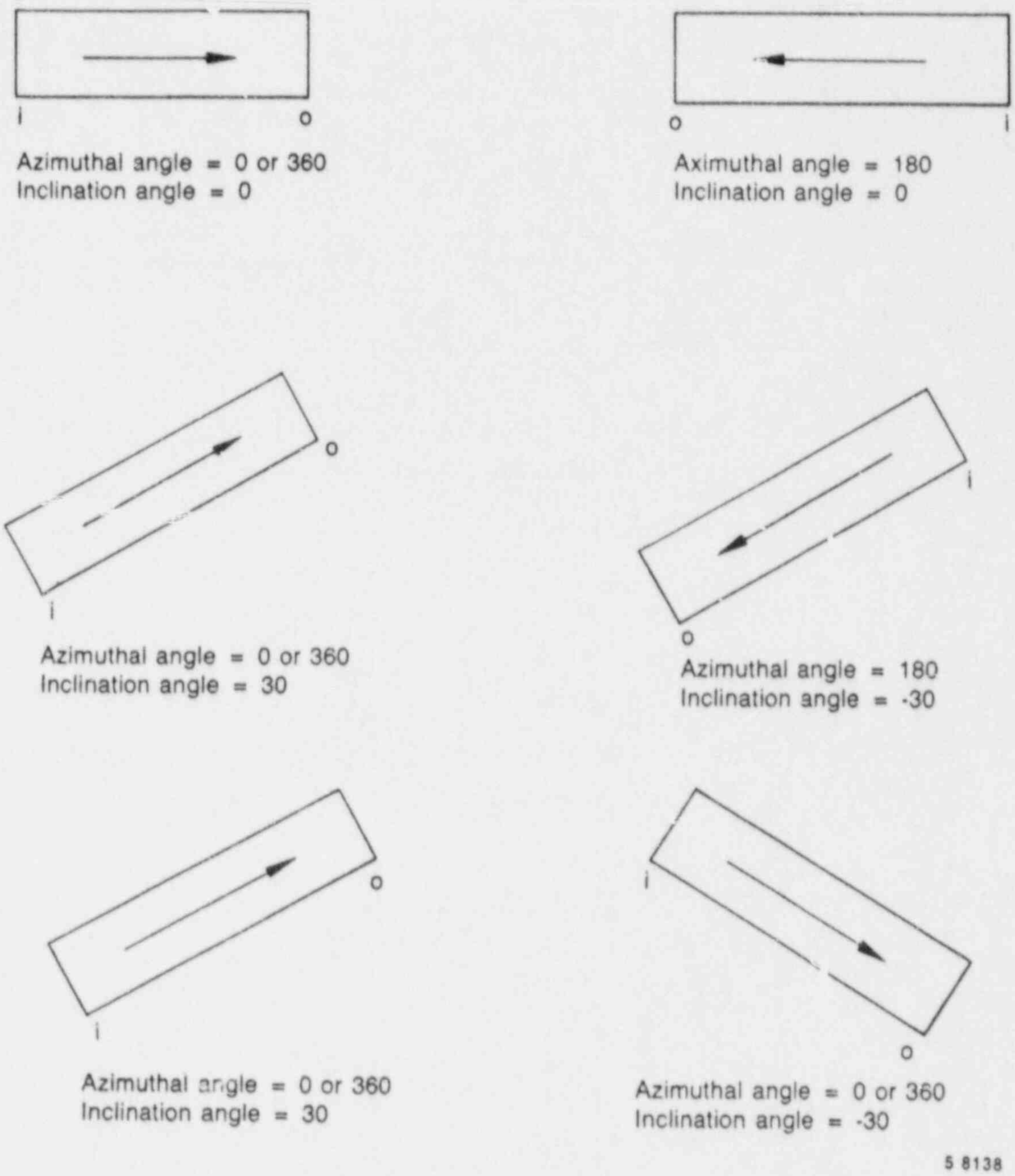


Figure 1. Possible volume orientation specifications.

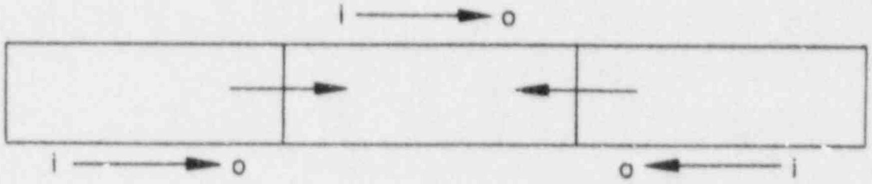


Figure 2. Sketch of possible coordinate orientation for three volumes and two junctions.

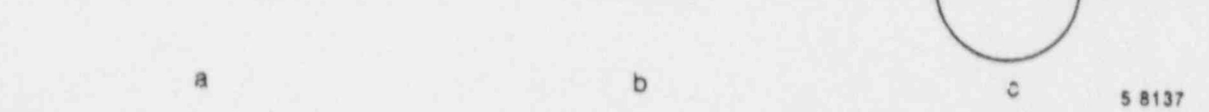


Figure 3. Sketch of possible vertical volume connections

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 junctions are printed out in the major edits in the hydrodynamic junction information sections (see Subsections 8.3.2.7 and 8.3.2.8 of this Volume of the manual). The from and to volumes are listed for each junction. In addition, the flow regimes for the from and to volumes are also listed using three letters. It is also possible to list the flow regime in the minor edits and plots, where a number is used. The following chart shows the three letter code and number used for each flow regime:

Flow Regime	Three Letter Code (major edits)	Number (minor edits/plots)
High mixing bubbly	CTB	1
High mixing transition	CTT	2
High mixing mist	CTM	3
Bubbly	BBY	4
Slug	SLG	5
Annular-mist	ANM	6
Inverted annular	IAN	7
Inverted slug	ISL	8
Mist	MST	9
Horizontal stratified	STR	10

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, and during reflood are all simulated in RELAP5 using specialized modeling. These particular processes are not peculiar to a component and will be discussed as a group. Some components also involve special process models such as pumps and separators, however 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. The purpose of this section will be to advise the user in this regard.

2.2.1 Abrupt Area Change

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

1. For junctions connecting volumes with sharp changes in flow area
2. For multiple junctions connected to or from a volume
3. For a junction connected to a time-dependent volume simulating a large or infinite reservoir boundary condition.

In addition to the code-computed form loss, users have the option to input form loss factors to achieve the desired pressure drop. If the area ratio between the volume and the junction is greater than 10, then the user should not use the abrupt area change option. In this case, the smooth area change option should be used along with an appropriate input form loss factor.

2.2.2 Choked Flow

The recommended input junction flags are abrupt and nonhomogeneous. However, several studies over the past two years have shown that under certain conditions (not completely defined at this point), the RELAP5 critical break flow model will predict unrealistically low mass flows. Under such conditions, the break junction flags should be specified as abrupt and homogeneous. Work has been initiated at the Idaho National Engineering Laboratory to isolate the cause of this problem.

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 is dependent 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 Equation (324) in Volume 1 of this manual, is calculated for the recommended abrupt area change option using the following formula:

$$(dA/dx)_{t,abrupt} = [A(K) - A_t]/[10.0\ D(K)]$$

where A(K) is the upstream volume flow area, A_t is the throat or junction area (minimum physical area), and D(K) is the upstream volume diameter. It is recommended that the user input the actual physical values for A(K), A_t, and D(K). This formula is empirical in nature 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, which is one of our developmental assessment separate effects test problems. In addition, it has been used successfully in many Semiscale test comparisons for the break flow. If the user selects the smooth area change option, the code uses the following formula:

$$(dA/dx)_{t,smooth} = [A(K) - A_t]/[0.5\ DelX(K)]$$

where A(K) and A_t are the same as defined in the abrupt area change option and DelX(K) is the upstream volume length. Since the smooth area change option is not recommended, this formula has had little assessment.

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. Internal choking is allowed, but may not be desirable under certain conditions.

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 simulation, 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 pull through and/or liquid entrainment models are used to predict the void fraction of the branched flow. The use of these models for modeling tees, plenums, and leak paths will be discussed in greater detail.

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 4. 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. However, the semi-implicit scheme in RELAP5/MOD2 has a time step scheme that permits violation of the material Courant limit in an isolated volume. Thus, this modeling practice will not result in a time step restriction unless the connecting volumes are also short (i.e., such as Volumes V1, V3, or V4). 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, while the half associated with Volume V2 is a crossflow junction. The junction specification is made using the junction flag vcahs which is Word W6(I) of cards CCC0101 through CCC0199 (see Appendix A, Section 7.4.1). 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.

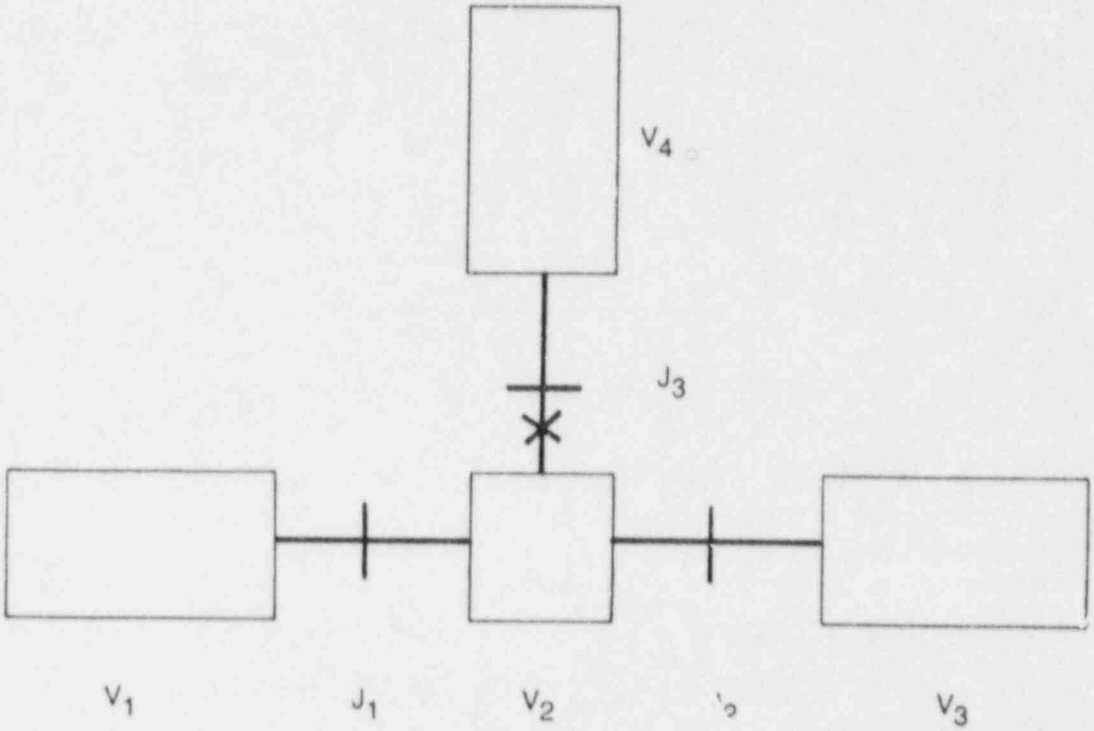


Figure 4. A 90-degree tee model using a crossflow junction.

A tee can also be modeled using the branch component as illustrated in Figure 5. 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 5 may be a more accurate representation of the physical process (such as for a wye).

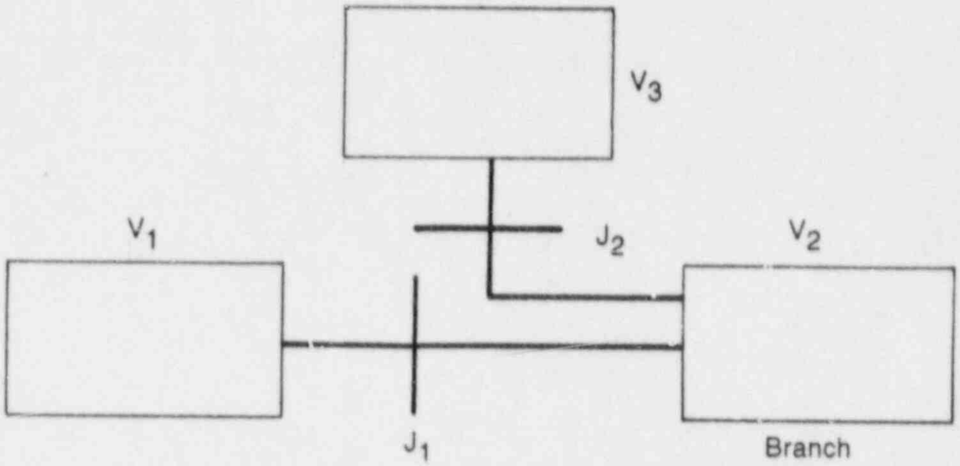


Figure 5. Tee model using a branch component.

2.2.3.2 Branch. The branch model is an approximation of the flow process that occurs at merging or dividing flows such as at wyes and plenums. This model does not include momentum transfer due to 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. The application of this model is discussed under the component section.

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 6. The figure is only one example and implies merging flow. Additional junctions

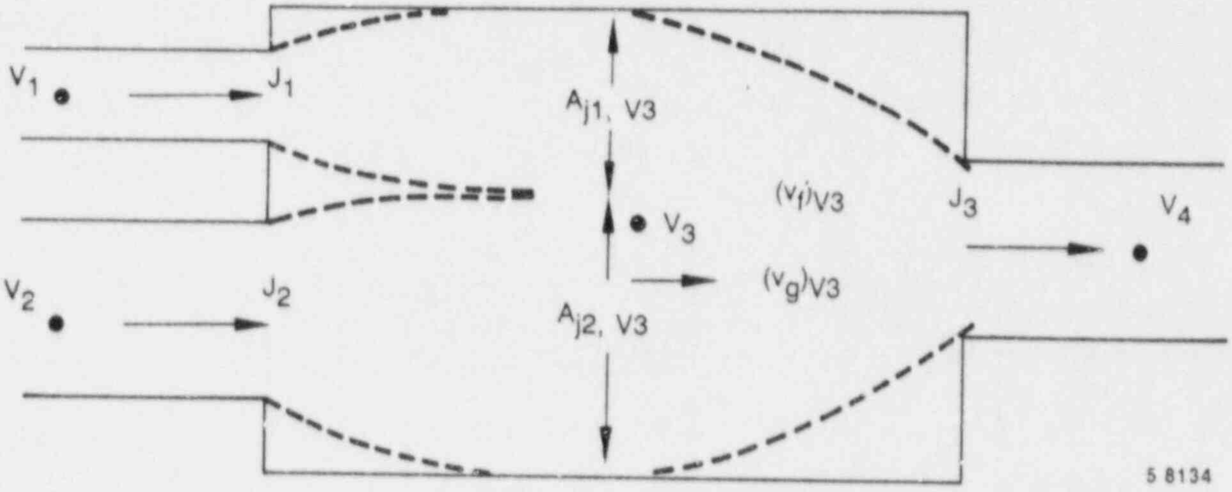


Figure 6. Typical branching junctions.

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, and thus, flow out of Volume V_3 through Junction J_1 and into Volume V_3 through Junction J_2 is permitted.

The volume velocities are the arithmetically averaged, volumetric flow weighted and volume flow area normalized inlet and outlet velocities. 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. The stream tube formulation is 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. Abrupt area or smooth area change options may be specified at each junction. However, if the smooth area change is specified, large changes in flow can lead to unphysical 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 7. The

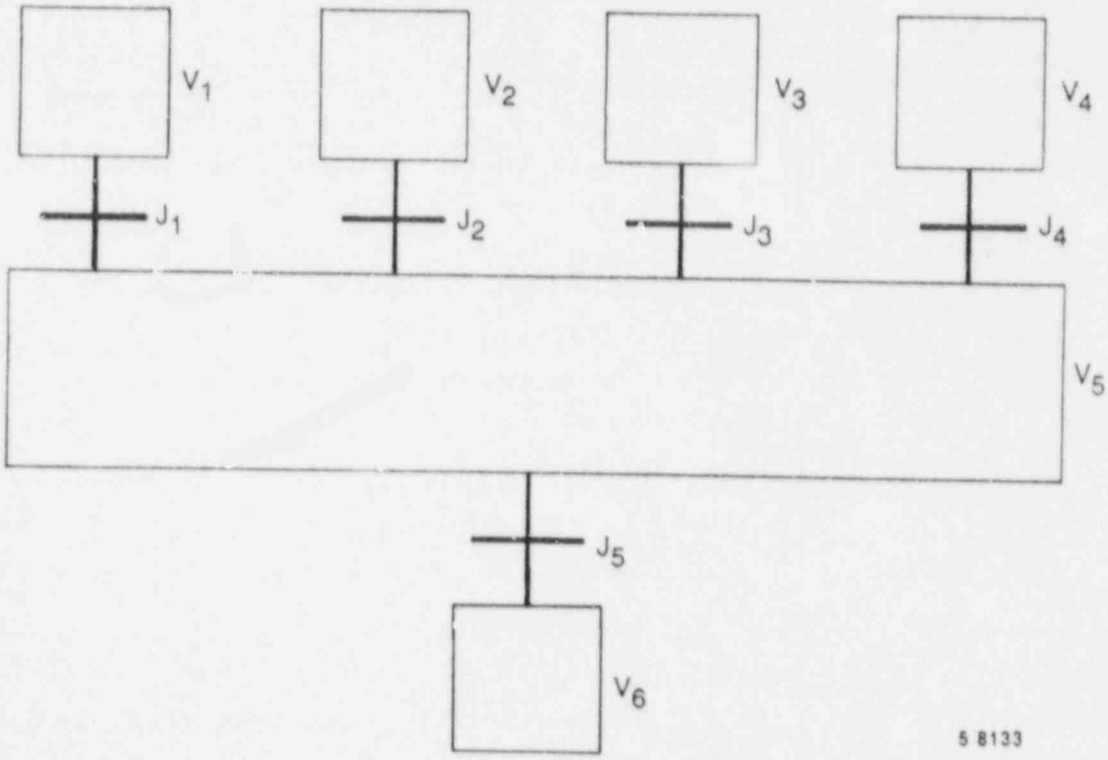


Figure 7. Plenum model using a branch.

flows in such a configuration can be either inflows or outflows. The junction 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; however, differences in loop elevation closure will occur due to the fact that no elevation change is associated with a crossflow junction.

A wye is modeled as illustrated in Figure 6 using the branch components. The flow can either merge or divide. Either the smooth or the abrupt area change option may be used depending upon whichever is appropriate. Here again, if large area changes occur either from volume to junction or from junction to junction, then the abrupt area change option is recommended.

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 junction. As a result, the momentum flux, wall friction, and hydrostatic head terms are omitted and the flow resistance is 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 and 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 8. In such an application it is necessary that the volume centers of Volumes V_1 and V_2 have the same elevation.

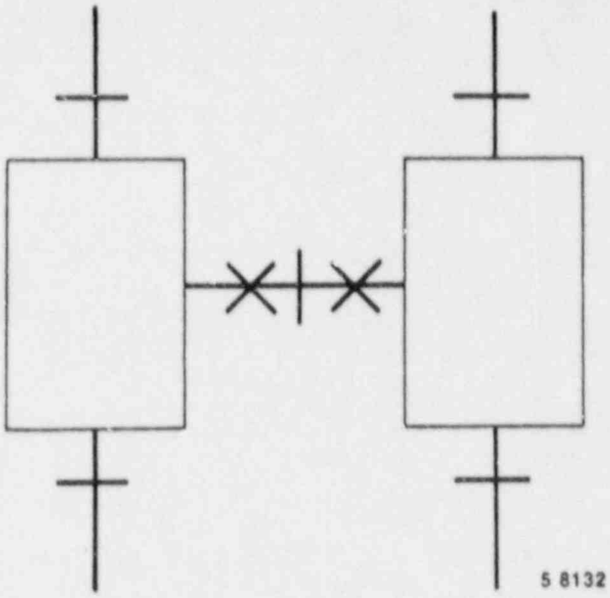


Figure 8. Leak path model using the crossflow junction.

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 option is used for the junction (the vcahs flag with a = 0) and the junction area is allowed to default (the minimum area of the adjoining volume areas). 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 nominal pressure drop, fluid density, junction area, and nominal mass flow rate in the loss factor, and is shown as

$$K = 2\Delta P A^2 \rho / \dot{m}^2 \qquad (1)$$

where all quantities are in SI units (Pa for pressure, m^2 for area, kg/m^3 for density and kg/s for the mass flow rate).

The value computed for K in this way may be very large because the default area is much larger than the actual flow area. Both the forward and reverse loss coefficients should be equal unless there is a reason why they are physically different. In this case, Equation (1) 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 9.

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 (<u>vcahs</u> with <u>a</u> = 0). The determination of the loss factor may require some experimentation because of the possible large momentum flux effect, which is ignored in the derivation of Equation (1). 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 (1) can be replaced by K+1 [i.e., the user input loss factor is computed by substituting K+1 for K in Equation (1)].

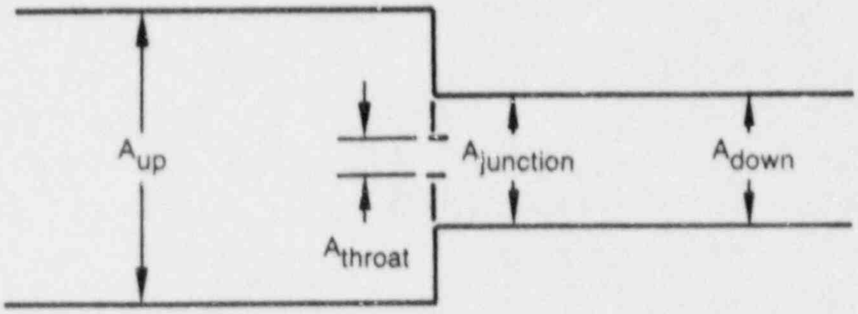
All of the development herein assumes that known pressure drop flow relations exist for the single-phase case and that compressibility effects are small. If such is not the case then the effective loss factor values must be determined experimentally by running the code for a series of cases. Some experimentation may be required since the actual momentum flux calculation is complicated by several factors and may differ slightly from the simple Bernoulli form.

2.2.4 <u>Reflood Model</u>

The reflood heat transfer correlations used in the nucleate and transition regions are specialized for the low pressure and low flow cases typical of reflood situations. Thus, the reflood model should only be used for pressures <1.0 MPa and mass fluxes $<200\ \mathrm{kg/s \cdot m^2}$.

The reflood model is designed so that it is activated either by low pressure or by user command through a trip. In general, the time when the

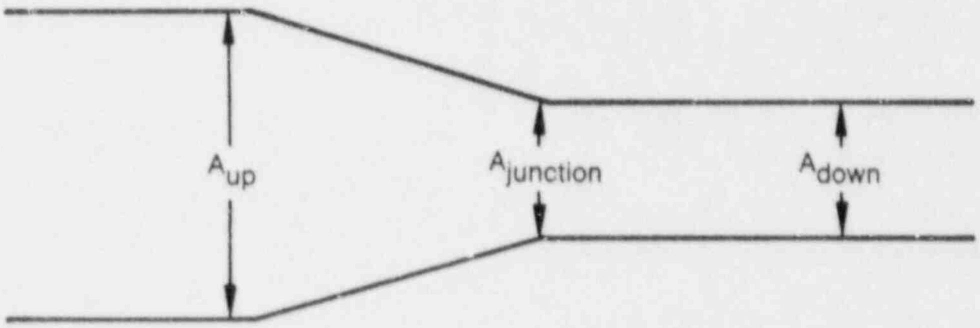
Abrupt area change (VCAHS = 0100)



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

Physical situation with a loss factor K_{actual}

Smooth area change (VCAHS = 0000)



Equivalent model with effective loss factor for the same pressure drop-flow relation

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

5 8139

Figure 9. High resistance flow path model.

reflood model is activated need not coincide with the time the liquid enters the core. In fact, the most appropriate time to activate the reflood model is when the pressure is <1 MPa and the core is nearly empty.

The reflood 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, 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. 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 0.6 ft long heat structures.

2. Appropriate length of hydrodynamic volumes is 0.5 to 2.0 ft.

3. Maximum user specified time step size is 0.01 to 0.05 s.

4. Reflood units may be connected in parallel or in series. However, series connection may yield unphysical results and is not recommended.

5. It is recommended that each reflood unit have its own flow channel and that parallel flow channels be connected by crossflow junctions.

6. Do not apply the model to cases where wall condensation effects are important.

The number of heat-structure geometries that can be specified for reflood calculation is limited only by computer storage capacity. Once the reflood model is activated for a particular heat-structure geometry, only the structure where the critical heat flux is located will have a value in the critical heat flux column of the output. Also, one of the following four heat transfer modes will appear in the mode column:

41 single-phase liquid ($\alpha_g = 0$)
42 nucleate, transition, and dispersed film boiling
43 dispersed film boiling ($\alpha_g > 0.999$)
44 single-phase vapor ($\alpha_g = 1.0$)

2.2.5 Noncondensibles

At the present time, a value of 4 for the control word in the volume initial condition card is recommended. Only a saturated noncondensible state (100% humidity) can be obtained by this option. To get a nonequilibrium state, a value of 6 for the control word must be used. This option, however, has not been fully tested and may not work under certain circumstances. Improvement of input conveniences for initial noncondensible states is currently under consideration.

2.2.6 Water Packing

There is no input required to use the water packing mitigation scheme. The scheme is invoked if the detection criteria are met. (See Subsection 3.1.4.6 in Volume 1 of this manual.)

There is one output change for the water packing model. Each time water packing is detected in a volume, the one line messages shown in Figure 10 are printed out. The message provides the time (TIMEHY), the number of attempted advancements (NCOUNT), the volume (VOLNO), and the junction (JUNNO) to which the large coefficient (10^6) is applied.

```
WATER PACKING OCCURRED, TIMEHY =   5.150000    , NCOUNT =        142, VOLNO = 003050000, JUNNO = 003050000
WATER PACKING OCCURRED, TIMEHY =   5.125000    , NCOUNT =        143, VOLNO = 003050000, JUNNO = 003050000
```

Figure 10. Output from the water packing model.

2.3 Specialized Hydrodynamic Components

2.3.1 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.

2.3.1.1 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.

2.3.1.1.1 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). This data is generally available from pump manufacturers. 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 required pump component input.

A pump component uses the homologous curve form of pump characteristics. The 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 , the regimes that are described.

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

Pump head data is 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. However, both head and torque are used to determine pump 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 would accelerate the flow in the volume coordinate direction; and the torque is that exerted by the fluid on the pump that 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.

2.3.1.1.2 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 by dimensional analysis that can only provide the conditions for similarity. Three independent parameters are obtained from application of Buckingham's Pi theorem. They are

$$\pi_1 = Q/(\nu D) \tag{2}$$

$$\pi_2 = NQ/(gH)^{3/4} \tag{3}$$

$$\pi_3 = Q/(ND^3) \quad . \tag{4}$$

A fourth parameter that is commonly used can be obtained from π_2 and π_3 for which

$$\pi_4 = gH/(N^2D^2) \quad . \tag{5}$$

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 due to skin friction are small and, in practice, the requirement to maintain π_1 constant is too restrictive. Thus, π_1 is not generally used in pump similarity analysis. The use of π_2 and π_3 or π_4 to account for dynamic effects has proven quite useful. In fact the parameter π_2 is called the specific speed and is often used as the single parameter to characterize the type of pump impeller combination best suited for a particular application. In practice, the g is dropped and the specific speed is defined as

$$N_s = NQ/(H)^{3/4} \tag{6}$$

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.

The other two performance parameters that are of interest for pump modeling in RELAP5 are the specific capacity

$$Q_s = Q/(ND^3) \tag{7}$$

and the specific head

$$H_s = H/(N^2D^2) \quad . \tag{8}$$

The D that appears in Equations (7) and (8) is a characteristic dimension of the pump and is assumed to be the impeller diameter. However, when scaling a pump using homologous parameters, the implication is that all pump dimensions are similar (i.e., changing D implies changing impeller width and leakage paths in proportion to any change in D).

When the pump power or torque performance is included, one additional homologous parameter is obtained from dimensional analysis and becomes

$$\pi_5 = \tau/(\rho N^2D^5) \tag{9}$$

where π_5 is the specific torque.

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

$$\tau_s = \tau/(N^2D^5) \quad . \tag{10}$$

Homologous states are states for which specific capacity, head, and torque are all constant. Thus, at any state it is possible to predict the performance for other combinations of speed, head, and flow that have the same homologous state. It is also possible to scale with reasonable accuracy to other pump sizes through the diameter D as long as the homologous parameters remain fixed.

Pump performance data usually display head and torque as functions of speed and volumetric flow. Figure 11 is called a four quadrant pump graph and has speed and flow as independent variables. Lines of constant head are plotted.

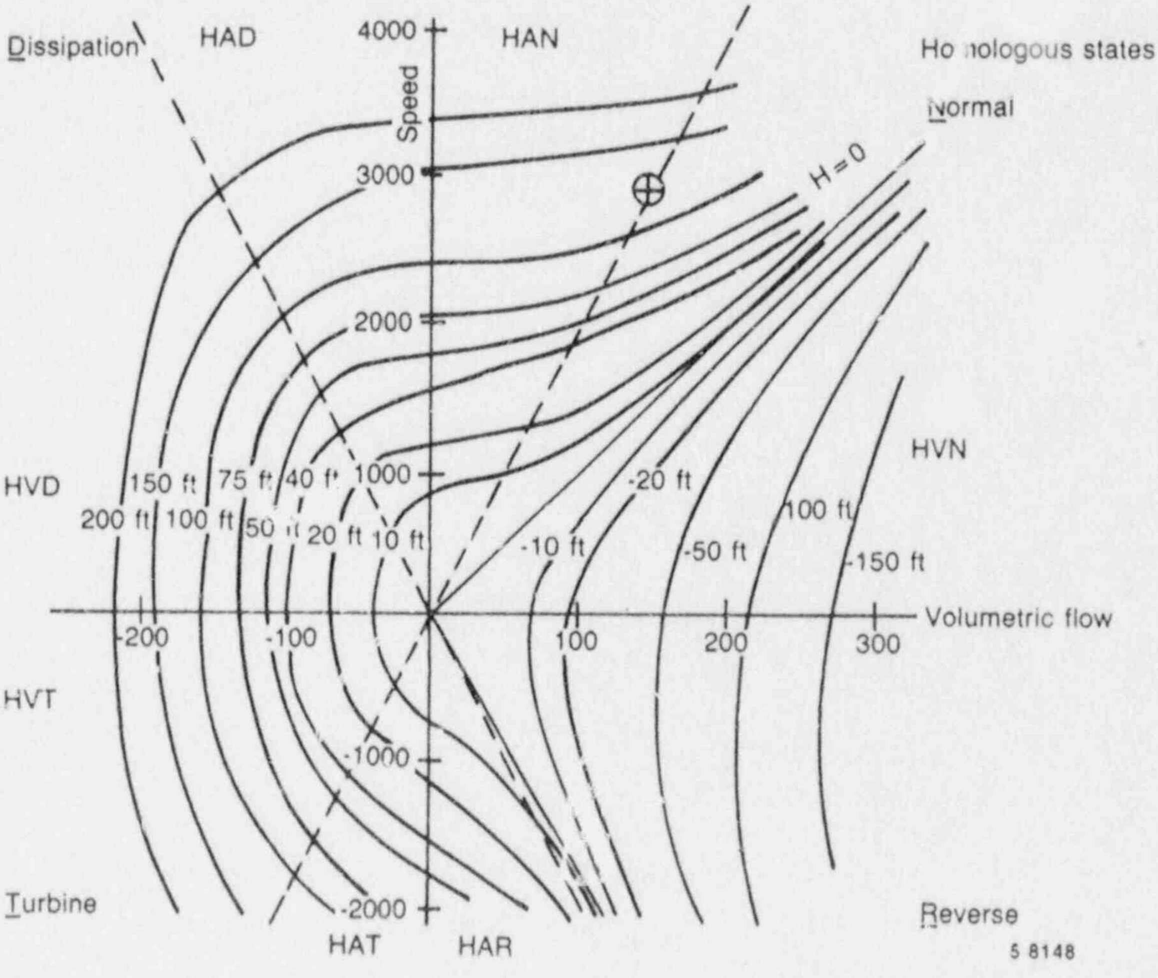


Figure 11. Four quadrant head curve.

Figure 12 is a comparable four quadrant plot of pump torque data. All possible operating states of the pump can be represented on such a plot. However, each pump can be approximately collapsed into a single curve by using the homologous specific head and capacity parameters.

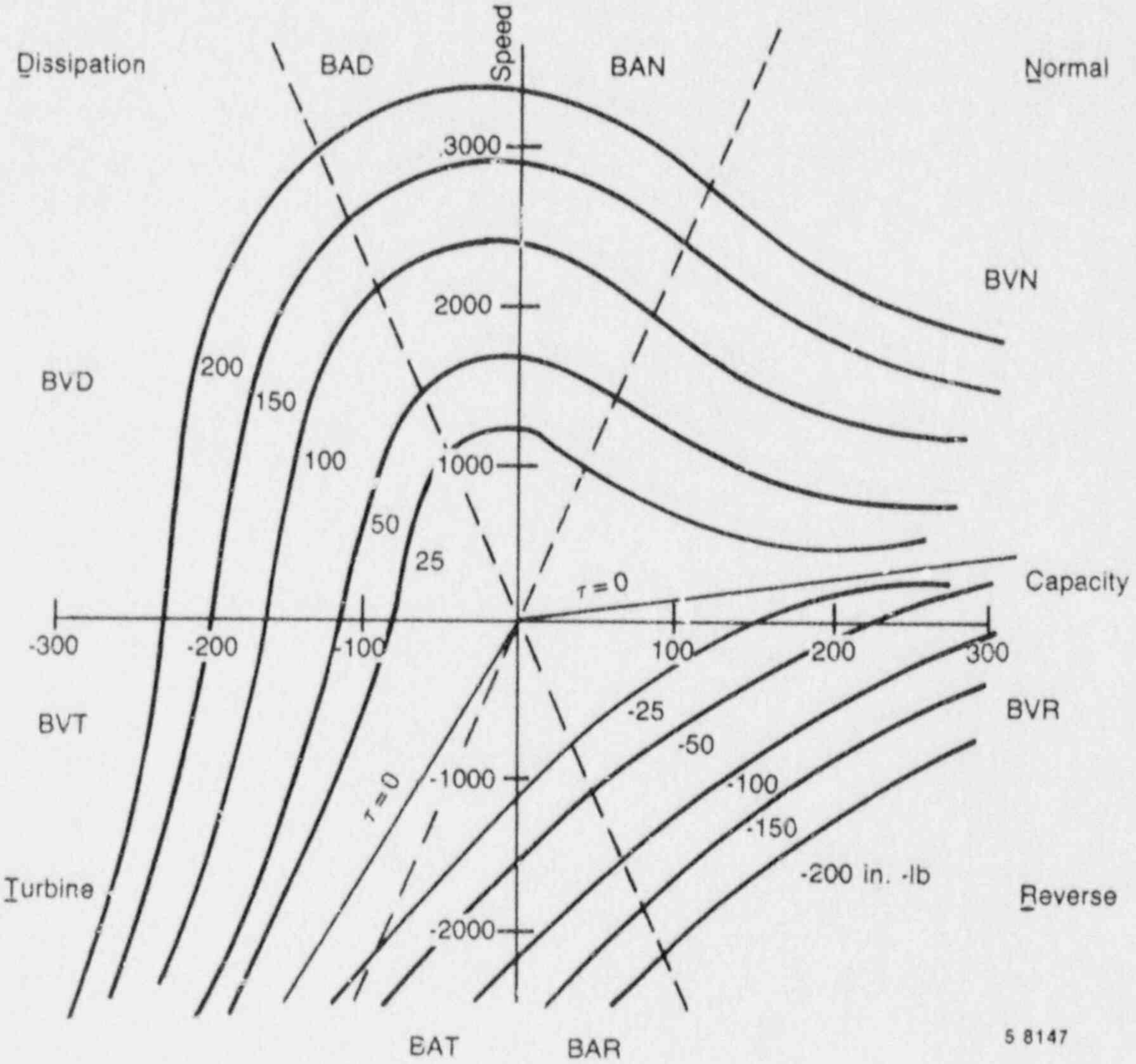


Figure 12. Four quadrant torque curve.

All points having the same specific capacity are straight lines passing through the origin (lines of constant Q/N). The design operating point is indicated by the cross. The homologous line 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 1.

TABLE 1. PUMP HOMOLOGOUS CURVE DEFINITIONS

							Dependent Variable	
Regime Number	Regime ID	Mode Name	α	v	v/α	Independent Variable	Head	Torque
1	HAN BAN	Normal	>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	Energy	>0	<0	≥ -1	v/α	h/α^2	β/α^2
4	HVD BVD	Dissipation	>0	<0	< -1	α/v	h/v^2	β/v^2
5	HAT BAT	Normal	≤ 0	≤ 0	≤ 1	v/α	h/α^2	β/α^2
6	HVT BVT	Turbine	≤ 0	≤ 0	>1	α/v	h/v^2	β/v^2
7	HAR BAR	Reverse	≤ 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

α = Rotational velocity ratio

v = Volumetric flow ratio

h = Head ratio

β = Torque ratio

The pump head and torque maps in Figures 11 and 12 can be reduced to the homologous curves by 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 the 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 ±1.0). Figure 13 is the homologous head curve that is obtained from the head map in Figure 11. Note that not all points fall on a single curve.

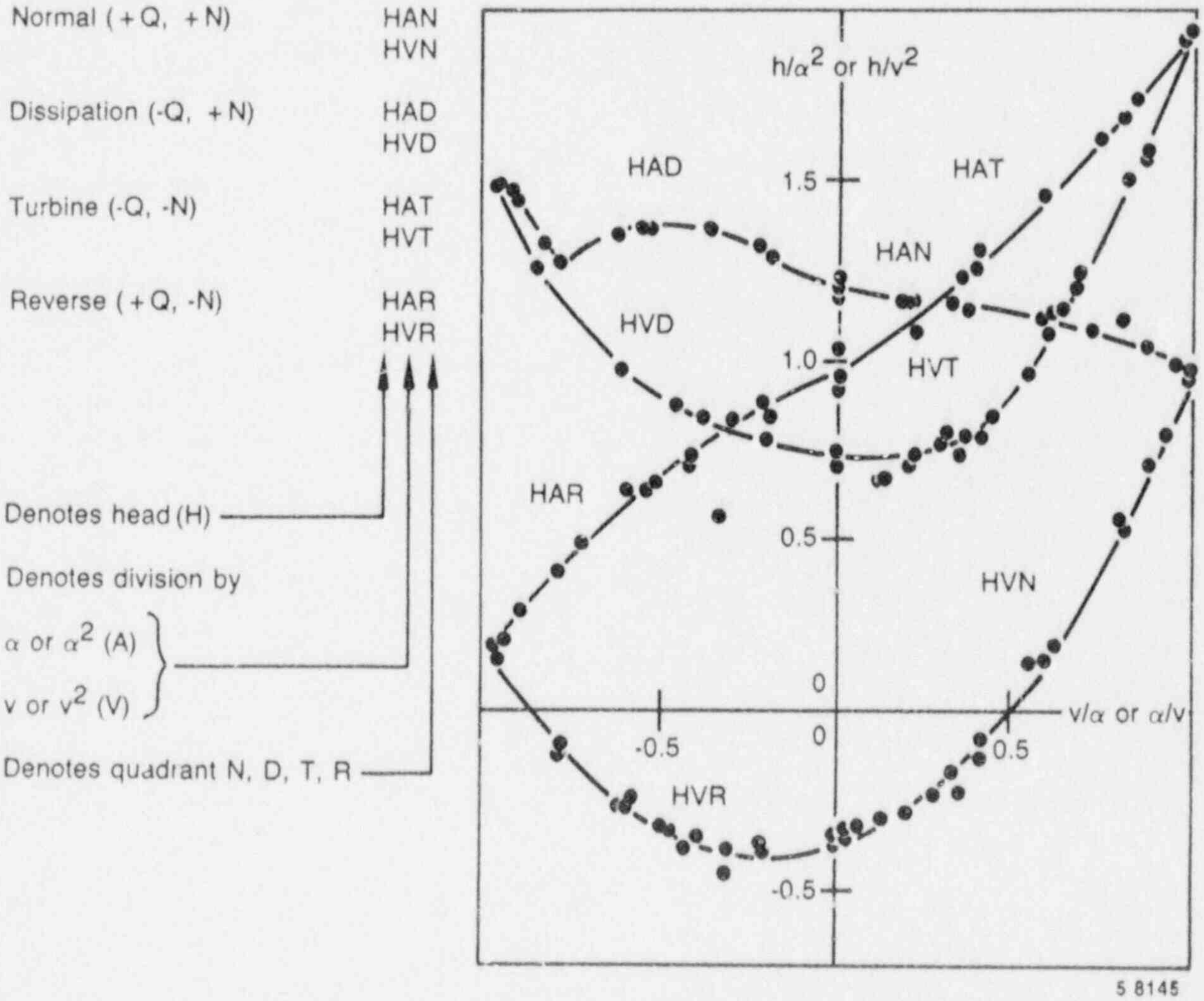


Figure 13. Homologous head curve.

This is a result of the inexact nature of the similarity relationships represented by the homologous parameters. Real pumps do not perform exactly according to the homologous relations, however, the correspondence is surprisingly close, as evidenced by the tight clustering of points. The homologous curve for the torque data of Figure 12 is shown on Figure 14. Since the data do not form a single curve, the 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 13 and 14 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 unique segment of the homologous curve.

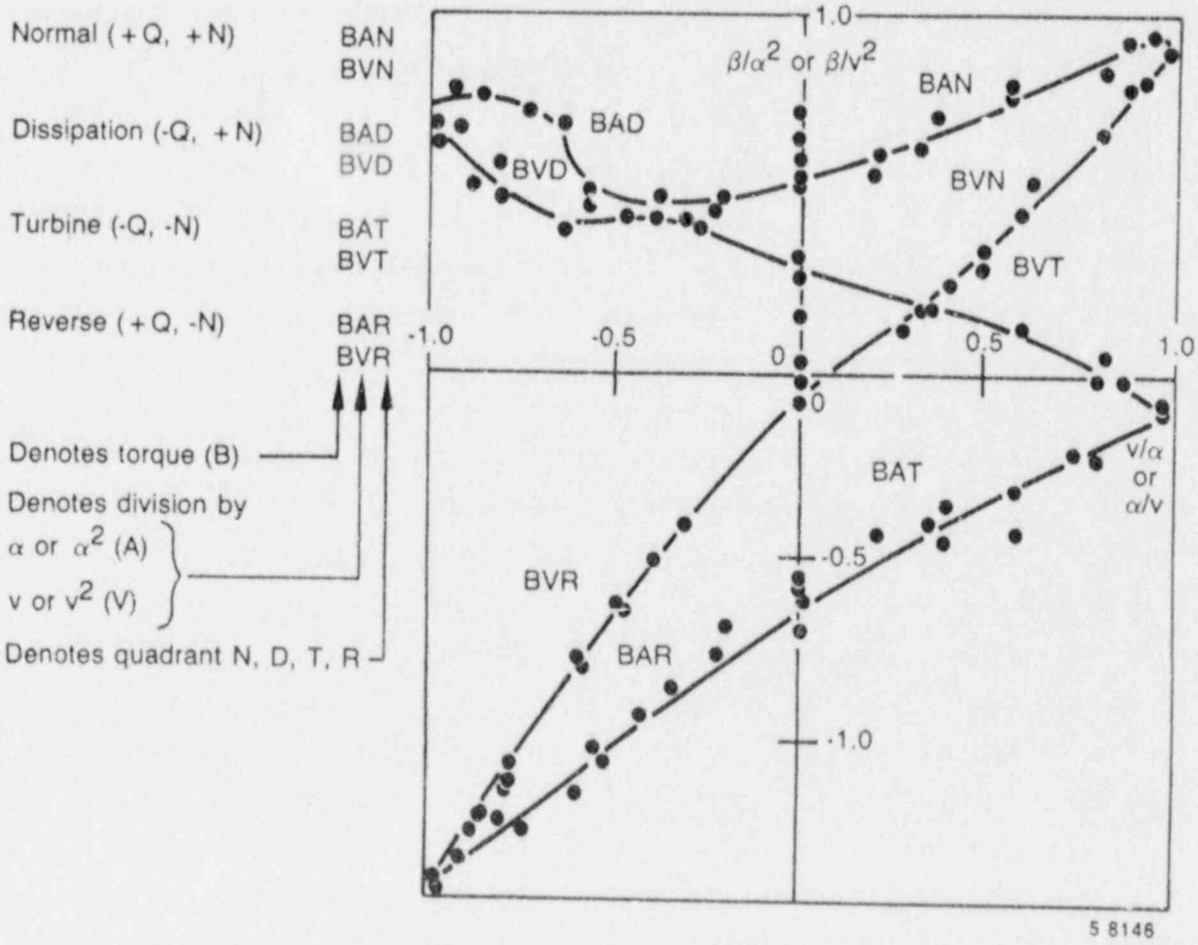


Figure 14. Homologous torque curve.

The advantage of using the homologous pump performance model in a computer code is obvious because two-dimensional data arrays and two-dimensional interpolation are avoided. Instead, only two parameter tables and one-dimensional interpolation are required.

2.3.1.1.3 Homologous Data and Scaling--In most system simulation tasks incomplete pump performance data are 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 not possible to test the pumps in all octants of operation or even very far from design conditions. The best approach to obtain data for such systems is through the use of scaled down pump tests.

The scaled pump test can be for the same physical pump operated at reduced speed or for a pump scaled in size. For the case of a pump scaled in size it is necessary to consider the specific head, capacity, speed, and torque parameters with the impeller diameter included (Note that the diameter was dropped in the development of the homologous performance model since a fixed configuration was considered). The homologous parameters including the impeller diameter are given in Equations (7), (8), and (10). When change in scale is considered, an additional degree of freedom is introduced since only two parameters are to be held constant, the rated specific head and capacity. There are many combinations of N and D for which this is possible. The specific speed is also held fixed whenever both specific head and capacity are kept fixed.

The usual situation encountered in applications work is that homologous data exist for a similar pump and the question arises, "Can we use this data to simulate our pump by adjusting the rated parameters?" This question can best be answered by the following statements. First, the best approach is to use only the rated conditions for the pump used to generate the data. Second, it may be possible if the pump used to generate the data has the same specific speed as the pump to be modeled. Similarity is assured if they also have the same specific head and capacity. The rated conditions are used to locate the region of pump operation on the homologous performance curve since they are the basis of the nondimensionalization and they provide the same reference as long as the relationship among the rated parameters is such that the specific head and specific capacity are kept constant (note that this implies that the specific speed is also constant). 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 that depends more heavily on the validity of the pump similarity relationships that are in turn only approximate.

2.3.1.1.4 Two-Phase Performance Representation--The previous discussion 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.[1] The approach is one in which the two-phase performance data is 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

$$H = H_{1\phi} - M_H(\alpha_g)\ \Delta H \tag{11}$$

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 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 this data is widely used for prediction of two-phase performance of other pumps.

2.3.1.1.5 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 Subsection 4.2.3 the available shaft component capabilities are described and user suggestions are given.

Pump frictional torque (TF) is modeled as a cubic function of the pump rotational velocity. The FORTRAN notation for the cubic function is

$$S = \frac{V}{VR} \tag{12}$$

$$SA = ABS(S) \tag{13}$$

$$TF = -SIGN(TF0 + TF1*SA + TF2*SA**2 + TF3*SA**3, S) \tag{14}$$

where V is pump rotational velocity, VR is rated pump rotational velocity, TF0, TF1, TF2, and TF3 are input data, and SIGN is a function whose result is the magnitude of the first argument with the sign of the second argument.

LOFT 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 (IP) is defined in FORTRAN notation,

$$S = ABS\left(\frac{V}{VR}\right) \qquad (15)$$

$$IP = IN \qquad S < SL \qquad (16)$$

$$IP = I0 + I1*S + I2*S**2 + I3*S**3 \qquad S \geq SL \qquad (17)$$

where V is pump rotational velocity, VR is rated pump rotational velocity, and IN, I0, I1, I2, I3, and SL 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.

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 by table lookup and interpolation 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.

2.3.1.2 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 water 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 due 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 the initial pump angular rotational velocity is zero and a pump motor torque curve for an induction motor is used. A typical motor torque curve is shown in Figure 32 in Volume 1 of this manual. 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 due 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.

2.3.1.3 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. These 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.

2.3.1.4 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.

2.3.2 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 15 contains a schematic showing the typical nodalization used for a jet pump mixing section.

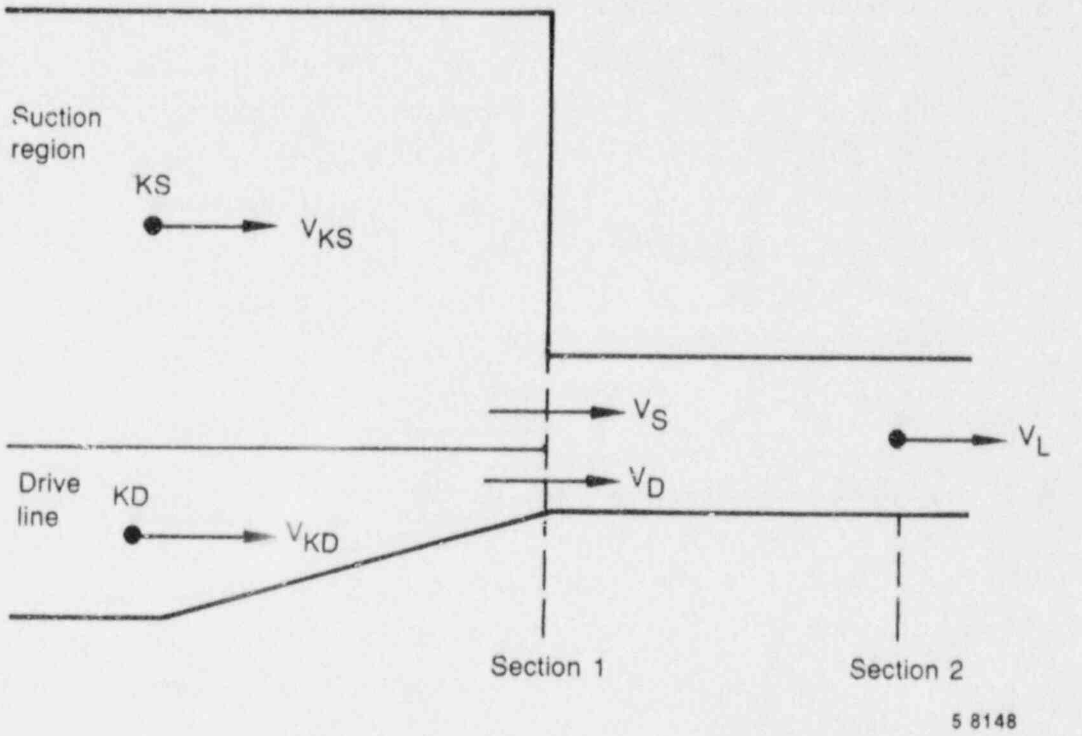


Figure 15. Schematic of mixing junctions.

2.3.2.1 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 ≠ 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 junction in the mixing section.

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

2.3.2.2 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 junction 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 (see Subsection 3.1.5.3 in Volume 1 of this manual) 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.

2.3.2.3 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,

$$M = W_S/W_D \tag{18}$$

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,

$$N = \frac{(P + \frac{1}{2}\rho v^2 + \rho gH)_{Dis} - (P + \frac{1}{2}\rho v^2 + \rho gH)_S}{(P + \frac{1}{2}\rho v^2 + \rho gH)_D - (P + \frac{1}{2}\rho v^2 + \rho gH)_{Dis}} \ . \tag{19}$$

Figure 16 shows an expanded view of the normal operating region (1st 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 mixing junction. This figure gives an indication of the quantitative change in performance caused by the respective drive, suction, or mixing 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 it is recommended that standard handbook losses be applied.

2.3.2.4 Output. There is no special output printed for the JETMIXER component. It is recommended 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.

2.3.3 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

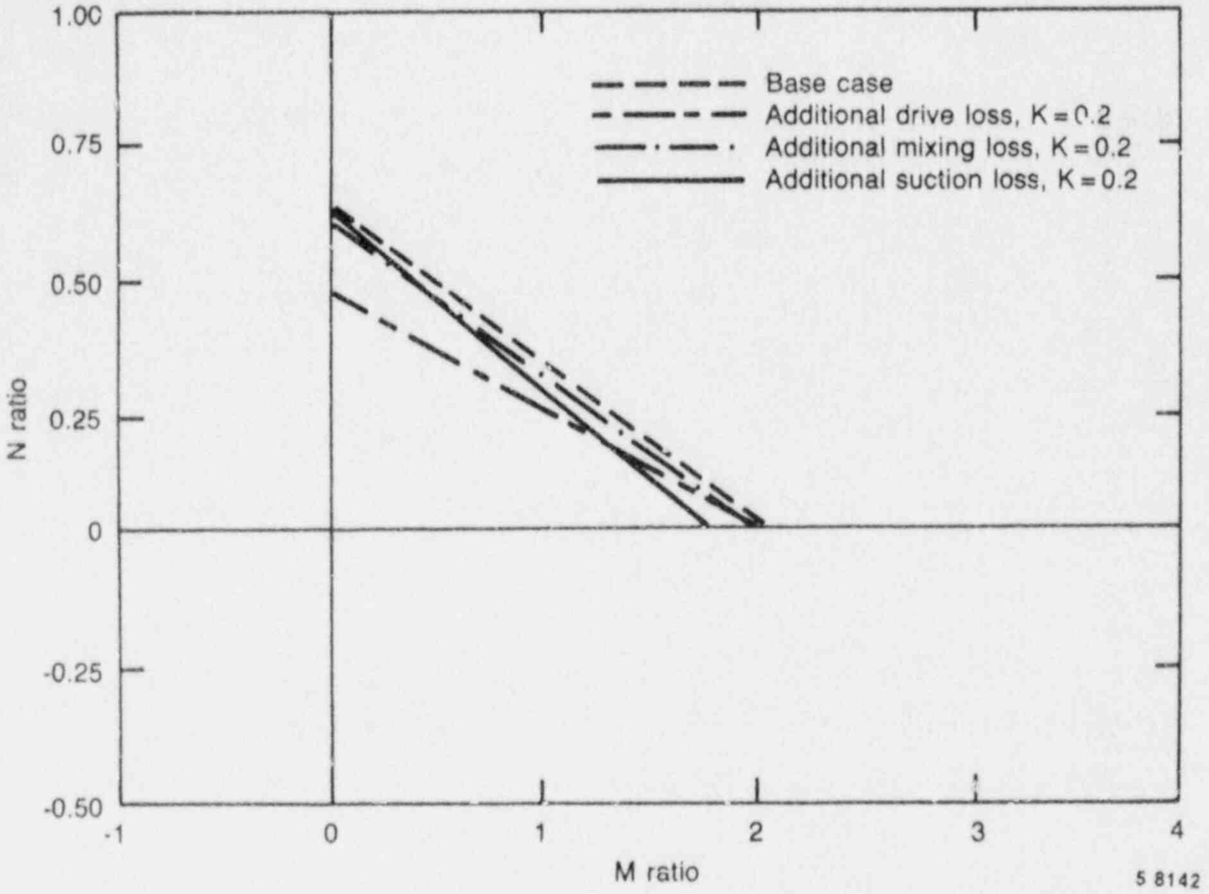


Figure 16. Jet pump model design.

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 <u>on/off</u> 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 utilize the valve models some characteristics and recommendations for each valve are discussed in the following subsections.

2.3.3.1 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.

2.3.3.1.1 Static Pressure Controlled Check Valve--Equation (423), Volume 1, models 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 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.

2.3.3.1.2 Flow Controlled Check Valve--Equations (423) and (425), Volume 1 of this manual, model 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 of Equation (423) 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, Equation (425) 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.

2.3.3.1.3 Dynamic Pressure Controlled Check Valve--Equations (424) and (425), Volume 1 of this manual, model 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 as for Equation (423). 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.

2.3.3.1.4 Check Valve Closing Back Pressure Term PCV--In the formulations of Equations (423) and (425), Volume 1 of this manual, the term PCV is used and in the input requirements this term is designated as the closing back pressure. However, to be precise, PCV is a constant representing an actuation setpoint. If positive, PCV behaves as a back pressure acting to close the valve. In both the static and the dynamic pressure controlled valves, PCV acts both as an actuation setpoint 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 setpoint for opening a closed valve.

2.3.3.2 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.

2.3.3.3 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 inertia effects simply input the flapper mass and moment of inertia as zero. The user must, however, use care in defining the flapper angle terms with respect to the implied junction forward direction or it may be made impossible for the model to open or close the valve. Also, 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.

2.3.3.4 Relief Valve Model. A scheme was designed to input the terms required to define the 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.

2.3.4 Separator

Figure 17 contains a schematic showing the typical nodalization used for a separator and the adjoining bypass and downcomer regions. If there is any possibility of a recirculation flow through a bypass region it is recommended that this flow path be included. In general, there will be a mixture level at some location in the downcomer volumes.

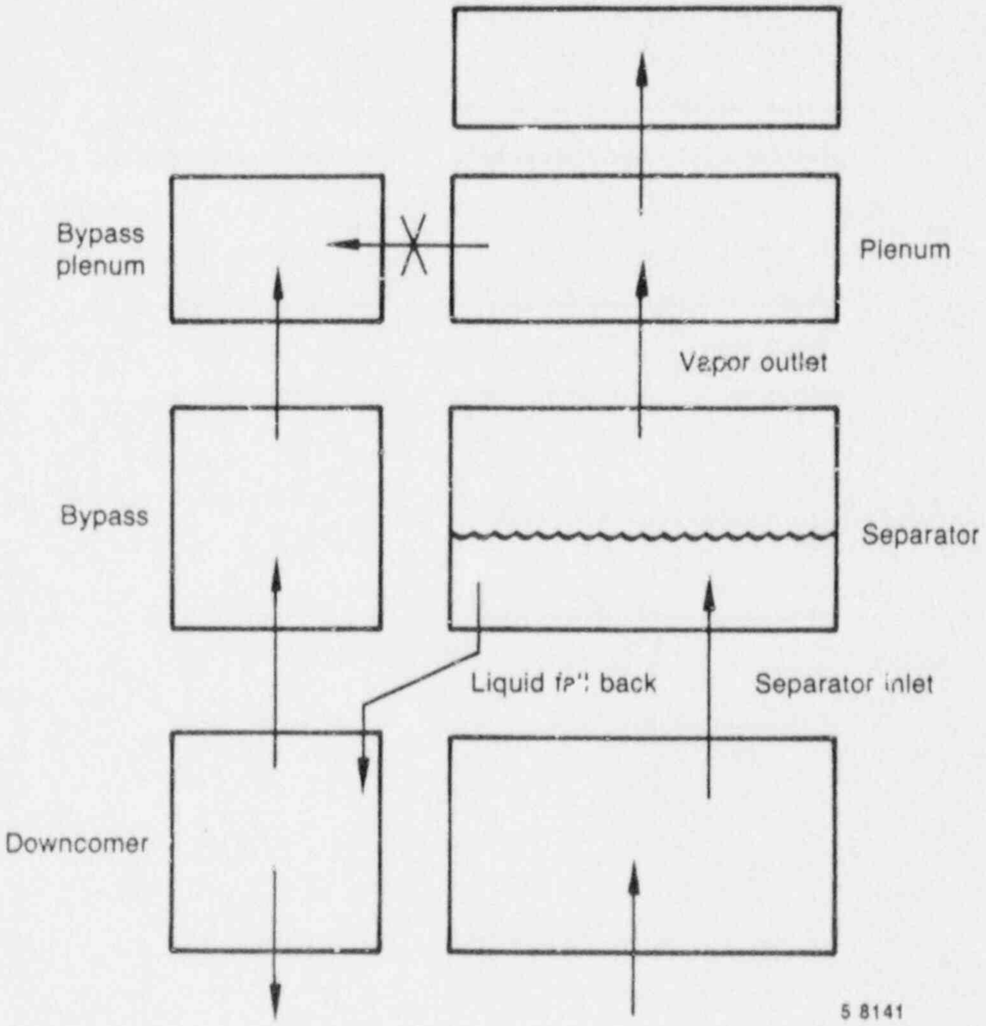


Figure 17. Schematic of separator.

2.3.4.1 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 as separate 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 junction must refer to the outlet of the separator (CCC010000). The FROM connection for the liquid return junction must refer to the inlet of the separator (CCC000000). The inlet junction should also be connected to the separator inlet side (CCC000000).

4. A word, W7(R), is added to the BRANCH component junction geometry cards CCCN101 for the SEPARATR component. 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.

2.3.4.2 Recommendations. 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, it is recommended that choking be turned off for all three junctions. The nonhomogeneous option 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 as preliminary.

The black box nature of the separator along with the use of VOVER and VUNDER may result in some changes to the inputted 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 Figure 22, 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, it is recommended that 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.

2.3.5 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 1 of this manual 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. It is recommended that 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 and 1.0 can be entered. If the turbine stage is a general impulse-reaction stage then the maximum efficiency η_0 is obtained when

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

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

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

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

$$v_t/v = 0.25 \quad . \tag{22}$$

Expressing v_t as $R\omega$ gives

$$R = \frac{0.25v}{\omega} \tag{23}$$

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 = 3). 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 that the smooth junction option should be used at both the inlet and outlet junctions. No special modeling has been included for slip effects nor is 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 cross flow 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 is 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

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

(see Figure 32 in Volume 1 of this manual for the subscript locations) 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.

One should 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. It will give slightly inaccurate storage terms during a transient. The transient storage terms are small so this should not be a problem.

2.3.6 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 1 of this manual. However, 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, hydraulic diameter, and elevation change are reset to

$$AVOL = V/(L_{TK} + L_L) \tag{25}$$

$$DHY = 4V/\pi\ (D_{TK}L_{TK} + D_L L_L) \tag{26}$$

$$DZ = (2DZ_{TK} + g\ DZ_L)/2 \tag{27}$$

respectively. 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 surge line 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. Also, the noncondensible used in the accumulator is that defined for the entire system being modeled. Hence the user must be sure to input the correct noncondensible name on card 110 as discussed in Subsection 2.7 of the Input Requirements in Appendix A.

3. HEAT STRUCTURE MODELING

Heat structures represent the solid portions of the thermal-hydrodynamic system. Being solid, there is no flow, but the total system response is dependent 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 pins, pipe walls, core barrels, pressure vessels, and heat exchanger tubing. 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, CCCGONN. The subfield, CCC, is the heat structure-geometry 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 different types of heat structures. Input data is organized by the 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.

3.1 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 rectangular coordinates and is along the radial coordinate in cylindrical or spherical coordinates. The one-dimensional form assumes no temperature variations along the other coordinates. Figure 18 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 interfaces 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.

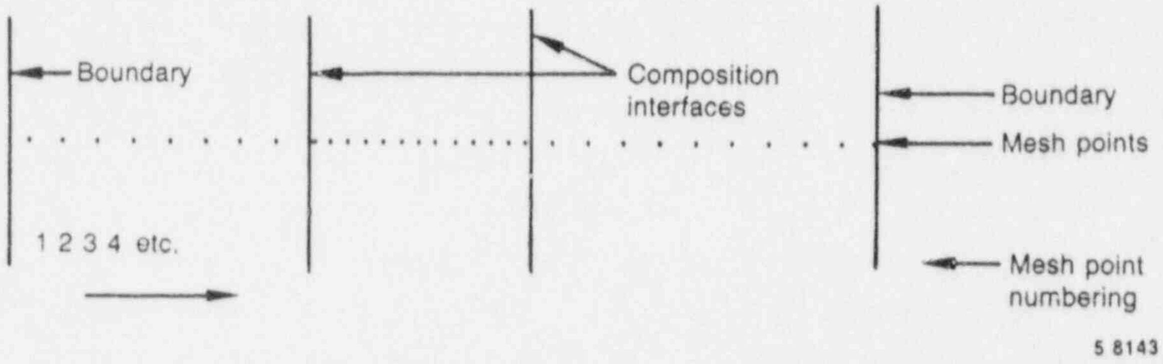


Figure 18. Mesh point layout.

The heat structure input processing provides a convenient means to enter the mesh point spacing and composition placement. Compositions are assigned a three-digit, nonzero number, which 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 property data for compositions not specified in any heat structure is not considered an error but does waste storage space. Thermal property data for aluminum, 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 should not be considered recommended values. Input editing includes the thermal properties and a listing 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,

$$S(x,t) = P_f\, Q(x)\, P(t) \tag{28}$$

where P_f is a scaling factor, Q(x) is a space distribution function, and P(t) is 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, and 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 temperature 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 is heat transferred 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, although the numerical techniques impose the condition regardless of the boundary condition specified. In a rectangular geometry structure 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 water and the reverse heat transfer from water to the surface. The heat transfer modes are listed below with the mode number used in the printed output:

Mode 0	Convection to noncondensible-water mixture
Mode 1	Single-phase liquid convection at critical and supercritical pressure
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

Mode 10 Condensation when void equals one

Mode 11 Condensation when void is less than one

If the noncondensible quality is greater than 0.0001, then 20 is added to the mode number. Thus, the mode number can be 20 to 31.

Generally the hydrodynamic volume would 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.

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 provided; a heat transfer surface area is entered, or, a geometry-dependent factor is entered. For rectangular geometry, the factor is the surface area and 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. 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 have previously been described as consisting of the product of a scaling factor, a space-dependent function, and a time function. The space-dependent distribution has already been discussed. The time function may be total reactor power, fission power, 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 provides 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. 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 3 factors over all the heat structures representing that power value should sum to 1.

This summing to 1 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 record prior to the termination by replacing the thermal property data.

3.5 Heat Structure Output

Two 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. The information on each line is: 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 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 second section prints the mesh point temperatures for each heat structure. This section can be suppressed by an input option.

3.6 Recommended Uses

For the heat structure additional boundary cards (1CCCG801 through 1CCCG899 and 1CCCG901-1CCCG999), we in general suggest using zero for the heat transfer hydraulic diameter. When zero is used, the heat transfer hydraulic diameter is set the same as the hydraulic diameter at the boundary volume, which is defined as

$$D_h = 4 \times \frac{\text{flow area}}{\text{wetted perimeter}} \quad . \qquad (29)$$

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 hydraulic calculation should be used in heat transfer calculation. If the heat structure does not represent the pipe walls, the default probably should not be taken. To scale the surface heat transfer area, the true surface area should be used for the surface area code of the boundary condition data cards (1CCCG501 through 1CCCG599 and 1CCCG601 through 1CCCG699).

4. CONTROLS

4.1 Trips

Extensive trip logic has been implemented in RELAP5. Each trip statement is a single logical statement, but because logical 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 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. 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 provided 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 401-599 for variable trips and Cards 601-799 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. This format is compatible with RELAP5/MOD1 even though MOD1 used only Cards 501-599 and 601-699 and was limited to 99 variable trips and 99 logical trips. An alternate format is selected by entering Card 20600000. Trip data is entered on Cards 206TTTT0, where TTTT is the trip number. Trip numbers 1-1000 are variable trips and trip numbers 1001-2000 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 must be entered.

Several options are available on restart. If no trip data is 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.

4.1.1 Variable Trips

A variable trip evaluates a comparison statement relating two variables and a constant using one of the options, 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 Description (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

$$\text{NUM VAR1 OP VAR2 + CONSTANT } \genfrac{}{}{0pt}{}{\text{L}}{\text{N}} \text{ TIMEOF}$$

where NUM is the card number, VAR1 and VAR2 each consist of two words that identify a variable, the first word is alphanumeric for the variable type, the second word is a number associated with the particular variable; OP is the comparison operation; CONSTANT is a signed number to be added to VAR2 before the 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 options AND, OR (inclusive), or XOR (exclusive). Table 2 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 2. 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

NUM ± TRIP1 OP ± TRIP2 $\genfrac{}{}{0pt}{}{\text{L}}{\text{N}}$

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 complex logical statement. With the definitions given in the examples above and using parentheses to indicate the order of logical evaluation, 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.

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. See also the discussion of trips in Volume 1. 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_o which is to be true when the valve should be opening, P_1 is true when the pressure is >11 bar, and P_2 is true when the pressure is >12 bar. Table 3, is a truth table that has been constructed by listing all possible combinations of the three input variables, V_o, 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, which is used to ensure that all combinations are listed. From the truth table, the following expression can be written,

TABLE 3. TRUTH TABLE EXAMPLES

Output	Input			
V_o	V_o	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

$$V_o = (\bar{V}_o * P_2 * P_1) + (V_o * \bar{P}_2 * P_1) + (V_o * P_2 * P_1) \tag{30}$$

where * indicates AND, + 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 3 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,

$$P_2 * P_1 = P_2 \qquad P_2 + P_1 = P_1 \ . \tag{31}$$

Using the Boolean identities from Table 4, the logical expression can be reduced to

$$V_o = (\bar{V}_o * P_2) + [V_o * P_1 * (\bar{P}_2 + P_2)] = (\bar{V}_o * P_2) + (V_o * P_1) \ . \tag{32}$$

TABLE 4. BOOLEAN ALGEBRA IDENTITIES

$A * A = A \qquad A + A = A \qquad A * 0 = 0 \qquad A + 0 = A$

$A * \bar{A} = 0 \qquad A + \bar{A} = 1 \qquad A * 1 = A \qquad A + 1 = 1$

$A * B = B * A \qquad A + B = B + A$

$A * (B + C) = (A * B) + (A * C)$

$A + (B * C) = (A + B) * (A + C)$

NOTE: * denotes AND, + denotes OR, - above quantity denotes complement.

The following trip input implements the logic. Trips 601 through 603 implement the rightmost expression above. Trip 603 would be specified as the open trip in a motor value and is written

```
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 TRM OF EQ)
602   603 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, 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 Volume 1 of this manual 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 by the 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.

Constant (CONSTANT)

$Y_i = S$

Addition-subtraction (SUM)

$Y_i = S(A_0 + A_1V_1 + A_2V_2 + \ldots)$

Multiplication (MULT)

$Y_i = S\ V_1V_2 \ldots$

Division (DIV)

$Y_i = S/V_1$ or $S\ V_2/V_1$

Integer exponentiation (POWERI)

$Y_i = SV_1^{\ I}$

Real exponentiation (POWERR)

$Y_i = SV_1^{\ R}$

Variable exponentiation (POWERX)

$Y_i = SV_1^{\ V_2}$

Table lookup function (FUNCTION)

$Y_i = S\,F(V_1)$

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

Standard functions (STDFNCTN)

$Y_i = SF(V_1, V_2, V_3, \ldots)$

where F can be V_1, $\exp(V_1)$, $\ln(V_1)$, $\sin(V_1)$, $\cos(V_1)$, $\tan(V_1)$, $\tan^{-1}(V_1)$, $(V_1)^{1/2}$, $\mathrm{MAX}(V_1, V_2, V_3, \ldots)$, and $\mathrm{MIN}(V_1, V_2, V_3, \ldots)$. Only MAX and MIN may have multiple arguments.

Delay (DELAY)

The delay component is defined by

$Y_i = SV_1(t - t_d)$

where t_d is the delay time. A user input h determines the length of 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.

Unit trip (TRIPUNIT)

$Y_i = SU(\pm t_r)$

Trip delay (TRIPDLAY)

$$Y_i = ST_r(t_r)$$

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, U is 0.0 or 1.0 depending on trip t_r (or its complement if t_r is negative) being false or true, and 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.

Integration (INTEGRAL)

$$Y_i = S \int_0^t V_1 \, dt \text{ or } Y_i(s) = \frac{S\, V_1(s)}{s}$$

Differentiation (DIFFERNI OR DIFFERND)

$$Y_i = S \frac{dV_1}{dt} \text{ or } Y_i(s) = S\ s\ V_1(s)$$

Use of DIFFERNI is <u>not</u> recommended and, if possible, any differentiation should be avoided. See the discussion in Volume 1 of this manual.

Proportional-Integral Component (PROP-INT)

$$Y_i = S \left(A_1 V_1 + A_2 \int_0^t V_1 \, dt \right) \text{ or } Y_i(s) = S \left[A_1 + \frac{A_2}{s} V_1(s) \right] .$$

Lag Component (LAG)

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

Lead-Lag Component (LEAD-LAG)

$$Y_i = \frac{A_1 S\ V_1}{A_2} + \int_0^t \frac{(S\ V_1 - Y_i)}{A_2}\,dt \text{ or } Y_i(s) = S\left(\frac{1 + A_1 s}{1 + A_2 s}\right) V_1(s)$$

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 use 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 Subsection 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 units conversion of the input scaling factors or multiplier constants is done when British input units are specified and no units 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 units 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 numbers 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 numbers 205CCCCN can be selected by entering card 20500000. With the alternate format only one digit is used for card sequencing and up to 4095 control components can be used with the four digit CCCC. (The limit of 4095 is due to using a 12 bit field in a packed word.) 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. Card input for the examples are shown except that symbols enclosed in parentheses are sometimes used where the actual card 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

$$W = \alpha_g \rho_g v_g A + \alpha_f \rho_f v_f A \tag{33}$$

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 and one addition-subtraction components 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 would be 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 being 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,1230100
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

$$A_2 \ddot{X} + A_1 \dot{X} + A_{10} \dot{X}X + A_0 X + B\int_0^t X dt = C \quad . \tag{34}$$

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, definition of an integral, and the assignments are

$$Y_1 = \dot{X}X = Y_3 Y_4 \tag{35}$$

$$Y_2 = \ddot{X} = \frac{1}{A_2}(C - A_1 Y_3 - A_{10} Y_1 - A_0 Y_4 - BY_5) \tag{36}$$

$$Y_3 = \dot{X} = \int_0^t \ddot{X}\, dt = \int_0^t Y_2 dt \tag{37}$$

$$Y_4 = X = \int_0^t \dot{X}\, dt = \int_0^t Y_3 dt \tag{38}$$

$$Y_5 = \int_0^t X dt = \int_0^t Y_4 dt \tag{39}$$

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

```
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 (-Ao), CNTRLVAR,4 (-B), CNTRLVAR,5
20500030 XD1 INTEGRAL 1.0 0.0 0
20500031 CNTRLVAR,2
20500049 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

$$\sum_i I_i \frac{d\omega}{dt} = \sum_i \tau_i - \sum_i f_i \omega + \tau_c \tag{40}$$

where I_i is moment of inertia 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 mode, 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 to[illegible] and has storage for its rotational velocity. For example, the [illegible] allows cubic expressions for inertia and friction. The friction [illegible] shown in Equation (40) is used for the shaft itself and the genera[illegible]ment. Each component also has a disconnect trip number. If zero ([illegible] 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

$$\sum_i I_i^n \frac{(\omega^{n+1} - \omega^n)}{\Delta t} = \sum_i \tau_i^n - \sum_i f_i^n \omega^n + \tau_c \qquad (41)$$

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 (41) 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 shaft's and each connected component's rotational velocity.

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 pump model can also be described through the control system and its torque applied to the shaft through a control variable [τ_c in Equation (41)].

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. That capability is discussed in Subsection 2.3.1. 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.

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,

$$\frac{d\omega}{dt} = \tau_m + \tau_h \tag{42}$$

where 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 Figure 30 of Volume 1. 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.

An optional pump component input card 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 and would be used when a turbine is attached to the shaft or 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 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 (described more completely in Subsection 2.3.5 of this volume of the manual) 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 steamline. 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 which can yield results identical to the pump without a shaft and using an implied motor.

4.2.3.5 Pump, Generator, Shaft Sample Problem. Figure 19 shows input data for a sample problem to test pump, generator, and shaft components. (The test problem is included in transmittal package as deck PUMP2.) 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, and the pump coasts down and flow velocities diminish. The second pump uses a pump motor torque table representing an

```
=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
355  P 3110000
356  P 3150000
357  P 3180000
358  P 4010000
359  VELFJ 3010000
360  VELFJ 3070000
361  VELFJ 3180000
362  VELFJ 4010000
363  VELFJ 4020000
364  PMPVEL 004
365  PMPHEAD 004
366  PMPTRQ 004
501  TIME  0  GE  NULL  0  20.0  L
```

Figure 19. Input data for a sample problem to test pump, generator, and shaft.

```
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,  2264.780,  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
23002  0.6,  0.97  0.8,  0.9  0.9,  0.8  0.96,  0.5  1.0,  0.0
23100  0
23101  0.0,  -0.17  0.0001,  -0.17  0.006,  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
31201  3,  2264.780,  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  2264.78  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  3528.,  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.
```

Figure 19. (continued).

```
=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
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  1.0  0  0
20500301  CNTRLVAR,  1  CNTRLVAR,  2
20500400  BR.TRQ  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  4320.0,  -1.90
20201003  5040.0,  -1.20  5760.0,  -1.05  6480.0,  -1.00
20201004  7200.0,  -0.98
20502000  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
```

Figure 19. (continued)

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.

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, and thus, all needed data must be entered even if it duplicates 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 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 decay product power; or fission, fission product decay, and actinide decay power. Actinide decay power is the power resulting from production of U^{239} by neutron absorption in U^{238} and subsequent two stage beta decay to Pu^{239}.

Two sets of fission product decay data are built into the code. The default set is the eleven group ANS standard proposed in 1973.[2] The other set of data is from the 1979 ANS Standard for Decay Heat Power in Light Water Reactors.[3] The 1979 data specifies data for three isotopes, U^{235}, U^{238}, and Pu^{239}, 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 U^{235} isotope data from the 1979 standard. Actinide data is 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 U^{238} atoms consumed per U^{235} atoms fissioned, but additional conservative factors can be applied. User supplied data can be entered for fission product and actinide data.

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 U^{238} is present. The new standard is recommended because it is an approved standard and the variance of the 1979 data to experimental data is much less than 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.

5.2 Reactivity Feedback Options

Three reactivity feedback options are provided; one assumes separability of feedback effects, the others use three or four dimensional table lookup and interpolation. The defining equations are given in Subsection 3.5.6 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_0, a bias reactivity r_B, and sums over scram curves and control variables.

The quantity r_0 is an input quantity and is the reactivity corresponding to the assumed state reactor power at time equal to zero. This quantity must be less than or equal to zero. A nonzero quantity indicates a neutron source is present. For most applications, r_0 equal to zero is acceptable.

The bias reactivity r_B is calculated during input processing such that $r(0) = r_0$. 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 at input level.

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 proceeds control system evaluation and 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; the other, reactivity as a function of volumetric average fuel temperatures. The tables allow nonlinear feedback due 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 operational 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, dr/dT. The input requires partial derivatives: the moderator density feedback is $\partial r/\partial \rho$; the temperature coefficient is $\partial r/\partial T$.

The four dimensional table lookup and interpolation computes reactivity as a function of moderator density, moderator temperature, volumetric average fuel temperature, and boron density. The three dimensional option does not include boron density. The multi-dimensional 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, Subsection 3.5.6 of this manual, 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 multi-dimensional table where reactivity is known to be very much shutdown, 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 computed for a volume or heat structure, and its contribution to the total reactivity is obtained by multiplying the effect by the weighting factor. This is reversed for the table option.

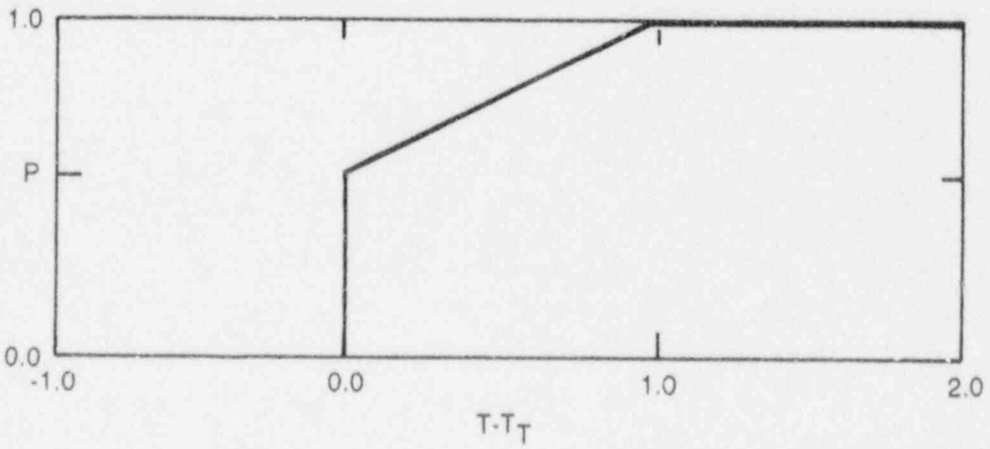
Weighted averaged independent variables for table lookup and interpolation are obtained by using volume or heat structure values and the weighting factors. Table evaluation for the total feedback uses the averaged values. It is possible to define a table equivalent to the separable data. However slightly different transient results would be obtained using the equivalent data due 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 is entered, reactor power will vary as the reactor system moves towards a steady state condition. To prevent this, a control system could be defined to adjust reactivity to maintain constant power. A more simple alternative is to omit reactivity feedback in steady state. At the restart to start the transient, the original reactor kinetics data plus feedback data can be entered.

6. GENERAL 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 transfer rate 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 units 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 is often needed for parameter studies, the input provides for conversion or scaling factors or both 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 use linear interpolation between table values, and the end point values are used when the search arguments are beyond the range of entered data.

Figure 20 shows card data for a power type general table, and the graph shows its time history. The first card identifies the table as a power table and that the data is scaled by 50 MW. The remaining cards



```
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
```

5 8144

Figure 20. Card data for a power type general table and graph.

define the time history. The first card also indicates a trip number of 605. 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 fu tion and delay. If a zero trip number is specified, current time is always the search argument. The tabular data shows 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, end point 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 functions, and the pump angular velocity tables permit entry of a trip number and in 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. 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 this capability 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 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 the kinetics calculations require the 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 insure 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 that are 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. Four options are provided for pure steam/water systems. The remaining three options allow noncondensibles. 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, noncondensible quality, and boron concentration. Secondary variables are quality, density, temperature, etc.

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, see Subsection 7.2.2 of 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 different 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 that is used, even if the option to compute the initial condition is selected. As previously stated, 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 thermal transient algorithm to converge to a steady state. The differences between the steady state and transient options are that a lowered 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 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, hence, reducing 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 of thumb 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.

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 by specifying 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 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. 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.

PLOT and STRIP are output type runs. PLOT generates plots from data stored on the restart-plot file. Any of the quantities that can be plotted in a NEW or RESTART problem except interior heat structure temperatures can be plotted in a PLOT run. 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.

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 number. 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.

Several time step control options are available. Transfer of information between the hydrodynamic and heat conduction advancements is explicit and the advancement routines are coded so that each advancement can use a different time step. Although not now used, each heat structure can also use its own time step. The time step control option is represented by a number between zero and fifteen that can be thought of as a four-bit octal 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 such that the Courant limit is satisfied. If out of range water property conditions are encountered, the 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 zero, 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 is 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, or 15) includes the features described for entering zero and in addition uses the halving and doubling procedures to maintain an estimate (mass error) of hydrodynamic truncation error within program defined limits. 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, or 15), 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, or 15), the heat transfer will use the maximum time step and the hydrodynamics will use the partially-implicit hydrodynamic and heat slab coupling. The time step control for the 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, or 15), the heat transfer will use the maximum time step and the hydrodynamics will use the nearly-implicit hydrodynamic numerical scheme. The time step can be as large as 5 times the Courant limit for the TRANSNT option and 10 times the Courant limit for the STDY-ST option. The time step control for the hydrodynamics is determined by the status of the first bit as described above.

Note that combinations of the effects of setting of the individual bits is achieved by setting bits in combination. For example, entering five (setting Bits three and one) results in the combined effects described above for Bits three and one. Also, note that entering two in previous versions of RELAP5 has now been changed to three. For the time being, if two is entered it will be converted to three during input processing. This is done to allow older input decks to run without modification.

Entering 0 is not recommended except for special program testing situations. If Bit 1 is set, 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 assure 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 explicit 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 but often with unnecessary calculations. Judicious use of this option during dryout and initial rewetting may be cost effective. Most LOFT and Semiscale simulations have entered three for the entire problem.

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; a plot file is written only if plot requests are entered; and plot and restart data are written on the restart-plot file only if the file is requested.

An option 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.

The control option is a packed word containing a major edit select option, a debug output option, and the timestep control. The major edit select option allows sections of major edits for the hydrodynamic volumes and junctions, heat structures, and statistics to be skipped. The debug output option 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. All options can be changed with each time step control card.

8.3 Printed Output

A program version identification and page number is printed at the top of every page. (Programs installed in computers not at the INEL may not have this feature.)

8.3.1 Input Editing

Printed output for a problem begins with a list of card images, one per line, preceded by a sequence number. The sequence number is not the same as the card number on data cards. 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 $ 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, 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, illegal multiple connections, 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.

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 (other than errors on problem type and options) input processing continues despite severe errors. 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 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 due to input errors.

8.3.2 Major Edits

Major edits are an editing of most of the key quantities being advanced in time. Output includes a time step summary, trip information, reactor kinetics information, two sections of hydrodynamic volume information, hydrodynamic volume time step control information, two sections of hydrodynamic junction information, heat structure/heat transfer information, heat structure temperatures, reflood information, reflood surface temperatures, 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 21.

A discussion of each section of information will next be presented 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 will be indicated.

8.3.2.1 Time Step Summary. As shown in Figure 21, 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 at the last advancement. Entering 1, 3, 5, 7, 9, 11, 13, or 15 for the time step control option will reduce or double the time step to keep this quantity between the limits 2.0×10^{-4} and 2.0×10^{-3}. 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

```
RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                               85/08/01.                                          PAGE     201

 ATTEMPTED ADV: TOT.=      58   EDIT=      10   MIN.DT=   1.000000E-03 SEC    LAST DT=   1.000000E-03 SEC    MS.ERR=  -5.926643E-05 KG
  REPEATED ADV: TOT.=      11   EDIT=       0   MAX.DT=   1.000000E-03 SEC    CRNT.DT=   9.559061E-03 SEC    TOT.MS=    14.5294      KG
SUCCESSFUL ADV: TOT.=      47   EDIT=      10   AVG.DT=   1.000000E-03 SEC    ERR.EST=   2.073774E-06        M.RATO=  -3.810446E-06
 REQUESTED ADV: TOT.=      20   EDIT=      10   REQ.DT=   1.000000E-03 SEC        CPU=    7.04400     SEC     TIME=   2.000000E-02 SEC

TRIP NUMBER, TRIP TIME (SEC)
     501   -1.0000          502  1.30000E-02      505  6.00000E-03
     601   -1.0000          602  -1.0000          603  0.

     TOTAL POWER        FISSION POWER      GAMMA POWER        REACTIVITY         REC. PERIOD
     (WATTS)            (WATTS)            (WATTS)            (DOLLARS)          (SEC-1)
     1.86360E+07        1.85606E+07         75414.             1.5010             110.73

   VOL.NO.   PRESSURE        VOIDG            TEMPF           TEMPG          SAT. TEMP.     NONCOND.       BORON DENS.   UF              UG              VOL.
             (PA)                             (K)             (K)            (K)            VAPOR QUAL.    (KG/M3)       (J/KG)          (J/KG)          FLAG

SYSTEM  1               MASS=   14.529        KG      MASS ERROR= -5.92664E-05 KG        ERR.EST.=  2.07377E-06
EDWARD'S     PIPE          COMPONENT
  3-010000   2.61969E+06   1.04269E-02     501.24          499.59         499.59         0.             0.            9.78151E+05    2.60161E+06   00
  3-020000   2.61978E+06   1.25528E-02     501.23          499.60         499.59         0.             0.            9.78073E+05    2.60161E+06   00
  3-030000   2.62013E+06   2.18719E-02     501.16          499.60         499.60         0.             0.            9.77765E+05    2.60161E+06   00
  3-040000   2.6[illegible]41E+06   2.91278E-02     501.11          499.63         499.63         0.             0.            9.77514E+05    2.60161E+06   00
  3-050000   2.[illegible]319E+06   2.96373E-02     501.10          499.66         499.66         0.             0.            9.77476E+05    2.60161E+06   00
  3-060000   2.62598E+06   3.05696E-02     501.09          499.72         499.72         0.             0.            9.77431E+05    2.60161E+06   00
  3-070000   2.62942E+06   2.98767E-02     501.09          499.78         499.79         0.             0.            9.77437E+05    2.60162E+06   00
  3-080000   2.63321E+06   2.65383E-02     501.11          499.86         499.87         0.             0.            9.77529E+05    2.60163E+06   00
  3-090000   2.63701E+06   2.28552E-02     501.14          499.94         499.95         0.             0.            9.77633E+05    2.60163E+06   00
  3-100000   2.64053E+06   1.95851E-02     501.16          500.00         500.02         0.             0.            9.77727E+05    2.60164E+06   00
  3-110000   2.64357E+06   1.97246E-02     501.16          500.07         500.08         0.             0.            9.77720E+05    2.60164E+06   00
  3-120000   2.64608E+06   1.98955E-02     501.15          500.11         500.13         0.             0.            9.77713E+05    2.60164E+06   00
  3-130000   2.64806E+06   1.95339E-02     501.16          500.15         500.17         0.             0.            9.77723E+05    2.60163E+06   00
  3-140000   2.64948E+06   1.82922E-02     501.17          500.18         500.20         0.             0.            9.77760E+05    2.60163E+06   00
  3-150000   2.65008E+06   1.70615E-02     501.17          500.18         500.21         0.             0.            9.77797E+05    2.60161E+06   00
  3-160000   2.64942E+06   1.62284E-02     501.18          500.16         500.20         0.             0.            9.77823E+05    2.60158E+06   00
  3-170000   2.64681E+06   1.70670E-02     501.17          500.09         500.15         0.             0.            9.77800E+05    2.60155E+06   00
  3-180000   2.63876E+06    .13882         500.25          499.97         499.98         0.             0.            9.73519E+05    2.60163E+06   00
  3-190000   2.56237E+06    .29981         498.71          498.38         498.41         0.             0.            9.66441E+05    2.60133E+06   00
  3-200000   2.44221E+06    .48401         495.87          495.85         495.85         0.             0.            9.53373E+05    2.60084E+06   00
RIGHT BDRY TMDPVOL      COMPONENT
  5-010000   1.00000E+05   1.0000          372.78          372.78         372.78         0.             0.            4.17407E+05    2.50606E+06   00

   VOL.NO.   RHOF            RHOG          LIQ.V.VEL.      VAP.V.VEL.     SOUNDE              STATIC QUAL.   TOT.HT.INP.   VAP.HT.INP.    VAPOR GEN.
             (KG/M3)         (KG/M3)       (M/SEC)         (M/SEC)        (M/SEC)                            (WATTS)       (WATTS)        (KG/M3-SEC)
  3-010000    829.79          13.109       4.99373E-02     -.20834         24.934             1.66434E-04     444.41       0.               3.0896
  3-020000    829.82          13.110       8.98479E-02     -.19184         24.913             2.00793E-04     513.57       0.               5.1044
  3-030000    829.91          13.111        .23175         -.14319         24.851             3.53148E-04     685.27       0.              13.153
  3-040000    829.98          13.118        .50986         6.22148E-02     24.738             4.73950E-04     860.87       0.              22.976
  3-050000    829.99          13.127        .84779          .39884         24.617             4.82812E-04     1006.3       0.              21.185
  3-060000    830.01          13.141       1.1795           .71453         24.440             4.98993E-04     1102.4       0.              22.290
  3-070000    830.00          13.158       1.5302          1.0363          24.231             4.87981E-04     1173.3       0.              23.690
  3-080000    829.98          13.177       1.8797          1.3640          24.009             4.32628E-04     1216.7       0.              22.308
  3-090000    829.95          13.196       2.1986          1.6807          23.790             3.71753E-04     1242.1       0.              19.869
  3-100000    829.92          13.214       2.4829          1.9757          23.588             3.17949E-04     1259.1       0.              17.806
  3-110000    829.93          13.229       2.7532          2.2837          23.405             3.20627E-04     1282.4       0.              17.993
  3-120000    829.93          13.241       3.0237          2.5997          23.256             3.23768E-04     1291.0       0.              17.759
  3-130000    829.93          13.251       3.2920          2.9394          23.140             3.18009E-04     1293.8       0.              17.791
  3-140000    829.92          13.259       3.5551          3.3234          23.058             2.97589E-04     1298.3       0.              17.190
```

Figure 21. Major edit from Edwards Pipe problem with extras.

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RELAP5/2(36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                    PAGE     202
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                          85/08/01.

   3-150000    829.91        13.262        3.8076       3.7435        23.026     2.77299E-04   1310.9     0.            16.454
   3-160000    829.90        13.259        4.0521       4.1741        23.067     2.63488E-04   1334.1     0.            16.035
   3-170000    829.91        13.247        4.3036       4.5517        23.220     2.77071E-04   1380.8     0.            17.058
   3-180000    831.15        13.205        6.3458       9.0650        23.300     2.55454E-03   2499.7     0.            276.26
   3-190000    833.17        12.826        13.127       15.897        27.437     6.54823E-03   6492.1     0.            634.53
   3-200000    836.88        12.229        20.830       22.082        33.546     1.37210E-02   12419.     0.            329.11
   5-010000    958.39        .59041        24.024       24.461        473.21     1.0000        0.         0.         0.

   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        3     17          0      0        0      0        0      3          0      0       0      0           0      0
   3-020000        0      2          0      0        0      0        0      3          0      0       0      0           0      0
   3-030000        1      3          0      0        0      0        0      2          0      0       0      0           0      0
   3-040000        1      2          0      0        0      0        0      2          0      0       0      0           0      0
   3-050000        0      0          0      0        0      0        0      1          0      0       0      0           0      0
   3-060000        0      0          0      0        0      0        0      1          0      0       0      0           0      0
   3-070000        0      0          0      0        0      0        0      1          0      0       0      0           0      0
   3-080000        0      0          0      0        0      0        0      1          0      0       0      0           0      0
   3-090000        0      1          0      0        0      0        0      0          0      0       0      0           0      0
   3-100000        0      0          0      0        0      0        0      0          0      0       0      0           0      0
   3-110000        0      0          0      0        0      0        0      0          0      0       0      0           0      0
   3-120000        0      0          0      0        0      0        0      0          0      0       0      0           0      0
   3-130000        0      0          0      0        0      0        0      0          0      0       0      0           0      0
   3-140000        0      2          0      0        0      0        0      0          0      0       0      0           0      0
   3-150000        0      0          0      0        0      0        0      0          0      0       0      0           0      0
   3-160000        0      1          0      0        0      0        0      0          0      0       0      0           0      0
   3-170000        0      1          0      0        0      0        0      0          0      0       0      0           0      0
   3-180000        0      0          0      0        0      0        0      0          0      0       0      0           0      0
   3-190000        4     10          0      0        0      0        0      0          0      0       0      0           0      0
   3-200000        1      8          0      0        0      0        0      2          0      0      10     46           0      0
   5-010000        0      0          0      0        0      0        0      0          0      0       0      0           0      0

   JUN.NO.    FROM VOL.     TO VOL.   LIQ.J.VEL.    VAP.J.VEL.    MASS FLOW    JUN.AREA      THROAT      JUNCTION  CHOKE  NO.ADVS.CHOKED
                                      (M/SEC)       (M/SEC)       (KG/SEC)     (M2)          RATIO         FLAGS   FLAG     EDIT  TOTAL

 SYSTEM  1
 EDWARD'S   PIPE        COMPONENT
   3-010000    3-010000    3-020000  4.99373E-02   -.20834       .18690      4.56037E-03   1.0000        00000     0        0      0
   3-020000    3-020000    3-030000   .12984       -.18237       .48516      4.56037E-03   1.0000        00000     0        0      0
   3-030000    3-030000    3-040000   .33462       -.11379       1.2398      4.56037E-03   1.0000        00000     0        0      0
   3-040000    3-040000    3-050000   .68640        .23822       2.5271      4.56037E-03   1.0000        00000     0        0      0
   3-050000    3-050000    3-060000   1.0093        .55660       3.7138      4.56037E-03   1.0000        00000     0        0      0
   3-060000    3-060000    3-070000   1.3498        .85747       4.9630      4.56037E-03   1.0000        00000     0        0      0
   3-070000    3-070000    3-080000   1.7105        1.2089       6.2943      4.56037E-03   1.0000        00000     0        0      0
   3-080000    3-080000    3-090000   2.0483        1.5385       7.5624      4.56037E-03   1.0000        00000     0        0      0
   3-090000    3-090000    3-100000   2.3484        1.8456       8.7008      4.56037E-03   1.0000        00000     0        0      0
   3-100000    3-100000    3-110000   2.6170        2.1273       9.7263      4.56037E-03   1.0000        00000     0        0      0
   3-110000    3-110000    3-120000   2.8894        2.4389       10.737      4.56037E-03   1.0000        00000     0        0      0
   3-120000    3-120000    3-130000   3.1580        2.7591       11.733      4.56037E-03   1.0000        00000     0        0      0
   3-130000    3-130000    3-140000   3.4260        3.1230       12.734      4.56037E-03   1.0000        00000     0        0      0
   3-140000    3-140000    3-150000   3.6839        3.5374       13.709      4.56037E-03   1.0000        00000     0        0      0
   3-150000    3-150000    3-160000   3.9311        3.9645       14.646      4.56037E-03   1.0000        00000     0        0      0
   3-160000    3-160000    3-170000   4.1731        4.3944       15.560      4.56037E-03   1.0000        00000     0        0      0
   3-170000    3-170000    3-180000   4.4342        4.7015       16.521      4.56037E-03   1.0000        00000     0        0      0
   3-180000    3-180000    3-190000   8.5245        9.6031       28.399      4.56037E-03   1.0000        00000     0        0      0
   3-190000    3-190000    3-200000   18.773        18.897       52.484      4.56037E-03   1.0000        00000     0        0      0
 RIGHT BDRY SNGLJUN     COMPONENT
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Figure 21. (continued).

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RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                          85/08/01.                                   PAGE    203

 4-000000    3-200000    5-010000    27.614        28.116        47.370       3.96752E-03   1.0000          00000      1          10      36
  JUN.NO.    VOIDFJ          VOIDGJ          FROM   TO     FIJ               FWALFJ       FWALGJ      FJUNF         FJUNR         FORMFJ        FORMGJ
                                                           (N-S2/MS)
  3-010000   .98957      1.25528E-02    BBY    BBY     1068.0            .124         .110      0.            0.            0.            0.
  3-020000   .98745      2.18719E-02    BBY    BBY     1564.5          8.216E-02    9.195E-02   0.            0.            0.            0.
  3-030000   .97813      2.91278E-02    BBY    STR     1340.9          5.944E-02     .434       0.            0.            0.            0.
  3-040000   .97087      2.91278E-02    STR    BBY     1941.2          4.719E-02     .218       0.            0.            0.            0.
  3-050000   .97036      2.96373E-02    BBY    BBY     2973.9          4.480E-02    6.691E-02   0.            0.            0.            0.
  3-060000   .96943      3.05696E-02    BBY    BBY     3045.6          4.261E-02    6.157E-02   0.            0.            0.            0.
  3-070000   .97012      2.98767E-02    BBY    BBY     2732.8          4.066E-02    5.656E-02   0.            0.            0.            0.
  3-080000   .97346      2.65383E-02    BBY    BBY     2203.7          3.939E-02    5.377E-02   0.            0.            0.            0.
  3-090000   .97714      2.28552E-02    BBY    BBY     1700.5          3.852E-02    5.195E-02   0.            0.            0.            0.
  3-100000   .98041      1.95851E-02    BBY    BBY     1394.4          3.795E-02    5.130E-02   0.            0.            0.            0.
  3-110000   .98028      1.97246E-02    BBY    BBY     1214.4          3.734E-02    5.019E-02   0.            0.            0.            0.
  3-120000   .98010      1.98955E-02    BBY    BBY     1047.9          3.685E-02    4.921E-02   0.            0.            0.            0.
  3-130000   .98047      1.95339E-02    BBY    BBY     944.29          3.637E-02    4.793E-02   0.            0.            0.            0.
  3-140000   .98171      1.82922E-02    BBY    BBY     877.91          3.595E-02    4.656E-02   0.            0.            0.            0.
  3-150000   .98294      1.70615E-02    BBY    BBY     821.59          3.558E-02    4.542E-02   0.            0.            0.            0.
  3-160000   .98377      1.62284E-02    BBY    BBY     808.44          3.524E-02    4.434E-02   0.            0.            0.            0.
  3-170000   .98293      1.70670E-02    BBY    BBY     33062.          3.990E-02    6.756E-02   0.            0.            0.            0.
  3-180000   .86118       .13882        BBY    BBY     62419.          3.174E-02    4.431E-02   0.            0.            0.            0.
  3-190000   .70019       .29981        BBY    BBY     1.29129E+07     2.011E-02    2.905E-02   0.            0.            0.            0.
  4-000000   .51599       .48401        BBY    MST     3.37755E+06     6.559E-03    9.334E-03   0.            0.            0.            0.
 STR.NO.   SIDE        BDRY.VOL.   SURFACE   HEAT TRF.     HEAT FLUX       CRITICAL         MODE   HEAT TRF.      INT. HEAT      NET HEAT       VOL.AVE.
                         NUMBER    TEMP.     RATE                          HEAT FLUX               COEF.          SOURCE         LOSS           TEMP.
                                   (K)       (WATT)        (WATT/M2)       (WATT/M2)               (WATT/M2-      (WATT)         (WATT)         (K)
                                                                                                   K)
 30-001    LEFT        3-010000    501.05     444.41        9064.5         3.44491E+06        4     6939.1        0.             444.41         502.07
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-002    LEFT        3-020000    501.15     513.57        10475.         3.43827E+06        4     7788.7        0.             513.57         502.08
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-003    LEFT        3-030000    501.36     685.27        13977.         5.87139E+06        4     9871.9        0.             685.27         502.10
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-004    LEFT        3-040000    501.53     860.87        17559.         4.43094E+06        4     12406.        0.             860.87         502.12
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-005    LEFT        3-050000    501.64     1006.3        20526.         3.75031E+06        4     14791.        0.             1006.3         502.13
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-006    LEFT        3-060000    501.72     1102.4        22485.         3.36786E+06        4     16704.        0.             1102.4         502.14
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-007    LEFT        3-070000    501.78     1173.3        23932.         3.09597E+06        4     18473.        0.             1173.3         502.15
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-008    LEFT        3-080000    501.83     1216.7        24816.         2.88788E+06        4     20074.        0.             1216.7         502.15
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-009    LEFT        3-090000    501.86     1242.1        25335.         2.72589E+06        4     21429.        0.             1242.1         502.16
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-010    LEFT        3-100000    501.89     1259.1        25681.         2.78242E+06        4     22575.        0.             1259.1         502.16
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-011    LEFT        3-110000    501.91     1282.4        26158.         2.63348E+06        4     23593.        0.             1282.4         502.16
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-012    LEFT        3-120000    501.91     1291.0        26333.         2.51922E+06        4     24562.        0.             1291.0         502.1'
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-013    LEFT        3-130000    501.91     1293.8        26390.         2.42732E+06        4     25519.        0.             1293.8         502.16
           RIGHT       0-000000    502.18    0.            0.              0.                 0    0.
 30-014    LEFT        3-140000    501.91     1298.3        26480.         2.35149E+06        4     26488.        0.             1298.3         502.16
           RIGHT       0-0000[illegible]   502.18    0.            0.              0.                 0    0.
```

Figure 21. (continued).

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                          PAGE     204
EDWARD'S PIPE PROBLEM B SE CASE WITH EXTRAS                                                  85/08/01.
  30-015  LEFT        3-150000     501.91    1310.9          26737.         2.28931E+06    4    27450.       0.              1310.9        502.16
          RIGHT       0-000000     502.18   0.              0.              0.             0   0.
  30-016  LEFT        3-160000     501.90    1334.1          27212.         2.23704E+06    4    28427.       0.              1334.1        502.16
          RIGHT       0-000000     502.18   0.              0.              0.             0   0.
  30-017  LEFT        3-170000     501.89    1380.8          28163.         2.19071E+06    4    29489.       0.              1380.8        502.16
          RIGHT       0-000000     502.18   0.              0.              0.             0   0.
  30-018  LEFT        3-180000     501.80    2499.7          50987.         2.08721E+06    4    34579.       0.              2499.7        502.16
          RIGHT       0-000000     502.18   0.              0.              0.             0   0.
  30-019  LEFT        3-190000     501.44    6492.1         1.32419E+05     1.72902E+06    4    53965.       0.              6492.1        502.13
          RIGHT       0-000000     502.18   0.              0.              0.             0   0.
  30-020  LEFT        3-200000     499.75    12419.         2.53310E+05     1.55893E+06    4    63000.       0.              12419.        502.01
          RIGHT       0-000000     502.18   0.              0.              0.             0   0.
 200-001  LEFT        0-000000       9.84   0.              0.              0.             0   0.           0.              14417.          6.25
          RIGHT       0-000000        .00    14417.         1.18176E+05     0.             0   0.

 STR.NO.  MESH POINT TEMPERATURES (K)
  30-001    501.05      501.70      502.07      502.16      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-002    501.15      501.74      502.08      502.17      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-003    501.36      501.84      502.10      502.17      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-004    501.53      501.93      502.12      502.17      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-005    501.64      501.98      502.14      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-006    501.72      502.02      502.15      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-007    501.78      502.05      502.16      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-008    501.83      502.07      502.16      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-009    501.86      502.09      502.16      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-010    501.89      502.10      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-011    501.91      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-012    501.91      502.12      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-013    501.91      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-014    501.91      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-015    501.91      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-016    501.90      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-017    501.89      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-018    501.80      502.10      502.17      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-019    501.44      502.05      502.16      502.18      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
  30-020    499.75      501.68      502.11      502.17      502.18      502.18      502.18      502.18      502.18      502.18
            502.18
 200-001    9.8389      9.7177      9.3573      8.7665      7.9598      6.9572      5.7832      4.4668      3.0404      1.5391
```

Figure 21. (continued).

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RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                85/08/01.                        PAGE      205

             0.

                     CONTROL VARIABLE EDIT
    1    CTL1        SUM                2.619735E+06             4    CTL4            MULT                1.221103E+06
    5    CTL5        MULT                166.412                10    CTL10           DIV                 4.094657E-07
   11    CTL10       DIV                 1.04920                12    CTL12           DIFFRENI             1.00000
   13    CTL13       INTEGRAL           2.000000E-04            14    CTL14           INTEGRAL            2.000000E-02
   15    CTL15       DIFFRENI           2.000000E-02            99    CTL99           DIFFREND             46.0000
  201    CTL201      FUNCTION            3.00000               202    CTL202          STDFNCTN            3.999733E-02
  203    CTL203      TRIPUNIT           0.                     204    CTL204          TRIPDLAY            -2.00000
  205    CTL205      POWERI              .200000               206    CTL206          POWERR              2.000000E-04
  207    CTL207      POWERX              .300000               300    CTL300          DELAY               0.
  301    CTL301      PROP-INT            .406000               302    CTL302          LAG                 1.872973E-02
  303    CTL303      LEAD-LAG            .109365               304    CTL304          CONSTANT             .387000
---RESTART NO.       58 WRITTEN, BLOCK NO.      1---
```

Figure 21. (continued).

is an estimate of the cumulative error in the total mass due to truncation error. M.RATO is the ratio of the mass error for the last advancement 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 is printed. The TIMEOF quantity is -1.0 when the trip is false, and when greater than or equal to zero indicates that the trip is true and is the time the trip last switched to true. Figure 21 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 21 includes an illustrative example of a reactor kinetics edit, however, it is not intended to be physically realistic.

8.3.2.4 Hydrodynamic Volume Information--First Section. 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 is VOIDG, which is the void fraction ($\alpha_{g,L}^{n+1}$) used in the equations. 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. Following this are NONCOND.

VAPOR QUAL. and BORON DENS., which are the noncondensible quality ($X_{n,L}^{n+1}$) and boron density ($\rho_{B,L}^{n+1}$), used in the equations. 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 (fe) input by the user for hydrodynamic volume components. Following the labels, the actual values of the quantities for each volume are printed out under the labels. The quantities are first grouped by system and within each system the quantities are grouped by component.

Systems are labeled SYSTEM followed to the right by the system number (1, 2, 3, etc.) and the name of the system (optional; left blank 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 while the Time Step Summary quantities are for all the systems. In Figure 21, 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. Figure 22 is a major edit from the Two Loops Problem with pumps (Figure 19) using a shaft component, and this has two systems (SYSTEM 1 and SYSTEM 2). Figure 22 shows how the first section of the hydrodynamic volume information looks for two systems. This figure illustrates how the mass, mass error, and error estimate printouts are related when there is more than one system. The masses of each system (labeled MASS) add to give the mass of the entire configuration (labeled TOT. MS). The mass errors (labeled MASS ERR) of each system add to give the mass error (labeled MS. ERR) of the entire configuration. Finally, 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 both Figure 21 and 22 illustrate, within each system quantities are grouped by component. Each component is first labeled with the component name (supplied by the user), the component type, and the label COMPONENT. Underneath this are the values for each volume within the component of the quantities corresponding to the labels discussed at the beginning of this section.

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 TWO LOOPS WITH PUMPS USING SHAFT COMPONENT                                                  85/08/02.

  ATTEMPTED ADV: TOT.=      385    EDIT=       15    MIN.DT=      .200000      SEC   LAST DT=      .200000     SEC   MS.ERR=    6.767011E-03 LB
   REPEATED ADV: TOT.=        0    EDIT=        0    MAX.DT=      .200000      SEC   CRNT.DT=      .430876     SEC   TOT.MS=     150.940     LB
 SUCCESSFUL ADV: TOT.=      385    EDIT=       15    AVG.DT=      .200000      SEC   ERR.EST=   5.196245E-07          M.RATO=    4.483056E-05
  REQUESTED ADV: TOT.=      295    EDIT=       15    REQ.DT=      .200000      SEC       CPU=    19.4460      SEC       TIME=     40.0000      SEC

TRIP NUMBER, TRIP TIME (SEC)
    5C1    20.000

   VOL.NO.   PRESSURE      VOIDG          TEMPF        TEMPG         SAT. TEMP.     NONCOND.      BORON DENS.   UF             UG             VOL.
             (LBF/IN2)                    (DEGF)       (DEGF)        (DEGF)         VAPOR QUAL.   (LB/FT3)      (BTU/LB)       (BTU/LB)       FLAG

SYSTEM  1               MASS=   75.471     LB     MASS ERROR=  2.10007E-03 LB      ERR.EST.=  2.52074E-08
LOOP         PIPE         COMPONENT
  1-010000    2473.3     0.                542.17        666.53        666.53       0.            0.                527.67         1035.1          00
  1-020000    2473.3     0.                542.17        666.53        666.53       0.            0.                527.67         1035.1          00
  1-030000    2473.3     0.                542.17        666.53        666.53       0.            0.                527.67         1035.1          00
  1-040000    2473.3     0.                542.16        666.53        666.53       0.            0.                527.66         1035.1          00
  1-050000    2473.0     0.                542.16        666.51        666.51       0.            0.                527.66         1035.1          00
  1-060000    2472.3     0.                542.16        666.47        666.47       0.            0.                527.66         1035.2          00
  1-070000    2471.6     0.                542.15        666.43        666.43       0.            0.                527.66         1035.2          00
  1-080000    2468.2     0.                542.14        666.23        666.23       0.            0.                527.65         1035.5          00
  1-090000    2467.5     0.                542.13        666.19        666.19       0.            0.                527.65         1035.6          00
  1-100000    2467.2     0.                542.13        666.16        666.16       0.            0.                527.65         1035.6          00
  1-110000    2467.2     0.                542.12        666.16        666.16       0.            0.                527.65         1035.6          00
  1-120000    2467.2     0.                542.12        666,16        666.16       0.            0.                527.64         1035.6          00
  1-130000    2467.2     0.                542.12        666.16        666.16       0.            0.                527.64         1035.6          00
  1-140000    2467.1     0.                542.12        666.16        666.16       0.            0.                527.64         1035.6          00
  1-150000    2467.5     0.                542.11        666.18        666.18       0.            0.                527.63         1035.6          00
  1-160000    2468.1     0.                542.11        666.22        666.22       0.            0.                527.63         1035.5          00
  1-170000    2468.8     0.                542.11        666.26        666.26       0.            0.                527.63         1035.5          00
  1-180000    2469.4     0.                542.11        666.30        666.30       0.            0.                527.62         1035.4          00
  1-190000    2470.1     0.                542.11        666.34        666.34       0.            0.                527.62         1035.4          00
LOOP         PUMP         COMPONENT
  RPM =   1122.5        (REV/MIN)     HEAD =     2.9347       (LBF/IN2)     TORQUE =   -3.7009       (LBF-FT)
  OCTANT = 2                                                                MTR.TORQUE =   0.          (LBF-FT)
  2-010000     2471.9     0.           542.17        666.45        666.45       0.            0.                527.67         1035.2          10

SYSTEM  2               MASS=   75.469     LB     MASS ERROR=  4.66694E-03 LB      ERR.EST.=  5.19624E-07
LOOP2        PIPE         COMPONENT
  3-010000    2646.4     0.                544.00        676.54        676.54       0.            0.                529.01         1018.9          00
  3-020000    2646.2     0.                543.99        676.53        676.53       0.            0.                529.01         1018.9          00
  3-030000    2645.9     0.                543.99        676.51        676.51       0.            0.                529.00         1018.9          00
  3-040000    2645.7     0.                543.98        676.50        676.50       0.            0.                528.99         1019.0          00
  3-050000    2645.1     0.                543.96        676.47        676.47       0.            0.                528.98         1019.0          00
  3-060000    2644.2     0.                543.95        676.42        676.42       0.            0.                528.96         1019.1          00
  3-070000    2643.3     0.                543.93        676.37        676.37       0.            0.                528.95         1019.2          00
  3-080000    2638.5     0.                543.90        676.10        676.10       0.            0.                528.93         1019.7          00
  3-090000    2637.6     0.                543.89        676.05        676.05       0.            0.                528.92         1019.8          00
  3-100000    2637.0     0.                543.88        676.01        676.01       0.            0.                528.92         1019.9          00
  3-110000    2636.8     0.                543.88        676.00        676.00       0.            0.                528.92         1019.9          00
  3-120000    2636.6     0.                543.88        675.99        675.99       0.            0.                528.92         1019.9          00
  3-130000    2636.3     0.                543.88        675.98        675.98       0.            0.                528.92         1020.0          00
  3-140000    2636.1     0.                543.89        675.96        675.96       0.            0.                528.93         1020.0          00
  3-150000    2636.2     0.                543.90        675.97        675.97       0.            0.                528.94         1020.0          00
  3-160000    2636.6     0.                543.90        675.99        675.99       0.            0.                528.94         1019.9          00
  3-170000    2637.1     0.                543.91        676.02        676.02       0.            0.                528.95         1019.9          00
  3-180000    2637.5     0.                543.91        676.04        676.04       0.            0.                528.94         1019.8          00
```

Figure 22. Major edit from two loops problem with pumps using shaft component.

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 TWO LOOPS WITH PUMPS USING SHAFT COMPONENT                                          85/08/02.

  3-190000   2637.9       0.              543.89        676.06        676.06      0.           0.            528.93        1019.8       00
LOOP2        PUMP        COMPONENT
  RPM -    1373.6       (REV/MIN)      HEAD -    6.6857      (LBF/IN2)     TORQUE -  -5.6445      (LBF-FT)
  OCTANT - 2                                                             MTR.TORQUE -  0.         (LBF-FT)
  4-010000   2642.4       0.              543.97        676.31        676.31      0.           0.            529.00        1019.3       10

   JUN.NO.     FROM VOL.       TO VOL.  LIQ.J.VEL.     VAP.J VEL.    MASS FLOW     JUN.AREA      THROAT      JUNCTION  CHOKE   NC.ADVS.CHOKED
                                        (FT/SEC)       (FT/SEC)      (LB/SEC)      (FT2)         RATIO          FLAGS   FLAG       EDIT   TOTAL

SYSTEM  1
LOOP         PIPE        COMPONENT
  1-010000     1-010000     1-020000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-020000     1-020000     1-030000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-030000     1-030000     1-040000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-040000     1-040000     1-050000    4.6170         4.6170        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-050000     1-050000     1-060000    4.6170         4.6170        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-060000     1-060000     1-070000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-070000     1-070000     1-080000    4.6171         4.6171        8.2465        3.76000E-02    .26596        00100     0          0       0
  1-080000     1-080000     1-090000    4.6172         4.6172        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-090000     1-090000     1-100000    4.6172         4.6172        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-100000     1-100000     1-110000    4.6172         4.6172        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-110000     1-110000     1-120000    4.6172         4.6172        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-120000     1-120000     1-130000    4.6172         4.6172        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-130000     1-130000     1-140000    4.6172         4.6172        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-140000     1-140000     1-150000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-150000     1-150000     1-160000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-160000     1-160000     1-170000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-170000     1-170000     1-180000    4.6170         4.6170        8.2465        3.76000E-02   1.0000         00000     0          0       0
  1-180000     1-180000     1-190000    4.6170         4.6170        8.2465        3.76000E-02   1.0000         00000     0          0       0
LOOP         PUMP        COMPONENT
  2-010000     1-190000     2-010000    4.6170         4.6170        8.2465        3.76000E-02   1.0000         00000     0          0       0
  2-020000     2-010000     1-010000    4.6171         4.6171        8.2465        3.76000E-02   1.0000         00000     0          0       0

SYSTEM  2
LOOP2        PIPE        COMPONENT
  3-010000     3-010000     3-020000    6.6972         6.6972        11.961        3.76000E-02   1.0000         00000     0          0       0
  3-020000     3-020000     3-030000    6.6969         6.6969        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-030000     3-030000     3-040000    6.6966         6.6966        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-040000     3-040000     3-050000    6.6964         6.6964        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-050000     3-050000     3-060000    6.6962         6.6962        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-060000     3-060000     3-070000    6.6960         6.6960        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-070000     3-070000     3-080000    6.6959         6.6959        11.959        3.76000E-02    .26596        00100     0          0       0
  3-080000     3-080000     3-090000    6.6961         6.6961        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-090000     3-090000     3-100000    6.6960         6.6960        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-100000     3-100000     3-110000    6.6960         6.6960        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-110000     3-110000     3-120000    6.6960         6.6960        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-120000     3-120000     3-130000    6.6961         6.6961        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-130000     3-130000     3-140000    6.6961         6.6961        11.959        3.76000E-02   1.0000         00000     0          0       0
  3-140000     3-140000     3-150000    6.6962         6.6962        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-150000     3-150000     3-160000    6.6964         6.6964        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-160000     3-160000     3-170000    6.6965         6.6965        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-170000     3-170000     3-180000    6.6967         6.6967        11.960        3.76000E-02   1.0000         00000     0          0       0
  3-180000     3-180000     3-190000    6.6969         6.6969        11.961        3.76000E-02   1.0000         00000     0          0       0
LOOP2        PUMP        COMPONENT
  4-010000     3-190000     4-010000    6.6972         6.6972        11.962        3.76000E-02   1.0000         00000     0          0       0
  4-020000     4-010000     3-010000    6.6976         6.6976        11.961        3.76000E-02   1.0000         00000     0          0       0
```

Figure 22. (continued).

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 TWO LOOPS WITH PUMPS USING SHAFT COMPONENT                                        85/08/02.                              PAGE     154

                           CONTROL VARIABLE EDIT
    1   MTR.TRQ            FUNCTION        47.4536                2   TRIP          TRIPUNIT      0.
    3   TORQUE             MULT            0.                     4   BR.TRQ        MULT          0.
   10   SHAFT4             SHAFT           1373.61               20   SHAFT2        SHAFT         1122.46

GENERATOR       TORQUE (FT-LBF)   INPUT POWER (WATT):
       20       0.                0.
```

Figure 22. (continued).

As Figure 22 illustrates, additional information is printed in this first hydrodynamic volume section that is unique to certain components. In this example, additional information for a pump is printed between the label for the component name-type and the volume number. Other components for which additional information is printed are accumulators and turbines. For a pump, five additional quantities are printed. In the normal operating mode, these are the rotational velocity (labeled RPM), pump head (labeled HEAD), torque exerted by the fluid (labeled TORQUE), pump octant number (labeled OCTANT), and torque generated from the pump motor (labeled MTR. TORQUE). These terms are discussed in Subsection 3.1.5.4 of Volume 1 and Subsection 2.3.1 of this volume. For an accumulator, four additional quantities are printed. These are the volume of liquid in the tank-standpipe-surge line (labeled LIQ. VOLUME), the mass of liquid in the tank-standpipe-surge line (labeled MASS), the liquid level of water contained in the tank above the standpipe entrance (labeled LEVEL), and the mean tank wall metal temperature (labeled WALL TEMP). These terms are discussed in Subsection 3.1.5.7 of Volume 1 and Subsection 2.3 of this volume. An example of this output is shown in Figure 23. 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 discussed in Subsection 3.1.5.5 of Volume 1 and Subsection 2.3.5 of this volume. An example of this output is also shown in Figure 23.

```
ACCUM        ACCUM         COMPONENT
LIQ. VOLUME =     .23794       M3,        MASS =   236.97      KG,       LEVEL =   2.4902

M,         WALL TEMP =   303.42     K,

STAGE3     TURBINE      COMPONENT
POWER=  1.96820E+07(WATT)          TORQUE=   34349.      (N-M)          SPEED=   573.00

(RAD/SEC)      EFFICIENCY=    .79998
```

Figure 23. Example of additional major edit printout for accumulator and turbine components.

8.3.2.5 Hydrodynamic Volume Information--Second Section. This section of output is optional and can be skipped by setting Bit three in the ss digits of Word four (W4) on the time step control card (201 through 299). This section was allowed to be printed in the Edwards Pipe Problem and thus is present in Figure 21. This section, however, was not allowed to be printed in the Two Loops Problem and thus is not present in Figure 22. 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 (labeled VOL.NO.) and nine other quantities are printed out on each line. These are printed out in numerical order within each system. The quantities are liquid density (labeled RHOF, denotes the variable $\rho_{f,L}^{n+1}$), vapor density (labeled RHOG, denotes the variable $\rho_{g,L}^{n+1}$), liquid volume-average velocity (labeled LIQ.V.VEL, denotes the variable $v_{f,L}^{n+1}$), vapor volume-average velocity (labeled VAP.V.VEL., denotes the variable $v_{g,L}^{n+1}$), isentropic sonic velocity for single-phase or homogenous equilibrium isentropic sonic velocity for two-phase (labeled SOUNDE, denotes the variable $a_{HE,L}^{n+1}$), static quality (labeled STATIC QUAL., denotes the variable X_{L}^{n+1}), total wall heat transfer rate to the liquid and vapor (labeled TOT.HT.INP., denotes the quantity $Q_{L}^{n} \cdot V_{L}$), wall heat transfer rate to the vapor (labeled VAP.HT.INP., denotes the quantity $Q_{wg,L}^{n} \cdot V_{L}$), and vapor generation rate per unit volume (labeled VAPOR GEN., denotes the variable $\Gamma_{g,L}^{n+1}$).

8.3.2.6 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 four (W4) on the time step control card (201-299). As with the previous section, this section is present in Figure 21 but not in Figure 22. As with the previous section, 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. 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 due to mass error and out-of-range thermodynamic properties. The MASS column is for reduction due to local mass error [Equation (749) in Volume 1] and it does not include reductions due to overall (global) mass error [Equation (750) in Volume 1]. The QUALITY column is for reductions due to problems with void fraction (α_g), noncondensible quality (X_n), and mixture density from the phasic continuity equations (ρ_m). Advancements that result in α_g and X_n being slightly <0.0 or slightly >1.0 are allowed, and the variable is reset to 0.0 or 1.0. Advancements that result in values much <0.0 or much >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 (2×10^{-3}). Advancements that result in ρ_m being less than or equal to zero 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 Subsection 3.1.1.6 of 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 meta-stable thermodynamic state causes problems. These problems are vapor density (ρ_g) ≤ 0.0, vapor temperature ≤ 274 K, and liquid density (ρ_f) ≤ 0.0. The COURANT column is for reductions due to the material Courant limit check (see Subsection 4.1 of Volume 1). 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 5 times the material Courant limit for the TRANSNT option and to 10 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.

8.3.2.7 Hydrodynamic Junction Information--First Section. This section of output is not optional and always appears in a major edit. 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. 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 (labeled LIQ.J.VEL. and VAP.J.VEL, denotes the variable $v_{f,j}^{n+1}$ and $v_{g,j}^{n+1}$). In single phase, the velocities are equal. This is followed by the mass flow rate

[labeled MASS FLOW, denotes the quantity $(\dot{\alpha}_{f,j}^{n}\,\dot{\rho}_{f,j}^{n}\,v_{f,j}^{n+1} + \dot{\alpha}_{g,j}^{n}\,\dot{\rho}_{g,j}^{n}\,v_{g,j}^{n+1})A_j$].

The next two quantities are junction area (labeled JUN. AREA, denotes the variable A_j) and throat ratio (labeled THROAT RATIO, denotes the quantity A_T/A_j). The next quantity is the junction flags (labeled JUNCTION FLAGS), which is the five digit packed number vcahs that the user inputs for each junction. Following this is the choking flag (labeled CHOKE FLAG) that will be set to 1 if the flow through the junction was determined to be choked by the choking model for the last advancement (otherwise, it is set to 0). The last two columns are a choking summary (labeled NO.ADVS.CHOKED), which indicates how many time steps the choking model was applied. The subheading EDIT lists the number since the last major edit; the subheading TOTAL lists the number 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, the component type, and the label COMPONENT printed above the quantities. Both Figure 21 (one system) and Figure 22 (two systems) show examples of this section of the major edit.

8.3.2.8 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 four (W4) on the time step control card (201-299). This section is present in Figure 21 but not in Figure 22. 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 (labeled JUN.NO.) and 11 other quantities are printed out on each line. These are printed out in numerical order within each system. The quantities are liquid junction void fraction (labeled VOIDFJ, denotes the variable $\dot{\alpha}_{f,j}^{n+1}$), vapor junction void fraction (labeled VOIDGJ, denotes the variable $\dot{\alpha}_{g,j}^{n+1}$), the from and to volume flow regime (labeled FROM and TO, see Subsection 2.1 of this volume of the manual for the meaning of the flow regime label), interphase drag (labeled FIJ, in most cases denotes the quantity $\alpha_{f,j}^{n} \alpha_{g,j}^{n} \rho_{f,j}^{n} \rho_{g,j}^{n} FI_{j}^{n} \Big/ \left| v_{g,j}^{n} - v_{f,j}^{n} \right|$), dimensionless liquid and vapor wall friction (labeled FWALFJ and FWALGJ, in most cases denotes the quantities $2 \cdot FWF_{j}^{n} \cdot \Delta x_{j} \Big/ \left| v_{f,j}^{n} \right|$ and $2 \cdot FWG_{j}^{n} \cdot \Delta x_{j} \Big/ \left| v_{g,j}^{n} \right|$), user specified dimensionless forward and reverse flow energy loss coefficients (labeled FJUNF and FJUNR), and the dimensionless abrupt area change liquid and vapor loss coefficients (labeled FORMFJ and FORMGJ, in most cases denotes the quantities $2 \cdot \mathrm{HLOSSF}_j^n \Big/ \left|v_{f,j}^n\right|$ and $2 \cdot \mathrm{HLOSSG}_j^n \Big/ \left|v_{g,j}^n\right|$). The last six quantities were all made dimensionless so that the relative importance of each in the momentum equations could be determined from the major edits.

8.3.2.9 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 [labeled STR.NO., denotes the heat structure-geometry number (CCCG) and the three digit individual heat structure subfield number (ONN)]. These numbers are separated by a hyphen (-). Following this, eight quantities are printed out for both sides of the heat structure. First, the surface indicator is printed for both sides (labeled SIDE, printed as either LEFT or RIGHT). Next the volume number for the hydrodynamic volume connected on each side is printed (labeled BDRY.VOL. NUMBER, 0-0000000 is printed if no volume is present). Then the surface temperature is printed for both sides (labeled SURFACE TEMP.). After this is the heat transfer rate out of the structure for both sides (labeled HEAT TRF. RATE). This is then followed by two fluxes for both sides, the heat flux and the critical heat flux (labeled HEAT FLUX and CRITICAL HEAT FLUX). After these the mode of heat transfer and the heat transfer coefficient are printed for both sides (labeled MODE and HEAT TRF. COEF.). Subsection 3.2 of this Volume of the manual describes the meaning of the modes. Finally, three quantities are printed for the individual heat structure. These are the heat transfer rate into the structure from an internal source (labeled INT. HEAT SOURCE), the net heat transfer rate out of the structure (labeled NET HEAT LOSS), and the volume-average temperature for the structure (VOL. AVE. TEMP.). Figure 21 shows an example of this section of the major edit.

When the reflood model is turned on, the critical heat flux and mode printout are altered. For the critical heat flux printout, only the individual structure where the critical heat flux is located will have a nonzero value. All the rest of these values for the heat-structure-geometry will be zeros. Figure 24 shows an example. For the mode column, four possible heat transfer modes can appear (41, 42, 43, or 44). Subsection 2.2.4 of this Volume of the manual discusses the meaning of these modes.

8.3.2.10 Heat Structure Temperature. This section of output is optional and can be skipped by setting Bit one in the ss digits of Word four (W4) on the time step control card (201 through 299). This bit was not set for the Edwards problem in Figure 21, and thus it is present in this figure. As in the first heat structure section, the individual heat structure number (labeled STR.NO) is printed in the first column. Then all the mesh point temperatures (labeled 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 21, 11 mesh point temperatures are printed out.

8.3.2.11 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 24 shows an example of this section preceded by the normal heat structure printouts. The section begins with the label REFLOOD EDIT. 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 (labeled AXIAL NODES NUMBER). The first of these columns is the assigned maximum number of axial nodes (sublabeled 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. Due 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 24, 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 [illegible] nodes used for the last time advancement (sublabeled EDIT) and in [illegible] it is fl[illegible]. If the

```
STR.NO.  SIDE     BDRY.VOL.  SURFACE  HEAT TRF.    HEAT FLUX     CRITICAL     MODE  HEAT TRF.      INT. HEAT   NET HEAT    VOL.AVE.
                     NUMBER  TEMP.    RATE                       HEAT FLUX          COEF.          SOURCE      LOSS        TEMP.
                             (DEGF)   (BTU/SEC)    (BTU/SEC-     (BTU/SEC-          (BTU/SEC-      (BTU/SEC)   (BTU/SEC)   (DEGF)
                                                   FT2)          FT2)               FT2-DEGF)
 61-001  LEFT      0-000000   263.71  0.           0.            0.              0  0.              14.976      9.2244      258.81
         RIGHT     6-010000   254.88   23.200       2.4529       0.             41  2.64191E-02
 61-002  LEFT      0-000000   286.69  0.           0.            0.              0  0.              14.976      2.9064      282.32
         RIGHT     6-020000   278.94   17.882       1.8906       0.             42  4.78079E-02
 61-003  LEFT      0-000000   709.56  0.           0.            0.              0  0.              14.976      100.27      698.97
         RIGHT     6-030000   689.19   115.25       12.185        117.32        42   .10063
 61-004  LEFT      0-000000   959.85  0.           0.            0.              0  0.              23.683     -13.404      955.36
         RIGHT     6-040000   952.37   10.278       1.0867       0.             44  2.67875E-03
 61-005  LEFT      0-000000  1169.72  0.           0.            0.              0  0.              30.648     -21.003     1164.43
         RIGHT     6-050000  1161.00   9.6455       1.0198       0.             44  2.44167E-03
 61-006  LEFT      0-000000  1366.21  0.           0.            0.              0  0.              38.659     -28.392     1360.10
         RIGHT     6-060000  1356.15   10.266       1.0854       0.             44  2.71976E-03
 61-007  LEFT      0-000000  1448.31  0.           0.            0.              0  0.              45.276     -36.269     1441.78
         RIGHT     6-070000  1437.65   9.0069        .95227      0.             44  2.89229E-03
 61-008  LEFT      0-000000  1551.34  0.           0.            0.              0  0.              51.893     -43.806     1544.39
         RIGHT     6-080000  1540.03   8.0874        .85505      0.             44  3.05757E-03
 61-009  LEFT      0-000000  1647.42  0.           0.            0.              0  0.              55.724     -48.414     1640.38
         RIGHT     6-090000  1635.97   7.3097        .77282      0.             44  3.20146E-03
 61-010  LEFT      0-000000  1735.66  0.           0.            0.              0  0.              57.814     -51.352     1728.67
         RIGHT     6-100000  1724.31   6.4616        .68316      0.             44  3.34841E-03
 61-011  LEFT      0-000000  1742.57  0.           0.            0.              0  0.              57.814     -53.325     1735.90
         RIGHT     6-110000  1731.80   4.4886        .47456      0.             44  3.45829E-03
 61-012  LEFT      0-000000  1702.33  0.           0.            0.              0  0.              55.724     -53.529     1696.14
         RIGHT     6-120000  1692.42   2.1950        .23207      0.             44  3.47942E-03
 61-013  LEFT      0-000000  1669.59  0.           0.            0.              0  0.              51.893     -51.472     1663.90
         RIGHT     6-130000  1660.53   .42073       4.44820E-02  0.             44  3.46522E-03
 61-014  LEFT      0-000000  1519.64  0.           0.            0.              0  0.              45.276     -47.230     1514.72
         RIGHT     6-140000  1511.94  -1.9539      -.20657       0.             44  2.39787E-03
 61-015  LEFT      0-000000  1366.75  0.           0.            0.              0  0.              38.659     -42.456     1362.45
```

Figure 24. Example of heat structure and reflood major edit.

```
          RIGHT      6-150000  1360.13  -3.7972       -.40146     0.           44  2.33646E-03
 61-016   LEFT       0-000000  1196.25  0.            0.          0.            0  0.
          RIGHT      6-160000  1190.91  -5.3494       -.55557     0.           44  2.30091E-03   30.648    -35.998    1192.69
 61-017   LEFT       0-000000   993.82  0.            0.          0.            0  0.
          RIGHT      6-170000   990.21  -6.6557       -.70368     0.           44  2.23669E-03   23.683    -30.338     991.30
 61-018   LEFT       0-000000   834.58  0.            0.          0.            0  0.
          RIGHT      6-180000   832.88  -6.9535       -.73516     0.           44  2.15551E-03   14.976    -21.929     833.26
 61-019   LEFT       0-000000   741.28  0.            0.          0.            0  0.
          RIGHT      6-190000   739.38  -6.2699       -.66289     0.           44  2.07061E-03   14.976    -21.246     739.85
 61-020   LEFT       0-000000   702.55  0.            0.          0.            0  0.
          RIGHT      6-200000   700.35  -5.0985       -.53904     0.           44  1.99348E-03   14.976    -20.074     700.96
STR.NO.   MESH POINT  TEMPERATURES (DEGF)
 61-001    263.71      263.64      261.24      258.76      256.77      255.82      254.88
 61-002    286.69      286.66      284.49      282.22      280.48      279.70      278.94
 61-003    709.56      708.87      704.81      699.58      694.22      691.80      689.19
 61-004    959.85      960.00      957.90      955.32      953.22      952.74      952.37
 61-005    1169.7      1170.0      1167.5      1164.0      1161.8      1161.4      1161.0
 61-006    1366.2      1366.5      1363.8      1359.5      1357.0      1356.5      1356.1
 61-007    1448.3      1448.7      1445.8      1441.1      1438.5      1438.0      1437.7
 61-008    1551.3      1551.8      1548.7      1543.6      1540.8      1540.3      1540.0
 61-009    1647.4      1647.9      1644.8      1639.6      1636.7      1636.3      1636.0
 61-010    1735.7      1736.2      1733.2      1727.9      1725.0      1724.6      1724.3
 61-011    1742.6      1743.1      1740.2      1735.1      1732.4      1732.0      1731.8
 61-012    1702.3      1702.9      1700.1      1695.3      1692.9      1692.6      1692.4
 61-013    1669.6      1670.1      1667.5      1663.1      1660.9      1660.6      1660.5
 61-014    1519.6      1520.1      1517.8      1514.0      1512.2      1512.0      1511.9
 61-015    1366.8      1367.2      1365.1      1361.7      1360.3      1360.1      1360.1
 61-016    1196.2      1196.7      1194.8      1192.0      1190.9      1190.8      1190.9
 61-017    993.82      994.19      992.73      990.76      990.07      990.07      990.21
 61-018    834.58      834.84      833.98      832.88      832.62      832.70      832.88
 61-019    741.28      741.53      740.61      739.48      739.16      739.22      739.38
 61-020    702.55      702.78      701.80      700.60      700.20      700.22      700.35
                      REFLOOD EDIT
GEOM.NO.   AXIAL NODES NUMBER  INC. BOIL.   CRITICAL     REWETTING    CRIT. TEMP.
           MAXIMUM     EDIT    TEMP.        TEMP.        TEMP.        POSITION
                               (DEGF)       (DEGF)       (DEGF)       (FT)
  61          153       61       270.75       323.72       558.57       1.2741
GEOM.NO.   SURFACE AXIAL MESH POINT TEMPERATURES (DEGF)
AND SIDE
 61 LEFT    263.66      263.71      276.89      286.69      298.40      709.56      860.33      959.85      1065.4      1169.7
            1270.7      1366.2      1407.8      1448.3      1500.1      1551.3      1599.6      1647.4      1692.0      1735.7
            1739.4      1742.6      1722.6      1702.3      1686.3      1669.6      1595.9      1519.6      1443.6      1366.8
            1283.4      1196.2      1095.4      993.82      914.39      834.58      787.72      741.28      721.74      702.55
            687.17
 61 RIGHT   254.84      254.88      268.12      278.74      286.86      689.19      851.17      952.37      1057.3      1161.0
            1261.3      1356.1      1397.5      1437.7      1489.1      1540.0      1588.2      1636.0      1680.6      1724.3
            1728.4      1731.8      1712.2      1692.4      1676.8      1660.5      1587.6      1511.9      1436.5      1360.1
            1277.4      1190.9      1091.0      990.21      911.73      832.88      785.94      739.38      719.69      700.35
            685.02
```

Figure 24. (continued).

EDIT column is ever larger than the MAXIMUM column, the code will abort. The next four quantities are discussed in Volume 1, Subsection 3.1.3.6 of this manual, and thus they will only be mentioned here. They are the wall temperature at incipience of boiling (labeled INC. BOIL. TEMP., denotes the variable T_{IB}), the wall temperature at critical heat flux (labeled CRITICAL TEMP., denotes the variable T_{CHF}), the wall rewetting or quench temperature (labeled REWETTING TEMP., denotes the variable T_Q), and the detailed location of the critical temperature (labeled CRIT. TEMP. POSITION). This location is the distance from the end of the first heat structure.

8.3.2.12 Reflood Surface Temperatures. This section of output is optional, and it is skipped when the heat structure temperatures (Subsection 8.3.2.10) 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 24. The first quantities printed are the heat structure-geometry number and side of the heat structure (labeled GEOM.NO. AND SIDE). The side is either LEFT or RIGHT. Then, for each side, the surface axial mesh point temperatures (labeled SURFACE AXIAL MESH POINT TEMPERATURES) are printed out. The temperatures are printed from left to right, beginning with the first heat structure. In this example of 20 heat structures, 41 axial mesh point surface temperatures are printed. One can verify that the even numbered ones correspond to the surface temperatures in the heat structure-heat transfer information section.

8.3.2.13 Control Variable Information. This section of output is not optional and always appears in a major edit when control systems are present. Figures 21 and 22 show 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.

8.3.2.14 Generator Information. This section of output is not optional and always appears when a generator component is present. As discussed in Subsection 3.3.7 of Volume 1 of this manual, and Subsection 4.2.3.4 of Volume 2, 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 (labeled 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 (labeled 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 25 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 left-most column on each page. Minor edits can print selected quantities at frequent intervals using much less paper than major edits. Section 4 of the RELAP5 Input Data Requirements (Appendix A of this volume of the manual) indicates how to request minor edits and what the user specified quantities represent.

8.3.4 Diagnostic Edit

During a transient (TRNSNT on Card 100) or steady state (STDY-ST on Card 100) problem, additional tables of variables can be printed out by a simple code update 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 that activates this output is the variable HELP. Normally, HELP = 0 and no diagnostic printout occurs.

```
RELAP5/2(36-01)      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
WATER FILL INTO STEAM - OPEN                                                                                    85/08/01.                                              PAGE      18
TIME          P            P            P            P            P            P            P            P            P
(SEC)          3010000      3020000      3030000      3040000      3050000      3060000      3070000      3080000      3090000
              (PA)         (PA)         (PA)         (PA)         (PA)         (PA)         (PA)         (PA)         (PA)

0.            4.00000E+05  4.00000E+05  4.00000E+05  4.00000E+05  4.00000E+05  4.00000E+05  4.00000E+05  4.00000E+05  4.00000E+05
5.00000E-02   4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .10000       4.00058E+05  4.00052E+05  4.00046E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .15000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .20000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .25000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .30000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .35000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .40000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .45000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .50000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .55000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .60000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .65000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .70000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .75000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .80000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .85000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .90000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
 .95000       4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.0000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.0500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.1000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.1500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.2000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.2500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.3000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.3500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.4000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.4500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.5000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.5500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.6000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.6500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.7000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.7500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.8000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.8500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.9000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
1.9500        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
2.0000        4.00057E+05  4.00051E+05  4.00045E+05  4.00039E+05  4.00033E+05  4.00027E+05  4.00021E+05  4.00015E+05  4.00009E+05
2.0500        3.99566E+05  3.99612E+05  3.99658E+05  3.99704E+05  3.99749E+05  3.99795E+05  3.99840E+05  3.99886E+05  3.99932E+05
2.1000        3.99486E+05  3.99537E+05  3.99590E+05  3.99642E+05  3.99694E+05  3.99746E+05  3.99799E+05  3.99851E+05  3.99903E+05
2.1250        3.99594E+05  3.99633E+05  3.99666E+05  3.99700E+05  3.99733E+05  3.99767E+05  3.99801E+05  3.99834E+05  3.99868E+05
2.1500        3.99743E+05  3.99767E+05  3.99781E+05  3.99795E+05  3.99809E+05  3.99823E+05  3.99837E+05  3.99851E+05  3.99865E+05
2.1750        4.00556E+05  4.00472E+05  4.00400E+05  4.00329E+05  4.00258E+05  4.00186E+05  4.00116E+05  4.00045E+05  3.99974E+05
2.2000        4.01002E+05  4.00848E+05  4.00739E+05  4.00630E+05  4.00521E+05  4.00412E+05  4.00303E+05  4.00194E+05  4.00086E+05
2.2500        4.00487E+05  4.00397E+05  4.00343E+05  4.00299E+05  4.00250E+05  4.00201E+05  4.00152E+05  4.00102E+05  4.00053E+05
2.3000        4.00258E+05  4.00154E+05  4.00135E+05  4.00117E+05  4.00099E+05  4.00081E+05  4.00063E+05  4.00044E+05  4.00026E+05
2.3500        4.00198E+05  4.00070E+05  4.00062E+05  4.00054E+05  4.00045E+05  4.00037E+05  4.00029E+05  4.00021E+05  4.00012E+05
```

Figure 25. Minor edit from water fill into steam problem (closed).

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 updating any of the hydrodynamic subroutines to set HELP $\geq$ 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 HELP is reset to 0. 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 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.

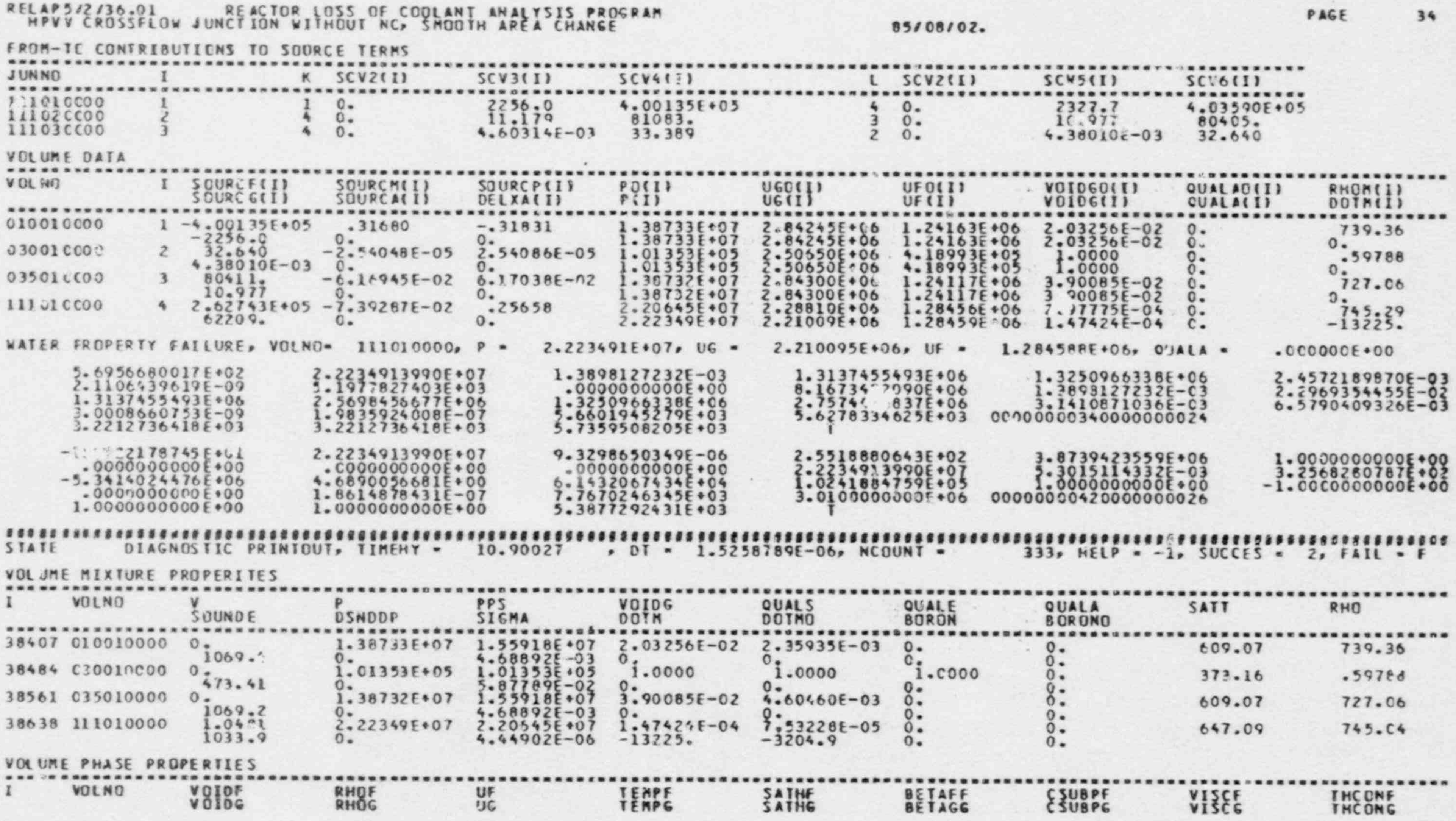
The final way a diagnostic edit can occur is when a code failure occurs. This does not occur for every code failure, but it does occur for a large number of them. When this occurs, HELP will be set to 1 in most cases. When it is set to 1, the diagnostic edit will be forced out for the remainder of the 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 8 asterisks (********). An example of this printout for the case of a water property failure at the minimum time step is shown at the bottom of Figure 26. Following this, the old time STATE subroutine 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 water property error, information from the STATEP subroutine concerning the faulty volume is printed out (see middle of Figure 27). The information is the label WATER PROPERTY FAILURE, the volume number (labeled VOLNO), pressure (labeled P), vapor specific energy (labeled UG), liquid specific energy (labeled UF), noncondensible quality (labeled QUALA), the 26 elements of the PROP array, the variable ERX, the 26 elements of S array, and the variable ERX. The Subroutines STATE and STATEP should be consulted for the meaning of the PROP array, S array, and ERX, which in general contain information calculated from the steam tables. 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 water property error mentioned above and shown in Figures 26 and 27 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. Water 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 Subsection 8.3.2.6 of this manual). Another example of a user-caused failure is when material property data is 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

```
RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
  HPVV CROSSFLOW JUNCTION WITHOUT NC, SMOOTH AREA CHANGE                               85/08/02.                                PAGE      25
  ATTEMPTED ADV: TOT.=    197   EDIT=    147   MIN.DT=    6.250000E-03 SEC   LAST DT=   2.500000E-02 SEC   MS.ERR=    83.7132       LB
   REPEATED ADV: TOT.=     27   EDIT=     27   MAX.DT=     .100000     SEC   CRNT.DT=   4.821907E-03 SEC   TOT.MS=    1718.23       LB
 SUCCESSFUL ADV: TOT.=    170   EDIT=    120   AVG.DT=    4.166667E-02 SEC   ERR.EST=   7.210184E-04        M.RATO=   4.731665E-02
  REQUESTED ADV: TOT.=    100   EDIT=     50   REQ.DT=     .100000     SEC       CPU=   1.57300      SEC       TIME=    10.0000       SEC
    VOL.NO.   PRESSURE       VOIDG           TEMPF           TEMPG          SAT. TEMP.    NONCOND.       BORON DENS.  UF              UG            VOL.
              (LBF/IN2)                      (DEGF)          (DEGF)         (DEGF)        VAPOR QUAL.    (LB/FT3)     (BTU/LB)        (BTU/LB)      FLAG
SYSTEM  1
UPSTREAM     TMDPVOL      MASS=   1718.2     LB      MASS ERROR=   83.713      LB      ERR.EST.=  7.21018E-04
                          COMPONENT
 10-010000     2021.4        2.23341E-02   545.45          637.31          637.31       0.             0.            533.94          1222.7         10
HPVV         TMDPVOL      COMPONENT
 30-010000     14.700         1.0000       212.01          212.01          212.01       0.             0.            180.13          1077.6         10
DOWNSTREAM   TMDPVOL      COMPONENT
 35-010000     2021.4        3.06682E-02   545.26          637.31          637.31       0.             0.            533.70          1223.1         10
CANE A TOP   BRANCH       COMPONENT
111-010000     1508.7        2.93529E-02   528.73          597.05          596.97       0.             0.            516.09          1092.8         00
    VOL.NO.   RHOF          RHOG           LIQ.V.VEL.      VAP.V.VEL.      SOUNDE        STATIC QUAL.  TOT.HT.INP.  VAP.HT.INP.     VAPOR GEN.
              (LB/FT3)      (LB/FT3)       (FT/SEC)        (FT/SEC)        (FT/SEC)                    (BTU/SEC)    (BTU/SEC)       (LB/FT3-SEC)
 10-010000    47.000          5.3944         1084.9          1084.9         3508.5       2.41509E-03   0.           0.              0.
 30-010000    59.813        3.73246E-02    6.23507E-07     6.23507E-07      1553.2        1.0000       0.           0.              0.
 35-010000    47.013          5.3944       4.06372E-02     4.06372E-02      3507.8       3.61718E-03   0.           0.              0.
111-010000    47.716          3.6325         1091.4          1091.0         3459.3       2.29682E-03   0.           0.             -3.2700
    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
 10-010000          0       0            0      0          0       0          0      0             0      0        0       0            0      0
 30-010000          0       0            0      0          0       0          C      0             0      0        0       0            0      0
 35-010000          0       0            0      0          0       0          0      0             0      0        0       0            0      0
111-010000        120     170            6      6          0       0         18     18             0      0      120     170            0      0
    JUN.NO.   FROM VOL.       TO VOL.   LIQ.J.VEL.      VAP.J.VEL.     MASS FLOW      JUN.AREA       THROAT            JUNCTION  CHOKE   NO.ADVS.CHOKED
                                        (FT/SEC)        (FT/SEC)       (LB/SEC)       (FT2)          RATIO                FLAGS   FLAG       EDIT  TOTAL
SYSTEM  1
CANE A TOP BRANCH        COMPONENT
111-010000    10-010000   111-010000     1084.9          1084.9        3.53339E+05    7.0689          1.0000              00000     0          0      0
111-020000   111-010000    35-010000     1097.9          1097.9        3.51603E+05    7.0689          1.0000              00000     1         86     86
111-030000   111-010000    30-010000     1102.7          1102.7         28.247        5.65432E-04     1.0000              10002     1        120    170
    JUN.NO.   VOIDFJ          VOIDGJ          FROM   TO      FIJ            FWALFJ       FWALGJ       FJUNF        FJUNR        FORMFJ       FORMGJ
                                                             (LB-S2/FT5)
111-010000    .97767        2.23341E-02       BBY    BBY      825.86        8.858E-03    8.790E-03    7.350E-02    7.350E-02    0.           0.
111-020000    .97065        2.93529E-02       BBY    STR      825.86        8.753E-03    8.686E-03    7.350E-02    7.350E-02    0.           0.
111-030000    .97065        2.93529E-02       BBY    MST      825.86        0.           0.           0.           0.           0.           0.
---RESTART NO.     197 WRITTEN, BLOCK NO.     5---
NUMBER OF ELEMENTS IN SPARSE MATRIX 1: ORIGINAL =     8, FACTORED =     8     ROUNDOFF ERROR =     1.000000E-12     NCOUNT =     198
******** WATER PROPERTY ERROR WITH MINIMUM TIME STEP, TRANSIENT BEING TERMINATED.
******** TROUBLE, LAST ADVANCEMENT BEING REPEATED WITH DEBUG PRINTOUT.
```

Figure 26. Example of printout before the diagnostic edit when a failure occurs.



```
RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                  PAGE      34
  HPVV CROSSFLOW JUNCTION WITHOUT NC, SMOOTH AREA CHANGE                               85/08/02.
FROM-TC CONTRIBUTIONS TO SOURCE TERMS
----------------------------------------------------------------------------------------------------------------------
JUNNO          I              K  SCV2(I)        SCV3(I)        SCV4(I)             L  SCV2(I)        SCV5(I)        SCV6(I)
----------------------------------------------------------------------------------------------------------------------
111010000      1              1  0.              2256.0        4.00135E+05         4  0.              2327.7        4.03590E+05
111020000      2              4  0.              11.179         81083.             3  0.              10.977         80405.
111030000      3              4  0.             4.60314E-03     33.389             2  0.             4.38010E-03     32.640
VOLUME DATA
------------------------------------------------------------------------------------------------------------------------------------
VOLNO          I  SOURCF(I)      SOURCM(I)      SOURCP(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)
------------------------------------------------------------------------------------------------------------------------------------
010010000      1 -4.00135E+05    .31680        -.31831        1.38733E+07    2.84245E+06    1.24163E+06    2.03256E-02    0.               739.36
                 -2256.0         0.             0.            1.38733E+07    2.84245E+06    1.24163E+06    2.03256E-02    0.             0.
030010000      2   32.640       -2.54048E-05   2.54086E-05    1.01353E+05    2.50650E+06    4.18993E+05     1.0000        0.               .59788
                  4.38010E-03    0.             0.            1.01353E+05    2.50650E+06    4.18993E+05     1.0000        0.             0.
035010000      3   80411.       -6.16945E-02   6.17038E-02    1.38732E+07    2.84300E+06    1.24117E+06    3.90085E-02    0.               727.06
                   10.977        0.             0.            1.38732E+07    2.84300E+06    1.24117E+06    3.90085E-02    0.             0.
111010000      4  2.62743E+05  -7.39287E-02     .25658        2.20645E+07    2.28810E+06    1.28456E+06    7.[illegible]7775E-04    0.               745.29
                   62209.        0.             0.            2.22349E+07    2.21009E+06    1.28459E+06    1.47424E-04    0.            -13225.
WATER PROPERTY FAILURE, VOLNO=  111010000, P =   2.223491E+07, UG =   2.210095E+06, UF =   1.284588E+06, QUALA =     .000000E+00

        5.6956680017E+02        2.2234913990E+07        1.3898127232E-03        1.3137455493E+06        1.3250966338E+06        2.4572189870E-03
        2.1106439619E-09        5.1977827403E+03         .0000000000E+00        8.16734[illegible]2090E+06        1.3898127232E-03        2.2969354455E-02
        1.3137455493E+06        2.5698456677E+06        1.3250966338E+06        2.7574[illegible]837E+06        3.1410871036E-03        6.5790409326E-03
        3.0008660753E-09        1.9835924008E-07        5.6601945279E+03        5.6278334625E+03  0000000034000000000024
        3.2212736418E+03        3.2212736418E+03        5.7359508205E+03              T

       -1.[illegible]22178745E+01        2.2234913990E+07        9.3298650349E-06        2.5518880643E+02        3.8739423559E+06        1.0000000000E+00
         .0000000000E+00         .0000000000E+00         .0000000000E+00        2.2234913990E+07        5.3015114332E-03        3.2568260787E+02
       -5.3414024476E+06        4.6890056681E+00        6.1432067434E+04        1.0241884759E+05        1.0000000000E+00       -1.0000000000E+00
         .0000000000E+00        1.8614878431E-07        7.7670246345E+03        3.0100000000E+06  0000000004200000000026
        1.0000000000E+00        1.0000000000E+00        5.3877292431E+03              T
####################################################################################################################################
STATE      DIAGNOSTIC PRINTOUT, TIMEHY =    10.90027     , DT =  1.5258789E-06, NCOUNT =        333, HELP = -1, SUCCES =  2, FAIL = F
VOLUME MIXTURE PROPERITES
------------------------------------------------------------------------------------------------------------------------------------
I     VOLNO       V              P              PPS            VOIDG          QUALS          QUALE          QUALA          SATT           RHO
                  SOUNDE         DSNDDP         SIGMA          DOTM           DOTMO          BORON          BORONO
------------------------------------------------------------------------------------------------------------------------------------
38407 010010000   0.             1.38733E+07    1.55918E+07    2.03256E-02    2.35935E-03    0.             0.               609.07         739.36
                     1069.4      0.             4.68892E-03    0.             0.             0.             0.
38484 030010000   0.             1.01353E+05    1.01353E+05     1.0000         1.0000         1.0000        0.               373.16         .59788
                     473.41      0.             5.87789E-02    0.             0.             0.             0.
38561 035010000   0.             1.38732E+07    1.55918E+07    3.90085E-02    4.60460E-03    0.             0.               609.07         727.06
                     1069.2      0.             4.68892E-03    0.             0.             0.             0.
38638 111010000    1.0481        2.22349E+07    2.20545E+07    1.47424E-04    7.53228E-05    0.             0.               647.09         745.04
                     1033.9      0.             4.44902E-06   -13225.        -3204.9         0.             0.
VOLUME PHASE PROPERTIES
------------------------------------------------------------------------------------------------------------------------------------
I     VOLNO       VOIDF          RHOF           UF             TEMPF          SATHF          BETAFF         CSUBPF         VISCF          THCONF
                  VOIDG          RHOG           UG             TEMPG          SATHG          BETAGG         CSUBPG         VISCG          THCONG
```

Figure 27. Example of printout buried in the diagnostic edit when a failure occurs.

reported to the development staff through the RELAP5 User Services. Such errors often result in negative densities, bad viscosities, bad thermal conductivities, or water property errors.

8.4 Plotted Output

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 of input plot comparison data tables has also been provided.

For convenience to the user a check plot option is provided that will produce plots of input data such as for time dependent volumes and functions, general tables, plot comparison data tables, valve area and flow coefficient, etc. This option can be utilized by the input of the "check plot" general plot request input card. 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 axis 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 be in 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 at a keypunch or 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 is 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 File Usage

The following descriptions assume standard CDC operating systems. A NOS system is assumed to be a Cyber-176 or -173 type machine operating under the NOS[4] system. A SCOPE-2 system is assumed to be a CDC-7600 operating under the SCOPE-2[5] system. Default file structures are used.

The program cards for RELAP5 are:

For NOS

```
PROGRAM RELAP5(INPUT=128, OUTPUT=512, RSTIN=0, RSTPLT=0, TALKER=10,
PLOTFL=0, STH2XT=0, DEBUG=OUTPUT, TAPE6=OUTPUT)
```

For SCOPE-2

```
PROGRAM RELAP5(INPUT,OUTPUT,RSTIN,RSTPLT,STH2XT,
*TAPE6=OUTPUT,DEBUG=OUTPUT,PLFILE,PLOTFL).
```

8.5.1 Input File

The input data uses the standard 80 column card or its equivalent. However, to accommodate card maintenance programs such as UPDATE[6] and interactive text editors such as FSE,[7] RELAP5 reads and echos to the output up to 90 columns of information. Only the first 80 columns are used for program input; the other 10 columns are for assistance in external manipulating of card data. If UPDATE is used, the D option should be specified, to specify 80 columns of data. Detailed input requirements are given in Appendix A.

8.5.2 Output File

The output file is a standard output file. The default line limits are used and if a large amount of printed output is expected, *PL = n, where n is somewhat more than the expected number of lines, should be added to the RELAP5 execute card.

8.5.3 RSTIN File

This file is required for all problem types except NEW. This file is the RSTPLT file written in a previous RELAP5 execution. The file may be a tape or disk file. If it is a tape file, a REQUEST (RSTIN, ...) control card for NOS or a STAGE (RSTIN, PRE, ...) control card for SCOPE-2 must be used. A disk file may be a local file created in a previous step or an attached permanent file. Input to the program can cause the attach and return of a permanent file (for NOS-BE or SCOPE), freeing the user from entering control cards.

8.5.4 RSTPLT File

This file is optionally written in NEW and RESTART type problems and is always written in STRIP problems. If a tape file is desired, a REQUEST (RSTPLT, ...) control card for NOS or a STAGE (RSTPLT, POST) control card for SCOPE-2 is required prior to the RELAP5 execution card. If a permanent disk file is desired, the user can use a DEFINE,RSTPLT card ahead of the RELAP5 execution card. The user may also request RELAP5 to create the permanent file or stage the tape (for NOS-BE and SCOPE) eliminating the need for the control cards.

8.5.4.1 RSTPLT File Written by NEW-RESTART Problems. This file can subsequently be read as the RSTIN file. It can also be read by other programs (such as plotting programs) that generate comparison plots with experimental data.

The file is written by BUFFER OUT (RSTPLT, 1) statements. The letters A, I, and R indicate alphanumeric, integer, or real type variables.

RSTPLT Record

This record is the first record.

Words 1-2(A)	Program identification identical to the first 10 columns at the top of every printed page. At the time of writing this document, the words contain RELAP5/2/3.
Words 3-4(A)	These words contain RESTART-PLOT FILE.
Word 5(I)	This word currently contains 0. It can be incremented whenever program changes make previously written RSTPLT files incompatible for restart with a newer version. The plot record philosophy should be immune to these changes.

Word 6(A) This word contains the date the file was written.

8.5.4.1.1 PLOTINF, PLOTALF, PLOTNUM, AND PLOTREC Records--These records are used to store simulation results and to provide for subsequent use of these results in the PLOT, REEDIT, and STRIP options of RELAP5. These records can also be used to pass simulation results to other computer programs, although the STRIP file is recommended because it is easier to use. Simulation quantities written to tape are time and hydrodynamic component, volume, junction, heat structure, reactor kinetics, and control system results. The amount of data is problem-dependent and can change at restart if the problem is changed.

The PLOTINF record is a three-word record containing PLOTINF in the first word and zero in the third word. The second word contains the length of the following PLOTALF, PLOTNUM, and PLOTREC records. PLOTALF and PLOTNUM records always immediately follow a PLOTINF record.

The PLOTALF, PLOTNUM, and PLOTREC records are of equal length and the words in the PLOTALF and PLOTNUM records are the identification for the quantities stored in the corresponding words of the PLOTREC records. The identification is the same as the request codes for plotting and minor edits. Word 1 of the PLOTALF contains PLOTALF; the remaining words contain the alphanumeric portion of the variable request code for the corresponding word in PLOTREC records. Word 1 of the PLOTNUM record contains PLOTNUM; the remaining words contain the numerical portion of the variable request code. The number of PLOTREC records depends on the minor edit frequencies on the time step control cards. Word 1 of the PLOTREC record contains PLOTREC. Word 2 contains time; the remaining words contain simulation quantities corresponding to the time value.

PLOTINF, PLOTALF, and PLOTNUM records are always written as the second, third, and fourth records of a RSTPLT file. These records define the length of the PLOTREC records and the position of the simulation results in the records. Whenever a problem changes at restart, the length or content of the PLOTREC records may also change, so PLOTINF, PLOTALF, and PLOTNUM records are again written to define the new length and position of the results.

8.5.4.1.2 <u>RESTART Records</u>--Whenever the printed output indicates that a restart record is written, in reality a block of records is written, and the number of records and their length are problem-dependent. These records are of use only to RELAP5 during a restart. For use outside of RELAP5, any record not having PLOTINF, PLOTALF, PLOTNUM, or PLOTREC as the first word should be skipped.

8.5.4.1.3 <u>Reading the RSTPLT File</u>--The following procedure is suggested for extracting information from the plot records of the RSTPLT file. Identification of quantities to be extracted are read from an input file. These should be the variable request code for each quantity consisting of an alphanumeric and a numeric word. These request codes relate directly to the quantities used in the RELAP5 run that generated the file. The first record of the RSTPLT file is read and checked to verify that it is a RSTPLT file from RELAP5. This and all other reads of the RSTPLT file should be made using appropriate combinations of the BUFFER IN statement and status checks made using the UNIT function.[8] Subroutine LENGTH[8] can be used to determine the actual length. Good programming practice is to attempt to read one more word than expected and check that only the expected number of words were actually read. Using the record length from the PLOTINF record, two buffers are established and the PLOTALF and PLOTNUM records are read.

For each variable request, a search is made of the information in the PLOTALF-PLOTNUM records for a match. Failure to obtain a match is not necessarily an input error. The desired quantity may not be present at the beginning of a RSTPLT file, but due to a problem change at a restart, may appear later in the file. Similarly, deletion of a desired quantity may occur at a restart. The program reading the file must provide for entering default data or terminating when there are missing quantities. If a match is found, the position of the match (index in the buffers) is saved for future retrieval of information from PLOTREC records. After all the input requests are processed, PLOTREC records can be read into the buffers previously containing the PLOTALF and PLOTNUM records using a double buffering technique if desired. If the first word of a record is not PLOTREC or PLOTINF, the record is ignored, since it is a record from the restart information. When a PLOTREC record is read, the desired information can be extracted from the positions of the data determined previously.

If a PLOTINF record is read, the buffer lengths are adjusted for the new record length given in the PLOTINF record and the process of reading PLOTALF and PLOTNUM records, attempting to match requests, and reading PLOTREC records is repeated. An end of file return from the IF (UNIT ...) test indicates the end of the RSTPLT file.

The above procedures allow programs processing a RSTPLT file to be used even when additional variables are added to the RSTPLT file.

8.5.4.2 <u>RSTPLT File Written by STRIP Problem</u>. For convenience, the RSTPLT file written by a STRIP type problem will be called the STRIP file and the RSTPLT file written by a NEW or RESTART problem will be called the RSTPLT file. The STRIP file is similar in structure to the RSTPLT file, but reading the STRIP file is much simpler than reading the RSTPLT file, since only the information requested by the user is written (in the order requested). No restart records are written on a STRIP file.

8.5.4.2.1 <u>STRIP Record</u>--This record is the first record. This record is identical to the RSTPLT (first) record of the RSTPLT file except Words 3-4 contain STRIP FILE, and Word 5 is always zero.

8.5.4.2.2 <u>PLOTINF, PLOTALF, PLOTNUM, and PLOTREC Records</u>--These records for the STRIP file are identical in structure and positioned the same as for the RSTPLT file. Word 2 of the PLOTREC records is time; the remaining words are quantities requested by the user in the order requested. The alphanumeric and numeric quantities in PLOTALF and PLOTNUM will be identical to user-supplied request codes. Since the input requests do not vary during a STRIP problem, the PLOTALF and PLOTNUM records never change. Thus, the PLOTINF, PLOTALF, and PLOTNUM records are written only once as the second, third, and fourth records. Whenever a requested variable is not present on the RSTIN file being processed, a negative indefinite quantity (60000000000000000000B) is written in place of the missing variable. A program reading the STRIP file can test for missing variables by an integer test for the indefinite value or through the LEGVAR[8] function.

8.5.4.2.3 Reading the STRIP File--The STRIP tape may be read using the same procedures as for reading the RSTPLT file. However, shortcuts can be taken since the order of information is controlled by the user. Consider a case where an analysis program needs a particular volume pressure and density from a RELAP5 simulation. One job step could be a STRIP type RELAP5 problem extracting the desired pressure and density (in that order). The STRIP file is rewound and the analysis program is executed. The analysis program skips the first four records (STRIP, PLOTINF, PLOTALF, and PLOTNUM records). Then, as needed, subsequent records are read and Words 2 to 4 of each record contain time, pressure, and density.

8.5.5 PLFILE File

The plotting capability uses the DISSPLA[9] package, and plotting commands are written on PLFILE. The commands are in a generalized form and an auxiliary DISSPLA program is needed to transform them to a particular plotting device. Because of the differences in DISSPLA between the two systems, this file appears on the PROGRAM card for SCOPE-2 systems, but not for NOS systems. The NOS version of RELAP5 is compiled with the STATIC[8] option. The DISSPLA subroutine writing the PLFILE may need modification to operate in the static mode.

8.5.6 PLOTFL File

PLOTFL is a scratch file on which information is written during problem advancement for plotting after transient termination.

8.5.7 STH2XT File

STH2XT is a water property table file consisting of two records read by BUFFER IN statements. The file is required only for NEW and RESTART problems. This file can be generated by the STH2XG program.

8.6 RELAP5 Control Card Requirements

Control card sequences used to execute RELAP5 on a Cyber-176 using the NOS operating system are shown in Figures 28 through 30. The control cards are described in the NOS reference manual.[4] Very general procedures using the Cyber control language statements have been developed to simplify RELAP5 execution. The procedures are documented in the last section of the Input Data Requirements, Appendix A. Part A of Figures 28 through 30 list the control cards required when not using the procedures so that the required cards can be shown without the added complexity of conditional Cyber control statements. Part B shows control cards to perform the same function as Part A but using the procedures. Use of the procedures is recommended.

The following files are assumed to be stored as permanent files:

RELAP5S	RELAP5 source in UPDATE OLDPL format
RELAP5L	RELAP5 object decks in library form (created by LIBEDIT)
RELAP5X	RELAP5 absolute binary
ENVRLX	Library containing SELECTA and SELECTC (programs to select compile time options)

PART A. NEW PROBLEM WITH NO PROCEDURE USE.

```
JOB CARDS AS REQUIRED BY SYSTEM
ATTACH(RELAP5D/UN=RL5)
UPDATE(Q,P=RELAP5D,D)
RETURN(RELAP5D)
ATTACH(RELAP5X/UN=RL5)
ATTACH(STH2X1/UN=RL5)
LABEL(RSTPLT,D=GE,LB=KU,VSN=0)
FILE(RSTIN,SBF=NO)
FILE(RSTPLT,SBF=NO)
FILE(TALKER,DFC=NO)
RFL(CM=270000,EC=200)
RELAP5X(COMPILE,PL=20000)
/EOR
*COMPILE EDHTRK
```

PART B. NEW PROBLEM WITH PROCEDURE USE.

```
JOB CARDS AS REQUIRED BY SYSTEM
GET(PROCS=RPROCS/UN=RL5)
LABEL(RSTPLT,D=GE,LB=KU,VSN=0)
BEGIN(RLP5X,PROCS,DPFN,DUPFN)
/EOR
*COMPILE EDHTRK
```

Figure 28. RELAP5 control cards for execution of a new problem.

PART A. RESTART PROBLEM WITH NO PROCEDURE USE.

```
JOB CARDS AS REQUIRED BY SYSTEM
ATTACH(RELAP5X/UN=RL5)
ATTACH(STH2XT/UN=RL5)
LABEL(RSTIN,D=GE,PO=R,VSN=?????)
LABEL(RSTPLT,D=GE,LB=KU,VSN=0)
FILE(RSTIN,SBF=NO)
FILE(RSTPLT,SBF=NO)
FILE(TALKER,DFC=0)
RFL(CM=270000,EC=200)
RELAP5X(PL=20000)
/EOR
=EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS--RESTART
103   546   *THIS NUMBER CAN CHANGE WITH DIFFERENT VERSIONS
204   0.600   1.0-7   0.001   1   10   50   100
.  END OF INPUT DATA
```

PART B. RESTART PROBLEM WITH PROCEDURE USE.

```
JOB CARDS AS REQUIRED BY SYSTEM
GET(PROCS=RPROCS/UN=RL5)
LABEL(RSTIN,D=GE,PO=R,VSN=?????)
LABEL(RSTPLT,D=GE,LB=KU,VSN=0)
BEGIN(RLP5X,PROCS)
/EOR
=EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS--RESTART
103   546   *THIS NUMBER CAN CHANGE WITH DIFFERENT VERSIONS
204   0.600   1.0-7   0.001   1   10   50   100
.  END OF INPUT DATA
```

Figure 29. RELAP5 control cards for execution of a restart problem.

PART A. SOURCE MODIFICATION WITHOUT PROCEDURE

```
JOB CARDS AS REQUIRED BY SYSTEM
ATTACH(OLDPL=RELAP5S/UN=RL5)
UPDATE.
RETURN(OLDPL)
ATTACH(ENVRLX=ENVR41X/UN=RL5)
LIBRARY(ENVRLX)
SELECTA(COMPILE,COMP)
LIBRARY.
RETURN(ENVRLX)
REWIND(COMP)
FTN5(I=COMP.DO,ET,STATIC,OPT=2,ROUND,LO=M/A/R/S)
RETURN(COMP)
REWIND(LGO)
ATTACH(RELAP5I=RELAP5L/UN=RL5)
GTR,RELAP5I,ADD.REL/*
LIBEDIT,P=RELAP5O,I=0,B=ADD,LO=F,U,C.
LIBEDIT,P=RELAP5O,B=LGO,I=0,LO=F,U,C.
RETURN(NULL,LGO,RELAP5I)
RETURN(RLP5F1,RLP5F2)
ATTACH(ENVRL/UN=RL5)
ATTACH(KXRLIB/UN=SUPPORT)
ATTACH(FRMLIB/UN=SUPPORT)
ATTACH(DISSPLA=DSSPL82/UN=SUPPORT.
FILE(RSTIN,RT=S,SBF=NO,USE,FO=SQ)
RFL(EC=200)
SEGLOAD(I=COMPILE,B=RELAP5X)
LDSET(LIB=RELAP5O/ENVRL/FRMLIB/DISSPLA)
LDSET(PRESETA=NGINDEF,ERR=NONE,MAP=SB)
LDSET(STAT=RSTIN)
LIBLOAD(ENVRL,$HDR=$)
LIBLOAD(FTN5LIB,$FERCAP.$,$RPVCAP.$,$FTNRP2.$,$Q2NTRY.$)
LIBLOAD(KXRLIB,CPA,TBL,BEENIN,BCLEAR,CPAX,GFI,IGA,BALANC)
LIBLOAD(KXRLIB,PPR,BEENOP,BOPEN,BEECLS,BEEHOP,BEERED,CONEK)
LIBLOAD(KXRLIB,BEEEXT,BEENIO,BCLOSE,GET64,PUT64,RTIME)
LIBLOAD(KXRLIB,XRECAL,BTZ,CFI,MOVRIG,BEELOC,BSQZ,QSORTA)
LIBLOAD(KXRLIB,BEECAT,BFIND,BLOAD,BTMIN,BTMOT,CFS,BADD,BSPLIT)
LIBLOAD(KXRLIB,BTREP,BLOC,BNODE,BPOP,BPUSH,BCMAIN,BINSRT,BNEW,BEENCL)
LIBLOAD(KXRLIB,KEYTST,BINSEQ,BEERLP)
NOGO.
RETURN(RELAP5O,ENVRL,KXRLIB,FRMLIB,DISSPLA,COMPILE)
ATTACH(RELAP5D/UN=RL5)
UPDATE(Q,P=RELAP5D,D)
RETURN,RELAP5D.
ATTACH(STH2XT/UN=RL5)
FILE(RSTIN,SBF-NO)
FILE(RSTPLT,SBF=NO)
FILE(TALKER.DFC=0)
RFL(CM=270000,EC-200)
REDUCE(-)
RELAP5X(COMPILE,*PL=20000)
```

Figure 30. RELAP5 control cards for program modification/ execution.

```
REDUCE.
RFL(EC=0)
RETURN(RELAP5X,STH2XT,PLOTFL,FTB1)
BEGIN(FR80POP)
/EOR
*I RELAP5.2
COMMENT.  JUST A HARMLESS CARD TO SHOW UPDATING OF THE PROGRAM
/EOR
*COMPILE EDNEWPL
```

PART B. SOURCE MODIFICATION TEST WITH PROCEDURE

```
JOB CARDS AS REQUIRED BY SYSTEM
GET(PROCS=RPROCS/UN=RL5)
BEGIN(RLP5CLX,PROCS,NOMESSG,LPFN,EDLIB,DPFN,DUPFN)
BEGIN(FR80POP)
/EOR
*I RELAP5.2
COMMENT.  JUST A HARMLESS CARD TO SHOW UPDATING OF THE PROGRAM
/EOR
*COMPILE EDNEWPL
```

Figure 30. (continued).

ENVRL	INEL Environmental Library
STH2XT	Water Property File
RELAP5D	Various input decks for RELAP5 stored in UPDATE OLDPL format.

These files can be obtained from the RELAP5 transmittal tape.

The control cards needed for execution of a NEW problem are shown in Figure 28. The UPDATE execution selects the problem labeled EDHTRK from a file containing input for several problems. The one card input data to UPDATE is the section of input following the control card section. The REQUEST card causes the RSTPLT file to be saved on tape. This can be omitted if the file is not to be saved on tape or the file could be saved on disk using a DEFINE control card. The program is executed from the absolute binary, RELAP5X, and uses the water property file, STH2XT. The FILE cards for the restart files RSTIN and RSTPLT can be omitted if LCM is not used. The RFL card defines the maximum amounts of SCM and LCM memory to be used during the execution. If a diagnostic message indicates that insufficient memory is available, the appropriate requested size should be increased. During certain phases of program execution such as transient advancements, the field lengths are reduced to the minimum needed in order to reduce computer costs. The reduced sizes are problem-dependent and are listed under FLS and FLL in the printout immediately preceding the first major edit. The FLS and FLL numbers could be used to judge whether smaller sizes could be used in the RFL request. When using the procedures, a GET is required to access the procedure file. Any cards for disposition of the RSTPLT file are also required. All remaining control cards are furnished by the procedure.

The control cards needed for execution of a RESTART problem are shown in Figure 29. The first REQUEST card indicates that the RSTIN file containing the restart information is a tape file. The second REQUEST card indicates that the RSTPLT file is to be stored on tape. Appropriate ATTACH and DEFINE cards can be used for disk files. Tape files are illustrated here since the size of files for any but trivial problems may be very large. The input data are for RELAP5 and they define the restart point.

Modification of the RELAP5 main program source, loading of the changed with the unchanged object decks, and execution of a problem is shown in Figure 30. The first UPDATE modifies the main program; in this case only a comment card is inserted. Whenever source decks are written on the COMPILE file, a *COMPILE DEFINE is required. This forces the DEFINE deck containing cards that define the compile time options to be written at the beginning of the COMPILE file. The *COMPILE SEGDIR card forces the directives to the segment loader[10] to be written onto the compile file. A *CWEOR card preceding the directives separates the modified program source from the directives. SELECTA implements the compile time options. More information on the compile time options and the selection process is given in Section 9. SELECTA writes the source decks to be compiled onto file COMP and leaves the COMPILE file positioned at the segment loader directives. FTN5 compiles the source decks on file COMP and writes relocatable object decks on file LGO. LIBEDIT creates a temporary new object deck library by replacing decks from the existing library RELAP5L with decks from file LGO. RELAP5L contains object decks corresponding to the source file RELAP5S. Decks are drawn from the temporary library as needed. In most cases, the LIBEDIT step is not needed. A LOAD(LGO) card can be added after the SEGLOAD card and the remaining required decks are obtained from RELAP5L. The LIBEDIT step is needed only if a COMDECK is changed that would cause subroutines stored on the source file but not currently being used to be compiled. The unneeded subroutines, if loaded, are placed in the root segment and resultant improper calls violate SEGLOAD requirements. (Also see EDLIB option in procedure description, Section 15 of Appendix A.) SEGLOAD initiates the load process. Object decks are loaded from the temporary library and the other libraries listed on the first LDSET card. Decks are first loaded in response to the deck names listed on the SEGLOAD directives and additional searches of the libraries are made to satisfy external references of decks from previous searches. Environmental library subroutines are loaded from ENVRL. Subroutines to link RELAP5 to the Nuclear Plant Analyzer (NPA) are loaded from KXRLIB. The NPA program for interactive execution and graphical display of the simulation is not included in the code transmittal package. The program can execute without this library as long as interactive execution is not attempted. The DISSPLA library is used for time history plots. It is a proprietary product and must be obtained from the vendor. RELAP5 can execute without DISSPLA if no plotting is requested. The LIBLOAD of the HDR=deck should be omitted if INEL modification of the CDC Subroutine OUTC= for page control is not used. The LIBLOAD, and KXRLIB cards should be omitted if the NPA linkage is not used. The resultant absolute binary is executed with a problem obtained through UPDATE from the set of sample problems. This problem generates plots and BEGIN (FR80POP) calls an INEL procedure that converts generalized DISSPLA commands to microfilm plotter commands.

8.7 Transient Termination

The transient advancement should not abort (terminate by operating system intervention) except for exceeding print line limits. (Program aborts are indications of programming errors.)

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 water 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. Requested plots are generated after a failure termination.

8.8 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 due to approaching the CPU time limit, the problem can be restarted with no changes to information obtained from the restart file. If the problem stopped due to advancement time reaching 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/MOD2 are summarized below. In all instances, the problem definition is that obtained from the restart tape unless input data is 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 and plot input data 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 plot request data 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. Alternately, the user can 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.

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

Heat structures, general tables, and material properties can also be deleted, changed, or added. An exception is a heat structure-geometry with the reflood option. The reflood option must be specified when the heat structure-geometry is first described. Once described, the heat structure-geometry with reflood cannot be deleted or changed. This limitation will be removed in a later version.

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, with the exception of kinetics and heat-structures with reflood, all modeling features in RELAP5 can be added, deleted or changed at restart.

9. RELAP5/MOD2 TRANSMITTAL INFORMATION

RELAP5/MOD2 is operational and in production use at the INEL on a Cyber-176 running under the NOS operating system. Early versions of RELAP5 operated on a Cyber-76 running under SCOPE-2. An attempt has been made to maintain SCOPE-2 capability on this version but no testing under SCOPE-2 has been done. Likewise an attempt has been made to maintain capability on NOS-BE systems. Coding has also been included to allow operation on Cyber-175 type computers (no LCM memory) but very little testing has been performed with this option. Some applications of RELAP5 to CDC machines without small core (SCM) and large core (LCM) have gotten into difficulties with LCM calls. It is recommended in these cases to simulate LCM. If this is impossible, all references to LCM must be removed in the define statements and in the PROCS. Cray-1 and Cray-XMP versions are operational under both COS and CTSS operating systems. The INEL personnel currently have the Cray version under production use.

Coding unique to the various computer versions and options within those versions are selected by compile time directives. Coding and directives for machines other than the CDC-7600-6600 and Cray type has been added to the source file but only the CDC and Cray versions are operational. The FTN5 compiler is now used for CDC versions. The Cray version has executed on the CFT-1.11 compiler. Maintenance of all versions on a common source file will be continued.

Coding to measure the execution time of the various phases of transient advancement can be included. Some computer time can be saved if the timing is omitted, since the timing subroutine involves calls to the operating system. Vector subroutines can be selected to replace equivalent FORTRAN coding. These features may be selected by compile time directives.

9.1 Selection of Compile Time Options

UPDATE[6] allows compile time selection of options through *IF and *ENDIF statements. *IF statements are written as *IF DEF,VAR,N. VAR represents one of several variables that may be defined or undefined. If

VAR is defined, the next N statements are included in the COMPILE file; if VAR is undefined, the next N statements are omitted. If N is missing, statements up to the terminating *ENDIF card are included or omitted. If a minus sign precedes DEF, the logic for including or omitting cards is reversed. VAR is defined if it appears in a *DEFINE VAR statement, otherwise it is undefined. Nesting of *IF with different VAR is permitted.

The above describes CDC UPDATE; the Cray UPDATE is similar but the N field is not allowed. Complete omission of statements leads to inconveniences when making changes unique to different versions. Since the FORTRAN listing shows only one version, other listings showing alternate versions or a listing of active cards from UPDATE must be used.

The SELECTA program provides a more convenient compile time selection of options even though the selection process is very similar to UPDATE. To use SELECTX, $IF, and $ENDIF, cards are placed in the source in exactly the same fashion as the * equivalent cards. However, with the $ in place of the *, the $ cards are treated as statements, not UPDATE cards, and thus are written to the COMPILE file. In addition, the first deck written to the COMPILE file contains none, one, or more $DEFINE VAR cards. SELECTA reads the $DEFINE VAR cards if any are present to set which variables are defined. SELECTA then reads the remaining COMPILE file and writes the file COMP with the options implemented. SELECTA processes $IF and $ENDIF cards in the same manner as UPDATE processes the * equivalent except that cards instead of being omitted are written with an * in column 1. The $IF and $ENDIF are also converted to *IF and *ENDIF. Since an * in column 1 is a comment card to FORTRAN, the $ control cards and omitted cards are listed but have no effect on compilation. In addition to SELECTA (A for all), SELECTC (for clean) is available and the execution procedures allow selection of either program. SELECTC uses the same selection process as SELECTA, but does not print any cards showing *IF, *ENDIF, or alternate versions. The clean listing, without the confusion of alternate versions, is useful for the initial study of a routine.

The PROGRAM card for SELECTA and SELECTC define files IN, OUT, and OUTPUT. IN is the COMPILE file from UPDATE, OUT is the processed file for input to the FORTRAN compiler, and OUTPUT is printed output.

In the Environmental Library and RELAP5 source files, the first deck is named DEFINE and contains the following pair of cards for each compile time option.

```
*IF DEF,VAR,1
$DEFINE VAR
```

Thus, for each variable defined by *DEFINE VAR, a corresponding $DEFINE VAR card is written to the COMPILE file. A *COMPILE DEFINE card must be used in the UPDATE input to force the DEFINE deck onto the COMPILE file. No *IF or *ENDIF statements appear in the remaining decks of the RELAP5 source, but they do appear in the loader directives. The environmental library source uses both UPDATE and SELECTA logic to select options.

9.2 Transmittal Package

A transmittal package contains the following:

1. RELAP5/MOD2 documentation (two volumes)

2. Environmental library manual

3. Transmittal tape

4. Dayfile showing creation of the transmittal tape

5. Microfiche containing printed output from a test of a CDC transmittal tape.

The transmittal tape contains eight partitions. (A partition is equivalent to a file on many other computer systems.)

Partition 1. Source file for RELAP5/MOD2
Partition 2. Source file for Environmental Library
Partition 3. Source file for sample problem input

Partition 4.	Procedures for the CDC-NOS system
Partition 5.	Updates to create the most recent cycle of RELAP5/MOD2
Partition 6.	Print file from a job that installs the code from the transmittal tape onto a CYBER-176 and executes sample problem EDNEWPL
Partition 7.	Print file from execution of sample problem PROB2
Partition 8.	Print file from execution of sample problem TYPPWR2, modified to limit execution time.

A transmittal tape is written in one of two formats, a CDC tape or a Non-CDC tape. The information on a transmittal tape is the same in either format.

Unless requested otherwise, CDC transmittal tapes are labeled with ASCII labels and Non-CDC tapes are unlabeled. The first five files are card image files; the last three files are print files.

The CDC tape is written using standard NOS defaults except that F = SI is specified. This should allow the tape to be read with standard defaults on a NOS-BE system and can also be read on SCOPE-2 systems. Thus, the format is RT = Z and display coding is used.

The Non-CDC tape uses EBCDIC coding. The FILE card for card image files is RT = F, BT = K, RB = 50, FL = 80, CM = YES and the FILE card for print files is the same except RB = 25, FL = 140. The IBM-OS equivalents are RECFM = FB, LRECL = 80, BLKSIZE = 4000 for card image files and RECFM = FB, LRECL = 140, BLKSIZE = 3500 for print files.

Refer to the LABEL and FILE (Non-CDC tape only) statements in the transmittal dayfile for details on the tape format.

The primary difference in the transmittal tape from previous RELAP5 transmittals is that the first three files of both CDC and Non-CDC tapes are SOURCE files. A SOURCE file contain cards images ready for input to either the CDC or Cray UPDATE programs. In the previous transmittals, the CDC tape contained UPDATE program libraries (OLDPL's). Also, larger blocks are now used in the Non-CDC format.

9.3 Installation Procedures

The first step in installing the program is to copy the first three SOURCE files from tape to disk, and then to create program libraries (OLDPL's) using the UPDATE program. For CDC computers, two updates are used for each file. The first UPDATE creates a temporary library from the source input; the second update adds the *DEFINE cards for the desired options. Since CDC UPDATE memorizes the *DEFINE cards, no *DEFINE cards are used on subsequent updates.

Before the Cray UPDATE program can be used to create OLDPL's, the RELAP5 and Environmental source files must be modified. Using an editor or other means, the RELAP5B deck and all subsequent decks must be removed from the RELAP5 source and the FETCHP deck and all following decks must be removed from the Environmental Library source. This undesirable feature of the Cray installation is due to the *COMPILE cards stored in these decks, which are the installation procedures for CDC NOS and NOS-BE versions. A *COMPILE card is an UPDATE directive but in the updates creating the program libraries, it is to be treated as a data card. Only when the procedure is extracted and executed is the *COMPILE card to be an UPDATE directive. This is accomplished through the use of *TEXT and *ENDTEXT cards on the CDC UPDATE, but the Cray UPDATE does not provide this capability. Use of the control character substitution might work on the Cray but did not work in a CDC test.

The Cray UPDATE does not memorize the *DEFINE cards so only one UPDATE per file is used to generate the program libraries.

*DEFINE statements must be entered for the desired compile time options. The following can be used to determine the proper options.

If CDC-6600-7600-170 etc.	*DEFINE CDC, CDCCRA
If SCOPE-2	*DEFINE SCOPE2,LCM
If NOS or NOS-BE	*DEFINE SCOPE1
If NOS	*DEFINE NOS
If NOS-BE	*DEFINE NOSBE
If LCM (must be LCM, not ECS)	*DEFINE LCM (optional)
If 7600 - 176 or similar CPU	*DEFINE VECTOR (optional)
If Cray	*DEFINE CDCCRA,CH8,CRAY,SCOPE1
If CTSS	*DEFINE CTSS
If Any Version	*DEFINE TIMED (optional)

Note that the above logic is nested. As one satisfies the If tests above, the indicated *DEFINEs are cumulative. Thus, the required options for a CYBER-176 operating under NOS are CDC, CDCCRA, SCOPE1, and NOS. LCM, TIMED, and VECTOR are optional. LCM is required for SCOPE2 system (CDC-7600) but is optional if available on other machines (176 - some 800 series machines). Larger problems may be run if LCM is used. Degradation in speed when using LCM is estimated to be small but has not been measured. Selection of the VECTOR options uses symbolic coded subroutines to execute vector operations in a few sections of the program. Equivalent FORTRAN is used if the VECTOR option is not specified. The symbolic coded subroutines use the special features of 7600 type CPU's to execute vector operations faster than the equivalent FORTRAN. The savings have not been measured. More extensive use of these subroutines has not been pursued because of the difficulty of coding and maintaining the special call statements needed for their use. The required Cray options are CDCCRA, CH8, CRAY, and SCOPE1. The TIMED option monitors the CPU time spent in major portions of the code, but an increased computation time. The TIMED option is usually defined for INEL installation but is recommended to be undefined for production use.

The CDC *DEFINE values are usually entered one per card so that they can be individually deleted if necessary. The cray *DEFINE values are usually entered on one card since they must be re-entered on each update.

For CDC, NOS, and NOS-BE, procedures are provided to aid the installation. The NOS procedures currently used at INEL have not yet been incorporated into the source file; instead they were written as File 4 of the transmittal tape. For Cray, the installation is similar, but the installer must provide all the control cards. Since the installation steps for Cray parallel those for CDC, it is recommended that both the CDC and Cray installation steps be reviewed when installing the Cray version.

9.3.1 Environmental Library Installation Procedures - CDC Version

To use the CDC procedures, the OLDPL of the environmental source must be stored on disk with permanent file name ENVRS. Its UN and password should be the same as all other files to be created as part of the installation. The source file must already have the *DEFINE parameters defined properly for the operating system and machine type.

The first step is to attach the permanent file ENVRS as a local file of the same name and to extract the procedure FETCHP. Control statements to do this are the following. All examples use UN=RJW and PW=RJW.

```
ATTACH(ENVRS/UN=RJW)
UPDATE(Q,P=ENVRS,C=FETCHP,D,8)
.
.
.
*EOR      or        7-8-9 card
*COMPILE FETCHP
```

The UPDATE call extracts the procedure FETCHP, which is used to extract the other procedures as needed. The following four procedures are used to install the library. They are called by

```
FETCHP, name
name, parameters
```

where name is the procedure name. All four procedures have the following parameters in common, UN and PW. ID and PW are keyword= type parameters and default to ID=RJW, PW=RJW. All files created by the procedures are cataloged with the UN and password entered with these keywords. All four procedure calls must use the same values for these parameters. The procedures must be called in the order presented here, but they need no all be called in the same job. One job could execute the first one, two, or three procedures, and one or more jobs could execute the rest as long as they are executed in the given order.

HEADERB - This procedure builds and catalogs a temporary library, ENVRL, with the specified ID and password. If the keyword HEADERX is not entered in the parameter list, the temporary library contains the INEL modification of the CDC FORTRAN output subroutine. The modification provides automatic page headings. IF HEADERX is entered, the library contains dummy subroutines and functions to satisfy subroutine/function references for page control in RELAP5. NOS and NOS-BE systems should be able to use the INEL modified subroutines. The procedure assumes text needed for the COMPASS assembly can be accessed through S=FORTRAN/FCLTEXT. SCOPE-2 systems use the HEADERX option.

SELECTB - This procedure builds the ENVRLX library containing executable versions of the SELECTA and SELECTC programs. The temporary library ENVRL is used in building ENVRLS.

ENVRLB - This procedure completes the ENVRL library. It uses SELECTA to select a particular computer version. The procedure purges the former ENVRL library and catalogs the complete library.

STH2OTB - This procedure builds a water property file, STH2OT, or STH2XT. The STH2XT, which is needed by RELAP5, is computed and cataloged if the keyword X is entered in the parameter list. This procedure uses SELECTA and the ENVRL library.

The library can be installed in either batch or interactive node. The following show the commands for interactive installation using RJW for both UN and password. The next section shows a batch installation. The ENVRS file is assumed to have been previously loaded from tape and stored as ENVRS,UN=RJW.

```
ATTACH,ENVRS/UN=RJW
CONNECT,INPUT
UPDATE,Q,P=ENVRS,C=FETCHP,D,8
*COMPILE FETCHP
%EOR
FETCHP,HEADERB
HEADERB,ID=RJW,PW=RJW
FETCHP,SELECTB
SELECTB,ID=RJW,PW=RJW
FETCHP,ENVRLB
ENVRLB,ID=RJW,PW=RJW
FETCHP,STH2OTB
STH2OTB,X,ID=RJW,PW=RJW
```

9.3.2 RELAP5 Installation Procedures - CDC Version

To use the procedure, the OLDPL of RELAP5 must be stored on disk with permanent file RELAP5S. Its UN and XR password should be the same as those to be used when invoking the procedure. The procedure is named RELAP5B and its parameters, ID and PW are identical to those for the environmental library procedures.

The procedure compiles the source decks, builds a library file of object decks, RELAP5L, and builds an absolute library file, RELAP5X, for execution. The ENVRLX and ENVRL libraries obtained from the environmental library are used.

The procedure must be extracted before use. The RELAP5 execution procedures are also stored on the OLDPL and should be extracted and stored for executing RELAP5. Extraction and use of the procedures are shown in the next section.

9.4 Installing RELAP5 Using the Transmittal Package

A listing of the job deck used to test a CDC transmittal tape is shown in Figure 31. Modification of this deck and the procedures should allow installation of RELAP5 on CDC computers. The fourth partition of the transmittal tape and the microfiche contain the printed output from a job using these cards.

The first group of cards mount the transmittal tape, copy the first three partitions containing OLDPL's to disk, catalog them as permanent files, and return the tape drive.

The second group of control cards and their associated input builds three files, ENVRL, ENVPLX, and STH2XT, from information in the environmental library source file. The procedures must be executed in the order shown since the following procedures need information prepared by previous procedures. The environmental library contains subroutines, utility programs, and test data used in several programs at the INEL. The procedures install the library as maintained at the INEL. Not all the subroutines are needed by RELAP5.

The use of the HEADERB procedure as shown in Figure 31 assembles a modified version of the CDC subroutine OUTC= that processes formatted WRITE statements. The modifications add entry points HEADER and LINES which are used in RELAP5. HEADER defines title lines which are automatically printed at the top of each page and LINES returns the number of lines remaining on

```
JOB CARDS AS REQUIRED BY SYSTEM
TRS,OP=R,LFN=TAPE,SYM=TESTAPE,I=0,F=SI,LB=KL,D=PE,
CV=AS,PO=R,R.
DEFINE,RELAP5S.
COPYBF,TAPE,RELAP5S.
RETURN,RELAP5S.
DEFINE,ENVRS.
COPYBF,TAPE,ENVRS.
RETURN,ENVRS.
DEFINE,RELAP5D.
COPYBF,TAPE,RELAP5D.
RETURN,RELAP5D.
COPYBF,TAPE,RPROCS.
SAVE,RPROCS.
RETURN,RPROCS,TAPE.
ATTACH,RELAP5S.
UPDATE,I=RELAP5S,N,L=0,C=0.
RETURN,RELAP5S.
DEFINE,RELP36S.
UPDATE,P=NEWPL,N=RELP36S,C=0.
RETURN,NEWPL,RELP36S.
ATTACH,ENVRS.
UPDATE,I=ENVRS,N,L=0,C=0.
RETURN,ENVRS.
DEFINE,ENVR41S.
UPDATE,P=NEWPL,N=ENVR41S,C=0.
RETURN,NEWPL,ENVR41S.
ATTACH,RELAP5D.
DEFINE,RELP01D.
UPDATE,I=RELAP5D,N=RELP01D,C=0.
RETURN,RELAP5D,RELP01D.
ATTACH,ENVRS=ENVR41S.
UPDATE,Q,P=ENVRS,C=FETCHP,D,8.
FETCHP,HEADERB.
HEADERB,ID=RL5,FTN5,CY=41.
FETCHP,SELECTB.
SELECTB,ID=RL5,FTN5,CY=41.
FETCHP,ENVRLB.
ENVRLB,ID=RL5,FTN5,CY=41.
FETCHP,STH2OTB.
STH2OTB,ID=RL5,FTN5,CY=41.
RETURN,ENVR41S.
ATTACH,RELP36S.
UPDATE,Q,P=RELP36S,C=PROCS,D,8.
RETURN,PROCS.
GET,PROCS=RPROCS.
UPDATE,Q,P=RELP36S,C=RELAP5B,D,8.
RELAP5B,ID=RL5,CY=36,EXCY=41,ECY=41.
BEGIN,RLP5X,PROCS,XCY=36,DPFN=RELP01D,DID=RL5,DUPFN,
SCM=210000,NOMESSG.
/EOR
```

Figure 31. Control cards to build disk files for RELAP5/MOD2 use from transmittal tape.

```
*IDENT YOURID
*DEFINE CDC
*DEFINE CDCCRA
*DEFINE FTN5
*DEFINE LCM
*DEFINE NOS
*DEFINE NPA
*DEFINE SCOPE1
*DEFINE TIMED
*DEFINE VECTOR
/EOR
*IDENT YOURID
*DEFINE CDC
*DEFINE CDCCRA
*DEFINE FTN5
*DEFINE LCM
*DEFINE NOS
*DEFINE NPA
*DEFINE SCOPE1
*DEFINE TIMED
*DEFINE VECTOR
/EOR
*COMPILE FETCHP
/EOR
*COMPILE PROCS
/EOR
*COMPILE RELAP5B
/EOR
*COMPILE EDHTRK
```

Figure 31. (continued)

a page (see description of subroutine HEADER in the INEL environmental library manual). Use of the modified OUTC= subroutine may be avoided by adding HEADERX as a parameter to the HEADERB procedure call. The result is that a dummy subroutine and function are compiled. These satisfy the HEADER and LINE entry points and issue a printer command to not print over paper folds. Program and problem titles will not appear at the top of each page during RELAP5 execution.

The next group of control cards and associated data builds the files, PROCS, RELAP5L, AND RELAP5X from the source file RELAP5S. The first DEFINE and UPDATE cards and associated input extract and catalog the file execution procedures. The second UPDATE and associated input extracts the RELAP5B PROCEDURE. Execution of RELAP5B builds the RELAP5L and RELAP5X files. The BEGIN,RLP5X card executes a sample problem. The RLP5X procedure is obtained from PROCS (local file name is PROCS), the executable file is RELAP5X, the STH2XT water property file is used, and the sample input data to RELAP5 is obtained from RELAP5D using UPDATE and the last data card. The BEGIN, FR80POP converts the generalized plot commands to microfilm plots.

Within the RELAP5B procedure the STATIC option is required for the compilation of RELAP5 since dynamic allocation of storage and adjustment of the field length are used to reduce computer costs. The library form of object decks is needed for NOS because transmittals often include subroutines for future capability not yet referenced by the current version. The library form of object decks prevent the unreferenced decks from being loaded and occasionally destroying the segmentation. If a DISSPLA library is not available, unresolved external references will exist, but the program will execute as long as no plots are requested. (Also see Subsection 8.5.)

The job deck listed in Figure 31 is stored in RELAP5 with the deck name TRTEST. It can be extracted using UPDATE in the same manner as shown for extracting RELAP5B except that the UPDATE input is *COMPILE TRTEST.

The installation can be broken into several jobs. The first job should include reading the files from the transmittal tape and storing them on disk. The various procedure calls could be done in separate jobs. The attach of ENVRS should precede environmental library related procedures and the attach of RELAP5S should precede RELAP5D related procedures. The RPROCS file must be attached for the BEGIN,RLP5X statements.

9.5 Installing RELAP5 on a Cray Computer

Figure 32 is a set of control cards for installing RELAP5 on a Cray system operating under COS. Comment cards separate the control cards into sections. The following paragraphs relate these sections to corresponding steps of the CDC installation.

```
*.  CRAY COS CARDS TO INSTALL RELAP5/MOD2
*.     ASSUMES THAT THE FIRST THREE SOURCE FILES HAVE BEEN
*.     READ FROM THE TRANSMITTAL TAPE AND SAVED AS RELAP5SS,
*.     ENVRSS, AND RELAP5DS.  RELEASES AND ACCESSES ENTERED
*.     SO THAT EACH SECTION IS INDEPENDENT.
*.
*.  CREATE OLDPL'S FROM SOURCE FILES.
ACCESS,DN=SOURCE,PDN=RELAP5SS,ID=RL5.
UPDATE,I=SOURCE,N=RELAP5S,C=0,ID.
SAVE,DN=RELAP5S,ID=RL5,RT=4095.
RELEASE,DN=SOURCE:RELAP5S.
ACCESS,DN=SOURCE,PDN=ENVRSS,ID=RL5.
UPDATE,I=SOURCE,N=ENVRS,C=0,ID.
SAVE,DN=ENVRS,ID=RL5,RT=4095.
RELEASE,DN=SOURCE:ENVRS.
ACCESS,DN=SOURCE,PDN=RELAP5DS,ID=RL5.
UPDATE,I=SOURCE,N=RELAP5D,C=0,ID.
SAVE,DN=RELAP5D,ID=RL5,RT=4095.
RELEASE,DN=SOURCE:RELAP5D.
*.     CREATE PRELIMINARY ENVRL.
ACCESS DN=ENVRS,ID=RL5.
UPDATE,P=ENVRS,Q,IN.
CFT,I=$CPL,ON=DJX,OFF=Q.
BUILD,CBL=0,I=0.
SAVE,DN=$NBL,PDN=ENVRL.ID=RL5,RT=4095.
RELEASE.DN=ENVRS:$CPL:$BLD:$NBL.
*.     CREATE SELECTA.
ACCESS,DN=ENVRS,ID=RL5.
UPDATE,P=ENVRS,Q,IN.
CFT,I=$CPL,ON=DJX,OFF=Q.
ACCESS,DN=ENVRL,ID=RL5.
LDR,LIB=ENVRL,AB,MAP,NX.
SAVE,DN=$ABD,PDN=SELECTA,ID=RL5,RT=4095.
RELEASE,DN=ENVRS:$CPL:$BLD:ENVRL:$ABD.
*.     CREATE FULL ENVRL.
ACCESS,DN=ENVRS,ID=RL5.
UPDATE,P=ENVRS,C=IN,Q,IN.
ACCESS,DN=SELECTA,ID=RL5.
ASSIGN,DN=$OUT,A=OUTPUT.
SELECTA.
REWIND,DN=OUT.
CFT,I=OUT,ON=DJX,OFF=Q.
ACCESS,DN=$OBL,PDN=ENVRL,ID=RL5,UQ.
BUILD,I=0.
DELETE,DN=$OBL.
SAVE,DN=$NBL,PDN=ENVRL,ID=RL5,RT=4095.
RELEASE,DN=ENVRS:SELECTA:IN:OUT:$CBL:$BLD:$NBL.
*.     CREATE WATER PROPERTY FILE.
ACCESS,DN=ENVRS,ID=RL5.
UPDATE,P=ENVRS,C=IN,Q,IN.
ACCESS,DN=SELECTA,ID=RL5.
```

Figure 32. Control cards to install RELAP5/MOD2 on the Cray-COS.

```
SELECTA.
REWIND,DN=OUT.
CFT,I=OUT,ON=DJX,OFF=Q.
UPDATE,P=ENVRS,C=INPUT,Q,IN,DW=80.
ACCESS,DN=ENVRL,ID=RL5.
SEGLDR.
ASSIGN,DN=$OUT,A=OUTPUT.
$ABD.
SAVE,DN=STH2XT,ID=RL5,RT=4095.
RETURN,DN=ENVRS:SELECTA:IN:OUT:ENVRS:$BLD:$ABD.
*.    CREATE RELAP5 FILES.
ACCESS,DN=RELAP5S,ID=RL5.
UPDATE,P=RELAP5S,C=IN,Q,IN.
ACCESS,DN=SELECTA,ID=RL5.
ASSIGN,DN=$OUT,A=OUTPUT.
SELECTA.
REWIND,DN=OUT.
CFT,I=OUT,ON=DJX,OFF=Q.
BUILD,I=0,NBL=RELAP5L.
SAVE,DN=RELAP5L,ID=RL5,RT=4095.
UPDATE,P=RELAP5S,C=IN,IN,Q.
ACCESS,DN=ENVRL,ID=RL5.
SEGLDR,I=IN.
SAVE,DN=RELAP5X,ID=RL5,RT=4095.
RELEASE,DN=RELAP5S:SELECTA:IN:OUT:RELAP5L,ENVRL:RELAP5X.
*.    EXECUTE RELAP5 USING SAMPLE PROBLEM FROM RELAP5D.
ACCESS,DN=RELAP5D,ID=RL5.
UPDATE,P=RELAP5D,C=INPUT,I=0,Q=EDHTRK,DW=80.
RELEASE,DN=RELAP5D.
ACCESS,DN=RELAP5X,ID=RL5.
ACCESS,DN=STH2XT,ID=RL5.
RELAP5X.
RELEASE,DN=RELAP5X:STH2XT,FTB1.
*/    INPUT DATA FOR THE ABOVE STEPS.
/EOF
*/    INPUT FOR CREATING PRELIMINARY ENVRL.
*DEFINE CDCCRA,CH8,CRAY,SCOPE1
*COMPILE HEADERX
/EOF
*/    INPUT FOR CREATING SELECTA.
*DEFINE CDCCRA,CH8,CRAY,SCOPE1
*COMPILE SELECTA
/EOF
*/    INPUT FOR CREATING COMPLETE ENVRL.
*DEFINE CDCCRA,CH8,CRAY,SCOPE1
*COMPILE DEFINE.ZEROUT
/EOF
```

Figure 32. (continued).

```
*/    INPUT FOR CREATING STH2XT
*DEFINE CDCCRA,CH8,CRAY,SCOPE1
*COMPILE STH2XG
/EOF
*COMPILE STH2ODL
/EOF
MAP=PART
BIN=$BLD
LIB=ENVRL
ORDER=LBC
PRESET=INDEF
/EOF
*/  INPUT FOR BUILDING RELAP5 FILES.
*DEFINE CDCCRA,CH8,CRAY,SCOPE1
*COMPILE DEFINE.JCP
/EOF
*DEFINE CDCCRA,CH8CRAY,SCOPE1
*COMPILE SEGDIR
```

Figure 32. (continued)

RELAP5/MOD2 also executes on a Cray operating under CTSS (Cray Timesharing System developed by Lawrence Livermore National Laboratory). Installation information is included in code transmittal letters and will be incorporated in this report in a subsequent update.

The Cray step for creating the preliminary environmental library corresponds the CDC HEADERB step. The CDC installation has an option to either use an INEL modification to a FORTRAN output subroutine to automatically title each output page or to use subroutines that satisfy external references but put the title only on the first output page. The Cray version allows only the latter option.

The CDC installation procedure SELECTB compiles two programs, SELECTA and SELECTC, and places the executable code into a library. The Cray installation shown only creates an executable form of SELECTA and does not store it in a library. On one Cray installation, an UPDATE error was encountered in handling nested *IF statements. The CDC and Cray versions of SELECTA are not interlaced but instead a complete Cray version follows the CDC versions. The error was bypassed by simply deleting all the CDC versions.

The Cray installation shows use of the segment loader for water property generation (STH2XG) and RELAP5. The segment loader is not required for STH2XG but is required for RELAP5. The segment loader provides control over the placement of common blocks. The FAST common in RELAP5 must precede other commons. This prevents negative subscripts which would cause failures when unpacked from an 18 bit field and used as 24 bit indexes on the Cray. Placement of the commons ahead of the coding is done to avoid more than 17 bits to be used in the addressing of common data. The segment loader can be used without segmenting. As shown in the Cray control cards, STH2XG does not use segments; RELAP5 does use segments. RELAP5/MOD2 fits easily on a Cray since it uses $\sim 250,000_{10}$ words of memory without segments, $200,000_{10}$ with segmentation. Segmentation is recommended since the reduced memory requirement results in reduced execution costs at most installations. Segmentation is efficient since segment swapping occurs only during input processing and no segment swapping is done during solution advancement.

At present, the Cray version does not vary the field length in order to dynamically adjust the length of the FAST common block. As transmitted, the Cray version uses a fixed length for FAST common of 128,000 words, close to the limit of $2^{17} - 1$. This allows much larger problems to be run on Cray than are possible in the CDC machines since on that machine a user is restricted to a field length of 2^{17} for the entire code. The length of FAST can be changed by changing the two occurrences of 128000 in Subroutine FTBMEM (in the RELAP5 source).

10. REFERENCES

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APPENDIX A

RELAP5/MOD2 INPUT DATA REQUIREMENTS

CONTENTS

APPENDIX A

RELAP5/MOD2 INPUT DATA REQUIREMENTS

1. INTRODUCTION

Complete descriptions of data deck organization and data card requirements for all problem types allowed in RELAP5/MOD2 are presented in this Appendix.

1.1 Control Format

RELAP5 input is described in terms of cards, where a card is an 80-character record. Data may be entered using 80 column punched cards or may be prepared with interactive editors or utility programs such as UPDATE. RELAP5 reads a 90-character record. If the actual input record is smaller, blank characters are added to the end of the input record to extend it to 90 characters. Each 90 column 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 columns are used for RELAP5 input; the additional 10 columns are for convenience with editors or UPDATE programs.

Most interactive editors allow the input of 80-character records. With many terminals allowing only 80 characters per line, it is convenient to limit the data record to 72 columns so that the data and editor supplied line numbers fit on one line (eight columns for line number and separator, 72 columns of data). Most 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 are stored in columns 73 to 80. The line numbers will be processed by RELAP5 as input since RELAP5 uses the first 80 characters. To avoid this, request the editor to store line numbers starting at character position 81 or don't store the line numbers. The line numbers, if saved, are listed in the output echo of the input data. Since a card sequence number is printed by RELAP5 and most editors can be instructed to use the same line sequencing (or 10 times the RELAP5 sequencing to facilitate insertions), it is recommended that the line numbers not be saved.

If the UPDATE program is used to maintain the input deck, the update command to specify that the card data is 80 columns instead of the default of 72 must be used. The RELAP5 execution procedures allow optional use of UPDATE for extracting input data and provide the appropriate command. The UPDATE card numbers are listed in the echo printout of the input data.

1.2 Data Deck Organization

A RELAP5 problem input consists of at least one title card, optional comment cards, data cards, and a terminator card. A listing of the 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. It is recommended 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 a card format error is detected, a line containing a dollar sign ($) 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. Usually this type of error will cause an additional error comment to be printed during further input processing when the program attempts to process the erroneous data.

1.3 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 every page. If more than one title card is entered, the last one entered is used.

1.4 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.

1.5 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. Real data punched by FORTRAN programs can be read. To permit this, 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  1.245E+1
```

Alphanumeric fields have three forms. The most common alphanumeric field 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 type has the form, 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 type fields can enter any desired characters. The maximum number of alphanumeric characters that can be stored in a word is ten. If the number of characters is less than ten, the word is left justified and padded to the right with blanks. If more than ten characters are entered, the field generates as many words as needed to store the field, ten 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.

The CDC-7600-6600 class of computers stores ten characters per word. 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 or processing options, have thus been limited to eight characters. It is highly recommended 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.

1.6 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.

1.7 Terminator Cards

The input data for each RELAP5 problem is 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.

The ability to process multiple problems is of little use in production runs of large, time consuming problems. Furthermore, magnetic tape considerations, especially when the restart-plot file written in one problem is used as input to the next, limit ability to use multiple problems. In the tape case, control cards for each RELAP5 case can be used. The multiple problem capability is useful for small test problems or for input checking of several problems.

1.8 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 pipe volume friction data format is three words per set for NV sets. 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.

1.9 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 which 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.

2. MISCELLANEOUS CONTROL CARDS

2.1 Card 100, Problem Type and Option

This card is always required.

W1(A) PROBLEM TYPE. Enter one of the following: NEW, RESTART, PLOT, REEDIT, or STRIP. The REEDIT type is not currently implemented.

W2(A) PROBLEM OPTION. This word is needed only if W1 is NEW or RESTART. If needed, enter one of the following: STDY-ST, or TRANSNT.

2.2 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.

2.3 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 = $kg\text{-}m/s^2\text{-}m^2$. 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. Note that 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.

2.4 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 RSTIN file up to the point of restart in copied to the RSTPLT file. If the problem options are different, data up to the point of restart are <u>not</u> copied, problem advancement time is reset to zero, and the RSTPLT file will contain information as if this problem type were NEW.

WI(I)	RESTART NUMBER. Must be a number printed in one of the restart print messages and whose associated restart information is stored in the RSTPLT file.
W2(A)	ID. Id for attach of permanent file (for NOS-BE systems).
W3-W6(A)	PERMANENT FILE NAME. Words 2 through 6 are used if the restart file is to be obtained from a permanent file. These words should not be entered if the file is already a local file or will be staged (SCOPE2) or read directly from tape (NOS-BE).

2.5 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 default action on the Restart-Plot file is the same as the NOACTION option. To prevent the Restart-Plot file from being written, a card with NONE must be entered.

W1(A)	ACTION OR ID FIELD. This word may not be blank. If NONE, no Restart-Plot file is written. If NOACTION, the file is rewound at the end of the problem but no further action is taken and the user should provide system control cards (REQUEST, STAGE, DEFINE,

CATALOG, etc.) to dispose of file. If STAGE (SCOPE-2 only) is entered, the file will be staged to tape when a RETURN(RSTPLT) control statement or end of job is reached. If STAGE-RTN (SCOPE-2 only) is entered, the action is the same as for STAGE except that the file is immediately returned by RELAP5 at the completion of the problem. If REQUEST (NOS-3E only) is entered, the file will be written on a nine track, phase encoded, 1600bpi labeled tape and saved when returned or at the end of the job. If REQUESTRTN (NOS-BE only) is entered, the action is the same as for REQUEST except that the file is returned by RELAP5 at the completion of the problem. If not blank and none of the above, this word is assumed to be an ID for cataloging the Restart-Plot file as a permanent file. Only nine characters are allowed and the next word must be nonblank. The ID is also used as a XR=ID, PW=ID password.

W2-W5(A) PERMANENT FILE NAME. These words are entered only if the Restart-Plot file is to be cataloged as a permanent file. The permanent file name can be up to forty characters. A prior Restart-Plot file is always returned at the beginning of a problem that writes a Restart-Plot file and this can limit the options in multiple case input.

2.6 Card 105, CPU Time Remaining Card

CPU time allocated for a job is specified on the JOB card. At the end of each time step, the CPU time remaining for the job is determined. 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 s. 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 s 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 RELAP5 execution.

W1(R) FIRST TIME VALUE. Tested every time step.

W2(R) SECOND TIME VALUE. Tested after successful advancement over requested time step.

2.7 Card 110, Noncondensible Gas Type

This card is optional. If this card is omitted, air is assumed as the noncondensible gas. This card cannot be entered on a restart problem.

W1(A) NONCONDENSIBLE GAS TYPE. Enter one of the following noncondensible gas types: AIR, ARGON, HELIUM, HYDROGEN, NITROGEN, or OXYGEN. If the accumulator model is used, this noncondensible gas type will be used in the accumulator.

2.8 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 is the primary and secondary system in a reactor in which 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.

These cards are optional. If not entered, each independent system contains water 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. If these cards are input, a four word set is entered for each independent system using one or more sets per card as desired.

W1(I) REFERENCE VOLUME NUMBER. Must be a volume in the hydrodynamic system.

W2(R) REFERENCE ELEVATION. (m, ft).

W3(A) FLUID TYPE. Enter WATER. (Water is the only fluid currently available in RELAP5).

W4(A) Optional alphanumeric name of system used in output editing. Blanks are used if this word not entered.

2.9 Cards 140 through 147, Self-Initialization Option Control Cards

These cards are optional. Data supplied on these cards are used to invoke the self-initialization option described in Section 4.4 of Volume 1. 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 as discussed in Volume 1. These latter options are invoked through input data cards 100 and 201-299, as described in Sections 2.1 and 3.0, respectively. In addition to the data cards described below, the user must furnish data on the controllers to be used, as described in Section 13.

2.9.1 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.

2.9.2 Cards 141 through 142, Self-Initialization Pump Controller 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 (see Sections 7.9.7, 7.9.16, and 7.9.17). The time dependent pump velocity data should be input so that the pump velocity is time invariant.

2.9.3 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.

And so on, for up to six control valve/controller pairs. Note that in the above it is assumed that a valve component is assumed to be the control component. However, the user is not constrained to use a valve and may opt to use some other type of component.

2.9.4 Cards 145-146, 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.

And so on, up to six control valve/controller pairs. Note that in the above it is assumed that a valve component is assumed to be the control component. However, the user is not constrained to use a valve and may opt to use some other type of component.

2.9.5 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.
W3(R)	Desired steady-state pressure.

3. CARDS 201 THROUGH 299, TIME STEP CONTROL CARDS

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 <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) TIME STEP CONTROL OPTION. This word has the packed format ssdtt.

The digits ss, that represent a number from 0 through 15, are used to control the printed content of 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 is set, the heat structure temperature block is omitted. If the second bit is set, the second portion of the junction block is omitted. If the third bit is set, the second portion of the volume block is omitted. If the fourth bit is set, the statistics block is omitted. (See Section 8.3.2 of this volume of the manual for what is printed in each block.)

The digit d, that 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 time step, and the bits indicate which output is obtained. If the first bit is set, major edits are obtained every time step. If the second bit is set, minor edits are obtained every time step. If the third bit is set, internal plot records are written every time step. These options should be used carefully, since considerable output can be generated. This extra output is generated only for the current run and is not written to the RSTPLT file.

The digits tt, that represent a number from 0 through 15, are used to control the time step. The number is treated as a four bit, binary number. 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. (See the next paragraph for the limitations when no bits are set). If the first bit is set, heat transfer uses the maximum time step and the hydrodynamics, 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. (See the next paragraph for the limitations of the first bit.) If the second bit is set, the heat structure time step is the same as the hydrodynamic time step, and the hydrodynamics uses the time step control described for no bits set. (See the next paragraph for limitations of the second bit.) If the third bit is set, heat transfer uses the maximum time step and the hydrodynamics, in addition to the time step control described for no bits set, uses a partially-implicit hydrodynamic and heat slab coupling. (See the next paragraph for limitations of the third bit.) If the fourth bit is set, heat transfer uses the maximum time step and the hydrodynamics, in addition to the time step control described for no bits set, uses the nearly-implicit hydrodynamic numerical scheme. (See the next paragraph for limitations of the fourth bit.)

Using tt=0 is not recommended except for special testing situations. The use of tt=1 is possible if the maximum time step is kept sufficiently small to assure that the explicit connection between the hydrodynamics and heat conduction/heat transfer calculations remains stable. If there is any doubt use tt=3 (sets first bit and second bit), which is the recommended way to run most calculations with the semi-implicit hydrodynamic scheme. If tt=2 is entered, this will be converted to a 3 during input processing at the present time. In the future, tt=2 will be changed to correspond to the definition indicated in the previous paragraph. At the present time, the third bit is not fully operational. This will be improved upon in the future. The fourth bit, which activates the nearly-implicit scheme, is recommended during the slower phases of a transient problem or a steady state and/or self-initialization case, where the time step is limited by the material Courant limit. See Subsection 8.2 of this volume of the manual for further discussion of these options.

W5(I) MINOR EDIT AND PLOT FREQUENCY. Number of maximum or requested time advances per minor edit and write of plot information. Must be $\leq$4096.

W6(I) MAJOR EDIT FREQUENCY. Number of requested time advances per major edit. Must be $\leq$4096.

W7(I) RESTART FREQUENCY. Number of requested time advances per write of restart information. Must be $\leq$4096.

4. 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.
W2(I)	PARAMETER.

The quantities that can be edited and the required input 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 6 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.

4.1 General Quantities

Code	Quantity
TIME	Time (s). The parameter is 0. This specification cannot be used for minor edit requests.

Code	Quantity
TIMEOF	Time of trip occurring (s). Parameter is trip number. This specification is allowed only on trip cards.
CPUTIME	The current CPU time for this problem (s). Parameter is zero.
NULL	Specifies null field; allowed only on trip cards. Parameter is 0.
TMASS	Total mass of water, steam and noncondensible in the system (kg, lb). Parameter is 0.
EMASS	Estimate of mass error (kg, lb). Parameter is 0.

4.2 Component Related Quantities

The quantities listed below are unique to certain components; for example, a pump velocity can only be requested for a pump component. Parameter is component number.

Code	Quantity
PMPVEL	Pump velocity in pump component (rad/s, rev/min).
PMPHEAD	Pump head in pump component (Pa, lb_f/in^2).
PMPTRQ	Pump torque in pump component (N-m, lb_f-ft).
VLVAREA	Valve area ratio in valve component.
VLVSTEM	Relative valve stem position in valve component.

Code	Quantity
ACVLIQ	Liquid volume in accumulator tank, standpipe, and surge line (m^3, ft^3).
ACVDM	Gas volume in accumulator tank, standpipe, and surge line (m^3, ft^3).
ACTTANK	Mean accumulator tank wall metal temperature (K, °F).
ACQTANK	Total energy transport to the gas by heat and mass transfer in the accumulator (W, Btu/s).
ACRHON	Accumulator noncondensible density (kg/m^3, lb/ft^3).
TURPOW	Power developed in turbine component (W, Btu/s).
TURTRQ	Torque developed in turbine component (N-m, lb_f-ft).
TURVEL	Rotational velocity of turbine component (rad/s, rev/min).
TUREFF	Efficiency of turbine component.

4.3 Volume Related Quantities

For the following variable codes, the parameter is the volume number.

Code	Quantity
RHO	Total density (kg/m^3, lb/ft^3).

Code	Quantity
RHOF	Liquid density (kg/m^3, lb/ft^3).
RHOG	Vapor density (kg/m^3, lb/ft^3).
UF	Liquid specific internal energy (J/kg, Btu/lb).
UG	Vapor specific internal energy (J/kg, Btu/lb).
VOIDF	Liquid void fraction.
VOIDG	Vapor void fraction.
VELF	Volume oriented liquid velocity (m/s, ft/s).
VELG	Volume oriented vapor velocity (m/s, ft/s).
P	Volume pressure (Pa, lb_f/in^2).
QUALS	Volume static quality.
QUALA	Volume noncondensible mass fraction.
QUALE	Volume equilibrium quality.
Q	Total volume heat source to liquid and vapor (W, Btu/s).
QWG	Volume heat source to vapor (W, Btu/s).
TEMPF	Volume liquid temperature (K, °F).
TEMPG	Volume vapor temperature (K, °F).
SATTEMP	Volume saturation temperature (K, °F).

SOUNDE	Volume sonic velocity (m/s, ft/s).
VAPGEN	Volume vapor generation rate per unit volume (kg/m^3-s, lb/ft^3-s).
BORON	Boron density (kg/m^3, lb/ft^3).
FLOREG	Flow regime number

4.4 Junction Related Quantities

For the following variable request codes, the parameter is the junction number.

Code	Quantity
VELFJ	Junction liquid velocity (m/s, ft/s).
VELGJ	Junction vapor velocity (m/s, ft/s).
VOIDFJ	Junction liquid void fraction.
VOIDGJ	Junction vapor void fraction.
QUALAJ	Junction noncondensible mass fraction.
RHOFJ	Junction liquid density (kg/m^3, lb/ft^3).
RHOGJ	Junction vapor density (kg/m^3, lb/ft^3).
UFJ	Junction liquid specific internal energy (J/kg, Btu/lb).
UGJ	Junction vapor specific internal energy (J/kg, Btu/lb).

MFLOWJ	Combined liquid and vapor flow rate (kg/s, lb/s).

4.5 Heat Structure Related Quantities

For the request code, HTVAT, the parameter is the heat structure-geometry number. For the remaining codes, the parameter is the heat structure-geometry number with a two digit number appended. For codes other than HTTEMP, the number is 00 for the left boundary and 01 for the right boundary. For HTTEMP, the number is the mesh point number. Only the surface temperatures are written in plot records on the RSTPLT file and thus plot requests in plot type problems and strip requests are limited to those temperatures.

Code	Quantity
HTVAT	Volume averaged temperature (K, °F).
HTRNR	Heat flux (W/m^2, Btu/s-ft^2).
HTCHF	Critical heat flux (W/m^2, Btu/s-ft^2).
HTHTC	Heat transfer coefficient (W/m^2-K, Btu/s-ft^2-°F).
HTTEMP	Mesh point temperature (K, °F).

4.6 Reactor Kinetic Quantities

The parameter is zero for reactor kinetic quantities.

Code	Quantity
RKTPOW	Total reactor power, i.e., sum of fission and fission product decay power (W).

RKFIPOW	Reactor power from fission (W).
RKGAPOW	Reactor power from fission product decay (W).
RKREAC	Reactivity (dollars).
RKRECPER	Reciprocal period (s^{-1})

4.7 Control System Quantities

The parameter is the control component number.

Code	Quantity
CNTRLVAR	Control component number. These quantities are assumed dimensionless except for a [illegible]mponent.

4.8 Expanded Edit/Plot Variables

Several additional quantities have been added to the list of variables, which may be used in minor edits, plot requests, control systems, and trip logic. The additional variables and their associated parameters are listed in Subsections 4.8.1 through 4.8.6.

These additional request variables are not written to the restart-plot file (necessary for plotting on restart or use with NPA) unless the user enters cards 20800XXX. The format of these cards is given below. They are only required for the additional variables which the user wants to have written on the restart-plot file. The user can specify that between 1 and 999 of these variables be written to the restart-plot file.

The additional variables can be used in the usual manner on minor edit cards, trip cards, control system input cards and on plot request cards.

The following cards are used to cause the requested variables to be written onto the RSTPLT file. These cards are not to be used for the previously available variable request codes (see Subsections 4.1 through 4.7) since they are always written to the RSTPLT file.

Cards 20800XXX

W1(A)	Variable request code--See Subsections 4.8.1 through 4.8.6 for valid request code.
W2(I)	Parameter--Enter the parameter associated with the variable request code.

4.8.1 General Quantities

Code	Quantity
DT	The current time step (s). The parameter is 0.
DTCRNT	The current Courant time step (s). The parameter is 0.

4.8.2 Component Related Quantities

The quantities listed below are unique to certain components; for example, a pump motor torque can only be requested for a pump component. The associated parameter is the component number.

Code	Component type	Quantity
PMPMT	Pump	Pump motor torque (N-m, lb_f-ft)
PMPNRT	Pump	Calculated pump inertia (kg-m^2, lb-ft^2)
THETA	Inertial Valve	Valve disk angular position (deg)
OMEGA	Inertial Valve	Valve disk angular velocity (rad/s, rev/min)
BETAV	Accumulator	Steam saturation coefficient of expansion (K^{-1}, $°F^{-1}$)

Code	Component type	Quantity
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)
ACPGTG	Accumulator	Vapor specific heat, C_p, at vapor temperature (J/kg-K, Btu/lb-°F)
ACVGTG	Accumulator	Vapor specific heat, C_v, at vapor temperature (J/kg-K, Btu/lb-°F)
AVISCN	Accumulator	Noncondensible viscosity (kg/m-s, lb/ft-s)
ACPNIT	Accumulator	Noncondensible specific heat, C_p, at vapor temperature (J/kg-K, Btu/lb-°F)
AHGTF	Accumulator	Vapor enthalpy at liquid temperature (J/kg, Btu/lb)
DMGDT	Accumulator	Time rate of change in dome vapor mass (kg/s, lb/s)

4.8.3 Volume Related Quantities

For the following variable codes, the parameter is the volume number.

Code	Quantity
RHOM	Total density for mass error check (kg/m^3, lb/ft^3)
DSNDDP	Partial derivative of SOUNDE with respect to pressure (m^2-s/kg, ft^2-s/lb)
SATHF	Liquid specific enthalpy at saturation conditions (J/kg, Btu/lb)
SATHG	Vapor specific enthalpy at saturation conditions (J/kg, Btu/lb)

Code	Quantity
BETAFF	Liquid isobaric coefficient of thermal expansion (K^{-1}, $°F^{-1}$)
BETAGG	Vapor isobaric coefficient of thermal expansion (K^{-1}, $°F^{-1}$)
CSUBPF	Liquid specific heat, C_p, bulk conditions (J/kg-K, Btu/lb-°F)
CSUBPG	Vapor specific heat, C_p, bulk conditions (J/kg-K, Btu/lb-°F)
VISCF	Liquid viscosity (kg/m-s, lb/ft-s)
VISCG	Vapor viscosity (kg/m-s, lb/ft-s)
SIGMA	Surface tension (J/m^2, Btu/ft^2)
THCONF	Liquid thermal conductivity (W/m-K, Btu/s-ft-°F)
THCONG	Vapor thermal conductivity (W/m-K, Btu/s-ft-°F)
PPS	Vapor partial pressure (Pa, $lb_f/in.^2$)
HIF	Liquid side interfacial heat transfer coefficient per unit volume (W/m^3-K, $Btu/s\text{-}ft^3$-°F)
HIG	Vapor side interfacial heat transfer coefficient per unit volume (W/m^3-K, $Btu/s\text{-}ft^3$-°F)
GAMMAW	Vapor generation rate at the wall per unit volume (kg/m^3-s, lb/ft^3-s)
DRFDP	Partial derivative of RHOF with respect to pressure (s^2/m^2, s^2/ft^2)
DRFDUF	Partial derivative of RHOF with respect to U_f ($kg\text{-}s^2/m^5$, $lb\text{-}s^2/ft^5$)

Code	Quantity
DRGDP	Partial derivative of RHOG with respect to pressure (s^2/m^2, s^2/ft^2)
DRGDUG	Partial derivative of RHOG with respect to U_g (kg-s^2/m^5, lb-s^2/ft^5)
DRGDXA	Partial derivative of RHOG with respect to X_n (kg/m^3, lb/ft^3)
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)
DTGXA	Partial derivative of T_g with respect to X_n (K, °F)
DTDP	Partial derivative of T_{sat} with respect to pressure (K/Pa, in^2-°F/lb_f)
DTDUG	Partial derivative of T_{sat} with respect to U_g (s^2-K/m^2, s^2-°F/ft^2)
DTDXA	Partial derivative of T_{sat} with respect to X_n (K, °F)
HTCOFF	Heat transfer coefficient between slab and liquid (W/m^2-K, Btu/s-ft^2-°F)

Code	Quantity
HTCOFG	Heat transfer coefficient between slab and vapor (W/m^2-K, Btu/s-ft^2-°F)
FWALF	Liquid wall frictional drag coefficient (kg/m^3-s, lb/ft^3-s)
FWALG	Vapor wall frictional drag coefficient (kg/m^3-s, lb/ft^3-s)

4.8.4 Junction Related Quantities

For the following variable codes, the parameter is the junction number.

Code	Quantity
FIJ	Interphase friction (N-s^2/m^5, lb_f-s^2/ft^5)
FORMFJ	Liquid form loss factor--dimensionless
FORMGJ	Vapor form loss factor--dimensionless

4.8.5 Reflood Related Quantities

For the following variable codes, the parameter is the heat structure geometry number.

Code	Quantity
ZTRWT	Position of CHF point (m, ft)
QFCHFN	Critical heat flux (W/m^2, Btu/s-ft^2)

Code	Quantity
TCHFQF	Temperature corresponding to QFCHFN (K, °F)
TREWET	Rewet Temperature (K, °F)
QFHTCN	Critical heat transfer coefficient (W/m^2-K, $Btu/s-ft^2$-°F)

4.8.6 Heat Structure Related Quantities

Code	Quantity
HTMODE	Boundary heat transfer mode number (unitless). The mode number indicates which heat transfer regime is currently in effect. The parameter is the heat structure-geometry number with a two digit number appended. The two digit number 00 specifies the left boundary and 01 specifies the right boundary. This same quantity is valid for reflood heat structures.

5. 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 (double that allowed in RELAP5/MOD1) and are compatible with trip data prepared for RELAP5/MOD1. Card numbers 20600010 through 20620000 allow 1000 variable trips and 1000 logical trips.

5.1 Card 400, Trips Cancellation Card

This card is allowed only for restart problems. This 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.

5.2 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. 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 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.

5.3 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 4. 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.

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. May be either EQ, NE, GT, GE, LT, or LE, 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.

5.4 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.

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. 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 W1 may be zero.

W3(I) TRIP NUMBER. 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 logical expression: CONDITION OF TRIP IN W1 OPERATOR CONDITION OF TRIP IN W3.

5.5 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.

6. CARDS 801 THROUGH 999, INTERACTIVE INPUT DATA

An interactive and color display capability exists in the NOS and NOS-BE versions of RELAP5. This capability allows a user to view selected results on a color graphics terminal and to modify user defined input quantities. This capability allows a user to view RELAP5 output in a format that enhances understanding of the transient phenomena and permits the user to 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. The interactive and display capability uses features of the Nuclear Plant Analyzer (NPA). A playback capability of a previously run simulation is also part of the NPA features.

This data may be entered for either batch or interactive jobs. The program determines whether the job is executing interactively or in batch mode. 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 CRT 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 4 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 request code and 1000000000 is the numeric part.

W1(A) VARIABLE NAME. Enter variable name or DELETE in a RESTART job to delete the variable.

W2(R) INITIAL VALUE. 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 CRT. 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. Note that 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 if only these input interactive variables or control variable defined in compatible units are used. 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, W3 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.

W4(A) ALPHANUMERIC PART OF VARIABLE REQUEST CODE. CNTRLVAR cannot be used.

W5(A) INTEGER PART OF VARIABLE REQUEST CODE. May be omitted if zero.

7. CARDS CCCXXNN, HYDRODYNAMIC COMPONENTS

These cards are required for NEW type problems and may be entered for RESTART problems. A hydrodynamic system is described in a NEW problem. In a RESTART problem, the hydrodynamic system 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.

7.1 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 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, VALVE, PUMP, or 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 are dependent on the type of component.

7.2 Single Volume Component

A single volume component is indicted by SNGLVOL on Card CCC0000. In junction references, the inlet code for this component is CCC000000 and the outlet code is CCC010000. The junction connection code determines the orientation of the volume. 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 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.

7.2.1 Cards CCC0101 through CCC0109, Single Volume Geometry Cards

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.

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.

W7(R) WALL ROUGHNESS. (m, ft).

W8(R) HYDRAULIC DIAMETER. (m, ft). If zero, the hydraulic diameter is computed from 2.0*(VOLUME AREA/π)**0.5. A check is made that the pipe roughness is less than half the hydraulic diameter.

W9(I) VOLUME CONTROL FLAGS. This word has the packed format fe.

The digit f specifies whether wall friction is to be computed or not, where 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 digit e specifies if nonequilibrium or equilibrium is to be used, where 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.

7.2.2 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.

The digit $\underline{\varepsilon}$ specifies the fluid, where $\underline{\varepsilon}=0$ is the default fluid, and $\underline{\varepsilon}=1$ specifies water. The default fluid is that set for the hydrodynamic system by cards 120 to 129, or this control word is 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 $\underline{\varepsilon}=0$, then water 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 following words are to be used to determine the initial thermodynamic state. Entering $\underline{t}=0$ through 3 specifies one component (steam/water). Entering $\underline{t}=4$ through 6 allows the specification of two components (steam/water and noncondensible 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 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 $\underline{t}=1$, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

If $\underline{t}=2$, 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.

If t=4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. This value of t=4 is for input of a noncondensible equilibrium state. The equilibrium quality must be greater than or equal to zero and less than or equal to one.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

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 noncondensible quality. The vapor void fraction must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

W2-W6(R) QUANTITIES AS DESCRIBED UNDER Word 1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. Boron concentration if entered follows the last required word for thermodynamic conditions.

7.3 Time Dependent Volume Component

This component is indicated by TMDPVOL on card CCC0000. In junction references, the connection code for this component is CCC000000 and no distinction is made between the inlet and outlet. Only one junction may be connected to this component.

7.3.1 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 less than or equal to 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 noding diagrams.
W5(R)	INCLINATION ANGLE. (degrees). The absolute value of this angle must be less than or equal to 90 degrees. The angle 0 degrees is horizontal and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation.
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.

W7(R) WALL ROUGHNESS. (m, ft).

W8(R) HYDRAULIC DIAMETER. (m, ft). If zero, the hydraulic diameter is computed from 2.0*(VOLUME AREA/π)**0.5. A check is made that the pipe roughness is less than half the hydraulic diameter.

W9(I) VOLUME CONTROL FLAGS. This word has the packed format fe.

The digit f specifies whether wall friction is to be computed or not, where 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 digit e specifies if nonequilibrium or equilibrium is to be used, where 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.

7.3.2 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 εbt.

The digit ε specifies the fluid, where ε=0 is the default fluid and ε=1 specifies water. The default fluid is that set for the hydrodynamic system by Cards 120 to 129, or this control word is another volume in this hydrodynamic system. The fluid type set on Cards 120 to 129 or these control words must be consistent (i.e., not specify different fluids). If Cards 120 to 129 are not entered, and all control words use the default ε=0, then water 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 water (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the words of the time dependent volume data in Cards CCC0201-CCC0299 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 noncondensible gas).

If t=0, the second, third, fourth, and fifth words of the time dependent volume data in Cards CCC0201-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.

If t=1, the second and third words of the time dependent volume data in Cards CCC0201-CCC0299 are interpreted as temperature (K, °F, and quality in equilibrium condition.

If t=2, the second and third words of the time dependent volume data in Cards CCC0201-CCC0299 are interpreted as pressure (Pa, lb_f/in^2) and quality in equilibrium condition.

If t=3, the second and third words of the time dependent volume data in Cards CCC0201-CCC0299 are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium condition.

If t=4, the second, third, and fourth words of the time dependent volume data in Cards CCC0201-CCC0299 are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. This value of t=4 is for input of a noncondensible equilibrium state. The equilibrium quality must be greater than or equal to zero and less than or equal to one.

If t=5, the second, third, and fourth words of the time dependent volume data in Cards CCC0201-CCC0299 are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

If t=6, the second, third, fourth, fifth, and sixth words of the time dependent volume data in Cards CCC0201-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 noncondensible quality. The vapor void fraction must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

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 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. Assumed zero if missing.

7.3.3 Cards CCC0201 through CCC0299, Time Dependent Volume Data Cards

These cards are required for time dependent volume components. 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 100 sets are allowed. A set of data is made up of the search variable followed by the required data indicated by the control word in CCC0200. 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 reliable fix for this is to make the search variable a control system output in the desired units while 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.

7.4 Single Junction Component

A single junction component is indicated by SNGLJUN on card CCC0000.

7.4.1 Cards CCC0101 through CCC0199, Single Junction Geometry Cards

This card (or cards) is required for single junction components.

W1(I) FROM CONNECTION CODE TO A COMPONENT. Refers to the component from which the junction coordinate direction originates. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W2(I) TO CONNECTION CODE TO A COMPONENT. Refers to the component at which the junction coordinate direction ends. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

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.

W5(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W6(I) JUNCTION CONTROL FLAGS. This word has the packed format vcahs.

The digit v specifies horizontal stratification options; v=0 means a centrally located junction; v=1 means an upward oriented junction; v=2 means a downward oriented junction; and v=3 means that the horizontal stratification model will not be applied.

The digit c specifies choking options, where 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, where 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 1.

The digit s specifies normal or crossflow junction. s=0 specifies a normal junction. s=1 specifies a crossflow junction and that the to volume is a crossflow volume. s=2 specifies a crossflow junction and that the from volume is a crossflow volume. s=3 specifies a crossflow junction and that the from and to volumes are crossflow volumes.

W7(R) SUBCOOLED DISCHARGE COEFFICIENT. This quantity is applied only to subcooled choked flow calculations. The quantity must be >0 and $\leq$2.0. If missing or zero, 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 and $\leq$2.0. If missing or zero, it is set to 1.0.

7.4.2 Card CCC0201, Single Junction Initial Conditions

This card is required for single junction components.

W1(I) CONTROL WORD. If 0, the next two words are velocities; if 1, the next two words are flows.

W2(R) INITIAL LIQUID VELOCITY. This quantity is either velocity (m/s, ft/s) or flow (kg/s, lb/s), depending on the control word.

W3(R) INITIAL VAPOR VELOCITY. This quantity is either velocity (m/s, ft/s) or flow (kg/s, lb/s), depending on the control word.

W4(R) INTERFACE VELOCITY. (m/s, ft/s). Enter zero.

7.5 Time Dependent Junction Component

This component is indicated by TMDPJUN on Card CCC0000.

7.5.1 Card CCC0101, Time Dependent Junction Geometry Card

This card is required for time dependent junction components.

W1(I) FROM CONNECTION CODE TO A COMPONENT. Refers to the component from which the junction coordinate direction originates. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W2(I) TO CONNECTION CODE TO A COMPONENT. Refers to the component at which the junction coordinate direction ends. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W3(R) JUNCTION AREA. (m^2, ft^2). If zero, the area is set to the minimum area of the adjoining volumes. There are no junction area restrictions for time dependent junctions.

7.5.2 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 0, the second and third words of the time dependent junction data in Cards CCC0201-CCC0299 are velocities. If 1, the second and third words of the time dependent junction data in Cards CCC0201-CCC0299 are flows.

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. Assumed zero if missing.

7.5.3 Cards CCC0201 through CCC0299, Time Dependent Junction Data

These cards are required for time dependent junction components. 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 100 sets may be entered. Each set consists of the search variable, liquid velocity (m/s, ft/s) or flow (kg/s, lb/s), vapor velocity (m/s, ft/s) or flow (kg/s, lb/s), and interface velocity (m/s, ft/s). Enter zero for interface velocity. The choice of velocity or flow depends on the value of control word W1 in Section 7.5.2. The interpolation and card formats for the time dependent data are identical to that in Section 7.3.3.

7.6 Pipe and Annulus Components

A pipe component is indicated by PIPE and an annulus component is indicated by ANNULUS on Card CCC0000. The PIPE and ANNULUS components are treated the same, except that the ANNULUS component must be vertical. The remaining input for both components is identical. In junction connections, the code for component inlet is CCC000000 and the code for component outlet is CCC010000. 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 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.

The discussion of the various cards needed to input a pipe or annulus component is next presented. This discussion assumes that the pipe has at least 2 volumes with 1 junction separating the 2 volumes. It is possible to input a 1 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 1. In addition, the user should not input any of the junction cards.

7.6.1 Card CCC0001, Pipe Information Card

This card is required for pipe components.

W1(I) NUMBER OF VOLUMES, NV. NV must be greater than 0 and less than 100. The number of associated junctions internal to the pipe is NV-1. The outer junctions are described by other components.

7.6.2 Cards CCC0101 through CCC0199, Pipe 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.

7.6.3 Cards CCC0201 through CCC0299, Pipe 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.

WI(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.

7.6.4 Cards CCC0301 through CCC0399, Pipe Volume Lengths

This card is 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.

7.6.5 Cards CCC0401 through CCC0499, Pipe Volume Volumes

The format is two words per set in sequential 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 program 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.

7.6.6 Cards CCC0501 through CCC0599, Pipe Volume Horizontal Angles

These cards are optional and if not entered, the horizontal angles are set to 0. The horizontal angles are not used in the calculation but are entered for possible automated noding graphics. 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 $\leq$360 degrees.

W2(I) VOLUME NUMBER.

7.6.7 Cards CCC0601 through CCC0699, Pipe 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) INCLINATION ANGLE. (degrees). The absolute value of the angle must be $\leq$90 degrees. The angle 0 degrees is horizontal, and a positive angle has an upward direction, i.e. the outlet is at a higher elevation than the inlet.

W2(I) VOLUME NUMBER.

7.6.8 Card CCC0701 through CCC0799, Pipe Volume Elevation Changes

These cards are optional. If these cards are missing, the elevation change is computed from the volume length times the sine of vertical angle. The card format is two words per set in sequential expansion format up to NV sets and card numbers need not be consecutive.

W1(R)	ELEVATION CHANGE. (m, ft). A positive value is an increase in elevation. The magnitude 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.
W2(I)	VOLUME NUMBER.

7.6.9 Cards CCC0801 through CCC0899, Pipe Volume Friction Data

These cards are required for pipe components. The card format is three words per set for NV sets and cards numbers need not be consecutive.

W1(R)	WALL ROUGHNESS. (m, ft).
W2(R)	HYDRAULIC DIAMETER. (m, ft). If 0, the hydraulic diameter is computed from 2.0*(VOLUME AREA/π)**0.5. A check is made that the roughness is less than half the hydraulic diameter.
W3(I)	VOLUME NUMBER.

7.6.10 Cards CCC0901 through CCC0999, Pipe 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.

W2(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W3(I) JUNCTION NUMBER.

7.6.11 Cards CCC1001 through CCC1099, Pipe Volume 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.

W1(I) VOLUME CONTROL FLAGS. This word has the packed format fe.

The digit f specifies whether wall friction is to be computed or not, where 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 digit e specifies if nonequilibrium or equilibrium is to be used, where 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.

7.6.12 Cards CCC1101 through CCC1199, Pipe 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 vcahs.

The digit v specifies horizontal stratification options; v=0 means a centrally located junction; v=1 means an upward oriented junction; v=2 means a downward oriented junction; and v=3 means that the horizontal stratification model will not be applied.

The digit c specifies choking options, where 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, where 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 1.

The digit s is not used and should be input as 0.

W2(I) JUNCTION NUMBER.

7.6.13 Cards CCC1201 through CCC1299, Pipe 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. The digit ε specifies the fluid, where ε=0 is the default fluid, and ε=1 specifies water. The default fluid is that set for the hydrodynamic system by cards 120 through 129, or this control word is 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 $\underline{\varepsilon}$=0, then water 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 water (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 noncondensible 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 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.

If t=4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. This value of t=4 is for inputting a noncondensible equilibrium state. The equilibrium quality must be greater than or equal to zero and less than or equal to one.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

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 noncondensible quality. The vapor void fraction must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

W2-W6(R) QUANTITIES AS DESCRIBED UNDER WORD 1 (W1). 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.

7.6.14 Cards CCC2001 through CCC2099, 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 water).

W2(I) VOLUME NUMBER.

7.6.15 Card CCC1300, Pipe Junction Conditions Control Words

This card is optional and if missing, velocities are assumed on Cards CCC1301 through CCC1399.

W1(I) CONTROL WORD. If 0, the first and second words of each set on Cards CCC1301 through CCC1399 are velocities. If 1, the first and second words of each set on Cards CCC1301 through CCC1399 are flows.

7.6.16 Cards CCC1301 through CCC1399, Pipe Junction Initial Conditions

W1(R) INITIAL LIQUID VELOCITY. (Velocity in m/s, ft/s or flow in kg/s, lb/s).

W2(R) INITIAL VAPOR VELOCITY. (Velocity in m/s, ft/s or flow in kg/s, lb/s).

W3(R) INTERFACE VELOCITY. (m/s, ft/s). Enter zero.

W4(I) JUNCTION NUMBER.

7.7 Branch, Separator, Jetmixer, or Turbine Component

A branch component is indicated by BRANCH, a steam separator is indicated by SEPARATR, a jetmixer is indicated by JETMIXER, and a turbine is indicated by TURBINE on Card CCC0000. In junction references, the code for the component inlet is CCC000000 and the code for the component outlet is CCC010000. 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 multiple junctions are connected on one end of a branch, each junction should be modeled as an abrupt area change.

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 3 junctions. Appropriate user input energy loss coefficients may be needed to match a known pressure drop across the separator. It is recommended that choking be turned off for all 3 junctions. The vapor outlet and liquid fall back junctions should use the nonhomogeneous option.

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 jet mixer (CCC000000) and the from part of the discharge junction must refer to the outlet end of the jet mixer (CCC010000). To model a jet pump properly, the junction flow areas of the drive and suction should equal the volume flow area.

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 1 exit junction (part of another component). The <u>to</u> part of the steam inlet junction (N=1) must refer to the inlet end of the turbine volume (CCC000000). A restriction (that will be removed in the future) currently exists such that the volume and junction upstream (normal 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 turbine with η=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. This restriction will also be removed in the future. The horizontal stratification flag should be turned off (v=3). 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 cross flow junction (s=1, 2, or 3).

7.7.1 <u>Card CCC0001, Branch Information Card</u>

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 and JETMIXER 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, flows are assumed.

7.7.2 Cards CCC0101 through CCC0109, Branch Volume Geometry Cards

This card (or cards) is required for branch, separator, jetmixer and turbine 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 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 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 $\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.

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.

W7(R) WALL ROUGHNESS. (m, ft).

W8(R) HYDRAULIC DIAMETER. (m, ft). If zero, the hydraulic diameter is computed from 2.0*(VOLUME AREA/π)**0.5. A check is made that the pipe roughness is less than half the hydraulic diameter.

W9(I) VOLUME CONTROL FLAGS. This word has the packed format fe.

The digit f specifies whether wall friction is to be computed or not, where 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 digit e specifies if nonequilibrium or equilibrium is to be used, where 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.

7.7.3 Card CCC0200, Branch Volume Initial Conditions

This card is required for branch, separator, jet mixer, and turbine components.

W1(I) CONTROL WORD. This word has the packed format εbt. The digit ε specifies the fluid, where ε=0 is the default fluid, and ε=1 specifies water. The default fluid is that set for the hydrodynamic system by cards 120 through 129, or this control word is 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 $\underline{\varepsilon}$=0, then water 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 following words 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 noncondensible 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 $\underline{t}$=1, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

If $\underline{t}$=2, the next two words are interpreted as pressure (Pa, lb_f/in^2) and quality in equilibrium condition.

If $\underline{t}$=3, the next two words are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium condition.

If $\underline{t}$=4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. This value of t=4 is for input of a noncondensible equilibrium state. The equilibrium quality must be greater than or equal to zero and less than or equal to one.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

If t=6, the next five words are interpreted as pressure (Pa, lb_f/in^2), [illegible] specific internal energy (J/kg, Btu/lb), vapor spec[illegible]ternal energy (J/kg, Btu/lb), vapor void fraction, and noncondensible quality. The vapor void fraction, must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

W2-W6(R) QUANTITIES AS DESCRIBED UNDER WORD 1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. Boron concentration if entered follows the last required word for thermodynamic conditions.

7.7.4 Cards CCCN101, Branch 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 and JETMIXER 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 Card CCC0101 of the Single Junction Geometry Card, Subsection 7.4.1, except that N instead of 0 is used in the fourth digit. Words 7 and 8 are not used for BRANCH, JETMIXER and TURBINE components and Word 8 is not used for SEPARATR components. Word 7 is defined for a SEPARATR component.

W1(I) FROM CONNECTION CODE TO A COMPONENT. Refers to the component from which the junction coordinate direction originates. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W2(I) TO CONNECTION CODE TO A COMPONENT. Refers to the component at which the junction coordinate direction ends. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

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.

W5(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W6(I) JUNCTION CONTROL FLAGS. This word has the packed format vcahs.

The digit v specifies horizontal stratification options; v=0 means a centrally located junction; v=1 means an upward oriented junction; v=2 means a downward oriented junction; and v=3 means that the horizontal stratification model will not be applied.

The digit c specifies choking options, where 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, where 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 1.

The digit s specifies normal or crossflow junction. This digit is used for the BRANCH, SEPARATR, and TURBINE components. The s=0 specifies a normal junction; s=1 specifies a crossflow junction and that the to volume is a crossflow volume; s=2 specifies a crossflow junction and that the from volume is a crossflow volume; and s=3 specifies a crossflow junction and that the from and to volumes are crossflow volumes. For the JETMIXER component, this digit is not used and should be input as 0.

W7(R) VOID FRACTION LIMIT (for SEPARATR only). 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.

7.7.5 Cards CCCN201, Branch Junction Initial Conditions

These cards are required depending on the value of NJ as described for Cards CCCN101.

W1(R) ITIAL LIQUID VELOCITY. (Velocity in m/s, ft/s or flow in kg/s, s).

W2(R) INITIAL VAPOR VELOCITY. (Velocity in m/s, ft/s or flow in kg/s, lb/s).

W3(R) INTERFACE VELOCITY. (m/s, ft/s). Enter zero.

7.7.6 Card CCC0300, Turbine/Shaft Geometry Card

This card is used only for TURBINE components.

W1(R) TURBINE STAGE SHAFT SPEED, ω. (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$_f$-ft-s). The frictional torque equals $f_i\omega$. 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 it is not used and can be neglected or set to zero.

7.7.7 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 η_0 AT THE MAXIMUM EFFICIENCY DESIGN POINT.

W3(R) DESIGN REACTION FRACTION, r. The fraction of the enthalpy decrease that takes place in the rotating blade system.

W4(R) MEAN STAGE RADIUS, R. (m, ft).

7.8 Valve Junction Component

A valve junction component is indicated by VALVE on Card CCC0000.

7.8.1 Cards CCC0101 through CCC0199, Valve Junction Geometry Cards

This card (or cards) is required for valve junction components.

W1(I) FROM CONNECTION CODE TO A COMPONENT. Refers to the component from which the junction coordinate direction originates. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W2(I) TO CONNECTION CODE TO A COMPONENT. Refers to the component at which the junction coordinate direction ends. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

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 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 Card 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 1.0×10^{-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.

W5(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W6(I) JUNCTION CONTROL FLAGS. This word has the packed format vcahs.

The digit v specifies horizontal stratification options. The v=0 means a centrally located junction; v=1 means an upward oriented junction; v=2 means a downward oriented junction; and v=3 means that the horizontal stratification model will not be applied.

The digit c specifies choking options, where 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. a=1 means an abrupt area change. Either option may be input for a motor or servo valve in that 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 a 1.

The digit s is not used and should be input as 0.

W7(R) SUBCOOLED DISCHARGE COEFFICIENT. This quantity is applied only to subcooled choked flow calculations. The quantity must be greater than zero and ≤ 2.0. If missing or zero, 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 greater than zero or ≤ 2.0. If missing or zero, it is set to 1.0.

7.8.2 Card CCC0201, Valve Junction Initial Conditions

This card is required for valve junction components.

W1(I) CONTROL WORD. If 0, the next two words are velocities; if 1, the next two words are flows.

W2(R) INITIAL LIQUID VELOCITY. This quantity is either velocity (m/s, ft/s), or flow (kg/s, lb/s), depending on the control word.

W3(R) INITIAL VAPOR VELOCITY. This quantity is either velocity (m/s, ft/s), or flow (kg/s, lb/s), depending on the control word.

W4(R) INTERFACE VELOCITY. (m/s, ft/s). Enter zero.

7.8.3 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.

7.8.4 Cards CCC0301 through CCC0399, Valve Data and Initial Conditions

These cards are required for valve junction components. Five 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.

7.8.4.1 Check Valve: Behaves as an on, off switch, where if the valve is on then it is fully open and if the valve is off 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), or -1 for a static/dynamic pressure controlled check valve (has hysteresis effect).
W2(I)	CHECK VALVE INITIAL POSITION. The valve is initially open if 0, closed if 1.
W3(R)	CLOSING BACK PRESSURE. (Pa, lb_f/in^2).
W4(R)	LEAK RATIO. 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.

7.8.4.2 Trip Valve: Behaves as an on, off switch as described for the check valve.

W1(I)	TRIP NUMBER. Must be a valid trip number. If the trip is false, the valve is closed; if the trip is true, the valve is open.

7.8.4.3 Inertial Valve: 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 0, valve either opens or closes only once if the latch option is 1.

W2(I)	VALVE INITIAL CONDITION. The valve is initially open if 0, initially closed if 1.
W3(R)	CLOSING BACK 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 W6 and W7.
W6(R)	MINIMUM ANGLE. (degrees).
W7(R)	MAXIMUM ANGLE. (degrees).
W8(R)	MOMENT OF INERTIA OF VALVE FLAPPER. ($kg\text{-}m^2$, $lb\text{-}ft^2$).
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).

7.8.4.4 Motor Valve: 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 Subsection 7.8.5 (i.e., Cards CCC0400 through CCC0499, CSUBV Table). 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 W5 is not entered, this quantity is the rate of change of the normalized valve area as the valve opens or closes. If Word W5 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 Section 14 (Cards 202TTTNN, General Table Data) and for this case the normalized item position in input as the argument value and the normalized valve area is input as the function value.

7.8.4.5 Servo Valve: 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 13 (Cards 205CCCNN or 205CCCCN, Control System Input Data). 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.

7.8.4.6 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. (See area A_D in Figure 34 in Volume 1 of this manual.)

W1(I) VALVE INITIAL CONDITION. The valve is initially closed if 0, open if 1.

W2(R) INLET DIAMETER. (m, ft). 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 CCC0199. 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 1.0×10^{-5} m^2. If the junction area is input as zero then this diameter must be input as nonzero. This term corresponds to D_D in Figure 34, in Volume 1 of this manual.

W3(R) VALVE SEAT DIAMETER. (m, ft). Required nonzero input. 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. This term corresponds to D_S in Figure 35 in Volume 1 of this manual.

W4(R) VALVE PISTON DIAMETER. (m, ft). If input as zero the default is to the valve seat diameter. This term corresponds to D_p in Figure 34 in Volume 1 of this manual.

W5(R) VALVE LIFT. (m, ft). Required nonzero input. Distance the valve piston rises above the valve seat at the fully open position. This term corresponds to X_1 in Figure 34 in Volume 1 of this manual.

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 greater than the valve seat diameter a nonzero input of W7(R), following, is allowed. This term corresponds to D_i in Figure 35 in Volume 1 of this manual. Also refer to the warning stated for W9(R) following.

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. Note that if the shoulder is below the seat this distance is negative. This term corresponds to H_i in Figure 35 in Volume 1 of this manual. Also refer to the warning stated for W9(R) following.

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) following 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) following is allowed only if this diameter is greater than the valve piston diameter. This term corresponds to D_O in Figure 35 in Volume 1 of this manual. Also refer to the warning stated for W9(R) following.

W9(R) HEIGHT OF INSIDE BOTTOM EDGE RELATIVE TO THE VALVE SEAT FOR OUTER ADJUSTMENT RING. (m, ft). 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. Note that if the bottom edge is below the valve seat this distance is negative. This term corresponds to H_O in Figure 35 in Volume 1 of this manual. Warning: input of this term and terms W6(R), W7(R), and W8(R) preceding must be done with care to insure that the resultant gap between the adjustment rings is positive and nonzero or 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. This term corresponds to D_B in Figure 34 in Volume 1 of this manual.

W11(R) VALVE SPRING CONSTANT. (N/m, lb_f/ft). Required positive, nonzero input. This term corresponds to K_s in Equation 442, in Volume 1 of this manual.

W12(R) VALVE SETPOINT PRESSURE. (Pa, lb_f/in^2). Required nonnegative input. This term is resolved to $K_s\ x_o$ in Equation 442, in Volume 1 of this manual.

W13(R) VALVE PISTON, ROD, SPRING, BELLOWS MASS. (kg, lb). Required nonzero input. This combined mass corresponds to m_v in Equation 442, in Volume 1 of this manual.

W14(R)	VALVE DAMPING COEFFICIENT. ($N\cdot s/m$, $lb_f\cdot s/ft$). This term corresponds to B in Equation 442, in Volume 1 of this manual.
W15(R)	BELLOWS INSIDE PRESSURE. (Pa, lb_f/in^2). Defaults to standard atmospheric pressure if omitted or input as zero. This term corresponds to P_a in Figure 34 and Equation 442, in Volume 1.
W16(R)	INITIAL STEM POSITION. Fraction of total lift. Required if W1(I) is input as 1. Total lift is input as W5(R).
W17(R)	INITIAL VALVE PISTON VELOCITY. (m/s, ft/s). Must be zero or omitted if W1(I) is input as 0. This term corresponds to v_v in Figure 34 and Equation 442, in Volume 1 of this manual.

7.8.5 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 CCC0199) and, conversely, 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.

7.8.5.1 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 FACTOR.
W2(R)	FLOW COEFFICIENT FACTOR.

7.8.5.2 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 and if the valve is fully open the normalized term is one and 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 RHO 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. $\left\{ \text{gal}/[\text{min}-(\text{lb}_f/\text{in}^2)**0.5] \right\}$. 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. $\left\{ \text{gal}/[\text{min}-(\text{lb}_f/\text{in}^2)**0.5] \right\}$.

7.9 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.

7.9.1 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 $\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 direction, i.e. the outlet is at a higher elevation than the inlet.
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.
W7(I)	VOLUME CONTROL FLAGS. This word has the packed format <u>fe</u>. The digit <u>f</u> that normally specifies whether wall friction is to be computed or not, is not used and no wall friction is computed for a pump since it is included in the homologous pump data. The major edit output will show <u>f</u>=1, which indicates that no friction flag is set.

The digit e specifies if nonequilibrium or equilibrium is to be used, where 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.

7.9.2 Card CCC0108, Pump Inlet (Suction) Junction Card

W1(I) VOLUME CODE OF CONNECTING VOLUME ON INLET SIDE. Refers to the component to which this junction connects. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W2(R) JUNCTION AREA. (m^2, ft^2). If zero, 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.

W3(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.

W4(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W5(I) JUNCTION CONTROL FLAGS. This word has the packed format vcahs.

The digit v specifies horizontal stratification options; v=0 means a centrally located junction; v=1 means an upward oriented junction; v=2 means a downward oriented junction; and v=3 means that the horizontal stratification model will not be applied.

The digit c specifies choking options, where 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, where 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 1.

The digit s is not used and should be input as 0.

7.9.3 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.

7.9.4 Card CCC0200, Pump Volume Initial Conditions

This card is required for a pump component.

W1(I) CONTROL WORD. This word has the packed format εbt. The digit ε specifies the fluid, where ε=0 is the default fluid, and ε=1 specifies water. The default fluid is that set for the hydrodynamic system by cards 120 through 129, or this control word is 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 ε=0, then water 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 water (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 noncondensible 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 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.

If t=4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. This value of t=4 is for inputting a noncondensible equilibrium state. The equilibrium quality must be greater than or equal to zero and less than or equal to one.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

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, Btu/lb), vapor void fraction and noncondensible quality. The vapor void fraction must be greater than or equal to zero and less than or equal to one. The noncondensible quality must be greater than or equal to zero and less than or equal to one.

W2-W6(R) QUANTITIES AS DESCRIBED UNDER WORD 1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. Boron concentration if entered follows the last required word for thermodynamic conditions.

7.9.5 Card CCC0201, Pump Inlet Junction Initial Conditions

This card is required for a pump component.

W1(I) CONTROL WORD. If 0, the next two words are velocities; if 1, the next two words are flow rates.

W2(R) INITIAL LIQUID VELOCITY. This quantity is either velocity (m/s, ft/s) or flow (kg/s, lb/s).

W3(R) INITIAL VAPOR VELOCITY. This quantity is either velocity (m/s, ft/s) or flow (kg/s, lb/s).

W4(R) INITIAL INTERFACE VELOCITY. (m/s, ft/s). Enter zero.

7.9.6 Card CCC0202, Pump Outlet Junction Initial Conditions

This card is similar to Card CCC0201 except data are for the outlet junction.

7.9.7 Card CCC0301, Pump Index and Option Card

This card is required for a pump component.

W1(I)	PUMP TABLE DATA INDICATOR. If 0, 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 two-phase option is not to be used. Enter 0 if two-phase option is desired and two-phase multiplier tables are entered with this component. Enter nonzero if two-phase option is desired and 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 two-phase difference table is not needed (i.e., if W2 is -1). Enter 0 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 0, 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 0, 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 is 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 0, no reverse is allowed; if 1, reverse is allowed.

7.9.8 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). 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 (absolutes 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). Constant frictional torque.
W11(R)	TF1, FRICTION TORQUE COEFFICIENT. (N-m, lb_f-ft). Multiplies the speed ratio to the first power.
W12(R)	TF3, FRICTION TORQUE COEFFICIENT. (N-m, lb_f-ft). Multiplies the speed ratio to the third power.

7.9.9 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

$$I = I_3S^3 + I_2S^2 + I_1S + I_o \qquad S > W1$$

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_o. ($kg\text{-}m^2$, $lb\text{-}ft^2$).

7.9.10 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.

7.9.11 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). Note that reverse velocity is a negative number.

7.9.12 Cards CCCXX00 through CCCXX99, Single Phase Homologous Curves

These cards are needed only if W1 of Card CCC0301 is 0. 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 1 for a head curve; enter 2 for a torque curve.

W2(I) CURVE REGIME. See Volume 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/α for W2(I)=1, 3, 5, or 7 and α/v for W2(I)=2, 4, 6, or 8.

W4(R) DEPENDENT VARIABLE. The variable is h/α^2 or β/α^2 for W2(I)=1, 3, 5, or 7 and h/v^2 or β/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.

7.9.13 Cards CCCXX00 through CCCXX99, Two-Phase Multiplier Tables

These cards are needed only if W2 of Card CCC0301 is 0; XX is 30 and 31 for the pump head multiplier table and the pump torque multiplier table respectively.

W1(I)	EXTRAPOLATION INDICATOR. Not used, enter 0.
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.

7.9.14 Cards CCCXX00 through CCCXX99, Two-Phase Difference Tables

These cards are required only if W3 of Card CCC0301 is 0. 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 the dependent variable is the difference between single-phase and fully degraded two-phase data.

7.9.15 Cards CCC6001 through CCC6099, Relative Pump Motor Torque Data

These cards are required only if W4 of Card CCC0301 is 0. 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.

7.9.16 Card CCC6100, Time Dependent Pump Velocity Control Card

This card is required only if W5 of Card CCC0301 is 0. 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.

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. Assumed zero if missing.

7.9.17 Cards CCC6101 through CCC6199, Time Dependent Pump Velocity

These cards are required only if W5 of Card CCC0301 is 0.

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.

7.10 Accumulator Component

An accumulator component is indicated by ACCUM on Card CCC0000.

An accumulator is a lumped parameter component treated by special numerical techniques that model both the tank and surge line 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 surge line 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 noncondensible gas in the accumulator is that defined by Card 110, Noncondensible Gas Type (Subsection 2.7) and that the gas and liquid are initially in equilibrium.

7.10.1 Cards CCC0101 through CCC0199, Volume Geometry Cards

W1(R) VOLUME FLOW AREA. (m^2, ft^2). Flow area of the tank.

W2(R) LENGTH OF VOLUME. (m, ft). Length of the tank above the standpipe/surge line inlet.

W3(R) VOLUME OF VOLUME. (m^3, ft^3). Volume of the tank above the standpipe/surge line inlet. The program requires that the volume equals the volume flow area times length (W3=W1*W2). 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. If none of the words are zero, they must satisfy the condition that volume equals area times length within a relative error 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 noding diagrams.

W5(R) INCLINATION ANGLE. (degrees). Only + or -90 degrees is allowed. The accumulator is assumed to be a vertical tank with the standpipe/surge line inlet at the bottom.

W6(R) ELEVATION CHANGE. (m, ft). The elevation change from the standpipe/surge line inlet 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.

W7(R) WALL ROUGHNESS [illegible] ft).

W8(R) HYDRAULIC DI[illegible]ero, the hydraulic diameter computed from 2.[illegible]*0.5. A check is made that the pipe roughness is [illegible] half the hydraulic diameter.

W9(I) VOLUME CONTROL FLAGS. Enter <u>fe</u> where <u>f</u>=0 if wall friction is to be computed, and <u>f</u>=1 if wall friction is not to be computed. The flag, <u>e</u>, must be 0 to specify a nonequilibrium (unequal temperature) calculation.

7.10.2 Card CCC0200, Accumulator Tank Initial Thermodynamics Conditions

W1(R) PRESSURE. (Pa, lb_f/in^2).

W2(R) TEMPERATURE. (K, °F).

W3(R) BORON CONCENTRATION. (Parts of boron per parts of liquid water).

7.10.3 Card CCC1101, Accumulator Junction Geometry Card

W1(I) TO CONNECTION CODE TO A COMPONENT. The <u>from</u> connection is not entered since it is always from the accumulator. The <u>to</u> connection code refers to the component at which the junction coordinate direction ends. If this is the inlet side of the component, CCC000000 is used. If this is the outlet side of the component, CCC010000 is used.

W2(R) JUNCTION AREA. (m^2, ft). Average area of the surge line and stand pipe.

W3(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.

W4(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W5(I) JUNCTION CONTROL FLAGS. This word has the packed format <u>vcahs</u>. 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 and the following terms are then enabled and used as defined.

The digit v specifies horizontal stratification options; v=0 means a centrally located junction and v=3 means that the horizontal stratification model will not be applied. Setting v=0 or 3 is allowed in the input, but v=0 will be changed to a 3. Using v=1 or 2 is not allowed.

The digit c specifies choking options, where 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, where 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 a 1.

The digit s specifies normal or crossflow junction; s=0 specifies a normal junction; s=1 specifies a crossflow junction and that the to volume is a crossflow volume; and s=2 or 3 is not allowed for an accumulator.

7.10.4 Card CCC2200, Accumulator Tank Initial Fill Conditions, Standpipe/Surge Line Length/Elevation and Tank Wall Heat Transfer Terms

W1(R) LIQUID VOLUME IN TANK. (m^3, ft^3). The volume of water contained in the tank above the standpipe surge line inlet.

W2(R) LIQUID LEVEL IN TANK. (m, ft). The liquid level of water contained in the tank above the standpipe entrance. Either W1 or W2 must be specified as nonzero.

W3(R)	LENGTH OF SURGE LINE AND STANDPIPE. (m, ft). If input as zero then the surge line and standpipe are not modeled.
W4(R)	ELEVATION DROP OF SURGE LINE AND STANDPIPE. (m, ft). This is the elevation drop from the standpipe/surge line inlet entrance to the injection point. A positive number denotes a decrease in elevation.
W5(R)	TANK WALL THICKNESS. (m, ft). Not allowed to be zero.
W6(I)	HEAT TRANSFER FLAG. If 0, heat transfer will be calculated. If 1, no heat transfer will be calculated.
W7(R)	TANK DENSITY. (kg/m^3, lb/ft^3). If 0, the density will default to that for carbon steel.
W8(R)	TANK VOLUMETRIC HEAT CAPACITY. (J/kg-K, Btu/lb-°F). If 0, the heat capacity will default to that for carbon steel.
W9(I)	TRIP NUMBER. If 0 or if no number is input, then no trip test is performed. If nonzero then this must be a valid trip number and 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.

8. 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:

<u>CCC</u> is a heat structure number. The heat structure numbers need not be consecutive. It is suggested, but not required, that where heat structures and hydrodynamic volumes are related, they be given the same number.

<u>G</u> is a geometry number. The combination CCCG is a heat structure-geometry combination that is referenced in 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.

<u>X</u> is the card type.

<u>NN</u> is the card number within a card type.

8.1 Card 1CCCG000, General Heat Structure Data

This card is required for heat structures.

8.1.1 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 >1 if no reflood is specified, >2 if reflood is specified, and <100.

W3(I) GEOMETRY TYPE. Enter 1 for rectangular, 2 for cylindrical, and 3 for spherical. Spherical geometry is not allowed if reflood is specified.

W4(I) STEADY STATE INITIALIZATION FLAG. Use 0 if the initial conditions are entered on input cards; use 1 if steady state condition is to be calculated for the initial temperature distribution.

W5(R) LEFT BOUNDARY COORDINATE. (m, ft).

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 of the fuel pin. 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. 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 when the connected hydrodynamic volumes are nearly empty. If 2 is entered, the reflood calculation begins when 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 0 or 1 to indicate that reflood heat transfer applies to the left or right boundary respectively.

W8(I) MAXIMUM NUMBER OF AXIAL INTERVALS. Enter 2, 4, 8, 16, 32, 64 or 128 to indicate the maximum number of axial subdivisions times a heat structure can have. Storage is allocated for the number indicated even though a transient may not require that level of subdivision.

8.1.2 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.

8.2 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, W1 of Card 1CCCG100 must be zero, cards 1CCCG011 through 1CCCG099 are required, and a table of the gas component name and mole fraction must be specified in the gap material data.

W1(R) INITIAL GAP INTERNAL PRESSURE. (Pa, lb_f/in^2).

8.3 Cards 1CCCG011 through 1CCG099, 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). Must be greater than or equal to zero. An appropriate value is 10^{-6}m. If a negative number is entered, it is interpreted as 10^{-6}m, and a message is printed, but no errors are set.

W2(R) CLADDING SURFACE ROUGHNESS. (m, ft). 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). Must be greater than or equal to zero. A negative entry is reset to zero. An appropriate value can be obtained from calculations using FRAPCON or FRAP-T.

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 of FRAP-T.

W5(I) HEAT STRUCTURE NUMBER.

8.4 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 Subsections 8.4 through 8.7 is not entered.

W2(I) MESH FORMAT FLAG. This word is needed only if W1 is zero although no error occurs if it is present when W1 is nonzero. The mesh interval data is given as a sequence of pairs of numbers in one of two formats. If this word is 1, the pairs of numbers contain the number of mesh 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 W5 of Card 1CCCG000; for succeeding pairs, the left coordinate is the right coordinate of the previous pair. If this word is 2, the format is sequential expansion of mesh intervals. That is: the distance in W1 is used for each interval starting from the leftmost as yet unspecified interval to and including the interval number specified in W2.

8.5 Cards 1CCCG101 through 1CCCG199, Heat Structure Mesh Interval Data

These cards are required if W1 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.

Format 1

W1(I) NUMBER OF INTERVALS.

W2(R) RIGHT COORDINATE. (m, ft).

Format 2

W1(R) MESH INTERVAL. (m, ft).

W2(I) INTERVAL NUMBER.

8.6 Cards 1CCCG201 through 1CCCG299, Heat Structure Composition Data

These cards are required if W1 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 Section 9 (Heat Structure Thermal Property Data). 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.

W2(I) INTERVAL NUMBER.

8.7 Cards 1CCCG301 through 1CCCG399, Heat Structure Source Distribution Data

These cards are required if W1 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(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.

8.8 Card 1CCCG400, Initial Temperature Flag

This card is optional and if missing, W1 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 data. If greater than zero, initial temperatures for this heat structure-geometry are taken from the heat structure-geometry number in this word.

8.9 Cards 1CCCG401 through 1CCG499, Initial Temperature Data

These cards are required if W1 of Card 1CCCG400 is zero or -1. If W1 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, °F).

W2(I) MESH POINT NUMBER.

If W1 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 does not fit on one card.

W1-WNP(R) TEMPERATURE. (K, °F). Enter the NP mesh point temperatures in order from left to right.

8.10 Cards 1CCCG501 through 1CCCG599, Left Boundary Condition Cards

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).

W1(I) BOUNDARY VOLUME NUMBER. This word specifies the hydrodynamic volume number or general table associated with the left surface of this heat structure. If zero, no volume or general table is associated with the left surface of this heat structure and 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. A general table is entered as a negative number (-1 through -999).

W2(I) INCREMENT. This word and W1 are treated differently from the standard sequential expansion. W1 of the first set applies to the first heat structure of the heat structure-geometry set. The increment is applied to W1, and that applies to the second heat structure. The increment is applied up to the limit in W6 of a set. W1 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.

W3(I) BOUNDARY CONDITION TYPE. If

0 a symmetry or insulated boundary condition is used. The boundary volume must be 0.

1 a convective boundary condition where the heat transfer coefficient is obtained from heat transfer Package 1 is used. The sink temperature is the temperature of the boundary volume. W1 must specify a boundary volume with this boundary condition type. Generally the boundary volume

would 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.

1000 the temperature of the boundary volume or the temperature from the general table (as specified in W1) is used as the left surface temperature. If W1 is zero, the surface temperature is set to zero.

1xxx the temperature in general table xxx is used as the left surface temperature.

2xxx the heat flux from table xxx is used as the left boundary condition.

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.

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.

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 0, W5 is the left surface area. If 1, W5 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 W4, 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).

W6(I) HEAT STRUCTURE NUMBER.

8.11 Cards 1CCCG601 through 1CCCG699, Right Boundary Condition Cards

These cards are the same as Cards 1CCCG501 through 1CCCG599 but for the right boundary. The left and right surface areas must be compatible with the geometry.

8.12 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 0, no source is used. If a positive number <1000, power from the general table with this number is used as the source. If 1000 through 1002, the source is taken from the reactor kinetics calculation; 1000 specifies total reactor power, 1001 specifies fission product decay power, and 1002 specifies fission power. If 10001 through 14095, the source is the control variable whose number is this quantity minus 10000.

W2(R) INTERNAL SOURCE MULTIPLIER.

W3(R) DIRECT HEATING MULTIPLIER FOR LEFT BOUNDARY VOLUME.

W4(R) DIRECT HEATING MULTIPLIER FOR RIGHT BOUNDARY VOLUME.

W5(I) HEAT STRUCTURE NUMBER.

8.13 Cards 1CCCG801 through 1CCCG899, Additional Left Boundary Cards

These cards are required whenever any of the left boundary conditions use heat transfer package 1. The card format is sequential expansion format, five words per set, describing NH heat structures.

W1(I)	CHF AND HEAT TRANSFER CORRELATION FLAGS. Enter zero.
W2(R)	HEAT TRANSFER HYDRAULIC DIAMETER. (m, ft). If zero, the hydraulic diameter of the boundary volume is used. If the heat structure does not represent the pipe walls, the default probably should not be taken. This word is used in the heat transfer correlations as the equivalent diameter (D_e).
W3(R)	HEATED EQUIVALENT DIAMETER. (m, ft). Enter zero. This word is currently not being used.
W4(R)	CHANNEL LENGTH. (m, ft). Enter zero. This word is currently not being used.
W5(I)	HEAT STRUCTURE NUMBER.

8.14 Cards 1CCCG901 through 1CCCG999, Additional Right Boundary Cards

These cards are the same as Cards 1CCCG801 through 1CCCG899 but apply to the right boundary.

9. CARDS 201MMMNN, HEAT STRUCTURE THERMAL PROPERTY DATA

These cards are used in NEW or RESTART problems. These cards are required if Cards 1CCCGXNN, Heat Structure Input Cards are entered. These data, if present, are processed and stored even if no Cards 1CCCGXNN 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.

9.1 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 (UO2), 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 is primarily to demonstrate capability. The user should check whether the data is 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. 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 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.

9.2 Cards 201MMM01 through 201MMM49, Thermal Conductivity 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 1 is performed if the sum of the mole fractions entered is not 1. The table of gas composition data is applicable to any gap and is required if Card 1CCCG001 is present.

9.2.1 Table Format

If only one word is entered, that word contains the thermal conductivity that is assumed constant. Otherwise pairs of numbers are entered. The number of pairs 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.

W2(R) THERMAL CONDUCTIVITY (W/m-K, Btu/s-ft-°F) or MOLE FRACTION.

9.2.2 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 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. (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).

9.3 Cards 201MMM51 through 201MMM99, Volumetric Heat Capacity Data

These cards are required if W1 of Card 210MMM00 contains TBL/FCTN. The card numbers need not be consecutive. Refer to Subsection 4.3.4 of Volume 1 of this manual for special treatment during steady state problems.

9.3.1 Table Format

If only one word is entered, that word contains the volumetric heat capacity that is assumed constant. Pairs of temperatures and volumetric heat capacities are entered if the temperatures are different from 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 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). 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)

9.3.2 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 = 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-$°F^2$)

W5(R)	A2. (J/m^3-K^3, Btu/ft^3-°F^3)
W6(R)	A3. (J/m^3-K^4, Btu/ft^3-°F^4)
W7(R)	A4. (J/m^3-K^5, Btu/ft^3-°F^5)
W8(R)	A5. (J/m^3, Btu/ft^3)
W9(R)	C. (K, °F)

10. CARDS 202TTTNN, GENERAL TABLE DATA

These cards are used only in NEW or RESTART type problems. These cards are required if any input references general tables. TTT is the table number, and table references such as for power, heat transfer coefficients, or 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.

10.1 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 length. 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 undesired 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 unit 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 transfer flux, heat transfer coefficient, normalized length, 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, 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 is the time supplied to the table for interpolation. If nonzero, the number is the trip number and the time argument 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.

10.2 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 length).

W2(R) FUNCTION VALUE. (W, MW, if power; K, °F, if temperature; W/m^2, $Btu/s\text{-}ft^2$, if heat flux; $W/m^2\text{-}K$, $Btu/s\text{-}ft^2\text{-}°F$, if heat transfer coefficient; dollars, if reactivity; dimensionless, if normalized area).

The tables use linear interpolation for arguments between table search argument values. For search arguments beyond the range of entered data, the end point values are used.

11. CARDS 30000000 THROUGH 30099999, SPACE INDEPENDENT REACTOR KINETICS

These cards are required only if a space independent (point) reactor kinetics calculation is desired. These cards may be entered in a new problem or on a restart. If no reactor kinetics is present in a restart problem, it will be added; if reactor kinetics is already present, it is 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.

11.1 Card 30000000, Reactor Kinetics Type Card

W1(A) KINETICS TYPE. Enter POINT for the only reactor kinetics option now available. Enter DELETE in a restart problem if reactor kinetics is to be deleted. No other data is needed if reactor kinetics is being deleted.

W2(A) FEEDBACK TYPE. Enter SEPARABL, TABLE3, or TABLE4. If Word 2 is not entered or if SEPARABL is entered, reactor kinetics feedback due to moderator density, moderator temperature, and fuel temperature is assumed to be separable and feedback data are entered on Cards 30000501 through 30000899. If TABLE3 or TABLE4 is entered, reactivity is obtained from a table defining reactivity as a function of three or four variables (moderator density, moderator temperature, fuel temperature, and boron density) using Cards 30001001 through 30002999.

11.2 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). Sum of fission power and fission product and actinide decay power.

W3(R) INITIAL REACTIVITY. (dollars). Must be less than or equal to zero.

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) U^{239} YIELD FACTOR. This is the number of U^{239} atoms produced per fission times any conservative factor desired. The factor, 1.0, is assumed if this word is not entered.

11.3 Card 30000002, Fission Product Decay Information

This card is optionally entered if W1 of Card 30000001 contains GAMMA or GAMMA-AC. If this card is not entered, the 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 1973 ANS standard data, ANS79-1 specifies the 1979 standard data for U^{235}, and ANS79-3 specifies the 1979 ANS standard data for the three isotopes, U^{235}, U^{238}, and Pu^{239}. 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 groups for each isotope also 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 U^{235}, U^{238}, and Pu^{239} must be entered in these three words. The sum of the fractions must add to 1.

W6-W8(I) NUMBER OF GROUPS PER ISOTOPE. If ANS79-3 is entered in W1 and default data is not being used, the number of decay groups for U^{235}, U^{238}, and Pu^{239} must be entered in these words.

11.4 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 decay 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 decay groups. Up to 50 delay groups may be entered.

W1(R) DELAYED NEUTRON PRECURSOR YIELD RATIO.

W2(R) DELAYED NEUTRON DECAY CONSTANT. (s^{-1}).

11.5 Cards 30000201 through 30000299, Fission Product Decay Constants

These cards are not needed if W1 of Card 30000001 is NOGAMMA. 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}).

11.6 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 is used to define actinide decay. If the cards are missing, default data are supplied.

W1(R) ENERGY YIELD FROM U^{239} DECAY. (Mev).

W2(R) DECAY CONSTANT OF U^{239}. (s^{-1}).

W3(R) ENERGY YIELD FROM Np^{239}. (Mev).

W4(R) DECAY CONSTANT OF Np^{239}. (s^{-1}).

11.7 Cards 30000401 through 30000499, Previous 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 greater than or equal to zero. 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 zero.

W3(A) TIME DURATION UNITS. Must be SEC, MIN, HR, DAYS, or WK.

W4-W6(R) POWER FRACTIONS. If ANS79-3 is entered in W1 of card 300000002, the power fractions for U^{235}, U^{238}, and Pu^{239} must be entered in these words.

11.8 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 >10000 indicate the control variable whose number is the entered number minus 10000.

11.9 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.

W1(R) MODERATOR DENSITY. (kg/m^3, lb/ft^3).

W2(R) REACTIVITY. (dollars).

11.10 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. Data are entered one or more pairs per card and card numbers need not be consecutive. Up to 100 pairs may be entered.

W1(R) TEMPERATURE. (K, °F)

W2(R) REACTIVITY. (dollars).

11.11 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. Words 3 and 4 are the reactivity data for the volume defined by Word 1, 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, $W_{\rho i}$. See Section 3.5.6 in Volume 1 of the manual for a discussion of the symbols.

W4(R) WATER TEMPERATURE COEFFICIENT, a_{Wi}. (dollars/K, dollars/°F). As defined in Volume 1, the weighting factor in word 3 is not applied to this quantity.

11.12 Cards 30000801 through 30000899, Heat Structure 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 is present. Each card contains the input for reactivity feedback due to conditions in one or more heat structures representing fueled portions of the reactor. Data is 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.

W2(I) INCREMENT.

W3(R) WEIGHTING FACTOR FOR DOPPLER FEEDBACK, W_{Fi}. See Section 3.5.6 in Volume 1 of the manual for a discussion of the symbols.

W4(R) FUEL TEMPERATURE COEFFICIENT, a_{Fi}. (dollars/K, dollars/°F). As defined in Volume 1, the weighting factor in word 3 is not applied to this quantity.

11.13 Cards 300001701 through 30001799, Volume Weighting Factors

These cards are used only if the SEPARABL option is not being used. Each card contains the weighting factor for reactivity feedback due to moderator density, moderator temperature, and boron density in one or more hydrodynamic volumes. 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 Subsection 11.11.

W1(I) HYDRODYNAMIC VOLUME NUMBER.

W2(I) INCREMENT.

W3(R) WEIGHT FACTOR.

11.14 Cards 30001801 through 30001899, Heat Structure Weighting Factors

These cards are used only if the SEPARABL option is not being used. Each card contains the weighting factor for reactivity feedback due to heat structure temperature in one or more heat structures. At least three quantities must be entered on each card. The use of the increment field is similar to that in Subsection 11.11.

W1(I) HEAT STRUCTURE NUMBER.

W2(I) INCREMENT.

W3(R) WEIGHT FACTOR.

11.15 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 (C = 1), 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 (C = 4). 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, °F for moderator and heat structure temperatures).

11.16 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. 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 which are filled in by interpolation.)

W2(R) TABLE VALUE.

12. CARDS 20300000 THROUGH 20399999, PLOT REQUEST INPUT DATA

These cards are used in NEW, RESTART, or PLOT problems. The input data for plotting permits extensive user control over the plots, and graphs suitable for report use can be generated. However if plots of selected quantities versus time are desired using default options then only the cards described in 12.6.1 need be entered.

For convenience to the user a check plot option is provided 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 utilized by the input of the "check plot" general plot request input card. 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.

12.1 Card 203000KK, Plot General Heading and Specifications

These cards are optional and may be input to define the general plot heading, plot options and plot size specifications if the user desires to specify these parameters. Input of these cards is equivalent to redefining the general plot default conditions. The number group KK designates either data group or card sequence numbers as noted in the following.

12.2 Cards 20300000 through 20300009, General Plot Heading Cards

Each card defines a line of the general heading for the plots. This general heading will be written at the top of each plot. Up to three lines of heading may by input, in which case each line of the heading will be written at the top of the plots in the ascending order of the card sequence number KK, where KK ranges from 00 through 09. If more than three lines are input an error will result. The cards need not be consecutively numbered. Each line of the heading must be composed of alphanumeric characters enclosed by apostrophe symbols. The length of each line is limited to ten computer words. The $ symbol may not be embedded in the character string. If more than one blank is input between any words the extraneous blanks are automatically deleted. All blanks preceding the first nonblank character are automatically deleted and the entire heading line is automatically left justified. However, each line of the heading is centered as it is written on the plot. If a heading line is composed of blanks the card will be ignored. If the cards are omitted the first heading line will default to the RELAP5 computer code heading printed in the output and the second heading line will default to the problem title as input on the title card described in Subsection 1.3. The heading may be suppressed by inputting =NONE on the 20300000 card.

For RESTART or PLOT runs it may be desired to modify previously defined headings. For these cases, if either of the keywords DELETE or DISCARD is input as the first word on Card 20300000 through 09, the existing plot heading will be deleted and replaced by the default heading. If the user wishes to specify a new heading, then input is done in the normal manner, which will replace the existing heading. The heading may also be suppressed as discussed above. Input of both a keyword and a new plot heading is not allowed and will result in an error.

12.3 Cards 20300010 through 20300019, General Plot Options Keywords

These cards are input to define the general plot options to be in effect for all of the plots. However, many of the options may be modified for an individual plot as described for the 203NNN50 through 203NNN59 cards. Options that may not be modified for individual plots are appropriately noted. Input of the general plot options allows the user to redefine the default conditions for the units of the plot, the drawing of the grid, the character style of the lettering, the page border, the axes frame, the mode of printing plot information in the printout and the plot orientation on the page. The plot option keywords may be input in any order or omitted. If any keyword is misspelled or an undefined keyword is input, an error will result. Keywords are also provided to enable a "debug dump" of plot related files at the three levels of data processing. These options are not recommended for the typical user and are provided for the convenience of code designers who wish to modify the plot capability or trace the effects of bugs discovered in the plot package. The keywords are described as follows:

PRINTUNITS	(Default). Plots are made in the same units as the printout.
SI	Plots are made in SI units.
BRITISH	Plots are made in British units.
NOGRID	(Default). No plot axes grid is drawn.
DOTGRID	A plot axes dotted line grid is drawn.
LINEGRID	A plot axes solid line grid is drawn.
STDCHAR	(Default). All lettering on the plot is in the simplest, fastest style. (Note: also refer to the intensity option.)
DUPLEX	Lettering of the plot is drawn in the engineering-drafting style with two passes per character to ensure high resolution. (Note: also refer to the intensity option.)
COMPLEX	Lettering on the plot is drawn in a high resolution textbook style. (Note: also refer to the intensity option.)
BORDER	(Default). A page border is drawn around the plot that includes a binder margin allowance.

NOBORDER	No page border is drawn.
FRAME	A frame is drawn around the axes extremities.
NOFRAME	(Default). No frame is drawn around the axes extremities.
NOPLPRINT	(Default). User input plot related data will not be printed and DISSPLA messages during plotting will not be printed in the printout. An ID message will be drawn on the plot page margin. If the PLPRINT option has been input as a general plot option the NOPLPRINT option may be input for an individual plot only to suppress the printout of DISSPLA messages during plotting.
PLPRINT	If input as a general plot option PLPRINT causes the printout of all plot related user input including plot comparison data table input. If the check plot request card is also input then the check plot data used for plotting will also be printed. DISSPLA messages during plotting will also be printed in the printout. If input as an individual plot option PLPRINT only causes DISSPLA messages to be printed during plotting.
HORIZONTAL	(Default). The plot is with the independent variable axis parallel with the long page axis.
VERTICAL	The plot is oriented with the dependent variable axis parallel with the long page axis.
INTENSITYN	The plot curves are drawn by performing m passes over the curve. The value of m is set according to the following values of N. If N is 0 or 1 then m = 1. This intensity is the default if the intensity option

	is omitted and the STDCHAR lettering option is activated. If N is 2 or 3 then m = 2. This intensity is the default if the intensity option is omitted and the DUPLEX lettering option is activated. N ≥ 4, then m = 4. This intensity is the default if the intensity option is omitted and the COMPLEX lettering option is activated.
DELETE	May be input only for RESTART and plot jobs. If input the general plot options are reset to their default values. Any of the keywords previously described may also be input with their noted effect.
DISCARD	Identical to DELETE.

The plot debug options are general plot options only and may not be input for individual plots. These options are not recommended for use by a typical user. They are provided for the convenience of code designers who desire debug dumps of plot related files for the purpose of modifying the plot package capability or for tracing the effects of "bugs" discovered during plot processing. The debug option keywords may be input in any order and any combination except the keyword "NODEBUG". Use of the "NODEBUG" keyword will cancel all plot debug options in the current input and for either restart or plot only jobs will cancel all plot debug options previously defined. Use of the plot debug options will automatically activate to PLPRINT option for which all plot related user input and check plot data will also be printed. The debug option keywords are listed as follows:

DEBUGP	Activates a debug dump and user input printout of plot related files at the second level of input processing (i.e., the "R" level subroutines).
DEBUGI	Activates a debug dump and check plot printout at the third level of input processing (i.e., the "I" level subroutines).

DEBUGP	Activates a debug dump of plot related files at the plot level (i.e., the PLOTMD level subroutines).
DEBUGRI	A single keyword combining the effects of DEBUGR and DEBUGI.
DEBUGALL	A single keyword combining the effects of DEBUGR, DEBUGI and DEBUGP.
DEBUGPR	Activates the debug options for plot requests.
DEBUGCR	Activates the debug options for plot comparison data table requests.
DEBUGPRCR	A single keyword combining the effects of DEBUGPR and DEBUGCR.
NODEBUG	Cancels all plot debug options currently input. For restart or plot only jobs, cancels all plot debug options previously defined.

12.4 Card 20300020, General Plot Size Dimensions

This card is optional and is input to define the general plot size dimensions. If the card is omitted, the plot size dimensions default to fit a standard page size of 8-1/2 by 11 inches. The general plot size dimensions are applied to all of the plots. However, any or all of the dimensions may be modified for an individual plot as described for the 203NNN60 cards.

Up to three real numbers may be input that are described as follows:

W1(R)	PWIDTH. The length of the plot axis extremities parallel to the short page axis. (The default of PWIDTH is 6 in.).

W2(R)	PHIGHT. The length of the plot axis extremities parallel to the long page axis. (The default of PHIGHT is 8 in.).
W3(R)	PMAGNF. A magnification factor to be applied to the overall plot (the default of PMAGNF is 1).

The Words W1 and W2 may be input in any order as PWIDTH is defined as the minimum of W1 or W2 and PHIGHT is defined as the maximum of W1 or W2.

For RESTART or PLOT jobs, input of the card will redefine the general plot size dimensions and if it is desired to reset these terms to their default values then each term must be input as zero.

12.5 Card 20300030, Input Check Plot Request Card

This card is optional and is input to direct the code to construct plot files and plot data file for plotting of component tabular data. This option is provided for user convenience to provide plots for a visual aid in checking input data or for graphical presentation of component input data in reports or presentations. Only one of the following keywords need be input:

CHK-PLT	Activates the check plot option.
DELETE	To be used only for restart or plot only jobs. Input causes deactivation of the check plot option for the current and all following restarts.
DISCARD	An equivalent of DELETE.

12.6 Cards 203NNNKK, Plot Requests and Specifications

These cards are input to define a plot request and to define the specifications for drawing the plot. The cards specifying the basic plot requests are required. All of the remaining cards are optional. If the optional cards are input and the corresponding plot request card is omitted an error will result.

12.6.1 Cards 203NNN00 through 203NNN09, Plot Requests

These cards are required for each plot. Any input card of the form 203NNNKK where KK ranges from 00 through 09, is a plot request card. The first word input on the card with the lowest sequence number KK must be a valid alphanumeric variable code followed by up to nine parameters as described for the minor edit requests (Cards 301 through 399) described in Section 4. However, the keywords DELETE or DISCARD may be input as a variable code for RESTART or PLOT runs as described below. The data format for the input of a plot request is described as follows:

W1(A)	DEPENDENT VARIABLE CODE, (required). Defined as for the minor edit request variable code described in Section 4.
W2(I)	PARAMETER(1), (required). Defined as for the minor edit request parameter described in Section 4.
W3-10(I)	PARAMETER(2)-(9), (optional). Defined as for W2.

Each VARIABLE CODE-PARAMETER combination defines a dependent variable to be plotted. The curve (or curves) to be plotted is determined by the INDEPENDENT VARIABLE REQUEST Card 203NNN10. If a variable code is omitted or input more than once in the request string an error will result. If more than 9 parameters are input an error will result. Invalid variable codes and parameters will also cause an error.

For restart or plot runs, the existing plot records are loaded from the restart records and these may be modified. If DELETE or DISCARD is input as the dependent variable code for a plot request (card 203NNN00 through 09), the entire plot request record will be deleted. If the user wishes to replace, insert, or add a plot request, the input is the same as for a normal execution. If the keywords DELETE or DISCARD are input, no other words or cards may be input for the deleted record or an error will result.

12.6.2 Cards 203NNN10 Through 203NNN19, Independent Variable Requests

These cards are optional and if omitted the independent variable defaults to TIME.

If these cards are input then any card of the form 203NNNLL, where LL ranges from 10 through 19, is an independent variable request card. The first word input on the card with the lowest sequence number KK must be a valid alphanumeric variable code followed by up to nine parameters as described for the plot requests (cards 203NNN00 through 203NNN09). If a variable code is input more than once an error will result. Independent variable requests may be input in any one of the following formats.

First, only the independent variable code word may be input with no parameters following, as follows:

W1(A)	INDEPENDENT VARIABLE CODE. Defined as for the minor edit request variable code described in Section 4. For this format, the parameters will default to those input on the plot request cards 203NNN00 through 203NNN09.

Second, only the independent variable code word followed by only one parameter may be input, as follows:

W1(A)	INDEPENDENT VARIABLE CODE. Defined as for the minor edit request variable code described in Section 4.
W2(I)	PARAMETER(1). Defined as for the minor edit request parameter described in Section 4. For this format, the independent variable code word and parameter will be assigned as the independent variable for each of the dependent variables input on the plot request cards 203NNN00 through 203NNN09.

Third and finally, the independent variable code word followed by several parameters may be input, as follows:

W1(A)	INDEPENDENT VARIABLE CODE. Defined as for the minor edit request variable code described in Section 4.
W2(I)	PARAMETER(1). Defined as for the minor edit request parameter described in Section 4.
W3-(N+1)(I)	PARAMETER(2)-(N). Defined as for W2, where N is the number of parameters input on the plot request cards 203NNN00 through 203NNN09.

For this format, each independent variable and parameter in the sequence is successively paired with its corresponding dependent variable and parameter in the sequence input on the plot request cards (Cards 203NNN00 through 203NNN09). If the number of independent variable parameters input does not correspond to the number of dependent variable parameters input on the plot request cards then an error will result.

12.6.3 Cards 203NNN20 through 203NNN29, Plot Comparison Data Table Reference

These cards define the table number for plot comparison input data to be plotted on the same graph as RELAP5 results for visual comparison. Up to 10 table numbers can be input. Each table number entered is defined by the 204MMM00 card described in Subsection 12.7 where the number MMM00 is the plot comparison data table number. Each number entered must refer to a plot comparison data table that has been input or an error will result.

For RESTART or PLOT jobs, if a plot request is deleted that references a plot comparison data table and if the plot comparison data table is not referenced by a remaining plot request, then an error will result unless the table is also deleted.

12.6.4 Cards 203NNN30 through 203NNN32, Plot Title and Axes Titles

These three cards are optional and input the plot title and the x and the y axes titles respectively. The format for each of the title cards is identical to that for the header cards (Cards 203000000-09). Any or all of the cards may be omitted. However when input, the card sequence number KK designates the type of title entered. The plot title is input on the 203NNN30 card and is written on the plot as the last line of the header. If the plot title card is omitted it defaults to a blank character string and is ignored. The x-axis title is input on the 203NNN31 card and written on the plot parallel to the independent variable axis (x-axis). If the x-axis title card is omitted it defaults to the independent variable code, parameter, and units encoded together. If the x-axis title card begins with the character string (=UNITS) the RELAP5 units label for the variable being plotted will be appended to the user input title. The y-axis title is input on the 203NNN32 card and is written on the plot parallel to the dependent variable axis (y-axis). If the y-axis title card is omitted it defaults to the dependent variable code, parameter and units encoded together. If the y-axis title card begins with the character string (=UNITS) the RELAP5 units label for the variable being plotted will be appended to the user input title.

12.6.5 Cards 203NNN40 through 203NNN41, Plot Axes Specifications

These cards input the specifications for drawing the plot independent and dependent variable axes, respectively. The cards are optional and may be omitted, in which case defaults are set that will produce optimal and attractive axes.

None of the input terms will completely define an axes specification except the keyword LINEAR, unless the following plot design criteria are satisfied. The plot axes are designed with respect to RELAP5 computational results. In order to achieve maximum visual effect the plotted curve of RELAP5 results must span as much of the independent variable axis as possible and the dependent variable axis must span all of the data plotted. The axes must also be subdivided into intervals rounded to the first significant figure for simple labeling. The terms input by each card are described as follows.

12.6.5.1 Card 203NNN40, Independent Variable Axis Specification. This card inputs the independent variable axis (x-axis) specification. The card is optional and may be omitted, in which case the default values will be set. If the card is input, the first two words are required, but up to five words of data may be input in the following format.

W1(R)	SPECIFIED X-AXIS MINIMUM OR MAXIMUM. Refer to W2(R).
W2(R)	SPECIFIED X-AXIS MAXIMUM OR MINIMUM. Input of W1(R) and W2(R) allows the user to define the independent variable (x) interval over which data is to be plotted. Hence, any comparison data point or RELAP5 result point will not be plotted if its corresponding independent variable point lies outside the interval XMIN $\leq$ x $\leq$ XMAX where XMIN in the minimum of W1(R) or W2(R) and XMAX in the maximum of W1(R) or W2(R). However, in the code, when the plot files are loaded, if it is found that the actual minimum x is >XMIN or the actual maximum x is <XMAX, then the corresponding user specification is reset to the actual minimum or maximum x, respectively. This is done to ensure maximum use of the plot space available. If the x-axis specification card is omitted, then XMIN and XMAX default to -1.0E+99 and +1.0E+99 respectively.
W3(I)	SPECIFIED NUMBER OF LABELED X-AXIS INTERVALS. (NDIVX). (Defaults to 5).
W4(I)	SPECIFIED NUMBER OF GRID SUBINTERVALS. (IXGRID). IXGRID is the number of grid subintervals per labeled interval. IXGRID is ignored if NOGRID is specified in the plot options. If IXGRID is omitted or input as 0 it defaults to 1 if a grid is specified in the plot options.

W5(A) X-AXIS TYPE KEYWORDS, LINEAR OR LOG. Defaults to LINEAR. (The LOG option has temporarily been disabled.)

XMIN specifies the independent variable minimum only if it is greater than or equal to the actual minimum of the data. Similarly, XMAX specifies the independent variable maximum only if it is less than or equal to the actual maximum of the data. If XMIN and XMAX satisfy these conditions then the curve will be plotted beginning at XMIN and ending at XMAX. However, the axis extremities must still be adjusted to the NDIVX and IXGRID specification.

The terms NDIVX and IXGRID specify the number of subintervals into which the axis is divided. The design criteria specify that these subintervals must be rounded to the first significant digit and that the axis must be spanned by as much of the data as possible. Therefore the axis extremities not only may be expanded but the number of labeled intervals specified by NDIVX may be reduced or increased to give an optimum axis.

The axis type keywords LINEAR or LOG specify that the axis is to be drawn as a linearly scaled or as a logarithmic (Base 10) scaled axis respectively. If the keyword is omitted the default is to LINEAR. If the keyword LOG has been specified and during the course of processing a plot data point is found to be zero or negative, an error message will be printed, the axis type will be reset to LINEAR, and the plot will be completed.

12.6.5.2 <u>Card 203NNN41, Dependent Variable Axis Specification</u>. This card inputs the dependent variable axis (y-axis) specification. The card is optional and may be omitted, in which case the default values will be set. If the card is input, the first two words are required, but up to five words of data may be input in the following format.

W1(R) SPECIFIED Y-AXIS MINIMUM OR MAXIMUM. Refer to W2(R).

W2(R) SPECIFIED Y-AXIS MAXIMUM OR MINIMUM. Input of W1(R) and W2(R) allows the user to define the dependent variable (*y*) interval within which data is to be plotted. By input of these two terms, the user is specifying the approximate y-axis extremities for the plot and any data point loaded for plotting must lie within the interval YMIN $\leq$ y < YMAX, where YMIN is the minimum of W1(R) or W2(R) and YMAX is the maximum of W1(R) or W2(R). However, in the code, when the plot files are loaded, if it is found that the actual minimum y is <YMIN or the actual maximum y is >YMAX then the corresponding user specification is reset to the actual minimum or maximum y, respectively. This is done to ensure that the plot contains all of the data points within the plot interval specifications. If the *y*-axis specification card is omitted then YMIN and YMAX default to -1.0E+99 and +1.0E+99 respectively.

W3(I) SPECIFIED NUMBER OF Y-AXIS INTERVALS. (NDIVY). (Defaults to 5).

W4(I) SPECIFIED NUMBER OF GRID SUBINTERVALS. (IYGRID). IYGRID is the number of grid subintervals per labeled interval. IYGRID is ignored if NOGRID is specified in the plot options. If IYGRID is omitted or input as 0 and a grid is specified in the plot options, then IYGRID defaults to 1.

W5(A) Y-AXIS TYPE KEYWORDS, LINEAR OR LOG. Defaults LINEAR. (The LOG option has temporarily been disabled.)

The rules that apply to the use of the dependent variable axis specifications are the same as those for the independent variable axis except for the terms YMIN and YMAX. To achieve an optimum plot design, all of the dependent variable data plotted must be included within the *y*-axis extremities. Therefore YMIN specifies the dependent variable minimum only if it is less than or equal to the actual minimum of the data. Similarly, YMAX specifies the dependent variable maximum only if it is greater than or equal to the actual maximum of the data.

12.6.6 Cards 203NNN50 through 203NNN59, Curve Drawing Specifications

These cards input the specifications for drawing each curve requested in a plot request (Cards 203NNN00 through 09). The sequence number of the card refers to the sequence number of the plot request for which the curve drawing specification is input. For example, 203NNN50 refers to the first plot request, 203NNN53 refers to the fourth plot request, etc. If a curve drawing specification refers to an undefined plot request an error will result. Any or all of the cards may be omitted, in which case appropriate defaults will be selected. The data entered on the cards specify a curve legend label, the type of line drawn for the curve, the type of symbol drawn for the curve, and the number of data points skipped between symbols. No provision is allowed for spline fitting or smoothing of calculational results. If only one curve is to be drawn the legend label is ignored and no legend is written on the plot. The data is input in the following format.

W1-W2(A) LEGEND LABEL. Defines the legend label and is composed of two alphanumeric words enclosed by quotation symbols (defaults to the variable code, parameter words described for the plot request Cards 203NNN00 through 09). If the legend label is entered it must be composed of sufficient characters for 2 words. The $ symbol may not be imbedded in the character string.

W3(A) CURVE LINE TYPE KEYWORD. Must be entered as one of the following.

LINE	A continuous line will be drawn connecting the data points.
DOTS	A dotted line will be drawn connecting the points.

DASHES	A dashed line will be drawn connecting the points.
CDOTS	A chain dotted line will be drawn connecting the points (The chain pattern is composed of a long dash followed by a space, a dot, and a space).
CDASHES	A chain dashed line will be drawn connecting the points (The pattern is composed of a long dash followed by a space, a short dash, and a space).

W4(I)	SYMBOL INDEX. Defines the plot symbol to be drawn at intervals of a specified number of data points. If W4 is omitted or input as 0 a symbol will not be drawn. However, if the line type keyword input for word W3 is NOLINE a default symbol will be selected. Similarly, if several curves are drawn with the same line specification, a default symbol will be selected. The symbol index is checked for each curve to be drawn. If a redundant symbol has been input an error message will be printed and the input symbol will be reset to the next available symbol.
W5(I)	NUMBER OF DATA POINT INTERVALS. Defines the number of data point intervals between plot symbols. The plot symbol defined by word W4 will be drawn at intervals of W5 data points. If W5 is omitted it will default to 5.

12.6.7 Cards 203NNN60 through 203NNN69, Plot Option Changes

These cards define changes to any or all of the general plot options input by cards 20300010 through 20300019. These changes will be in effect for only the NNN00 plot and the general plot options will remain in effect for all other plots. The input format for these cards is identical to that for the 20300010 through 20300019 cards.

12.6.8 Card 203NNN70, Plot Size Dimension Changes

This card defines changes to the general plot size dimensions input by Card 20300020. The changes will be in effect only for the NNN00 plot and the general plot size dimensions will remain in effect for all other plots. The input format for this card is identical to that for the 20300020 card.

12.7 Cards 204MMMLL, Plot Comparison Data Tables

These cards input tables of data that are to be plotted on the same graphs as RELAP5 results for visual comparison. Each set of cards defines the table dependent and independent variables and the format by which the data are input. The plot curve specifications for each table are also defined.

12.7.1 Card 204MMM00, Plot Comparison Data Table Request

This card inputs the variable code naming the plot comparison data table dependent variable, its corresponding units keyword and the two keywords defining the table data input format. The card is required in order to define a plot comparison data table. If the card is omitted and table specifications or data are entered, an error will result. The data input by the card are entered in the following format.

W1(A) TABLE DEPENDENT VARIABLE CODE (YNAME). YNAME is required and may not be omitted. The variable code is defined similarly to that for Cards 300 through 399 and 203NNN00 through 09, except that the keywords DELETE or DISCARD may also be entered. The variable code YNAME for a plot comparison data table must be identical to the variable code PARNAM for a plot request referencing the table or an error will result. For RESTART or PLOT jobs if the keyword DELETE or DISCARD is input as YNAME, the entire data table record will be deleted. If the user wishes to replace, insert, or add a plot comparison data table, the input is the same as for a NEW job. If keywords "DELETE" or "DISCARD" are input, no other cards may be input for the deleted record, or an error will result. If a plot request is deleted that references a plot comparison data table and if the plot comparison data table is not referenced by a remaining plot request, then an error will result.

W2(A) DEPENDENT VARIABLE UNITS KEYWORD. RELAP5 calculations are performed in SI units throughout the code. Therefore plot comparison data must be converted upon input to SI units for use by the code even though the units in which a plot is to be made may not be SI units. The units keywords allowed are described as follows. If omitted, the default is SI.

SI	(Default). The dependent variable data is input in SI units.
BRITISH	The dependent variable data is input in British units. The code will automatically correct the input to SI units.
SPECIAL	The dependent variable data is input in special units. For this card the coefficients for a units equation must be input on Cards 204MMM01 through 08 or an error will result.

W3(A) TABLE FORMAT SPECIFICATION KEYWORD. Enter one of the two table format specification keywords PAIRS or SETS. If PAIRS is entered the table data must be input as pairs of independent, dependent variables (or vice versa). If SETS is entered the table data must be input in complete sets of independent and dependent variables (or vice versa). Refer to the 204NNN20 through 99 cards for additional explanation. If W3 is omitted or input as " ", it defaults to PAIRS.

W(A) TABLE FORMAT SPECIFICATION KEYWORD. Enter one of the two table format specification keywords INDEPFIRST or DEPFIRST. If INDEPFIRST is entered the table data must be input with the independent variable occurring first. If DEPFIRST is entered the table data must be input with the dependent variable occurring first. Refer to the 204NNN20 through 99 cards for additional explanation. If W4 is omitted or input as " ", it defaults to INDEPFIRST.

12.7.2 Cards 204MMM01 through 204MMM08, Dependent Variable Units Conversion

These cards are required if SPECIAL is entered as W2 on Card 204NNN00. Each card inputs a unit conversion coefficient a(K), where the coefficient index K is implied by the card number 204NNN0K and where K ranges from 1 through 8. The units conversion equation is

$$\begin{aligned} Y(SI) = {} & a(8)*\ (a(1) + Y*\ a(2) + Y*[a(3) + Y*a(4)] \\ & + a(5)*Y**a(6) + a(7)*ALOG(Y))\ . \end{aligned}$$

Any of the cards may be omitted, in which case the omitted coefficient will default. However, at least one card must be input or an error will result. The coefficients default to the following values:

a(1)=0.0
a(2)=1.0
a(3) through a(5)=0.0
a(6)=1.0
a(7)=0.0
a(8)=1.0

Any value may be entered for a coefficient providing the following conditions are satisfied. At least one of the coefficients a(1) through a(5) or a(7) must be nonzero. The coefficient a(6) may not be entered as zero. Y may not be entered as zero if a(7) is nonzero. The coefficient a(8) may not be entered as zero. If any of these conditions is not satisfied an error will result.

12.7.3 Card 204NNN10, Table Independent Variable

This card inputs the variable code naming the plot comparison data table independent variable and its corresponding table units keyword. The card may be omitted, in which case the variable code will default to TIME and the units keyword will default to SI. The format for the data must be entered as follows.

W1(A) VARIABLE CODE FOR THE TABLE INDEPENDENT VARIABLE (XNAME). XNAME is the variable code for the table independent variable. The variable code is defined similarly to that for Cards 300 through 399 and 203NNN10. The variable code XNAME must be identical to the variable code XARNAM for a plot request referencing the table or an error will result (XNAME defaults to the variable code TIME).

W2(A) TABLE INDEPENDENT VARIABLE UNITS KEYWORD. Enter a units keyword defining the units of the table independent variable input data. The keywords and the rules for entering them are identical to those for Word W2 of Card 204MMM00. If the keyword entered is SPECIAL, then the appropriate units coefficient cards 204MMM11 through 18 must be entered as described for Cards 204MMM01 through 08.

12.7.4 Cards 204MMM11 through 204MMM18, Independent Variable Units Conversion

These cards are required if SPECIAL is entered as Word W2 on Card 204MMM10. Each card inputs a unit conversion coefficient b(K) where the coefficient index K is implied by the card number 204MMM1K and where K ranges from 1 through 8. The units conversion equation is

```
X(SI) = b(8)*(b(1) + X* b(2) + X*[b(3) + X*b(4)]
        + b(5)*X**b(6) + b(7)*ALOG(X))  .
```

The rules applying to the b and X terms are the same as those explained for the a and Y terms for Cards 204MMM01 through 08.

12.7.5 Card 204NNN19, Data Curve Specification

This card is optional and the data entered are similar to that explained for the 203NNN40 card, except that a SPLINE option is included for smoothing of the curve drawn for the table data. The data is input in the following format.

W1-W2(A) LEGEND LABEL. Defines the legend label and is composed of two alphanumeric words enclosed by quotation symbols (defaults to YNAME as entered on the 204MMM00 card and the table number MMM00 encoded together). If the legend label is entered, it must be composed of sufficient characters for 2 words.

W3(A) CURVE LINE TYPE KEYWORD. Must be entered as one of the following:

NOLINE	No line will be drawn connecting the data points. This automatically requires that a plot symbol is drawn at each data point. To define the plot symbol refer to word W4.
LINE	A continuous line will be drawn connecting the data points.
DOTS	A dotted line will be drawn connecting the points.
DASHES	A dashed line will be drawn connecting the points.
CDOTS	A chain dotted line will be drawn connecting the points (The chain pattern is composed of a long dash followed by a space, a dot, and a space).

CDASHES A chain dashed line will be drawn connecting the points (The pattern is composed of a long dash followed by a space, a short dash, and a space).

W4(I) SYMBOL INDEX. Defines the plot symbol to be drawn at intervals of a specified number of data points. If W4 is omitted or input as 0, a symbol will not be drawn. If the line type keyword input for word W3 is NOLINE a default symbol will be selected. Similarly, if several curves are drawn with the same line specification a default symbol will be selected. The symbol index is checked for each curve to be drawn. If a redundant symbol has been input, an error message will be printed and the input symbol will be reset to the next available symbol.

W5(I) NUMBER OF DATA POINT INTERVALS. Defines the number of data point intervals between plot symbols. The plot symbol defined by word W4 will be drawn at intervals of W5 data points. If W5 is omitted, it will default to 5. However, if the line type keyword input for Word W3 is NOLINE, then W5 is set to 1 unconditionally.

W6(A) SPLINE INTERPOLATION KEYWORD. The keywords that may be entered are SPLINE and NOSPLINE. If W6 is omitted or input as " " it will default to NOSPLINE and the curve will be drawn with straignt line segments connecting each data point. If W6 is entered as the keyword SPLINE, the curve will be drawn as a smooth continuous curve by means of spline interpolation between data points. If W6 is entered as any word other than SPLINE or NOSPLINE an error will result.

12.7.6 Cards 204MMM20 through 204MMM99, Plot Comparison Data Table Input Data

These cards contain the plot comparison data and are required if a 204MMM00 card is input. Storage has been allocated for up to 4000 data points. The same number of independent and dependent variable data points must be entered or an error will result. The order of the card numbering sequence determines the order in which the independent variables are plotted. The cards need not be numbered successively and need not be input in the order in which the code will sort them. If more than one independent variable is entered per card, the independent variables must be entered in the order in which they are to be plotted. The dependent variable data points must be entered in a one-to-one correspondence order with the independent variable data. If more than 80 cards are required to input the data, continuation cards may be used.

The format for entering the data is defined by Words W3 and W4 on the 204MMM00 card. For example, if word W3 is PAIRS and word W4 is INDEPFIRST, then the data must be entered as an independent-dependent variable pair followed by the next independent-dependent variable pair, etc. If word W3 is SETS and word W4 is DEPFIRST, then the data must be entered as the entire set of dependent variable data followed by the entire set of independent variables. If the number of dependent variables entered is not equal to the number of independent variables, an error will result.

13. 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 (see Section 2.9). 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. The card format 205CCCNN allows 999 control variables where CCCC ranges from 001 through 999. The card format 205CCCCN allows 4095 control variables where CCCC ranges from 1 through 4095.

If the self-initialization option is selected, the data cards described in Sections 13.2, 13.3.19, and 13.3.20 must be included. If loop flow control is to be included, the data cards described in Section 13.3.18 must also be included.

13.1 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 4095 to select the 205CCCCN format.

13.2 Card 205NNN00 or 205NNNN0, 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 Cray, Cyber 205, and IBM 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, PUMPCTL, STEAMCTL, FEEDCTL or SHAFT, 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, and no additional words are entered on this card and cards 205NNN01 through 205NNN09 or 205NNNN1 through 205NNNN9 are not entered. For the PUMPCTL, STEAMCTL, or FEEDCTL components this is the gain multiplier (G) for the output signal as described in Section 4.4.5 of Volume 1.
W4(R)	INITIAL VALUE.
W5(I)	INITIAL VALUE FLAG. 0 means no initial condition calculation and W4 is used as the initial condition; 1 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.

13.3 Cards 205NNN01 through 205NNN98 or 205NNNN1 through 205NNNN8, 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 205NNN00 or 205NNNN0. The variables V_j use the code's internal units (SI). In order to use British units, the user must convert from SI to British using the scale factor S and the constants A_j.

13.3.1 Sum-difference Component

This component is indicated by SUM in Word 2 of Card 205NNN00 or 205NNNN0. The sum-difference component is defined by

$$Y = S*(A_0 + A_1*V_1 + A_2*V_2 + . . . + A_J*V_J)$$

W1(R) CONSTANT A_0.

W2(R) CONSTANT A_1.

W3(A) ALPHANUMERIC PART OF VARIABLE REQUEST CODE FOR V_1.

W4(I) NUMERIC PART 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 2-4 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.

13.3.2 Multiplier Component

This component is indicated by MULT in Word 2 of Card 205NNN00 or 205NNNN0. The multiplier component is defined by

$$Y = S V_1 V_2 \ . \ . \ . \ V_J$$

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART 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.

13.3.3 Divide Component

This component is indicated by DIV in Word 2 of Card 205NNN00 or 205NNNN0. The divide component is defined by

$$Y = S/V_1 \text{ or } Y = S V_2/V_1.$$

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 PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_2.

W4(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_2.

13.3.4 Differentiating Components

These components are indicated by DIFFRENI or DIFFREND in Word 2 of Card 205NNN00 or 205NNNN0. The differentiating component is defined by

$$Y = \frac{SdV_1}{dt} \quad .$$

This is evaluated by

$$Y = S*[2(V1 - V1o)/\Delta t] - Yo \qquad \text{(DIFFRENI)}.$$

$$Y = S*(V1 - V1o)/\Delta t \qquad \text{(DIFFREND)}$$

where Δt is the time step, and V1o and Yo 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 which is less accurate, is not consistent with the integration approximation, but does not require an initial value. Use of DIFFRENI is not recommended.

Since differentiation, especially numerical differentiation, can introduce <u>noise</u> 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 part of variable request code for V1.

W2(I) Integer part of variable request code for V1.

13.3.5 Integrating Component

This component is indicated by INTEGRAL in Word 2 of Card 205NNN00. The integrating component is defined by

$$S\int_0^t V_1 dt$$

or in Laplace notation

$$Y(s) = \frac{SV_1(s)}{s}$$

This is evaluated by

$$Y = Y_o + S*(V_1 + V_{1o})*\Delta t/2$$

where Δt is the time step and Y_o and V_{1o} are values at the beginning of the time step.

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

13.3.6 Functional Component

This component is indicated by FUNCTION in Word 2 of Card 205NNN00 or 205NNNN0. 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 PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(I) GENERAL TABLE NUMBER OF THE FUNCTION.

13.3.7 Standard Function Component

This component is indicated by STDFNCTN in Word 2 of Card 205NNN00 or 205NNNN0. 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 PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

13.3.8 Delay Component

This component is indicated by DELAY in Word 2 of Card 205NNN00 or 205NNNN0. The component is defined by

$Y = S\ V_1(T - T_D)$

where T is time and T_D is the delay time.

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART 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 $\leq$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 values replace values that are older than the delay time. There are no restrictions on T_D or D_{TM} relative to the time steps on Cards 2NN.

13.3.9 Unit Trip Component

This component is indicated by TRIPUNIT in Word 2 of Card 205NNN00 or 205NNNN0. 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, T_1. A minus sign may prefix the trip number to indicate that the complement of the trip is to be used.

13.3.10 Trip Delay Component

This component is indicated by TRIPDLAY in Word 2 of Card 205NNN00 or 205NNNN0. The component is defined by

$$Y = S\ T_{RPTIM}(T_1)$$

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.

13.3.11 Integer Power Component

This component is indicated by POWERI in Word 2 of Card 205NNN00 or 205NNNN0. The component is defined by

$$Y = SV_1^{I_1} \quad .$$

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(I) I_1.

13.3.12 Real Power Component

This component is indicated by POWERR in Word 2 of Card 205NNN00 or 205NNNN0. The component is defined by

$$Y = SV_1^{R_1} \quad .$$

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(R) R_1.

13.3.13 Variable Power Component

This component is indicated by POWERX in Word 2 of Card 205NNN00 or 205NNNN0. The component is defined by

$$Y = SV_1^{V_2}$$

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_2.

W4(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_2.

13.3.14 Proportional-Integral Component

This component is indicated by PROP-INT in Word 2 of Card 205NNN00 or 205NNNN0. 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,

$$Y(s) = S\left[A_1 + \frac{A_2}{s}\ V_1(s)\right] .$$

If the control variable is initialized,

$$Y(t_o) = SA_1 V_1(t_o) \quad .$$

W1(R) A_1.

W2(R) A_2.

W3(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W4(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

13.3.15 Lag Component

This component is indicated by LAG in Word 2 of Card 205NNN00 or 205NNNN0. This component is defined by

$$Y = \int_0^t \frac{(SV_1 - Y)}{A_1} dt$$

or in Laplace transform notation,

$$Y (s) = S\left(\frac{1}{1 + A_1 s}\right) V_1(s)$$

If the control variable is initialized,

$$Y(t_o) = SV_1 (t_o) \quad .$$

W1(R) LAG TIME, A_1 (s).

W2(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W3(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

13.3.16 Lead-Lag Component

This component is indicated by LEAD-LAG in Word 2 of Card 205NNN00 or 205NNNN0. The component is defined by

$$Y = \frac{A_1\ SV_1}{A_2} + \int_0^t \frac{(SV_1 - Y)}{A_2}\, dt$$

or in Laplace transform notation,

$$Y(s) = S\left(\frac{1 + A_1 s}{1 + A_2 s}\right) V_1(s) \quad .$$

If the control variable is initialized,

$$Y(t_o) = SV_1\ (t_o) \quad .$$

W1(R) LEAD TIME, A_1 (s).

W2(R) LAG TIME, A_2 (s).

W3(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_1.

W4(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_1.

13.3.17 Shaft Component

This component is indicated by SHAFT in Word 2 of Card 205NNN00 or 205NNNN0. A GENERATR component may optionally be associated with a SHAFT component. The SHAFT component advances the rotational velocity equation

$$\sum_i I_i \frac{d\omega}{dt} = \sum_i \tau_i - \sum_i f_i\omega + \gamma_c$$

where I_i is 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 γ_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 205NNN00 or 205NNNN0 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.

13.3.17.1 Card 205NNN01 through 205NNN05 or 205NNNN1 through 205NNNN5, Shaft Description Card

W1(I) TORQUE CONTROL VARIABLE NUMBER. If 0, 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-m^2, lb-ft^2).

W3(R) FRICTION FACTOR FOR THE SHAFT, f_i • (N-m-s, lb_f-ft-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.

13.3.17.2 Card 205NNN06 or 205NNNN6, 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 • ($kg\text{-}m^2$, $lb\text{-}ft^2$).

W4(R) FRICTION FACTOR, f_i • (N-m-s, lb_f-ft-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.

13.3.18 PUMPCTL Component

This component is specified when using the self-initialization option and loop flow control is desired (see Section 4.4.5.1 of Volume 1). 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. Must be nonzero.

W6(R) Integral part time constant (T_2) (sec).

W7(R) Proportional part time constant (T_1) (sec).

Note: Standard use of the PUMPCTL controller would require the following interpretation of the input data (refer to Section 4.4.5.1 of Volume 1). W1 and W2 would contain CNTRLVAR and NNN respectively, where NNN is a CONSTANT-type control element containing the desired (setpoint) flowrate. W3 would be MFLOWJ and W4 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 flowrate to produce the error signal (E_1). W6 and W7 are the T_2 and T_1 values respectively, described in Section 4.4.5.1 of Volume 1. (See guidelines in Appendix C, Section 8.) All variables having units must be in SI units.

13.3.19 STEAMCTL Component

This component is specified when using the self-initialization option to control steam flow from one or more steam generators. Input data requirements are identical to the PUMPCTL controller, with the following interpretation of the input values for standard use (refer to Section 4.4.5.2 of Volume 1). W1 and W2 would contain CNTRLVAR and NNN respectively where NNN 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 to be 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). W6 and W7 are the T_4 and T_3 values respectively, described in Section 4.4.5.2 of Volume 1 (See guidelines in Appendix C, Section 8.) All variables having units must be in SI units.

13.3.20 FEEDCTL Component

This component is specified when using the self-initialization option to control feedwater flow to a steam generator. 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).
W6(A)	Alphanumeric name of second setpoint variable.
W7(I)	Parameter part of sensed 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).
W11(R)	Integral part time constant (sec).
W12(R)	Proportional part time constant (sec).

Note: Standard use of the FEEDCTL controller would require the following interpretation of the input data (refer to Section 4.4.5.3 of Volume 1). W1 and W2 would contain CNTRLVAR and NNN respectively where NNN 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 would be SUM and W4 the component number 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 would be MFLOWJ and W7 the junction number of the steam exit junction from the steam generator. W8 would be MFLOWJ and W9 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). W11 and W12 are the T_6 and T_5 values respectively, described in Section 4.4.5.3 of Volume 1. (See guidelines in Appendix C, Section 8.) All variables having units must be in SI units.

14. 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 RSTPLT (strip) file in the order of increasing card numbers.

W1(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE.

W2(I) INTEGER PART OF THE VARIABLE REQUEST CODE.

15. RELAP5 OPERATING PROCEDURES

Operating procedures have been written using CDC Cyber Control Language to simplify the execution of the RELAP5 computer program. The following procedures reflect the operating philosophy at the INEL. Other installations may choose to define comparable procedures.

Two series of RELAP5 are typically maintained. The first series, called the RELAP5 series, contains publically released versions, modified versions of the publically released version containing only error corrections and no model additions, and recently developed versions considered sufficiently reliable for production use. The second series is called the XELAP5 series and contains versions under development. Each series may have one or more versions. For the RELAP5 series, the higher version number is more reliable, and the lower numbered versions are retained only to permit completion of parameter studies without switching versions. Because of the developmental nature of the XELAP5 series, the higher versions generally have more modeling capability but are not always more reliable. Production work with the XELAP5 series should only be done with close contact with the development staff.

Each version has three files: RELAP5S, the source file in UPDATE OLDPL format; RELAP5L, object decks in library format; and RELAP5X, and absolute binary. Several input data decks are maintained in a file RELAP5D. The version number of RELAP5D does not match the other files since the data are changed infrequently. The XELAP5 series has similar files, XELAP5S, XELAP5L, XELAP5X, and XELAP5D.

Two procedures are provided. One executes RELAP5 from an absolute binary; the other executes RELAP5 after updating, compiling, and loading the program. The procedures optionally issue a message block, stating the availability and status of various versions of RELAP5.

Before the first use of a procedure, the file containing the procedures must be attached by

```
GET,PROCS=RPROCS/UN=RL5.
```

Each procedure is called by

```
BEGIN,proc,PROCS,parameters.
```

where proc is the procedure name and parameters indicates that one or more parameters separated by commas and terminated by a period are entered to specify the options.

The procedure, RLP5X, executes from an absolute binary file and the procedure, RLP5CLX, updates, compiles, loads, and executes from the generated absolute binary file. Many of the parameters are common to both procedures; those unique to a procedure are so indicated. No options are provided for the RSTIN, RSTPLT, and PLFILE files. Appropriate REQUEST, DEFINE, and RETURN statements should be placed before and after the procedure call (BEGIN) statement as required. All other files are attached and returned as needed. These procedures can be used in batch jobs or interactively.

NOMESSG or not entered.

If not entered, information describing sthe tatus of available RELAP5 versions is printed. If entered, the status information is not printed.

X, X=Z, or not entered.

Either user specified on the default files, RELAP5S, RELAP5L, RELAP5X, RELAP5D, XELAP5S, etc., can be selected. If a default file is selected (SPFN=, LPFN=, or XPFN= not used), X not entered means that a RELAP5 file is used, entering X means that a XELAP5 file is used, and entering X=Z means that a file formed by concatenating the character string Z to ELAP5 is used. Thus X=Z leads to ZELAP5 and X=ZZ leads to ZZELAP5 (During development of RELAP5, some developmental versions are temporarily maintained for special use or testing. Naming these versions ZELAP5, VELAP5, etc., allows the convenient use of X=Z, X=V, etc. to access the versions).

PW=Password or not entered.

Some versions of RELAP5 require a password for access. Enter the password if required.

SPFN=sfile or not entered

SID=sname or not entered

SCY=snum or not entered.

These parameters are used for RLP5CLX only and specify the source file. If SPFN is not entered, the default source file is used. If SPFN is entered, sfile is the permanent file name of the source file and sname is the ID. If SCY is missing, the most recent version is used; if entered, version snum is used.

SUPFN=ufile or not entered

SUID=uname or not entered

SUCY=unum or not entered.

SUPW=upw or not entered.

These parameters are used only in RLP5CLX. If SUPFN is not entered, the input file for the update is the file INPUT. If SUPFN is entered, ufile is the permanent file name and SUID is the ID of a permanent file containing the update input. If SUCY is not entered, the most recent version is used; if entered, unum is the cycle number. Enter SUPW=upw where upw is the appropriate read password.

NOFTN or not entered.

This parameter is used for RLP5CLX only and if entered, specifies that the UPDATE did not generate any FORTRAN statements to be compiled. The procedure assumes that the update issues the segload directives.

FLIST, FLIST = $LO = option$, or not entered.

This parameter is used for RLP5CLX only and specifies the FORTRAN listing options. If not entered, LO=0 is used; if FLIST is entered, LO=A/M/R/S is used. As shown, a specification can be entered and it must be enclosed in "$".

CLEAN or not entered.

This parameter is used for RLP5CLX only. If this parameter is not entered, the FORTRAN listing shows all versions with all option selection statements (*IF and *ENDIF) shown and FORTRAN statements for nonselected options having a * in Column 1 (thus a comment card). If this parameter is entered, no option selection statements are shown and only FORTRAN statements for the selected version are listed.

LPFN, LPFN=lfile, or not entered

LID = lname or not entered

LCY = lnum or not entered.

These parameters are used for RLP5CLX only and specify the object deck library file. If LPFN is not entered, no object library file is used. If LPFN is entered, the default library file is used. If LPFN=lfile is entered, lfile is the permanent file name and lname is the ID of the object library file. If LCY is not entered, the highest cycle is used; if entered, cycle lnum is used.

EDLIB

Entering this parameter causes LIBEDIT to be called to form a temporary new library from the library specified by LPFN and the object decks from compilation. Loading to create the executable file does not load the newly compiled objects directly but obtains all RELAP5 object decks from the temporary library. The LIBEDIT step takes more computer time but is necessary when the updates cause compilation of subroutines stored in the RELAP5 source file but not invoked in the current version (such as modifying COMDECKS). These subroutines, if loaded but not properly placed by SEGLOAD directives, can cause execution failures, By loading from the temporary library, only needed subroutines are loaded. In particular, if a loader diagnostic message is printed which says that a segment is being loaded by a nonexecutable trend, the parameter should be used.

LMAP, LMAP=SBEX, or not entered.

This parameter specifies the load map options. If not entered, the map options are the standard, SB; if LMAP is entered, no load map is generated. As shown, other map options can be specified.

EPFN=efile, or not entered

ECY=enum or not entered

EID=ename or not entered.

These parameters are used for RLP5CLX only and specify the environmental library. The default is ENVRL/UN=RL5 and the most recent version.

XPFN, XPFN=xfile or not entered

XID=xname or not entered

XCY=xnum or not entered.

These parameters are used in the RLP5X and RLP5CLX procedures and specify the absolute binary file. The use is somewhat different in the two procedures. For RLP5X: If not entered, the default file is used. If entered, the absolute binary file is the permanent file with permanent file name xfile and UN=XID. If XCY is not entered, the most recent version is used; if entered, xnum is the version number. For RLP5CLX: If not entered, the absolute binary file created during the load is not saved by a DEFINE statement. If entered, the absolute binary file is saved by a DEFINE statement using the XPFN and XID parameters for the permanent file name and UN.

DPFN, DPFN=dfile, or not entered

DID=dname or not entered

DCY=dnum or not entered

DPW=dpw or not entered.

These parameters specify the input data file. If DPFN is not entered, the input data to RELAP5 is on the file INPUT and the DUPFN parameter is not tested. If DPFN is entered, the default file is RELAP5D. If DPFN=dfile is entered, dfile is the permanent file name, and dname is the UN of a permanent file to be used as an input file. The file is treated as direct input to RELAP5 or as an UPDATE format file depending on the DUPFN entry. If DCY is not entered, the highest cycle is used; if entered, dnum is the version number. If the file is read password protected, enter DPW=dpw where dpw is the appropriate read password.

DUPFN, DUPFN=dufile, or not entered

DUID=duname, or not entered

DUCY=dunum, or not entered

DUPW=dupw or not entered.

These parameters specify the UPDATE input to extract RELAP5 input from an update file. They are effective only if some entry for DPFN is made. If DUPFN is not entered, the file DPFN is not in UPDATE format and contains input for RELAP5. If DUPFN is entered, DPFN is in UPDATE format and the file INPUT contains input to UPDATE to generate the input file. If DUPFN=dufile is entered, dufile is the permanent file name and DUID is the UN of a permanent file containing input for UPDATE to generate the input data for RELAP5. If DUCY is not entered, the most recent version is used. If entered dunum is the version number. If the file is read password protected, enter DUPW=dupw where dupw is the appropriate read password. The input consists of 90 column records, the first 80 columns contains the RELAP5 input, the last 10 columns contain the UPDATE line number. RELAP5 input processing reads and edits 90 columns but processes only 80 columns.

WPPFN=wpfile or not entered

WPID=wpname or not entered

WPCY=wpnum or not entered.

These parameters specify the water property file. If not entered the default file of STH2XT/UN=RL5 (most recent version number) is used. If entered, the permanent file with permanent file name wpfile and UN=wpname is used. IF WPCY is not entered, the most recent version is used; if entered, wpnum is the version number.

PL=plimit or not entered.

This parameter sets the RELAP5 execution print line limit. If not entered, the default limit is 20,000 lines. If entered, plimit is the line limit.

SCM=nnnnnn

LCM=mmm.

These parameters specify the maximum memory to be used. If not entered, the default values of SCM=270000 and LCM=200 are used.

DMP1=$L1,L2$

DMP2=$L1,L2$

DMP3=$L1,L2$.

Enter these parameters [illegible]) to three different parts of memory are to be dumped after an abnormal termination. Use DMP1 if only one part of memory is to be dumped, use DMP1 and DMP2 if two parts are to be dumped, etc. Substitute the first and last words of memory to be dumped for L1 and L2.

SV=nn

SVT=symname

These parameters are used when creating a new version. When SV=nn is entered, a new program library RL36nnS, a new RELAP5 object deck library RL36nnL, and a new absolute library (executable) RL36nnX are created. When SV=nn is entered, EDLIB must also be specified. Entering SVT=symname causes a backup tape containing the RELAP5 source OLDPL, environmental source OLDPL, and the sample problem OLDPL to be written with symname being the tape symbolic name under the TRS (tape reservation system). SV=nn must also be specified when SVT is entered.

The control statements to execute the most recent version of the production series of RELAP5 from input data entered with the job are:

```
BEGIN,RLP5X,PROCS.
*EOR
RELAP5 input data.
```

The control statements to execute the most recent version of the production series of RELAP5 from input data stored as permanent file MYDATA/UN=RL5 are:

```
BEGIN,RLP5X,PROCS,DPFN=MYDATA,DID=RL5.
```

The control statements to modify the most recent version of the experimental series of RELAP5 with updates from permanent file XLP5U15/, UN=RL5 and execute EDHTRK problem from the standard input data file are:

```
BEGIN,RLP5CLX,PROCS,X,SUPFN=XLP5U15,SUID=RL5,LPFN,

DPFN,DUPFN.
*EOR
*COMPILE EDHTRK.
```

APPENDIX B

EXAMPLE OF A DIAGNOSTIC EDIT

APPENDIX B

EXAMPLE OF A DIAGNOSTIC EDIT

This appendix contains an example (Figure B-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 Subsection 2.4 of Volume 1 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.

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 (labeled TIMEHY), the time step size (labeled DT), the total attempted advancements (labeled NCOUNT), and the value of the variables HELP, SUCCES, and FAIL. HELP is explained in Subsection 8.3.4 of this volume of the 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 (labeled F) until the code fails, and then it becomes true (labeled T).

The order of the subroutines in the diagnostic edit printed in Figure B-1 is as follows:

Heat Transfer subroutines (HTRC1 + appropriate correlation subroutine)
VALVE
VOLVEL
PHAINT

FWDRAG
VEXPLT
JCHOKE
JPROP (ICHOKE = 1)
PRESEQ
SYSSOL
JPROP (ICHOKE = 1)
VFINL
EQFINL
STATE (CHECK = 1)
Mass Error (in STATE (CHECK = 1))
JPROP (ICHOKE = 0)
VLVELA

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 the index I followed by either the volume number (labeled VOLNO) or the junction number (labeled JUNNO). The definition of many of these volume and junction terms indexed by I are listed in the comment common blocks VOLDATC and JUNDATC in the main program RELAP5. A copy of these blocks is contained in Figures B-2 and B-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.

```
RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                         85/08/01.                                     PAGE      27

 HTRC1 INITIAL :     ID =        30001    VOLNO =    3010000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
  5.021830E+02   7.620002E-02   4.902718E-02   7.000000E+06   5.589400E+02   5.589400E+02    .000000E+00   1.000000E-03
  DITTUS - TF                 THCONS            VISCS              CPS
             5.021830E+02   6.356293E-01   1.176840E-04   4.640751E+03
             HTCOEF         QFLUXO
             1.410267E+01   3.159250E-06
HTRC1 FINAL OUTPUT: CHF=    .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

 HTRC1 INITIAL :     ID =        30002    VOLNO =    3020000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
  5.021830E+02   7.620002E-02   4.902718E-02   7.000000E+06   5.589400E+02   5.589400E+02    .000000E+00   1.000000E-03
  DITTUS - TF                 THCONS            VISCS              CPS
             5.021830E+02   6.356293E-01   1.176840E-04   4.640751E+03
             HTCOEF         QFLUXO
             1.410267E+01   3.159250E-06
HTRC1 FINAL OUTPUT: CHF=    .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

 HTRC1 INITIAL :     ID =        30003    VOLNO =    3030000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
  5.021830E+02   7.620002E-02   4.902718E-02   7.000000E+06   5.589400E+02   5.589400E+02    .000000E+00   1.000000E-03
  DITTUS - TF                 THCONS            VISCS              CPS
             5.021830E+02   6.356293E-01   1.176840E-04   4.640751E+03
             HTCOEF         QFLUXO
             1.410267E+01   3.159250E-06
HTRC1 FINAL OUTPUT: CHF=    .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

 HTRC1 INITIAL :     ID =        30004    VOLNO =    3040000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
  5.021830E+02   7.620002E-02   4.902718E-02   7.000000E+06   5.589400E+02   5.589400E+02    .000000E+00   1.000000E-03
  DITTUS - TF                 THCONS            VISCS              CPS
             5.021830E+02   6.356293E-01   1.176840E-04   4.640751E+03
             HTCOEF         QFLUXO
             1.410267E+01   3.159250E-06
HTRC1 FINAL OUTPUT: CHF=    .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

 HTRC1 INITIAL :     ID =        30005    VOLNO =    3050000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
  5.021830E+02   7.620002E-02   4.902718E-02   7.000000E+06   5.589400E+02   5.589400E+02    .000000E+00   1.000000E-03
  DITTUS - TF                 THCONS            VISCS              CPS
             5.021830E+02   6.356293E-01   1.176840E-04   4.640751E+03
             HTCOEF         QFLUXO
             1.410267E+01   3.159250E-06
HTRC1 FINAL OUTPUT: CHF=    .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

 HTRC1 INITIAL :     ID =        30006    VOLNO =    3060000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
  5.021830E+02   7.620002E-02   4.902718E-02   7.000000E+06   5.589400E+02   5.589400E+02    .000000E+00   1.000000E-03
  DITTUS - TF                 THCONS            VISCS              CPS
             5.021830E+02   6.356293E-01   1.176840E-04   4.640751E+03
             HTCOEF         QFLUXO
             1.410267E+01   3.159250E-06
HTRC1 FINAL OUTPUT: CHF=    .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

 HTRC1 INITIAL :     ID =        30007    VOLNO =    3070000     IVERT =   0
   TW              HTDIAM            HTAREA             P                TSAT              SATT              VOIDG             G
```

Fig. B-1.   Diagnostic edit from Edwards Pipe Problem with extras.

```
RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                    85/08/01.                                    PAGE      28
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E 02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS        VISCS         CPS
               5.021830E+02  6.356293E-01  1.176340E-04  4.640751E+03
               HTCOEF        QFLUXO
               1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-05 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

  HTRC1 INITIAL :     ID =      30008    VOLNO =     3080000    IVERT =  0
   TW            HTDIAM        HTAREA        P             TSAT          SATT          VOIDG         G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS        VISCS         CPS
               5.021830E+02  6.356293E-01  1.176340E-04  4.640751E+03
               HTCOEF        QFLUXO
               1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

  HTRC1 INITIAL :     ID =      30009    VOLNO =     3090000    IVERT =  0
   TW            HTDIAM        HTAREA        P             TSAT          SATT          VOIDG         G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS        VISCS         CPS
               5.021830E+02  6.356293E-01  1.176340E-04  4.640751E+03
               HTCOEF        QFLUXO
               1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-05 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

  HTRC1 INITIAL :     ID =      30010    VOLNO =     3100000    IVERT =  0
   TW            HTDIAM        HTAREA        P             TSAT          SATT          VOIDG         G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS        VISCS         CPS
               5.021830E+02  6.356293E-01  1.176340E-04  4.640751E+03
               HTCOEF        QFLUXO
               1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

  HTRC1 INITIAL :     ID =      30011    VOLNO =     3110000    IVERT =  0
   TW            HTDIAM        HTAREA        P             TSAT          SATT          VOIDG         G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS        VISCS         CPS
               5.021830E+02  6.356293E-01  1.176340E-04  4.640751E+03
               HTCOEF        QFLUXO
               1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2

  HTRC1 INITIAL :     ID =      30012    VOLNO =     3120000    IVERT =  0
   TW            HTDIAM        HTAREA        P             TSAT          SATT          VOIDG         G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS        VISCS         CPS
               5.021830E+02  6.356293E-01  1.176340E-04  4.640751E+03
               HTCOEF        QFLUXO
               1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=   .00000E+00 GAMW=   .00000E+00 MODE=  2
```

Fig. B-1 Continued.

```
RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                  85/08/01.                         PAGE      29

 HTRC1 INITIAL :    ID =      30013   VOLNO =    3130000    IVERT =  0
   TW          HTDIAM          HTAREA          P              TSAT           SATT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS          VISCS           CPS
           5.021830E+02  6.356293E-01  1.176840E-04  4.640751E+03
           HTCOEF        QFLUXO
           1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

 HTRC1 INITIAL :    ID =      30014   VOLNO =    3140000    IVERT =  0
   TW          HTDIAM          HTAREA          P              TSAT           SATT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS          VISCS           CPS
           5.021830E+02  6.356293E-01  1.176840E-04  4.640751E+03
           HTCOEF        QFLUXO
           1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

 HTRC1 INITIAL :    ID =      30015   VOLNO =    3150000    IVERT =  0
   TW          HTDIAM          HTAREA          P              TSAT           SATT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS          VISCS           CPS
           5.021830E+02  6.356293E-01  1.176840E-04  4.640751E+03
           HTCOEF        QFLUXO
           1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

 HTRC1 INITIAL :    ID =      30016   VOLNO =    3160000    IVERT =  0
   TW          HTDIAM          HTAREA          P              TSAT           SATT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS          VISCS           CPS
           5.021830E+02  6.356293E-01  1.176840E-04  4.640751E+03
           HTCOEF        QFLUXO
           1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

 HTRC1 INITIAL :    ID =      30017   VOLNO =    3170000    IVERT =  0
   TW          HTDIAM          HTAREA          P              TSAT           SATT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS          VISCS           CPS
           5.021830E+02  6.356293E-01  1.176840E-04  4.640751E+03
           HTCOEF        QFLUXO
           1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=   .00000E+00 QO= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

 HTRC1 INITIAL :    ID =      30018   VOLNO =    3180000    IVERT =  0
   TW          HTDIAM          HTAREA          P              TSAT           SATT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
   DITTUS - TF                 THCONS          VISCS           CPS
           5.021830E+02  6.356293E-01  1.176840E-04  4.640751E+03
           HTCOEF        QFLUXO
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Fig. B-1 Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                   85/08/01.                          PAGE      30

              1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=  .00000E+00 QD= 3.15925E-05 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

  HTRC1 INITIAL :    ID =      30019   VOLNO =    3190000    IVERT =  0
    TW             HTDIAM           HTAREA           P               TSAT             SAIT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
    DITTUS - TF                THCONS          VISCS          CPS
              5.021830E+02  6.356293E-01  1.176940E-04  4.640751E+03
              HTCOEF        QFLUXO
              1.410267E+01  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=  .00000E+00 QD= 3.15925E-06 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2

  HTRC1 INITIAL :    ID =      30020   VOLNO =    3200000    IVERT =  0
    TW             HTDIAM           HTAREA           P               TSAT             SAIT            VOIDG           G
   5.021830E+02  7.620002E-02  4.902718E-02  7.000000E+06  5.589400E+02  5.589400E+02   .000000E+00  1.000000E-03
    DITTUS - TF                THCONS          VISCS          CPS
              5.021830E+02  6.356293E-01  1.176940E-04  4.640751E+03
              HTCOEF        QFLUXO
              1.410267E'  .  3.159250E-06
 HTRC1 FINAL OUTPUT: CHF=  .00000E+00 QD= 3.15925E-05 HTC= 1.41027E+01  TCHF= 5.59940E+02 QFGO=  .00000E+00 GAMW=  .00000E+00 MODE=  2
#########################################################################################################################################
VALVE       DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =              1, HELP =  3, SUCCES =  0, FAIL = F

NO VALVE COMPONENTS ARE DEFINED, NOVLV = T

#########################################################################################################################################
VOLVEL      DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =              1, HELP =  3, SUCCES =  0, FAIL = F
TRACEBACK INITIATED BY VOLVEL AT LINE 376, REL(ABS) ADDRESS 267(150240).
CALLED BY HYDRO AT LINE 52, ADDRESS 7(123603) WITH NO AP-LIST.
CALLED BY TRAN AT LINE 76, ADDRESS 54(161233) WITH NO AP-LIST.
CALLED BY TRNCTL AT LINE 22, ADDRESS 7(46512) WITH NO AP-LIST.
CALLED BY RELAP5 AT LINE 1445, ADDRESS 3745(10563) WITH NO AP-LIST.

VOLUME INLET AND OUTLET TERMS
------------------------------------------------------------------------------------------------------------------------------------
I       VOLNO(I)        L      J      K       AVOL(I)
        JUNNO(JX)       FLAG   LOOP   JX      AJUN(JX)     INJUT   VOIDFJ(JX)    RHOFJ(JX)    SN    VELFJ*SN      ARAT(JX)     IVR     CVELF(IVR)
                                              ATHROT(JX)           VOIDGJ(JX)    RHOGJ(JX)          VELGJ*SN      ARAT(JX+1)           CVELG(IVR)
------------------------------------------------------------------------------------------------------------------------------------
38369 003010000         42547 42548 42548   4.56037E-03
      003C10000        OUTLET 42548 39988   4.56037E-03      2    1.0000        832.67      1   0.             1.0000      44140    1.0000
                                             1.0000                0.            36.532           0.             1.0000               1.0000
38446 003020000         42549 42550 42551   4.56037E-03
      003010000        INLET  42550 39988   4.56037E-03      1    1.0000        832.67      1   0.             1.0000      44142    .50000
                                             1.0000                0.            36.532           0.             1.0000               .50000
      003020000        OUTLET 42551 40023   4.56037E-03      2    1.0000        832.67      1   0.             1.0000      44144    .50000
                                             1.0000                0.            36.532           0.             1.0000               .50000
38523 003030000         42552 42553 42554   4.56037E-03
      003020000        INLET  42553 40023   4.56037E-03      1    1.0000        832.67      1   0.             1.0000      44146    .50000
                                             1.0000                0.            36.532           0.             1.0000               .50000
      003030000        OUTLET 42554 40058   4.56037E-03      2    1.0000        832.67      1   0.             1.0000      44148    .50000
                                             1.0000                0.            36.532           0.             1.0000               .50000
38600 003040000         42555 42556 42557   4.56037E-03
      003030000        INLET  42556 40058   4.56037E-03      1    1.0000        832.67      1   0.             1.0000      44150    .50000
                                             1.0000                0.            36.532           0.             1.0000               .50000
      003040000        OUTLET 42557 40093   4.56037E-03      2    1.0000        832.67      1   0.             1.0000      44152    .50000
                                             1.0000                0.            36.532           0.             1.0000               .50000
38677 003050000         42558 42559 42560   4.56037E-03
      003040000        INLET  42559 40093   4.56037E-03      1    1.0000        832.67      1   0.             1.0000      44154    .50000
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Fig. B-1 Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                              PAGE    31
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                        85/08/01.
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003050000   OUTLET 42560 40128  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44156  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
38754 003060000    42561 42562 42563  4.56037E-03
      003050000   INLET  42562 40128  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44158  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003060000   OUTLET 42563 40163  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44160  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
38831 003070000    42564 42565 42566  4.56037E-03
      003060000   INLET  42565 40163  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44162  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003070000   OUTLET 42566 40198  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44164  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
38908 003080000    42567 42568 42569  4.56037E-03
      003070000   INLET  42568 40198  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44166  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003080000   OUTLET 42569 40233  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44168  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
38985 003090000    42570 42571 42572  4.56037E-03
      003080000   INLET  42571 40233  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44170  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003090000   OUTLET 42572 40268  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44172  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39062 003100000    42573 42574 42575  4.56037E-03
      003090000   INLET  42574 40268  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44174  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003100000   OUTLET 42575 40303  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44176  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39139 003110000    42576 42577 42578  4.56037E-03
      003100000   INLET  42577 40303  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44178  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003110000   OUTLET 42578 40338  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44180  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39216 003120000    42579 42580 42581  4.56037E-03
      003110000   INLET  42580 40338  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44182  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003120000   OUTLET 42581 40373  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44184  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39293 003130000    42582 42583 42584  4.56037E-03
      003120000   INLET  42583 40373  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44186  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003130000   OUTLET 42584 40408  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44188  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39370 003140000    42585 42586 42587  4.56037E-03
      003130000   INLET  42586 40408  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44190  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003140000   OUTLET 42587 40443  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44192  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39447 003150000    42588 42589 42590  4.56037E-03
      003140000   INLET  42589 40443  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44194  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003150000   OUTLET 42590 40478  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44196  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
39524 003160000    42591 42592 42593  4.56037E-03
      003150000   INLET  42592 40478  4.56037E-03   1  1.0000     832.67   1 0.           1.0000    44198  .50000
                                        1.0000         0.         36.532     0.           1.0000           .50000
      003160000   OUTLET 42593 40513  4.56037E-03   2  1.0000     832.67   1 0.           1.0000    44200  .50000
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Fig. B-1 Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                              85/08/01.                                    PAGE      32
                                        1.0000          0.               36.532          0.            1.0000                .50000
39601 003170000       42594 42595 42596 4.56037E-03
      003160000       INLET  42595 40513 4.56037E-03  1  1.0000          832.67      1   0.            1.0000      44202     .50000
                                        1.0000          0.               36.532          0.            1.0000                .50000
      003170000       OUTLET 42596 40548 4.56037E-03  2  1.0000          832.67      1   0.            1.0000      44204     .50000
                                        1.0000          0.               36.532          0.            1.0000                .50000
39678 003180000       42597 42598 42599 4.56037E-03
      003170000       INLET  42598 40548 4.56037E-03  1  1.0000          832.67      1   0.            1.0000      44206     .50000
                                        1.0000          0.               36.532          0.            1.0000                .50000
      003180000       OUTLET 42599 40583 4.56037E-03  2  1.0000          832.67      1   0.            1.0000      44208     .50000
                                        1.0000          0.               36.532          0.            1.0000                .50000
39755 003190000       42600 42601 42602 4.56037E-03
      003180000       INLET  42601 40583 4.56037E-03  1  1.0000          832.67      1   0.            1.0000      44210     .50000
                                        1.0000          0.               36.532          0.            1.0000                .50000
      003190000       OUTLET 42602 40618 4.56037E-03  2  1.0000          832.67      1   0.            1.0000      44212     .50000
                                        1.0000          0.               36.532          0.            1.0000                .50000
39832 003200000       42603 42604 42605 4.56037E-03
      003190000       INLET  42604 40618 4.56037E-03  1  1.0000          832.67      1   0.            1.0000      44214     .69686
                                        1.0000          0.               36.532          0.            1.0000               1.42242E-13
      004000000       OUTLET 42605 40653 3.96752E-03  2   .46490         895.53      1   0.            1.0000      44216     .26373
                                        1.0000          1.59045E-02      18.561          0.            1.0000                .87000
39909 005010000       42606 42607 42607 4.56037E-03
      004000000       INLET  42607 40653 3.96752E-03  1   .46490         895.53      1   0.            1.0000      44218     .87000
                                        1.0000          1.59045E-02      18.561          0.            1.0000                .87000
VOLUME AVERAGE TERMS
************************************************************************************************************************************
I     VOLNO(I)    SUMVFX(IXP)   DIFVFX(IXP)   VFX(IXP)     VFX(IXP+1)   VFA(IXP)     VFA(IXP+1)   VRHOF(IXP)   VRHOF(IXP+1)  AREA(IXP)
IXP               SUMVGX(IXP)   DIFVGX(IXP)   VGX(IXP)     VGX(IXP+1)   VGA(IXP)     VGA(IXP+1)   VRHOG(IXP)   VRHOG(IXP+1)  AREA(IXP+1)
************************************************************************************************************************************
38369 003010000   0.            0.            0.           0.           0.           0.           0.            3.7973       0.
43474             0.            0.            0.           0.           0.           0.           0.           1.66599E-16   4.56037E-03
38446 003020000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43500             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38523 003030000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43526             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38600 003040000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43552             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38677 003050000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43578             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38754 003060000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43604             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38831 003070000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43630             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38908 003080000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43656             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
38985 003090000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43682             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
39062 003100000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43708             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
39139 003110000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43734             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
39216 003120000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43760             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
39293 003130000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
43786             0.            0.            0.           0.           0.           0.           1.66599E-16  1.66599E-16   4.56037E-03
39370 003140000   0.            0.            0.           0.           0.           0.            3.7973       3.7973       4.56037E-03
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Fig. B-1. Continued.

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RELAP5/2/36.01         REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                    85/08/01.                                        PAGE       33
43812            0.            0.            0.            0.            0.            0.            1.66599E-16  1.66599E-16  4.56037E-03
39447 003150000  0.            0.            0.            0.            0.            0.             3.7973       3.7973      4.56037E-03
43838            0.            0.            0.            0.            0.            0.            1.66599E-16  1.66599E-16  4.56037E-03
39524 003160000  0.            0.            0.            0.            0.            0.             3.7973       3.7973      4.56037E-03
43864            0.            0.            0.            0.            0.            0.            1.66599E-16  1.66599E-16  4.56037E-03
39601 003170000  0.            0.            0.            0.            0.            0.             3.7973       3.7973      4.56037E-03
43890            0.            0.            0.            0.            0.            0.            1.66599E-16  1.66599E-16  4.56037E-03
39678 003180000  0.            0.            0.            0.            0.            0.             3.7973       3.7973      4.56037E-03
43916            0.            0.            0.            0.            0.            0.            1.66599E-16  1.66599E-16  4.56037E-03
39755 003190000  0.            0.            0.            0.            0.            0.             3.7973       3.7973      4.56037E-03
43942            0.            0.            0.            0.            0.            0.            1.66599E-16  1.66599E-16  4.56037E-03
39832 003200000  0.            0.            0.            0.            0.            0.             3.7973       1.6518      4.56037E-03
43968            0.            0.            0.            0.            0.            0.            1.66599E-16  1.17124E-03  3.96752E-03
39909 005010000  0.            0.            0.            0.            0.            0.             1.6518      0.           3.96752E-03
43994            0.            0.            0.            0.            0.            0.            1.17124E-03  0.           0.
MASS TRANSFER COEFFICIENTS
      I = 38369          VOLNO =    3010000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07   AVELF =  0.            RHOCPF =  3.86420E+06   XLIQH =  1.04342E-03
 XVAPH =    1.6937        TERM =  1.0000       TERM1 =  0.             HIGC =  3.34194E+07   HIGC1 =  1.0000         HIFC =  0.
 HIFC1 =    1.0000        HIFO =  0.            HIGO =  0.           HIGSUB =  10000.         DTSFM =  1.0000       DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000      DTSFSP =  0.          DTSFSB =  1.0000       AVELFG =  0.            ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232    DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38446          VOLNO =    3020000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07   AVELF =  0.            RHOCPF =  3.86420E+06   XLIQH =  1.04342E-03
 XVAPH =    1.6937        TERM =  1.0000       TERM1 =  0.             HIGC =  3.34194E+07   HIGC1 =  1.0000         HIFC =  0.
 HIFC1 =    1.0000        HIFO =  0.            HIGO =  0.           HIGSUB =  10000.         DTSFM =  1.0000       DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000      DTSFSP =  0.          DTSFSB =  1.0000       AVELFG =  0.            ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232    DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38523          VOLNO =    3030000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07   AVELF =  0.            RHOCPF =  3.86420E+06   XLIQH =  1.04342E-03
 XVAPH =    1.6937        TERM =  1.0000       TERM1 =  0.             HIGC =  3.34194E+07   HIGC1 =  1.0000         HIFC =  0.
 HIFC1 =    1.0000        HIFO =  0.            HIGO =  0.           HIGSUB =  10000.         DTSFM =  1.0000       DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000      DTSFSP =  0.          DTSFSB =  1.0000       AVELFG =  0.            ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232    DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38600          VOLNO =    3040000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07   AVELF =  0.            RHOCPF =  3.86420E+06   XLIQH =  1.04342E-03
 XVAPH =    1.6937        TERM =  1.0000       TERM1 =  0.             HIGC =  3.34194E+07   HIGC1 =  1.0000         HIFC =  0.
 HIFC1 =    1.0000        HIFO =  0.            HIGO =  0.           HIGSUB =  10000.         DTSFM =  1.0000       DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000      DTSFSP =  0.          DTSFSB =  1.0000       AVELFG =  0.            ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232    DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
```

Fig. B-1. Continued.

```
RELAP5/2(36.2)     REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                      85/08/01.                                    PAGE    34
      I = 38677         VOLNO =   3050000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.              DTSG =  0.
SCRATCH, S ARRAY
  DTSF =   56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =   1.6937        TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07   HIGC1 =   1.0000       HIFC =  0.
 HIFC1 =   1.0000        HIFO =  0.            HIGO =  0.          HIGSUB =   10000.       DTSFM =   1.0000     DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =   1.0000      DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232   DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38754         VOLNO =   3060000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.              DTSG =  0.
SCRATCH, S ARRAY
  DTSF =   56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =   1.6937        TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07   HIGC1 =   1.0000       HIFC =  0.
 HIFC1 =   1.0000        HIFO =  0.            HIGO =  0.          HIGSUB =   10000.       DTSFM =   1.0000     DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =   1.0000      DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232   DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38831         VOLNO =   3070000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.              DTSG =  0.
SCRATCH, S ARRAY
  DTSF =   56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =   1.6937        TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07   HIGC1 =   1.0000       HIFC =  0.
 HIFC1 =   1.0000        HIFO =  0.            HIGO =  0.          HIGSUB =   10000.       DTSFM =   1.0000     DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =   1.0000      DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232   DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38908         VOLNO =   3080000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.              DTSG =  0.
SCRATCH, S ARRAY
  DTSF =   56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =   1.6937        TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07   HIGC1 =   1.0000       HIFC =  0.
 HIFC1 =   1.0000        HIFO =  0.            HIGO =  0.          HIGSUB =   10000.       DTSFM =   1.0000     DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =   1.0000      DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232   DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 38985         VOLNO =   3090000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.              DTSG =  0.
SCRATCH, S ARRAY
  DTSF =   56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =   1.6937        TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07   HIGC1 =   1.0000       HIFC =  0.
 HIFC1 =   1.0000        HIFO =  0.            HIGO =  0.          HIGSUB =   10000.       DTSFM =   1.0000     DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =   1.0000      DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
 VAPNU =  1.43937-232   DRPNU =   .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39062         VOLNO =   3100000        HIF =  0.               HIG =  3.34194E+07 GAMMAW =  0.              DTSG =  0.
SCRATCH, S ARRAY
  DTSF =   56.757         HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =   1.6937        TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07   HIGC1 =   1.0000       HIFC =  0.
 HIFC1 =   1.0000        HIFO =  0.            HIGO =  0.          HIGSUB =   10000.       DTSFM =   1.0000     DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =   1.0000      DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
```

Fig. B-1. Continued.

```
RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                              85/08/01.                                  PAGE      35
EDWARDS PIPE PROBLEM BASE CASE WITH EXTRAS
 VAPNU =  1.43937-232  DRPNU =    .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39139        VCLNO =   3110000        HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757       HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =    1.6937      TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
 HIFC1 =    1.0000      HIFO =  0.            HIGO =  0.          HIGSUB =   10000.      DTSFM =   1.0000      DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000    DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.          DELTAF =  4.01782-231
 VAPNU =  1.43937-232  DRPNU =    .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39216        VCLNO =   3120000        HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757       HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =    1.6937      TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
 HIFC1 =    1.0000      HIFO =  0.            HIGO =  0.          HIGSUB =   10000.      DTSFM =   1.0000      DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000    DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.          DELTAF =  4.01782-231
 VAPNU =  1.43937-232  DRPNU =    .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39293        VCLNO =   3130000        HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757       HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =    1.6937      TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
 HIFC1 =    1.0000      HIFO =  0.            HIGO =  0.          HIGSUB =   10000.      DTSFM =   1.0000      DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000    DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.          DELTAF =  4.01782-231
 VAPNU =  1.43937-232  DRPNU =    .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39370        VCLNO =   3140000        HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757       HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =    1.6937      TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
 HIFC1 =    1.0000      HIFO =  0.            HIGO =  0.          HIGSUB =   10000.      DTSFM =   1.0000      DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000    DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.          DELTAF =  4.01782-231
 VAPNU =  1.43937-232  DRPNU =    .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39447        VCLNO =   3150000        HIF =  0.                HIG   3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757       HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =    1.6937      TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
 HIFC1 =    1.0000      HIFO =  0.            HIGO =  0.          HIGSUB =   10000.      DTSFM =   1.0000      DTSGMS =  0.
SCRATCH, PROP ARRAY
 DTSGM =    1.0000    DTSFSP =  0.          DTSFSB =   1.0000     AVELFG =  0.           ABRELV =  0.          DELTAF =  4.01782-231
 VAPNU =  1.43937-232  DRPNU =    .38700        RVC =  1.00000E-03
MASS TRANSFER COEFFICIENTS
      I = 39524        VCLNO =   3160000        HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.               DTSG =  0.
SCRATCH, S ARRAY
  DTSF =    56.757       HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
 XVAPH =    1.6937      TERM =   1.0000      TERM1 =  0.            HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
```

Fig. B-1. Continued.

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RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                PAGE      36
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                               85/08/01.
  HIFC1 =    1.0000         HIFO =  0.              HIGO =  0.             HIGSUB =   10000.      DTSFM =   1.0000    DTSGMS =  0.
SCRATCH, PROP ARRAY
  DTSGM =    1.0000      DTSFSP =  0.            DTSFSB =   1.0000       AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
  VAPNU =  1.43937-232    DRPNU =   .38700           RVC =  1.00000E-03

MASS TRANSFER COEFFICIENTS
       I = 39601          VOLNO =   3170000          HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.             DTSG =  0.
SCRATCH, S ARRAY
   DTSF =    56.757          HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
  XVAPH =    1.6937         TERM =   1.0000       TERM1 =  0.                HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
  HIFC1 =    1.0000         HIFO =  0.              HIGO =  0.             HIGSUB =   10000.      DTSFM =   1.0000    DTSGMS =  0.
SCRATCH, PROP ARRAY
  DTSGM =    1.0000      DTSFSP =  0.            DTSFSB =   1.0000       AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
  VAPNU =  1.43937-232    DRPNU =   .38700           RVC =  1.00000E-03

MASS TRANSFER COEFFICIENTS
       I = 39678          VOLNO =   3180000          HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.             DTSG =  0.
SCRATCH, S ARRAY
   DTSF =    56.757          HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
  XVAPH =    1.6937         TERM =   1.0000       TERM1 =  0.                HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
  HIFC1 =    1.0000         HIFO =  0.              HIGO =  0.             HIGSUB =   10000.      DTSFM =   1.0000    DTSGMS =  0.
SCRATCH, PROP ARRAY
  DTSGM =    1.0000      DTSFSP =  0.            DTSFSB =   1.0000       AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
  VAPNU =  1.43937-232    DRPNU =   .38700           RVC =  1.00000E-03

MASS TRANSFER COEFFICIENTS
       I = 39755          VOLNO =   3190000          HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.             DTSG =  0.
SCRATCH, S ARRAY
   DTSF =    56.757          HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
  XVAPH =    1.6937         TERM =   1.0000       TERM1 =  0.                HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
  HIFC1 =    1.0000         HIFO =  0.              HIGO =  0.             HIGSUB =   10000.      DTSFM =   1.0000    DTSGMS =  0.
SCRATCH, PROP ARRAY
  DTSGM =    1.0000      DTSFSP =  0.            DTSFSB =   1.0000       AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
  VAPNU =  1.43937-232    DRPNU =   .38700           RVC =  1.00000E-03

MASS TRANSFER COEFFICIENTS
       I = 39832          VOLNO =   3200000          HIF =  0.                HIG =  3.34194E+07 GAMMAW =  0.             DTSG =  0.
SCRATCH, S ARRAY
   DTSF =    56.757          HFG =  1.50604E+06   RHFG =  6.63994E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
  XVAPH =    1.6937         TERM =   1.0000       TERM1 =  0.                HIGC =  3.34194E+07  HIGC1 =   1.0000        HIFC =  0.
  HIFC1 =    1.0000         HIFO =  0.              HIGO =  0.             HIGSUB =   10000.      DTSFM =   1.0000    DTSGMS =  0.
SCRATCH, PROP ARRAY
  DTSGM =    1.0000      DTSFSP =  0.            DTSFSB =   1.0000       AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
  VAPNU =  1.43937-232    DRPNU =   .38700           RVC =  1.00000E-03

MASS TRANSFER COEFFICIENTS
       I = 39909          VOLNO =   5010000          HIF =  1.00000E+12       HIG =  0.          GAMMAW =  0.             DTSG =  0.
SCRATCH, S ARRAY
   DTSF =  0.                HFG =  2.25792E+06   RHFG =  4.42885E-07  AVELF =  0.           RHOCPF =  3.86420E+06  XLIQH =  1.04342E-03
  XVAPH =    1.6937         TERM =   1.0000       TERM1 =  0.                HIGC =   1.0000      HIGC1 =   1.0000        HIFC =   1.0000
  HIFC1 =    1.0000         HIFO =  1.00000E+07     HIGO =  1.00000E+07 HIGSUB =   10000.      DTSFM =   1.0000    DTSGMS =  0.
SCRATCH, PROP ARRAY
  DTSGM =    1.0000      DTSFSP =  0.            DTSFSB =   1.0000       AVELFG =  0.           ABRELV =  0.            DELTAF =  4.01782-231
  VAPNU =  1.43937-232    DRPNU =   .38700           RVC =  1.00000E-03
```

Fig. B-1. Continued.

```
RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                        PAGE      37
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                          85/08/01.

###################################################################################################################################
PHAINT      DIAGNOSTIC PRINTOUT, TIMEHY -   1.0000000E-03, DT -   1.0000000E-03, NCOUNT -           1, HELP -   3, SUCCES -   0, FAIL - F
     I     VOLNO             IMAP              FIVOL         VOIDF          FWALF           M    FLOMAP   FWFXAF        PFINRG
                                                             VOIDG          FWALG                       FWFXAG
  38369    3010000   0100010000000000002    21.466          1.0000         1.0000        43474       4   1.0000       0.
                                                          0.             0.                          0.
  38446    3020000   0100010000000000002    21.466          1.0000         1.0000        43500       4   1.0000       0.
                                                          0.             0.                          0.
  38523    3030000   0100010000000000002    21.466          1.0000         1.0000        43526       4   1.0000       0.
                                                          0.             0.                          0.
  38600    3040000   0100010000000000002    21.466          1.0000         1.0000        43552       4   1.0000       0.
                                                          0.             0.                          0.
  38677    3050000   0100010000000000002    21.466          1.0000         1.0000        43578       4   1.0000       0.
                                                          0.             0.                          0.
  38754    3060000   0100010000000000002    21.466          1.0000         1.0000        43604       4   1.0000       0.
                                                          0.             0.                          0.
  38831    3070000   0100010000000000002    21.466          1.0000         1.0000        43630       4   1.0000       0.
                                                          0.             0.                          0.
  38908    3080000   0100010000000000002    21.466          1.0000         1.0000        43656       4   1.0000       0.
                                                          0.             0.                          0.
  38985    3090000   0100010000000000002    21.466          1.0000         1.0000        43682       4   1.0000       0.
                                                          0.             0.                          0.
  39062    3100000   0100010000000000002    21.466          1.0000         1.0000        43708       4   1.0000       0.
                                                          0.             0.                          0.
  39139    3110000   0100010000000000002    21.466          1.0000         1.0000        43734       4   1.0000       0.
                                                          0.             0.                          0.
  39216    3120000   0100010000000000002    21.466          1.0000         1.0000        43760       4   1.0000       0.
                                                          0.             0.                          0.
  39293    3130000   0100010000000000002    21.466          1.0000         1.0000        43786       4   1.0000       0.
                                                          0.             0.                          0.
  39370    3140000   0100010000000000002    21.466          1.0000         1.0000        43812       4   1.0000       0.
                                                          0.             0.                          0.
  39447    3150000   0100010000000000002    21.466          1.0000         1.0000        43838       4   1.0000       0.
                                                          0.             0.                          0.
  39524    3160000   0100010000000000002    21.466          1.0000         1.0000        43864       4   1.0000       0.
                                                          0.             0.                          0.
  39601    3170000   0100010000000000002    21.466          1.0000         1.0000        43890       4   1.0000       0.
                                                          0.             0.                          0.
  39678    3180000   0100010000000000002    21.466          1.0000         1.0000        43916       4   1.0000       0.
                                                          0.             0.                          0.
  39755    3190000   0100010000000000002    21.466          1.0000         1.0000        43942       4   1.0000       0.
                                                          0.             0.                          0.
  39832    3200000   0100010000000000002    21.466          1.0000         1.0000        43968       4   1.0000       0.
                                                          0.             0.                          0.
  39909    5010000   0100022000000000002  5.66500E-02     0.             0.              43994       9   0.           0.
                                                            1.0000         1.0000                        1.0000
VOLUME TERMS
***********************************************************************************************************************************
I       VOLNO        TEMPF          TEMPG          TEMPF-SATT    TEMPG-SATT    HIF           HIG              GAMMAW         QWF            QWG
***********************************************************************************************************************************
38369 003010000     502.18         558.94         -56.757       0.            0.            3.34194E+07      0.             1.54890E-07    0.
38446 003020000     502.18         558.94         -56.757       0.            0.            3.34194E+07      0.             1.54890E-07    0.
38523 003030000     502.18         558.94         -56.757       0.            0.            3.34194E+07      0.             1.54890E-07    0.
38600 003040000     502.18         558.94         -56.757       0.            0.            3.34194E+07      0.             1.54890E-07    0.
38677 003050000     502.18         558.94         -56.757       0.            0.            3.34194E+07      0.             1.54890E-07    0.
```

Fig. B-1. Continued.

```
RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                        85/08/01.                                    PAGE      38
38754 003060000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
38831 003070000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
38908 003080000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
38985 003090000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39062 003100000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39139 003110000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39216 003120000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39293 003130000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39370 003140000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39447 003150000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39524 003160000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39601 003170000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39678 003180000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39755 003190000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39832 003200000     502.18          558.94        -56.757        0.              0.               3.34194E+07  0.              1.54890E-07  0.
39909 005010000     372.78          372.78        0.             0.              1.00000E+12      0.           0.              0.           0.
*****************************************************************************************************************************************
FWDRAG      DIAGNOSTIC PRINTOUT, TIMEHY -   1.0000000E-03, DT -   1.0000000E-03, NCOUNT -           1, HELP -   3, SUCCES -   0, FAIL - F

VOLUME TERMS
---------------------------------------------------------------------------------------------------------------------
  I    VOLNO(I)     VCTRL(I)                VOIDF(I)       RHOF(I)         VISCF(I)        RECRIT(I)       FWALF(I)
                    IMAP(I)                 VOIDG(I)       RHOG(I)         VISCG(I)        ROUGHV(I)       FWALG(I)
---------------------------------------------------------------------------------------------------------------------
38369 003010000    12634400010000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38446 003020000    12634700020000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38523 003030000    12635200030000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38600 003040000    12635500040000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38677 003050000    12636000050000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38754 003060000    12636300060000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38831 003070000    12636600070000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38908 003080000    12637100100000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
38985 003090000    12637400110000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39062 003100000    12637700120000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39139 003110000    12640200130000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39216 003120000    12640500140000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39293 003130000    12641000150000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39370 003140000    12641300160000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39447 003150000    12641600170000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
39524 003160000    12642100200000000000     1.0000          832.67         1.17684E-04      .92576         9.88422E-02
                   01000100000000000002    0.               36.532         1.90439E-05     8.63785E-03     0.
```

Fig. B-1. Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                       85/08/01.                                        PAGE      39
39601 003170000  1264240021000000000000   1.0000         832.67        1.17684E-04   .92576       9.88422E-02
                 0100010000000000000002  0.               36.532        1.90439E-05  8.63785E-03  0.
39678 003180000  1264270022000000000000   1.0000         832.67        1.17684E-04   .92576       9.88422E-02
                 0100010000000000000002  0.               36.532        1.90439E-05  8.63785E-03  0.
39755 003190000  1264320023000000000000   1.0000         832.67        1.17684E-04   .92576       9.88422E-02
                 0100010000000000000002  0.               36.532        1.90439E-05  8.63785E-03  0.
39832 003200000  1264350024000000000000   1.0000         832.67        1.17684E-04   .92576       9.88422E-02
                 0100010000000000000002  0.               36.532        1.90439E-05  8.63785E-03  0.
39909 005010000  5264370025000000000000  0.              958.39        2.80062E-04   .92576       0.
                 0100022000000000000002   1.0000          .59041       1.20200E-05  8.63785E-03  0.
SCRATCH TERMS, FRICTION FACTOR LOOP
***************************************************************************************************************************************
  I      L               SUMVFX(L)      FLAMF(L)      FWFAF1(L)      REYNF1(L)      FWF1(L)      FWFXAF(L)      REYNF2(L)      FWF2(L)
         PFINRG(L)       SUMVGX(L)      FLAMG(L)      FWFAGI(L)      REYNGI(L)      FWG1(L)      FWFXAG(L)      REYNG2(L)      FWG2(L)
***************************************************************************************************************************************
38369 43474              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38446 43500              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38523 43526              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38600 43552              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38677 43578              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38754 43604              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38831 43630              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38908 43656              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
38985 43682              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39062 43708              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39139 43734              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39216 43760              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39293 43786              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39370 43812              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
 9447 43838              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39524 43864              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39601 43890              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39678 43916              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39755 43942              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
39832 43968              1.00000E-20   1.18706E-04    1.0000        0.             0.             1.0000        -.18921       1.18706E-04
         0.              1.00000E-20   4.37833E-04   0.             0.             0.            0.             -.18921       0.
```

Fig. B-1. Continued.

```
WALL FRICTION TERMS, PHASE APPORTIONING LOOP
--------------------------------------------------------------------------------------------
  I      FWALF(I)     L            REYNF1(L)     DPDXFX(L)     ZAMBDA(L)     IPOPDX(L)
         FWALG(I)     GFWABS(L)    REYNG1(L)     DPDXGX(L)     CTERMX(L)     RATDPF(L)
--------------------------------------------------------------------------------------------
33369    .64857       43474        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38446    .64857       43500        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38523    .64857       43526        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38600    .64857       43552        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38677    .64857       43578        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38754    .64857       43604        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38831    .64857       43630        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38908    .64857       43656        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
38985    .64857       43682        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39062    .64857       43708        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39139    .64857       43734        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39216    .64857       43760        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39293    .64857       43786        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39370    .64857       43812        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39447    .64857       43838        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39524    .64857       43864        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39601    .64857       43890        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39678    .64857       43916        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39755    .64857       43942        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
39832    .64857       43968        0.            0.            0.            0.
         0.           0.           0.            0.            0.            1.0000
```

Fig. B-1. Continued

```
RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                        85/08/01.                                   PAGE     41

################################################################################################################################
VEXPLT      DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =          1, HELP =   3, SUCCES =   0, FAIL = F
SUM AND DIFFERENCE TERMS
--------------------------------------------------------------------------------------------------------------------------------
I       JUNNO(I)    SUMF           SUMG           SUMOLD         DIFF         DIFG           DIFOLD         AVRF           AVRG           FJFG
--------------------------------------------------------------------------------------------------------------------------------
39988 003010000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40023 003020000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40058 003030000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40093 003040000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40128 003050000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40163 003060000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40198 003070000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40233 003080000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40268 003090000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40303 003100000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40338 003110000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40373 003120000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40408 003130000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40443 003140000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40478 003150000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40513 003160000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40548 003170000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40583 003180000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40618 003190000     170.53         7.48177E-15  0.               1.20340E+09 -1.20340E+09  0.                 832.67       3.65319E-14  1.20340E+12
40653 004000000     74.181         3.25457E-15   6900.0          4.55428E+08 -4.55428E+08  -180.57            832.67       3.65319E-14  4.55428E+11
VOLUME TERMS
--------------------------------------------------------------------------------------------------------------------------------
I       VOLNO(I)    DL(I)          VOIDF(I)       RHOF(I)        FWALF(I)       VELF(I)        IX     DIFVFX(IX)     IXE    SOURCF(IXE)    SOURCM(IXE)
                    DZ(I)          VOIDG(I)       RHOG(I)        FWALG(I)       VELG(I)               DIFVGX(IX)            SOURCG(IXE)    SOURCA(IXE)
--------------------------------------------------------------------------------------------------------------------------------
38369 003010000      .20480         1.0000         832.67         .64857        0.             43474  0.             44401  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.             -2.82724+140
38446 003020000      .20480         1.0000         832.67         .64857        0.             43500  0.             44405  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.             0.
38523 003030000      .20480         1.0000         832.67         .64857        0.             43526  0.             44409  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.               502.18
38600 003040000      .20480         1.0000         832.67         .64857        0.             43552  0.             44413  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.               502.18
38677 003050000      .20480         1.0000         832.67         .64857        0.             43578  0.             44417  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.               502.18
38754 003060000      .20480         1.0000         832.67         .64857        0.             43604  0.             44421  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.               502.18
38831 003070000      .20480         1.0000         832.67         .64857        0.             43630  0.             44425  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.               502.18
38908 003080000      .20480         1.0000         832.67         .64857        0.             43656  0.             44429  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.               502.18
38985 003090000      .20480         1.0000         832.67         .64857        0.             43682  0.             44433  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.             0.
39062 003100000      .20480         1.0000         832.67         .64857        0.             43708  0.             44437  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.             0.
39139 003110000      .20480         1.0000         832.67         .64857        0.             43734  0.             44441  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.             0.
39216 003120000      .20480         1.0000         832.67         .64857        0.             43760  0.             44445  1.54890E-10    0.
                    0.             0.              36.532        0.             0.                    0.                    0.             0.
```

Fig. B-1. Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                      PAGE    42
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                   85/08/01.
39293 003130000   .20480       1.0000       832.67      .64857      0.            43786  0.            44449  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39370 003140000   .20480       1.0000       832.67      .64857      0.            43812  0.            44453  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39447 003150000   .20480       1.0000       832.67      .64857      0.            43838  0.            44457  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39524 003160000   .20480       1.0000       832.67      .64857      0.            43864  0.            44461  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           2.12808E-07
39601 003170000   .20480       1.0000       832.67      .64857      0.            43890  0.            44465  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39678 003180000   .20480       1.0000       832.67      .64857      0.            43916  0.            44469  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39755 003190000   .20480       1.0000       832.67      .64857      0.            43942  0.            44473  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39832 003200000   .20480       1.0000       832.67      .64857      0.            43968  0.            44477  1.54890E-10  0.
                 0.           0.            36.532     0.           0.                   0.                   0.           0.
39909 005010000  0.           0.            958.39     0.           0.            43994  0.            44481  0.           0.
                 0.           1.0000        .59041     0.           0.                   0.                   0.            502.18
JUNCTION TERMS
*****************************************************************************************************************************
I      JUNNO(I)    FIJ(I)       AJUN(I)       ARAT(I)     FJUNF(I)     FORMFJ(I)    VELFJO(I)    VELGJO(I)    J       V.   (J)
                                ATHROT(I)     ARAT(I+1)   FJUNR(I)     FORMGJ(I)    VELFJ(I)     VELGJ(I)             VGUPX J)
*****************************************************************************************************************************
39988 003010000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44485   5.85404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40023 003020000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44489   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40058 003030000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44493   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40093 003040000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44497   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40128 003050000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44501   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40163 003060000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44505   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40198 003070000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44509   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40233 003080000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44513   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40268 003090000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44517   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40303 003100000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44521   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40338 003110000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44525   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40373 003120000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44529   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40408 003130000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44533   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40443 003140000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44537   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40478 003150000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44541   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40513 003160000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44545   5.86404E-06
                                1.0000       1.0000      0.           0.           0.           0.                   5.86404E-06
40548 003170000   21.466       4.56037E-03   1.0000      0.           0.           0.           0.           44549   5.86404E-06
```

Fig. B-1. Continued.

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RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                          85/08/01.                                        PAGE      43
                             1.0000        1.0000      0.          0.
40583 003180000    21.466   4.56037E-03    1.0000      0.          0.          0.          0.                 5.86404E-06
                             1.0000        1.0000      0.          0.          0.          0.         44553   5.86404E-06
40618 003190000    21.466   4.56037E-03    1.0000      0.          0.          0.          0.                 5.86404E-06
                             1.0000        1.0000      0.          0.          0.          0.         44557   5.86404E-06
40653 004000000    18.675   3.96752E-03    1.0000      0.          0.          0.          0.                 5.86404E-06
                             1.0000        1.0000      0.          0.          0.          0.         44561   1.34806E-05
                                                       0.          0.            93.016      93.016           1.34806E-05
###########################################################################################################################
JCHOKE      DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =            1, HELP =  3, SUCCES =  0, FAIL = F
FROM JCHOKE      4000000             1  1.00000E-03
JUNCTION VOID FRACTION      1.59045E-02FLOW DIRECTION        1.00000E+00
  PSMF          PSMG          PSLD          PJUN          CHOKE             PRES           PSAT           PO-UP          PO-DN
  5.77801E-02    .00000E+00    .00000E+00   7.00000E+06                 F  2.74835E+06    2.74835E+06    7.00000E+06    1.00000E+05
  SOUNDE-UP     SONIC         DSONDP        QUALE-UP      QUALSO-UP         VELFJ(I)       VELGJ(I)       VC
 1.23569E+03   1.06342E+02   1.25060E-05    .00000E+00     .00000E+00   9.30158E+01    9.30158E+01    9.30158E+01
###########################################################################################################################
JPROP       DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =            1, HELP =  3, SUCCES =  0, FAIL = F
TRACEBACK INITIATED BY JPROP AT LINE 275, REL(ABS) ADDRESS 244(125407).
CALLED BY HYDRO AT LINE 92, ADDRESS 56(123652) WITH APLIST 167(123763).
CALLED BY TRAN AT LINE 76, ADDRESS 54(161233) WITH NO AP-LIST.
CALLED BY TRNCTL AT LINE 22, ADDRESS 7(46512) WITH NO AP-LIST.
CALLED BY RELAP5 AT LINE 1445, ADDRESS 3745(10563) WITH NO AP-LIST.

JUNCTION DONORED PROPERTIES, ICHOKE =  1
---------------------------------------------------------------------------------------------------------------------------
I      JUNNO(I)   VELFJ(I)      VOIDFJ(I)     RHOFJ(I)      QUALAJ(I)     UFJ(I)        JC(I)                  K      VOLNO(K)    VOIDG(K)
                  VELGJ(I)      VOIDGJ(I)     RHOGJ(I)      VOIDS         UGJ(I)        JC(I+1)                L      VOLNO(L)    VOIDG(L)
---------------------------------------------------------------------------------------------------------------------------
39988 003010000   0.            1.0000        832.67        0.            9.78293E+05   00126561126344126345   38369  003010000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126565126347126346   38446  003020000   0.
40023 003020000   0.            1.0000        832.67        0.            9.78293E+05   00126565126347126350   38446  003020000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126571126352126351   38523  003030000   0.
40058 003030000   0.            1.0000        832.67        0.            9.78293E+05   00126571126352126353   38523  003030000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126575126355126354   38600  003040000   0.
40093 003040000   0.            1.0000        832.67        0.            9.78293E+05   00126575126355126356   38600  003040000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126601126360126357   38677  003050000   0.
40128 003050000   0.            1.0000        832.67        0.            9.78293E+05   00126601126360126361   38677  003050000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126605126363126362   38754  003060000   0.
40163 003060000   0.            1.0000        832.67        0.            9.78293E+05   00126605126363126364   38754  003060000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126611126366126365   38831  003070000   0.
40198 003070000   0.            1.0000        832.67        0.            9.78293E+05   00126611126366126367   38831  003070000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126615126371126370   38908  003080000   0.
40233 003080000   0.            1.0000        832.67        0.            9.78293E+05   00126615126371126372   38908  003080000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126621126374126373   38985  003090000   0.
40268 003090000   0.            1.0000        832.67        0.            9.78293E+05   00126621126374126375   38985  003090000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126625126377126376   39062  003100000   0.
40303 003100000   0.            1.0000        832.67        0.            9.78293E+05   00126625126377126400   39062  003100000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126631126402126401   39139  003110000   0.
40338 003110000   0.            1.0000        832.67        0.            9.78293E+05   00126631126402126403   39139  003110000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126635126405126404   39216  003120000   0.
40373 003120000   0.            1.0000        832.67        0.            9.78293E+05   00126635126405126406   39216  003120000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126641126410126407   39293  003130000   0.
40408 003130000   0.            1.0000        832.67        0.            9.78293E+05   00126641126410126411   39293  003130000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126645126413126412   39370  003140000   0.
40443 003140000   0.            1.0000        832.67        0.            9.78293E+05   00126645126413126414   39370  003140000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126651126416126415   39447  003150000   0.
40478 003150000   0.            1.0000        832.67        0.            9.78293E+05   00126651126416126417   39447  003150000   0.
                  0.            0.            36.532        1.0000        2.58184E+06   10126655126421126420   39524  003160000   0.
40513 003160000   0.            1.0000        832.67        0.            9.78293E+05   00126655126421126422   39524  003160000   0.
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Fig. B-1. Continued.

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RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                              PAGE      44
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                          85/08/01.
                  0.            0.             36.532        1.0000        2.58184E+06  10126661126424126423 39601 003170000  0.
40548 003170000   0.             1.0000        832.67       0.             9.78293E+05  00126661126424126425 39601 003170000  0.
                  0.            0.             36.532        1.0000        2.58184E+06  10126665126427126426 39678 003180000  0.
40583 003180000   0.             1.0000        832.67       0.             9.78293E+05  00126665126427126430 39678 003180000  0.
                  0.            0.             36.532        1.0000        2.58184E+06  10126671126432126431 39755 003190000  0.
40618 003190000   0.             1.0000        832.67       0.             9.78293E+05  00126671126432126433 39755 003190000  0.
                  0.            0.             36.532        1.0000        2.58184E+06  10126675126435126434 39832 003200000  0.
40653 004000000    93.016        1.0000        832.67       0.             9.78293E+05  00126675126435126436 39832 003200000  0.
                   93.016       0.             36.532        1.0000        2.58184E+06  10126701126437000000 39909 005010000   1.0000

################################################################################################################################
PRESEQ     DIAGNOSTIC PRINTOUT, TIMEHY =   1.0000000E-03, DT =  1.0000000E-03, NCOUNT =            1, HELP =  3, SUCCES =  0, FAIL = F

VOLUME TERMS
--------------------------------------------------------------------------------------------------------------------------------
I      VOLNO        PO           UFO          UGO          VOIDGO       QUALAO       RHOF         RHOG         SATHF        SATHG
                    DRFDP        DRFDUF       DRGDP        DRGDUG       DRGDXA       DTFDP        DTFDUF       DTGDP        DTGDUG
                    DTGDP        DTDP         DTDUG        DTDXA        HIF          HIG          GAMMAW       QWF          QWG
--------------------------------------------------------------------------------------------------------------------------------
38369 003010000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38446 003020000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38523 003030000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38600 003040000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38677 003050000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38754 003060000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38831 003070000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38908 003080000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
38985 003090000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
39062 003100000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
39139 003110000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
39216 003120000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
                  0.           9.65762E-06  0.           0.           0.           3.34194E+07  0.           1.54890E-07  0.
39293 003130000   7.00000E+06  9.78293E+05  2.58184E+06  0.           0.            832.67       36.532      1.26742E+06  2.77345E+06
                  6.56824E-07 -2.90385E-04  5.32805E-06 -5.39207E-05  0.           2.08283E-07  2.16114E-04  1.20541E-05  2.54756E-04
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Fig. B-1. Continued.

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 RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD*S PIPE PROBLEM BASE CASE WITH EXTRAS                                   85/08/01.                                           PAGE     45
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39370 003140000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39447 003150000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39524 003160000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39601 003170000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39678 003180000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39755 003190000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39832 003200000  7.00000E+06   9.78293E+05  2.58184E+06   0.           0.              832.67      36.532       1.26742E+06  2.77345E+06
                 6.56824E-07  -2.90385E-04  5.32805E-06  -5.39207E-05  0.            2.08283E-07  2.16114E-04   1.20541E-05  2.54756E-04
                 0.            9.65762E-06  0.            0.           0.            3.34194E+07  0.            1.54890E-07  0.
39909 005010000  1.00000E+05   4.17407E+05  2.53606E+06   1.0000       0.              958.39        .59041     4.17511E+05  2.67543E+06
                 4.32702E-07  -1.71157E-04  5.88662E-06  -1.10920E-06  0.            6.94527E-08  2.37240E-04   6.66091E-05  6.50426E-04
                 0.            2.79462E-04  0.            0.           1.00000E+12  0.            0.            0.           0.
JUNCTION TERMS
**********************************************************************************************************************************************
I      JUNNO(I)   AJUN(I)      VOIDFJ(I)      RHOFJ(I)     UFJ(I)       VELFJO(I)      VELGJO(I)      IXV    VFDPK(IXV)    VFDPL(IXV)
                  QUALAJ(I)    VOIDGJ(I)      RHOGJ(I)     UGJ(I)       VELFJ(I)       VELGJ(I)              VGDPK(IXV)    VGDPL(IXV)
**********************************************************************************************************************************************
39988 003010000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44485  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40023 003020000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44489  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40058 003030000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44493  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40093 003040000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44497  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40128 003050000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44501  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40163 003060000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44505  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40198 003070000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44509  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40233 003080000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44513  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40268 003090000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44517  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40303 003100000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44521  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40338 003110000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44525  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40373 003120000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44529  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
40408 003130000   4.56037E-03   1.0000         832.67      9.78293E+05  0.             0.             44533  5.86404E-06   5.86404E-06
                  0.            0.             36.532      2.58184E+06  0.             0.                    5.86404E-06   5.86404E-06
```

Fig. B-1. Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM B/SE CASE WITH EXTRAS                                                   85/08/01.                                   PAGE     46
40443 003140000  4.56037E-03   1.0000        832.67      9.78293E+05  0.          0.              44537  5.86404E-06  5.86404E-06
                 0.            0.             36.532     2.58184E+06  0.          0.                     5.86404E-06  5.86404E-06
40478 003150000  4.56037E-03   1.0000        832.67      9.78293E+05  0.          0.              44541  5.86404E-06  5.86404E-06
                 0.            0.             36.532     2.58184E+06  0.          0.                     5.86404E-06  5.86404E-06
40513 003160000  4.56037E-03   1.0000        832.67      9.78293E+05  0.          0.              44545  5.86404E-06  5.86404E-06
                 0.            0.             36.532     2.58184E+06  0.          0.                     5.86404E-06  5.86404E-06
40548 003170000  4.56037E-03   1.0000        832.67      9.78293E+05  0.          0.              44549  5.86404E-06  5.86404E-06
                 0.            0.             36.532     2.58184E+06  0.          0.                     5.86404E-06  5.86404E-06
40583 003180000  4.56037E-03   1.0000        832.67      9.78293E+05  0.          0.              44553  5.86404E-06  5.86404E-06
                 0.            0.             36.532     2.58184E+06  0.          0.                     5.86404E-06  5.86404E-06
40618 003190000  4.56037E-03   1.0000        832.67      9.78293E+05  0.          0.              44557  5.86404E-06  5.86404E-06
                 0.            0.             36.532     2.58184E+06  0.          0.                     5.86404E-06  5.86404E-06
40653 004000000  3.96752E-02   1.0000        832.67      9.78293E+05  0.          0.              44561  1.34806E-05  1.34806E-05
                 0.            0.             36.532     2.58184E+06   93.016      93.016                1.34806E-05  1.34806E-05
SCRATCH STORAGE VOLUME TERMS
*****************************************************************************************************************************************
I     VOLNO(I)  IH      COEFP(IH)     IS     SOURCP(IS)  ISE    SOURCF(ISE)  SOURCM(ISE) IXP    AINV51(IXP)  AINV52(IXP)  AINV53(IXP)
                                                                SOURCG(ISE)  SOURCA(ISE)        AINV54(IXP)  AINV55(IXP)
*****************************************************************************************************************************************
38369 003010000 44260    37.405      44380  8.80534E-08 44401  1.54890E-10  0.          43474  0.             18.624       .53095
                                                                0.          -2.82724+140        -8.92617E+06 -7.92311E+06
38446 003020000 44263    73.809      44381  8.80534E-08 44405  1.54890E-10  0.          43500  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
38523 003030000 44266    73.809      44382  8.80534E-08 44409  1.54890E-10  0.          43526  0.             18.624       .53095
                                                                0.            502.18            -8.92617E+06 -7.92311E+06
38600 003040000 44269    73.809      44383  8.80534E-08 44413  1.54890E-10  0.          43552  0.             18.624       .53095
                                                                0.            502.18            -8.92617E+06 -7.92311E+06
38677 003050000 44272    73.809      44384  8.80534E-08 44417  1.54890E-10  0.          43578  0.             18.624       .53095
                                                                0.            502.18            -8.92617E+06 -7.92311E+06
38754 003060000 44275    73.809      44385  8.80534E-08 44421  1.54890E-10  0.          43604  0.             18.624       .53095
                                                                0.            502.18            -8.92617E+06 -7.92311E+06
38831 003070000 44278    73.809      44386  8.80534E-08 44425  1.54890E-10  0.          43630  0.             18.624       .53095
                                                                0.            502.18            -8.92617E+06 -7.92311E+06
38908 003080000 44281    73.809      44387  8.80534E-08 44429  1.54890E-10  0.          43656  0.             18.624       .53095
                                                                0.            502.18            -8.92617E+06 -7.92311E+06
38985 003090000 44284    73.809      44388  8.80534E-08 44433  1.54890E-10  0.          43682  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39062 003100000 44287    73.809      44389  8.80534E-08 44437  1.54890E-10  0.          43708  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39139 003110000 44290    73.809      44390  8.80534E-08 44441  1.54890E-10  0.          43734  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39216 003120000 44293    73.809      44391  8.80534E-08 44445  1.54890E-10  0.          43760  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39293 003130000 44296    73.809      44392  8.80534E-08 44449  1.54890E-10  0.          43786  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39370 003140000 44299    73.809      44393  8.80534E-08 44453  1.54890E-10  0.          43812  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39447 003150000 44302    73.809      44394  8.80534E-08 44457  1.54890E-10  0.          43838  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39524 003160000 44305    73.809      44395  8.80534E-08 44461  1.54890E-10  0.          43864  0.             18.624       .53095
                                                                0.           2.13808E-07        -8.92617E+06 -7.92311E+06
39601 003170000 44308    73.809      44396  8.80534E-08 44465  1.54890E-10  0.          43890  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39678 003180000 44311    73.809      44397  8.80534E-08 44469  1.54890E-10  0.          43916  0.             18.624       .53095
                                                                0.           0.                 -8.92617E+06 -7.92311E+06
39755 003190000 44314    73.809      44398  8.80534E-08 44473  1.54890E-10  0.          43942  0.             18.624       .53095
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Fig. B-1. Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                     PAGE      47
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                      85/08/01.

                                                                 0.            0.                     -8.92617E+06 -7.92311E+06
39832 003200000 44317    110.21       44399 -5.02383E+08 44477  1.54890E-10   0.            43968    0.                 18.624       .53095
                                                                 0.            0.                     -8.92617E+06 -7.92311E+06
39909 005010000 44319    1.0000       44400  0.          44481  0.            0.            43994    0.                  .31914      9.91147E-02
                                                                 0.             502.18                -2.94338E+05 -3.35581E+05

PRESSURE MATRIX
**************************************************************************************************************************************
EQ.NO. VOLNO      EL.NO.   COEFP          EL.NO.   COEFP          EL.NO.   COEFP          EL.NO.   COEFP          EL.NO.   COEFP          DIA.DOM.TERM
**************************************************************************************************************************************
  38369 003010000      1     37.405            2   -36.405                                                                            1.0000
  38446 003020000      1    -36.405            2    73.809            3   -36.405                                                     1.0000
  38523 003030000      2    -36.405            3    73.809            4   -36.405                                                     1.0000
  38600 003040000      3    -36.405            4    73.809            5   -36.405                                                     1.0000
  38677 003050000      4    -36.405            5    73.809            6   -36.405                                                     1.0000
  38754 003060000      5    -36.405            6    73.809            7   -36.405                                                     1.0000
  38831 003070000      6    -36.405            7    73.809            8   -36.405                                                     1.0000
  38908 003080000      7    -36.405            8    73.809            9   -36.405                                                     1.0000
  38985 003090000      8    -36.405            9    73.809           10   -36.405                                                     1.0000
  39062 003100000      9    -36.405           10    73.809           11   -36.405                                                     1.0000
  39139 003110000     10    -36.405           11    73.809           12   -36.405                                                     1.0000
  39216 003120000     11    -36.405           12    73.809           13   -36.405                                                     1.0000
  39293 003130000     12    -36.405           13    73.809           14   -36.405                                                     1.0000
  39370 003140000     13    -36.405           14    73.809           15   -36.405                                                     1.0000
  39447 003150000     14    -36.405           15    73.809           16   -36.405                                                     1.0000
  39524 003160000     15    -36.405           16    73.809           17   -36.405                                                     1.0000
  39601 003170000     16    -36.405           17    73.809           18   -36.405                                                     1.0000
  39678 003180000     17    -36.405           18    73.809           19   -36.405                                                     1.0000
  39755 003190000     18    -36.405           19    73.809           20   -36.405                                                     1.0000
  39832 003200000     19    -36.405           20    110.21           21   -72.809                                                     1.0000
  39909 005010000     21     1.0000                                                                                                   1.0000
NUMBER OF ELEMENTS IN SPARSE MATRIX 1: ORIGINAL =    51, FACTORED =    61      ROUNDOFF ERROR =      1.000000E-12      NCOUNT =        1

##############################################################################################################################################
SYSSOL      DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =              1, HELP =  3, SUCCES =  0, FAIL = F

SOLUTION ARRAY (SOURCP = P - PO)
**************************************************************************************************************************
I        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)
**************************************************************************************************************************
44380 -5.02765E+05 -5.16575E+05 -5.44576E+05 -5.87535E+05 -6.46633E+05 -7.23494E+05 -8.20228E+05 -9.39493E+05 -1.08456E+06
44389 -1.25943E+06 -1.46889E+06 -1.71869E+06 -2.01571E+06 -2.36810E+06 -2.78554E+06 -3.27949E+06 -3.86353E+06 -4.55369E+06
44398 -5.36894E+06 -6.33167E+06  0.

SINGULARITY PARAMETER (IF GERR .LT. 0.0, THE MATRIX SOLUTION IS SINGULAR)
GERR =  1.00000E-12
```

Fig. B-1. Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                    PAGE       48
 EDWARD'S PIPE PRCBLEM BASE CASE WITH EXTRAS                                          85/08/01.

##############################################################################################################################
JPROP       DIAGNOSTIC PRINTOUT, TIMEHY -  1.0000000E-03, DT  -  1.0000000E-03, NCOUNT -            1, HELP -  3, SUCCES -  0, FAIL - F
TRACEBACK INITIATED BY JPROP AT LINE 275, REL(ABS) ADDRESS 244(125407).
CALLED BY VFINL AT LINE 228, ADDRESS 117(147205) WITH APLIST 604(147672).
CALLED BY HYDRO AT LINE 98, ADDRESS 65(123661) WITH NO AP-LIST.
CALLED BY TRAN AT LINE 76, ADDRESS 54(161233) WITH NO AP-LIST.
CALLED BY TRNCTL AT LINE 22, ADDRESS 7(46512) WITH NO AP-LIST.
CALLED BY RELAP5 AT LINE 1445, ADDRESS 3745(10563) WITH NO AP-LIST.

JUNCTION DONORED PROPERTIES, ICHOKE -  1
------------------------------------------------------------------------------------------------------------------------------
I       JUNNO(I)    VELFJ(I)      VOIDFJ(I)      RHOFJ(I)     QUALAJ(I)     UFJ(I)        JC(I)                 K      VOLNO(K)    VOIDG(K)
                    VELGJ(I)      VOIDGJ(I)      RHOGJ(I)     VOIDS         UGJ(I)        JC(I+1)               L      VOLNO(L)    VOIDS(L)
------------------------------------------------------------------------------------------------------------------------------
39988 0C3010000   8.09849E-02    1.0000          832.67     0.              9.78293E+05   00126561126344126345 38369 003010000   0.
                  8.09849E-02   0.                36.532      1.0000        2.58184E+06   10126565126347126346 38446 003020000   0.
40023 003020000     .16419       1.0000          832.67     0.              9.78293E+05   00126565126347126350 38446 003020000   0.
                    .16419      0.                36.532      1.0000        2.58184E+06   10126571126352126351 38523 003030000   0.
40058 003030000     .25191       1.0000          832.67     0.              9.78293E+05   00126571126352126353 38523 003030000   0.
                    .25191      0.                36.532      1.0000        2.58184E+06   10126575126355126354 38600 003040000   0.
40093 003040000     .34655       1.0000          832.67     0.              9.78293E+05   00126575126355126356 38600 003040000   0.
                    .34655      0.                36.532      1.0000        2.58184E+06   10126601126360126357 38677 003050000   0.
40128 003050000     .45071       1.0000          832.67     0.              9.78293E+05   00126601126360126361 38677 003050000   0.
                    .45071      0.                36.532      1.0000        2.58184E+06   10126605126363126362 38754 003060000   0.
40163 003060000     .56725       1.0000          832.67     0.              9.78293E+05   00126605126363126364 38754 003060000   0.
                    .56725      0.                36.532      1.0000        2.58184E+06   10126611126366126365 38831 003070000   0.
40198 003070000     .69937       1.0000          832.67     0.              9.78293E+05   00126611126366126367 38831 003070000   0.
                    .69937      0.                36.532      1.0000        2.58184E+06   10126615126371126370 38908 003080000   0.
40233 003080000     .85071       1.0000          832.67     0.              9.78293E+05   00126615126371126372 38908 003080000   0.
                    .85071      0.                36.532      1.0000        2.58184E+06   10126621126374126373 38985 003090000   0.
40268 0C3090000    1.0254        1.0000          832.67     0.              9.78293E+05   00126621126374126375 38985 003090000   0.
                   1.0254       0.                36.532      1.0000        2.58184E+06   10126625126377126376 39062 003100000   0.
40303 003100000    1.2283        1.0000          832.67     0.              9.78293E+05   00126625126377126400 39062 003100000   0.
                   1.2283       0.                36.532      1.0000        2.58184E+06   10126631126402126401 39139 003110000   0.
40338 003110000    1.4649        1.0000          832.67     0.              9.78293E+05   00126631126402126403 39139 003110000   0.
                   1.4649       0.                36.532      1.0000        2.58184E+06   10126635126405126404 39216 003120000   0.
40373 003120000    1.7417        1.0000          832.67     0.              9.78293E+05   00126635126405126406 39216 003120000   0.
                   1.7417       0.                36.532      1.0000        2.58184E+06   10126641126410126407 39293 003130000   0.
40408 003130000    2.0664        1.0000          832.67     0.              9.78293E+05   00126641126410126411 39293 003130000   0.
                   2.0664       0.                36.532      1.0000        2.58184E+06   10126645126410126412 39370 003140000   0.
40443 003140000    2.4479        1.0000          832.67     0.              9.78293E+05   00126645126413126414 39370 003140000   0.
                   2.4479       0.                36.532      1.0000        2.58184E+06   10126651126416126415 39447 003150000   0.
40478 003150000    2.8966        1.0000          832.67     0.              9.78293E+05   00126651126416126417 39447 003150000   0.
                   2.8966       0.                36.532      1.0000        2.58184E+06   10126655126421126420 39524 003160000   0.
40513 003160000    3.4248        1.0000          832.67     0.              9.78293E+05   00126655126421126422 39524 003160000   0.
                   3.4248       0.                36.532      1.0000        2.58184E+06   10126661126424126423 39601 003170000   0.
40548 003170000    4.0472        1.0000          832.67     0.              9.78293E+05   00126661126424126425 39601 003170000   0.
                   4.0472       0.                36.532      1.0000        2.58184E+06   10126665126427126426 39678 003180000   0.
40583 003180000    4.7807        1.0000          832.67     0.              9.78293E+05   00126665126427126430 39678 003180000   0.
                   4.7807       0.                36.532      1.0000        2.58184E+06   10126671126432126431 39755 003190000   0.
40618 003190000    5.6455        1.0000          832.67     0.              9.78293E+05   00126671126432126433 39755 003190000   0.
                   5.6455       0.                36.532      1.0000        2.58184E+06   10126675126435126434 39832 003200000   0.
40653 004000000    7.6614        1.0000          832.67     0.              9.78293E+05   00126675126435126436 39832 003200000   0.
                   7.6614       0.                36.532      1.0000        2.58184E+06   10126701126437000000 39909 005010000     1.0000
```

Fig. B-1. Continued.

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RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                    85/08/01.                        PAGE     49

TRACEBACK INITIATED BY JPROP AT LINE 275, REL(ABS) ADDRESS 244(125407).
CALLED BY VFINL AT LINE 317, ADDRESS 330(1474:6) WITH APLIST 604(147672).
CALLED BY HYDRO AT LINE 98, ADDRESS 65(123661) WITH NO AP-LIST.
CALLED BY TRAN AT LINE 76, ADDRESS 54(161233) WITH NO AP-LIST.
CALLED BY TRNCTL AT LINE 22, ADDRESS 7(46512) WITH NO AP-LIST.
CALLED BY RELAP5 AT LINE 1445, ADDRESS 3745(10563) WITH NO AP-LIST.

JUNCTION DONORED PROPERTIES, ICHOKE =  1
************************************************************************************************************************************
I      JUNNO(I)    VELFJ(I)      VOIDFJ(I)      RHOFJ(I)     QUALAJ(I)    UFJ(I)        JC(I)                 K      VOLNO(K)    VOIDG(K)
                   VELGJ(I)      VOIDGJ(I)      RHOGJ(I)     VOIDS        UGJ(I)        JC(I+1)               L      VOLNO(L)    VOIDG(L)
************************************************************************************************************************************
39988 003010000  8.09849E-02   1.0000          832.67      0.            9.78293E+05   00126561126344126345  38369  003010000   0.
                 8.09849E-02   0.               36.532      1.0000       2.58184E+06   10126565126347126346  38446  003020000   0.
40023 003020000   .16419       1.0000          832.67      0.            9.78293E+05   00126565126347126350  38446  003020000   0.
                  .16419       0.               36.532      1.0000       2.58184E+06   10126571126352126351  38523  003030000   0.
40058 003030000   .25191       1.0000          832.67      0.            9.78293E+05   00126571126352126353  38523  003030000   0.
                  .25191       0.               36.532      1.0000       2.58184E+06   10126575126355126354  38600  003040000   0.
40093 003040000   .34655       1.0000          832.67      0.            9.78293E+05   00126575126355126356  38600  003040000   0.
                  .34655       0.               36.532      1.0000       2.58184E+06   10126601126360126357  38677  003050000   0.
40128 003050000   .45071       1.0000          832.67      0.            9.78293E+05   00126601126360126361  38677  003050000   0.
                  .45071       0.               36.532      1.0000       2.58184E+06   10126605126363126362  38754  003060000   0.
40163 003060000   .56725       1.0000          832.67      0.            9.78293E+05   00126605126363126364  38754  003060000   0.
                  .56725       0.               36.532      1.0000       2.58184E+06   10126611126366126365  38831  003070000   0.
40198 003070000   .69937       1.0000          832.67      0.            9.78293E+05   00126611126366126367  38831  003070000   0.
                  .69937       0.               36.532      1.0000       2.58184E+06   10126615126371126370  38908  003080000   0.
40233 003080000   .85071       1.0000          832.67      0.            9.78293E+05   00126615126371126372  38908  003080000   0.
                  .85071       0.               36.532      1.0000       2.58184E+06   10126621126374126373  38985  003090000   0.
40268 003090000  1.0254        1.0000          832.67      0.            9.78293E+05   00126621126374126375  38985  003090000   0.
                 1.0254        0.               36.532      1.0000       2.58184E+06   10126625126377126376  39062  003100000   0.
40303 003100000  1.2283        1.0000          832.67      0.            9.78293E+05   00126625126377126400  39052  003100000   0.
                 1.2283        0.               36.532      1.0000       2.58184E+06   10126631126402126401  39139  003110000   0.
40338 003110000  1.4649        1.0000          832.67      0.            9.78293E+05   00126631126402126403  39139  003110000   0.
                 1.4649        0.               36.532      1.0000       2.58184E+06   10126635126405126404  39216  003120000   0.
40373 003120000  1.7417        1.0000          832.67      0.            9.78293E+05   00126635126405126406  39216  003120000   0.
                 1.7417        0.               36.532      1.0000       2.58184E+06   10126641126410126407  39293  003130000   0.
40408 003130000  2.0664        1.0000          832.67      0.            9.78293E+05   00126641126410126411  39293  003130000   0.
                 2.0664        0.               36.532      1.0000       2.58184E+06   10126645126413126412  39370  003140000   0.
40443 003140000  2.4479        1.0000          832.67      0.            9.78293E+05   00126645126413126414  39370  003140000   0.
                 2.4479        0.               36.532      1.0000       2.58184E+06   10126651126416126415  39447  003150000   0.
40478 003150000  2.8966        1.0000          832.67      0.            9.78293E+05   00126651126416126417  39447  003150000   0.
                 2.8966        0.               36.532      1.0000       2.58184E+06   10126655126421126420  39524  003160000   0.
40513 003160000  3.4248        1.0000          832.67      0.            9.78293E+05   00126655126421126422  39524  003160000   0.
                 3.4248        0.               36.532      1.0000       2.58184E+06   10126661126424126423  39601  003170000   0.
40548 003170000  4.0472        1.0000          832.67      0.            9.78293E+05   00126661126424126425  39601  003170000   0.
                 4.0472        0.               36.532      1.0000       2.58184E+06   10126665126427126426  39678  003180000   0.
40583 003180000  4.7807        1.0000          832.67      0.            9.78293E+05   00126665126427126430  39678  003180000   0.
                 4.7807        0.               36.532      1.0000       2.58184E+06   10126671126432126431  39755  003190000   0.
40618 003190000  5.6455        1.0000          832.67      0.            9.78293E+05   00126671126432126433  39755  003190000   0.
                 5.6455        0.               36.532      1.0000       2.58184E+06   10126675126435126434  39832  003200000   0.
40653 004000000  7.6614        1.0000          832.67      0.            9.78293E+05   00126675126435126436  39832  003200000   0.
                 7.6614        0.               36.532      1.0000       2.58184E+06   10126701126437000000  39909  005010000     1.0000
```

Fig. B-1. Continued.

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RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                          PAGE     50
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                        85/08/01.
##########################################################################################################################
VFINL       DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =         1, HELP =  3, SUCCES =  0, FAIL = F

FINAL JUNCTION VELOCITIES AND FLOWS
--------------------------------------------------------------------------------------------------------------------------
I      JUNNO(I)    FLAG         AJUN(I)       VOIDFJ(I)     RHOFJ(I)      VELFJ(I)     J      VFDPK(J)      VGDPK(J)       K   P(K)-PC(K)
                                MFLOWJ(I)     VOIDGJ(I)     RHOGJ(I)      VELGJ(I)            VFDPL(J)      VGDPL(J)       L   P(L)-PO(L)
--------------------------------------------------------------------------------------------------------------------------
39988 003010000                 4.56037E-03    1.0000        832.67       8.09849E-02 44485  5.86404E-06   5.86404E-06     1  -5.02765E+05
                                 .30752       0.             36.532       8.09849E-02        5.86404E-06   5.86404E-06     2  -5.16575E+05
40023 003020000                 4.56037E-03    1.0000        832.67        .16419     44489  5.86404E-06   5.86404E-06     2  -5.16575E+05
                                 .62349       0.             36.532        .16419            5.86404E-06   5.86404E-06     3  -5.44576E+05
40058 003030000                 4.56037E-03    1.0000        832.67        .25191     44493  5.86404E-06   5.86404E-06     3  -5.44576E+05
                                 .95658       0.             36.532        .25191            5.86404E-06   5.86404E-06     4  -5.87535E+05
40093 003040000                 4.56037E-03    1.0000        832.67        .34655     44497  5.86404E-06   5.86404E-06     4  -5.87535E+05
                                1.3160        0.             36.532        .34655            5.86404E-06   5.86404E-06     5  -6.46633E+05
40128 003050000                 4.56037E-03    1.0000        832.67        .45071     44501  5.86404E-06   5.86404E-06     5  -6.46633E+05
                                1.7115        0.             36.532        .45071            5.86404E-06   5.86404E-06     6  -7.23494E+05
40163 003060000                 4.56037E-03    1.0000        832.67        .56725     44505  5.86404E-06   5.86404E-06     6  -7.23494E+05
                                2.1540        0.             36.532        .56725            5.86404E-06   5.86404E-06     7  -8.20228E+05
40198 003070000                 4.56037E-03    1.0000        832.67        .69937     44509  5.86404E-06   5.86404E-06     7  -8.20228E+05
                                2.6557        0.             36.532        .69937            5.86404E-06   5.86404E-06     8  -9.39493E+05
40233 003080000                 4.56037E-03    1.0000        832.67        .85071     44513  5.86404E-06   5.86404E-06     8  -9.39493E+05
                                3.2304        0.             36.532        .85071            5.86404E-06   5.86404E-06     9  -1.08456E+06
40268 003090000                 4.56037E-03    1.0000        832.67       1.0254      44517  5.86404E-06   5.86404E-06     9  -1.08456E+06
                                3.8937        0.             36.532       1.0254             5.86404E-06   5.86404E-06    10  -1.25943E+06
40303 003100000                 4.56037E-03    1.0000        832.67       1.2283      44521  5.86404E-06   5.86404E-06    10  -1.25943E+06
                                4.6641        0.             36.532       1.2283             5.86404E-06   5.86404E-06    11  -1.46889E+06
40338 003110000                 4.56037E-03    1.0000        832.67       1.4649      44525  5.86404E-06   5.86404E-06    11  -1.46889E+06
                                5.5625        0.             36.532       1.4649             5.86404E-06   5.86404E-06    12  -1.71869E+06
40373 003120000                 4.56037E-03    1.0000        832.67       1.7417      44529  5.86404E-06   5.86404E-06    12  -1.71869E+06
                                6.6138        0.             36.532       1.7417             5.86404E-06   5.86404E-06    13  -2.01571E+06
40408 003130000                 4.56037E-03    1.0000        832.67       2.0664      44533  5.86404E-06   5.86404E-06    13  -2.01571E+06
                                7.8467        0.             36.532       2.0664             5.86404E-06   5.86404E-06    14  -2.36810E+06
40443 003140000                 4.56037E-03    1.0000        832.67       2.4479      44537  5.86404E-06   5.86404E-06    14  -2.36810E+06
                                9.2952        0.             36.532       2.4479             5.86404E-06   5.86404E-06    15  -2.78554E+06
40478 003150000                 4.56037E-03    1.0000        832.67       2.8966      44541  5.86404E-06   5.86404E-06    15  -2.78554E+06
                               10.999         0.             36.532       2.8966             5.86404E-06   5.86404E-06    16  -3.27949E+06
40513 003160000                 4.56037E-03    1.0000        832.67       3.4248      44545  5.86404E-06   5.86404E-06    16  -3.27949E+06
                               13.005         0.             36.532       3.4248             5.86404E-06   5.86404E-06    17  -3.86353E+06
40548 003170000                 4.56037E-03    1.0000        832.67       4.0472      44549  5.86404E-06   5.86404E-06    17  -3.86353E+06
                               15.368         0.             36.532       4.0472             5.86404E-06   5.86404E-06    18  -4.55369E+06
40583 003180000                 4.56037E-03    1.0000        832.67       4.7807      44553  5.86404E-06   5.86404E-06    18  -4.55369E+06
                               18.153         0.             36.532       4.7807             5.86404E-06   5.86404E-06    19  -5.36894E+06
40618 003190000                 4.56037E-03    1.0000        832.67       5.6455      44557  5.86404E-06   5.86404E-06    19  -5.36894E+06
                               21.437         0.             36.532       5.6455             5.86404E-06   5.86404E-06    20  -6.33167E+06
40653 004000000                 3.96752E-03    1.0000        832.67       7.6614      44561  1.34806E-05   1.34806E-05    20  -6.33167E+06
                               25.310         0.             36.532       7.6614             1.34806E-05   1.34806E-05    21   0.
```

Fig. B-1. Continued.

```
RELAP5/2/36.01      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                    PAGE      51
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                           85/06/01.
**************************************************************************************************************************
EQFINL     DIAGNOSTIC PRINTOUT, TIMEHY =  1.0000000E-03, DT =  1.0000000E-03, NCOUNT =           1, HELP =  3, SUCCES =  0, FAIL = F
COMMON 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     1.0000         832.67        8.09849E-02    9.78293E+05   3.07521E-04 -3.07521E-04  3.07521E-04
                  0.             0.               36.532       8.09849E-02    2.58184E+06   0.
003020000      2  4.56037E-03     1.0000         832.67         .16419        9.78293E+05   6.23490E-04 -6.23490E-04  6.23490E-04
                  0.             0.               36.532        .16419        2.58184E+06   0.
003030000      3  4.56037E-03     1.0000         832.67         .25191        9.78293E+05   9.56585E-04 -9.56585E-04  9.56585E-04
                  0.             0.               36.532        .25191        2.58184E+06   0.
003040000      4  4.56037E-03     1.0000         832.67         .34655        9.78293E+05   1.31596E-03 -1.31596E-03  1.31596E-03
                  0.             0.               36.532        .34655        2.58184E+06   0.
003050000      5  4.56037E-03     1.0000         832.67         .45071        9.78293E+05   1.71148E-03 -1.71148E-03  1.71148E-03
                  0.             0.               36.532        .45071        2.58184E+06   0.
003060000      6  4.56037E-03     1.0000         832.67         .56725        9.78293E+05   2.15401E-03 -2.15401E-03  2.15401E-03
                  0.             0.               36.532        .56725        2.58184E+06   0.
003070000      7  4.56037E-03     1.0000         832.67         .69937        9.78293E+05   2.65571E-03 -2.65571E-03  2.65571E-03
                  0.             0.               36.532        .69937        2.58184E+06   0.
003080000      8  4.56037E-03     1.0000         832.67         .85071        9.78293E+05   3.23036E-03 -3.23036E-03  3.23036E-03
                  0.             0.               36.532        .85071        2.58184E+06   0.
003090000      9  4.56037E-03     1.0000         832.67        1.0254         9.78293E+05   3.89374E-03 -3.89374E-03  3.89374E-03
                  0.             0.               36.532       1.0254         2.58184E+06   0.
003100000     10  4.56037E-03     1.0000         832.67        1.2283         9.78293E+05   4.66408E-03 -4.66408E-03  4.66408E-03
                  0.             0.               36.532       1.2283         2.58184E+06   0.
003110000     11  4.56037E-03     1.0000         832.67        1.4649         9.78293E+05   5.56254E-03 -5.56254E-03  5.56254E-03
                  0.             0.               36.532       1.4649         2.58184E+06   0.
003120000     12  4.56037E-03     1.0000         832.67        1.7417         9.78293E+05   6.61380E-03 -6.61380E-03  6.61380E-03
                  0.             0.               36.532       1.7417         2.58184E+06   0.
003130000     13  4.56037E-03     1.0000         832.67        2.0664         9.78293E+05   7.84673E-03 -7.84673E-03  7.84673E-03
                  0.             0.               36.532       2.0664         2.58184E+06   0.
003140000     14  4.56037E-03     1.0000         832.67        2.4479         9.78293E+05   9.29520E-03 -9.29520E-03  9.29520E-03
                  0.             0.               36.532       2.4479         2.58184E+06   0.
003150000     15  4.56037E-03     1.0000         832.67        2.8966         9.78293E+05   1.09990E-02 -1.09990E-02  1.09990E-02
                  0.             0.               36.532       2.8966         2.58184E+06   0.
003160000     16  4.56037E-03     1.0000         832.67        3.4248         9.78293E+05   1.30049E-02 -1.30049E-02  1.30049E-02
                  0.             0.               36.532       3.4248         2.58184E+06   0.
003170000     17  4.56037E-03     1.0000         832.67        4.0472         9.78293E+05   1.53681E-02 -1.53681E-02  1.53681E-02
                  0.             0.               36.532       4.0472         2.58184E+06   0.
003180000     18  4.56037E-03     1.0000         832.67        4.7807         9.78293E+05   1.81534E-02 -1.81534E-02  1.81534E-02
                  0.             0.               36.532       4.7807         2.58184E+06   0.
003190000     19  4.56037E-03     1.0000         832.67        5.6455         9.78293E+05   2.14374E-02 -2.14374E-02  2.14374E-02
                  0.             0.               36.532       5.6455         2.58184E+06   0.
004000000     20  3.96752E-03     1.0000         832.67        7.6614         9.78293E+05   2.53102E-02 -2.53102E-02  2.53102E-02
                  0.             0.               36.532       7.6614         2.58184E+06   0.
FROM-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.             0.             303.43                   2  0.            0.            303.43
003020000      2               2  0.             0.             615.20                   3  0.            0.            615.20
003030000      3               3  0.             0.             943.86                   4  0.            0.            943.86
003040000      4               4  0.             0.             1298.5                   5  0.            0.            1298.5
```

Fig. 5-1. Continued.

```
RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                  PAGE      52
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                       83/08/01.
003050000        5              5  0.              0.              1698.7               6  0.              0.              1688.7
003060000        6              6  0.              0.              2125.4               7  0.              0.              2125.4
003070000        7              7  0.              0.              2620.4               8  0.              0.              2620.4
003080000        8              8  0.              0.              3187.4               9  0.              0.              3187.4
003090000        9              9  0.              0.              3842.0              10  0.              0.              3842.0
003100000       10             10  0.              0.              4602.1              11  0.              0.              4602.1
003110000       11             11  0.              0.              5488.6              12  0.              0.              5488.6
003120000       12             12  0.              0.              6525.8              13  0.              0.              6525.8
003130000       13             13  0.              0.              7742.4              14  0.              0.              7742.4
003140000       14             14  0.              0.              9171.6              15  0.              0.              9171.6
003150000       15             15  0.              0.              10853.              16  0.              0.              10853.
003160000       16             16  0.              0.              12832.              17  0.              0.              12832.
003170000       17             17  0.              0.              15164.              18  0.              0.              15164.
003180000       18             18  0.              0.              17912.              19  0.              0.              17912.
003190000       19             19  0.              0.              21152.              20  0.              0.              21152.
004000000       20             20  0.              0.              24974.              21  0.              0.              24764.
VOLUME DATA
*****************************************************************************************************************************************
VOLNO            I  SOURCF(I)      SOURCM(I)    SOURCP(I)     PO(I)         UGO(I)        UFO(I)        VOIDGO(I)     QUALAU(I)     RHOM(I)
                    SOURCG(I)      SOURCA(I)    DELXA(I)      P(I)          UG(I)         UF(I)         VOIDG(I)      QUALA(I)      DOTM(I)
*****************************************************************************************************************************************
003010000        1  -303.43        3.07521E-04 -3.07521E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.34
                    0.             0.           0.            6.49723E+06   2.58657E+06   9.78290E+05   0.            0.            0.
003020000        2  -311.77        3.15969E-04 -3.15969E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.33
                    0.             0.           0.            6.48342E+06   2.58670E+06   9.78290E+05   0.            0.            0.
003030000        3  -328.66        3.33095E-04 -3.33095E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.31
                    0.             0.           0.            6.45542E+06   2.58696E+06   9.78289E+05   0.            0.            0.
003040000        4  -354.59        3.59372E-04 -3.59372E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.28
                    0.             0.           0.            6.41247E+06   2.58737E+06   9.78289E+05   0.            0.            0.
003050000        5  -390.26        3.95520E-04 -3.95520E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.24
                    0.             0.           0.            6.35337E+06   2.58792E+06   9.78289E+05   0.            0.            0.
003060000        6  -436.65        4.42532E-04 -4.42532E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.19
                    0.             0.           0.            6.27651E+06   2.58865E+06   9.78288E+05   0.            0.            0.
003070000        7  -495.03        5.01700E-04 -5.01700E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.13
                    0.             0.           0.            6.17977E+06   2.58956E+06   9.78288E+05   0.            0.            0.
003080000        8  -567.01        5.74650E-04 -5.74650E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              832.05
                    0.             0.           0.            6.06051E+06   2.59068E+06   9.78287E+05   0.            0.            0.
003090000        9  -654.56        6.63385E-04 -6.63385E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              831.96
                    0.             0.           0.            5.91544E+06   2.59204E+06   9.78286E+05   0.            0.            0.
003100000       10  -760.10        7.70342E-04 -7.70342E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              831.84
                    0.             0.           0.            5.74057E+06   2.59369E+06   9.78285E+05   0.            0.            0.
003110000       11  -886.51        8.98459E-04 -8.98459E-04   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              831.70
                    0.             0.           0.            5.53111E+06   2.59566E+06   9.78283E+05   0.            0.            0.
003120000       12  -1037.3        1.05126E-03 -1.05126E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              831.54
                    0.             0.           0.            5.28131E+06   2.59801E+06   9.78282E+05   0.            0.            0.
003130000       13  -1216.5        1.23293E-03 -1.23293E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              831.35
                    0.             0.           0.            4.98429E+06   2.60080E+06   9.78280E+05   0.            0.            0.
003140000       14  -1429.2        1.44847E-03 -1.44847E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              831.12
                    0.             0.           0.            4.63190E+06   2.60412E+06   9.78277E+05   0.            0.            0.
003150000       15  -1681.1        1.70380E-03 -1.70380E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              830.84
                    0.             0.           0.            4.21446E+06   2.60804E+06   9.78275E+05   0.            0.            0.
003160000       16  -1979.3        2.00593E-03 -2.00593E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              830.52
                    0.             0.           0.            3.72051E+06   2.61269E+06   9.78271E+05   0.            0.            0.
003170000       17  -2331.7        2.36317E-03 -2.36317E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              830.14
                    0.             0.           0.            3.13647E+06   2.61819E+06   9.78267E+05   0.            0.            0.
003180000       18  -2748.3        2.78531E-03 -2.78531E-03   7.00000E+06   2.58184E+06   9.78293E+05   0.            0.              829.68
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Fig. B-1. Continued.

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RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                                            PAGE     53
 EDWARD'S PIFE PROBLEM BASE CASE WITH EXTRAS                                                                85/08/01.
                    0.               0.            0.            2.44631E+06  2.62468E+06  9.78263E+05  0.           0.           0.
003190000     19  -3240.3        3.28397E-03  -3.28397E-03  7.00000E+06  2.58184E+06  9.78293E+05  0.           0.            829.15
                    0.               0.            0.            1.63106E+06  2.63235E+06  9.78258E+05  0.           0.           0.
003200000     20  -3821.3        3.87283E-03  -3.87283E-03  7.00000E+06  2.58184E+06  9.78293E+05  0.           0.            828.52
                    0.               0.            0.            6.68327E+05  2.64140E+06  9.78251E+05  0.           0.           0.
005010000     21   24764.       -2.53102E-02   2.53102E-02  1.00000E+05  2.50606E+06  4.17407E+05   1.0000      0.            .59041
                    0.               0.            0.            1.00000E+05  2.50606E+06  4.17407E+05   1.0000      0.           0.
#######################################################################################################################################
STATE      DIAGNOSTIC PRINTOUT, TIMEHY =   1.0000000E-03, DT =   1.0000000E-03, NCOUNT =              1, HELP =   3, SUCCES =   1, FAIL = F
VOLUME MIXTURE PROPERITES
---------------------------------------------------------------------------------------------------------------------------------------
I      VOLNO      V            P            PPS          VOIDG        QUALS        QUALE        QUALA        SATT         RHO
                  SOUNDE       DSNDLP       SIGMA        DOTM         JOTMO        BORON        BORONO
---------------------------------------------------------------------------------------------------------------------------------------
38369 003010000  9.33968E-04  6.49723E+06  6.49723E+06  0.           0.           0.           0.            553.94       832.34
                   1233.7     0.           1.88803E-02  0.           0.           0.           0.
38446 003020000  9.33968E-04  6.48342E+06  6.48342E+06  0.           0.           0.           0.            553.80       832.33
                   1233.6     0.           1.89137E-02  0.           0.           0.           0.
38523 003030000  9.33968E-04  6.45542E+06  6.45542E+06  0.           0.           0.           0.            553.51       832.31
                   1233.5     0.           1.89816E-02  0.           0.           0.           0.
38600 003040000  9.33968E-04  6.41247E+06  6.41247E+06  0.           0.           0.           0.            553.07       832.28
                   1233.3     0.           1.90863E-02  0.           0.           0.           0.
38677 003050000  9.33968E-04  6.35337E+06  6.35337E+06  0.           0.           0.           0.            552.46       832.24
                   1233.1     0.           1.92312E-02  0.           0.           0.           0.
38754 003060000  9.33968E-04  6.27651E+06  6.27651E+06  0.           0.           0.           0.            551.65       832.19
                   1232.8     0.           1.94214E-02  0.           0            0.           0.
38831 003070000  9.33968E-04  6.17977E+06  6.17977E+06  0.           0.           0.           0.            550.63       832.13
                   1232.[illegible] 0.     1.95634E-02  0.           0.           0.           0.
38908 003080000  9.33968E-04  6.06051E+06  6.06051E+06  0.           0.           0.           0.            549.35       832.05
                   1231.9     0.           1.99659E-02  0.           0.           0.           0.
38985 003090000  9.33968E-04  5.91544E+06  5.91544E+06  0.           0.           0.           0.            547.78       831.95
                   1231.3     0.           2.03405E-02  0.           0.           0.           0.
39062 003100000  9.33968E-04  5.74057E+06  5.74057E+06  0.           0.           0.           0.            545.83       831.84
                   1230.6     0.           2.08017E-02  0.           0.           0.           0.
39139 003110000  9.33968E-04  5.53111E+06  5.53111E+06  0.           0.           0.           0.            543.44       831.70
                   1229.7     0.           2.13689E-02  0.           0.           0.           0.
39216 003120000  9.33968E-04  5.28131E+06  5.28131E+06  0.           0.           0.           0.            540.50       831.54
                   1228.7     0.           2.20678E-02  0.           0.           0.           0.
39293 003130000  9.33968E-04  4.98429E+06  4.98429E+06  0.           0.           0.           0.            536.86       831.34
                   1227.5     0.           2.29328E-02  0.           0.           0.           0.
39370 003140000  9.33968E-04  4.63190E+06  4.63190E+06  0.           0.           0.           0.            532.33       831.10
                   1226.1     0.           2.40118E-02  0.           0.           0.           0.
39447 003150000  9.33968E-04  4.21446E+06  4.21446E+06  0.           0.           0.           0.            526.60       830.83
                   1224.4     0.           2.53732E-02  0.           0.           0.           0.
39524 003160000  9.33968E-04  3.72051E+06  3.72051E+06  0.           0.           0.           0.            519.23       830.50
                   1222.4     0.           2.71206E-02  0.           0.           0.           0.
39601 003170000  9.33968E-04  3.13647E+06  3.13647E+06  0.           0.           0.           0.            509.47       830.11
                   1220.1     0.           2.94221E-02  0.           0.           0.           0.
39678 003180000  9.33968E-04  2.44631E+06  2.44631E+06  0.           0.           1.49001E-02  0.            495.94       829.77
                   35.027     0.           3.25839E-02  0.           0.           0.           0.
39755 003190000  9.33968E-04  1.63106E+06  1.63106E+06  0.           0.           6.77102E-02  0.            475.45       831.83
                   84.477     0.           3.72867E-02  0.           0.           0.           0.
39832 003200000  9.33966E-04  6.68327E+05  6.68327E+05  0.           0.            .15414      0.            436.25       842.21
                   151.64     0.           4.59283E-02  0.           0            0.           0.
39909 005010000  0.           1.00000E+05  1.00000E+05   1.0000       1.0000       1.0000      0.            372.78       .59041
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Fig. B-1. Continued.

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RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM B.SE CASE WITH EXTRAS                              85/08/01.                          PAGE       54
               473.21         0.              5.89515E-02  0.           0.           0.           0.
VOLUME PHASE PROPERTIES
-----------------------------------------------------------------------------------------------------------------------------------
I       VOLNO       VOIDF        RHOF        UF            TEMPF       SATHF         BETAFF        CSUBPF        VISCF         THCONF
                    VOIDG        RHOG        UG            TEMPG       SATHG         BETAGG        CSUBPG        VISCG         THCONG
-----------------------------------------------------------------------------------------------------------------------------------
38369 003010000    1.0000       832.34      9.78290E+05   502.08      1.24112E+06   1.61824E-03   4644.3        1.17618E-04    .63574
                   0.            33.632     2.58609E+06   553.94      2.77927E+06   5.50549E-03   4811.4        1.87911E-05   6.13144E-02
38446 003020000    1.0000       832.33      9.78290E+05   502.07      1.24038E+06   1.61837E-03   4644.4        1.17616E-04    .63574
                   0.            33.554     2.58621E+     553.80      2.77944E+06   5.49726E-03   4805.1        1.87841E-05   6.12477E-02
38523 003030000    1.0000       832.31      9.78289E+0    502.07      1.23887E+06   1.61862E-03   4644.6        1.17612E-04    .63574
                   0.            33.394     2.58646E+06   553.51      2.77976E+06   5.48052E-03   4792.2        1.87700E-05   6.11126E-02
38600 003040000    1.0000       832.28      9.78289E+05   502.06      1.23654E+06   1.61901E-03   4644.9        1.17606E-04    .63575
                   0.            33.150     2.58683E+06   553.07      2.78027E+06   5.45469E-03   4772.4        1.87483E-05   6.09055E-02
38677 003050000    1.0000       832.24      9.78289E+05   502.05      1.23332E+06   1.61955E-03   4645.3        1.17599E-04    .63577
                   0.            32.815     2.58735E+06   552.46      2.78096E+06   5.41888E-03   4744.9        1.87184E-05   6.06211E-02
38754 003060000    1.0000       832.19      9.78288E+05   502.03      1.22911E+06   1.62025E-03   4645.8        1.17588E-04    .63578
                   0.            32.380     2.58804E+06   551.65      2.78187E+06   5.37179E-03   4708.9        1.86795E-05   6.02521E-02
38831 003070000    1.0000       832.13      9.78288E+05   502.01      1.22374E+06   1.62114E-03   4646.5        1.17576E-04    .63580
                   0.            31.835     2.58891E+06   550.63      2.78302E+06   5.31171E-03   4663.1        1.86304E-05   5.97887E-02
38908 003080000    1.0000       832.05      9.78287E+05   501.99      1.21709E+06   1.62223E-03   4647.3        1.17560E-04    .63583
                   0.            31.166     2.58991E+06   549.35      2.78436E+06   5.24133E-03   4508.7        1.85697E-05   5.92194E-02
38985 003090000    1.0000       831.95      9.78286E+05   501.96      1.20897E+06   1.62356E-03   4648.4        1.17541E-04    .63586
                   0.            30.357     2.59094E+06   547.78      2.78580E+06   5.16575E-03   4548.6        1.84956E-05   5.85296E-02
39062 003100000    1.0000       831.84      9.78285E+05   501.92      1.19903E+06   1.62517E-03   4649.6        1.17518E-04    .63590
                   0.            29.389     2.59211E+06   545.83      2.78744E+06   5.07725E-03   4477.5        1.84058E-05   5.77019E-02
39139 003110000    1.0000       831.70      9.78283E+05   501.87      1.18683E+06   1.62710E-03   4651.1        1.17490E-04    .63594
                   0.            28.238     2.59355E+06   543.44      2.78943E+06   4.96763E-03   4390.1        1.82975E-05   5.67154E-02
39216 003120000    1.0000       831.54      9.78282E+05   501.82      1.17182E+06   1.62942E-03   4652.9        1.17438E-04    .63599
                   0.            26.878     2.59533E+06   540.50      2.79182E+06   4.83133E-03   4282.5        1.81670E-05   5.55446E-02
39293 003130000    1.0000       831.34      9.78280E+05   501.76      1.15349E+06   1.63218E-03   4655.0        1.17419E-04    .63606
                   0.            25.278     2.59711E+06   536.86      2.79428E+06   4.68234E-03   4161.9        1.80096E-05   5.41588E-02
39370 003140000    1.0000       831.10      9.78277E+05   501.68      1.13091E+06   1.63548E-03   4657.5        1.17373E-04    .63613
                   0.            23.404     2.59882E+06   532.33      2.79673E+06   4.51842E-03   4025.5        1.78189E-05   5.25206E-02
39447 003150000    1.0000       830.83      9.78275E+05   501.60      1.10266E+06   1.63942E-03   4660.5        1.17318E-04    .63622
                   0.            21.214     2.60056E+06   526.60      2.79922E+06   4.32664E-03   3864.2        1.75860E-05   5.05829E-02
39524 003160000    1.0000       830.50      9.78271E+05   501.49      1.06678E+06   1.64411E-03   4664.1        1.17254E-04    .63633
                   0.            18.662     2.60200E+06   519.23      2.80136E+06   4.10819E-03   3676.0        1.72973E-05   4.82829E-02
39601 003170000    1.0000       830.11      9.78267E+05   501.37      1.02009E+06   1.64970E-03   4668.3        1.17179E-04    .63645
                   0.            15.695     2.60250E+06   509.47      2.80234E+06   3.86587E-03   3457.8        1.69304E-05   4.55297E-02
39678 003180000    1.0000       829.77      9.78263E+05   501.24      9.56644E+05   1.58054E-03   4632.7        1.19928E-04    .63658
                   0.            12.249     2.60087E+06   495.94      2.80059E+06   3.59623E-03   3199.3        1.64419E-05   4.21748E-02
39755 003190000    1.0000       831.83      9.78258E+05   501.49      8.62790E+05   1.34409E-03   4509.1        1.32267E-04    .63633
                   0.            8.2370     2.59417E+06   475.45      2.79218E+06   3.29055E-03   2876.3        1.57262E-05   3.79097E-02
39832 003200000    1.0000       842.21      9.78251E+05   502.93      6.89042E+05   1.02843E-03   4349.3        1.65653E-04    .63488
                   0.            3.5107     2.56941E+06   436.25      2.75978E+06   2.95691E-03   2428.4        1.43636E-05   3.16966E-02
39909 005010000    0.           958.39      4.17407E+05   372.78      4.17511E+05   7.52775E-04  -3.31054E+05   2.80062E-04   0.
                   1.0000        .59041     2.50606E+06   372.78      2.67543E+06   2.88839E-03    .24748       1.20200E-05   3.31069E+05
DERIVATIVES
-----------------------------------------------------------------------------------------------------------------------------------
I       VOLNO       DRFDP         DRFDUF         DRGDP         DRGDUG         DRGDXA      DTFDP         DTFDUF        DTGDP         DTGDUG
                    DTGDXA        DTDP           DTDJG         DTDXA
-----------------------------------------------------------------------------------------------------------------------------------
38369 003010000    6.58868E-07  -2.90809E-04    5.26998E-06  -4.94050E-05    0.          2.08853E-07   2.15906E-04   1.25550E-05   2.66819E-04
                   0.             1.02272E-05   0.             0.
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Fig. B-1.   Continued.

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RELAP5/2/36.01       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                                   85/08/01.                                       PAGE       55
38446 003020000  6.58924E-07 -2.90821E-04  5.26880E-06 -4.92811E-05  0.         2.08868E-07  2.15901E-04  1.25680E-05  2.67173E-04
                 0.           1.02438E-05  0.           0.
38523 003030000  6.59037E-07 -2.90844E-04  5.26647E-06 -4.90300E-05  0.         2.08900E-07  2.15889E-04  1.25942E-05  2.67897E-04
                 0.           1.02777E-05  0.           0.
38600 003040000  6.59210E-07 -2.90881E-04  5.26308E-06 -4.86449E-05  0.         2.08949E-07  2.15871E-04  1.26340E-05  2.69018E-04
                 0.           1.03302E-05  0.           0.
38677 003050000  6.59449E-07 -2.90931E-04  5.25875E-06 -4.81150E-05  0.         2.09017E-07  2.15847E-04  1.26878E-05  2.70582E-04
                 0.           1.04033E-05  0.           0.
38754 003060000  6.59758E-07 -2.90997E-04  5.25373E-06 -4.74260E-05  0.         2.09105E-07  2.15815E-04  1.27562E-05  2.72656E-04
                 0.           1.05001E-05  0.           0.
38831 003070000  6.60147E-07 -2.91079E-04  5.24838E-06 -4.65588E-05  0.         2.09215E-07  2.15775E-04  1.28394E-05  2.75334E-04
                 0.           1.06247E-05  0.           0.
38908 003080000  6.60626E-07 -2.91181E-04  5.24012E-06 -4.55080E-05  0.         2.09352E-07  2.15726E-04  1.29519E-05  2.78588E-04
                 0.           1.07837E-05  0.           0.
38985 003090000  6.61218E-07 -2.91305E-04  5.22471E-06 -4.42743E-05  0.         2.09519E-07  2.15665E-04  1.31197E-05  2.82331E-04
                 0.           1.09863E-05  0.           0.
39062 003100000  6.61939E-07 -2.91455E-04  5.20600E-06 -4.28072E-05  0.         2.09720E-07  2.15593E-04  1.33329E-05  2.86886E-04
                 0.           1.12425E-05  0.           0.
39139 003110000  6.62799E-07 -2.91635E-04  5.18816E-06 -4.10514E-05  0.         2.09961E-07  2.15505E-04  1.35794E-05  2.92650E-04
                 0.           1.15668E-05  0.           0.
39216 003120000  6.63820E-07 -2.91851E-04  5.17352E-06 -3.89583E-05  0.         2.10250E-07  2.15401E-04  1.38551E-05  3.00012E-04
                 0.           1.19812E-05  0.           0.
39293 003130000  6.65029E-07 -2.92109E-04  5.15185E-06 -3.65465E-05  0.         2.10596E-07  2.15277E-04  1.42384E-05  3.08772E-04
                 0.           1.25234E-05  0.           0.
39370 003140000  6.66499E-07 -2.92415E-04  5.123[illegible]-06 -3.37711E-05  0.         2.11008E-07  2.15129E-04  1.47672E-05  3.19358E-04
                 0.           1.32473E-05  0.           0.
39447 003150000  6.68227E-07 -2.92782E-04  5.09680E-06 -3.05469E-05  0.         2.11499E 07  ?.14953E-04  1.54417E-05  3.32813E-04
                 0.           1.42407E-05  0.           0.
39524 003160000  6.70281E-07 -2.93218E-04  5.07114E-06 -2.68352E-05  0.         2.12084E-0    .14744E-04  1.63565E-05  3.50019E-04
                 0.           1.56679E-05  0.           0.
39601 003170000  6.72674E-07 -2.93739E-04  5.03651E-06 -2.25956E-05  0.         2.12781E-07  2.14498E-04  1.77085E-05  3.72396E-04
                 0.           1.78638E-05  0.           0.
39678 003180000  6.40019E-07 -2.83380E-04  5.03126E-06 -1.77544E-05  0.         2.05602E-07  2.16075E-04  1.98708E-05  4.03057E-04
                 0.           2.16364E-05  0.           0.
39755 003190000  5.38245E-07 -2.48100E-04  5.05310E-06 -1.21835E-05  0.         1.79428E-07  2.21904E-04  2.38014E-05  4.49503E-04
                 0.           2.96308E-05  0.           0.
39832 003200000  4.22209E-07 -1.99187E-04  5.22985E-06 -5.56459E-06  0.         1.41111E-07  2.29967E-04  3.45252E-05  5.36050E-04
                 0.           5.97763E-05  0.           0.
39909 005010000  4.32702E-07 -1.71157E-04  5.88662E-06 -1.10920E-06  0.         6.94527E-08  2.37240E-04  6.66091E-05  6.56426E-04
                 0.           2.79462E-04  0.           0.
######################################################C#######################################################################
MASS ERROR DIAGNOSTIC PRINTOUT, TIMEHY =   1.0000000E-03, DT  =  1.0000000E-03, NCOUNT =          1, HELP =  3, SUCCES =  1, FAIL = F
VOLUME PROPERTIES
-----------------------------------------------------------------------------------------------------
I      VOLNO       V               RHO              RHOM             DRHO/RHOF      DRHO/RHO      V*DRHO
-----------------------------------------------------------------------------------------------------
38369 003010000   9.33968E-04     832.34           832.34          2.26722E-07   2.26722E-07 -1.76248E-07
38446 003020000   9.33968E-04     832.33           832.33          2.48562E-07   2.48562E-07 -1.93224E-07
38523 003030000   9.33968E-04     832.31           832.31          2.9541[illegible]-07   2.95414E-07 -2.29640E-07
38600 003040000   9.33968E-04     832.28           832.28          3.7399[illegible]-07   3.73992E-07 -2.90713E-07
38677 003050000   9.33968E-04     832.24           832.24          4.95348E-07   4.95348E-07 -3.85028E-07
38754 003060000   9.33968E-04     832.19           832.19          6.76172E-07   6.76172E-07 -5.25548E-07
38831 003070000   9.33968E-04     832.13           832.13          9.40755E-07   9.40755E-07 -7.31137E-07
38908 003080000   9.33968E-04     832.05           832.05          1.32383E-06   1.32383E-06 -1.02876E-06
38985 003090000   9.33968E-04     831.95           831.96          1.93760E-06   1.93760E-06 -1.50555E-06
```

Fig. B-1. Continued.

```
RELAP5/2/36.01        REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
 EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                  85/08/01.                        PAGE      56
39062 003100000  9.33968E-04   831.84        831.84       2.85599E-06  2.85599E-06 -2.21885E-06
39139 003110000  9.33968E-04   831.70        831.70       4.13552E-06  4.13552E-06 -3.21240E-06
39216 003120000  9.33968E-04   831.54        831.54       5.91829E-06  5.91829E-06 -4.59631E-06
39293 003130000  9.33968E-04   831.34        831.35       8.41523E-06  8.41523E-06 -6.53396E-06
39370 003140000  9.33968E-04   831.10        831.12       1.21500E-05  1.21500E-05 -9.43118E-06
39447 003150000  9.33968E-04   830.83        830.84       1.73071E-05  1.73071E-05 -1.34297E-05
39524 003160000  9.33968E-04   830.50        830.52       2.46078E-05  2.46078E-05 -1.90872E-05
39601 003170000  9.33968E-04   830.11        830.14       3.58471E-05  3.58471E-05 -2.77920E-05
39678 003180000  9.33968E-04   829.77        829.68       1.07800E-04  1.07800E-04  8.35432E-05
39755 003190000  9.33968E-04   831.83        829.15       3.21637E-03  3.21637E-03  2.49879E-03
39832 003200000  9.33968E-04   842.21        829.52       1.62543E-02  1.62543E-02  1.27856E-02
-----------------------------------------------------------------------------------------------
TOTAL MASS ERROR INCREMENT FOR THIS TIME STEP---------------------------------  1.52765E-02

#############################################################################################################################
JPROP        DIAGNOSTIC PRINTOUT, TIMEHY =   1.0000000E-03, DT =   1.0000000E-03, NCOUNT =         1, HELP =  3, SUCCES =  1, FAIL = F
TRACEBACK INITIATED BY JPROP AT LINE 275, REL(ABS) ADDRESS 244(125407).
CALLED BY HYDRO AT LINE 149, ADDRESS 150(123744) WITH APLIST 171(123765).
CALLED BY TRAN AT LINE 76, ADDRESS 54(161233) WITH NO AP-LIST.
CALLED BY TRNCTL AT LINE 22, ADDRESS 7(46512) WITH NO AP-LIST.
CALLED BY RELAP5 AT LINE 1445, ADDRESS 3745(10363) WITH NO AP-LIST.

JUNCTION DONOREL PROPERTIES, ICHOKE =  0
-----------------------------------------------------------------------------------------------------------------------------
I      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)       JC(I+1)               K             VOLNO(L)   VOIDG(L)
-----------------------------------------------------------------------------------------------------------------------------
39988 003010000  8.09849E-02    1.0000       832.34       0.           9.78290E+05  00126561126344126345  38369  003010000  0.
                 8.09849E-02    0.           33.632        1.0000      2.58609E+06  10126565126347126346  38446  003020000  0.
40023 003020000   .16419        1.0000       832.33       0.           9.78290E+05  00126565126347126350  38446  003020000  0.
                  .16419        0.           33.554        1.0000      2.58621E+06  10126571126352126351  38523  003030000  0.
40058 003030000   .25191        1.0000       832.31       0.           9.78289E+05  00126571126352126353  38523  003030000  0.
                  .25191        0.           33.394        1.0000      2.58646E+06  10126575126355126354  38600  003040000  0.
40093 003040000   .34655        1.0000       832.28       0.           9.78289E+05  00126575126355126356  38600  003040000  0.
                  .34655        0.           33.150        1.0000      2.58683E+06  10126601126360126357  38677  003050000  0.
40128 003050000   .45071        1.0000       832.24       0.           9.78289E+05  00126601126360126361  38677  003050000  0.
                  .45071        0.           32.815        1.0000      2.58735E+06  10126605126363126362  38754  003060000  0.
40163 003060000   .56725        1.0000       832.19       0.           9.78288E+05  00126605126363126364  38754  003060000  0.
                  .56725        0.           32.380        1.0000      2.58804E+06  10126611126366126365  38831  003070000  0.
40198 003070000   .69937        1.0000       832.13       0.           9.78288E+05  00126611126366126367  38831  003070000  0.
                  .69937        0.           31.835        1.0000      2.58891E+06  10126615126371126370  38908  003080000  0.
40233 003080000   .85071        1.0000       832.05       0.           9.78287E+05  00126615126371126372  38908  003080000  0.
                  .85071        0.           31.166        1.0000      2.58991E+06  10126621126374126373  38985  003090000  0.
40268 003090000  1.0254         1.0000       831.95       0.           9.78286E+05  00126621126374126375  38985  003090000  0.
                 1.0254         0.           30.357        1.0000      2.59094E+06  10126625126377126376  39062  003100000  0.
40303 003100000  1.2283         1.0000       831.84       0.           9.78285E+05  00126625126377126400  39062  003100000  0.
                 1.2283         0.           29.389        1.0000      2.59211E+06  10126631126402126401  39139  003110000  0.
40338 003110000  1.4649         1.0000       831.70       0.           9.78283E+05  00126631126402126403  39139  003110000  0.
                 1.4649         0.           28.238        1.0000      2.59355E+06  10126635126405126404  39216  003120000  0.
40373 003120000  1.7417         1.0000       831.54       0.           9.78282E+05  00126635126405126406  39216  003120000  0.
                 1.7417         0.           26.878        1.0000      2.59533E+06  10126641126410126407  39293  003130000  0.
40408 003130000  2.0664         1.0000       831.34       0.           9.78280E+05  00126641126410126411  39293  003130000  0.
                 2.0664         0.           25.278        1.0000      2.59711E+06  10126645126413126412  39370  003140000  0.
40443 003140000  2.4479         1.0000       831.10       0.           9.78277E+05  00126645126413126414  39370  003140000  0.
                 2.4479         0.           23.404        1.0000      2.59882E+06  10126651126416126415  39447  003150000  0.
40478 003150000  2.8966         1.0000       830.83       0.           9.78275E+05  00126651126416126417  39447  003150000  0.
                 2.8966         0.           21.214        1.0000      2.60056E+06  10126655126421126420  39524  003160000  0.
40513 003160000  3.4248         1.0000       830.50       0.           9.78271E+05  00126655126421126422  39524  003160000  0.
                 3.4248         0.           18.662        1.0000      2.60200E+06  10126661126424126423  39601  003170000  0.
40548 003170000  4.0472         1.0000       830.11       0.           9.78267E+05  00126661126424126425  39601  003170000  0.
                 4.0472         0.           15.695        1.0000      2.60250E+06  10126665126427126426  39678  003180000  0.
40583 003180000  4.7807         1.0000       829.77       0.           9.78263E+05  00126665126427126430  39678  003180000  0.
```

Fig. B-1. Continued.

```
                       4.7807       0.              12.249         1.0000           2.60087E+06  1012667112643212643I 39755 003190000  0.
40618 003190000        5.6455         1.0000        831.83        0.                9.78258E+05  0012667112643212643 3 39755 003190000  0.
                       5.6455       0.               8.2370          1.0000         2.59417E+06  10126675126435126434 39832 003200000  0.
40653 004000000        7.6614         1.0000        842.21        0.                9.78251E+05  00126675126435126436 39832 003200000  0.
                       7.6614       0.               3.5107         1.0000          2.56941E+06  10126701126437000000 39909 005010000    1.0000
#######################################################################################################################################
VLVELA      DIAGNOSTIC PRINTOUT, TIMEHY =   1.0000000E-03, DT =   1.0000000E-03, NCOUNT =          1, HELP =   3, SUCCES -   1, FAIL = F
TRACEBACK INITIATED BY VLVELA AT LINE 288, REL(ABS) ADDRESS 176(63027).
CALLED BY HYDRO AT LINE 150, ADDRESS 152(123746) WITH NO AP-LIST.
CALLED BY TRAN AT LINE 76, ADDRESS 54(161233) WITH NO AP-LIST.
CALLED BY TRNCTL AT LINE 22, ADDRESS 7(46512) WITH NO AP-LIST.
CALLED BY RELAP5 AT LINE 1445, ADDRESS 3745(10563) WITH NO AP-LIST.

VOLUME INLET AND OUTLET TERMS
-----------------------------------------------------------------------------------------------------------------------------
I       VOLNO(I)          L      J      K
        AVOL(I)         FLAG   LOOP    JX      JUNNO(JX) SN   AJUN(JX)      VOIDFJ(JX)     RHOFJ(JX)      VELFJ*SGN       ARAT(JX)
                                                              ATHROT(JX)    VOIDGJ(JX)     RHOGJ(JX)      VELGJ*SGN       ARAT(JX+1)
-----------------------------------------------------------------------------------------------------------------------------
38369 003010000          42547 42548 42548
        4.56037E-03 OUTLET 42548 39988 003010000  1  4.56037E-03    1.0000          832.34      8.09849E-02     1.0000
                                                      1.0000        0.              33.632      8.09849E-02     1.0000
38446 003020000          42549 42550 42551
        4.56037E-03 INLET  42550 39988 003010000  1  4.56037E-03    1.0000          832.34      8.09849E-02     1.0000
                                                      1.0000        0.              33.632      8.09849E-02     1.0000
                    OUTLET 42551 40023 003020000  1  4.56037E-03    1.0000          832.33        .16419        1.0000
                                                      1.0000        0.              33.554        .16419        1.0000
38523 003030000          42552 42553 42554
        4.56037E-03 INLET  42553 40023 003020000  1  4.56037E-03    1.0000          832.33        .16419        1.0000
                                                      1.0000        0.              33.554        .16419        1.0000
                    OUTLET 42554 40058 003030000  1  4.56037E-03    1.0000          832.31        .25191        1.0000
                                                      1.0000        0.              33.394        .25191        1.0000
38600 003040000          42555 42556 42557
        4.56037E-03 INLET  42556 40058 003030000  1  4.56037E-03    1.0000          832.31        .25191        1.0000
                                                      1.0000        0.              33.394        .25191        1.0000
                    OUTLET 42557 40093 003040000  1  4.56037E-03    1.0000          832.28        .34655        1.0000
                                                      1.0000        0.              33.150        .34655        1.0000
38677 003050000          42558 42559 42560
        4.56037E-03 INLET  42559 40093 003040000  1  4.56037E-03    1.0000          832.28        .34655        1.0000
                                                      1.0000        0.              33.150        .34655        1.0000
                    OUTLET 42560 40128 003050000  1  4.56037E-03    1.0000          832.24        .45071        1.0000
                                                      1.0000        0.              32.815        .45071        1.0000
38754 003060000          42561 42562 42563
        4.56037E-03 INLET  42562 40128 003050000  1  4.56037E-03    1.0000          832.24        .45071        1.0000
                                                      1.0000        0.              32.815        .45071        1.0000
                    OUTLET 42563 40163 003060000  1  4.56037E-03    1.0000          832.19        .56725        1.0000
                                                      1.0000        0.              32.380        .56725        1.0000
38831 003070000          42564 42565 42566
        4.56037E-03 INLET  42565 40163 003060000  1  4.56037E-03    1.0000          832.19        .56725        1.0000
                                                      1.0000        0.              32.380        .56725        1.0000
                    OUTLET 42566 40198 003070000  1  4.56037E-03    1.0000          832.13        .69937        1.0000
                                                      1.0000        0.              31.835        .69937        1.0000
38908 003080000          42567 42568 42569
        4.56037E-03 INLET  42568 40198 003070000  1  4.56037E-03    1.0000          832.13        .69937        1.0000
                                                      1.0000        0.              31.835        .69937        1.0000
                    OUTLET 42569 40233 003080000  1  4.56037E-03    1.0000          832.05        .85071        1.0000
                                                      1.0000        0.              31.166        .85071        1.0000
38985 003090000          42570 42571 42572
        4.56037E-03 INLET  42571 40233 003080000  1  4.56037E-03    1.0000          832.05        .85071        1.0000
                                                      1.0000        0.              31.166        .85071        1.0000
                    OUTLET 42572 40268 003090000  1  4.56037E-03    1.0000          831.95       1.0254         1.0000
```

Fig. B-1. Continued.

```
39062 003100000        42573 42574 42575                          1.0000       0.            30.357     1.0254     1.0000
          4.56037E-03 INLET   42574 40268 003090000  1  4.56037E-03    1.0000       831.95     1.0254     1.0000
                                                        1.0000       0.            30.357     1.0254     1.0000
                      OUTLET 42575 40303 003100000  1  4.56037E-03    1.0000       831.84     1.2283     1.0000
                                                        1.0000       0.            29.389     1.2283     1.0000
39139 003110000        42576 42577 42578
          4.56037E-03 INLET   42577 40303 003100000  1  4.56037E-03    1.0000       831.84     1.2283     1.0000
                                                        1.0000       0.            29.389     1.2283     1.0000
                      OUTLET 42578 40338 003110000  1  4.56037E-03    1.0000       831.70     1.4649     1.0000
                                                        1.0000       0.            28.238     1.4649     1.0000
39216 003120000        42579 42580 42581
          4.56037E-03 INLET   42580 40338 003110000  1  4.56037E-03    1.0000       831.70     1.4649     1.0000
                                                        1.0000       0.            28.238     1.4649     1.0000
                      OUTLET 42581 40373 003120000  1  4.56037E-03    1.0000       831.54     1.7417     1.0000
                                                        1.0000       0.            26.878     1.7417     1.0000
39293 003130000        42582 42583 42584
          4.56037E-03 INLET   42583 40373 003120000  1  4.56037E-03    1.0000       831.54     1.7417     1.0000
                                                        1.0000       0.            26.878     1.7417     1.0000
                      OUTLET 42584 40408 003130000  1  4.56037E-03    1.0000       631.34     2.0664     1.0000
                                                        1.0000       0.            25.278     2.0664     1.0000
39370 003140000        42585 42586 42587
          4.56037E-03 INLET   42586 40408 003130000  1  4.56037E-03    1.0000       831.34     2.0664     1.0000
                                                        1.0000       0.            25.278     2.0664     1.0000
                      OUTLET 42587 40443 003140000  1  4.56037E-03    1.0000       831.10     2.4479     1.0000
                                                        1.0000       0.            23.404     2.4479     1.0000
39447 003150000        42588 42589 42590
          4.56037E-03 INLET   42589 40443 003140000  1  4.56037E-03    1.0000       831.10     2.4479     1.0000
                                                        1.0000       0.            23.404     2.4479     1.0000
                      OUTLET 42590 40478 003150000  1  4.56037E-03    1.0000       830.83     2.8966     1.0000
                                                        1.0000       0.            21.214     2.8966     1.0000
39524 003160000        42591 42592 42593
          4.56037E-03 INLET   42592 40478 003150000  1  4.56037E-03    1.0000       830.83     2.8966     1.0000
                                                        1.0000       0.            21.214     2.8966     1.0000
                      OUTLET 42593 40513 003160000  1  4.56037E-03    1.0000       830.50     3.4248     1.0000
                                                        1.0000       0.            18.662     3.4248     1.0000
39601 003170000        42594 42595 42596
          4.56037E-03 INLET   42595 40513 003160000  1  4.56037E-03    1.0000       830.50     3.4248     1.0000
                                                        1.0000       0.            18.662     3.4248     1.0000
                      OUTLET 42596 40548 003170000  1  4.56037E-03    1.0000       830.11     4.0472     1.0000
                                                        1.0000       0.            15.695     4.0472     1.0000
39678 003180000        42597 42598 42599
          4.56037E-03 INLET   42598 40548 003170000  1  4.56037E-03    1.0000       830.11     4.0472     1.0000
                                                        1.0000       0.            15.695     4.0472     1.0000
                      OUTLET 42599 40583 003180000  1  4.56037E-03    1.0000       829.77     4.7807     1.0000
                                                        1.0000       0.            12.249     4.7807     1.0000
39755 003190000        42600 42601 42602
          4.56037E-03 INLET   42601 40583 003180000  1  4.56037E-03    1.0000       829.77     4.7807     1.0000
                                                        1.0000       0.            12.249     4.7807     1.0000
                      OUTLET 42602 40618 003190000  1  4.56037E-03    1.0000       831.83     5.6455     1.0000
                                                        1.0000       0.            8.2370     5.6455     1.0000
39832 003200000        42603 42604 42605
          4.56037E-03 INLET   42604 40618 003190000  1  4.56037E-03    1.0000       831.83     5.6455     1.0000
                                                        1.0000       0.            8.2370     5.6455     1.0000
                      OUTLET 42605 40653 004000000  1  3.96752E-03    1.0000       842.21     7.6614     1.0000
                                                        1.0000       0.            3.5107     7.6614     1.0000
39909 005010000        42606 42607 42607
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Fig. B-1.   Continued.

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RELAP5/2/36.01         REACTOR LOSS OF COOLANT ANALYSIS PROGRAM
EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                    85/08/01.                          PAGE      59

       4.56037E-03 INLET  42607 40653 004000000  1  3.96752E-03   1.0000          842.21        7.6614         1.0000
                                                       1.0000       0.             3.5107        7.6614         1.0000

VOLUME AVERAGE TERMS
*********************************************************************************************************************
I
IXP     VOLNO(I)     VELF(I)        VFX(IXP)        VFX(IXP+1)      VRHOF(IXP)      VRHOF(IXP+1)    AREA(IXP)
                     VELG(I)        VGX(IXP)        VGX(IXP+1)      VRHOG(IXP)      VRHOG(IXP+1)    AREA(IXP+1)
*********************************************************************************************************************
38369 003010000   8.09849E-02   0.                .30740         0.                3.7958        0.
43474             8.09849E-02   0.               1.24212E-17     0.               1.53376E-16    4.56037E-03
38446 003020000    .12259        .30740           .62324         3.7958            3.7957        4.56037E-03
43500              .12254       1.24212E-17      2.51246E-17     1.53376E-16       1.53018E-16   4.56037E-03
38523 003030000    .20805        .62324           .95617         3.7957            3.7956        4.56037E-03
43526              .20795       2.51246E-17      3.83642E-17     1.53018E-16       1.52291E-16   4.56037E-03
38600 003040000    .29923        .95617          1.3153          3.7956            3.7955        4.56037E-03
43552              .29906       3.83642E-17      5.23910E-17     1.52291E-16       1.51177E-16   4.56037E-03
38677 003050000    .39863       1.3153           1.7106          3.7955            3.7953        4.56037E-03
43578              .39837       5.23910E-17      6.74486E-17     1.51177E-16       1.49649E-16   4.56037E-03
38754 003060000    .50898       1.7106           2.1528          3.7953            3.7951        4.56037E-03
43604              .50859       6.74486E-17      8.37641E-17     1.49649E-16       1.47666E-16   4.56037E-03
38831 003070000    .63331       2.1528           2.5540          3.7951            3.7948        4.56037E-03
43630              .63275       8.37641E-17      1.01535E-16     1.47666E-16       1.45180E-16   4.56037E-03
38908 003080000    .77504       2.6540           3.2280          3.7948            3.7945        4.56037E-03
43656              .77424       1 01535E-16      1.20911E-16     1.45180E-16       1.42130E-16   4.56037E-03
38985 003090000    .93805        .2280           3.8904          3.7945            3.7940        4.56037E-03
43682              .93691       1.20911E-16      1.41957E-16     1.42130E-16       1.38440E-16   4.56037E-03
39062 003100000   1.1268        3.8904           4.6595          3.7940            3.7935        4.56037E-03
43708             1.1252        1.41957E-16      1.64617E-16     1.38440E-16       1.34023E-16   4.56037E-03
39139 003110000   1.3466        4.6595           5.5561          3.7935            3.7929        4.56037E-03
43734             1.3442        1.64617E-16      1.88639E-16     1.34023E-16       1.28774E-16   4.56037E-03
39216 003120000   1.6033        5.5561           6.6048          3.7929            3.7921        4.56037E-03
43760             1.5999        1.88639E-16      2.13488E-16     1.28774E-16       1.22573E-16   4.56037E-03
39293 003130000   1.9041        6.6048           7.8342          3.7921            3.7912        4.56037E-03
43786             1.8991        2.13488E-16      2.38212E-16     1.22573E-16       1.15278E-16   4.56037E-03
39370 003140000   2.2571        7.8342           9.2778          3.7912            3.7901        4.56037E-03
43812             2.2498        2.38212E-16      2.61258E-16     1.15278E-16       1.06729E-16   4.56037E-03
39447 003150000   2.6722        9.2778          10.975           3.7901            3.7889        4.56037E-03
43838             2.6612        2.61258E-16      2.80219E-16     1.06729E-16       9.67420E-17   4.56037E-03
39524 003160000   3.1606       10.975           12.971           3.7889            3.7874        4.56037E-03
43864             3.1438        2.80219E-16      2.91475E-16     9.67420E-17       8.51066E-17   4.56037E-03
39601 003170000   3.7359       12.971           15.321           3.7874            3.7856        4.56037E-03
43890             3.7091        2.91475E-16      2.89682E-16     8.51066E-17       7.15767E-17   4.56037E-03
39678 003180000   4.4138       15.321           18.090           3.7856            3.7841        4.56037E-03
43916             4.3687        2.89682E-16      2.67042E-16     7.15767E-17       5.58588E-17   4.56037E-03
39755 003190000   5.2136       18.090           21.416           3.7841            3.7934        4.56037E-03
43942             5.1284        2.67042E-16      2.12066E-16     5.58588E-17       3.75639E-17   4.56037E-03
39832 003200000   6.1231       21.416           25.600           3.7934            3.3415        4.56037E-03
43968             5.9214        2.12066E-16      1.06712E-16     3.75639E-17       1.39286E-17   3.96752E-03
39909 005010000   6.6654       25.600           0.               3.3415            0.            3.96752E-03
43994             6.6654        1.06712E-16      0.               1.39286E-17       0.            0.
```

Fig. B-1. Continued.

```
NJUNS    NUMBER OF JUNCTIONS
NJSKP    JUNCTION SKIP FACTOR
IJ1      FROM VOLUME INFORMATION.  TIME DEPENDENT FLAG (1 BIT),
         INDEX TO VOLUME (17 BITS), VOLUME NUMBER (12 BITS),
         INPUT CODE (30 BITS).
IJ2      TO VOLUME INFORMATION.  CHOKING FLAG (1 BIT), REST IS THE
         SAME AS IJ1.
JC(1)    FLAG FOR REVERSED "FROM" VOLUME CONNECTION (1 BIT),
         CHOKING TEST FLAG FOR JUCTION CONNECTED TO ACCUMULATOR
         VOLUME (1 BIT), ABRUPT AREA CHANGE FLAG (1 BIT),
         TWO VELOCITY, ONE VELOCITY (1 BIT), SPECIAL CROSS
         FLOW JUNCTION OPTIONS (2 BITS), INDEXES FOR "FROM"
         CONNECTION SET IN TSETSL FOR PRESEQ (3 18 BIT INDEXES).
JC(2)    FLAG FOR REVERSED "TO" VOLUME CONNECTION (1 BIT), FLAG FOR
         NO CHOKING CALCULATION (1 BIT), INPUT FLAG (1 BIT),
         SEPARATOR FLAG  (1 BIT), OLD TIME CHOKING FLAG (1 BIT),
         STRATIFIED FLOW FLAG (1 BIT), INDEXES FOR "TO"
         CONNECTION SET IN TSETSL FOR PRESEQ (3 18 BIT INDEXES).
JUNNO    JUNCTION NUMBER FOR OUTPUT EDITING
IMREC    SUBCOOLED DISCHARGE COEFFICIENT (15 BITS), TWO-PHASE
         DISCHARGE COEFICIENT (15 BITS), STRATIFICATION FLAGS
         (3 BITS), UNUSED (3 BITS), VALVE FLAG (1 BIT),
         CROSS FLOW FLAG (1 BIT),
         JETMIXER FLAGS (3 BITS), SEPARATOR FLAGS (3 BITS),
         FLOW REGIME (16 BITS).
JUNFTL   FROM POINTER IN OUTPUT FORM WITHOUT SIGN (30 BITS), SAME FOR
         TO POINTER (30 BITS).
AJUN     AREA OF JUNCTION
ATHRCT   RATIO OF ORIFICE AREA TO JUNCTION AREA
ARAT(1)  MIXTURE VOLUMETRIC FLOW RATE FOR THE JUNCTION DIVIDED BY
         THE TOTAL MIXTURE VOLUMETRIC FLOW RATE ON THAT END OF THE
         VOLUME.  MIXTURE IS OBTAINED BY USING SUM OF ABSOLUTE VALUE
         OF PHASIC VOLUMETRIC FLOW RATES. 1 IS FOR "FROM" VOLUME.
ARAT(2)  SAME AS ARAT(1), EXCEPT 2 IS FOR "TO" VOLUME.
DIAMJ    DIAMETER OF JUNCTION
******   WARNING! THE ORDERING OF VELFJ, VELFJO, VELGJ, VELGJO, UFJ,
******   UGJ, VOIDFJ, VOIDGJ, QUALAJ, RHOFJ, AND RHOGJ MUST BE
******   MAINTAINED SINCE VFINL ASSUMES THIS ORDER.
VELFJ    LIQUID VELOCITY
VELFJO   LIQUID VELOCITY PREVIOUS TIME STEP
VELGJ    VAPOR VELOCITY
VELGJO   VAPOR VELOCITY PREVIOUS TIME STEP
UFJ      JUNCTION LIQUID SPECIFIC INTERNAL ENERGY
UGJ      JUNCTION VAPOR SPECIFIC INTERNAL ENERGY
VOIDFJ   JUNCTION LIQUID VOID FRACTION
VOIDGJ   JUNCTION VAPOR VOID FRACTION
QUALAJ   JUNCTION NONCONDENSIBLE QUALITY
RHOFJ    JUNCTION LIQUID DENSITY
RHOGJ    JUNCTION VAPOR DENSITY
VELFJS   INTERMEDIATE LIQUID VELOCITY USED WHEN HAVE BAD DONORING
VELGJS   INTERMEDIATE VAPOR VELOCITY USED WHEN HAVE BAD DONORING
FJUNF    FORM LOSS COEFFICIENT FOR AREA CHANGES, FOWARD
FJUNR    FORM LOSS COEFFICIENT FOR AREA CHANGES, REVERSE
FORMFJ   LIQUID FORM LOSS TERM
FORMGJ   VAPOR FORM LOSS TERM
MFLOWJ   MASS FLOW RATE
FAAJ     VIRTUAL MASS
FIJ      INTERPHASE FRICTION
FIJO     INTERPHASE FRICTION PREVIOUS TIME STEP
JCATN    DENSITY CORRECTION FACTOR (SQRT OF RHOT/RHOJ) APPLIED TO
         THE JUNCTION CONVECTIVE TERM IN CHOKING
JACTO    DENSITY CORRECTION FACTOR APPLIED TO THE JUNCTION CONVECTIVE
         TERM IN CHOKING PREVIOUS TIME STEP
```

Fig. B-2. Listing of common block JUNDATC from program RELAP5.

```
NVOLS     NUMBER OF VOLUMES
NVSKP     VOLUME SKIP FACTOR
VCTRL     CONTAINS PACKED CONTROL DATA.  TIME DEPENDENT VOLUME FLAG
          (1 BIT), INPUT FLAG (1 BIT), INITIALIZATION TYPE (10 BITS),
          UNUSED (18 BITS), OLD STATUS FLAGS (11 BITS), NEW STATUS
          FLAGS (11 BITS), NEW MOOT FLAGS (2 BITS), OLD MOOT FLAGS
          (2 BITS), UNUSED (1 BIT), COMPLETION FLAG (1 BIT), WALL
          FRICTION FLAG (1 BIT), EQUILIBRIUM FLAG (1 BIT).
          IN SOLUTION ROUTINES, FIRST 30 BITS ARE TIME DEPENDENT
          VOLUME FLAG (1 BIT), INDEX FOR DIAGONAL POSITION IN SOLUTION
          MATRIX (17 BITS), AND SOLUTION VOLUME NUMBER EXCLUDING TIME
          DEPENDENT VOLUMES (12 BITS)
VOLNO     VOLUME NUMBER FOR EDITING
IMAP      ISAC (6 BITS), ACCUMULATOR FLAG (1 BIT),
          VAPOR DISAPPEARANCE FLAG (1 BIT), UNUSED (2 BITS),
          REFLOOD FLAGS (5 BITS), FLOW REGIME (5 BITS),
          UNUSED (5 BITS), VERTICAL STRATIFICATION FLAGS (3 BITS),
          UNUSED (24 BITS), HORIZONTAL STRATIFICATION FLAGS (2 BITS),
          MAP INFORMATION (6 BITS)
V         VOLUME
RECIPV    RECIPROCAL OF VOLUME (V), ZERO IF V IS ZERO
AVOL      AREA OF VOLUME
DZ        ELEVATION CHANGE
DL        VOLUME LENGTH
DIAMV     EQUIVALENT FLOW DIAMETER
ROUGHV    WALL ROUGHNESS FACTOR...AS INPUT
          RESET IN ICMPN1 TO COLEBROOK FULL TURB FRICTION FAC
RECRIT    CRITICAL REYNOLDS NO, FRIC FAC = CONST...SEE ROUGHV
P         AVERAGE PRESSURE
PO        AVERAGE PRESSURE PREVIOUS TIME STEP
UF        LIQUID SPECIFIC INTERNAL ENERGY
UFO       LIQUID SPECIFIC INTERNAL ENERGY PREVIOUS TIME STEP
UG        VAPOR SPECIFIC INTERNAL ENERGY
UGO       VAPOR SPECIFIC INTERNAL ENERGY PREVIOUS TIME STEP
VOIDF     LIQUID VOID FRACTION
VOIDG     VAPOR VOID FRACTION
VOIDGO    VAPOR VOID FRACTION PREVIOUS TIME STEP
QUALA     NONCONDENSIBLE QUALITY
QUALAO    NONCONDENSIBLE QUALITY PREVIOUS TIME STEP
BORON     BORON DENSITY (MASS OF BORON PER CELL VOLUME)
BORONO    BORON DENSITY PREVIOUS TIME STEP
QUALS     STATIC QUALITY
QUALE     EQUILIBRIUM QUALITY
RHO       TOTAL DENSITY
RHOM      TOTAL DENSITY FOR MASS ERROR CHECK
RHOO      TOTAL DENSITY PREVIOUS TIME STEP
******    WARNING: THE ORDERING OF RHOF AND RHOG MUST BE MAINTAINED
******    SINCE FIDIS ASSUMES THIS ORDER.
RHOF      LIQUID DENSITY
RHOG      VAPOR DENSITY
SATT      SATURATION TEMPERATURE
TEMPF     LIQUID TEMPERATURE
TEMPG     VAPOR TEMPERATURE
VELF      AVERAGE LIQUID VELOCITY IN A VOLUME
VELG      AVERAGE VAPOR VELOCITY IN A VOLUME
SOUNDE    HOMOGENEOUS EQUILIBRIUM SOUND SPEED
DSNDDP    PARTIAL DERIVATIVE OF SOUNDE W/R TO PRESSURE
SATHF     LIQUID SPECIFIC ENTHALPY AT SATURATION CONDITIONS
SATHG     VAPOR SPECIFIC ENTHALPY AT SATURATION CONDITIONS
BETAFF    LIQUID ISOBARIC COEFFICIENT OF THERMAL EXPANSION AT BULK
          CONDITIONS. ALSO, USED TO STORE A15 IN PRESEQ FOR EQFINL.
BETAGG    VAPOR ISOBARIC COEFFICIENT OF THERMAL EXPANSION AT BULK
          CONDITIONS. ALSO, USED TO STORE A25 IN PRESEQ FOR EQFINL.
CSUBPF    LIQUID SPECIFIC HEAT CAPACITY AT CONSTANT PRESSURE AT BULK
          CONDITIONS. ALSO, USED TO STORE A35 IN PRESEQ FOR EQFINL.
CSUBPG    VAPOR SPECIFIC HEAT CAPACITY AT CONSTANT PRESSURE AT BULK
          CONDITIONS. ALSO, USED TO STORE A45 IN PRESEQ FOR EQFINL.
VISCF     LIQUID VISCOSITY. ALSO, USED FOR SCRATCH IN HYDRO IN
          SIMPLT.
VISCG     VAPOR VISCOSITY. ALSO, USED FOR SCRATCH IN HYDRO IN
          SIMPLT.
SIGMA     SURFACE TENSION
THCONF    LIQUID THERMAL CONDUCTIVITY. ALSO, USED FOR SCRATCH IN HYDRO
          AFTER THE FRICTION HAS BEEN CALCULATED
THCONG    VAPOR THERMAL CONDUCTIVITY. ALSO, USED FOR SCRATCH IN HYDRO
          AFTER THE FRICTION HAS BEEN CALCULATED
PPS       VAPOR PARTIAL PRESSURE
DOTM      VAPOR GENERATION RATE PER UNIT VOLUME
DOTMO     VAPOR GENERATION RATE PER UNIT VOLUME PREVIOUS TIME STEP
HIF       LIQUID SIDE INTERFACIAL HEAT TRANSFER COEFFICIENT PER UNIT
          VOLUME
HIG       VAPOR SIDE INTERFACIAL HEAT TRANSFER COEFFICIENT PER UNIT
          VOLUME
```

Figure B-3. Listing of common block VOLDATC from program RELAP5.

```
GAMMAW   VAPOR GENERATION RATE AT THE WALL PER UNIT VOLUME
Q        TOTAL HEAT TRANSFER RATE FROM WALL TO FLUID
QWG      HEAT TRANSFER RATE FROM WALL TO VAPOR
HTCCFF   HEAT TRANSFER COEFFICIENT BETWEEN SLAB AND FLUID-LIQUID
HTCCFG   HEAT TRANSFER COEFFICIENT BETWEEN SLAB AND FLUID-VAPOR
DRFDP    PARTIAL DERIVATIVE OF RHOF W/R TO PRESSURE
DRFDUF   PARTIAL DERIVATIVE OF RHOF W/R TO LIQUID SPECIFIC INTERNAL
         ENERGY
DRGDP    PARTIAL DERIVATIVE OF RHOG W/R TO PRESSURE
DRGDUG   PARTIAL DERIVATIVE OF RHOG W/R TO VAPOR SPECIFIC INTERNAL
         ENERGY
DRGDXA   PARTIAL DERIVATIVE OF RHOG W/R TO NONCONDENSIBLE QUALITY
DTFDP    PARTIAL DERIVATIVE OF TEMPF W/R TO PRESSURE
DTFDUF   PARTIAL DERIVATIVE OF TEMPF W/R TO LIQUID SPECIFIC INTERNAL
         ENERGY
DTGDP    PARTIAL DERIVATIVE OF TEMPG W/R TO PRESSURE
DTGDUG   PARTIAL DERIVATIVE OF TEMPG W/R TO VAPOR SPECIFIC INTERNAL
         ENERGY
DTGDXA   PARTIAL DERIVATIVE OF TEMPG W/R TO NONCONDENSIBLE QUALITY
DTDP     PARTIAL DERIVATIVE OF SATT W/R TO PRESSURE
DTDUG    PARTIAL DERIVATIVE OF SATT W/R TO VAPOR SPECIFIC INTERNAL
         ENERGY
DTDXA    PARTIAL DERIVATIVE OF SATT W/R TO NONCONDENSIBLE QUALITY
FLOREG   FLOW REGIME NUMBER IN REAL FORMAT.
HIFO     LIQUID SIDE INTERFACIAL HEAT TRANSFER COEFFICIENT PER UNIT
         VOLUME PREVIOUS TIMESTEP
HIGO     VAPOR SIDE INTERFACIAL HEAT TRANSFER COEFFICIENT PER UNIT
         VOLUME PREVIOUS TIMESTEP
FWALF    LIQUID WALL FRICTION COEFFICIENT
FWALG    VAPOR WALL FRICTION COEFFICIENT
TEMP     USED IN R LEVEL SUBROUTINES AND IS USUALLY THE SAME AS SATT
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Figure B-3. (continued).

APPENDIX C

RELAP5/MOD2 INPUT DECK PREPARATION GUIDELINES

APPENDIX C

RELAP5/MOD2 INPUT DECK PREPARATION GUIDELINES

1. INTRODUCTION

The purpose of this appendix is to provide the RELAP5/MOD2 user with general guidelines for developing an input deck (system model) capable of simulating nuclear power plant, test facility, or individual component response to imposed transient or accident conditions. Since specific recommendations relating to the application of the RELAP5/MOD2 code are discussed in the main body of this manual, that type of information is not repeated here. Rather, this appendix includes a discussion of the data requirements for input model construction, plant data acquisition, plant data documentation, plant nodalization, input deck preparation, plant model documentation, and plant model initialization. As the preparation of a RELAP5/MOD2 system model can represent a significant and time consuming effort, it is hoped that the guidelines contained herein will help to facilitate that effort.

2. DEFINING DATA REQUIREMENTS FOR INPUT MODEL CONSTRUCTION

Construction of an input model for a specific facility requires the acquisition of sufficient geometric and operational data to accurately represent the systems physical characteristics and the overall response of the system for the transients of interest. Generally, the data requirements for a given system model will depend on the type of transient, or plant operation, to be simulated. Thus, a first step in identifying data requirements for an input model is to determine which portions of the plant must be modeled, to simulate the type of transients to be performed. For example, if a large break is postulated in the pump discharge leg of a PWR system, only the primary and secondary sides of the nuclear steam supply system (NSSS) need be modeled. The balance of the plant components would be of little consequence to the outcome of this calculation, since the MSIVs isolate the NSSS from the balance early in the transient. On the other hand, balance of plant components can play a key role in the outcome of an event such as a loss-of-offsite power transient in a PWR system, and thus should be included in the input model used to calculate this type of transient. A third case could be the modeling of a plant component (such as a steam generator or pump) or a simulator that represents a plant component. For this situation, the portions of the plant outside the boundary of the component might simply be modeled as boundary conditions, and only the component itself need be modeled explicitly. Usually, it is better to include as much of the plant in the input model as is practical, as this approach will provide much greater flexibility in the types of transients that can be calculated with the model.

An additional consideration in identifying the data requirements for an input model is the degree of detail to be included in the modeling of the various plant components. Depending on the type of phenomena to be calculated, an increase in the degree of detail included in the input model can often lead to more realistic calculated results. For example, modeling of the leakage paths between the inlet and outlet plena of a PWR system is necessary to accurately predict vessel liquid level depression when performing primary loop small break calculations. Engineering insight into the type of phenomena to be expected during the course of a transient will aid in the decision of how much detail is to be included in the model.

Having identified the input model data requirements (relative to the portions of the plant to be modeled and the detail to be included in the model), the appropriate plant information that will enable construction of the input model must be gathered. The types of data required fall into the four general categories listed below.

1. Hydrodynamic component data--This data will consist of the information necessary to describe the geometry of internal flow paths of system components including: system piping, reactor vessel, steam generators, pressurizer, accumulator, pumps, valves, separators, turbines, heat exchangers, jet pumps, and any other components through which fluid flow can occur. Quantities that are required for all hydrodynamic components include: length, fluid volume, flow area (including areas of all restrictions), hydraulic diameters, relative elevations and orientation, loss coefficients (for both forward and reverse directions), and surface roughness.

2. Heat structure data--This data will include geometric data, thermophysical property information, and heat source information for the solid portions of the thermal-hydrodynamic system. System components simulated by heat structures include piping walls, pressure vessels, insulating materials, heat exchanger tubes, fuel pins, pressurizer heaters, piping wall heaters, and any structures internal to pressure boundaries (such as core barrel, core support plates, guide tubes, control rod elements, steam generator tube support plates, separators, etc.). Geometric quantities required for all heat structures include length, thickness, surface area, and hydraulic diameter. Required thermophysical quantities include the thermal conductivity and heat capacity (both as a function of temperature) for each material composition included in a heat structure. For those heat structures that are to represent heat sources, the heat addition rate is required. For electrical type heaters (such as pressurizer heaters in a PWR system, piping, heat loss makeup heaters, and electrical fuel rod simulators in a

test facility), surface heat flux or electrical power to the heaters should be obtained. Control systems may also be an integral part of electrical heater systems, and control system information, should be obtained (see 3 below). For nuclear fuel rods, the axial power profile, pellet radial power profile, steady state operating power (core total), and decay power are needed. Note that fuel rod parameters such as the power profiles and the fuel rod geometry vary over the life of the core, and thus core operational history must be taken into consideration when specifying the requirements for core data.

3. Control system and trip information--This information will be used to simulate the various control systems, which provide both steady state and transient control of a plant. Generally, it is necessary to model only those portions of a control system that will be activated during the transients of interest. Also, from the code calculation standpoint, only the input to, and output from, the control system are important. Thus, individual components of a control system may be lumped together and treated as a black box, although the capability exists to model each portion of a control system explicitly, if so desired. The information required to describe a control system includes both the action to be taken by the overall control system, and quantities relating to the individual components of the control system, including gain factors, constants, minimum and maximum limits, and initial values. Also necessary are associated trip and set points. Plant data monitored by the control system should also be identified so that the input model can be designed to monitor a similar parameter in the calculation.

4. Initial and boundary conditions--Initial and boundary condition data are required to provide the constraints necessary to characterize the specific transients to be calculated. The initial plant conditions from which accident scenarios, or operational transients begin, generally represent a steady state operating condition at a given power level. Required steady

state information includes: flow rates for all modeled flow paths, pressure and fluid temperature distributions for hydrodynamic components, liquid levels for those components in which a liquid-vapor interface exists (such as a pressurizer or steam generator secondary), temperature distribution for solid structures, core power level, heater power levels, boron concentrations, valve positions, and control system initial values. The boundary conditions for a transient calculation are those parameters that are governed by conditions outside of the problem boundaries, and can take forms such as mass sources or sinks (e.g., an auxiliary feedwater pump or the containment atmosphere), operator actions, or energy sources that are not explicitly modeled as part of the system. Information relating to operator action should include the action taken (such as opening or closing valves or starting pumps), the time or plant condition at which the action was taken, and the duration over which the action was in effect. For boundary conditions that represent mass sources (or sinks), such information as flow rate and fluid condition (pressure, temperature, enthalpy, etc.) are required. In addition, the flow rate may be a function of some other system parameter (such as pressure), and the functional relationship should be specified. Energy addition rates (power or heat flux) are necessary for heat source.

Specific data requirements for each of the categories listed above are discussed in detail in Appendix A of this volume.

3. PLANT DATA ACQUISITION

The type of plant most often modeled by the RELAP5 user will either be an experimental facility, or a commercial nuclear plant. For either case, various sources of plant information will be available. Data necessary for modeling an experimental facility can usually be obtained from the organization performing the tests. A test facility description document generally is available, and will provide much of the data required to create and input model. Additional information can be obtained from facility drawings and from test results reports. The test results reports will usually include initial and boundary condition information for each of the tests performed, as well as other test conduct information that can be useful in setting up the plant model.

Information pertaining to a commercial nuclear plant is generally more difficult to obtain and may require negotiation and special agreements with the plant vendor or utility that owns the plant. Past experience indicates that the most comprehensive data package (consisting of plant information and steady state and/or transient data) can be obtained from the plant owner. The utility will have the most up-to-date information (including as-built drawings), as well as data for the current fuel load. They will also have information relating to balance of plant components and operation. However, the utility may not be able to supply information that is considered proprietary by a vendor. In this instance, it may be necessary to negotiate an agreement with the plant vendor, or particular component supplier, to obtain the required information. Usually some form of assurance that the proprietary information will be protected (i.e., will not be made available to the public) is required. However, due to possible political/financial implications, some vendors may not be willing sources of information.

Another source of information that is readily available for each commercial nuclear plant is the Final Safety Analysis Report (FSAR). The FSAR will contain general information that can be useful in setting up a plant deck, but will not contain sufficient detail to address more specific data needs. The FSARs for newer plants tend to be more comprehensive than those for earlier plants, but again will not include the detail required for a plant model.

Because of the rather large amounts of data required to assemble a plant model, the data gathering process can represent a significant and time consuming effort, both on the part of the analyst preparing the model and on the part of the organizations that may be called upon to provide the plant data. It, therefore, can be very beneficial to spend the time necessary to identify exactly what data, or other types of information, are required prior to actually attempting to acquire the data. Arrangements can then be made with the appropriate test facility or commercial nuclear plant organization to obtain the specific data required. This approach will tend to minimize the possible impact (both timewise and costwise) on the organization being asked to supply the information.

4. PLANT DATA DOCUMENTATION

Having acquired the information necessary to create an input deck, it is advisable to devise a documentation system to provide easy reference to the data collected. Any workable system can be used. However, the documentation system should contain some form of key work reference so that the source of each piece of data used in the input model can be readily identified. This will greatly facilitate the job of referring to the data when the input model is being prepared, and will allow easier updating of the data file and input model when plant configuration changes are identified. Keeping track of possible changes is especially important in the case of experimental facilities where changes to the facility configuration are frequently made. Precautions should be taken to ensure that the data contained in the plant data file are representative of the actual system configuration for the transient calculations to be performed.

5. PLANT NODALIZATION

Application of the RELAP5 computer code to calculate the response of a thermal-hydraulic facility requires simulating the physical system being modeled by a network of control volumes connected by junctions. Establishing this network, or nodalization, involves splitting the system to be modeled into discrete segments that can then be described by the various RELAP5 components. As is readily evident, the transformation of the physical system characteristics to the system of volumes and junctions described by the model is an inexact process, and many different nodalization schemes can be devised for any given plant. Therefore, it is not practical to have step-by-step procedures for establishing a plant nodalization scheme. However, much practical experience has been gained through application work with RELAP5, and general guidelines for establishing nodalization schemes for the various types of plant configurations and possible plant transients have evolved. It is thus the intent of this section to present these general nodalization guidelines. In addition, an example of a RELAP5 plant nodalization is presented to provide further insight into the process of establishing a nodalization scheme.

5.1 Nodalization Guidelines

As indicated above, establishing a nodalization scheme for a particular plant involves splitting the system to be modeled into segments that are then described by the RELAP5 component input. The nodalization scheme defines the number of hydrodynamic volumes to be used in the model, and the location and size of each volume. The process of determining exactly how finely the system should be split (or alternatively, how many hydrodynamic volumes should be included in the model) is strongly dependent on the type of transient to be calculated. For example, if the accurate prediction of a liquid level in a vertical portion of a plant (such as a vessel downcomer, or a pressurizer) is considered to be of prime importance in determining the outcome of a transient, it would be desirable to include a relatively fine nodalization (i.e., a large number of hydrodynamic volumes) in this region. On the other hand, for a transient in which the same vertical section of the plant remains liquid full, a coarse nodalization (i.e., small number of hydrodynamic volumes) would be appropriate. Generally, the nodalization for a plant should be specified with the intent of capturing the correct phenomena for the particular transients of interest, while keeping the number of hydrodynamic volumes at a reasonable level to enhance calculation efficiency and reduce cost. Consideration of possible hydrodynamic (as well as thermal) response of each segment of the plant will aid in the determination of how finely those plant segments should be nodalized. The nodalization example, presented in Section 5.2 below, represents a good starting point relative to the number of hydrodynamic volumes and junctions to be used to model the various segments of a plant. If the nature of the transient response is unknown, a finer nodalization should be used to ensure that the code predicts phenomena in the most realistic manner practical. In cases where it appears that the calculated results may be sensitive to the nodalization, a sensitivity study should be conducted to investigate the uncertainty due to nodalization changes.

An integral part of establishing a nodalization scheme is identifying the location of the junctions (i.e., the boundaries across which flow can occur) to be associated with each hydrodynamic volume. Although the location of a junction is usually a completely arbitrary choice, the physical characteristics of the plant will often influence where the junctions should be located. In many instances, a junction can be located where any one of the following characteristics is found:

1. A position between two adjacent fluid volumes that have significantly different flow areas (e.g., in a PWR system, the transition points between: the annular downcomer and the vessel inlet nozzles or the lower plenum; the upper plenum and the vessel outlet nozzles; the hot leg and steam generator inlet plenum; the steam generator tube bundle region and the inlet or outlet plenum; the steam generator outlet plenum and the pump suction leg; the accumulator vessel and accumulator piping, etc.).

2. A flow restriction between two adjacent fluid volumes, both of which have different flow areas than the restriction (e.g., grid spacers in a core, or tube support plates in a steam generator secondary).

3. A location where one pipe connects to another (e.g., a pressurizer surge line pipe connecting to a hot leg, or an accumulator pipe connecting to a cold leg).

For cases such as a long section of pipe with constant cross section, junctions may be located at any position desired. In some instances, it may also be desirable to locate a junction at a position that corresponds to the location of a flow measurement device, as this will enhance the comparison of calculated results with measured flow data. As a general rule, however, the position of junctions in any given flow loop should be such that the hydrodynamic volumes in that loop will have roughly equivalent lengths.

In conjunction with establishing the location of junctions and the number of hydrodynamic volumes to be included in a plant model, the type of RELAP5 component to be used for each hydrodynamic volume and junction must be determined. Various types of component models are available to represent the different hydrodynamic components found in a thermal-hydraulic system. A brief description of the application of each of the available RELAP5 components follows:

1. Single volume (SNGLVOL)[a]--As the name implies, this component can be used to represent a fluid volume that can be considered separate from other volumes. Examples of its use include such areas as steam generator inlet or outlet plenum, a surge tank, or the lower volume of a two volume vessel lower plenum where only a single flow path exists between the two volumes. Note that a one volume PIPE component can generally be used interchangeably with the SNGLVOL component.

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[a] RELAP5 component designation.

2. Single junction (SNGLJUN)--This component is used to describe the junction between two hydrodynamic volumes, when neither of the volume components contain junction descriptions, such as would be the case if one of the volumes were a BRANCH, VALVE, PUMP, etc. (see below). An example of the use of the SNGLJUN component is to connect a surge tank (modeled as a SNGLVOL or PIPE) with a surge line (modeled as a PIPE). The junctions described by this component are usually located between SNGLVOL, TMDPVOL, PIPE, and ANNULUS components.

3. Time dependent volumes (TMDPVOL)--This component is used to specify the fluid conditions (temperature, pressure, internal energy, quality, etc.) for a volume that is to represent a mass source or sink, or a pressure boundary condition. If the TMDPVOL is used with a normal junction, inflow or outflow will depend on the pressure difference between the TMDPVOL and a connecting volume. If it is used with a time dependent junction (TMDJUN), inflow or outflow will be as specified for the TMDPJUN component, and can be completely independent of the pressure of the volume to which the TMDPVOL is connected. Examples of the TMDPVOL as a source of fluid include representing high and low pressure emergency core cooling systems, pressurizer sprays, leakage makeup systems, main and auxiliary feedwater systems, and any portion of a system for which the fluid conditions are known or can be calculated. For example, if an input model is to consist of only the primary and secondary sides of a steam generator, the hot leg fluid volume, which supplies fluid to the steam generator inlet plenum, may be modeled as a TMDPVOL. As a sink, the TMDPVOL can be used to represent a containment atmosphere, the balance of plant beyond a steam generator secondary, or any portion of a system that can act as discharge volume. Additionally, a TMDPVOL can be used specifically to provide a pressure boundary condition (thus controlling a system pressure) as is the case when using the self-initialization option.

4. Time dependent junction (TMDPJUN)--The TMDPJUN is used in conjunction with the TMDPVOL to specify the phasic mass flow

rates, or velocities, for all fluid source volumes. This component should not be used to define a junction connecting the system model to a discharge volume. A valve is the preferred component for this case, since the code is then allowed to impose calculated conditions on the junction, as opposed to conditions specified by the user.

5. Pipe (PIPE)--This component should be used where several geometrically similar fluid volumes can be linked together. Examples of its use include most piping runs, steam generator tubes (primary side), the fuel rod region in a reactor vessel, guide tube, support column flow channels, core bypass flow channels, the boiler region on a steam generator secondary side, and some pressure vessels (such as a pressurizer).

6. Annulus (ANNULUS)--The ANNULUS component can be used for all vertical annular regions such as a reactor vessel downcomer, or the annular downcomer region in a U-tube steam generator. The code treats the ANNULUS and PIPE components the same, except the ANNULUS component must be vertical.

7. Branch (BRANCH)--This component provides the means of modeling a fluid volume that has multiple inlet or outlet side flow paths. Examples of its use include modeling a reactor vessel lower or upper plenum, the portion of a hot leg connecting to a pressurizer surge line, the portion of a cold leg connecting to emergency core cooling system piping, the segment of a steam generator downcomer to which the feedwater and auxiliary feedwater lines are connected, and parts of the upper head portion of some reactor vessels. Since the BRANCH model does not include momentum transfer due to mixing, it is not suited for high velocity merging flows (see JETMIXER below). A detailed discussion of the various applications of the BRANCH component is presented in Section 2.2.3 of this manual.

8. Separator (SEPARATR), turbine (TURBINE), and jetmixer (JETMIXER)--The SEPARATR, TURBINE, and JETMIXER components are specialized branch components. The SEPARATR component is used

to model the liquid/vapor phase separation process, such as occurs in a steam generator separator/dryer. The TURBINE component is used to simulate the process of converting thermal energy contained in high pressure, high temperature steam to mechanical work, as occurs in a steam turbine. The JETMIXER component is provided for modeling the mixing of high velocity parallel streams in which a pumping action is caused by the momentum mixing of a high speed drive line flow with the slower suction line flow. This component is used to represent a jet pump. Detailed descriptions of the application of SEPARATR, TURBINE, and JETMIXER are presented in Sections 2.3.4, 2.3.5, and 2.3.2, respectively, of this manual.

9. Valves (VALVE)--The VALVE component provides the means to model both the various types of valves found in a thermal-hydraulic system, and instantaneous valve actions. Six types of valves are modeled including inertial swing check, motor, servo, relief, check, and trip. The first four valve models represent real valves, and opening/closing rates are considered in the models. The trip and check valves are modeled as instantaneous on/off switches, and can be used to represent such events as a pipe rupture (trip valve), or the initiation of flow through a section of pipe at some preset pressure (check valve). Section 2.3.3 of this manual describes the actions of the various types of valves, and presents a detailed discussion of the application of each valve type.

10. Pump (PUMP)--The PUMP component is used to model pumps. A detailed description of this component is presented in Section 2.3.1 of this manual.

11. Accumulator (ACCUM)--This component is used to represent an accumulator type emergency core coolant injection tank. A detailed description of the ACCUM component is presented in Section 2.3.6 of this manual.

Having identified the number of hydrodynamic volumes, the locations of junctions, and the type of component to be used to represent each volume and junction, the process of developing the nodalization scheme for the plant is complete, and specification of the input values for each component can be initiated. At this point, it is useful to construct a detailed nodalization diagram that incorporates, in a graphical form, the various decisions made in the nodalization process. The nodalization diagram should include a representation for each component (hydrodynamic volume and junction) to be used in the input model, and should include all flow paths, with direction of flow for normal operating conditions indicated. A baseline elevation (such as a cold leg centerline) should also be chosen, and the elevation of each vertical junction relative to the baseline should be indicated. This will be of use when preparing the component geometric input. In addition, a numbering scheme should be devised to identify each component. The numbering scheme should provide an indication of where the component is located (e.g., vessel components could be numbered 100 through 199, and one of the recirculation loops could have components numbered 200 through 299, etc.). The numbering scheme should also provide room for the addition of components at a later time.

5.2 Plant Nodalization Example

In this section, an example of a RELAP5 plant nodalization is presented. As many types of facilities can be modeled with RELAP5, and numerous different nodalization schemes can be devised for any given plant, the example discussed here is not meant to serve as a representative model for all possible applications. However, nodalization schemes similar to this example have been used with success in performing a wide variety of plant transient and accident calculations. Thus, with appropriate modifications, the nodalization scheme presented here can be used as a good starting point for developing a new facility model. In particular, such items as the number of hydrodynamic volumes used to represent the various segments of the system, the number of nodes used to model the different system heat structures, and the types of RELAP5 hydrodynamic components used to model segments of the plant, all represent good first attempt choices for use in a new plant model.

Figure C-1 presents the nodalization diagram for this example, and includes representations for vessel components, intact and broken loop piping components, (including both primary and secondary-side steam generator components), and balance of plant equipment. Also included are representations for all system heat structures (such as piping walls, fuel rods, vessels, etc.). A description of each of the hydrodynamic components shown in the nodalization diagram is included in Table C-1, while Table C-2 presents a complete list of the heat structures used in the model. The nodalization scheme described here is that for a typical pressurized water reactor system with multiple coolant loops, each containing a U-tube steam generator. For this case, the nodalization was set up to perform small cold leg break loss-of-coolant accident calculations. Thus, only the primary and secondary sides of the nuclear steam supply system are modeled explicitly, while balance of plant components are represented (where required) by time dependent boundary conditions. Also, note that the intact loop (i.e., loop without the break) can be representative of more than 1 loop in an actual plant, especially if similar fluid response is to be expected in all intact loops (as would be the case for a small break LOCA). Thus, for example, if the model intact loop is to represent 3 actual loops in the PWR plant, flow areas and fluid volumes in the model would be 3 times as large as for a single loop, while volume lengths would be maintained the same as for a single loop. In instances where different fluid behavior might be expected for each loop (such as would be the case if each steam generator were operated in a different manner), each loop should be modeled separately.

As indicated above, the general nodalization scheme depicted by Figure C-1 represents a good starting point for modeling a new facility. Some of the more important aspects of the nodalization scheme are highlighted here. With respect to loop piping, the following is noted. The hot leg is represented by 5 hydrodynamic volumes,[a] with one of the junctions being located at the point where the pressurizer surge line

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[a] Note that the number of hydrodynamic volumes used to represent a segment of the facility is not necessarily the same as the number of hydrodynamic components used to represent the same segment. For example, a single pipe component may contain several hydrodynamic volumes.

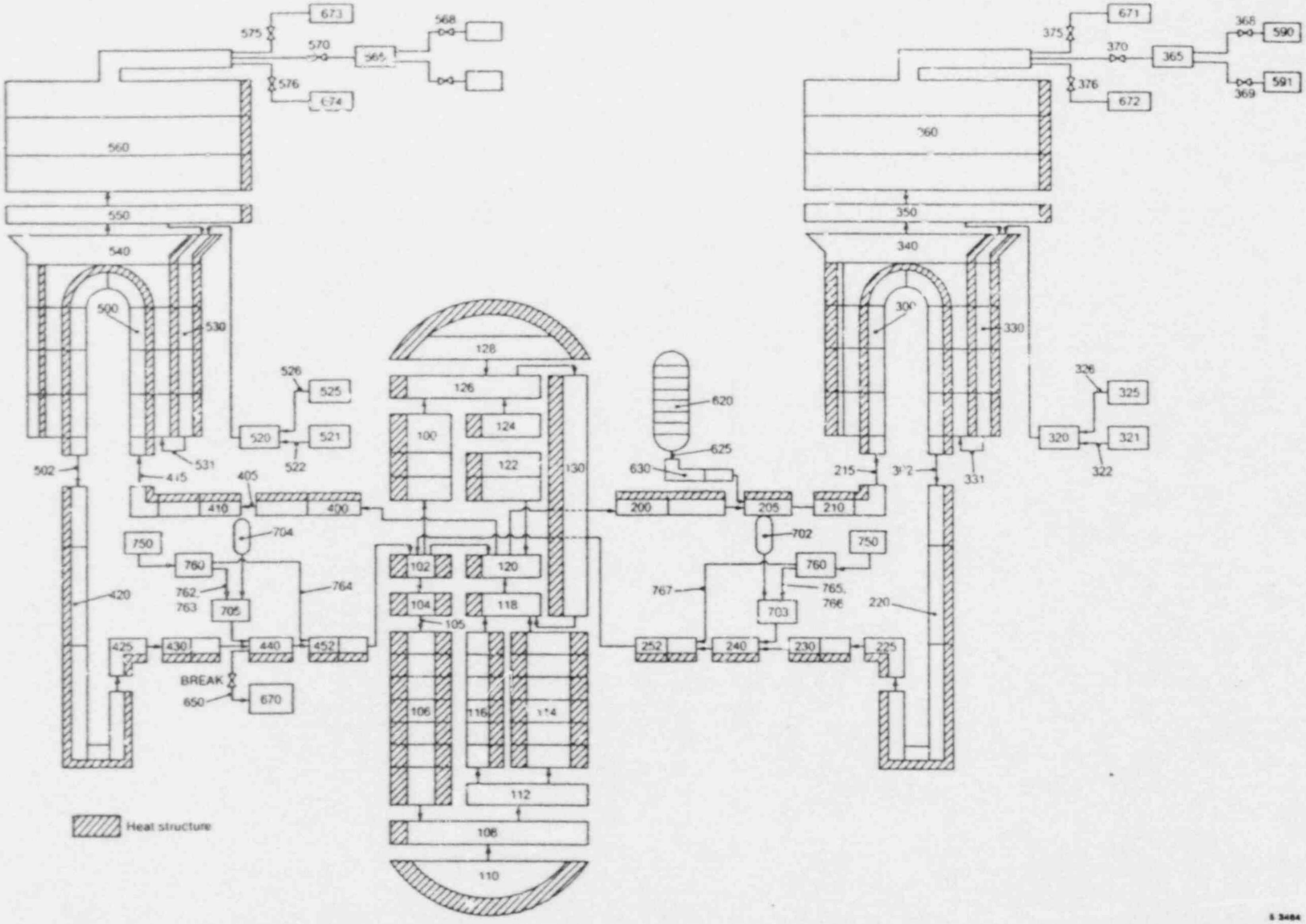

Figure C-1. RELAP5 nodalization diagram for a multiple loop pressurized water reactor plant.

TABLE C-1. RELAP5 HYDRODYNAMIC COMPONENT DESCRIPTION FOR PWR PLANT MODEL

Component	Component Description	Component Type	Number of Volumes
100	Vessel inlet annulus above cold leg centerline	ANNULUS	3
102	Vessel inlet annulus below cold leg centerline (upper volume)	BRANCH	1
104	Vessel inlet annulus below cold leg centerline (lower volume)	ANNULUS	1
105	Junction between inlet annulus and downcomer	SNGLJUN	--
106	Downcomer	ANNULUS	7
108	Lower plenum (upper volume)	BRANCH	1
110	Lower plenum (lower volume)	SNGLVOL	1
112	Core inlet	BRANCH	1
114	Core flow channel	PIPE	6
116	Core bypass channel	PIPE	6
118	Upper plenum below hot leg centerline (lower volume)	BRANCH	1
120	Upper plenum below hot leg centerline (upper volume)	BRANCH	1
122	Upper plenum above hot leg centerline	PIPE	2
124	Upper head (lower volume)	SNGLVOL	1
126	Upper head (middle volume)	BRANCH	1
128	Upper head (upper volume)	PIPE	2
130	Guide tubes	SNGLVOL	1
200	Intact loop hot leg to pressurizer surge line segment	PIPE	2
205	Intact loop hot leg segment containing connection to surge line	BRANCH	1
210	Intact loop hot leg from surge line segment to steam generator	PIPE	2

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
215	Junction between hot leg and steam generator inlet plenum	SNGLJUN	--
220	Intact loop pump suction piping	PIPE	5
225	Intact loop pump	PUMP	1
230	Intact loop cold leg from pump discharge to accumulator line	PIPE	2
240	Intact loop cold leg from accumulator line to SI line	BRANCH	1
245	Junction between cold leg segments	SNGLJUN	--
252	Intact loop cold leg from SI line to vessel	PIPE	2
300	Intact loop steam generator inlet plenum, primary tubes, outlet plenum	PIPE	10
320	Intact loop feedwater line from isolation valve to feedwater nozzle	BRANCH	1
321	Intact loop feedwater source	TMDPVOL	1
322	Intact loop feedwater flow rate controlling junction	TMDPJUN	--
325	Intact loop auxiliary feedwater source (motor, pump)	TMDPVOL	1
326	Intact loop auxiliary feedwater flow rate controlling junction (motor, pump)	TMDPJUN	--
327	Intact loop auxiliary feedwater source (turbine pump)	TMDPVOL	1
328	Intact loop auxiliary feedwater flow rate controlling junction (turbine pump)	TMDPJUN	--
330	Intact loop steam generator downcomer (lower section)	ANNULUS	5
331	Intact loop steam generator downcomer to riser junction	SNGLJUN	--
340	Intact loop steam generator riser up to feed ring	PIPE	5

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
350	Intact loop steam generator separator	SEPARATR	1
360	Intact loop steam generator steam dome plus steamline to MSIV	PIPE	3 3
365	Intact loop steamline from MSIV to turbine stop valve	BRANCH	1
368	Intact loop turbine stop valve (MTRVLV)	VALVE	--
369	Intact loop steam dump junction	TMDPJUN	--
370	Intact loop steam generator main steam isolation valve (MTVLV)	VALVE	--
375	Intact loop steam generator atmospheric dump valve (TRPVLV)	VALVE	--
376	Intact loop steam generator main steam line safety relief valve (TRPVLV)	VALVE	-
400	Broken loop hot leg	PIPE	2
405	Junction between hot leg segments	SNGLJUN	--
410	Broken loop hot leg	PIPE	3
415	Junction between hot leg and steam generator inlet plenum	SNGLJUN	--
420	Broken loop pump suction piping	PIPE	5
425	Broken loop pump	PUMP	1
430	Broken loop cold leg from pump discharge to accumulator line/break	PIPE	2
440	Broken loop cold leg from accumulator line/break to SI line	BRANCH	1
452	Broken loop cold leg from SI line to vessel	PIPE	2
500	Broken loop steam generator inlet plenum, primary tubes, outlet plenum	PIPE	10
502	Junction between steam generator outlet plenum and pump suction	SNGLJUN	--

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
520	Broken loop feedwater line from isolation valve to the feedwater nozzle	BRANCH	1
521	Broken loop feedwater source	TMDPVOL	1
522	Broken loop feedwater flow rate controlling junction	TMDPJUN	--
525	Broken loop auxiliary feedwater source (motor pump)	TMDPVOL	1
526	Broken loop auxiliary feedwater flow rate controlling junction (motor pump)	TMDPJUN	--
527	Broken loop auxiliary feedwater source (turbine pump)	TMDPVDL	1
528	Broken loop auxiliary feedwater flow rate controlling junction (turbine pump)	TMDPJUN	--
530	Broken loop steam generator downcomer (lower section)	ANNULUS	5
531	Broken loop steam generator downcomer to riser junction	SNGLJUN	--
540	Broken loop steam generator riser up to feed ring	PIPE	5
550	Broken loop steam generator separator	SEPARATR	1
560	Broken loop steam generator steam dome plus steam line to MSIV	PIPE	3
565	Broken loop steamline from MSIV to turbine stop valve	BRANCH	1
568	Broken loop turbine stop valve (MTRVLV)	VALVE	--
569	Broken loop steam dump valve	TMDPJUN	--
570	Broken loop steam steam generator main steam isolation valve (MTRVLV)	VALVE	--
575	Broken loop steam generator atmospheric dump valve (TRPVLV)	VALVE	--
576	Broken loop steam generator main steam line safety relief valve (TRPVLV)	VALVE	--

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
590 591	Volumes used to control pressure of intact loop steam generator and accept steam from steam dump system	TMDPVOL	1
592 593	Volumes used to control pressure of broken loop steam generator and accept steam from steam dump system	TMDPVOL	1
620	Pressurizer vessel	PIPE	8
625	Junction between pressurizer and surge line	SNGLJUN	--
630	Surge line	PIPE	3
650	Break (TRPVLV)	VALVE	--
670	Containment simulator for break	TMDPVOL	1
671	Containment simulator for intact loop atmospheric dump valve	TMDPVOL	1
672	Containment simulator for intact loop safety relief valve	TMDPVOL	1
673	Containment simulator for broken loop atmospheric dump valve	TMDPVOL	1
674	Containment simulator for broken loop safety relief valve	TMDPVOL	1
702	Intact loop accumulator	ACCUM	1
703	Intact loop accumulator/ECC line	BRANCH	1
704	Broken loop accumulator	ACCUM	1
705	Broken loop accumulator/ECC line	BRANCH	1
750	ECC water source	TMDPVOL	1
760	ECC line	BRANCH	1
762	Flow controlling junction for broken loop LPIS	TMDJUN	--
763	Flow controlling junction for broken loop HPIS	TMDPJUN	--

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
764	Flow controlling junction for broken loop charging system	TMDPJUN	--
765	Flow controlling junction for intact loop LPIS	TMDPJUN	--
766	Flow controlling junction for intact loop HPIS	TMDPJUN	--
767	Flow controlling junction for intact loop charging system	TMDPJUN	--

TABLE C-2. RELAP5 HEAT STRUCTURE DESCRIPTION FOR PWR PLANT MODEL

Heat Structure	Heat Structure Description	Number of Mesh Points
1001	Vessel wall in inlet annulus region	8
1021	Core barrel wall	3
1061	Vessel wall in downcomer region	8
1071	Neutron panel assemblies in downcomer	4
1081	Vessel wall in lower plenum region	6
1101	Lower plenum/core inlet volume internals	3
1111	Lower core support plate	6
1131	Lower core plate and fuel assembly bottom nozzles	3
1141	Core fuel rods in average core	17
1151	Hot fuel rod	17
1161	Core baffle assembly	3
1181	Upper core plate and fuel assembly top nozzles	3
1211	Upper core support columns	4

TABLE C-2. (continued)

Heat Structure	Heat Structure Description	Number of Mesh Points
1221	Guide tube lower assembly walls	3
1231	Support plate portion of upper core support assembly	5
1241	Guide tube upper assembly walls	3
1251	Cylindrical portion of upper core support assembly	3
1281	Vessel closure head	8
3001	Intact loop steam generator tubes	3
3002	Intact loop steam generator channel head	6
3301	Intact loop steam generator shell transition cone	6
3302	Intact loop steam generator lower shell	5
3401	Intact loop steam generator downcomer wrapper	3
3402	Intact loop steam generator upper boiler region internals	3
3411	Intact loop steam generator wrapper transition cone	3
3501	Intact loop steam generator riser barrel from bottom to feedring	3
3601	Intact loop steam generator driers	5
3602	Intact loop steam generator dome head	5
3603	Intact loop steam generator upper shell	5
4001	Intact and broken loop hot leg piping	6
4201	Intact and broken loop pump suction piping	6
4251	Intact and broken loop pump casings	9
4301	Intact and broken loop cold leg piping	5
5001	Broken loop steam generator tubes	3

TABLE C-2. (continued)

Heat Structure	Heat Structure Description	Number of Mesh Points
5002	Broken loop steam generator channel head	6
5301	Broken loop steam generator shell transition cone	6
5302	Broken loop steam generator lower shell	5
5401	Broken loop steam generator downcomer wrapper	3
5402	Broken loop steam generator upper boiler region internals	3
5411	Broken loop steam generator wrapper transition cone	3
5501	Broken loop steam generator riser barrel from bottom to feedring	
5601	Broken loop steam generator driers	5
5602	Broken loop steam generator dome head	5
5603	Broken loop steam generator upper shell	5
6201	Pressurizer upper head	5
6202	Pressurizer shell	5
6203	Pressurizer lower head	5

connects to the hot leg. The downflow portion of the pump suction leg is modeled with 3 hydrodynamic volumes, while the upflow portion is modeled with two hydrodynamic volumes. If the suction leg contains a horizontal section at the bottom of the suction loop, it should be modeled with a single volume, with junctions located at the horizontal ends of the 90 degree elbows that connect this section with the downflow and upflow legs. The pump discharge leg should be represented with 5 hydrodynamic volumes, with two of the junctions being located at points where accumulator and ECC system lines connect to the cold leg piping. Generally, an attempt should be made (where practical) to have all piping volumes be approximately the same length. Also, piping walls should be modeled for most transient calculations. Five or six mesh points are usually adequate for the heat structures used to describe pipe walls.

For the steam generators, the primary inlet and outlet plena should be modeled with 1 hydrodynamic volume each (note that the plena may be combined as part of a PIPE component that describes the whole of the inlet plenum, primary tube, and outlet plenum region). The primary side of the U-tubes is modeled with 8 volumes (4 up and 4 down for Westinghouse steam generators, 3 up, 2 across, and 3 down for Combustion Engineering (CE) steam generators, and 8 volumes stacked vertically for Babcock and Wilcox (B&W) once-through steam generators). The boundaries between volumes on the secondary side are at the same elevations as boundaries on the primary side. Thus for Westinghouse and CE steam generators 4 volumes represent the heated length of the boiler, while for B&W steam generators the boiler region would contain 8 volumes. The portion of the secondary above the boiler and below the separator deck in Westinghouse and CE generators is represented with 2 volumes. The downcomer is represented with 6 ANNULUS volumes, with the divisions between the volumes taken at the same elevations as on the boiler side. The separator component is the upper-most volume in the downcomer. The steam dome above the separator is modeled with 2 volumes. Heat structures representing the steam generator shell, plenum divider plate, tube sheet, tube bundle, tube support plates and flow baffles, secondary downcomer shroud, and separator and dryer metal mass should be modeled for most transient calculations.

The pressurizer is represented with 8 hydrodynamic volumes, with two of the volumes representing the upper and lower heads being smaller in size than the remaining six. The pressurizer surge line is represented with 3 volumes. The pressurizer shell, heaters, and surge line piping should all be modeled with heat structures.

The nodalization of the reactor vessel is based on using 6 volumes to represent the reactor core. The boundaries between the downcomer volumes are at the same elevations as the boundaries between the volumes in the core. The portion of the downcomer between the cold leg centerline and the bottom of the core is modeled with 8 volumes. Similarly, 8 volumes are used to model the upper plenum and the core between the hot leg centerline and the bottom of the core. The vessel upper head and lower plenum are each modeled with two volumes. The core inlet volume, defined as the region between the bottom of the core and the top of the lower plenum (or bottom of the downcomer) is represented with 1 volume. If present, core bypass paths are usually combined in a single channel, with volume boundaries at the same elevations as in the core/downcomer. Three volumes represent the downcomer above the cold leg centerline. Three volumes also represent the upper plenum above the hot leg centerline. The guide tubes are represented with a single volume that connects the upper head and the upper plenum. Heat structures should be used to represent the vessel shell, core barrel, core shroud, core thermal shield, all lower plenum internals, fuel rods, upper plenum internals (such as guide tubes and core support columns), core support plates, and upper head internals. With the exception of the fuel rods, 2 to 7 mesh intervals (depending on structure thickness) are usually sufficient to adequately describe the various vessel heats structures. The fuel rods should generally be modeled using 8 mesh intervals; 5 for the fuel, 1 for the gap, and 2 for the cladding; although for the case involved here a larger number of intervals was used to obtain a more detailed rod response.

6. INPUT DECK PREPARATION AND DOCUMENTATION

The preparation of a RELAP5 input deck involves determining the appropriate values for each of the various types of input required by the code, including:

1. Miscellaneous control data
2. Time step control data
3. Minor edit requests
4. Trip input
5. Hydrodynamic component data
6. Heat structure data
7. Heat structure thermal property data
8. General table data
9. Space independent reactor kinetic data
10. Plot request information
11. Control system input
12. Strip request information.

A complete description of the data requirements and input format for each of the above areas is presented in Appendix A.

The process of preparing the code model input involves large numbers of calculations, and numerous modeling assumptions must be made in the course of developing the input data. Determination of the input values should, therefore, be performed in a manner that assures the accuracy of the final product. To this end, it is advisable to create a workbook that contains all the information necessary to develop the model input. For each component in the model, the complete input required by the code should be developed in the worksheets. The sequence of the information contained in the worksheets should be nearly identical to the input requirements specified by the RELAP5 input manual, as this approach will greatly facilitate the transfer of this information to a computer input file. The information sources used to obtain data for the calculation should be referenced to the tabulated list of the plant data base described in Section 3. Each calculation should include sufficient detail to allow easy checking. Any assumptions required in the calculations, or any special method required to derive a given quantity, must be included in the worksheets, as should trip set points and initial conditions. Development of the logic involved in modeling the control systems to be used to provide transient control of the plant conditions should also be documented.

Having completed the development of the input values, an independent check of the deck development workbook should be performed as a means of ensuring that the model is complete and accurate. Good documentation in the input deck development phase will ensure quick reference to the modeling rationale and will facilitate the quality assurance check of the model.

7. STEADY-STATE INITIALIZATION

Completion of the basic input data deck preparation as described through Section 6 prepares the way for the steady-state and transient calculations. The plant conditions prior to the initiation of the transient will dictate the conditions required of a RELAP5/MOD2 steady-state calculation. The self-initialization option provides a convenient method for achieving the desired steady-state with minimal computer time.

As described in Section 4.4 of Volume 1, the self-initialization option makes use of generic control components (PUMPCTL, STEAMCTL, and FEEDCTL) to guide the plant model to a desired steady-state condition. When used in conjunction with the nearly-implicit solution scheme and steady-state options, an accelerated relaxation to steady-state may be achieved. The following subsections provide guidance on the effective use of the self-initialization option.

7.1 General Considerations

The self-initialization option makes use of three generic control components to drive a plant model to steady-state. In view of the wide variety of models that the option might be applied to, a degree of generality needed to be adopted in designing the controllers. Thus, while a "cookbook" approach would seem desirable from an ease-of-use standpoint, it was quickly recognized that too many restrictions on its usage (i.e., the nature of the plant model) would lead to a very limited range of applicability. In adopting the current design, a compromise was struck between ease-of-use and generality of applicability.

Resource limitations precluded testing the self-initialization option on an extensive number of plant model configurations. Verification did include a two-loop U-tube steam generator model, a single-loop U-tube steam generator model, and a two-loop once-through steam generator model. Testing included both secondary pressure and primary cold leg temperature control of the steam generator steam flow. Through that verification process, experience was gained in defining the controllers and their associated constants. This subsection highlights some general considerations on usage of the controllers based on the configuration of the plant model.

7.1.1 Single-Loop Models

A single-loop model, consisting of a reactor vessel, hot leg, pressurizer, steam generator, cold leg, and pump is the most simple representation of a PWR or experimental system and requires one each of the PUMPCTL (if loop flow is to be controlled), STEAMCTL, and FEEDCTL control components. A time dependent volume is also required to "replace" the pressurizer during the null transient to provide pressure and volume control. At the completion of the self-initialization calculation, the problem can be "renodalized" and restarted to initiate the desired transient. In this case, renodalization means removing the time dependent volume providing pressure control (in favor of the actual pressurizer), disabling the generic controllers, and incorporating (or enabling) all of the trips and controls appropriate to the transient.

7.1.2 Multi-Loop Models

Ordinarily, a multi-loop model will contain two or more symmetric or asymmetric[a] loops, each consisting of a hot leg, steam generator, pump, and cold leg piping. Under normal circumstances, steam flow control would be effected downstream of a header joining the outlets of the steam generators. This scheme assures nearly equal steam generator secondary pressures. In defining the STEAMCTL control component in this circumstance, the sensed variable should be the average of the loops. If secondary pressure control is being employed, the steam dome pressures from

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[a] Asymmetric in this context means the loops are not volumetrically equivalent, since the user has chosen to lump two or more loops together in the model.

the generators would be averaged. Likewise, if cold leg temperature control is used, the loop cold leg temperatures would be averaged. If the loops are asymmetric, the averaging should be weighted based on the volumetric proportion of each loop.

Individual steam generator steam flow control for multi-loop systems will likely create an unstable situation. In any event, such control is not likely to be desirable in achieving a specified steady-state condition.

A separate FEEDCTL control component should be used for each steam generator, as well as separate PUMPCTL control components (if loop flow is to be specified) for each pump. Each PUMPCTL control component should control flow for the loop in which the corresponding pump is located. Therefore if a total specific vessel flow is being sought, it should be proportioned among the loops.

7.2 Summary of Input Data Requirements

Preparation of the input deck for self-initialization includes the insertion of data cards to invoke the option as well as the disabling of transient-oriented controls and models. This subsection summarizes these requirements.

7.2.1 Self-Initialization Data Cards

Table C-3 lists the required data cards to invoke the self-initialization option, and the subsection in this volume where they are described.

7.2.2 Supplementary Requirements and Restrictions

The following additional requirements and/or restrictions must be adhered to when using the self-initialization option:

TABLE C-3. SUMMARY OF INPUT DATA CARDS FOR SELF-INITIALIZATION OPTION[a]

Card Number	Subsection	Description/Purpose
100	2.1	Problem Type and Option; used to specify steady-state option
140	2.9.1	Self-Initialization Control Card; used to specify number of each type of generic controller
141-142	2.9.2	Self-Initialization Pump Controller Identification Cards; used to relate pump controllers to pumps being controlled
143-144	2.9.3	Self-Initialization Steam Flow Controller Identification Cards; used to relate steam flow controllers to valves being controlled
145-146	2.9.4	Self-Initialization Feedwater Controller Identification Cards; used to relate feedwater flow controllers to valves being controlled
147	2.9.5	Pressure and Volume Control Component Identification Card; used to identify time dependent volume, its connection point, and pressure level
201-299	13.2	Time Step Control Cards; used to specify nearly-implicit solution scheme option
205NNN00	13.2	Control Component Type Card; one entry for each control component (NNN is the component number); provides characteristics of component
205NNNXX	13.3	Control Component Data Cards; one entry for each control component (NNN is the component number); provides data on setpoint, sensed parameter, and control constants

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[a] This is not an exhaustive list of all data that will be required (e.g., time dependent volume data is also needed). However, these data cards are uniquely required for the self-initialization option.

1. The core power must be imposed as a constant boundary condition using a general table (see Sections 6 and 10). If the point kinetics model is to be used for the ensuing transient analysis, it must be disabled for the self-initialization null transient.

2. Modeling of the makeup and let down flow systems should be suppressed for the null transient. The same is true for pressurizer heater and spray modeling. These functions are accomplished by the time dependent volume that replaces the pressurizer.

3. A time dependent volume should be connected to the hot leg control volume where the pressurizer normally is connected. The time dependent volume should be defined to contain subcooled liquid at the desired system pressure level, with the liquid temperature set to equal the anticipated hot leg temperature. The normal pressurizer volume should be valved-out and the time dependent volume valved-in during the null transient.

4. All trips and controls intended for the ensuing transient must be excluded or disabled during the null transient.

5. The conventional use of the generic control components assumes that the PUMPCTL component will control the speed of a pump component, the STEAMCTL component will modulate a valve component (i.e., steam valve), and the FEEDCTL component will modulate another valve component (i.e., feedwater valve) or time dependent junction. Successful operation of the latter two components has been demonstrated when the valves were connected to time dependent volumes. For the feedwater supply, this means a time-invariant source of feedwater, and for the steam exit, it means a low pressure sink that ensures choking at the steam valve. If the balance-of-plant is modeled in some degree of detail, it may or may not provide similar boundary conditions. Many balance-of-plant modeling configurations are possible, and a

generalized approach to including the balance-of-plant in the self-initialization option was not practical. Consequently, the user has two principal approaches to take if the model includes balance-of-plant components. These are:

a. Include control components to the balance-of-plant to ensure stable boundary conditions are imposed on the steam generator(s), or

b. Exclude the balance-of-plant system during the null transient (i.e., disconnect it), and separately "steady-state" it after the self-initialization calculation indicates the required secondary flow conditions.

7.3 Control Component Input Data Guidelines

It would be highly desirable to completely define generic controllers for the control of steam flow, feed flow, and reactor coolant system flow that would function satisfactorily for every conceivable model. But the reality is that successful control is uniquely related to the characteristics of the system being controlled. Moreover, because a reactor coolant system behaves as a non-linear system, it is not possible to mathematically derive ideal control system gains, time constants, etc. However, there are some general principles that should be considered.

The self-initialization controllers described earlier are all based on P-I (proportional-integral) control. This means that the active component being controlled is sent a control signal based on current error in the sensed variable as well as accumulated error. The proportional (or current) part of the control signal provides direct coupling between the error signal and the control signal, whereas the integral part of the control provides indirect coupling. The proportional component provides for rapid response and approach to steady-state while the integral component produces a zero steady state error so that the desired setpoint will have no offset bias.

An important aspect of system control is the dynamic behavior of interrelated control systems. For the case of PWR systems, the feedwater and steam flow control systems are obviously interrelated. It is essential that the interrelated control systems do not interact in a detrimental way, that is conflict with each other. The important control concept is to "slave" one control system to the other through the appropriate selection of controller constants, and in recognition of which drives the more sluggish characteristic of the system.

The following subsections present guidelines for each of the generic self-initialization controllers. A summary of these guidelines is presented in Table C-4.

7.3.1 PUMPCTL Component

The relationship between primary coolant pump speed and loop flowrate is tightly coupled. This is because the pump is positive displacement and the propagation time for a change in flow with a change in speed is very rapid.

The standard use of the PUMPCTL controller calls for the sensed signal to be a loop flowrate and the control variable a pump speed. Recalling the control expression as:

$$Y_1^{n+1} = G_1 \left[\frac{E_1}{T_1} + \frac{\int^{t_n} E_1 dt}{T_2} \right] + (Y_1)_0 \qquad \text{(C-1)}$$

and that

$$E_1 = \frac{V_1 - V_2}{S_i} \qquad \text{(C-2)}$$

TABLE C-4. SUMMARY OF GUIDELINES FOR GENERIC CONTROL COMPONENT CONSTANTS

[To be supplied]

where Y is in terms of speed and V in terms of flow, it follows that S_i should relate the speed of the pump and the consequential flow produced so that the control signal is in the units of speed and is also indicative of the characteristics of the pump. One approximate measure of the pump's characteristics in this regard is the ratio of the rated flow to the rated speed:

$$\phi = \frac{\rho Q_R}{N_R} \qquad \text{(C-3)}$$

where Q_R is the rated volumetric flow, N_R the rated speed and ρ is the coolant density. This is an appropriate value for S_i. Note that the sign of S_i has to be consistent with the relationship between the sign of the error and the sign of the resulting change in output signal. For the standard application of the PUMPCTL controller S_i must be positive since a positive error (i.e., flow is lower than setpoint) should correspond to a positive increase in pump speed.

The time constants T_1 and T_2 are divisors of the flow error and therefore diminish the error signal if they are greater than one. Physically they may be interpreted as a measure of the time it will take to recover the error. Reasonably good results have been obtained by setting T_1 at approximately 2 and T_2 at Δt_{max}, where Δt_{max} is the user-specified maximum time step size. Ordinarily the gain (G_1) would be set to unity.

7.3.2 STEAMCTL Component

[To be supplied]

7.3.3 FEEDCTL Component

[To be supplied]

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

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-4312
EGG-2396
Revision 1

2 TITLE AND SUBTITLE
RELAP5/MOD2 Code Manual
Volume 2: Users Guide and Input Requirements

3 LEAVE BLANK

4 DATE REPORT COMPLETED
MONTH March YEAR 1987

5 AUTHOR(S)
V. H. Ransom, R. J. Wagner, et al.

6 DATE REPORT ISSUED
MONTH March YEAR 1987

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
EG&G Idaho, Inc.
Idaho Falls, ID 83415

8 PROJECT/TASK/WORK UNIT NUMBER

9 FIN OR GRANT NUMBER
A6052

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

11a TYPE OF REPORT
Technical

b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)

The RELAP5/MOD2 code has been developed for best estimate transient simulation of pressurized water reactors and associated systems. The code modeling capability includes simulation of large and small break loss-of-coolant accidents as well as operational transients such as anticipated transient without SCRAM, loss-of-offsite power, loss of feedwater, and loss of flow. A generic modeling approach is utilized, which permits as much of a particular system to be modeled as necessary. Control system and secondary system components are included to permit modeling of plant controls, turbines, condensers, and secondary feedwater conditioning systems.

14 DOCUMENT ANALYSIS – a KEYWORDS/DESCRIPTORS

b IDENTIFIERS/OPEN ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

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

17 NUMBER OF PAGES

18 PRICE

EG&G Idaho
P.O. Box 1625
Idaho Falls, Idaho
83415