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SCDAP/RELAP5/MOD2 Code Manual

User's Guide and Input Requirements

Edited by C. M. Allison, E. C. Johnson

EG&G Idaho, Inc.

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U.S. Nuclear Regulatory Commission

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ABSTRACT

The SCDAP/RELAP5 code has been developed for best-estimate transient simulation of light water reactor coolant systems during a severe accident. The code models the coupled behavior of the reactor coolant system, the core, and the fission products and aerosols in the system during a severe accident transient as well as large and small break loss-of-coolant accidents, operational transients such as anticipated transient without SCRAM, loss of offsite power, loss of feedwater, and loss of flow. A generic modeling approach is used that permits 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 Volumes I and II to acquaint the user with the modeling base and thus aid in effective use of the code. Volume III contains detailed instructions for code application and input data preparation. In addition, Volume III contains user guidelines that have evolved over the past several years from application of the RELAP5 and SCDAP codes at the Idaho National Engineering Laboratory, at other national laboratories, and by users throughout the world.

EXECUTIVE SUMMARY

The light water reactor (LWR) severe accident transient analysis code, SCDAP/RELAP5, has been developed at the Idaho National Engineering Laboratory (INEL) for the U. S. Nuclear Regulatory Commission (NRC) to provide an advanced best-estimate predictive capability for use in severe accident applications in support of the regulatory process. Code uses include analysis required to support rulemaking, licensing audit calculations, evaluation of accident mitigation strategies, and experiment planning and analysis. Specific applications of this capability have included analytical support for the loss-of-fluid test (LOFT), Power Burst Facility (PBF), ACRR, MIST, ROSA IV, and NRU experimental programs, as well as simulations of transients that lead to severe accidents, such as loss of coolant, anticipated transients without scram (ATWS), and operational transients in LWR systems. SCDAP/RELAP5 is a highly generic code that, in addition to calculating the behavior of a reactor coolant system (RCS) during a severe accident transient, can be used for simulation of a wide variety of hydraulic and thermal transients in both nuclear and nonnuclear systems involving steam-water noncondensible solute fluid mixtures.

SCDAP/RELAP5 was developed by integrating three separate codes, RELAP5/MOD2, SCDAP, and TRAP-MELT. These codes were combined to model the coupled interactions that occur between the core, the RCS, and the fission products during a severe accident. For example, blockage in the core, caused by fuel rod ballooning and meltdown, can have a significant effect on RCS flows. Fission products released from the core can have a significant effect on the RCS because of the heat produced during decay. These and many other coupled effects can have a significant effect on the release of fission products from the RCS.

The RELAP5/MOD2 code is based on a nonhomogeneous and nonequilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients. The objective of the RELAP5 development effort from the outset was to produce a code that includes important first-order effects necessary for

accurate prediction of system transients but is sufficiently simple and cost-effective such that parametric or sensitivity studies are possible. The development of SCDAP/RELAP5 has this same focus.

The SCDAP code models the core behavior during a severe accident. Treatment of the core includes fuel rod heatup, ballooning and rupture, fission product release, rapid oxidation, zircaloy melting, UO_2 dissolution, ZrO_2 breach, flow and freezing of molten fuel and cladding, and debris formation and behavior. The code also models control rod and flow shroud behavior.

The TRAP-MELT code models the behavior of fission products and aerosols within the RCS. This treatment includes aerosol agglomeration (including Brownian motion, gravitational settling, and turbulent eddy effects), aerosol deposition (including gravitational settling, thermophoresis, and diffusion from laminar or turbulent flow), fission product evaporation and condensation, and chemsorption of vapors by stainless steel.

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

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

The development of the models and codes that constitute SCDAP/RELAP5 has spanned approximately 12 years from the early states of RELAP5 numerical scheme development to the present. SCDAP/RELAP5 represents the aggregate accumulation of experience in modeling core behavior during severe accidents, fission product and aerosol behavior, two-phase flow process, and LWR systems. The code development has benefited from extensive application and comparison to experimental data in the LOFT, PBF, Semiscale, ACRR, NRU, and other experimental programs.

Volumes I and II describe the basic theory and numerical methods used for the various system models. Volume III gives detailed descriptions of the input preparation and execution procedures and provides general guidelines on code application.

ACKNOWLEDGMENT

Development of a complex computer code such as SCDAP/RELAP5 is the result of a team effort. Acknowledgment is made of those who made significant contributions to the earlier versions of RELAP5, SCDAP, and TRAP-MELT; in particular, K. E. Carlson, Dr. H. H. Kuo, Dr. J C. Lin, Dr. H. Chow, Dr. C. C. Tsai, L. R. Feinauer, and Dr. W. Bryce (UKAEA) for contributions to the RELAP5 code; G. H. Beers, E. R. Carlson, and T. M. Howe for contributions to the SCDAP code; and M. R. Kulman, J. A. Gieseke, H. Jordan, and P. Baybutt for contributions to the TRAP-MELT code. Acknowledgment is also made to E. C. Johnson for her work in SCDAP/RELAP5 configuration control and user services.

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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 and SCDAP codes. 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.

1.1 General

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

1.2 Areas of Application

SCDAP/RELAP5 is based on RELAP5/MOD2,[1-1] which 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 LWRs. In particular, a point neutronics model, pumps, turbines, generator, valves, separator, and controls are included. The code also contains a jet pump component.

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

1.3 Modeling Philosophy

SCDAP/RELAP5 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 pressurized water reactor (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. This is an important feature for calculating the RCS behavior when the core geometry changes significantly. 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. (In other words, a countercurrent liquid-liquid flow cannot be represented by a single junction.) For flows in pipes, there is little confusion with respect to nodalization. However, in a steam generator having a separator and recirculation flow paths, some experience is needed to select a nodalization that will give correct results under all conditions of interest. Nodalization of branches or tees also requires some guidance.

The severe accident core behavior models treat the core as consisting of one or more radial rings. Each ring is made up of some combination of fuel rods, control rods, and flow shrouds. These structures communicate heat with the fluid within the associated core control volumes, much as is done with the heat structures.

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. Both axial and radial conduction are modeled, and the axial mesh spacing is refined as needed to resolve the axial thermal gradient. The hydrodynamic volume associated with the heat structure is not rezoned, and a spatial boiling curve is constructed and used to establish the convection heat transfer boundary condition. At present, this capability is specialized to the LWR core reflood process; but 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 when doing a RELAP5-only calculation. 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 prior 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 SCDAP/RELAP5 contains numerous approximations to the behavior of a real, continuous system. These approximations are necessitated by the finite storage capability of computers, by the need to obtain a calculated result in a reasonable amount of computer time, and in many cases because of limited knowledge about the physical behavior of the components and processes that are modeled. For example, knowledge is limited for components such as pumps and separators, processes such as two-phase flow, and heat transfer. Examples of approximations required due to limited computer resources are limited spatial nodalization for hydrodynamics, heat transfer, and 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; 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.

1.4 References

1-1. V. H. Ransom et al., RELAP5/MOD2 Code Manual, Volumes 1 and 2, NUREG/CR-4312, EGG-2396, Revision 1, April 1987.

2. CORE STRUCTURES

The core structures represent the solid portions within the reactor core region. This includes fuel rods, control rods, flow shrouds, and grid spacers and excludes the upper and lower core support plates.

The input for core structures differs from that for the balance of the RCS and the fission product and aerosol behavior (discussed in the following sections). It employs free-form input but must be provided in a specific order. The initial part of the input consists of time step control, the problem time convergence criterion, bundle cross-sectional area, grid spacer locations, and the number and type of components. Once the number and type of core components are specified, input is provided for each component as a block of input followed by block for the next component. Depending on which type of component is specified (fuel rod, control rod, or flow shroud), a different set of inputs is required.

2.1 Fuel Rod

OThe fuel rod behavior model calculates the thermal, mechanical, and chemical response of fuel rods during severe accidents. The fuel rod behavior models consider nuclear heat generation, temperature distribution, zircaloy cladding oxidation, fuel deformation, liquefaction, and fission product release. Nuclear heat generation, in combination with the heat generation of cladding oxidation, determines the fuel rod temperature. The rod temperature is computed by a one-dimensional finite element mode. The oxidation heat of zircaloy is the dominant heat source after temperatures reach 1500 K. Cladding deformation is based on mechanical models developed for FRAP-T6[2-1] and FRAPCON-2.[2-2] The model considers both axisymmetric cladding collapse or ballooning and asymmetric localized ballooning. The melt, flow, and refreezing of liquefied U-O-Zr is also considered. The liquid material is assumed to flow as an axisymmetric slug depositing both heat and a frozen crust upon the underlying ZrO_2 layer. The release of inert gases (krypton, xenon, helium) and volatile fission product (cesium, iodine) is modeled using the PARAGRASS[2-3] model.

The major inputs for fuel rods include axial and radial radiation fuel rod geometry, rod fabrication characteristics, burnup, number of like rods in the bundle, initial temperature distribution, and axial and radial power distribution.

2.2 Control Rod

Control rod temperatures are computed using the same heat conduction model as the fuel rods. User-specified nuclear heating, chemical heating due to oxidation of the zircaloy guide tube and stainless steel cladding, and convective and radiative heat transfer from the coolant and adjacent fuel rods are considered. The melting and relocation of control rod materials are described in the following manner. If the stainless steel is below its melting temperature, no relocation of molten Ag-In-Cd occurs. If the guide tube melts, or is breached, molten absorber moves through the breach in the zircaloy guide tube and moves as a film on the outside of the guide tube. Unlike the flow of molten Zr-U-O for fuel rods, the momentum and energy equations are not solved to describe the freezing of the molten Ag-In-Cd; rather, the material freezes when it reaches a lower elevation where the guide tube temperature is 200 K less than the solid temperatures of Ag-In-Cd. For subsequent heatup and melting of stainless steel and zircaloy, the molten material relocates internally downward within the oxidized ZrO_2 on the guide tube, filling up the voids formed by the allocation of molten Ag-In-Cd. The molten mixture of stainless steel and zircaloy will remain contained within the ZrO_2 shell until the ZrO_2 is either melted, allowing the molten mixture to flow downward in the flow channel until it freezes, or is shattered upon reflood.

The major inputs for control rods include axial nodalization, number of like rods in the bundle, control rod and guide tube geometry and fabrication characteristics, initial temperature distribution, and any power produced in the control rod.

2.3 Flow Shroud

The structures internal to the core other than fuel and control rods can be modeled using the basic heat conduction equation. Heat generation can be user-specified and oxidation-related. The structures can be defined by multiple layers of materials, with the oxidation and relocation of exterior layers due to melting considered. Zircaloy layers are oxidized using the same kinetics as described for fuel rods. The molten zircaloy relocates downward to a region where the structural surface temperature is 200 K less than the solidus temperature of zircaloy. Structures with exterior layers or composed entirely of nonzircaloy materials can also be modeled; however, oxidation rate equations must be user-specified and no material relocation or loss of geometry can be considered. Both melting and nonmelting models can be used for the structures outside the core as well. The same material limitations apply.

The major inputs for a flow shroud include axial and radial nodalization and temperature distribution.

2.4 Simulator Rod

The simulator rod is used in out-of-pile experiments to simulate the behavior of fuel rods during a severe accident scenario. The simulator rod is heated electrically by tungsten wire at the center. The simulator rod behavior model calculates the thermal, mechanical, and chemical response of simulator rods during severe accidents. The model considers electric heat generation, temperature distribution, zircaloy cladding oxidation, and fuel deformation and liquefaction. Electric heat generation, in combination with the heat generation of cladding oxidation, determines the fuel rod temperature. The rod temperature is computed by a two-dimensional finite difference mode. Cladding deformation is based on mechanical models developed for FRAP-T6[2-1] and FRAPCON.[2-2] The melt, flow, and refreezing of liquefied U-O-Zr are also considered.

The major inputs for simulator rods include axial and radial radiation simulator rod geometry and rod fabrication characteristics, radius of tungsten wire, number of like rods in the bundle, initial temperature distribution, and axial power distribution based on nodal resistivity calculations.

2.5 References

2-1. L. J. Siefken et al., FRAP-T6: A Computer Code for the Transient Analysis of Oxide Fuel Rods, EGG-CDAP-5410, April 1981.

2-2. G. A. Berna et al., FRAPCON-2 Developmental Assessment, NUREG/CR-1949, PNL-3849, July 1981.

2-3. J. Rest and S. A. Zawadzki, "FASTGRASS-VFP/PARAGRASS-VFP Version 50531, Users Guide," Argonne National Laboratory Quarterly Report, January through March 1983, Volume I, NUREG/CR-3689, ANL-83-85 Volume I, June 1983.

3. 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 connected by junctions. A physical system consisting of flow paths, volumes, areas, etc., is simulated by constructing a network of control volumes connected by junctions. The transformation of the physical system to a system of volumes and junctions is an inexact process, and there is no substitute for experience. General guidelines have evolved through application work using SCDAP/RELAP5, and the purpose here will be to summarize these guidelines.

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

1. The length of volumes should be such that all have similar material Courant limits, i.e., $\Delta x/v$ 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 ~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 core level depression in a PWR under small break loss-of-coolant accident conditions.

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

3.1 Basic Flow Model

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

The hydrodynamic boundaries of a system are modeled using time-dependent volumes and junctions. For example, a reservoir condition would normally be modeled as a constant pressure source of mass and energy (a sink in the case of an outflow boundary). The reservoir is connected to the system through a normal junction, and the inflow velocity is determined from the momentum equation solution. For this type of boundary, some caution is required since the energy boundary condition is in terms of the thermal energy rather than total energy. Thus, as the velocity increases, the total energy inflow increases 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, or else flow reversals may occur.

A second way of specifying a flow boundary is using the time-dependent junction in addition to a time-dependent volume. This type of boundary condition is analogous to a positive displacement pump where the inflow rate is independent of the system pressure. In this case, the cross-sectional area of the time-dependent volume is not used because the velocity is fixed and the time-dependent volume is only used to specify the properties of the inflow. Thus the total energy of the inflow is specified. When only time-dependent junctions are used as boundary conditions, the system pressure 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 SCDAP/RELAP5, any volume that does not have a connecting junction at an inlet or outlet is treated as a closed end. Thus, no special boundary conditions are required to simulate a closed end.

The fluid properties at an outflow boundary are not used unless flow reversal occurs. In this respect, some caution is necessary and is best illustrated by an example. In the modeling of 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. 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 3-1.

The junction coordinate direction is established through input of the junction connection code (Words W1 and W2 of Cards CCC0101-CCC0109, see Subsection A-7.4.1 of Appendix A). The junction connection codes designate a <u>from</u> and a <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 codes can be entered in an old or an expanded format. The expanded format is recommended, but the old format is still valid and no changes are required to existing decks.

A connection code has the format CCCVV000N, where CCC is the component number, VV is the volume number, and N is the face number, where zero indicates the old format and nonzero indicates the expanded format. For connecting to a time-dependent volume, the only connection code allowed is CCC000000, where CCC is the component number of the time-dependent volume component and such a component has only one volume. The other components that are available in the code and that describe volumes are currently oriented to one-dimensional flow. As such, a single coordinate direction is defined with an inlet and outlet such that flow entering an inlet and leaving an outlet is positive flow along the coordinate direction. The average volume velocity is computed along the coordinate direction. Crossflow is defined to be flow entering or leaving a volume in a direction orthogonal to the volume's coordinate direction. Crossflows are not used

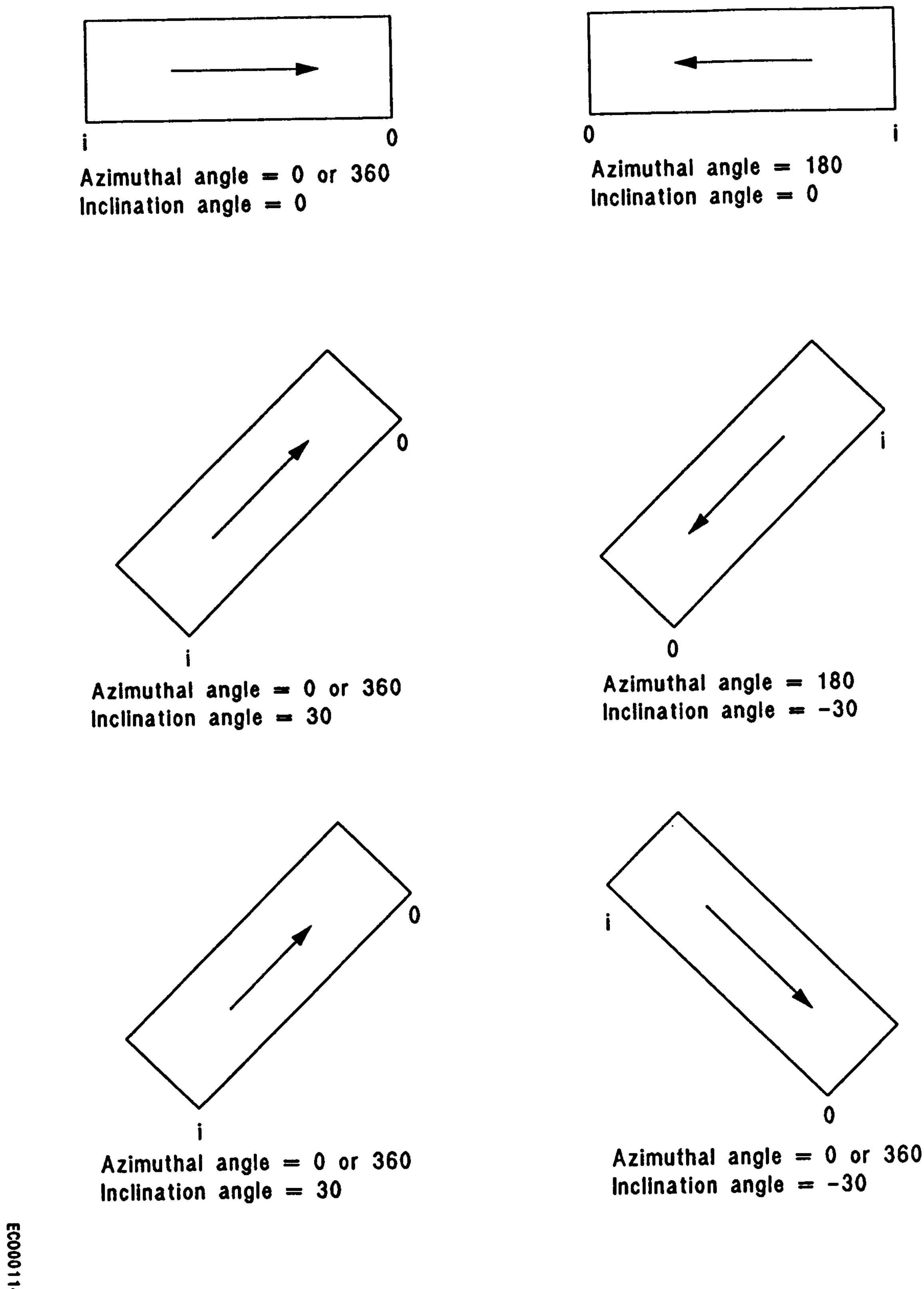


Figure 3-1. Possible volume orientation specifications.

in average volume flow calculations because they are orthogonal to the average volume flow. In the old format (N=0), VV=00 specified the inlet face, VV=01 specified the outlet face, the volume number is only implied, and flags specified normal as crossflow junctions. For components specifying single volumes (currently only a PIPE specifies multiple volumes), normal flow (as opposed to crossflow) to either the inlet or outlet face and crossflow can be specified. For a pipe, however, the old format allows specification of normal flow only to the inlet of the first pipe volume, to the outlet of the last pipe volume, and crossflow only to the first and last pipe volumes.

The expanded connection code assumes that a volume has six faces, i.e., an inlet and outlet for each of three coordinate directions. The expanded connection code indicates the volume being connected and through which face it is being connected. In the new format (N nonzero), N is the face number and VV is the volume number. For components specifying single volumes, VV is 01; but for pipes, VV can vary from 01 for the first pipe volume to the last pipe volume number. The quantity N is 1 and 2 for the inlet and outlet face, respectively, for the volume's coordinate direction. The quantity N is 3 through 6 to indicate crossflow. The current crossflow capability does not require face orientation information; but in future extensions, N equal to 5 and 6 would indicate inlet and outlet faces for the second coordinate direction, and similarly N is 5 and 6 for the third coordinate direction.

In major edits and similar input edit, the junction connection code is edited in the new format. When inputting junction data in the old format and crossflow is indicated by junction flags, N is set to 4 for the <u>from</u> volume and to 3 for the <u>to</u> volume. In the new format, the crossflow part of the junction flags is ignored at input processing but set appropriately for output editing. Note that the new logic allows branch flow (i.e., multiple junctions at a face) at any volume, including interior pipe volumes. The primary reason for this change is to permit crossflow to all volumes in a pipe. Now it is possible to use pipe volumes to represent axial levels in a vessel and to use multiple pipe components to represent radial or azimuthal dependence. Single junctions can crosslink any of the pipe volumes at the same axial level.

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

A sketch showing a series of three horizontal volumes connected by two junctions is shown in Figure 3-2 to illustrate some of the possible coordinate orientations that result from combinations of the connection codes and the volume orientation data. In Figure 3-3, two possible combinations are illustrated for the connection of two vertical volumes. Figure 3-3a shows the two volumes unconnected; 3-3b shows the result when the outlet of Volume 1 is joined to the inlet of Volume 2; and 3-3c 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, the summation of the volume elevations must close when they are summed according to the junction connection codes and sequence or an unbalanced gravitational force will result. SCDAP/RELAP5 has an input processing feature that finds all loops or closed systems (which are defined by the input) and checks for elevation closure around each loop.The error criterion is 10^{-4} m. If closure is not obtained, the fail flag is set, and no transient or steady-state calculations will be made. The elevation checker will print out that elevation closure does not occur at a particular junction that formed a closed loop during input processing. The junction at which closure of the loop occurs is somewhat arbitrary and depends on the input order of the components.

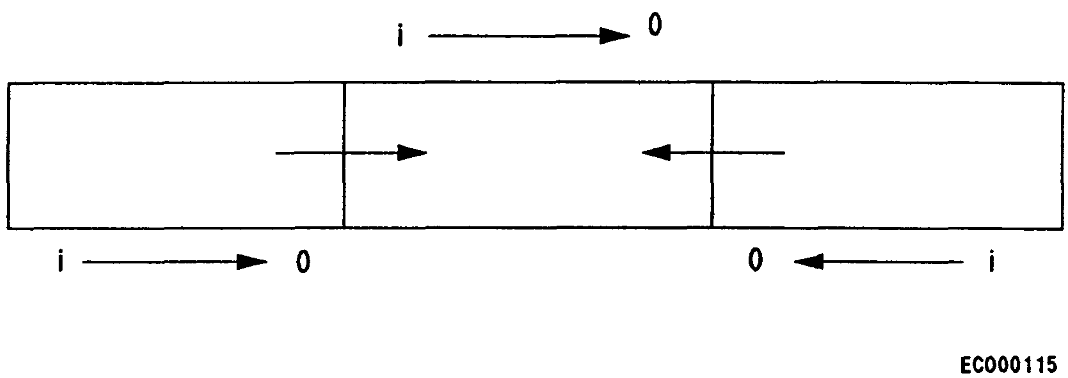
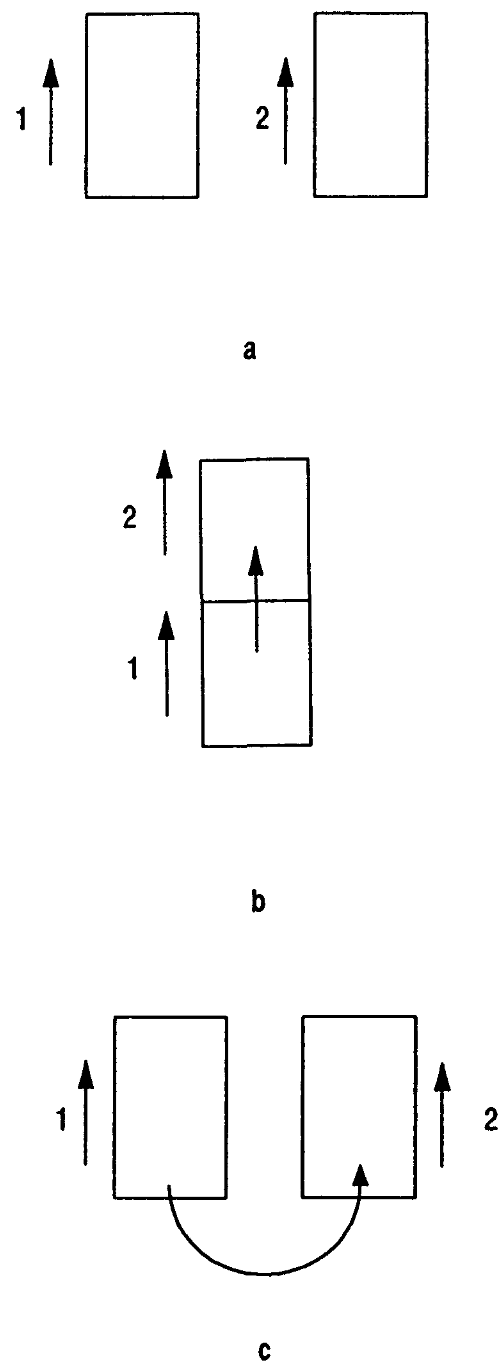


Figure 3-2. Sketch of possible coordinate orientation for three volumes and two junctions.



EC000116

Figure 3-3. Sketch of possible vertical volume connections.

The junctions are printed out in the major edits in the hydrodynamic junction information sections (see Subsections 9.3.2.7 and 9.3.2.8). 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	HST	10
Vertical stratified	VST	11

The Bestion/Analytis[3-1,3-2] interphase friction model for bundles (i.e., core and steam generator) can be activated with a volume control flag (b). The model should be restricted to bundles where the pressure is in the range 1-20 bar and the hydraulic diameter is less than 12 cm.

3.2 Process Models

In SCDAP/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 reflood are all simulated using specialized modeling. These particular processes are not peculiar to a component and will be discussed as a group. Some components, such as pumps and separators, also involve special process models; these models will be discussed with the component models. The use of the process models is specified through input, and proper application is the responsibility of the user. As a general rule, it is recommended that the user not mix process models; e.g., it is recommended the user not use the choking model at a multiple junction where the abrupt area change is activated. The purpose of this section is to advise the user in this regard.

3.2.1 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 ten, 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. The loss factor should be determined for the code's velocity, which is based on the smaller of the two connecting areas.

3.2.2 Choked Flow

The choked flow option is specified in the junction flags on the junction geometry card. In general, the choked flow model should be used at all exit junctions of a system. It is recommended that the choked flow model be used at the choke plane and that the user not model anything past this plane. (Therefore, just use a time-dependent volume downstream of the choke plane.) Internal choking is allowed, but may not be desirable under certain conditions.

The recommended input junction flags are abrupt and nonhomogeneous. However, several studies over the past two years have show that under certain conditions (not completely defined at this point) the SCDAP/RELAP5 critical break flow model will predict unrealistically low mass flows. Under such conditions, the break junction flags should be specified as abrupt and nonhomogeneous. 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 $(dA/dx)_2$ in Volume 1 of this manual is calculated differently for the abrupt area option and the smooth area option. For the recommended abrupt area change option the following formula is used:

$$(dA/dx)_{t,abrupt} = [A(K) - A_t] / [10.0\ D(K)] \tag{3-1}$$

where

$A(K)$ = the upstream volume flow area,

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

$D(K)$ = 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 emperical 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,[3-3] which is one of the developmental assessment separate-effects test problems. In addition, it has been used successfully in many Semiscale test comparisons for the break flow.[3-4] If the user selects the smooth area change option, the code uses the following formula:

$$(dA/dx)_{t,smooth} = [A(K) - A_t] /[0.5 \; DelX(K)] \tag{3-2}$$

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.

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.

3.2.3 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 pullthrough 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.

3.2.3.1 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 3-4. 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 SCDAP/RELAP5 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 fvcahs, which is Word W6(I) of Cards CCC0101 through CCC0109 (see Appendix A, Section A-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.

A tee can also be modeled using the branch component, as illustrated in Figure 3-5. 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

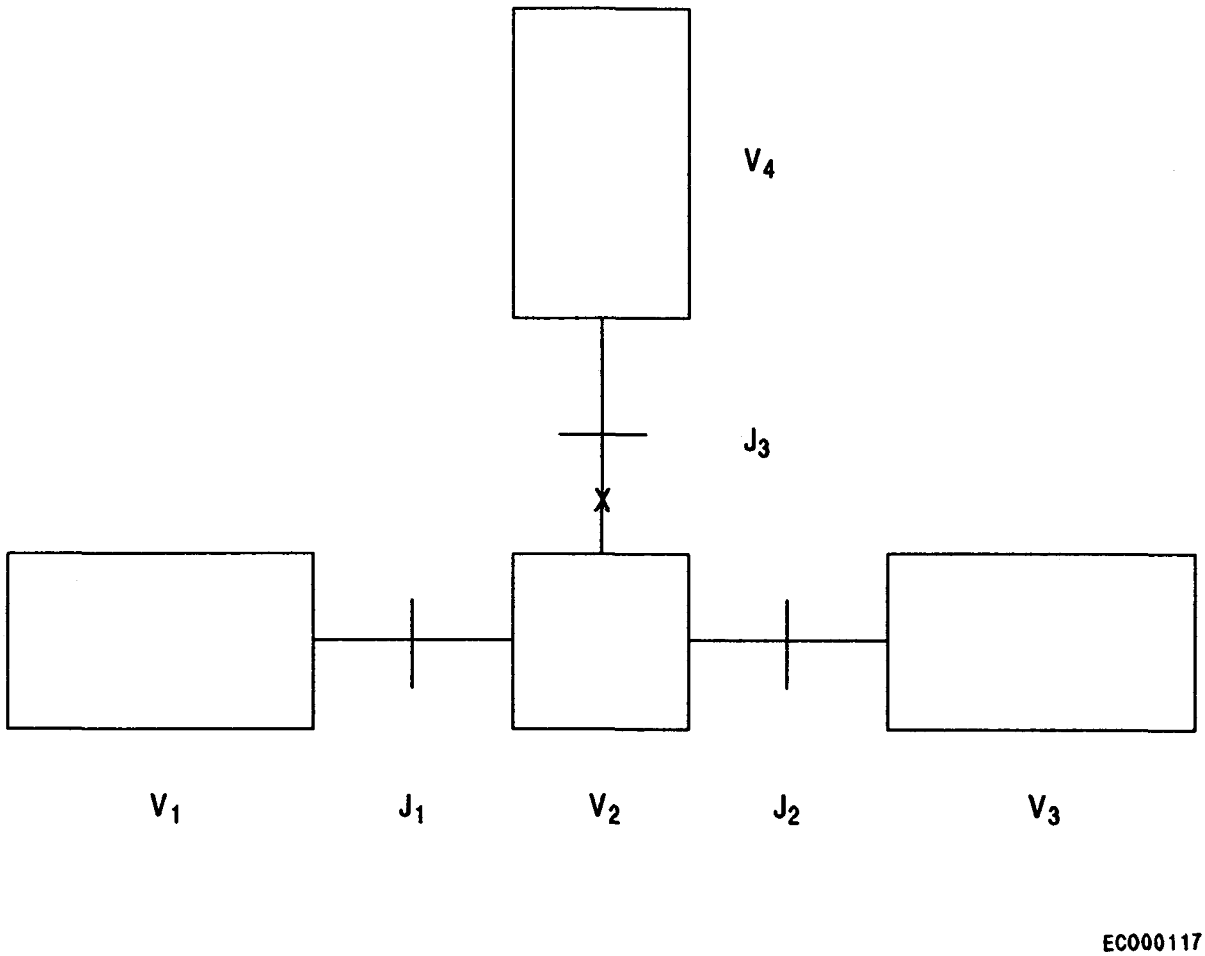


Figure 3-4. A 90-degree tee model using a crossflow junction.

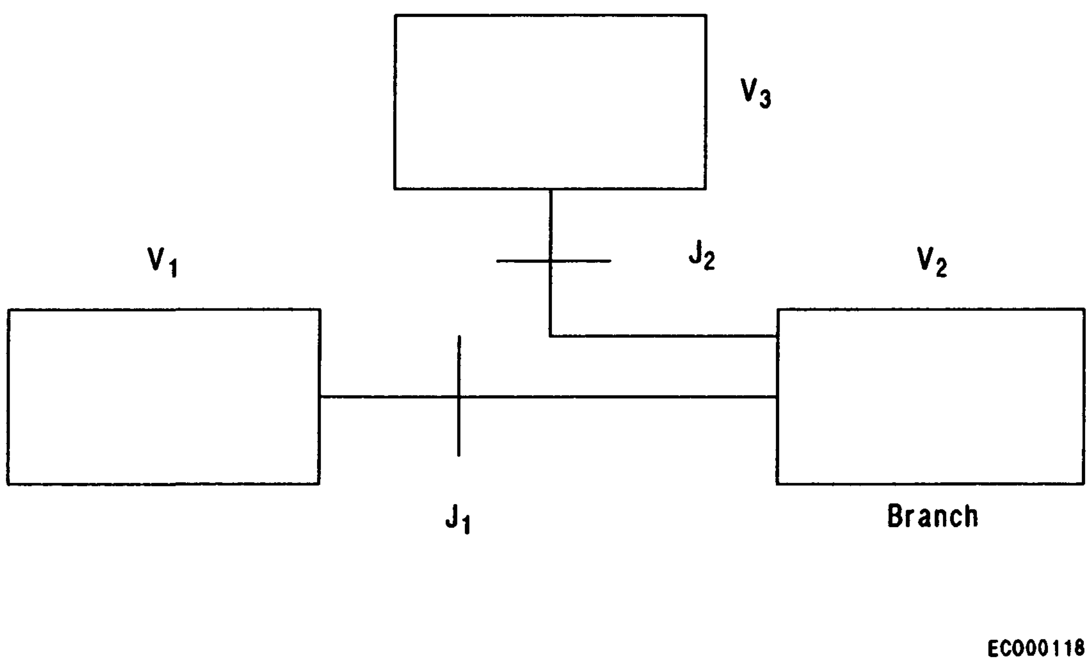


Figure 3-5. Tee model using a branch component.

nearly parallel, the model illustrated in Figure 3-5 may be a more accurate representation of the physical process (such as for a wye).

3.2.3.2 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 in Section 3.3.

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 3-6. The figure is only one example and implies merging flow. Additional junctions could be attached to both ends, and any of the volume and junction coordinate directions could be changed. The actual flows may be in any direction; thus, flow out of Volume V_3 through Junction J_1 and into Volume V_3 through Junction J_2 is permitted.

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 based on the assumption that the fraction of volume flow area associated with a junction stream tube is the same as the volumetric flow

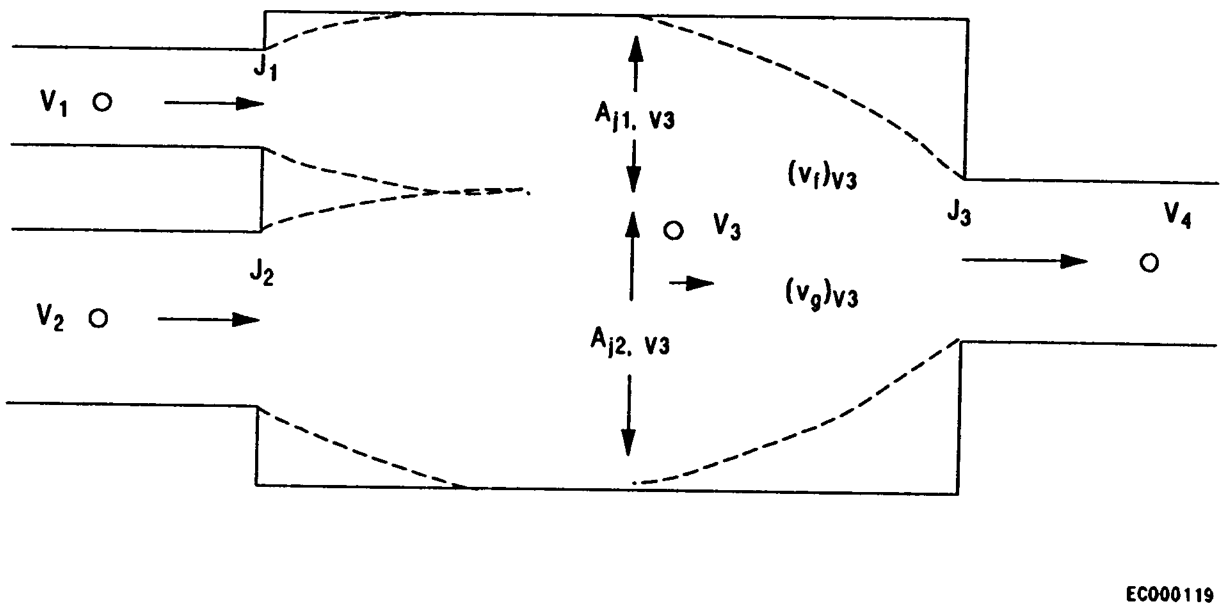


Figure 3-6. Typical branching junctions.

reaction 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, it 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 3-7. The 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 3-6 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.

3.2.3.3 <u>Leak Paths</u>. 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

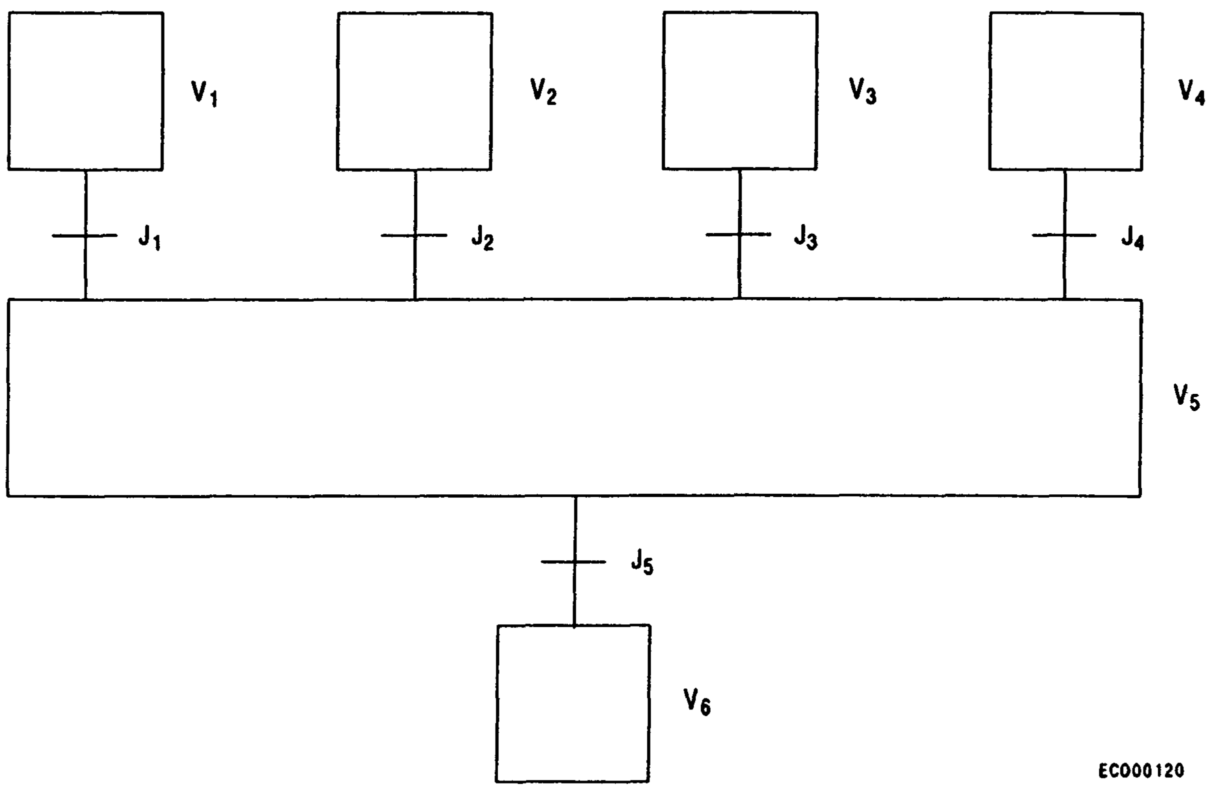


Figure 3-7. Plenum model using a branch.

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. 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 3-8. In such an application, it is necessary that the volume centers of Volumes V_1 and V_2 have the same elevation.

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 <u>vcahs</u> flag with <u>a</u> = 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

$$K = 2\Delta P A^2 \Gamma / \dot{m}^2 \tag{3-3}$$

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

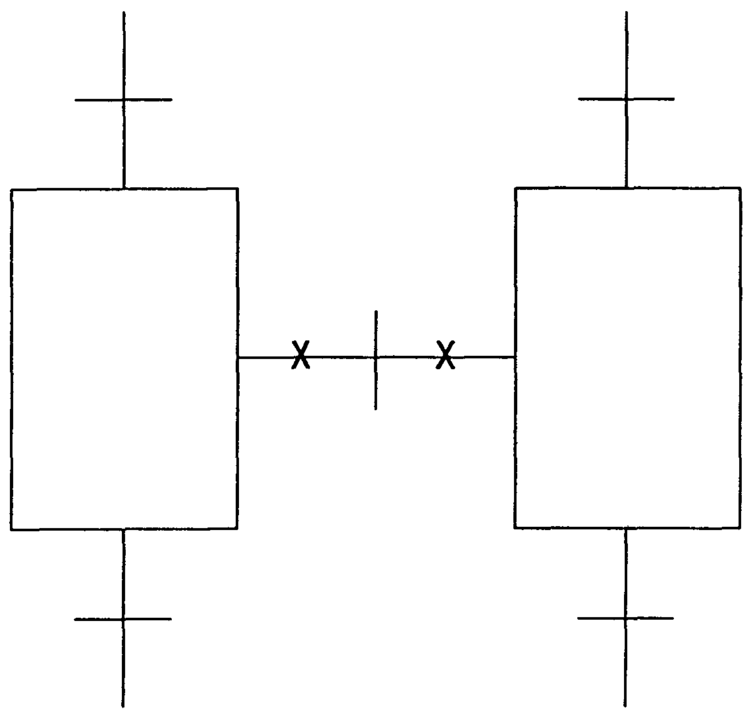


Figure 3-8. Leak path model using the crossflow junction.

they are physically different. In this case, Equation (3-3) should be used to calculate the effective loss factor for both the forward and reverse flow conditions (i.e., assume ΔP and m also correspond to the reverse flow case). The geometric relationship between the actual situation and the model is illustrated schematically in Figure 3-9.

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 (fvcahs with a = 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 (3-3). 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 (3-3) can be replaced by K+1. [In other words, the user input loss factor is computed by substituting K+1 for K in Equation (3-3)].

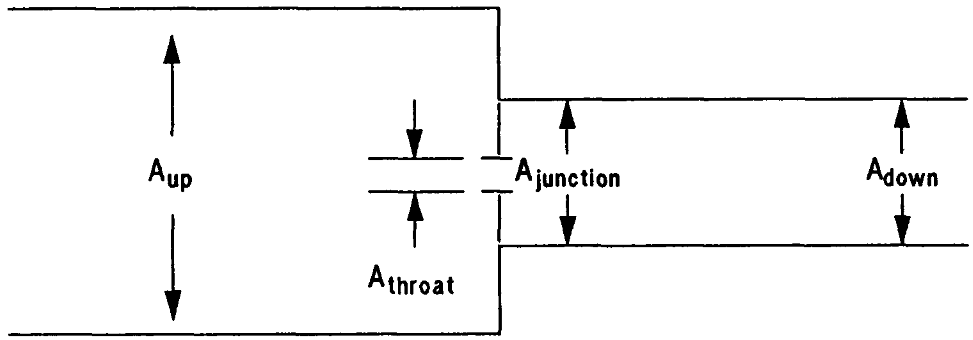
All of the development herein assumes that known pressure drop flow relations exist for the single-phase case and that compressibility effects are small. If such is not the case, then the effective loss factor values must be determined experimentally by running the code for a series of cases. Some experimentation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

3.2.4 Reflood Model (for use when performing a RELAP5 only calculation)

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 $kg/s \cdot m^2$.

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

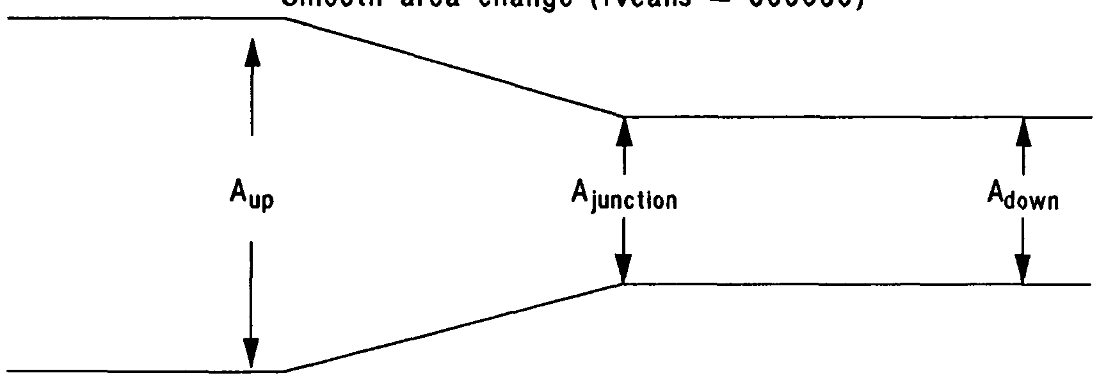
Abrupt area change (fvcahs = 000100)



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

Physical situation with a loss factor K_{actual}

Smooth area change (fvcahs = 000000)



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

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

EC000122

Figure 3-9. 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.

7. Do not apply the model when noncondensible gas is present.

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 film boiling ($0 < \alpha_g \leq 0.999$)

43 dispersed film boiling ($0.999 < \alpha_g \leq 0.9999$)

44 single-phase vapor ($\alpha_g > 0.9999$)

3.2.5 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.

3.2.6 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 4.1.4.6).

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 3-10 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.

```
RELAP5/2/36.05      REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                        PAGE      31
 WATER FILL INTO STEAM - CLOSED                                          89/07/12.
WATER PACKING OCCURRED, TIMEHY =   2.775000    , NCOUNT =        61, VOLNO = 003010000, JUNNO = 003010000
```

Figure 3-10. Output from the water packing model.

3.2.7 Countercurrent Flow Limitation Model

The countercurrent flow limitation (CCFL) flag (f) can e used with a single junction, pipe, annulus, branch, valve, pump, and multiple junction. It cannot be used with a time-dependent junction, separator, jet mixer, turbine, and accumulator. Setting f = 1 will activate the CCFL model if all other conditions are met, and setting f = 0 will not activate the model. The other conditions are as follows:

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

2. Both gas and liquid phases must be present.

3. Counter-current flow must exist, with liquid flowing down and gas flowing up.

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

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

$$D_j = 2(A_j/\omega)^{1/2}$$
$$\beta = 0$$
$$c = 1$$
$$m = 1.$$

This corresponds to the Wallis CCFL correlation 4 with a gas intercept of 1 and a slope of 1 which is the case for turbulent flow ($m = 1$) and when end effects are minimized ($c = 1$).

The input was made general so that the user can input CCFL correlations for the particular geometry of interest. Wallis,[3-5] Bankoff et al.,[3-6] and Tien et al.[3-7] discuss numerous examples; and these, along with other references, should be consulted in order to justify the use of a particular correlation for a given geometry. Wallis suggests $m = 1$ for turbulent flow, $c = 0.725$ for tubes with sharp-edged flanges, and $c = 0.88 - 1.0$ for tubes when end effects are minimized. Bankoff suggests $\beta = \tanh(\gamma k_c D_j)$ where the critical wave number $k_c = 2\omega/t_p$ corresponds to the maximum wavelength that can be sustained on a interface of length t_p (the plate thickness) and γ is the perforation ratio (fraction of plate area occupied by holes). Bankoff suggests $m = 1$ and c of the form

$$c = \begin{cases} 1.07 + 4.33 \times 10^{-3} L^* & L^* < 200 \\ 2 & L^* > 200 \end{cases} \tag{3-4}$$

where L^* is a Bond number defined as

$$L^* = n\omega D \left[g(\rho f - \rho g)/\sigma\right]^{1/2} \tag{3-5}$$

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

$$c = c_7 \tanh c_8 (D^*)^{1/4}, \tag{3-6}$$

where D^* is a Bond number defined as

$$D^* = D[g(\rho f - \rho g)/\sigma]^{1/2}. \tag{3-7}$$

The values of m, c_7, and c_8 he found for four conditions are provided in Table 3-1. For plant-specific geometry (i.e., tie plates, support plates, etc.), flooding data from the plant geometry should be used to generate an appropriate CCFL model that can be input with CCFL junction data cards.

Wallis,[3-5] Bankoff,[3-6] and Tien [3-7] discuss the effects of viscosity, surface tension, and subcooling on the correlations. At the present time, these effects have not been directly incorporated into the form of the CCFL correlation used in SCDAP/RELAP5. It is anticipated that these, particularly the subcooling effects, will be addressed in future modifications to the code.

3.3 Specialized Hydrodynamic Components

3.3.1 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.

3.3.1.1 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

TABLE 3-1. VALUES OF m, c_7, AND c_8 FOR TIEN'S CCFL CORRELATION FORM

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

term, the hydrodynamic model for the pump volume and junctions is identical to that for normal volumes and junctions.

3.3.1.1.1 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). There data are 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 for 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 are always used in the momentum equations. Torque data may or may not be used in computing pump rotational velocity, depending on the pump motor model selected. 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 SCDAP/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.

3.3.1.1.2 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.[3-8] They are

$$\pi_1 = Q/(\nu D) \tag{3-8}$$

$$\pi_2 = NQ/(gH)^{3/4} \tag{3-9}$$

$$\pi_3 = Q/(ND^3) \tag{3-10}$$

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

$$\pi_4 = gH/(N^2D^2) \quad . \tag{3-11}$$

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

$$N_S = NQ/(H)^{3/4} \tag{3-12}$$

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 SCDAP/RELAP5 are the specific capacity

$$Q_S = Q/(ND^3) \tag{3-13}$$

and the specific head

$$H_S = H/(N^2D^2) \tag{3-14}$$

The D that appears in Equations (3-13) and (3-14) 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

$$\pi_5 = \tau/(\rho N^2 D^5) \tag{3-15}$$

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

$$\tau_S = \tau/(N^2 D^5) \quad . \tag{3-16}$$

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 3-11 is called a four-quadrant pump graph and has speed and flow as independent variables. Lines of constant head are plotted.

Figure 3-12 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.

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 3-2.

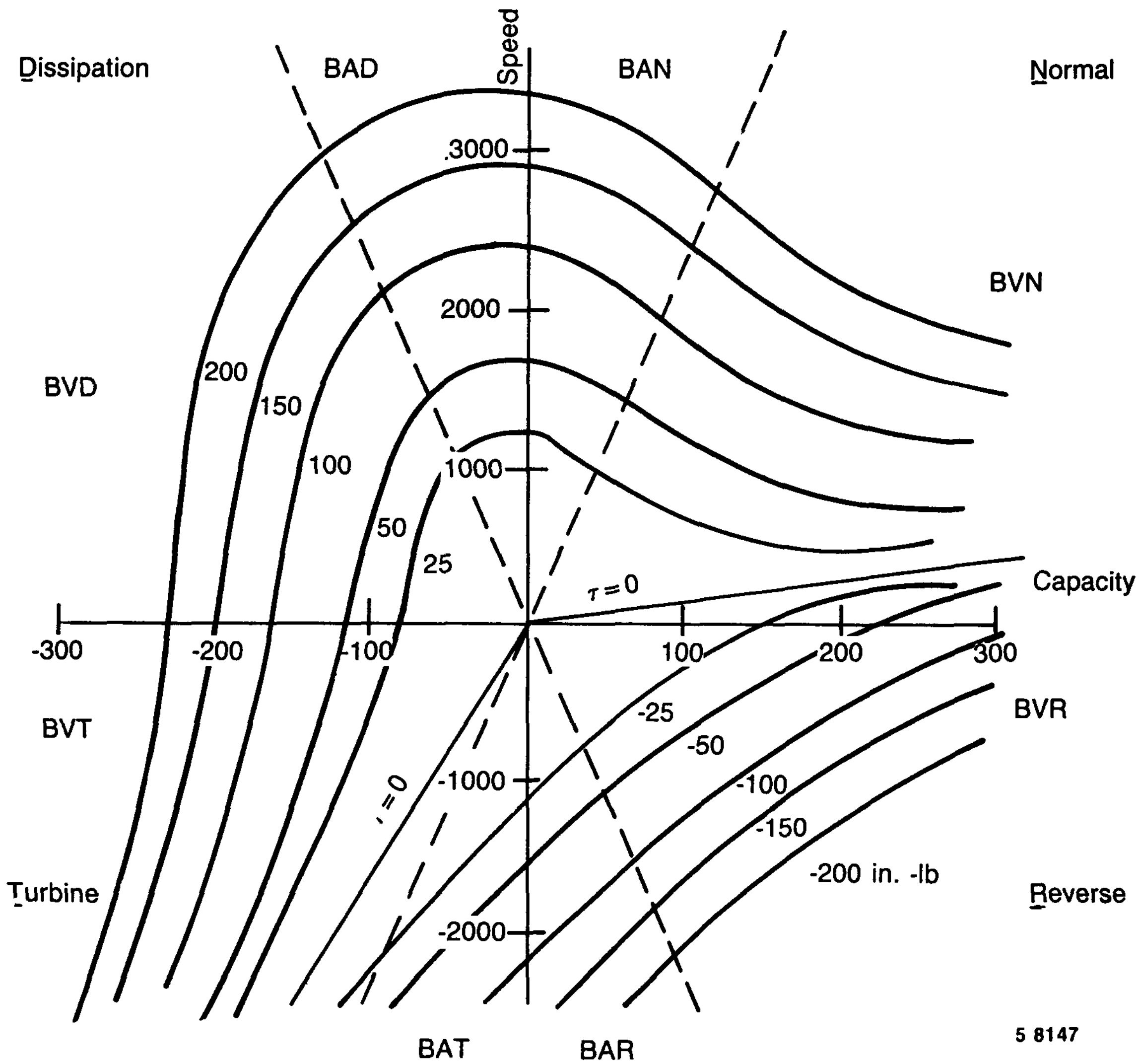


Figure 3-11. Four-quadrant head curve.

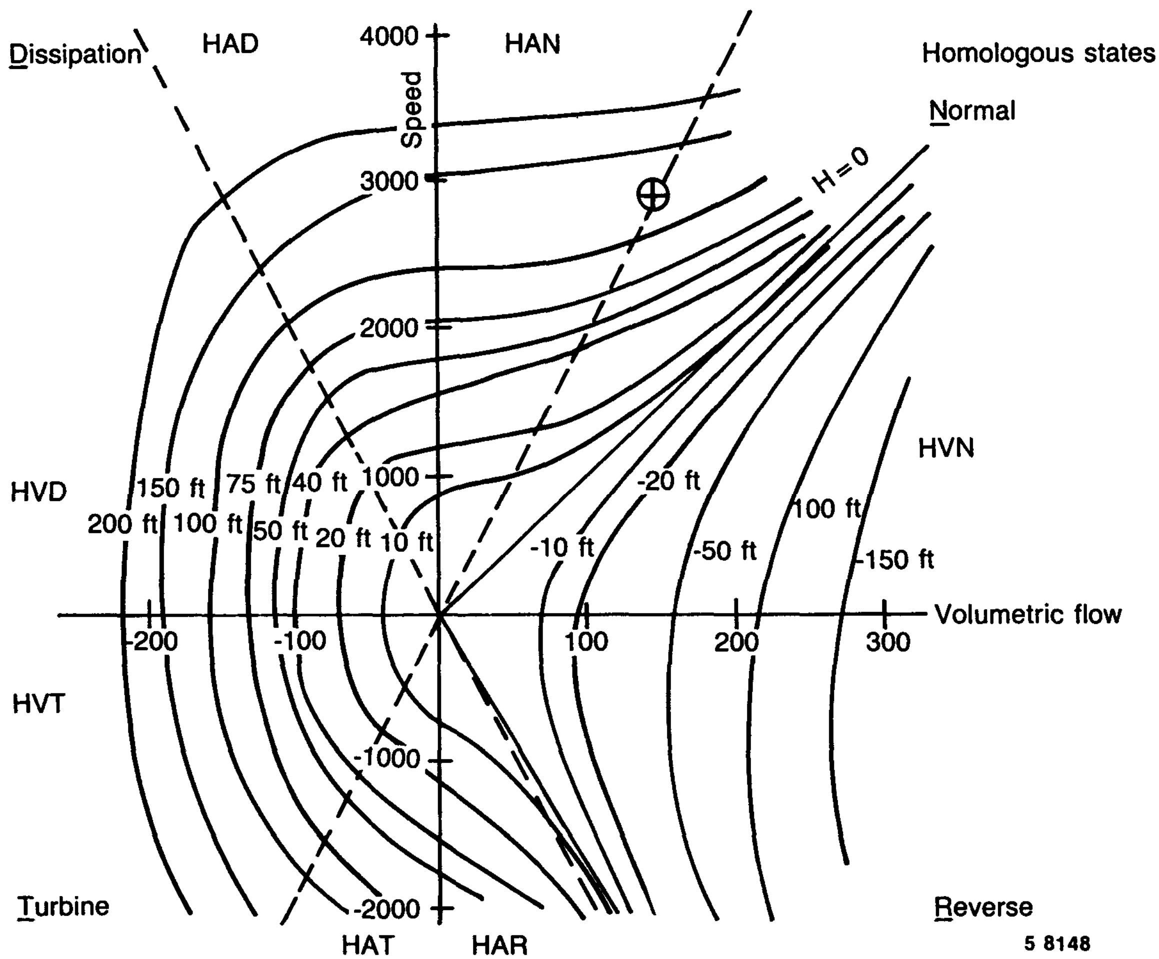


Figure 3-12. Four-quadrant torque curve.

TABLE 3-2. PUMP HOMOLOGOUS CURVE DEFINITIONS

Regime Number	Regime Mode ID Name	α	v	v/α	Independent[a] Variable	Dependent[a] Variable: Head	Dependent[a] Variable: 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

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

The pump head and torque maps in Figures 3-11 and 3-12 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 3-13 is the homologous head curve that is obtained from the head map in Figure 3-11. Note that not all points fall on a single 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 3-12 is shown on Figure 3-14. 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 Figures 3-13 and 3-14 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.

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.

3.3.1.1.3 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

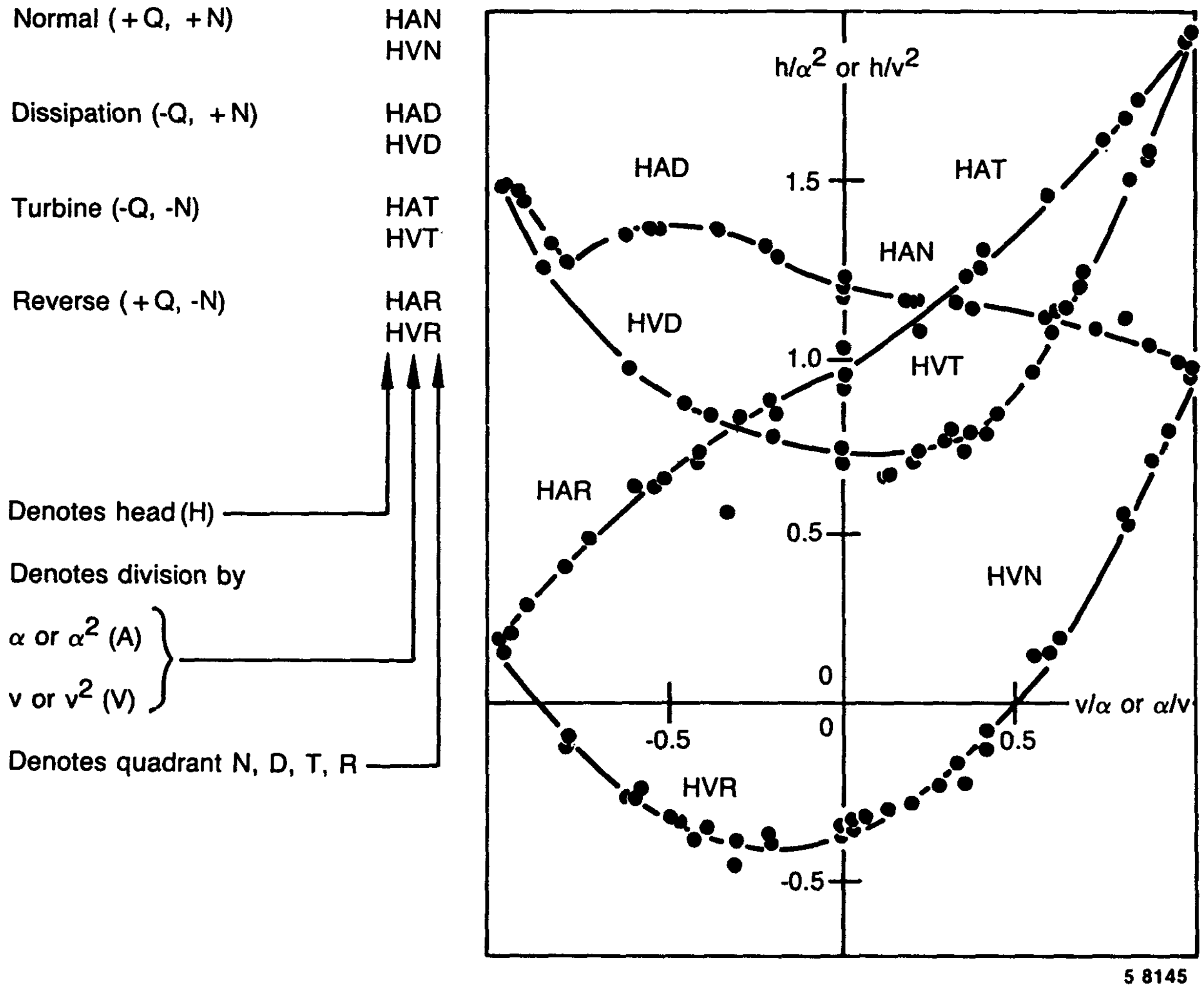


Figure 3-13. Homologous head curve.

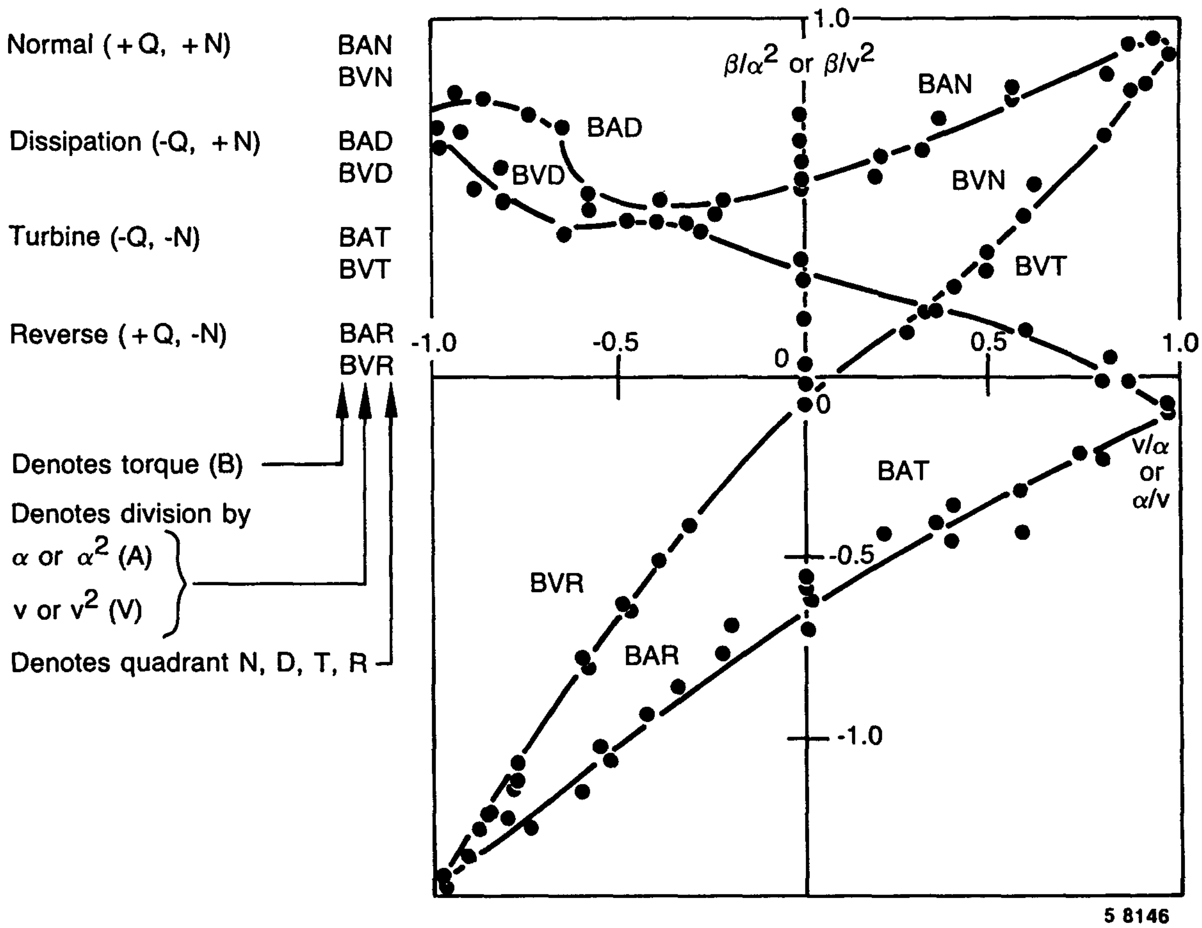


Figure 3-14. Homologous torque curve.

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 (3-13), (3-14), and (3-16). When change in scale is considered, an additional degree of freedom is introduced since only two parameters, the rated specific head and capacity, are to be held constant. 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 these 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.

3.3.1.1.4 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 SCDAP/RELAP5 two-phase pump model is the same as that developed for RELAP4.[3-9] The approach is one in which the two-phase performance data are plotted and a lowest performance envelope is constructed. This curve is called the fully degraded two-phase performance. The fully degraded performance and the single-phase performance data are used to form two-phase difference homologous performance curves for head or torque. The pump performance is then expressed in terms of the single-phase data and the difference data using a two-phase multiplier that is a function of void fraction. The pump head is expressed as

$$H = H_{1\phi} - M_H(\alpha_g)\ \Delta H \tag{3-17}$$

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 these data are widely used for prediction of two-phase performance of other pumps.

3.3.1.1.5 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 5.2.3, 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

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

SA = ABS(S)

TF = -SIGN(TF0 + TF1*SA + TF2*SA**2 + TF3*SA**3, S),

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,

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

$$IP = IN \qquad S < SL$$

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

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. If the problem time limit = 0, then the problem time test is ignored.

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

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

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

3.3.1.2 <u>Pump Modeling Examples</u>. 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. 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.

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

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

3.3.1.4 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.

3.3.2 Jet Pump

A jet pump is modeled in SCDAP/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 3-15 contains a schematic showing the typical nodalization used for a jet pump mixing section.

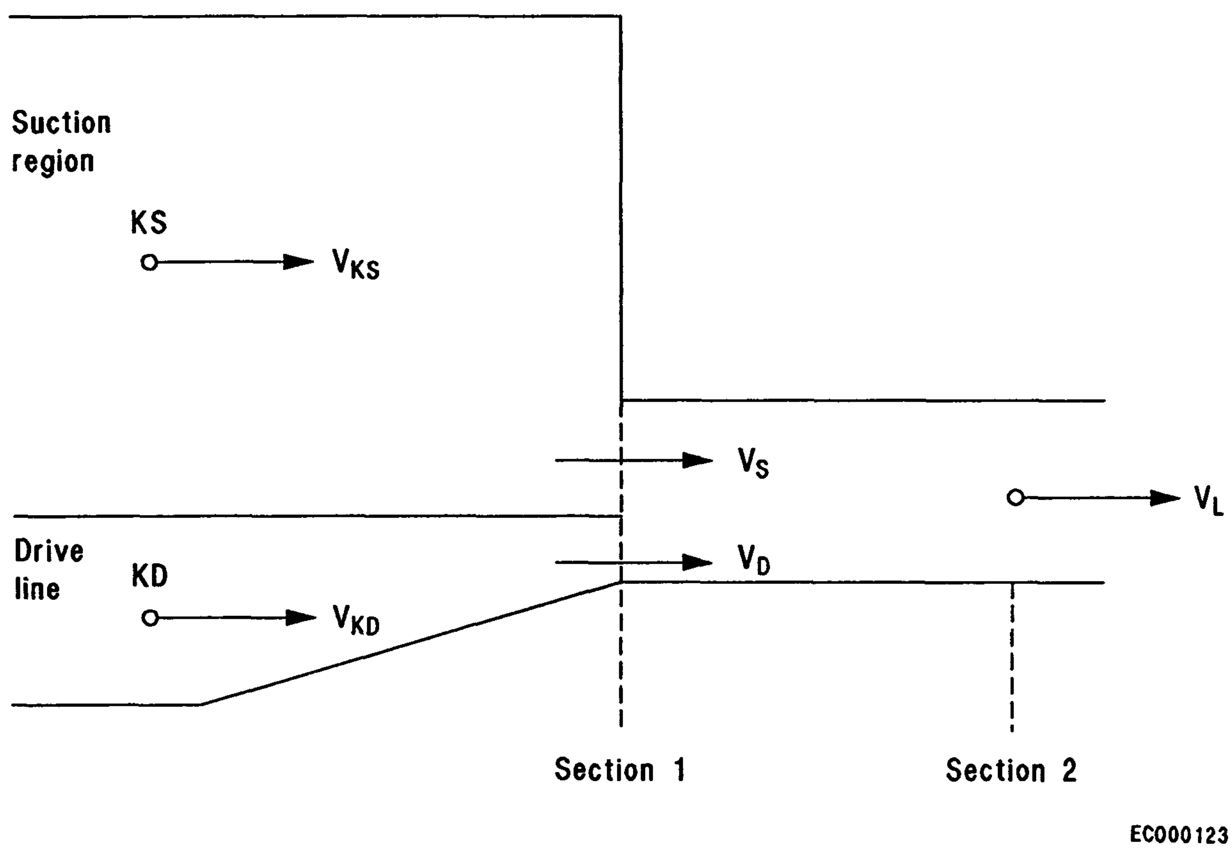


Figure 3-15. Schematic of mixing junctions.

3.3.2.1 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.

3.3.2.2 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 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.

3.3.2.3 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,

$$M = W_S/W_D. \tag{3-18}$$

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,

$$N = \frac{(P + \frac{1}{2}\rho v^2 + \rho gH)_{Dis} - (P + \frac{1}{2}\rho v^2 + \rho gH)_S}{(P + \frac{1}{2}\rho v^2 + \rho gH)_D - (P + \frac{1}{2}\rho v^2 + \rho gH)_{Dis}} . \tag{3-19}$$

Figure 3-16 shows an expanded view of the normal operating region (first quadrant) with several curves representing different flow resistances. This figure can be used as a guide for modeling different jet pump geometries. Each curve shows the M-N performance generated with base-case loss coefficients plus a single additional loss coefficient

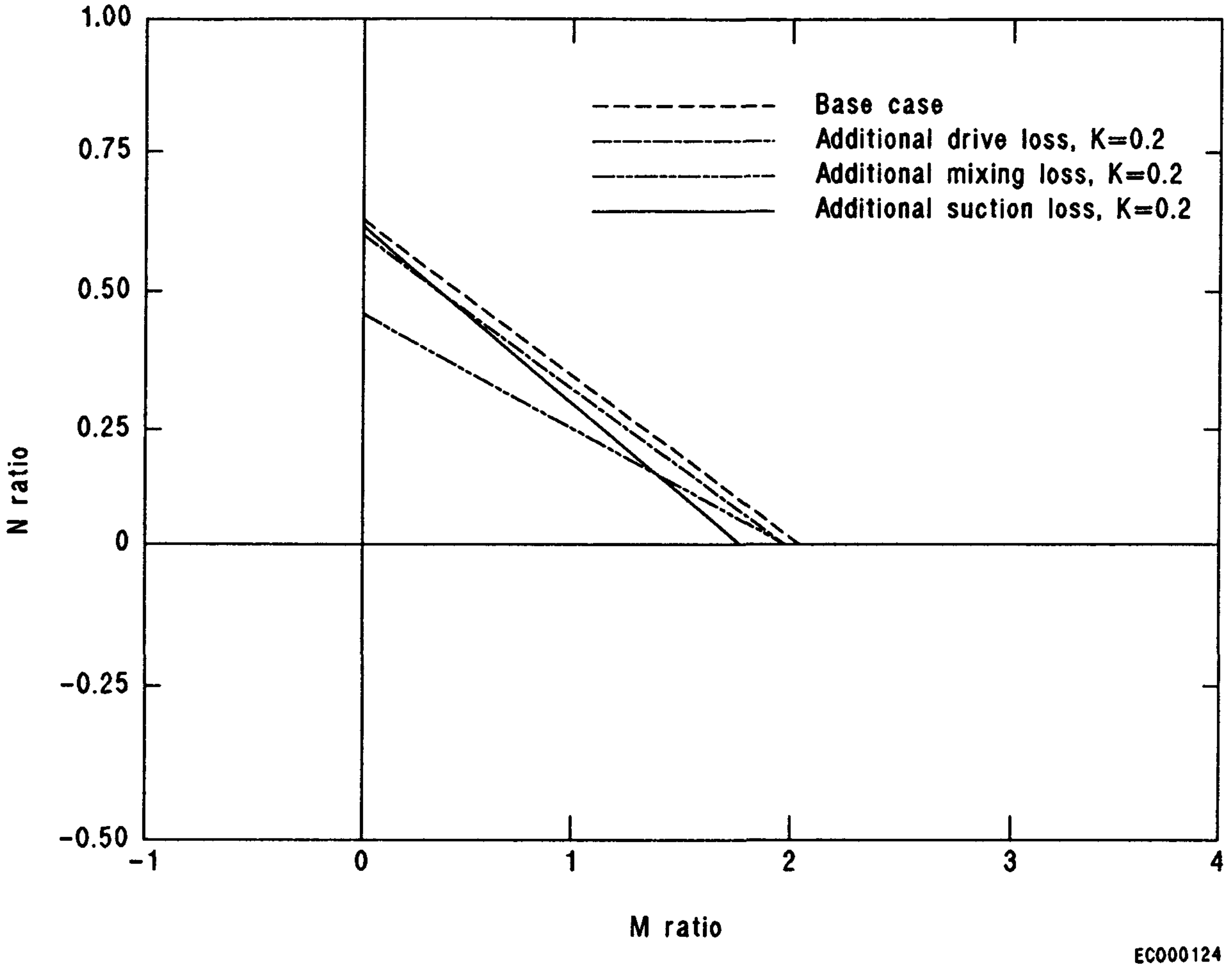


Figure 3-16. Jet pump model design.

(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.

3.3.2.4 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.

3.3.3 Valves

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

3.3.3.1 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.

3.3.3.1.1 Static Pressure Controlled Check Valve--Equation (3-443) in 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.

3.3.3.1.2 Flow Controlled Check Valve--Equations (3-443) and (3-444) 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 (3-443) 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 (3-444) 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.

3.3.3.1.3 Dynamic Pressure Controlled Check Valve--Equations (3-443) and (3-445) 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 (3-443). 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.

3.3.3.1.4 Check Valve Closing Back Pressure Term PCV--In the formulations of Equations (3-443) and (3-445) the term PCV is used; in the input requirements, this term is designated as the closing back pressure. However, to be precise, PCV is a constant representing an actuation set point. If positive, PCV behaves as a back pressure acting to close the valve. In both the static and dynamic pressure-controlled valves, PCV acts both as an actuation set point for opening a closed valve and as a closing force for closing an open valve. For the flow-controlled valve, the back pressure acts only as an actuation set point for opening a closed valve.

3.3.3.2 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 SCDAP/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 SCDAP/RELAP5 and hence lag the calculational results by one time step.

3.3.3.3 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.

3.3.3.4 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 SCDAP/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.

3.3.4 Separator

Figure 3-17 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.

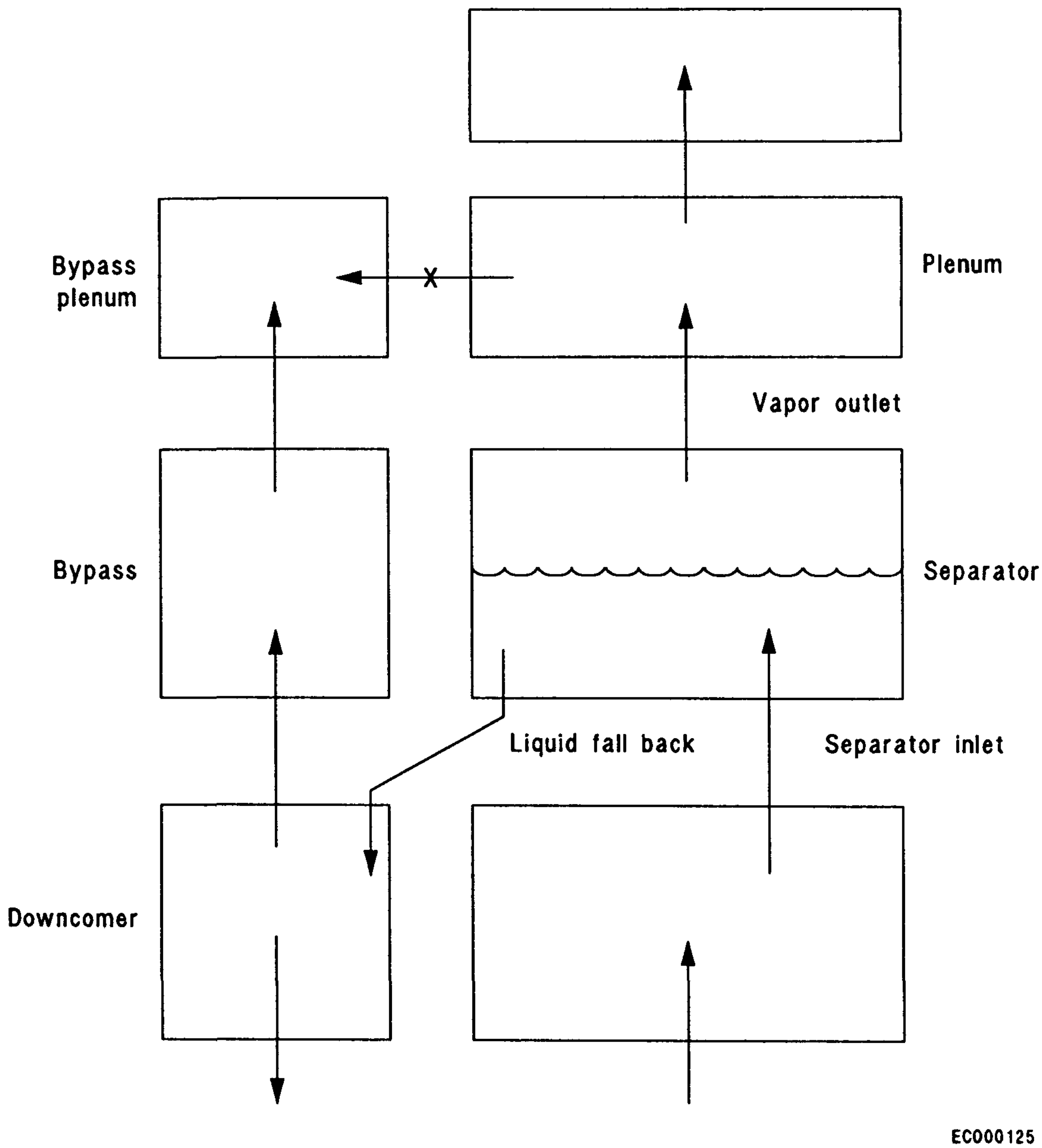


Figure 3-17. Schematic of separator.

3.3.4.1 Input Requirements. The input for a SEPARATE 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 SEPARATE, the three junctions, representing the vapor outlet, liquid fall back, and separator inlet, must be input with the SEPARATE 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 SEPARATE 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.

3.3.4.2 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 to be preliminary.

The black-box nature of the separator, along with the use of VOVER and VUNDER, may result in some changes to the 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. 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.

3.3.5 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 I, where all the terms are defined.

The mean stage radius needed in the efficiency formulas may not be known from the actual turbine design diagrams. 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

$$v_t/v = \frac{0.5}{1 - r} \quad . \tag{3-20}$$

Using $v_t = R\omega$ and the input values v, r, and ω at the design operating point, Equation (3-20) gives for R,

$$R = \frac{0.5v}{\omega(1 - r)} \quad . \tag{3-21}$$

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

$$v_t/v = 0.25 \quad . \tag{3-22}$$

Expressing v_t as $R\omega$ gives

$$R = \frac{0.25v}{\omega} \tag{3-23}$$

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 component (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 are there any data that could be used as a guide. Thus, the inlet and outlet junctions must be input as homogeneous junctions (h = 2). If a steam extraction (bleed) junction is present, it must be a crossflow junction (S = 1, 2, or 3).

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

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

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

$$v_j (v_j - v_{j-1}) = - \frac{1 - \eta}{\rho} (P_L - P_K) \tag{3-24}$$

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

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, but it will give slightly inaccurate storage terms during a transient. The transient storage terms are small, so this should not be a problem.

3.3.6 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

$$AVOL = V/(L_{TK} + L_L) \tag{3-25}$$

$$DHY = 4V/\pi \, (D_{TK}L_{TK} + D_L L_L) \tag{3-26}$$

$$DZ = (2DZ_{TK} + g \, DZ_L)/2 \tag{3-27}$$

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 A.2.11 in Appendix A.

3.4 References

3-1. D. Bestion, "Interfacial Friction Determination for the 1D-6 Equations Two-Fluid Model Used in the CATHARE Code," European Two-Phase Flow Group Meeting, Southampton, England, June 3-7, 1985.

3-2. G. th. Analytis and M. Richner, Implementation and Assessment of a New Bubbly/Slug Flow Interfacial Friction Correlation in RELAP5/MOD2/36.02, TM-32-86-10, January 1986.

3-3. V. H. Ransom et al., RELAP5/MOD3 Code Manual, Volume 3: Development Assessment Problems, EGG-TFM-7952, December 1987, pp. 14-17.

3-4. Ibid., pp. 61-63.

3-5. G. B. Wallis, One-Dimensional Two-Phase Flow, New York: McGraw-Hill, 1969, pp. 336-341.

3-6. S. G. Bankoff, R. S. Tankin, M. C. Yuen, and C. L. Hsieh, "Countercurrent Flow of Air/Water and Steam/Water Through a Horizontal Perforated Plate," International Journal of Heat and Mass Transfer, 24, 1981, pp. 1381-1385.

3-7. C. L. Tien, K. S. Chueng, and C. P. Lin, Flooding in Two-Phase Countercurrent Flow, EPRI NP-984, February 1979.

3-8. E. Buckingham, "Model Experiments and the Forms of Empirical Equations," Transactions of the ASME, 37, 1915, p. 263.

3-9. Aerojet Nuclear Company, RELAP4/MOD5, A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems User's Manual, Volume 1, RELAP4/MOD5 Description, ANCR-NUREG-1335, September 1976.

4. HEAT STRUCTURE MODELING

Heat structures represent the solid portions of the thermal-hydrodynamic system that are not part of the reactor core. 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 pipe walls, core barrels, pressure vessels, and heat exchanger tubing. In simulations that do not involve core damage, heat structures can represent fuel pins, control rods, and other structural components. In core damage simulations, these should be simulated by SCDAP components. 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 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. The combined field, CCCG, is the heat structure-geometry number, and input data are organized by this heat structure-geometry number. Up to 99 individual heat structures may be defined using the geometry described for the heat structure-geometry number. The individual heat structures are numbered consecutively starting at 01; this number is the subfield, NN, of the heat structure number. The heat structure input requirements are divided into input common to all heat structures with the heat structure geometry number, Cards 1CCCG000 through 1CCCG499, and input needed to uniquely define each heat structure, 1CCCG501 through 1CCCG999.

4.1 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 4-1 illustrates placement of mesh points at which temperatures are computed. The mesh point spacing is taken in the positive direction from left to right. A composition is a material with associated thermal conductivity and volumetric heat capacity. Mesh points must be placed such that they lie on the two external boundaries and at any 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.

The heat structure input processing provides a convenient means to enter the mesh point spacing and composition placement. Each composition is assigned a three-digit, nonzero number, 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.

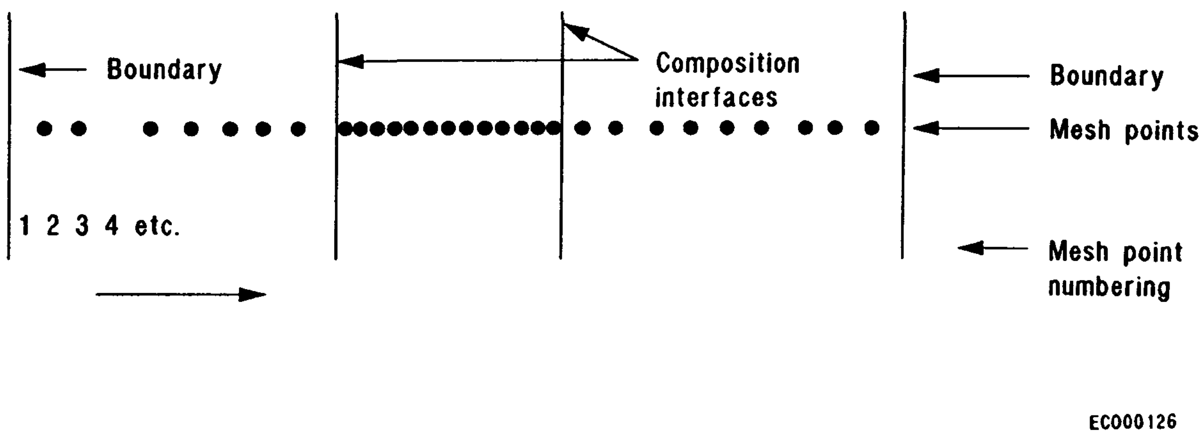


Figure 4-1. Mesh point layout.

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,

$$S(x,t) = P_f \, Q(x) \, P(t) \tag{4-1}$$

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.

4.2 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; either 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.

4.3 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, or fission product decay power from the reactor kinetics calculation; a control variable; or may be obtained from a table of power versus time. Input data provide for three factors. The first factor is applied to the power to indicate the internal heat source generated in the structure. This means that in steady state, heat equal to the factor times the power value would be generated in the heat structure and transferred out through its left and right surfaces. If P(t) is the power in Watts and P_t 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 SCDAP/RELAP5 model, then the sum of these three factors over all the heat structures representing that power value should equal one. The summing to one is not required, and no checks are performed by the code. In many instances, the power will not only be applied to the heat structures representing the fuel but also to the heat structures representing such items as the downcomer and pressure vessel walls.

4.4 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.

4.5 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.

4.6 Recommended Uses

For the heat structure additional boundary cards (1CCCG801 through 1CCCG899 and 1CCCG901 through 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 of the boundary volume, which is defined as

$$D_h = 4 \times \frac{\text{flow area}}{\text{wetted perimeter}} \tag{4-2}$$

Because the heat transfer coefficient in SCDAP/RELAP5 is obtained from the correlations developed from tube and parallel channel tests, for consistency the same scaling method used in hydraulic calculations should be used in heat transfer calculations. 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).

5. AEROSOL AND FISSION PRODUCT BEHAVIOR

When fission products are released from fuel rods, they become suspended in fluids and are transported by moving fluids. By definition, they are also aerosols. SCDAP/RELAP5 has the capability of tracking the transport and deposition of these fission products. In addition, the gamma and beta decay heat associated with deposited fission products and aerosols in the volume interfaced with the heat structures are accounted for as an interior heat source for the heat structures using the SCDAP/RELAP5 fission product decay heat model described in Volume 1.

5.1 List of Species

Although it is possible to input the inventories of as many as 16 species, the code currently has the capability of tracking only seven species: I_2, cesium iodide, cesium hydroxide, tellurium, tin, silver, and cadmium. The code, however, does calculate the fractional release of the other species. The code user inputs the number of aerosol size bins. Because the run time is roughly proportional to the product of the number of species times the number of bins, it is advised that the user keeps both numbers as small as possible.

5.1.1 Fission Product Decay Heat

It is possible to enter fission product decay heat as an interior heat source in heat transfer calculations for rectangular, cylindrical, and spherical heat structures. (Currently, spherical heat structures are treated in the same fashion as cylindrical heat structures in decay heat calculations.) The user only needs to add a 1CCCG300 card in front of a 1CCCG301 card. It should be noted, however, that once this is done, the source factor on the 1CCCG301 card is read in as a gamma attenuation coefficient by the code. In other words, if that heat structure originally has any internal heat source, it will now be replaced by fission product decay heat as an internal heat source.

5.1.2 Output

The code has extensive printout information for fission product behavior.

5.1.2.1 Output Format. The output format for fission product transport is indicated by the following example:

325-010000	I	SRC	0.000	LIQ	0.000
RELAP5 Volume Number	Iodine Species	Source for volume 325	2(kg/s)	Liquid phase	Mass of Iodine in liquid phase (kg)
	VAP	0.000	TOT	0.000	
	Vapor phase	Mass of Iodine in vapor phase (kg)	Total	Total mass in particle state (kg)	
	1	0.000	2	0.000	
	First bin	Mass in first bin (kg)	Second bin	Mass in second bin (kg)	

The sum of LIQ, VAP, and TOT produces the total in kilograms of the species in a volume.

3251-001	Left	CsI	MC	0.000	MA	0.000	MP	0.000
Heat		CsOH	MC	0.000	MA	0.000	MP	0.000
structure interfacing with Volume 325		Te	MC	0.000	MA	1.27E-16	MP	0.000

Here, CsI, CsOH, and tellurium are the species in the heat structure 3251.

MC Gives the mass condensed from vapor to liquid and solid state (kg). It is strictly the mass of the chemical compound indicated.

MA Gives the mass in kg of the compound that is chemically absorbed by the heat structure.

MP Gives the mass in kg of the compound that adheres to the surface as particles due to settling.

The fission product decay heat, on the other hand shows up as an interior heat source in watts. A typical printout will read as follows:

STR. NO.	SIDE	BDRY VOL. NUMBER	SURFACE TEMP (K)	HEAT TRF. RATE (WATT)
1020-001	LEFT	102-010000	795.15	-244.45

HEAT FLUX ($WATT/M^2$)	CRITICAL HEAT FLUX ($WATT/M^2$)	MODE	HEAT TRF. COEF ($WATT/M^2$-K)	INT. HEAT SOURCE (WATT)
-4986.0	0.000	29	64.946	7.097E-17

NET HEAT LOSS (WATT)	VOL. AVE. TEMP. (K)
-244.45	794.95

5.1.2.2 Plot Variables. The code can plot any legitimate plot variable requested by a 208 card. The fission product plot variable names are defined as follows:

Fission Product:	Chemical Compounds
SR	i.e.
LI	I
VA	CsI
TO	CsOH
01	Te
02	Sn
•	Ag
•	Cd
MA	
MC	
MP	

FP = fission product

SR = source

LI = liquid

VA = vapor

TO = total

01 = bin no. 1

02 = bin no. 2

MA = mass absorbed

MC = mass condensed

MP = mass precipitated

bgtfprn = fission product release rate for noncondensibles

bgtfprs = fission product release rate for cesium and iodine

A typical 208 card will be as follows:

```
    20800080     FPMCCSI     241000100
```

Here, 2410001 is the heat structure number and 00 denotes the left side. (01 would denote the right side.) Fission product plot variables can also be used in a control system to yield values for control variables. For example, suppose the user would like to sum up all releases for cesium iodide in a control system. The user may proceed as follows:

[a]CSIREL = total release of CsI

20507000	CSIREL	SUM	1.	0.0	0
control variable number			scaling factor	initial value	initial condition calculation
20507001	0.0	1.0	FPSRCSI	233010000	
	Ao	multiplier		first index in variable to be summed	
20507002	0.0	1.0	FPSRCSI	234010000	
				second index in variable to be summed	
20507003	0.0	1.0	FPSRCSI	235010000	

a. Integrate the release rate of CsI.

20507004	0.0	1.0	FPSRCSI	236010000	
20507005	0.0	1.0	FPSRCSI	237010000	
20507500	CSIACCM	INTEGRAL	1.	0.0	0
	name shown in printout	function	scaling factor	value on first time step	
20507501	CNTRLVAR	70			
	variable to be integrated	index of CNTRLVAR for CsI			

*Plot total release of CsI.

20800106	CNTRLVAR	75

5.1.3 Restart

Fission product transport has full restart capabilities. For instance, a user can turn off fission product transport, execute the calculation to 1000 s, and then restart with fission product transport turned on by the user of three 207 cards specifying the number of bins, the number of species, and the type of species.

6. CONTROLS

6.1 Trips

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

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

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

A TIMEOF quantity is associated with each trip. This quantity is always -1.0 for a trip with the value false. When a trip is switched to true, the time at which it switches replaces the value in TIMEOF. For a latched trip, this quantity once set to other than -1.0 always retains that value. An unlatched trip may have several TIMEOF values other than -1.0. 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. An alternate format is selected by entering Card 20600000. Trip data are entered on Cards 206TTTT0, where TTTT is the trip number. Trip numbers 1-1000 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, 0.0 must be entered.

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

6.1.1 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:

```
NUM   VAR1   OP   VAR2 + CONSTANT   L   TIMEOF
                                    N
```

where NUM is the card number; VAR1 and VAR2 each consist of two words that identify a variable, the first word being alphanumeric for the variable type, and the second word being a number associated with the particular variable; OP is the comparison operation; CONSTANT is a signed number to be added to VAR2 before 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 ≥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.

6.1.2 Logical Trips

A logical trip evaluates a logical statement relating two trip quantities with the operations AND, OR (inclusive), or XOR (exclusive). Table 6-1 defines the logical operations where 0 indicates false, 1 indicates true. Each trip quantity may be the original value or its complement. (Complement means reversing the true and false values; that is, the complement of true is false.)

The logical trip statement is

$$\text{NUM} \pm \text{TRIP1} \quad \text{OP} \pm \text{TRIP2} \quad {}^{\text{L}}_{\text{N}} \quad \text{TIMEOF}$$

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

601	501	OR	502	N
602	601	AND	510	N
620	-510	OR	-510	N

Trip 602 involves a previous logical trip and illustrates the construction of a complex logical statement. With the definitions given in the examples above and using parentheses to indicate the order of logical 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.

TABLE 6-1. LOGICAL OPERATIONS

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

6.1.3 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.

6.1.4 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_1 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 6-2, is a truth table that has been constructed by listing all possible combinations of the three input variables, V_1, P_2, and P_1, and the desired output, V_o. The number in the rightmost column is the number resulting from assuming the input values form a binary number, which is used to ensure that all combinations are listed. From the truth table, the following expression can be written,

$$V_o = (\bar{V}_1 * P_2 * P_1) + (V_1 * \bar{P}_2 * P_1) + (V_1 * P_2 * P_1) \qquad (6\text{-}1)$$

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 6-2 shows that two of the combinations are impossible. This is because if P_2 is true, P_1 must also be true; that is if the pressure is >12 bar, it is also >11 bar. Because of the relationship between P_2 and P_1,

$$P_2 * P_1 = P_2 \qquad P_2 + P_1 = P_1 \quad . \qquad (6\text{-}2)$$

Using the Boolean identities from Table 6-3, the logical expression can be reduced to

TABLE 6-2. TRUTH TABLE EXAMPLES

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

TABLE 6-3. BOOLEAN ALGEBRA IDENTITIES

$A * A = A$ $A + A = A$ $A * 0 = 0$ $A + 0 = A$

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

$A * B = B * A$ $A + B = B + A$

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

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

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

$$V_o = (\bar{V}_1 * P_2) + [V_1 * P_1 * (\bar{P}_2 + P_2)] = (\bar{V}_1 * P_2) + (V_1 * P_1) \quad . \qquad (6\text{-}3)$$

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 valve 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 TERM 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.

6.2 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.

6.2.1 Basic Control Components

The control system capability consists of several types of control components, each type of component defining a control variable as a specific function of time-advanced quantities. The time-advanced quantities include hydrodynamic volume, junction, pump, valve, heat structure, reactor kinetics, and trip quantities; and the control variables themselves including the control variable being defined. Permitting control variables to be input to control components allows complex expressions to be developed from components that perform simple, basic operations. The basic control components are listed below, followed by a brief review of the evaluation procedure. Familiarity with the control system numerical techniques documented in Volume 1 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 SCDAP/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.

<u>Constant</u> (CONSTANT)

$$Y_i = S \tag{6-4}$$

<u>Addition-subtraction</u> (SUM)

$$Y_i = S(A_0 + A_1V_1 + A_2V_2 + \ldots) \tag{6-5}$$

<u>Multiplication</u> (MULT)

$$Y_i = S\ V_1V_2\ \ldots \tag{6-6}$$

<u>Division</u> (DIV)

$$Y_i = S/V_1 \text{ or } S\ V_2/V_1 \tag{6-7}$$

<u>Integer exponentiation</u> (POWERI)

$$Y_i = SV_1^{\ I} \tag{6-8}$$

<u>Real exponentiation</u> (POWERR)

$$Y_i = SV_1^{\ R} \tag{6-9}$$

Variable exponentiation (POWERX)

$$Y_i = SV_1^{V_2} \tag{6-10}$$

Table lookup function (FUNCTION)

$$Y_i = S\,F(V_1) \tag{6-11}$$

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

Standard functions (STDFNCTN)

$$Y_i = S\,F(V_1, V_2, V_3, \ldots) \tag{6-12}$$

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

Delay (DELAY)

The delay component is defined by

$$Y_i = SV_1(t - t_d) \tag{6-13}$$

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)

$$Y_i = SU(\pm t_r) \tag{6-14}$$

Trip delay (TRIPDLAY)

$$Y_i = ST_r(t_r) \tag{6-15}$$

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

Integration (INTEGRAL)

$$Y_i = S\int_0^t V_1\,dt \text{ or } Y_i(s) = \frac{S\,V_1(s)}{s} \tag{6-16}$$

Differentiation (DIFFERNI OR DIFFERND)

$$Y_i = S\frac{dV_1}{dt} \text{ or } Y_i(s) = S\,s\,V_1(s) \tag{6-17}$$

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

Proportional-Integral Component (PROP-INT)

$$Y_i = S\left(A_1 V_1 + A_2\int_0^t V_1\,dt\right) \text{ or } Y_i(s) = S\left(A_1 + \frac{A_2}{s}\,V_1(s)\right) . \tag{6-18}$$

Lag Component (LAG)

$$Y_i = \int_0^t \frac{(S\,V_1 - Y_i)}{A_1}\,dt \text{ or } Y_i(s) = S\left(\frac{1}{1 + A_1\,s}\;V_1(s)\right) \tag{6-19}$$

Lead-Lag Component (LEAD-LAG)

$$Y_i = \frac{A_1 S\,V_1}{A_2} + \int_0^t \frac{(S\,V_1 - Y_i)}{A_2}\,dt \text{ or } Y_i(s) = S\left(\frac{1 + A_1 s}{1 + A_2 s}\right) V_1(s) \tag{6-20}$$

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 5.2.2.

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, SCDAP/RELAP5 treats control system variables as dimensionless quantities. No unit conversion of the input scaling factors or multiplier constants is done when British input units are specified, and no unit conversion is done on output when British output units are specified. All dimensioned variables are stored within the program in SI units, and the units for variables that can be used in control components are stated in the input description. The user may assume any desired 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 9999 control components can be used with the four digit CCCC. Control variables are printed in major edits, can be specified for minor edits, and can be plotted.

6.2.2 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

$$W = \alpha_g \rho_g v_g A + \alpha_f \rho_f v_f A \quad , \tag{6-21}$$

where α is void fraction, ρ is density, v is velocity, A is flow area, the subscript g denotes vapor, and the subscript f denotes liquid. Two multiplication components and one addition-subtraction component are used. The time-advanced quantities, α, ρ, and v, are specified as V_1, V_2, and V_3, respectively, in the two multiplication components, one for each phase. The area A 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,123010000
20500202 VELG,123010000
20500300 TFLOW SUM 1.0 0.0 1
20500301 0.0 1.0, CNTRLVAR, 1 1.0, CNTRLVAR, 2
```

The second example is to solve

$$A_2 X + A_1 \dot{X} + A_{10} \dot{X}X + A_0 X + B\int_0^t Xdt = C \quad . \tag{6-22}$$

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

$$Y_1 = \dot{X}X = Y_3Y_4 \tag{6-23}$$

$$Y_2 = X = \frac{1}{A_2} (C - A_1Y_3 - A_{10}Y_1 - A_0Y_4 - BY_5) \tag{6-24}$$

$$Y_3 = \dot{X} = \int_0^t X \, dt = \int_0^t Y_2dt \tag{6-25}$$

$$Y_4 = \dot{X} = \int_0^t \ddot{X} \, dt = \int_0^t Y_3dt \tag{6-26}$$

$$Y_5 = \int_0^t Xdt = \int_0^t Y_4dt \quad . \tag{6-27}$$

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 (-A0), CNTRLVAR,4 (-B), CNTRLVAR,5
20500030 XD1 INTEGRAL 1.0 0.0 0
20500031 CNTRLVAR,2
20500040 X INTEGRAL 1.0 0.0 0
20500041 CNTRLVAR,3
20500050 "INT OF X" INTEGRAL 1.0 0.0 0 3,0.0,1.0
20500051 CNTRLVAR,4
```

6.2.3 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

$$\sum_i I_i \frac{d\omega}{dt} = \sum_i \tau_i - \sum_i f_i \omega + \tau_c \tag{6-28}$$

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 torque and has storage for its rotational velocity. For example, the pump model allows cubic expressions for inertia and friction. The friction expression shown in Equation (39) is used for the shaft itself and the generator component. Each component also has a disconnect trip number. If zero (no trip), the component is always connected to the shaft. If a trip is specified, the component is connected when false and disconnected when true. Any disconnected component is advanced separately and thus can have a different rotational velocity than the shaft. All connected components have the same rotational velocity.

The shaft equation is advanced explicitly by

$$\sum_i I_i^n \frac{(\omega^{n+1} - \omega^n)}{\Delta t} = \sum_i \tau_i^n - \sum_i f_i^n \omega^n + \tau_c \tag{6-29}$$

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 (6=29) for ω^{n+1} separately for each component disconnected from the shaft (if any) and for the shaft and the connected components as one system. For separated components, the new rotational velocity is stored with the component data and the summations are only over terms within the component. (Each component has only one term, except the pump/motor component which has two terms.) For the shaft and the connected components, the new rotational velocity is stored as the rotational velocity of the shaft and each connected component.

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

6.2.3.1 Motor Component. No separate motor component exists in SCDAP/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 (6-29)].

6.2.3.2 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 3.3.1. 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,

$$\frac{d\omega}{dt} = \tau_m + \tau_h \ , \qquad (6\text{-}30)$$

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 SCDAP/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 51 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.

6.2.3.3 Turbine Component. A turbine component (described more completely in Subsection 3.3.5) is a hydrodynamic component consisting of one volume and has additional modeling to compute torque based on volume conditions and rotational velocity. One junction may connect to the turbine volume inlet to represent the steam line. Multiple junctions may connect to the outlet to represent steam exit, extraction steam for regenerative heating of feedwater, and drain lines to remove liquid. A small turbine, such as might be used to drive a pump, is usually modeled by one turbine component. The turbine used to drive the electrical generator typically has steam extraction points and drain lines and thus is usually modeled by two or more turbine components. The shaft component is the only mechanism for providing the rotational velocity common to each turbine component and summing the torque developed in each turbine component. The shaft is also the only mechanism to couple the turbine to a pump or generator.

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

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

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

6.2.3.5 Pump, Generator, Shaft Sample Problem. Figure 6-1 shows input data for a sample problem to test pump, generator, and shaft components. The test problem consists of two identical but separate loops. Each loop has a pump and a pipe connecting the pump discharge to the pump suction. The normal wall friction model is used, and an orifice is included for additional dissipation. The loops are filled with subcooled water at zero velocity. The two pumps are driven differently. The first pump uses an implied pump motor operating at normal speed. The water is accelerated to near steady-state velocity within a few seconds. A true steady-state is not possible, since there is no provision for removing dissipation heat. The pump is then tripped; the pump coasts down, and flow velocities diminish. The second pump uses a pump motor torque table representing an induction motor with the rotational velocity initially zero. The pump accelerates to near the synchronous velocity, and in turn the water velocity is accelerated similarly to the first loop. The second loop is tripped similarly to the first loop.

```
=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 puop is initially at"rest.  The
*   pump"accelerates to near synchronows 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  pmpvrq 004
501  time  2  g  null  0  20.2  1
```

Figure 6-1. 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,  2244.780,  540.0,  0,  0,  0,  19
11301  0,  0,  0,  18
20000  loop pump
20101  0.0468  0  0.1660  0  0  0  0
20108  1010000  .0376 "0  0  0
20109  1000000  .0376  0  0  0
20200  3  2264.78  540.0  0
20201  0  0  0  0
20202  0  0  0  0
20301  -1  0  -2  -1  -1  501  -1
20302  3560.0  0.66573  180.0  192.0  34.8  38.3  62.3  0  6.7  0  0  0
23000  0
23001  0.0,  0.0   0.1,  0.0  0.15,  0.05  0.24,  0.8  0.3,  0.96  0.4,  0.98
23002  0.6,  0.97  0.8,  0.9  0.9,   0.8   0.96,  0.5  1.0,  1.0
23100  0
23101  0.0,  -.17  0.0001,  -.017  0.006,  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  2244.78  540.0  0
40201  0  0  0  0
40202  0  0  0  0
40301  2  2  2  0  -1  501  1
40302  3560.0  0.0  180.0  192.0  34.8  38.3  62.3  35.0  6.7  0  0  0
46001  1440.,   1.00  2160.,   1.10  2880.,   1.50
46002  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 6-1. (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  I92.0  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  0.7375621495  0  0
20500401  cntrlvar,  3
20501000  shaft4  shaft  1.0  0.0 0
20501001  3  0.3  0.0  pump,  4
20201000  reac-t  0  0.10471975512  1.0
20201001  1440.0,   1.00  2160.0,   1.10  2880.0,  1.50
20201002  3528.0,   2.80  3672.0,  -2.70  4120.0, -1.90
20201003  5040.0,  -1.20  5760.0,  -1.05  6480.0, -1.00
20201004  7200.0,  -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 6-1. (continued)

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.

7. 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.

This capability would not normally be used when SCDAP components are used to represent the core.

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

7.1 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 ^{239}U by neutron absorption in ^{238}U and subsequent two-stage beta decay to ^{239}Pu.

Two sets of fission product decay data are built into the code. The default set is the eleven-group ANS standard proposed in 1973.[7-1] The other set of data is from the 1979 ANS Standard for Decay Heat Power in Light Water Reactors.[7-2] The 1979 data specifies data for three isotopes, ^{235}U, ^{238}U, and ^{239}Pu, using 23 groups for each isotope. To use the three isotope data, the user must furnish the fraction of power produced by each isotope. An option exists to use only the ^{235}U isotope data from the 1979 standard. Actinide data 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 ^{238}U atoms consumed per ^{235}U 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 ^{238}U is present. The new standard is recommended, because it is an approved standard and the variance between 1979 data and experimental data is much less than 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.

7.2 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 4.5.6 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 precedes control system evaluation; thus, feedback from control variables is delayed one time step.

The separable option uses two tables, one defining reactivity as a function of volume density and the other defining reactivity as a function of volumetric average fuel temperatures. The tables allow nonlinear feedback 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 operating data, reactor physics calculations, or a combination of the two. The required moderator temperature coefficient is not the usually quoted quantity. Assume the moderator feedback is a function of density and temperature, $r(\rho, T)$, and density is a function of temperature, $\rho(T)$. The usual temperature coefficient is the total derivative, 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 4.5.6, 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 shut down 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 shut down, data can be determined from extrapolation and need not be accurate. Similarly, some parts of the table may contain large values of reactivity. The user does not expect the transient to use this portion of the table, but the code input requires all tabular points to be entered. Again, accurate data need not be entered; if the transient should enter this area, the large power rises will be evident and the user can investigate the modeling difficulty. In some instances, a coordinate value is introduced to ensure accuracy in one section of a table, but the detail is not needed in other parts of the table. Where the detail is not needed, data could be obtained at a more coarse mesh; and the user can interpolate to meet the input requirements of the code.

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

The use of the weights is different between the separable and table options. In the separable option, a reactivity effect is 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 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 are 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.

7.3 References

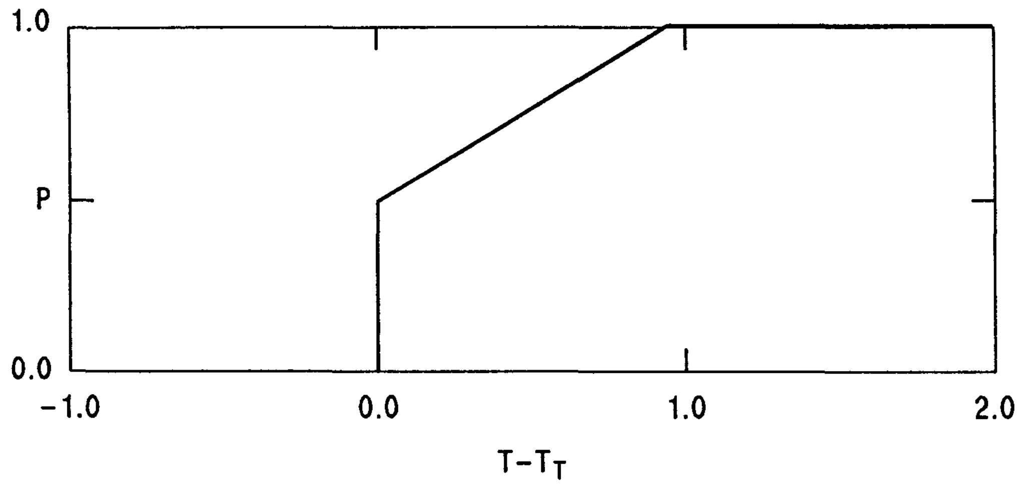
7-1. American Nuclear Society Proposed Standard, ANS 5.1, Decay Energy Release Rates Following Shutdown of Uranium-Fueled Thermal Reactors, October 1971, revised October 1973.

7-2. American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1-1979.

8. 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 parametric studies, the input provides for conversion and/or scaling factors for these tables. Input editing of these tables includes both the original and scaled data. General tables can be entered, deleted, or replaced at restart. The tables are linearly interpolated between table values, and the end-point values are used when the search arguments are beyond the range of entered data.

Figure 8-1 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 with the data scaled by 50 MW. The remaining cards 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 function and delay. If a zero trip number is specified, current time is always the search argument. The tabular data show two data points having the same time value, zero, but having different power values. This allows entry of step changes, as shown on the graph. The graph also illustrates that when search arguments are beyond the range of entered data, end-point values are used rather than extrapolation.



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		

EC000132

Figure 8-1. Card data for a power-type general table and graph.

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

Time-dependent volumes, time-dependent junctions, and 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.

9. 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 and SCDAP components require the initial temperature at each node, control systems require the initial value of all control variables, and kinetics calculations require initial power and reactivity. All of these parameters are established through the code input and initialization process for a new problem. For a restart problem, the values are established from the previous calculation. For restart with renodalization or problem changes, the initialization will result from a combination of the two processes; and care must be exercised to ensure that the input values are compatible with those from the restart, especially if an initial steady state is to be simulated.

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

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

9.1 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.

9.1.1 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, and 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 A-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.

9.1.2 Steady-State Initialization

SCDAP/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. (See Appendix C for the self-initialization option.)

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.

9.2 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.

9.2.1 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.

9.2.2 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.

10. PROBLEM CONTROL

10.1 Problem Types and Options

SCDAP/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. STRIP writes selected information from a restart-plot file onto a new file. The new file consists of records containing time and the user-selected variables in the order selected by the user. Data to be plotted or stripped are limited to that written in the plot records on the restart-plot file. Quantities written in the plot records by default are noted in the input data description. User-specified input can add additional quantities to the plot records.

10.2 Time Step Control

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

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 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 are used. If necessary, the new requested time step is reduced by halving until the new actual time step is <1.5 times the last successful time step.

Setting bit one (entering 1, 3, 5, 7, 9, 11, 13, 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 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 hydrodynamics will use the nearly implicit hydrodynamic numerical scheme. The time step can be as large as five times the Courant limit for the TRANSNT option and ten times the Courant limit for the STDY-ST option. The time step control for hydrodynamics is determined by the status of the first bit, as described above.

Note that combinations of the effects of setting of the individual bits are 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. Older versions of RELAP5 and SCDAP/RELAP5 would convert 2 to 3 to maintain compatibility with older versions. This is no longer done.

Entering 0 is not recommended except for special program-testing situations. If bit one 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.

10.3 Printed Output

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

10.3.1 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, 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.

10.3.2 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 10-1.

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.

10.3.2.1 Time Step Summary. As shown in Figure 10-1, the first section of a major edit prints the problem time and statistics concerning time step control. ATTEMPTED ADV. is the total number of successful and repeated advancements. REPEATED ADV. is the number of advancements that were not accepted and were retried with a halved time step. SUCCESSFUL ADV. is the number of accepted advancements. REQUESTED ADV. is the number of advancements with the specified requested maximum time step. These are presented in two columns. The TOT. column is over the entire problem; the EDIT column contains the number since the previous major edit. MIN. DT, MAX. DT, and AVG. DT are the minimum, maximum, and average time step used since the last major edit. REQ. DT is the requested maximum time step used since the last major edit. This quantity may not be the requested time step entered on the card if the major edit is for the final time value on the card. LAST DT is the time step used in the last advancement. CRNT. DT is the time step limit based on the Courant stability criterion for the last advancement. ERR. EST is the estimate of the truncation mass error 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 8.0×10^{-4} and 8.0×10^{-3}. CPU is the CPU time for the entire problem up to the time of the major edit. TOT. MS is

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RELAP5/2/36.02       REACTOR LOSS OF COOLANT ANALYSIS PROGRAM                                                          PAGE      32
EDWARD'S PIPE PROBLEM BASE CASE WITH EXTRAS                                          89/07/12.

 ATTEMPTED ADV: TOT.=     58   EDIT=     10   MIN.DT=   1.000000E-03 SEC   LAST DT=   1.000000E-03 SEC   MS.ERR=  -5.926586E-05 KG
 REPEATED ADV:  TOT.=     11   EDIT=      0   MAX.DT=   1.000000E-03 SEC   CRNT.DT=   9.558596E-03 SEC   TOT.MS=    14.5294      KG
SUCCESSFUL ADV: TOT.=     47   EDIT=     10   AVG.DT=   1.000000E-03 SEC   ERR.EST=   2.073590E-06       M.RATO=  -3.810409E-06
 REQUESTED ADV: TOT.=     20   EDIT=     10   REQ.DT=   1.000000E-03 SEC       CPU=     29.0300     SEC     TIME=   2.000000E-02 SEC

TRIP NUMBER, TRIP TIME (SEC)
    501  -1.000000         502   1.000000E-02       505   6.000000E-03
    601  -1.000000         602  -1.000000           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= -5.92659E-05 KG       ERR.EST.=  2.07359E-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  2.16719E-02    501.16        499.60        499.60        0.             0.            9.77765E+05   2.60161E+06   00
   3-040000  2.62141E+06  2.91278E-02    501.11        499.63        499.63        0.             0.            9.77514E+05   2.60161E+06   00
   3-050000  2.62319E+06  2.96373E-02    501.10        499.66        499.66        0.             0.            9.77476E+05   2.60161E+06   00
   3-060000  2.62598E+06  3.05096E-02    501.09        499.72        499.72        0.             0.            9.77431E+05   2.60161E+06   00
   3-070000  2.62942E+06  2.96767E-02    501.09        499.78        499.79        0.             0.            9.77437E+05   2.60162E+06   00
   3-080000  2.63322E+06  2.65383E-02    501.11        499.86        499.87        0.             0.            9.77529E+05   2.60163E+06   00
   3-090000  2.63701E+06  2.28553E-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  1.97244E-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  1.82921E-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  1.62282E-02    501.18        500.16        500.20        0.             0.            9.77823E+05   2.60158E+06   00
   3-170000  2.64682E+06  1.70667E-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  2.56238E+06   .29981        498.71        498.38        498.41        0.             0.            9.66441E+05   2.60133E+06   00
   3-200000  2.44221E+06   .48402        495.87        495.85        495.85        0.             0.            9.53374E+05   2.60084E+06   00
RHTBDY      TMDPVOL     COMPONENT
   3-010000  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        2.30793E-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       6.22149E-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         .71452       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        3.17950E-04    1259.1        0.             17.806
   3-110000  829.93       13.229         2.7532        2.2837        23.405        3.20625E-04    1282.4        0.             17.993
   3-120000  829.93       13.241         3.0237        2.5997        23.256        3.23767E-04    1291.0        0.             17.759
   3-130000  829.93       13.251         3.2920        2.9394        23.140        3.18008E-04    1293.6        0.             17.790
   3-140000  829.92       13.259         3.5551        3.3234        23.058        2.97588E-04    1298.3        0.             17.190
```

Figure 10-1. Major edit from Edwards Pipe problem with extras.

the total mass currently contained in the hydrodynamic systems, and MS. ERR is an estimate of the cumulative error in the total mass due to truncation error. M.RATO is the ratio of the cumulative mass error to the total mass at the start of the transient; M.RATN is the ratio of the cumulative mass error to the current total mass. The output lists the ratio with the largest denominator, thus the smaller of the two ratios. TIME is the simulated time for the entire problem up to the time of the major edits.

10.3.2.2 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 10-1 includes an example of a trip edit.

10.3.2.3 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 10-1 includes an illustrative example of a reactor kinetics edit; however, it is not intended to be physically realistic.

10.3.2.4 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 ($X^{n+1}_{n,L}$) and boron density ($\rho^{n+1}_{B,L}$), used in the equations. After this are UF and UG, which are the liquid-specific internal energy ($U^{n+1}_{f,L}$) and the vapor-specific internal energy ($U^{n+1}_{g,L}$) used in the equations. Finally, the label VOL. FLAG is listed, which is the volume control flag (bfe) 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; *none* if no name is input on Cards 120 through 129). To the right of this are the labels MASS, MASS ERROR, and ERR EST. for this system, followed immediately by the actual value and unit. These three quantities correspond to the TOT. MS, MS. ERR, and ERR. EST listed in the Time Step Summary, except that these are only for the particular system while the Time Step Summary quantities are for all the systems. In Figure 10-1, there is only one system (SYSTEM 1); and thus the MASS, MASS ERROR, and ERR. EST. are the same as the corresponding quantities in the Time Step Summary. Figure 10-2 is a major edit from the Two Loops Problem with pumps (Figure 6-1) using a shaft component, and this has two systems (SYSTEM 1 and SYSTEM 2). Figure 10-2 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 10-1 and 10-2 illustrate, quantities are grouped by component within each system. 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.

RELAP5/2/36 05   REACTOR LOSS OF COOLANT ANALYSIS PROGRAM   PAGE 151
TWO LOOPS WITH PUMPS USING SHAFT COMPONENT   89/07/18

ATTEMPTED ADV	TOT =	385	EDIT=	15	MIN DT=	200000	SEC	LAST DT=	200000	SEC	MS ERR=	6 766978E-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 413704E-07		M RATO=	4 483034E-05	
REQUESTED ADV	TOT =	295	EDIT=	15	REQ DT=	200000	SEC	CPU=	219 084	SEC	TIME=	40 0000	SEC

TRIP NUMBER TRIP TIME (SEC)
501 20 00000

VOL NO	PRESSURE (LBF/IN2)	VOIDG	TEMPF (DEGF)	TEMPG (DEGF)	SAT TEMP (DEGF)	NONCOND VAPOR QUAL	BORON DENS (LB/FT3)	UF (BTU/LB)	UG (BTU/LB)	VOL FLAG
SYSTEM 1		MASS= 75 471	LB	MASS ERROR= 2 10007E-03 LB		ERR EST = 2 52073E-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 66691E-03 LB		ERR EST = 5 19387E-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 1	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 10-2. Major edit from the Two Loops Problem with pumps using shaft component.

As Figure 10-2 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 3.2.5.4 of Volume 1 and Subsection 3.3.1 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-standpipe-surge line (labeled LEVEL), and the mean tank wall metal temperature (labeled WALL TEMP). These terms are discussed in Subsection 3.2.5.7 of Volume 1 and Subsection 3.3.6 of this volume. An example of this output is shown in Figure 10-3. 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 non-ideal internal processes (EFFICIENCY). These terms are discussed in Subsection 3.2.5.5 of Volume 1 and Subsection 3.3.5 of this volume. An example of this output is also shown in Figure 10-3.

10.3.2.5 Hydrodynamic Volume Information--Second Section. This information appears in every major edit if noncondensible species were specified in the input. Figure 10-4 provides sample output for this edit from Simple Cheap Problem 2. In this section, no system or component label information is printed. The volume number (labeled VOL.NO.) and three to seven other quantities are printed on each line. These are printed out in numerical order within each system. The quantities are the mass of soluble species (labeled SOLUTE MASS), denoting the variable ($M_{B,L}^{n+1}$); noncondensible mass (labeled NONCOND. VAPOR MASS), denoting the variable ($M_{n,L}^{n+1}$); and the mass fraction of each of the noncondensible species

```
   Vol.no.  pressure     part-press    voidf         voidg         tempf         tempg         sat. temp.       uf            ug          volume
              (pa)          (pa)                                    (k)           (k)           (k)          (j/kg)        (j/kg)        flag
inlet     tmdpvol

200-010000  6.00000E+06  6.00000E+06  0.00000        1.0000        548.700       748.000       548.700     1.20578E+06  3.03583E+06  11010
pre       snglvol
300-010000  2.81648E+06  2.81648E+06  0.00000        1.0000        503.517       652.644       503.517     9.88622E+05  2.90078E+06  00010
stage0    turbine
power=  0.00000       (watt)        torque=  0.00000        (n-m)          speed=   573.00       (rad/sec)      efficiency=  0.00000
400-010000  2.37193E+06  2.37193E+06  0.00000        1.0000        494.314       628.815       494.314     0.94630E+06  2.86542E+06  10010
stage1    turbine
power=  2.46382E+08 (watt)          torque=  0.42999E+06  (n-m)          speed=   573.00       (rad/sec)      efficiency=  0.79980
500-010000  1.31150E+06  1.31150E+06  0.00000        1.0000        465.164       562.376       465.164     0.81508E+06  2.76878E+06  10010
stage2    turbine
power=  3.93440E+08 (watt)          torque=  0.68663E+06  (n-m)          speed=   573.00       (rad/sec)      efficiency=  0.79992
600-010000  0.42192E+06  0.42192E+06  0.00000        1.0000        418.706       468.947       418.706     0.61253E+06  2.63798E+06  10010
stage3    turbine
power=  1.96820E+07 (watt)          torque=   34349.        (n-m)          speed=   573.00       (rad/sec)      efficiency=  0.79998
700-010000  0.39789E+06  0.39789E+06  0.00000        1.0000        416.583       462.243       416.583     0.60342E+06  2.62898E+06  10010
stage4    turbine
power=  0.00000       (watt)        torque=  0.00000        (n-m)          speed=   573.00       (rad/sec)      efficiency=  0.00000

800-010000  0.44901E+06  0.44901E+06  0.00000        1.0000        420.986       476.854       420.986     0.62235E+06  2.64909E+06  10010
post      tmdpvol
900-010000  0.50000E+06  0.50000E+06  0.00000        1.0000        424.994       429.968       424.994     0.63967E+06  2.56778E+06  11010
```

Figure 10-3. Example of an additional major edit printout for accumulator and turbine components.

```
MAJOR EDIT !!!time=   2500.00     sec

 attempted adv: tot.=   4688   edit=    181   min.dt=   0.175000     sec   last dt=   0.700000     sec   ms.red=   0.768331     kg
  repeated adv: tot.=   1033   edit=     25   max.dt=   0.700000     sec   crnt.dt=    2.19671     sec   tot.ms=   0.584313     kg
successful adv: tot.=   3655   edit=    156   avg.dt=   0.448717     sec   err.est=   1.865268E-04          m.rato=    1.29952
 requested adv: tot.=   2281   edit=    100   req.dt=   0.700000     sec      cpu=    153.730      sec     time=    2500.00      sec

Trip number, trip time (sec)
    401  -1.000000

System  1    *none*  mass=  0.58431    kg    mass error=  0.76833     kg    err.est.=  1.86527E-04

   Vol.no.  pressure     part-press    voidf         voidg         tempf         tempg         sat. temp.      uf           ug           volume
              (pa)          (pa)                                    (k)           (k)           (k)         (j/kg)       (j/kg)         flag
sourvol  tmdpvol
 10-010000  6.90000E+06  6.90000E+06   1.0000       0.00000       530.000       557.968       557.968      1.11037E+06  2.58267E+06  11011
testbun  pipe
100-010000  6.89204E+06  6.89204E+06   1.0000       0.00000       553.018       557.890       557.890      1.22688E+06  2.58273E+06  00000
100-020000  6.89104E+06  6.89104E+06   1.0000       1.00000E-10   555.021       557.881       557.881      1.23746E+06  2.58274E+06  00000
100-030000  6.89014E+06  6.89014E+06  7.73815E-02   0.92261       557.149       557.872       557.872      1.24869E+06  2.58275E+06  00000
100-040000  6.89006E+06  6.89006E+06  0.00000        1.0000       557.871       1561.59       557.871      1.25250E+06  4.64264E+06  00000
100-050000  6.89005E+06  6.89005E+06  0.00000        1.0000       557.871       2316.84       557.871      1.25250E+06  6.41534E+06  00000
100-060000  6.89004E+06  6.89004E+06  0.00000        1.0000       557.871       2598.24       557.871      1.25250E+06  7.12020E+06  00000
100-070000  6.89004E+06  6.89004E+06  0.00000        1.0000       557.871       2442.27       557.871      1.25250E+06  6.72952E+06  00000
100-080000  6.89003E+06  6.89003E+06  0.00000        1.0000       557.871       2282.08       557.871      1.25250E+06  6.32828E+06  00000
platout  snglvol
102-010000  6.89002E+06  6.89002E+06  0.00000        1.0000       557.871       1667.71       557.871      1.25250E+06  4.87789E+06  00000
platout2 snglvol
104-010000  6.89001E+06  6.89001E+06  0.00000        1.0000       557.871       1059.81       557.871      1.25250E+06  3.61270E+06  00000
sinkvol  tmdpvol
200-010000  6.89000E+06  6.89000E+06  7.10543E-15    1.0000       557.870       557.870       557.870      1.25250E+06  2.58275E+06  11011

   Vol.no.  solute       noncond.      hydrogen      helium        krypton       xenon
            mass         vapor mass    ncond. qual   ncond. qual   ncond. qual   ncond. qual
            (kg)         (kg)
 10-010000  0.00000      0.00000       0.00000       0.00000       0.00000       0.00000
100-010000  1.03175E-09  0.00000       0.00000       0.00000       0.00000       0.00000
100-020000  2.41407E-09  0.00000       0.00000       0.00000       0.00000       0.00000
100-030000  3.04164E-08  6.66930E-12   4.59324E-07   1.14816E-25   0.10122       0.89877
100-040000  1.34483E-11  5.41626E-12   3.14326E-07   7.85711E-26   0.10122       0.89877
100-050000  1.84897E-11  5.79846E-12   2.64675E-07   6.61601E-26   0.10122       0.89877
100-060000  2.50321E-11  7.16882E-12   2.49565E-07   6.23831E-26   0.10122       0.89877
100-070000  3.54883E-11  9.68657E-12   2.58595E-07   6.46403E-26   0.10122       0.89877
100-080000  6.29908E-11  1.65688E-11   3.04143E-07   7.60258E-26   0.10122       0.89877
102-010000  8.42689E-11  2.23243E-11   5.79268E-07   1.44781E-25   0.10122       0.89877
104-010000  1.25455E-10  3.35627E-11   6.59090E-04   1.95148E-20   0.10116       0.89818
200-010000  0.00000      0.00000       0.00000       0.00000       0.00000       0.00000

   Vol.no.   rhof          rhog          rho-mix      rho-boron     vel-liquid    vel-vapor     sounde        quality     quality     quality
            (kg/m3)       (kg/m3)       (kg/m3)      (kg/m3)        (m/sec)       (m/sec)      (m/sec)        mix-cup     static     non-cond.
 10-010000   791.88        35.949        791.88      0.00000       3.84678E-06   3.84678E-06    1124.0       -0.947E-01  0.000        0.000
100-010000   751.58        35.903        751.58      2.73063E-06   3.82268E-04   3.82497E-04    1005.9       -0.171E-01  0.000        0.000
100-020000   747.68        35.897        747.68      7.04205E-06   2.96887E-02   0.60683        994.92       -0.100E-01  0.000        0.000
100-030000   743.45        35.892        90.644      1.21685E-04   6.08178E-04   1.27221E-02    251.17        0.401      0.365        0.806E-09
100-040000   741.99        9.6906        9.6906      4.38640E-08   1.93549E-02   1.69523E-02    927.14        2.70        1.00        0.182E-08
100-050000   741.99        6.5317        6.5317      5.95142E-08   4.30912E-02   4.15985E-02    452.03        4.10        1.00        0.286E-08
100-060000   741.99        5.8243        5.8243      7.92156E-08   5.45664E-02   5.44295E-02    452.03        4.65        1.00        0.390E-08
100-070000   741.99        6.1962        6.1962      1.11078E-07   5.60976E-02   5.60410E-02    1146.1        4.35        1.00        0.489E-08
100-080000   741.99        6.6311        6.6311      1.54389E-07   4.08799E-02   4.08321E-02    1109.4        4.04        1.00        0.612E-08
102-010000   741.99        9.0740        9.0740      2.00071E-07   3.32967E-02   3.25212E-02    956.14        2.89        1.00        0.584E-08
104-010000   741.99        14.289        14.289      2.97856E-07   2.53184E-02   2.42867E-02    452.03        1.87        1.00        0.558E-08
```

Figure 10-4. Example of a major edit printout for hydrodynamic volumes.

200-010000	741.99	35.891	35.891	0.00000	2.07362E-04	2.07362E-04	452.03	1.00	1.00	0.000

vol.no.	tot.ht.inp (watts)	vap.ht.inp (watts)	vapor-gen. (kg/sec-m3)	wall-flashing (kg/sec-m3)	liq.int.htc (watts/m3-k)	vap.int.htc (watts/m3-k)	mass-flux (kg/sec-m2)	Reynolds liquid	Reynolds vapor	flow regi
10-010000	0.00000	0.00000	0.00000	0.00000	1.00000E-02	1.00000E+12	1.52309E-03	9.3905	2.35357E-15	bby
100-010000	116.30	0.00000	0.00000	1.89762-116	1.00000E-02	3.34194E+07	0.30245	39.817	9.59124E-15	bby
100-020000	0.00000	0.00000	0.00000	0.00000	1.00000E-02	1.41872E+06	22.255	43.123	2.12362E-13	bby
100-030000	1402.4	0.00000	3.6723	3.7084	75731.	0.81461E+06	0.43800	0.16148	0.74701	vst
100-040000	2358.6	2358.6	0.00000	0.00000	0.21337E+06	1.00000E-02	0.34270	1.27683E-12	52.211	mst
100-050000	1925.2	1925.2	0.00000	0.00000	0.20556E+06	1.00000E-02	0.33698	3.18810E-12	34.790	mst
100-060000	987.40	987.40	0.00000	0.00000	0.46072E+06	1.00000E-02	0.33605	4.13821E-12	31.593	mst
100-070000	-462.74	-462.74	0.00000	0.00000	2.67870E+09	1.00000E-02	0.33688	4.32519E-12	34.283	mst
100-080000	-460.78	-460.78	0.00000	0.00000	6.31649E+09	1.00000E-02	0.26299	4.63735E-12	42.050	mst
102-010000	-1571.1	-1571.1	0.00000	0.00000	6.31650E+09	1.00000E-02	0.25598	1.79377E-11	269.24	mst
104-010000	-1405.2	-1405.2	0.00000	0.00000	6.31650E+09	1.00000E-02	0.26072	1.25894E-11	440.14	mst
200-010000	0.00000	0.00000	0.00000	0.00000	1.00000E+12	7.10543E-02	1.48146E-03	5.25933E-13	50.439	mst

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
100-010000	0	233	0	8	0	2	0	0	0	2	0	0	0	0
100-020000	0	673	0	309	0	0	0	0	0	0	0	26	0	0
100-030000	0	151	0	4	0	0	0	125	0	1	0	1025	0	0
100-040000	1	236	0	0	0	0	0	6	0	0	0	15	0	0
100-050000	0	592	0	0	0	0	0	33	0	0	13	349	0	0
100-060000	138	537	0	0	0	0	21	71	0	0	66	1961	0	0
100-070000	14	257	0	0	0	0	0	3	0	0	77	188	0	0
100-080000	0	137	0	0	0	0	0	11	0	0	0	7	0	0
102-010000	0	111	0	0	0	0	0	1	0	0	0	10	0	0
104-010000	3	728	0	0	0	0	2	85	0	0	0	74	0	0
200-010000	0	0	0	0	0	0	0	0	0	0	0	0	0	0

System 1 *none*

Jun.no.	from vol.	to vol.	liq.j.vel. (m/sec)	vap.j.vel. (m/sec)	mass flow (kg/sec)	jun.area (m2)	throat ratio	junction flags	no. last	advs. edit	choked total
sourjun tmdpjun											
50-000000	10-010000	100-010001	3.82010E-04	3.82010E-04	1.00000E-03	3.30573E-03	1.0000	000000	0	0	0
testbun pipe											
100-010000	100-010002	100-020001	2.96895E-02	3.08798E-02	9.99670E-04	4.48000E-05	1.0000	000000	0	0	0
100-020000	100-020002	100-030001	2.96878E-02	1.1829	9.94407E-04	4.48000E-05	1.0000	000000	0	0	0
100-030000	100-030002	100-040001	-9.47442E-05	1.27221E-02	9.21598E-04	2.18688E-03	1.0000	000000	0	0	0
100-040000	100-040002	100-050001	3.51978E-02	3.52846E-02	9.15974E-04	2.68233E-03	1.0000	000000	0	0	0
100-050000	100-050002	100-060001	5.13378E-02	5.15224E-02	9.14136E-04	2.71809E-03	1.0000	000000	0	0	0
100-060000	100-060002	100-070001	5.85906E-02	5.85915E-02	9.59793E-04	2.76465E-03	1.0000	000000	0	0	0
100-070000	100-070002	100-080001	5.42650E-02	5.42650E-02	9.29657E-04	2.79520E-03	1.0000	000000	0	0	0
platout sngljun											
101-000000	100-080002	102-010001	3.96167E-02	3.96167E-02	9.40264E-04	3.56956E-03	1.0000	000000	0	0	0
platout2 sngljun											
103-000000	102-010002	104-010001	2.83769E-02	2.83769E-02	9.50671E-04	3.68500E-03	1.0000	000000	0	0	0
sinkjun sngljun											
150-000000	104-010002	200-010000	4.13464E-02	4.13464E-02	9.75550E-04	1.64640E-03	1.0000	000000	0	0	0

Jun.no.	voidfj	voidgj	fij (n-s2/m5)	fwalfj	fwalgj	fjunf	fjunr	formfj	formgj	no last	advs edit	ccfl total
50-000000	1.0000	0.00000	2485.0	7.64	0.000	0.000	0.000	0.000	0.000	0	0	0
100-010000	1.0000	0.00000	1162.4	458.	0.366E+04	0.000	0.000	0.000	0.000	0	0	0
100-020000	1.0000	0.00000	2785.7	0.190E+04	8.55	0.000	0.000	0.000	0.000	0	0	0
100-030000	0.00000	0.92261	7.6201	2.225E+08	2.935E+04	0.000	0.000	0.000	0.000	0	0	0
100-040000	0.00000	1.0000	2.84041E-04	0.000	22.0	0.000	0.000	0.000	0.000	0	0	0
100-050000	0.00000	1.0000	1.91289E-04	0.000	24.0	0.000	0.000	0.000	0.000	0	0	0
100-060000	0.00000	1.0000	4.72176E-02	0.000	21.6	0.000	0.000	0.000	0.000	0	0	0
100-070000	0.00000	1.0000	0.70543	0.000	14.2	0.000	0.000	0.000	0.000	0	0	0
101-000000	0.00000	1.0000	0.92056	0.000	5.25	0.000	0.000	0.000	0.000	0	0	0
103-000000	0.00000	1.0000	0.99300	0.000	0.248	0.000	0.000	0.000	0.000	0	0	0
150-000000	0.00000	1.0000	0.50786	0.000	2.385E-02	0.000	0.000	0.000	0.000	0	0	0

Figure 10-4 (continued).

in the problem (labeled by the element name and NCOND. QUAL), denoting the variable ($X^{N+1}_{ni,L}$). The noncondensible qualities (X_{ni}) sum to 1.0 in each volume.

10.3.2.6 <u>Hydrodynamic Volume Information--Third Section</u>. This section of output is optional and can be skipped by setting bit three in the <u>ss</u> digits of Word 4 (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 10-1. This section, however, was not allowed to be printed in the Two Loops Problem and thus is not present in Figure 10-2. 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 ten 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), denoting the variable ($\rho^{n+1}_{f,L}$); vapor density (labeled RHOG), denoting the variable ($\rho^{n+1}_{g,L}$); liquid volume-average velocity (labeled LIQ.V.VEL), denoting the variable ($v^{n+1}_{f,L}$); vapor volume-average velocity (labeled VAP.V.VEL.), denoting the variable ($v^{n+1}_{g,L}$); isentropic sonic velocity for single-phase or homogenous equilibrium isentropic sonic velocity for two-phase (labeled SOUNDE), denoting the variable ($a^{n+1}_{HE,L}$); static quality (labeled STATIC QUAL.), denoting the variable (X^{n+1}_{L}); total wall heat transfer rate to the liquid and vapor (labeled TOT.HT.INP.), denoting the quantity ($Q^{n}_{L} \cdot V_L$); wall heat transfer rate to the vapor (labeled VAP.HT.INP.), denoting the quantity ($Q^{n}_{wg,L} \cdot V_L$); vapor generation rate per unit volume (labeled VAPOR GEN.), denoting the variable ($\Gamma^{n+1}_{g,L}$); and flow regime (labeled FLOW REG).

10.3.2.7 <u>Hydrodynamic Volume Time Step Control Information</u>. This section is also optional and can be skipped by setting bit four in the <u>ss</u> digits of Word 4 (W4) on the time step control card (cards 201 through 299). As with the previous section, this section is present in Figure 10-1 but not in Figure 10-2. 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 (1044) in Volume 1] and it does not include reductions due to overall (global) mass error [Equation (1045) 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 (8×10^{-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 3.2.1.6 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) $\leq$0.0, vapor temperature $\leq$274 K, and liquid density (ρ_f) $\leq$0.0. The COURANT column is for reductions due to the material Courant limit check (see Subsection 5.1 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 five times the material Courant limit for the TRANSNT option and to ten 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.

10.3.2.8 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., it denotes the component number (CCC) and the six-digit junction subfield number (XXYYZZ) within the component.] These numbers are separated by a hyphen (-). The next two quantities are the volume numbers for the from and to volumes associated with the junction (labeled FROM VOL. and TO VOL.). A minus sign will be printed in front of the from volume number if it is not the outlet end of the volume. Similarly, a minus sign will be printed in front of the to volume number if it is not the inlet end of the volume. Next are the liquid junction velocity and vapor junction velocity [labeled LIQ.J.VEL. and VAP.J.VEL, denoting the variables ($v_{f,j}^{n+1}$) and ($v_{g,j}^{n+1}$)]. In single phase, the velocities are equal. This is followed by the mass flow rate

[labeled MASS FLOW, denoting 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, denoting the variable A_j) and throat ratio (labeled THROAT RATIO, denoting the quantity A_T/A_j). For the smooth area option, A_j is the physical area (full open area if a valve). For the abrupt area option, A_j is the minimum area of the two connecting volumes. The next quantity is the junction control flag (labeled JUNCTION FLAGS), which is the five-digit packed number fvcahs that the user inputs for each junction. The last three columns are a choking summary (labeled NO.ADVS.CHOKED). The subheading LAST indicates whether the choking model was applied on the last time step (set to 1 if it was, set to 0 if it was not). The subheading EDIT lists the number of times the choking model was applied since the last major edit; the subheading TOTAL lists the number of times the choking model was applied for the entire problem. As with the first section of the hydrodynamic volume information, quantities within each system are grouped by component, with the component name, the component type, and the label COMPONENT printed above the quantities. Both Figure 10-1 (one system) and Figure 10-2 (two systems) show examples of this section of the major edit.

10.3.2.9 Hydrodynamic Junction Information--Second Section. This section of output is optional and can be skipped by setting bit two in the ss digits of Word 4 (W4) on the time step control card (Cards 201 through 299). This section is present in Figure 10-1 but not in Figure 10-2. 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 nine other quantities are next printed out on each line. These are printed out in numerical order within each system. The quantities are liquid junction void fraction [labeled VOIDFJ, denoting the variable $(\dot{\alpha}^{n+1}_{f,j})$], vapor junction void fraction [labeled VOIDGJ, denoting the variable $(\dot{\alpha}^{n+1}_{g,j})$], interphase drag [labeled FIJ, in most cases denoting the quantity $(\alpha^n_{f,j}\ \alpha^n_{g,j}\ \rho^n_{f,j}\ \rho^n_{g,j}\ FI^n_j / \left| v^n_{g,j} - v^n_{f,j} \right|)$], dimensionless liquid and vapor wall friction [labeled FWALFJ and FWALGJ, in most cases denoting the quantities ($2 \cdot FWF_j^n \cdot \Delta x_j / \left| v_{f,j}^n \right|$) and ($2 \cdot FWG_j^n \cdot \Delta x_j / \left| v_{g,j}^n \right|$)], 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 denoting the quantities ($2 \cdot HLOSSF_j^n / \left| v_{f,j}^n \right|$) and ($2 \cdot HLOSSG_j^n / \left| v_{g,j}^n \right|$)]. 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. The last three quantities are a countercurrent flow limitation (CCFL) model summary (labeled NO. ADVS. CCFL). The subheading LAST indicates whether the CCFL model was applied on the last time step (set to 1 if it was, or set to 0 if it was not); the subheading EDIT lists the number of times the CCFL model was applied since the last major edit; the subheading TOTAL lists the number of times the CCFL model was applied for the entire problem.

10.3.2.10 <u>Heat Structure-Heat Transfer Information</u>. 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., denoting 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, 0-000000 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.). Subsections 4.2 and 3.2.4 describe the meaning of the modes. Finally, three quantities are printed for the individual heat structure.

These are the heat generated within the structure (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 10-1 shows an example of this section of the major edit.

10.3.2.11 Heat Structure Temperature. This section of output is optional and can be skipped by setting bit one in the ss digits of Word 4 (W4) on the time step control card (Cards 201 through 299). This bit was not set for the Edwards problem in Figure 10-1, 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 10-1, 11 mesh point temperatures are printed out.

10.3.2.12 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 10-5 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 10-5, the user requested 16, so the theoretical maximum is 321, which is larger than the assigned maximum of 153. The next column is the actual number of axial nodes used for the last time advancement (sublabeled

STR.NO.	SIDE	BDRY.VOL. NUMBER	SURFACE TEMP. (K)	HEAT TRF. RATE (WATT)	HEAT FLUX (WATT/M2)	CRITICAL HEAT FLUX (WATT/M2)	MODE	HEAT TRF. COEF. (WATT/M2-K)	INT. HEAT SOURCE (WATT)	NET HEAT LOSS (WATT)	VOL.AVE. TEMP. (K)
30-001	LEFT	3-010000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-002	LEFT	3-020000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-003	LEFT	3-030000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-004	LEFT	3-040000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-005	LEFT	3-050000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-006	LEFT	3-060000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-007	LEFT	3-070000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-008	LEFT	3-080000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-009	LEFT	3-090000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-010	LEFT	3-100000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-011	LEFT	3-110000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-012	LEFT	3-120000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-013	LEFT	3-130000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-014	LEFT	3-140000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-015	LEFT	3-150000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-016	LEFT	3-160000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-017	LEFT	3-170000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-018	LEFT	3-180000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-019	LEFT	3-190000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
30-020	LEFT	3-200000	502.18	4.10031E-08	8.36334E-07	0.	2	4.6982	0.	4.10031E-08	502.18
	RIGHT	0-000000	502.18	0.	0.	0.	0	0.			
200-001	LEFT	0-000000	10.00	0.	0.	0.	0	0.	0.	14647.	6.35
	RIGHT	0-000000	.00	14647.	1.20060E+05	0.	0	0.			

STR.NO.	MESH POINT TEMPERATURES (K)									
30-001	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18
	502.18									
30-002	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18
	502.18									
30-003	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18
	502.18									
30-004	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18	502.18

Figure 10-5. Example of a heat structure and reflood major edit.

EDIT), and in this case it is 61. If the EDIT column is ever larger than the MAXIMUM column, the code will abort. The next four quantities are discussed in Volume 1, Subsection 3.2.3.6, of this manual, and thus they will only be mentioned here. They are the wall temperature at incipience of boiling (labeled INC. BOIL. TEMP., denoting the variable T_{IB}), the wall temperature at critical heat flux (labeled CRITICAL TEMP., denoting the variable T_{CHF}), the wall rewetting or quench temperature (labeled REWETTING TEMP., denoting 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.

10.3.2.13 Reflood Surface Temperatures. This section of output is optional, and it is skipped when the heat structure temperatures (Subsection 9.3.2.10) 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 10-5. 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 for two axial intervals for each heat structure. 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.

10.3.2.14 Control Variable Information. This section of output is not optional and always appears in a major edit when control systems are present. Figures 10-1 and 10-2 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.

10.3.2.15 Generator Information. This section of output is not optional and always appears when a generator component is present. As discussed in Subsection 4.3.7 of Volume 1 and Subsection 5.2.3.4, 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.

10.3.3 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 10-6 shows one page of minor edits. The selected quantities are held until 50 time values are stored. The minor edit information is then printed, 50 time values on a page, nine of the selected quantities per page, with time printed in the leftmost column on each page. Minor edits can print selected quantities at frequent intervals using much less paper than major edits. Section 4 of the SCDAP/RELAP5 Input Data Requirements (Appendix A) indicates how to request minor edits and what the user-specified quantities represent.

10.3.4 Diagnostic Edit

During a transient (TRANSNT on Card 100) or steady-state (STDY-ST on Card 100) problem, additional tables of variables can be printed out by 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.

TIME (SEC)	P 3010000 (PA)	P 3020000 (PA)	P 3030000 (PA)	P 3040000 (PA)	P 3050000 (PA)	P 3060000 (PA)	P 3070000 (PA)	P 3080000 (PA)	P 3090000 (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
5.000000E-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
.100000	4.00058E+05	4.00052E+05	4.00045E+05	4.00039E+05	4.00033E+05	4.00027E+05	4.00021E+05	4.00015E+05	4.00009E+05
.150000	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
.200000	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
.250000	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
.300000	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
.350000	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
.400000	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
.450000	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
.500000	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
.550000	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
.600000	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
.650000	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
.700000	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
.750000	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
.800000	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
.850000	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
.900000	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
.950000	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
1.00000	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
1.05000	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
1.10000	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
1.15000	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
1.20000	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
1.25000	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
1.30000	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
1.35000	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
1.40000	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
1.45000	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
1.50000	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
1.55000	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
1.60000	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
1.65000	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
1.70000	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
1.75000	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
1.80000	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
1.85000	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
1.90000	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
1.95000	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
2.00000	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
2.05000	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
2.10000	3.99466E+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
2.12500	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
2.15000	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
2.17500	4.00556E+05	4.00472E+05	4.00403E+05	4.00329E+05	4.00258E+05	4.00186E+05	4.00116E+05	4.00045E+05	3.99974E+05
2.20000	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
2.22500	4.00905E+05	4.00747E+05	4.00658E+05	4.00568E+05	4.00477E+05	4.00387E+05	4.00296E+05	4.00206E+05	4.00115E+05
2.25000	4.00389E+05	4.00276E+05	4.00244E+05	4.00212E+05	4.00179E+05	4.00147E+05	4.00114E+05	4.00081E+05	4.00048E+05
2.27500	4.00193E+05	4.00084E+05	4.00078E+05	4.00067E+05	4.00057E+05	4.00046E+05	4.00036E+05	4.00026E+05	4.00015E+05

Figure 10-6. 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 10-7. 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 10-8). 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 10-7 and 10-8 can occur as a result of this. This can occur when the user inputs state properties that are undetected in input processing and thus get into the transient calculation. 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 9.3.2.6). Another example of a user-caused failure is when material property data are out of range. Two more user-caused failures can occur in the case of valves. If both motor valve trips become true at the same time, a failure will result. In addition, if the control system is set up incorrectly and this results in the servo valve stem position not

```
17474 003150000  18.779      36.171      36.303       2.0075      1.8517      4.56037E-03
27567            19.489     0.48697     0.57613     2.64879E-02  2.80622E-02  4.56037E-03
17593 003160000  20.554      36.303      35.720       1.8517      1.6524      4.56037E-03
27667            21.589     0.57613     0.68655     2.80622E-02  3.04243E-02  4.56037E-03
17712 003170000  22.148      35.720      36.135       1.6524      1.5919      4.56037E-03
27767            23.409     0.68655     0.74842     3.04243E-02  3.08759E-02  4.56037E-03
17831 003180000  23.370      36.135      37.375       1.5919      1.5536      4.56037E-03
27867            25.076     0.74842     0.80751     3.08759E-02  3.11720E-02  4.56037E-03
17950 003190000  24.853      37.375      39.064       1.5536      1.5220      4.56037E-03
27967            26.681     0.80751     0.86236     3.11720E-02  3.14163E-02  4.56037E-03
18069 003200000  25.214      39.064      40.642       1.5220      1.4297      4.56037E-03
28067            29.128     0.86236     0.92395     3.14163E-02  2.57865E-02  3.96752E-03
18188 005010000  24.732      40.642     0.00000       1.4297     0.00000      3.96752E-03
28167            31.173     0.92395     0.00000     2.57865E-02  0.00000      0.00000

##################################################################################################################
   volvel Diagnostic printout, timehy =  0.1030000    , dt =  1.0000000E-03, ncount =      123, help = -1, succes =  1, fail = T

Volume inlet and outlet terms
==================================================================================================================
i      volno(i)    l        invcnt(l)
       avol(i)     iiflag   loop jx    junno(jx)  ivf ajun(jx)     voidfj(jx)    rhofj(jx)     velfjo*ivf    arat(jx)     ivr    cvelf(i
                                                      athrot(jx)   voidgj(jx)    rhogj(jx)     velgjo*ivf    arat(jx+1)          cvelg(i
==================================================================================================================
 15808 003010000    21931   1
       4.56037E-03 outlet   1     18308 003010000  1  4.56037E-03  0.92584       830.23        0.20472       1.0000     25786    1.0000
                                                        1.0000     7.41587E-02   12.725        0.17269       1.0000             0.00000
 15927 003020000    21935   2
       4.56037E-03 inlet    1     18308 003010000  1  4.56037E-03  0.92584       830.23        0.20472       1.0000     25788    1.3980
                                                        1.0000     7.41587E-02   12.725        0.17269       1.0000            -0.23250
                   outlet   2     18374 003020000  1  4.56037E-03  0.80996       831.38        0.53975       1.0000     25790    2.1752
                                                        1.0000     0.19003       12.727        0.37274       1.0000            -0.54028
 16046 003030000    21942   2
       4.56037E-03 inlet    1     18374 003020000  1  4.56037E-03  0.80996       831.38        0.53975       1.0000     25792 -0.31329
                                                        1.0000     0.19003       12.727        0.37274       1.0000              1.5658
                   outlet   2     18440 003030000  1  4.56037E-03  0.76723       831.94        0.87666       1.0000     25794 -0.20776
                                                        1.0000     0.23276       12.728        0.71177       1.0000            -0.48985
 16165 003040000    21949   2
       4.56037E-03 inlet    1     18440 003030000  1  4.56037E-03  0.76723       831.94        0.87666       1.0000     25796    1.8312
                                                        1.0000     0.23276       12.728        0.71177       1.0000            -0.33093
                   outlet   2     18506 003040000  1  4.56037E-03  0.78994       831.77         1.1429       1.0000     25798 -0.30769
                                                        1.0000     0.21005       12.729        0.96004       1.0000              1.5335
 16284 003050000    21956   2
       4.56037E-03 inlet    1     18506 003040000  1  4.56037E-03  0.78994       831.77         1.1429       1.0000     25800 -0.18894
                                                        1.0000     0.21005       12.729        0.96004       1.0000            -0.48340
                   outlet   2     18572 003050000  1  4.56037E-03  0.81880       831.44         1.4271       1.0000     25802    1.8324
                                                        1.0000     0.18119       12.735         1.2107       1.0000            -0.27777
 16403 003060000    21963   2
       4.56037E-03 inlet    1     18572 003050000  1  4.56037E-03  0.81880       831.44         1.4271       1.0000     25804 -0.28659
                                                        1.0000     0.18119       12.735         1.2107       1.0000              1.4785
                   outlet   2     18638 003060000  1  4.56037E-03  0.84695       831.12         1.7160       1.0000     25806 -0.16641
                                                        1.0000     0.15305       12.742         1.4723       1.0000            -0.57501
 16522 003070000    21970   2
       4.56037E-03 inlet    1     18638 003060000  1  4.56037E-03  0.84695       831.12         1.7160       1.0000     25808    1.9630
                                                        1.0000     0.15305       12.742         1.4723       1.0000            -0.27901
                   outlet   2     18704 003070000  1  4.56037E-03  0.84694       831.10         2.0303       1.0000     25810 -0.16021
                                                        1.0000     0.15305       12.750         1.7604       1.0000              1.2735
 16641 003080000    21977   2
       4.56037E-03 inlet    1     18704 003070000  1  4.56037E-03  0.84694       831.10         2.0303       1.0000     25812 -0.10987
                                                        1.0000     0.15305       12.750         1.7604       1.0000            -0.62371
                   outlet   2     18770 003080000  1  4.56037E-03  0.87647       830.82         2.3165       1.0000     25814    2.0392
                                                        1.0000     0.12352       12.758         2.0501       1.0000            -0.28909
 16760 003090000    21984   2
       4.56037E-03 inlet    1     18770 003080000  1  4.56037E-03  0.87647       830.82         2.3165       1.0000     25816 -0.20429
                                                        1.0000     0.12352       12.758         2.0501       1.0000              1.3432
                   outlet   2     18836 003090000  1  4.56037E-03  0.89091       830.66         2.5964       1.0000     25818 -0.12012
```

Figure 10-7. Example of printout before the diagnostic edit when a failure occurs.

```
               502.18
   30-007      501.08      501.54      501.82      501.99      502.09      502.14      502.17      502.18      502.18      502.18
               502.18
   30-008      501.13      501.59      501.85      502.01      502.10      502.15      502.17      502.18      502.18      502.18
               502.18
   30-009      501.16      501.62      501.89      502.03      502.11      502.15      502.17      502.18      502.18      502.18
               502.18
   30-010      501.18      501.64      501.91      502.05      502.12      502.16      502.17      502.18      502.18      502.18
               502.18
   30-011      501.17      501.64      501.91      502.06      502.13      502.16      502.17      502.18      502.18      502.18
               502.18
   30-012      501.12      501.64      501.92      502.06      502.13      502.16      502.18      502.18      502.18      502.18
               502.18
   30-013      500.91      501.61      501.92      502.06      502.13      502.16      502.18      502.18      502.18      502.18
               502.18
   30-014      499.85      501.31      501.85      502.05      502.13      502.16      502.18      502.18      502.18      502.18
               502.18
   30-015      499.12      501.02      501.75      502.02      502.12      502.16      502.18      502.18      502.18      502.18
               502.18
   30-016      498.22      500.48      501.52      501.94      502.10      502.16      502.17      502.18      502.18      502.18
               502.18
   30-017      497.64      500.04      501.28      501.84      502.06      502.14      502.17      502.18      502.18      502.18
               502.18
   30-018      497.13      499.56      500.97      501.68      502.00      502.12      502.16      502.18      502.18      502.18
               502.18
   30-019      496.72      499.16      500.69      501.52      501.92      502.09      502.15      502.17      502.18      502.18
               502.18
   30-020      496.29      498.72      500.35      501.31      501.80      502.03      502.13      502.17      502.18      502.18
               502.18
  200-001      109.17      109.01      108.48      107.38      105.21      101.01      93.220      79.887      59.449      31.971
              0.00000

                    control variable edit; at time=    0.100000      sec
   1     ctl1        sum          0.254366E+07            4      ctl4         mult          0.113657E+07
   5     ctl5        mult          231.568               10      ctl10        div           4.399219E-07
  11     ctl10       div           1.00423               12      ctl12        diffreni       1.00000
  13     ctl13       integral     5.000000E-03           14      ctl14        integral      0.100000
  15     ctl15       diffreni     0.100000               99      ctl99        diffrend       12.5393
 201     ctl201      function      3.00000              202      ctl202       stdfnctn      0.199666
 203     ctl203      tripunit     0.000000              204      ctl204       tripdlay      -2.00000
 205     ctl205      poweri       0.200000              206      ctl206       powerr        5.000000E-03
 207     ctl207      powerx       0.300000              300      ctl300       delay         0.000000
 301     ctl301      prop-int      2.15000              302      ctl302       lag           0.367876
 303     ctl303      lead-lag     0.683938              304      ctl304       constant      0.387000
 401     con1        constant     0.000000              402      con2         constant      0.100000
 403     pumpctl     pumpctl     -1.000000E-03          404      steamctl     steamctl       2.00167
 405     feedctl     feedctl     -2.500000E-04

---restart no.    119 written, block no.    2---

number of elements in sparse matrix 1: original =   61, factored =   61     roundoff error =    2.000000E-12     ncount =    120

******** temperature  1.029236E+02 for material   4 in heat structure  200001 is out of range for thermal conductivity table.

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

###########################################################################################################################
     state Diagnostic printout, timehy =  0.102000     , dt =  1.0000000E-03, ncount =      122, help = -1, succes =  1, fail = T

Volume mixture properties
===========================================================================================================================
i     volno       v             p            voidg        quals        dotm         quala        boron        sounde       rho
                                pps          voidf        quale        dotmo        sigma        borono       dsnddp       satt
===========================================================================================================================
15808 003010000  9.33968E-04  2.54222E+06  7.41587E-02  1.22619E-03   12.636       0.00000      0.00000       29.587       769.61
                              2.54222E+06  0.92584      9.45616E-03   12.636       3.21089E-02  0.00000      2.80105E+06   497.98
```

Figure 10-8. Example of printout buried in the diagnostic edit when a failure occurs.

being between 0 and 1, a failure will result. Another example is when a divide by 0 occurs in a control variable. The second case occurs as the result of a coding failure, which can be caused by a programming error or a model deficiency. Such a failure should be reported to the development staff through the SCDAP/RELAP5 User Services. Such errors often result in negative densities, bad viscosities, bad thermal conductivities, or water property errors.

10.3.5 Edits of SCDAP Heat Structures

The values of variables that describe the state of SCDAP heat structures are printed at the same times that major edits are performed for the RELAP5 calculations. The printout describes the temperature, deformation, and oxidation of fuel rods and control rods and the fission product release from fuel rods. The state of each SCDAP heat structure is printed in the order of its number identifier. In other words, component 1 is printed first, then component 2, and so forth. An example of the printout for a SCDAP heat structure is shown in Figure 10-9.

10.3.5.1 Temperature Distribution. As shown in Figure 10-9, the first section of printout shows the temperature distribution of the SCDAP heat structure with a component identification number of 1. The fuel centerline and cladding surface temperatures are printed for each axial node. The temperatures have the units of degrees Kelvin. The elevation of each axial node in units of meters is also printed. The radial temperature distribution is shown at the elevation of the midplane of the SCDAP heat structure, and the temperature at each radial node is printed for the midplane elevation.

10.3.5.2 Cladding Radius. The next section of printout shows the inner and outer radii of the fuel rod cladding. This printout indicates the extent of cladding ballooning. The inner and outer radii are printed for each axial node. The leftmost radius that is printed applies to the lowest axial node and the rightmost radius applies to the highest axial node.

```
fuel rod analysis for component  1 at time   500.1     sec

  heat conduction solution
axial node  1 elevation 0.3048      (m)      fuel centerline temperature  2958.    cladding surface temperature  2958.
axial node  2 elevation 0.9144      (m)      fuel centerline temperature  2958.    cladding surface temperature  2958.
axial node  3 elevation  1.524      (m)      fuel centerline temperature  2958.    cladding surface temperature  2958.
axial node  4 elevation  2.134      (m)      fuel centerline temperature  2958.    cladding surface temperature  2958.
axial node  5 elevation  2.743      (m)      fuel centerline temperature  2723.    cladding surface temperature  2721.
axial node  6 elevation  3.353      (m)      fuel centerline temperature  2212.    cladding surface temperature  2212.

temperature at each radial node at axial node     3
 0.2958E+04  0.2958E+04  0.2958E+04  0.2958E+04  0.2958E+04  0.2958E+04

 radius to outside cladding surface  (m)
 0.5542E-02  0.6448E-02  0.6435E-02  0.6419E-02  0.5766E-02  0.5532E-02

 radius to inside cladding surface  (m)
 0.4880E-02  0.6276E-02  0.6301E-02  0.6332E-02  0.5700E-02  0.5498E-02


 output from cladding oxidation model

 oxide weight gain in frozen film (kg)
 0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

 oxide weight gain in zro2  (kg/m2)
 0.1234E-01  0.1797      0.1413      0.9920E-01  0.8872E-01  0.6325E-01

fraction of cladding oxidized at each axial node
 0.8652E-02  0.3008E+00  0.2366E+00  0.1661E+00  0.1303E+00  0.4414E-01
indicator of double-sided oxidation: 0=no; 1=yes
          0          1          1          1          1          0

 hydrogen generation rate (kg/s)
 0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

  cladding oxidation heat generation (w/m)
 0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

  solidified mixture oxidation heat generation (w/m)
 0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

 inner radius or leftmost coordinate of outer alpha layer (m)
 0.5534E-02  0.6114E-02  0.6173E-02  0.6247E-02  0.5632E-02  0.5449E-02

 inner radius or leftmost coordinate of outer oxide layer (m)
 0.5542E-02  0.6276E-02  0.6301E-02  0.6332E-02  0.5700E-02  0.5498E-02

 steam removal rate (kg/s)
 0.0000      0.0000      0.0000      0.0000      0.0000      0.0000


 output from liquefaction and solidification model

 average outer radius of frozen zry-uo2 on outside of cladding in axial zone (m)
 0.6320E-02  0.6448E-02  0.6435E-02  0.6419E-02  0.5766E-02  0.5532E-02

 inner radius of annulus of dissolved uo2   (m)
 0.4699E-02  0.2970E-02  0.2591E-02  0.4546E-02  0.4699E-02  0.4699E-02

indicator of cohesive debris at each axial node, 0=no, 1=yes
             1          1          1          1          0          0

fractional height of cohesive debris at each axial node
```

Figure 10-9. Example of printout of SCDAP components.

```
 0.2534E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
mass of uo2 solidified in each axial zone (kg)
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
mass of zr solidified in each axial zone (kg)
 0.1117E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
mass of oxygen from liquefied and relocated zro2 (kg)
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
mass of uo2 liquefied by melting and removed from axial node (kg)
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
mass of uo2 liquefied by dissolution and removed from axial node (kg)
 0.0000E+00  0.2593E+00  0.3005E+00  0.2759E-01  0.0000E+00  0.0000E+00
mass of zr removed from each axial zone (kg)
 0.0000E+00  0.2272E-01  0.2635E-01  0.3072E-01  0.3295E-01  0.7875E-01
mass of zro2 liquefied at each axial zone (kg)
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

mass of tin at each axial node (kg)   (mass per rod)
0.12998E-02 0.12998E-02 0.12998E-02 0.12998E-02 0.12998E-02 0.12998E-02

mass of tellurium at each axial node (kg) (total for all rods)
0.89248E-01 0.33926-367 0.63591-262 0.19665-149 0.10479E-92 0.47847E-04

 output from fission gas release from fuel model

 volatile fission product inventory within fuel matrix at axial node i, 1-xe, 2-kr, 3-cs, 4-i   (kg)
 0.1890E-04   0.8879E-05   0.5784E-05   0.2875E-04   0.1496E-04   0.1469E-04
 0.2129E-05   0.1000E-05   0.6515E-06   0.3239E-05   0.1685E-05   0.1654E-05
 0.1094E-04   0.5140E-05   0.3349E-05   0.1665E-04   0.8661E-05   0.8502E-05
 0.7626E-06   0.3583E-06   0.2334E-06   0.1160E-05   0.6036E-06   0.5926E-06
 0.1756E-05   0.8249E-06   0.5374E-06   0.2671E-05   0.1390E-05   0.1364E-05
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.8925E-01   0.3393-367   0.6359-262   0.1967-149   0.1048E-92   0.4785E-04
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000


 output from fission gas release from gap model

 gap gas inventory  1-xe, 2-kr, 3-cs, 4-i, 5-he   (kg)
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 cumulative gap gas released to coolant  1-xe, 2-kr, 3-cs, 4-i, 5-he, 6-h2  (kg)
 0.3911E-08   0.4562E-09   0.2571E-08   0.1792E-09   0.4218E-05   0.0000       0.0000       0.0000       0.0000       0.0000
 0.0000       0.0000       0.4463       0.0000       0.0000       0.0000       0.1265E-03   0.1758E-10
```

Figure 10-9 (continued).

```
gas inventory = fill gas +released fission gases ( gm mole)
0.0000

total release rate of all noncondensible gases into t he coolant from the gap  xe+kr+he+h2   (kg/sibl)
0.2093E-11

total release rate of all soluble gases into the coolant from the gap   csi+csoh   (kg/s)
0.1528E-11


. output from cladding deformation model
component node at which local deformation takes place. if cladding burst, this is a failure node.
    4

hoop strain of inside surface of cladding at midplane of axial zone
0.1925E-01  0.2165      0.2165      0.2165      0.6680E-01  0.1419E-01


output from gas pressure model
    pressure of gas inside fuel rod  (n/m2)  =  0.44390E+07

nuclear heat generation at each axial node (w/m)
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.4162E+03  0.4086E+03

decay heat generation at each axial node (w/m)
0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.4162E+03  0.4086E+03

                nuclear heat generation at  0.50020E+03 seconds
avg. total nuclear heat generation:  0.50279E+03 (w)  avg. total nuclear heat generation for melted/disrupted fuel 0.50279E+03 (w)


output from fuel rod damage state model

total uo2 mass at axial zone  (kg)
0.4318      0.1725      0.1313      0.4042      0.4318      0.4318

mass of uo2 which has not yet melted in axial zone   (kg)
0.4318      0.1725      0.1313      0.4042      0.4318      0.4318

total zr mass at axial zone  (kg)
0.1975      0.4579E-01  0.4619E-01  0.4667E-01  0.4739E-01  0.3962E-02

total zro2 mass at axial zone  (kg)
0.1008E-02  0.2432E-01  0.1889E-01  0.1234E-01  0.8342E-02  0.5145E-02

indicator of uo2 mass balance calculation, 0=mass balanced, 1=mass not balanced
    1

indicator of zr mass balance calculation, 0=mass bala nced, 1=mass not balanced
    1


output from fragmentation model
indicator of fragmentation at axial nodes
    0           0           0           0           0           0

indicator of a severe disruption such that all gap gases are released instantly  0=no, 1=yes
    0
```

Figure 10-9 (continued).

10.3.5.3 <u>Cladding Oxidation</u>. The next ten lines of numbers that are printed show the results of calculations of cladding oxidation. The oxidation variables are printed for each axial node, with the lowest axial node printed leftmost and the top axial node printed rightmost. The extent of the cladding oxidation is displayed by the line printing the fraction of cladding oxidation at each node. If the value of the fraction of cladding oxidation is equal to one, then the cladding is entirely a shell of ZrO_2.

10.3.5.4 <u>Meltdown</u>. The next eleven lines of numbers show the extent of fuel rod liquefaction and meltdown. The extent to which liquefied cladding has dissolved the outer part of fuel pellets is shown by the line printing the inner radius of annulus of dissolved UO_2. If no fuel dissolution has occurred, then the printed value of the inner radius is equal to the outer radius of the fuel pellets. The next line of numbers indicates whether a cohesive debris is located at each axial node. If the value of the indicator is 1 at an axial node, then liquefied material from a higher axial node has slumped down and solidified at that axial node. The solidified material has completely filled in the space between fuel rods and has the configuration of a hardpan. The thickness of the hardpan is shown in the next line of numbers. If the fractional height of cohesive debris is 1.0, then the hardpan thickness is equal to the height of the axial node. The next several lines of printout show the relocation of fuel and cladding. Unless fuel has slumped below the fuel rod, the sum of the mass of UO_2 solidified at each axial node per rod equals the sum of the mass of UO_2 removed from each axial node per rod. The same rule holds for cladding. If the mass of zirconium removed from an axial node is greater than zero, then all the metallic zirconium has slumped from that node and oxidation no longer occurs at that node.

10.3.5.5 <u>Fission Product and Aerosol Release</u>. The next several lines of printout show the results of calculations of fission product and aerosol releases. The fission product inventory within the fuel is shown by the printout of a matrix of numbers. The leftmost column of numbers applies to the lowest axial node (axial node 1), and the rightmost applies to the highest axial node. Each row of the matrix shows the mass in units of kilograms per axial node per fuel rod of a certain species of fission product. The first row shows the inventory of xenon, the second row krypton, the third row cesium, the fourth row iodine, and the fifth row is the inventory of tellurium as calculated by the PARAGRASS[10-1] fission gas release model.

The balance of the rows show the inventory of aerosols for which the initial masses are input by the code user and for which the release is calculated by the CORSOR model.[10-2] The sixth row shows the retained mass of zirconium. If no aerosol release of zirconium has been calculated by the CORSOR model, then the mass of zirconium will equal the user input mass of zirconium per axial node. Similarly, the seventh row shows the inventory per axial node per rod for iron, the ninth row ruthenium, the tenth row a special isotope of zirconium, the eleventh row barium, the twelfth row strontium, the thirteenth row tellurium, the fourteenth row silver, the fifteenth row a special isotope of cesium, and the sixteenth row a special isotope of iodine.

The next line of numbers shows the inventory of fission products in the fuel cladding gap. The species are printed in the same order as for the printout of the fuel inventory. The leftmost species is xenon, the second leftmost species is krypton, and so forth. In addition, the mass of helium in the gap is printed as the seventeenth number.

The next line of numbers shows the cumulative release of fission products to the coolant. The mass in units of kilograms per rod is shown for each species. The species are printed in the same order as for the printout of the fuel inventory. In addition, the cumulative release of helium and hydrogen are shown as the seventeenth and eighteenth numbers, respectively.

The code user can also obtain cumulative release of fission products to the coolant by subtracting the current inventory from the initial inventory. The difference in initial and current inventories is the amount released to the coolant in the case that the cladding has failed. If the cladding has not failed, then the difference is the amount released to the fuel cladding gap.

10.3.5.6 Cladding Ballooning and Rupture. The next three lines of numbers show the results of the cladding ballooning model. The first line shows the axial node at which the maximum amount of cladding ballooning is occurring. If the cladding has ruptured, it shows the axial node at which rupture occurred. The next line shows the cladding hoop strain at each axial node. The next line shows the pressure of gases in the fuel cladding gap. If the cladding has ruptured, the gas pressure is equal to the coolant pressure at that location.

10.3.5.7 Fuel Rod Power. The next three lines of numbers show the fuel rod heat generation rate. The first line shows the total heat generation rate (sum of prompt fission power, fission product decay heat, and actinide product decay heat) in units of W/m at each axial node. The next line of numbers is redundant data that are to be ignored by the code user. The third line shows the axially averaged linear heat generation rate.

The remaining lines of printout for the component are redundant and should be ignored by the code user.

10.3.6 Edits of Fission Product Transport Results

An edit of fission product transport results is included with major edits (see Figure 10-10). This edit is not produced until fission products are released from SCDAP components unless the user initializes the fission product transport model with nonzero masses. The edit is ordered in numerically increasing order by the hydrodynamic system, then by the volumes within the system. Only hydrodynamic systems having fission product transport are listed.

For each volume, the following information is presented for each quantity being tracked. The labels in the left column are the identifiers for the quantities:

fission product transport

hydrodynamic system 1

1-010000	csi	src	0.0000	liq	0.0000	vap	0.0000	tot	0.0000	1	0.0000	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	0.0000	liq	0.0000	vap	0.0000	tot	0.0000	1	0.0000	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
2-010000	csi	src	0.0000	liq	0.0000	vap	0.0000	tot	0.0000	1	0.0000	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	0.0000	liq	0.0000	vap	0.0000	tot	0.0000	1	0.0000	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
3-010000	csi	src	0.0000	liq	0.0000	vap	3.7270E-12	tot	3.6480E-05	1	6.4029E-07	2	3.5812E-05
		3	2.7970E-08	4	1.3913E-16	5	0.0000	6	0.0000				
	csoh	src	0.0000	liq	0.0000	vap	3.0068E-09	tot	2.9803E-04	1	3.9071E-06	2	2.9327E-04
		3	8.5339E-07	4	2.9944E-14	5	0.0000	6	0.0000				
30-010000	csi	src	1.0529E-09	liq	2.2189E-12	vap	1.1338E-14	tot	8.0184E-09	1	4.8922E-09	2	3.1250E-09
		3	1.2634E-12	4	2.4176E-20	5	9.3642E-38	6	0.0000				
	csoh	src	3.0657E-07	liq	1.8714E-09	vap	1.4520E-11	tot	2.4609E-06	1	1.4445E-06	2	1.0159E-06
		3	4.5151E-10	4	8.7622E-18	5	3.3943E-35	6	0.0000				
30-020000	csi	src	1.0529E-09	liq	0.0000	vap	7.1179E-09	tot	6.6009E-11	1	5.3872E-11	2	1.2133E-11
		3	4.9089E-15	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	1.7160E-06	tot	4.7744E-07	1	3.6702E-07	2	1.1022E-07
		3	1.9686E-10	4	2.9815E-17	5	2.4810E-34	6	0.0000				
30-030000	csi	src	1.0529E-09	liq	0.0000	vap	7.8454E-09	tot	3.5361E-11	1	3.5251E-11	2	1.1063E-13
		3	4.4797E-17	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	2.3943E-06	tot	1.4431E-08	1	1.3456E-08	2	9.7317E-10
		3	1.7247E-12	4	2.6900E-19	5	0.0000	6	0.0000				
30-040000	csi	src	1.0529E-09	liq	0.0000	vap	4.9727E-09	tot	3.4729E-11	1	3.4728E-11	2	1.3918E-15
		3	5.6394E-19	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	1.5087E-06	tot	1.0293E-08	1	1.0281E-08	2	1.1446E-11
		3	2.1030E-14	4	3.3854E-21	5	0.0000	6	0.0000				
30-050000	csi	src	1.0529E-09	liq	0.0000	vap	5.7983E-09	tot	3.5121E-11	1	3.5121E-11	2	3.5964E-17
		3	1.4581E-20	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	1.7535E-06	tot	1.0366E-08	1	1.0366E-08	2	2.7501E-13
		3	5.4388E-16	4	0.0000	5	0.0000	6	0.0000				
30-060000	csi	src	1.0529E-09	liq	0.0000	vap	7.4519E-09	tot	3.5262E-11	1	3.5262E-11	2	9.3979E-19
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	2.2557E-06	tot	1.0408E-08	1	1.0408E-08	2	7.0436E-15
		3	1.4924E-17	4	0.0000	5	0.0000	6	0.0000				
30-070000	csi	src	1.0529E-09	liq	0.0000	vap	9.3845E-09	tot	3.5270E-11	1	3.5270E-11	2	2.1759E-20
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	2.8522E-06	tot	1.0410E-08	1	1.0410E-08	2	1.7485E-16
		3	3.7106E-19	4	0.0000	5	0.0000	6	0.0000				
30-080000	csi	src	1.0529E-09	liq	0.0000	vap	1.1875E-08	tot	3.5286E-11	1	3.5286E-11	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	3.6345E-06	tot	1.0415E-08	1	1.0415E-08	2	4.2637E-18
		3	8.3471E-21	4	0.0000	5	0.0000	6	0.0000				
30-090000	csi	src	1.0529E-09	liq	0.0000	vap	1.5321E-08	tot	3.5304E-11	1	3.5304E-11	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	4.7384E-06	tot	1.0420E-08	1	1.0420E-08	2	9.7193E-20
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
30-100000	csi	src	1.0529E-09	liq	0.0000	vap	2.8942E-08	tot	3.5477E-11	1	3.5477E-11	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	3.0657E-07	liq	0.0000	vap	9.1884E-06	tot	1.0473E-08	1	1.0473E-08	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
40-010000	csi	src	0.0000	liq	0.0000	vap	7.6749E-08	tot	3.8230E-13	1	3.8230E-13	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				
	csoh	src	0.0000	liq	0.0000	vap	2.6888E-09	tot	1.1561E-10	1	1.1561E-10	2	0.0000
		3	0.0000	4	0.0000	5	0.0000	6	0.0000				

Figure 10-10. Example of printout of fission product major edit.

```
50-010000    csi    src  0.0000       liq  0.0000       vap  3.0912E-08   tot  1.4533E-15    1  1.4533E-15    2  0.0000
                      3  0.0000         4  0.0000         5  0.0000         6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  1.7330E-06   tot  2.1341E-05    1  4.1874E-06    2  1.7016E-05
                      3  1.3738E-07     4  1.3493E-11     5  1.6044E-17     6  0.0000
       502-001  rightcsi          mc   0.0000       ma   0.0000       mp   7.5668E-07
                    csoh          mc   2.8230E-06   ma   0.0000       mp   4.7779E-05
       512-001  left csi          mc   1.8173E-06   ma   0.0000       mp   3.0244E-06
                    csoh          mc   2.4710E-05   ma   0.0000       mp   1.8867E-04
50-020000    csi    src  0.0000       liq  0.0000       vap  2.0288E-09   tot  3.9027E-08    1  8.2042E-09    2  3.0764E-08
                      3  5.8912E-11     4  5.9856E-18     5  5.0540E-27     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  7.5894E-08   tot  2.7146E-05    1  2.8510E-06    2  2.4208E-05
                      3  8.6964E-08     4  8.5782E-13     5  3.7149E-19     6  0.0000
       502-002  rightcsi          mc   2.8578E-09   ma   0.0000       mp   8.9263E-07
                    csoh          mc   7.8539E-08   ma   0.0000       mp   2.8582E-05
       512-002  left csi          mc   2.6838E-08   ma   0.0000       mp   3.5502E-06
                    csoh          mc   8.4923E-07   ma   0.0000       mp   1.1317E-04
50-030000    csi    src  0.0000       liq  0.0000       vap  3.7028E-10   tot  7.6020E-08    1  5.9030E-09    2  6.9978E-08
                      3  1.3842E-10     4  1.2156E-18     5  1.2721E-29     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  2.1912E-08   tot  2.8400E-05    1  1.7957E-06    2  2.6542E-05
                      3  6.2112E-08     4  4.4519E-15     5  3.0215E-24     6  0.0000
       502-003  rightcsi          mc   6.3264E-11   ma   0.0000       mp   9.4173E-07
                    csoh          mc   3.8512E-10   ma   0.0000       mp   1.9396E-05

       522-001  left csi          mc   1.0146E-09   ma   0.0000       mp   4.0475E-06
                    csoh          mc   2.0162E-08   ma   0.0000       mp   8.3354E-05
50-040000    csi    src  0.0000       liq  0.0000       vap  5.0319E-11   tot  1.9825E-07    1  5.0652E-09    2  1.9279E-07
                      3  3.8970E-10     4  2.9741E-18     5  6.2665E-30     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  5.4829E-09   tot  2.9704E-05    1  1.2773E-06    2  2.8367E-05
                      3  5.9193E-08     4  8.3462E-16     5  6.0540E-26     6  0.0000
       502-004  rightcsi          mc   6.3567E-12   ma   0.0000       mp   1.0001E-06
                    csoh          mc   1.6770E-10   ma   0.0000       mp   1.7231E-05
       522-002  left csi          mc   9.1820E-11   ma   0.0000       mp   4.2981E-06
                    csoh          mc   4.3061E-09   ma   0.0000       mp   7.4065E-05
50-050000    csi    src  0.0000       liq  0.0000       vap  9.9060E-12   tot  3.5673E-07    1  4.3701E-09    2  3.5145E-07
                      3  9.0633E-10     4  1.1273E-17     5  2.0729E-30     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  1.6981E-09   tot  2.5753E-05    1  8.4106E-07    2  2.4849E-05
                      3  6.2473E-08     4  8.5690E-16     5  9.6027E-27     6  0.0000
       522-003  left csi          mc   7.0134E-12   ma   0.0000       mp   3.6254E-06
                    csoh          mc   7.7573E-10   ma   0.0000       mp   6.0019E-05
60-010000    csi    src  0.0000       liq  0.0000       vap  3.0510E-12   tot  5.6541E-07    1  4.4820E-09    2  5.5944E-07
                      3  1.4838E-09     4  1.9932E-17     5  4.7798E-31     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  7.2750E-10   tot  2.3033E-05    1  6.1298E-07    2  2.2361E-05
                      3  5.8616E-08     4  8.0280E-16     5  1.8825E-27     6  0.0000
       522-004  left csi          mc   1.5199E-12   ma   0.0000       mp   3.2728E-06
                    csoh          mc   3.9085E-10   ma   0.0000       mp   5.3064E-05
70-010000    csi    src  0.0000       liq  0.0000       vap  1.2321E-12   tot  8.8848E-07    1  3.0994E-09    2  8.8214E-07
                      3  3.2439E-09     4  6.8955E-17     5  3.5895E-31     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  4.5754E-10   tot  2.1982E-05    1  3.3248E-07    2  2.1576E-05
                      3  7.8693E-08     4  1.5673E-15     5  1.0428E-27     6  0.0000
       702-001  left csi          mc   1.7691E-12   ma   0.0000       mp   2.3304E-05
                    csoh          mc   4.3287E-10   ma   0.0000       mp   8.4413E-04
70-020000    csi    src  0.0000       liq  0.0000       vap  3.2628E-13   tot  7.7751E-07    1  1.3029E-09    2  7.7357E-07
                      3  2.6404E-09     4  3.3536E-17     5  3.3819E-32     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  1.3039E-10   tot  1.2316E-05    1  1.0665E-07    2  1.2169E-05
                      3  4.0404E-08     4  5.4398E-16     5  2.5993E-27     6  0.0000
       702-002  left csi          mc   5.9007E-13   ma   0.0000       mp   1.6549E-05
                    csoh          mc   4.6197E-10   ma   0.0000       mp   3.6310E-04
70-030000    csi    src  0.0000       liq  0.0000       vap  1.3198E-13   tot  6.9856E-07    1  6.1945E-10    2  6.9662E-07
                      3  1.3219E-09     4  6.6333E-18     5  5.7602E-35     6  0.0000
             csoh   src  0.0000       liq  0.0000       vap  9.9458E-11   tot  7.1981E-06    1  3.6023E-08    2  7.1471E-06
                      3  1.4963E-08     4  7.9154E-17     5  6.9695E-34     6  0.0000
       702-003  left csi          mc   7.8747E-13   ma   0.0000       mp   1.1350E-05
                    csoh          mc   4.7578E-10   ma   0.0000       mp   1.6812E-04
```

Figure 10-10 (continued).

Src Fission product source to volume (kg/s).

liq Fission product mass in volume carried by the liquid phase (kg).

vap Fission product mass in the volume in vapor form (kg).

tot Total fission product mass in both vapor and aerosol form in the volume (kg).

nn Fission product mass in aerosol bin number nn (kg).

For volumes connected to heat structures, the bordering surface is identified and the following quantities are edited for each quantity being tracked.

mc Vapor phase fission product mass condensed on heat transfer surface (kg).

ma Vapor phase fission product mass absorbed in heat transfer surface (kg).

mp Aerosol fission product mass deposited on heat transfer surface (kg).

10.4 Plotted Output

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

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 cards. The plots are constructed upon completion of the third phase of input data processing so that all information processed by the code will be included. Once the option is activated, it will remain in effect for all subsequent restarts and plot only jobs, including restarts with renodalization, until cancelled by the user with appropriate input.

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

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

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

Some user inconvenience is apparent for input of plot comparison data tables because this input must 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 SCDAP/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 SCDAP/RELAP5 STRIP option may be used to retrieve results and build plot comparison data tables. If the data are contained on user tapes or disk files, the user can provide programs to build plot comparison data tables in the format required by SCDAP/RELAP5.

10.5 SCDAP/RELAP5 Control Card Requirements

Very general procedures using the control language statements have been developed to simplify SCDAP/RELAP5 execution. Control card sequences used to execute SCDAP/RELAP5 on a CRAY using the UNICOS operating system are documented in the last section of the Input Data Requirements, Appendix A.

10.6 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.

10.7 Problem Changes at Restart

The most common use of the restart option is simply to continue a problem after a normal termination. If the problem terminated 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 SCDAP/RELAP5 are summarized below. In all instances, the problem definition is that obtained from the restart tape unless input data are entered for deletions, modifications, or additions. The problem defined after input changes must meet the same requirements as a new problem.

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

Minor edit 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. If a component is changed, all of the cards for the component must be entered.

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

Heat structures, general tables, and material properties can also be deleted, changed, or added. If these are changed, all of the cards for heat structures, general tables, and material properties must be entered. 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 SCDAP core structures, fission product and aerosol models (with renodalization), and heat structures with reflood, all modeling features in SCDAP/RELAP5 can be added, deleted or changed at restart.

10.8 References

10-1. W. T. Shack et al., Materials Science and Technology Division Light Water Reactor Safety Research Program Quarterly Report, January through March 1983, Volume I, NUREG/CR-3689, ANL-83-85 Volume I, June 1983.

10-2. M. R. Kuhlman et al., CORSOR User's Manual, NUREG/CR-4173, BMI-2122, March 1985.

APPENDIX A

SCDAP/RELAP5 INPUT DATA REQUIREMENTS

CONTENTS

APPENDIX A

SCDAP/RELAP5 INPUT DATA REQUIREMENTS

A.1. INTRODUCTION

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

A.1.1 Control Format

SCDAP/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 prepared with interactive editors or utility programs such as UPDATE. SCDAP/RELAP5 reads a 96-character record. If the actual input record is smaller, blank characters are added to the end of the input record to extend it to 96 characters. Each 96-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 SCDAP/RELAP5 input; the additional 16 columns are for use 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). Some editors provide for the optional storing of editor line numbers following the data portion of the record. If the data field is 72 columns, the line numbers might be stored in columns 73 to 80. These line numbers will be processed by SCDAP/RELAP5 as input, since SCDAP/RELAP5 uses the first 80 characters. To avoid this, either 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.

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

A.1.2 Data Deck Organization

A SCDAP/RELAP5 problem input deck consists of two parts: input for the models derived from RELAP5 thermal-hydraulics, aerosol behavior models, and input for the SCDAP core behavior models. Both parts are self-formatting input, but slightly different rules apply to each part. The first part of the input consists of at least one title card, optional comment cards, data cards, and a terminator card. A listing of these input cards is printed at the beginning of each SCDAP/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 SCDAP/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.

The second part of the input consists of a title card (up to 100 characters), optional comment cards, and data cards. No terminator card is used. Again, a listing of these input cards is printed. The order of the cards is important in this part of the input. Comments can either be added to each card after all input for that card has been entered or can be placed on comment cards, which start with the word "COMMENT."

A.1.3 Title Card

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

A.1.4 Comment Cards

An asterisk (*) or a dollar sign ($) appearing as the first nonblank character identifies the card as a comment card for the thermal-hydraulics and aerosol behavior input. 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.

A.1.5 Data Cards

For the thermal-hydraulics and aerosol behavior input, data cards may contain varying numbers of fields that may be integer, real (floating point), or alphanumeric. Blanks preceding and following fields are ignored.

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

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

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

```
12.45,+12.45  0.1245+2  1.245+1,1.245E 1  1.245E+1
```

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

It should be noted that the CDC-7600-6600 class of computers stores ten characters per word, while most other computers (e.g., Cray, Cyber 205, and IBM) hold only eight characters per word. All alphanumeric words required by SCDAP/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.

A.1.6 Continuation Cards

For the thermal-hydraulics and aerosol behavior input, 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.

A.1.7 Terminator Cards

The input data for the thermal-hydraulics and aerosol behavior input of each problem are terminated by a slash or a period card. The slash and period cards have a slash (/) and a period (.) respectively as the first nonblank character. Comments may follow the slash and period on these cards.

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

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

A.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.

A.1.9 Upper/Lower Case Sensitivity

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

A.1.10 Data Card Requirements

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

A.2. MISCELLANEOUS CONTROL CARDS

A.2.1 Card 100, Problem Type and Option

This card is always required.

W1(A) PROBLEM TYPE. Enter one of the following: NEW, NEWSLP, RESTART, PLOT, REEDIT, or STRIP.

NEW or NEWSLP specifies a new simulation problem. If the code was not compiled with the *DEFINE SELAP option, NEW may be entered for a new problem, no SCDAP input is expected, and multiple cases are possible. If the code was compiled with *DEFINE SELAP, enter NEW for a RELAP5-type input deck and enter NEWSLP for a SCDAP/RELAP5-type input deck. If NEW is entered, the code does not expect SCDAP input following the first period or slash terminating card and multiple problems can be run. If NEWSLP is entered, SCDAP input is expected following the first period or slash terminating card and no attempt is made to run multiple sets of problems. RESTART specifies continuation from some point in a previous problem using information from the RSTPLT file. PLOT specifies plotting results from a previous simulation run using the RSTPLT file. REEDIT has not been implemented. STRIP specifies that data are to be extracted (stripped) from the RSTPLT file, and only the data specified are written to the STRIP file.

W2(A) PROBLEM OPTION. This word is needed if W1 is NEW or RESTART and is optional if W1 is STRIP. If NEW is entered, enter either STDY-ST or TRANSNT to specify the type of simulation. When STRIP is entered in W1, W2 may be optionally entered with BINARY or FMTOUT. BINARY is assumed if W2 is not entered. BINARY indicates the unformatted (BUFFER OUT) file described in the RELAP5/MOD2 user's manual. FMTOUT indicates that the same information is to be written as 80-column formatted records. One use of this option is to allow simulation results to be transmitted to a different type of computer. Formats are:

STRIP Record 1.	(5A8,10X,A8)
STRIP Record 2.	(A10,2I10)
STRIP Record 3.	(8A10)
STRIP Record 4.	(A10,7I10/(8I10))
STRIP Record 5.,	...., N (A10, 5X,1P,4E15.6/(5E15.6))

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

A.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.

A.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 = $kg \cdot m/s^2 \cdot m^2$. 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.

A.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 RSTPLT file up to the point of restart are saved. If the restart continues from the point the previous problem terminated, restart and plot information is added to the end of the previous RSTPLT file. If the restart is prior to the termination point of the previous simulation, restart and plot data after the point of restart are overwritten by new results. A copy should be saved if RSTPLT files from each simulation are needed. If the problem options are different, data up to the point of restart are not saved, problem advancement time is reset to zero, and the RSTPLT file will contain information as if this problem type were NEW.

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

A.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 restart-plot file is rewound at the end of the problem but no further action is taken. The user may need to provide system control cards to dispose of the file. To prevent the restart-plot file from being written, a card with NONE must be entered.

W1(A) ACTION. This word may not be blank. If NONE, no restart-plot file is written.

A.2.6 Card 105, CPU Time Remaining Card

Card 105 controls termination of transient advancement based on the CPU time remaining for the job. Some operating systems allow specification of the CPU time allocated for a job as part of the job control language and also provide a means to determine the CPU time remaining during job execution. As an alternative, W3 of this card may be entered as the CPU time allocated. An alternative CPU remaining time is computed by decrementing this quantity by the CPU used as measured by the program. If W3 is omitted or zero, the alternative CPU remaining time is assumed infinite. At the end of each time step, the CPU time remaining for the job is determined from the minimum of the system (if available) and alternative CPU remaining times. If the remaining CPU time is less than Word 1, the transient is immediately terminated. The advancement may not be at the end of a requested time step due to time step reduction; the hydrodynamic, heat conduction, and reactor kinetics may not be advanced to the same point; or the advancement may not be successful and the advancement is scheduled to be repeated with reduced time step. Major edits, minor edits, plot edits, and a restart record are forced. The transient can be restarted from this point as if the problem had not been interrupted. The transient is also terminated after successful advancement over a requested time step and the CPU time is less than Word 2. Word 2 should be larger than Word 1. The default values for Words 1 and 2 are 1.0 and 2.0 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 SCDAP/RELAP5 execution. This card is optional, but its use with W3 non-zero is strongly recommended on systems that do not provide a system CPU limit.

W1(R) CPU REMAINING LIMIT 1(s).

W2(R) CPU REMAINING LIMIT 2(s).

W3(R) CPU TIME ALLOCATED (s). This quantity is optional.

If the program is compiled with compile time option, CTSS undefined, entering W1 as 0.0 will cause no testing for CPU termination and normal CTSS termination at end of CPU time can occur. In this case, the problem can be restarted from the drop file.

A.2.7 Card 106, Debris Control Card

This card is optional for both new and restart SCDAP-type problems.

W1(I) NOBROK This flag indicates breakup of COUPLE debris. The default value is 0.

- 0 Debris may be broken up.
- 1 Debris is never broken up.

W2(R) TFRAG Fragmentation temperature of core (K). The default value is 100.0.

W3(I) NTFRAG Indicator for TFRAG. Default value is 1.

- 0 Use TFRAG directly.
- 1 Add TSAT to TFRAG.

A.2.8 Card 107, Card to Identify Volume Above Core

This card is required in a new SCDAP-type problem. It is not read in a restart problem, so NVOLTP cannot be changed.

W1(I) NVOLTP This is the RELAP5 volume at top center of core. The bottom of this volume is contiguous with the top of the core.

A.2.9 Card 108, Core Slumping Control Card

Values on this card must always be in SI units.

For a new SCDAP/RELAP5 problem, this card is required with at least the first constant present. Default values are provided for all remaining constants on the card; if a given input is <1.0E-10 or is absent, then that constant is set to its default value.

For a restart run, this card is optional. For words 2 through 8, if input values are absent or are <10.E-10, respective constants will be obtained from the restart file.

W1(I)	NCVOL	This is the number of the volume to receive any slumped core material. On a restart run, NCVOL will not be changed; may be input as 0 or original value.
W2(R)	TMPCBR	This is the temperature at which breach occurs in hardpan in core region that supports liquefied core. Default value = 2500 K.
W3(R)	TIMCBR	This is the period of time over which massive core slumping is spread. Default = 10.0 s.
W4(R)	TIMQCH	This is the period of time over which small core slumping is spread. Default = 10.0 s.
W5(R)	TARXTO	This is the period of time over which area changes due to core meltdown are spread. Default = 10.0 s.
W6(R)	TVRXTO	This is the period of time over which volume changes due to core meltdown are spread. Default = 10.0 s.
W7(R)	AFLWR1	This is the minimum flow area per fuel rod in cohesive debris in core region. Default = 1.4E-6 m^2.

W8(R) HCSLMP This is the heat transfer coefficient at top of debris in lower plenum after massive slumping. Default = 2000.0 W/M^2K.

A.2.10 Card 109, COUPLE Debris Bed Model Control Card

If this card is absent in a new problem, then the COUPLE model is not used. If this card is absent in a restart problem, then the COUPLE model is left off or on, whichever it was in the previous run from which the restart is made.

W1(I) ICIN This is the COUPLE flag and input indicator:

0 Leave off/turn off the COUPLE model.

-1 For a new run, same as 0 above; for a restart run, read this card only, but no new COUPLE input.

1 COUPLE model used; read COUPLE input, which is placed at the end of the SCDAP/RELAP5 input deck.

For a restart run, this option can be used to turn on the COUPLE model or to change the COUPLE input if the model is already on, as long as the restart time is before any debris has slumped into the lower vessel head.

Note: for a restart run, if ICIN = 1, then the problem type on Card 1100 must be RESTARTS instead of RESTART.

W2(I) NTSC This is the maximum number of SCDAP/RELAP5 hydraulic time steps to use per COUPLE time step. If absent or less than 0 on a new problem, NTSC is set to 200. If absent, less than 0, or a restart problem, NTSC comes from the restart file.

W3(R) DTCOUP This is the maximum COUPLE time step. If absent or less than 0.0 on a new problem, DTCOUP is set to 10.0. If absent or less than 0.0 on a restart problem, DTCOUP comes from the restart file.

The frequency of the COUPLE calculation is determine by NTSC and DTCOUP above and by debris slumping. On a given SCDAP/RELAP5 hydraulic time step, the COUPLE subroutine is called if over 20 kg of debris has slumped since the last call to COUPLE. If this figure is greater than 40 kg, then COUPLE is also called for the next two SCDAP/RELAP5 time steps. In addition, COUPLE is called for the first two time steps of a new problem and for the first two time steps of a restart problem if new COUPLE input has been read.

A.2.11 Card 110, Noncondensible Gas Type

This card is required for all SCDAP/RELAP5 calculations and for RELAP5 calculations that use noncondensibles. Hydrogen may be included for SCDAP/RELAP5 problems. Nitrogen must be included for any problem having accumulators or specifying noncondensibles in initial conditions or time-dependent volumes. This card cannot be entered on a restart problem.

W1(A)-W5(A) NONCONDENSIBLE GAS TYPE. Enter any number of words (maximum 5) of the following noncondensible gas types: ARGON, HELIUM, HYDROGEN, NITROGEN, XENON, KRYPTON, or AIR.

A.2.12 Card 115, Initial Mass Fraction for Each Noncondensible Gas Type

This card is required if Card 110 is entered, unless only one species is entered on Card 110 and then the mass fraction is set to 1.0. The number of words on Card 115 must equal the number of words on Card 110. This word cannot be entered on a restart problem.

W1(R) - W5(R) INITIAL MASS FRACTION FOR EACH NONCONDENSIBLE GAS TYPE.

A.2.13 Card 118, Heat Transfer Control Card

This card is not used; the number is reserved for future use.

A.2.14 Cards 120 through 129, Hydrodynamic System Control Cards

Independent hydrodynamic systems can be described by the hydrodynamic component input. The term independent hydrodynamic systems means that there is no possibility of flow between the independent systems. A typical example would be the primary and secondary systems in a reactor where heat flows from the primary system to the secondary system in the steam generator but there is no fluid connection. If a tube rupture were modeled, the two systems would no longer be independent. Input processing lists an elevation for each volume in each independent hydrodynamic system and includes a check on elevation closure for each loop within a system. A reference volume is established for each system through input or default.

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. This must be a volume in the hydrodynamic system.

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

W3(A) FLUID TYPE. Enter WATER, D2O, or HYDROGEN.

W4(A) OPTIONAL ALPHANUMERIC NAME OF SYSTEM USED IN OUTPUT EDITING. *NONE* is used if this word not entered.

A.2.15 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. These data describe which and how many of each controller will be used. To retain generality and flexibility, the self-initialization option does not require that the steady-state and nearly implicit solution scheme options be concurrently turned on. However, this is the recommended procedure. These latter options are invoked through input data Cards 100 and 201-299. In addition to the data cards described below, the user must furnish data on the controllers to be used, as described in Section A-13.

A.2.15.1 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

A.2.15.2 Cards 141 through 142, Self-Initialization Pump Controller and Identification Cards

These cards establish the relationship between the pump number and the number of the pump controller. For each pump so referenced, the user must use the time-dependent pump velocity option. The time-dependent pump velocity data should be input so that the pump velocity is time invariant.

W1(I) COMPONENT NUMBER OF PUMP NUMBER 1

W2(I) CONTROLLER ID NUMBER FOR PUMP NUMBER 1

W3(I) COMPONENT NUMBER OF PUMP NUMBER 2

W4(I) CONTROLLER ID NUMBER FOR PUMP NUMBER 2

A maximum of six pump/controller pairs may be entered.

A.2.15.3 Cards 143 through 144, Self-Initialization Steam Flow Controller Identification Cards.

These cards establish the relationship between the steam flow control valve number and the steam flow controller number.

W1(I) COMPONENT NUMBER OF STEAM FLOW CONTROL VALVE NUMBER 1

W2(I) CONTROLLER NUMBER OF STEAM FLOW CONTROLLER FOR STEAM FLOW CONTROL VALVE NUMBER 1

W3(I) COMPONENT NUMBER OF STEAM FLOW CONTROL VALVE NUMBER 2

W4(I) CONTROLLER NUMBER OF STEAM FLOW CONTROLLER FOR STEAM FLOW CONTROL VALVE NUMBER 2

A maximum of six control valve/controller pairs may be entered. Note that in the above it is assumed that the valve component is assumed to be the control component. However, the user is not constrained to use a valve and may use a pump or time-dependent junction. CAUTION: only a servo valve, a time-dependent junction, or a pump may be used or a diagnostic error will result.

A.2.15.4 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

A maximum of six control valve/controller pairs may be entered. Note that in the above it is assumed that a valve component is the control component. However, the user is not constrained to use a valve and may use a pump or time-dependent junction. CAUTION: only a servo valve, time-dependent junction, or a pump is allowed or a diagnostic will result, such as a time-dependent junction with the controller output used as the independent variable in place of time.

A.2.15.5 Card 147, Pressure and Volume Control Component Identification Card

This card identifies the component number, connection data, and pressure level for the time-dependent volume that is to provide pressure and volume control during the self-initialization null transient.

W1(I) COMPONENT NUMBER OF TIME DEPENDENT VOLUME THAT REPLACES THE PRESSURIZER.

W2(I) COMPONENT NUMBER TO WHICH THE ABOVE TIME DEPENDENT VOLUME IS CONNECTED. CAUTION: only a single junction is allowed or an error will result.

W3(R) DESIRED STEADY-STATE PRESSURE.

A.3. CARDS 200 THROUGH 299, TIME STEP CONTROL CARDS

A.3.1 Card 200, Initial Time Value

This card is optional. If not entered, the simulation time at the start of the advancements is zero. If this card is entered, the simulation time is set to the entered value. This should only be used for NEW problems.

W1(R) INITIAL TIME. Value must be greater than or equal to zero.

A.3.2 Cards 201 through 299, Time Step Control

At least one card of this series is required for NEW problems. If this series is entered for RESTART problems, it replaces the series from the problem being restarted. This series is not used for other problem types. Card numbers need not be consecutive.

W1(R) TIME END FOR THIS SET (s). This quantity must increase with increasing card number.

W2(R) MINIMUM TIME STEP (s). This quantity should be a positive number <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.

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, internal 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. 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. If the second bit is set, the heat structure time step is the same as the hydrodynamic time step. 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. 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 bit settings.)

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. 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 problem, where the time step is limited by the material Courant limit. The use of tt=11 (sets first, second, and fourth bits) is the recommended way at this time to run most calculations with the nearly implicit hydrodynamic scheme.2 for further discussion of these options.

W5(I) MINOR EDIT AND PLOT FREQUENCY. This is the number of maximum or requested time advances per minor edit and write of plot information.

W6(I) MAJOR EDIT FREQUENCY. This is the number of requested time advances per major edit.

W7(I) RESTART FREQUENCY. This is the number of requested time advances per write of restart information.

A.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 A-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.

A.4.1 General Quantities

Code	Quantity
TIME	Time (s). The parameter is zero. 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 zero.
TMASS	Total mass of water, steam, and noncondensibles in all the system (kg, lb). Parameter is zero.
EMASS	Estimate of mass error (kg, lb). Parameter is zero.

A.4.2 Component Quantities

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

A.4.3 Volume Quantities

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

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

Code	Quantity
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).

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

A.4.4 Junction 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).

Code	Quantity
UGJ	Junction vapor specific internal energy (J/kg, Btu/lb).
MFLOWJ	Combined liquid and vapor flow rate (kg/s, lb/s).

A.4.5 Heat Structure Quantities

For the request code, HTVAT, the parameter is the heat structure number. For the remaining codes, the parameter is the heat structure 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 by default in plot records on the RSTPLT file, and thus plot requests in plot type problems and strip requests are limited to those temperatures unless the interior temperatures are forced to the RSTPLT file through 2080000 cards.

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

A.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}).

A.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 SHAFT component.

A.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 A.4.8.1 through A.4.8.4.

These additional request variables are not written to the restart-plot file (necessary for plotting) unless the user enters cards 2080XXXX. 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 9999 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 A.4.1 through A.4.7) since they are always written to the RSTPLT file.

Cards 20800XXX

W1(A) VARIABLE REQUEST CODE. See Subsections A.4.8.1 through A.4.8.4 for valid request code.

W2(I) PARAMETER. Enter the parameter associated with the variable request code.

A.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.
STDTRN	Steady-state/transient flag: 0.0 = steady state; 1.0 = transient.

A.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}, $°F^{-1}$).
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).

Code	Component Type	Quantity
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).

A.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).
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).

Code	Quantity
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•ft^3•°F).
HIG	Vapor side interfacial heat transfer coefficient per unit volume (W/m^3•K, Btu/s•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•s^2/m^5, lb•s^2/ft^5).
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).

Code	Quantity
DTFDP	Partial derivative of T_f with respect to pressure (K/Pa, $in^2 \cdot °F/lb_f$).
DTFDUF	Partial derivative of T_f with respect to U_f ($s^2 \cdot K/m^2$, $s^2 \cdot °F/ft^2$).
DTGDP	Partial derivative of T_g with respect to pressure (K/Pa, $in^2 \cdot °F/lb_f$).
DTGDUG	Partial derivative of T_g with respect to U_g ($s^2 \cdot K/m^2$, $s^2 \cdot °F/ft^2$).
DTGDXA	Partial derivative of T_g with respect to X_n (K, °F).
DTDP	Partial derivative of T_{sat} with respect to pressure (K/Pa, $in^2 \cdot °F/lb_f$).
DTDUG	Partial derivative of T_{sat} with respect to U_g ($s^2 \cdot K/m^2$, $s^2 \cdot °F/ft^2$).
DTDXA	Partial derivative of T_{sat} with respect to X_n (K, °F).
HTCOFF	Heat transfer coefficient between slab and liquid ($W/m^2 \cdot K$, $Btu/s \cdot ft^2 \cdot °F$).
HTCOFG	Heat transfer coefficient between slab and vapor ($W/m^2 \cdot K$, $Btu/s \cdot ft^2 \cdot °F$).
FWALF	Liquid wall frictional drag coefficient ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).
FWALG	Vapor wall frictional drag coefficient ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).

Code	Quantity
AVOL	Area of the volume (m^2, ft^2).

A.4.8.4 Junction-Related Quantities

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

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

A.4.8.5 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.

A.4.8.6 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).

Code	Quantity
QFCHFN	Critical heat flux (W/m^2, Btu/s•ft^2).
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).

A.4.8.7 Couple/Debris Bed Quantities

None are currently available.

A.4.8.8 Fission Product Quantities

The alphanumeric part of the variable code for fission product transport has the form FPtti, where tt and i are substituted as follows. The notation V and H indicate hydrodynamic Volume and Heat structure surface quantities, respectively.

tt	Volume or Surface	Quantity
SR	V	Fission product source to volume (kg/s).
LI	V	Fission product mass in volume or carried by liquid phase (kg).
VA	V	Fission product mass in volume in vapor form (kg).
TO	V	Total fission product mass in both vapor and aerosol form in volume (kg).

tt	Volume or Surface	Quantity
nn	V	Fission product mass in aerosol bin number nn in volume (kg). Aerosol bin number ranges from 01 up to the number of bins.
MA	H	Vapor phase fission product mass absorbed in heat transfer surface (kg).
MC	H	Vapor phase fission product mass condensed on heat transfer surface (kg).
MP	H	Aerosol fission product mass deposited on heat transfer surface (kg).

Part i is one of the species listed in Section A-14.4, Cards 20700011 through 20700018 (Species Selection Cards). For hydrodynamic volume quantities, the parameter is the volume number. For heat structure surface quantities, the parameter is the heat structure number appended with 00 for the left surface and 01 for the right surface.

A.4.8.9 SCDAP Quantities

Code	Index[a]	Quantity
CADCT	IIkkJJ	Component temperatures (K).
BGTH	0	Core total hydrogen generation rate (kg/s).
BGNHG	0	Core nuclear heat generation (W).
BGMCT	0	Core maximum surface temperature (K).
BGTFPRS	0	Core cumulative soluble fission product release (kg).
BGTFPRN	0	Core cumulative noncondensible fission product release (kg).
SHQIN	0	Total heat flowing through inside surface of flow shroud (W). (Available only if shroud component input.)

Code	Index [a]	Quantity
SHQOUT	0	Shroud total heat out (W). (Available only if shroud component input.)
BGTHQ	0	Core total oxidation heat generation (W).
CAOXDEO	kkjj	Component axial oxide thickness (m).
WDTQLP	jj	Thermal energy in material from component jj that slumped below bottom of component jj (J).

a. II is the radial node number minus one, kk is the axial node number, and jj is the component number. For example, if temperature is to be plotted at the sixth radial node of the fourth axial node of the third component, then the code CADCT with index 050403 would be specified.

A.4.8.10 COUPLE Quantities

Code	Index	Quantity
TMPCOU	iijjj	Temperature of jjj-th node in ii-th COUPLE.mesh. The index ii always has the value of 01. (K).
TMPDMX	ii	Maximum temperature of debris in the ii-th COUPLE mesh (K).
HGTOEB	ii	Height of debris in the ii-th COUPLE mesh (m).

A.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. Card numbers 20600010 through 20620000 allow 1000 variable trips and 1000 logical trips.

A.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.

A.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.

A.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 A-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. This 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.

A.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. The operator may be AND, OR, or XOR. For restart problems, this quantity may also contain DISCARD or RESET. DISCARD deletes the trip and RESET sets the trip to false. If DISCARD or RESET are entered, no further words are entered on the card and W1 may be zero.

W3(I) TRIP NUMBER. This is similar to Word 1 (W1).

W4(A) LATCH INDICATOR. If L, the trip when set remains set. If N, the trip is tested each time advancement.

W5(R) TIMEOF QUANTITY (s). This word is optional. If not entered, the trip is initialized as false and the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized as false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true. TIMEOF must not be greater than zero for NEW problems and must not be greater than the time of restart for RESTART problems.

The trip condition is given by the result of the logical expression: CONDITION OF TRIP IN W1 OPERATOR CONDITION OF TRIP IN W3.

A.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.

A.6. CARDS 801 THROUGH 999, INTERACTIVE INPUT DATA

An interactive and color display capability exists when the code is interfaced with Nuclear Plant Analyzer (NPA) software. This capability allows a user to view selected results on a color graphics terminal and to modify user-defined input quantities. A user can view SCDAP/RELAP5 output in a format that enhances understanding of the transient phenomena and enter commands during the simulation. This input, coupled with trip and control system capability, allows a user to initiate operator-like actions, such as opening/closing valves, starting/stopping/changing speed on pumps, and changing operating power settings.

These data may be entered for either batch or interactive jobs. These cards may be used in a NEW or RESTART job; in a restart job, they add to or replace data in the restarted problem.

These cards define variables that may be changed during execution by data input from a 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 SCDAP/RELAP5 coding even if they are spelled the same. These user-defined variables can appear wherever variables listed in Section A-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 the variable name or DELETE in a RESTART job to delete the variable.

W2(R) INITIAL VALUE. This is not needed if DELETE is entered in Word 1.

In interactive execution, the initial value is used until changed by a terminal entry. The value can be changed at any time and as often as needed. One or more variables can be changed by entering the variable name and value pairs on the 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 only if these input interactive variables are used with control variables defined in compatible units. This word, if nonzero, is the conversion factor. If this word is positive, the conversion is: V(converted) = V(input)*W3. If negative, V(converted) = V(input)/1.8 - W3. For temperature conversion from °F to K, 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. This may be omitted if zero.

A.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.

A.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 most other computers, e.g., Cray, Cyber 205, and IBM computers.

W2(A) COMPONENT TYPE. Enter one of the following component types, SNGLVOL, TMDPVOL, SNGLJUN, TMDPJUN, PIPE, ANNULUS, BRANCH, SEPARATR, JETMIXER, TURBINE, VALVE, PUMP, MTPLJUN, 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.

A.7.2 Single-Volume Component

A single-volume component is indicted by SNGLVOL on Card CCC0000. The junction connection code determines the orientation of the volume. More than one junction may be connected to an inlet or outlet. If an end has no junctions, that end is considered a closed end. Normally only a branch has more than one junction connected to a volume end.

A.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 $\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 <u>pvbfe</u>.

The digit <u>p</u> specifies whether or not the water packing scheme is to be used; <u>p</u>=0 specifies that the water packing scheme is to be used for the volume, and <u>p</u>=1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer.

The digit <u>v</u> specifies whether or not the vertical stratification model is to be used; <u>v</u>=0 specifies that the vertical stratification model is to be used for the volume, and <u>v</u>=1 specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer.

The digit <u>b</u> specifies the interphase friction that is used. <u>b</u>=1 means that the Bestion/Analytis rod bundle interphase friction model will be applied, and <u>b</u>=0 means that the normal interphase friction model will be applied.

The digit <u>f</u> specifies whether wall friction is to be computed or not; <u>f</u>=0 specifies that wall friction effects are to be computed for the volume, and <u>f</u>=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; 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.

A.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 εbt.

The digit ε specifies the fluid. ε=0 is the default fluid, ε=1 specifies water, ε=2 specifies D_2Om, and ε = 3 specifies hydrogen. The default fluid is that set for the hydrodynamic system by Cards 120 to 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If Cards 120 through 129 are not entered and all control words use the default 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=0 through 3 specifies only one component (steam/water). Entering t=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 the volume control flag. If equilibrium, the static quality is checked; but only the pressure and internal energies are used to define the thermodynamic state.

If t=1, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

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

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

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 ≥ 0 and ≤ 1.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality and the noncondensible quality must be ≥ 0 and ≤ 1.

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 and the noncondensible quality must be ≥ 0 and ≤ 1.

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. If entered, boron concentration follows the last required word for thermodynamic conditions.

A.7.3 Time-Dependent-Volume Component

This component is indicated by TMDPVOL on card CCC0000.

A.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 <u>pvbfe</u>.

The digit <u>p</u> is not used and should be input as 0.

The digit <u>v</u> is not used and should be input as 0.

The digit <u>b</u> specifies the interphase friction that is used. <u>b</u>=1 means that the Bestion/Analytis rod bundle interphase friction model will be applied, and <u>b</u>=0 means that the normal interphase friction model will be applied.

The digit <u>f</u> specifies whether wall friction is to be computed or not; <u>f</u>=0 specifies that wall friction effects are to be computed for the volume, and <u>f</u>=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; 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.

A.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. ε=0 is the default fluid, ε=1 specifies water, ε = 2 specifies D_2O, and ε=3 specifies hydrogen. The default fluid is that set for the hydrodynamic system by Cards 120 to 129 or this control word in 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-CCC0209 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 $\underline{t}$=0, the second, third, fourth, and fifth words of the time-dependent-volume data on 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 $\underline{t}$=1, the second and third words of the time-dependent-volume data on Cards CCC0201-CCC0299 are interpreted as temperature (K, °F) and quality in equilibrium condition.

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

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

If $\underline{t}$=4, the second, third, and fourth words of the time-dependent-volume data on Cards CCC0201-CCC0299 are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and equilibrium quality. This value of $\underline{t}$=4 is for input of a noncondensible equilibrium state. The equilibrium quality must be $\geq$0 and $\leq$1.

If $\underline{t}$=5, the second, third, and fourth words of the time-dependent-volume data on Cards CCC0201-CCC0299 are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality and the noncondensible quality must be $\geq$0 and $\leq$1.

If $\underline{t}$=6, the second, third, fourth, fifth, and sixth words of the time-dependent-volume data on 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 and the noncondensible quality must be $\geq$0 and $\leq$1.

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. This is assumed zero if missing.

A.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 500 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.

A.7.4 Single-Junction Component

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

A.7.4.1 Cards CCC0101 through CCC0109, Single-Junction Geometry Cards

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

W1(I) FROM CONNECTION CODE TO A COMPONENT. This refers to the component from which the junction coordinate direction originates. For connecting to a time-dependent volume, the connection code is CCC000000, where CCC is the component number of the time-dependent volume. An old or an expanded format can be used to connect all other volumes. In the old format, use

CCC000000 if the connection is to the inlet side of the component and use CCC010000 if the connection is to the outlet side of the volume. In the old format, W6 is used to specify a crossflow connection. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A non-zero N specifies the expanded format. N equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. N equal to 3 through 6 specifies crossflow. Current crossflow models do not require inlet-outlet orientation; but, in future versions, N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction, N equal to 5 and 6 would do the same for the third coordinate direction. Since crossflows are specified directly in the expanded format, the crossflow flag in W6 is ignored on input but set appropriately for output edits. Note: there is an important difference in the capability between the old and expanded formats with volumes in a pipe component. With the old format, connections are possible only to the inlet or crossflow faces of the first pipe volume or to the outlet or crossflow faces of the last pipe volume. With the expanded format, connections can be made to any face of any pipe volume. Output edits use the expanded format regardless of the input format.

W2(I) <u>TO</u> CONNECTION CODE TO A COMPONENT. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) JUNCTION AREA (m^2, ft^2). If zero, the area is set to the minimum volume 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 fvcahs.

The digit f specifies CCFL options; f=1 means that the CCFL model will be applied, and f=0 means that the CCFL model will not be applied.

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. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous; h=0 specifies the nonhomogeneous (two-velocity momentum equations) option, and h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a 1.

The digit s specifies 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 both 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, 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, it is set to 1.0.

A.7.4.2 Card CCC0110, Single-Junction CCFL Data Card

This card is optional. If this card is input but the junction flag _f_ is set to 0, an input error will occur.

W1(R) JUNCTION HYDRAULIC DIAMETER, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and must be $\geq$0. If zero is entered, the junction diameter is computed from 2.0*(JUNCTION AREA/π)**0.5.

W2(R) FLOODING CORRELATION FORM, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be $\geq$0 and $\leq$1.

W3(R) GAS INTERCEPT, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2}$ = 0) and must be >0.

W4(R) SLOPE, m. This quantity is the slope used in the CCFL correlation and must be >0.

A.7.4.3 Card CCC0201, Single-Junction Initial Conditions

This card is required for single-junction components.

W1(I) CONTROL WORD. If zero, the next two words are velocities; if one, the next two words are mass flows.

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

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

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

A.7.5 Time-Dependent-Junction Component

This component is indicated by TMDPJUN on Card CCC0000.

A.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. This refers to the component from which the junction coordinate direction originates. See the description of W1 for Cards CCC0101 through CCC0199 (Section A.7.4.1).

W2(I) TO CONNECTION CODE TO A COMPONENT. This refers to the component at which the junction coordinate direction ends. See the description of W1 for Cards CCC0101 through CCC0199 (Section A.7.4.1).

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.

A.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 zero, the second and third words of the time dependent junction data in Cards CCC0201-CCC0299 are velocities. If one, the second and third words of the time-dependent junction data in Cards CCC0201-CCC0299 are mass 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. This is assumed zero if missing.

A.7.5.3 <u>Cards CCC0201 through CCC0299, Time-Dependent-Junction Data Cards</u>

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 mass flow (kg/s, lb/s), vapor velocity (m/s, ft/s) or mass flow (kg/s, lb/s), and interface velocity (m/s, ft/s). Enter zero for interface velocity. The choice of velocity or mass flow depends on the value of control word W1 in Section A.7.5.2. The interpolation and card formats for the time-dependent data are identical to that in Section A.7.3.3.

A.7.6 Pipe or Annulus Component

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. 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.

The discussion of the various cards needed to input a pipe or annulus component is presented next. This discussion assumes that the pipe has at least two volumes with one junction separating the two volumes. It is possible to input a one-volume pipe or annulus. In order to implement this special case, the user must set the number of volumes and the volume number on the volume cards to one. In addition, the user should not input any of the junction cards.

A.7.6.1 Card CCC0001, Pipe or Annulus Information Card

This card is required for pipe components.

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

A.7.6.2 Cards CCC0101 through CCC0199, Pipe or Annulus 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.

A.7.6.3 Cards CCC0201 through CCC0299, Pipe or Annulus Junction Flow Areas

These cards are optional; and, if entered, the card numbers need not be consecutive. The format is two words per set in sequential expansion format for NV-1 sets.

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.

A.7.6.4 Cards CCC0301 through CCC0399, Pipe or Annulus 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.

A.7.6.5 Cards CCC0401 through CCC0499, Pipe or Annulus 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.

A.7.6.6 Cards CCC0501 through CCC0599, Pipe or Annulus Volume Horizontal Angles

These cards are optional, and, if not entered, the horizontal angles are set to zero. 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.

A.7.6.7 Cards CCC0601 through CCC0699, Pipe or Annulus Volume Vertical Angles

These cards are required for pipe components. The format is two words per set in sequential expansion format for NV sets, and card numbers need not be consecutive.

W1(R) 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.

A.7.6.8 Cards CCC0701 through CCC0799, Pipe or Annulus 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.

A.7.6.9 Cards CCC0801 through CCC0899, Pipe or Annulus Volume Friction Data

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

W1(R) WALL ROUGHNESS (m, ft).

W2(R) HYDRAULIC DIAMETER (m, ft). If zero, 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.

A.7.6.10 Cards CCC0901 through CCC0999, Pipe or Annulus Junction Loss Coefficients

These cards are optional, and, if missing, the energy loss coefficients are set to zero. The card format is three words per set in sequential expansion format for NV-1 sets, and card numbers need not be consecutive.

W1(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.

W2(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W3(I) JUNCTION NUMBER.

A.7.6.11 Cards CCC1001 through CCC1099, Pipe or Annulus 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 pvbfe.

The digit p specifies whether or not the water packing scheme is to be used; p=0 specifies that the water packing scheme is to be used for the volume, and p=1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer.

The digit v specifies whether or not the vertical stratification model is to be used; v=0 specifies that the vertical stratification model is to be used for the volume, and v=1 specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer.

The digit b specifies the interphase friction that is used. b=1 means that the Bestion/Analytis rod bundle interphase friction model will be applied, and b=0 means that the normal interphase friction model will be applied.

The digit f specifies whether wall friction is to be computed or not. 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. 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.

A.7.6.12 Cards CCC1101 through CCC1199, Pipe or Annulus Junction Control Flags

These cards are required for pipe components. The card format is two words per set in sequential expansion format for NV-1 sets, and card numbers need not be consecutive.

W1(I) JUNCTION CONTROL FLAGS. This word has the packed format fvcahs.

The digit f specifies CCFL options. f=1 means that the CCFL model will be applied, and f=0 means that the CCFL model will not be applied.

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. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous; h=0 specifies the nonhomogeneous (two-velocity momentum equations) option, and h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a one.

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

W2(I) JUNCTION NUMBER.

A.7.6.13 Cards CCC1201 through CCC1299, Pipe or Annulus Volume Initial Conditions

These cards are required for pipe components. The card format is seven words per set in sequential expansion format for NV sets, and card numbers need not be consecutive.

W1(I) CONTROL WORD. This word has the packed format εbt. The digit ε specifies the fluid. ε=0 is the default fluid, ε=1 specifies water, ε=2 specifies D_2O, and ε=3 specifies hydrogen. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If Cards 120 through 129 are not entered and all control words use the default 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 the volume control flag. If equilibrium, the static quality is checked, but only the pressure and internal energies are used to define the thermodynamic state.

If t=1, the next two words are interpreted as temperature (K, °F) and quality in equilibrium condition.

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

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

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 ≥ 0 and ≤ 1.

If t=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality and the noncondensible quality must be ≥ 0 and ≤ 1.

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 and the noncondensible quality must be $\geq$0 and $\leq$1.

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.

A.7.6.14 <u>Cards CCC2001 through CCC2099, Pipe or Annulus Initial Boron Concentrations</u>

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.

A.7.6.15 <u>Card CCC1300, Pipe or Annulus Junction Conditions Control Words</u>

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

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

A.7.6.16 Cards CCC1301 through CCC1399, Pipe or Annulus Junction Initial Conditions

W1(R) INITIAL LIQUID VELOCITY OR MASS FLOW (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R) INITIAL VAPOR VELOCITY OR MASS FLOW (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

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

W4(I) JUNCTION NUMBER.

A.7.6.17 Cards CCC1401 through CCC1499, Pipe and Annulus Junction CCFL Data Cards

These cards are optional. If these cards are input but the junction flag f is set to 0, an input error will occur.

W1(R) JUNCTION HYDRAULIC DIAMETER, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and must be ≥ 0. If a zero is entered, the junction diameter is computed from 2.0 * (JUNCTION AREA/π)**0.5.

W2(R) FLOODING CORRELATION FORM, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1.

W3(R) GAS INTERCEPT, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0.

W4(R) SLOPE, m. This quantity is the slope used in the CCFL correlation and must be >0.

W5(I) JUNCTION NUMBER.

A.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 three 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 three junctions. The vapor outlet and liquid fall back junctions should use the nonhomogeneous option. The CCFL flag must be turned off (f=0) for all three junctions. The Bestion/Analytis rod bundle interphase friction flag must be turned off (b=0) in the separator volume. The vertical stratification model flag is not used in the separator volume and should be set to zero (v=0). The water packing scheme flag is not used in the separator volume and should be set to zero (p=0).

A jetmixer component is a specialized branch using three junctions numbered in the same manner as the separator. For the junctions, N=1 represents the drive, N=2 represents the suction, and N=3 represents the discharge. The to part of the drive and suction junctions must refer to the inlet end of the 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. The CCFL flag must be turned off (f=0) for all three junctions. The Bestion/Analytis rod bundle interphase friction flag must be turned off (b=0) in the jetmixer volume. The vertical stratification model flag is not used in the separator volume and should be set to zero (v=0). The water packing scheme flag is not used in the separator volume and should be set to zero (p=0).

A turbine component is a specialized branch with additional input to describe the turbine characteristics. A simple turbine might use only one turbine component. A multistage turbine with steam extraction points might require several turbine components. NJ must be equal to 1 or 2. For the junctions, N=1 is the turbine junction that models the stages, and N=2 is the steam extraction (bleed) junction that must be crossflow. The primary steam inlet junction (N=1) is a normal junction, and the steam extraction line (N=2) is modeled as a crossflow junction. The turbine junction (N=1) must be the only entrance junction, and there must be only one exit junction (part of another component). The to part of the steam inlet junction (N=1) must refer to the inlet end of the turbine volume (CCC000000). A restriction (that will be removed in the future) currently exists such that the volume and junction upstream (usual flow) must be the numerically preceding volume and junction. For the first turbine, there must be an artificial turbine component preceding it (i.e., constant-efficiency 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 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 smooth junction option (a=0) should be used at both inlet and outlet junctions. The inlet and outlet junctions must be input as homogeneous junctions (h=2). If a steam extraction (bleed) junction is present, it must be a crossflow junction (s=1, 2, or 3). The CCFL flag must be turned off ($\underline{f}$=0) for both junctions. The Bestion/Analytis rod bundle interphase friction flag must be turned off ($\underline{b}$=0) in the turbine volume. The vertical stratification model flag is not used in the turbine volume and should be set to zero ($\underline{v}$=0). The water packing scheme flag is not used in the separator volume and should be set to zero ($\underline{p}$=0).

A.7.7.1 Card CCC0001, Branch, Separator, Jetmixer, or Turbine Information Card

This card is required for branch components.

W1(I) NUMBER OF JUNCTIONS, NJ. NJ is the number of junctions described in the input data for this component and must be equal to or greater than zero and less than ten. This number must be 3 for SEPARATR 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, mass flows are assumed.

A.7.7.2 Cards CCC0101 through CCC0109, Branch, Separator, Jetmixer, or Turbine 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 pvbfe.

The digit p specifies whether or not the water packing scheme is to be used; p=0 specifies that the water packing scheme is to be used for the volume, and p=1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer. This digit is used for the BRANCH component. For the SEPARATR, JETMIXER, and TURBINE components, the digit is not used and should be input as 0.

The digit v specifies whether or not the vertical stratification model is to be used; v=0 specifies that the vertical stratification model is to be used for the volume, and v=1 specifies that the vertical stratification model is not to be used for the volume. The vertical stratification model is recommended when modeling a pressurizer. This digit is used for the BRANCH component. For the SEPARATR, JETMIXER, and TURBINE components, the digit is not used and should be input as 0.

The digit b specifies the interphase friction that is used. b=1 means that the Bestion/Analytis rod bundle interphase friction model will be applied, and _b_=0 means that the normal interphase friction model will be applied. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, and TURBINE component, the digit is not used and should be set to zero.

The digit _f_ specifies whether wall friction is to be computed or not. _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. For a separator, the code will set _f_ to 1 and no wall friction will be calculated.

The digit _e_ specifies if nonequilibrium or equilibrium is to be used. _e_=0 specifies that a nonequilibrium (unequal temperature) calculation is to be used, and _e_=1 specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison to other codes.

A.7.7.3 Card CCC0200, Branch, Separator, Jetmixer, or Turbine Volume Initial Conditions

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

W1(I) CONTROL WORD. This word has the packed format $\underline{\varepsilon bt}$. The digit $\underline{\varepsilon}$ specifies the fluid. $\underline{\varepsilon}$=0 is the default fluid, $\underline{\varepsilon}$=1 specifies water, $\underline{\varepsilon}$=2 specifies D_2O, and $\underline{\varepsilon}$=3 specifies hydrogen. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If Cards 120 through 129 are not entered and all control words use the default $\underline{\varepsilon}$=0, then water is assumed to be 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 input of a noncondensible equilibrium state. The equilibrium quality must be $\geq$0 and $\leq$1.

If $\underline{t}$=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium and the noncondensible quality must be $\geq$0 and $\leq$1.

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 and the noncondensible quality must be $\geq$0 and $\leq$1.

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. If entered, boron concentration follows the last required word for thermodynamic conditions.

A.7.7.4 Cards CCCN101, Branch, Separator, Jetmixer, or Turbine 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 Words 1 through 6 on Card CCC0101 of the Single Junction Geometry Card, Subsection A.7.4.1, except that N instead of 0 is used in the fourth digit. Word 7 is not used for BRANCH, JETMIXER and TURBINE components. Word 7 is defined for a SEPARATR component.

W1(I) FROM CONNECTION CODE TO A COMPONENT. This refers to the component from which the junction coordinate direction originates. See description of W1 for Cards CCC0101 through CCC0199 (Section A.7.4.1).

W2(I) TO CONNECTION CODE TO A COMPONENT. This refers to the component at which the junction coordinate direction ends. See description of W1 for Cards CCC0101 through CCC0199 (Section A.7.4.1).

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 fvcahs.

The digit f specifies CCFL options. f=1 means that the CCFL model will be applied, and f=0 means that the CCFL model will not be applied. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, and TURBINE components, this digit is not used and should be set to zero.

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. c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options. a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous; h=0 specifies the nonhomogeneous (two-velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a one.

The digit 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 zero.

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.

A.7.7.5 Cards CCCN110 Branch, Separator, Jetmixer, or Turbine Junction CCFL Data Cards

These cards are optional. If these cards are input but the junction flag f is set to 0, an input error will occur.

W1(R) JUNCTION HYDRAULIC DIAMETER, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation. This number must be $\geq$0. If a zero is entered, the junction diameter is computed from 2.0 * (JUNCTION AREA/π)**0.5.

W2(R) FLOODING CORRELATION FORM, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1.

W3(R) GAS INTERCEPT, c. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0.

W4(R) SLOPE, m. This quantity is the slope used in the CCFL correlation and must be >0.

A.7.7.6 Cards CCCN201, Branch, Separator, Jetmixer, or Turbine Junction Initial Conditions

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

W1(R) INITIAL LIQUID VELOCITY OR MASS FLOW (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R) INITIAL VAPOR VELOCITY OR MASS FLOW (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

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

A.7.7.7 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_1 ($kg \cdot m^2$, $lb \cdot ft^2$).

W3(R) SHAFT FRICTION COEFFICIENT, f_1 (N•m•s, lb•ft•s). The frictional torque equals $f_1\omega$. 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, this is not used and can be neglected or set to zero.

A.7.7.8 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. This is the fraction of the enthalpy decrease that takes place in the rotating blade system.

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

A.7.8 Valve Junction Component

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

A.7.8.1 Cards CCC0101 through CCC0109, Valve Junction Geometry Cards

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

W1(I) FROM CONNECTION CODE TO A COMPONENT. This refers to the component from which the junction coordinate direction originates. See description of W1 for Cards CCC0101 through CCC0109 (Section A.7.4.1).

W2(I) TO CONNECTION CODE TO A COMPONENT. This refers to the component at which the junction coordinate direction ends. See description of W1 for Cards CCC0101 through CCC0109 (Section A.7.4.1).

W3(R) JUNCTION AREA (m^2, ft^2). This quantity is the full-open area of the valve except in the case of a relief valve. For valves other than relief valves, if this area is input as zero, the area is set to the minimum area of adjoining volumes. If nonzero, this area is used. For relief valves, this term is the valve inlet throat area. If this term is input as zero, it will default to the area calculated from the inlet diameter term input on 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 fvcahs.

The digit f specifies CCFL options. f=1 means that the CCFL model will be applied, and f=0 means that the CCFL model will not be applied.

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. 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. 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 one.

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

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, it is set to 1.0.

W8(R) TWO PHASE DISCHARGE COEFFICIENT. This quantity is applied only to two-phase choked flow calculations. The quantity must be >0 or $\leq$2.0. If missing, it is set to 1.0.

A.7.8.2 Card CCC0110, Valve Junction CCFL Data Card

This card is optional. If this card is input but the junction flag f is set to 0, an input error will occur.

W1(R) JUNCTION HYDRAULIC DIAMETER, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and must be ≥ 0. If a zero is entered, the junction diameter is computed from 2.0* (JUNCTION AREA/π)**0.5.

W2(R) FLOODING CORRELATION FORM, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1.

W3(R) GAS INTERCEPT, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0.

W4(R) SLOPE, m. This is the slope used in the CCFL correlation and must be >0.

A.7.8.3 Card CCC0201, Valve Junction Initial Conditions

This card is required for valve junction components.

W1(I) CONTROL WORD. If zero, the next two words are velocities; if one, the next two words are mass flows.

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

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

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

A.7.8.4 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.

A.7.8.5 Cards CCC0301 through CCC0399, Valve Data and Initial Conditions

These cards are required for valve junction components. Six different types of valves are allowed. The following words may be placed on one or more cards, and the card numbers need not be consecutive. The card format of these cards depends on the valve type.

A.7.8.5.1 Check Valve. This behaves as an on, off switch. 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 zero, closed if one.

W3(R) CLOSING BACK PRESSURE (Pa, lb_f/in^2).

W4(R) LEAK RATIO. This is the fraction of the junction area for the leakage when the valve is nominally closed. If omitted or input as zero, then either the smooth or the abrupt area change model may be specified. If input as nonzero, then the abrupt area change model must be specified.

A.7.8.5.2 Trip Valve. This behaves as an on, off switch as described for the check valve.

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

A.7.8.5.3 Inertial Valve. This behaves realistically in that the valve area varies considering the hydrodynamic forces and the flapper inertia, momentum, and angular acceleration. The abrupt area change model must be specified.

W1(I) LATCH OPTION. The valve can open and close repeatedly if the latch option is zero. The valve either opens or closes only once if the latch option is one.

W2(I) VALVE INITIAL CONDITION. The valve is initially open if zero, initially closed if one.

W3(R) 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 ($kg \cdot m^2$, $lb \cdot ft^2$).

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).

A.7.8.5.4 Motor Valve. This behaves realistically in that the valve area varies as a function of time by either of two models specified by the user. The user must also select the model for valve hydrodynamic losses by specifying either the smooth or the abrupt area change model. If the smooth area change model is selected a table of flow coefficients must also be input as described in Subsection A.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 A-10.2 (Cards 202TTTNN, General Table Data). For this case, the normalized stem position is input as the argument value and the normalized valve area is input as the function value.

A.7.8.5.5 Servo Valve. This behaves as described for a motor valve except that the valve flow area or stem position is calculated by a control system. Input for control systems is discussed in Section A-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.

A.7.8.5.6 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 3-34 in Volume 1 of this manual.)

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

W2(R) INLET DIAMETER (m, ft). This is the inside diameter of the valve inlet. If this term is input as zero, it will default to the diameter calculated from the junction area input on Card CCC0101 through CCC0109. If both this diameter and the junction area are input as nonzero, care must be taken that these terms are input with enough significant digits so that the areas agree within 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 3-34, in Volume 1 of this manual.

W3(R) VALVE SEAT DIAMETER (m, ft). Nonzero input is required. This term is the outside diameter of the valve seat, including the minimum diameter of the inner adjustment ring. This term must also be greater than or equal to the inlet diameter and corresponds to D_S in Figure 3-35 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 3-34 in Volume 1 of this manual.

W5(R) VALVE LIFT (m, ft). Nonzero input is required. Distance the valve piston rises above the valve seat at the fully open position. This term corresponds to X_1 in Figure 3-34 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 is greater than the valve seat diameter, a nonzero input of W7(R), is allowed. This term corresponds to D_1 in Figure 3-35 in Volume 1 of this manual. Also refer to the warning stated for W9(R).

W7(R) HEIGHT OF OUTSIDE SHOULDER RELATIVE TO THE VALVE SEAT FOR INNER ADJUSTMENT RING (m, ft). Input of a positive, nonzero value is not allowed. Input of a zero value is required if W6(R) preceding is defaulted or input equal to the valve seat diameter. Note that if the shoulder is below the seat, this distance is negative. This term corresponds to H_1 in Figure 3-35 in Volume 1 of this manual. Also refer to the warning stated for W9(R).

W8(R) MINIMUM INSIDE DIAMETER OF THE OUTER ADJUSTMENT RING (m, ft). If this input is zero, it will default to the valve piston diameter, in which case W9(R) must be input as positive and nonzero. If this input is nonzero, the value must be greater than or equal to the valve piston diameter. Input of a negative W9(R) is allowed only if this diameter is greater than the valve piston diameter. This term corresponds to D_0 in Figure 3-35 in Volume 1 of this manual. Also refer to the warning stated for W9(R).

W9(R) HEIGHT OF INSIDE BOTTOM EDGE RELATIVE TO THE VALVE SEAT FOR OUTER ADJUSTMENT RING (m, ft). This may be input as positive, zero, or negative. If this input is negative, then W8(R) preceding must be greater than the valve piston diameter. Note that if the bottom edge is below the valve seat, this distance is negative. This term corresponds to H_0 in Figure 3-35 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 ensure that the resultant gap between the adjustment rings is positive and nonzero; otherwise, an input error will result.

W10(R) BELLOWS AVERAGE DIAMETER (m, ft). If this term is input as zero, it will default to the valve piston diameter, resulting in a model not containing a bellows for which the valve bonnet region is vented to the atmosphere. This term corresponds to D_B in Figure 3-34 in Volume 1 of this manual.

W11(R) VALVE SPRING CONSTANT (N/m, lb_f/ft). Positive, nonzero input is required. This term corresponds to K_s in Equation (3-455) in Volume 1 of this manual.

W12(R) VALVE SETPOINT PRESSURE (Pa, lb_f/in^2). Non-negative input is required. This term is resolved to $K_s\ x_o$ in Equation (3-455) in Volume 1 of this manual.

W13(R) VALVE PISTON, ROD, SPRING, BELLOWS MASS (kg, lb). Nonzero input is required. This combined mass corresponds to m_v in Equation (3-455) in Volume 1 of this manual.

W14(R) VALVE DAMPING COEFFICIENT (N•s/m, lb_f•s/ft). This term corresponds to B in Equation (3-455) 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 3-34 and Equation (3-456) in Volume 1.

W16(R) INITIAL STEM POSITION. This is the fraction of total lift and is required if W1(I) is input as one. Total lift is input as W5(R).

W17(R) INITIAL VALVE PISTON VELOCITY (m/s, ft/s). This must be zero or omitted if W1(I) is input as zero. This term corresponds to v_v in Figure 3-34 and Equation (3-455) in Volume 1 of this manual.

A.7.8.6 Cards CCC0400 through CCC0499, Valve CSUBV Table

The CSUBV table may be input only for motor and servo valves. If the CSUBV table is input, the smooth area change model must be specified on the valve junction geometry card (Card CCC0101 through CCC0109); 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.

A.7.8.6.1 <u>Cards CCC0400 Factors</u>. 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.

A.7.8.6.2 <u>Cards CCC0401 through CCC0499, Table Entries</u>. The table is entered by using three-word sets. W1 is the flow area or stem position and must be normalized. The factor W1 on Card CCC0400 can be used to normalize the flow area or stem position. In either case, the implication is that if the valve is fully closed, the normalized term is zero. If the valve is fully open, the normalized term is one. Any value may be input that is between zero and one. The forward and reverse flow coefficients are W2 and W3, respectively. The code internally converts flow coefficients to energy loss coefficients by the formula $K = 2*A_j**2/(RHO*CSUBV**2)$, where 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 $\{gal/[min\cdot(lb_f/in^2)**0.5]\}$. The CSUBV is input in British units only and is converted to SI units using 7.598055E-7 as the conversion factor.

W3(R) REVERSE CSUBV {gal/[min•(lb_f/in^2)**0.5]}.

A.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.

A.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 pvbfe.

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

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

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

The digit f that normally specifies whether wall friction is to be computed or not is not used. No wall friction is computed for a pump, since it is included in the homologous pump data. The major edit output will show f=1, which indicates that no friction flag is set.

The digit e specifies if nonequilibrium or equilibrium is to be used; e=0 specifies that a nonequilibrium (unequal temperature) calculation is to be used, and e=1 specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison to other codes.

A.7.9.2 Card CCC0108, Pump Inlet (Suction) Junction Card

This card is required for a pump component.

W1(I) VOLUME CODE OF CONNECTING VOLUME ON INLET SIDE. This refers to the component to which this junction connects. See description of W1 for Cards CCC0101 through CCC0109 (Section A.7.4.1).

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 fvcahs.

The digit f specifies CCFL options; f=1 means that the CCFL model will be applied, and f=0 means that the CCFL model will not be applied.

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; c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options; a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous; h=0 specifies the nonhomogeneous (two-velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a one.

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

A.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.

A.7.9.4 Card CCC0110, Pump Inlet (Suction) Junction CCFL Data Card

This card is optional. If this card is input and the junction flag f is set to zero, an input error will occur.

W1(R) JUNCTION HYDRAULIC DIAMETER, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and must be ≥ 0. If a zero is entered, the junction diameter is computed from 2.0*(JUNCTION AREA/π)**0.5.

W2(R) FLOODING CORRELATION FORM, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1.

W3(R) GAS INTERCEPT, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0.

W4(R) SLOPE, m. This is the slope used in the CCFL correlation and must be > 0.

A.7.9.5 Card CCC0111, Pump Outlet (Discharge) Junction CCFL Data Card

This card is optional. The format for this card is identical to Card CCC0110 except that data are for the outlet junction.

A.7.9.6 Card CCC0200, Pump Volume Initial Conditions

This card is required for a pump component.

W1(I) CONTROL WORD. This word has the packed format $\underline{\varepsilon bt}$. The digit $\underline{\varepsilon}$ specifies the fluid. $\underline{\varepsilon}$=0 is the default fluid, $\underline{\varepsilon}$=1 specifies water, $\underline{\varepsilon}$=2 specifies D_2O, and $\underline{\varepsilon}$=3 specifies hydrogen. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words must be consistent (i.e., not specify different fluids). If cards 120 through 129 are not entered and all control words use the default $\underline{\varepsilon}$=0, then water is assumed to be 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 $\underline{t}$=4 is for inputting a noncondensible equilibrium state. The equilibrium quality must be $\geq$ 0 and $\leq$ 1.

If $\underline{t}$=5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensible quality. The equilibrium quality and the noncondensible quality must be $\geq$0 and $\leq$1.

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 and noncondensible quality must be $\geq$ 0 and $\leq$ 1.

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. If entered, boron concentration follows the last required word for thermodynamic conditions.

A.7.9.7 Card CCC0201, Pump Inlet Junction Initial Conditions

This card is required for a pump component.

W1(I) CONTROL WORD. If zero, the next two words are velocities; if one, the next two words are mass flow rates.

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

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

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

A.7.9.8 Card CCC0202, Pump Outlet Junction Initial Conditions

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

A.7.9.9 Card CCC0301, Pump Index and Option Card

This card is required for a pump component.

W1(I) PUMP TABLE DATA INDICATOR. If zero, single-phase homologous tables are entered with this component. A positive nonzero number indicates that the single-phase tables are to be obtained from the pump component with this number. If -1, use built-in data for the Bingham pump. If -2, use built-in data for the Westinghouse pump.

W2(I) TWO-PHASE INDEX. Enter -1 if two-phase option is not to be used. Enter zero 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 zero if a table is entered with this component. Enter a positive nonzero number if the table is to be obtained from pump component with this number. Enter -1 for built-in data for the Bingham pump. Enter -2 for built-in data for the Westinghouse pump.

W4(I) PUMP MOTOR TORQUE TABLE INDEX. If -1, no table is used. If zero, a table is entered for this component. If nonzero, use the table from the component with this number.

W5(I) TIME DEPENDENT PUMP VELOCITY INDEX. If -1, no time-dependent pump rotational velocity table is used and the pump velocity is always determined by the torque-inertia equation. If zero, a table is entered with this component. If nonzero, the table from the pump component with this number is used. A pump velocity table cannot be used when the pump is connected to a shaft control component.

W6(I) PUMP TRIP NUMBER. When the trip is off, electrical power is supplied to the pump motor; when the trip is on, electrical power is disconnected from the pump motor. The pump velocity depends on the pump velocity table and associated trip, the pump motor torque data, and this trip. If the pump velocity table is being used, the pump velocity is always computed from that table. If the pump velocity table is not being used, the pump velocity depends on the pump motor torque data and this trip. If the trip is off and no pump motor torque data are present, the pump velocity is the same as for the previous time step. This will be the initial pump velocity if the pump trip has never been set. Usually the pump trip is a latched trip, but that is not necessary. If the trip is off and a pump` motor torque table is present, the pump velocity is given by the torque-inertia equation where the net torque is given by the pump motor torque data and the homologous torque data. If the trip is on, the torque-inertia equation is used and the pump motor torque is set to zero. If the pump trip number is zero, no trip is tested and the pump trip is assumed to always be off.

W7(I) REVERSE INDICATOR. If zero, no reverse is allowed; if one, reverse is allowed.

A.7.9.10 Cards CCC0302 through CCC0304, Pump Description Card

This card (or cards) is required for a pump component.

W1(R) RATED PUMP VELOCITY (rad/s, rev/min).

W2(R) RATIO OF INITIAL PUMP VELOCITY TO RATED PUMP VELOCITY. Used for calculating initial pump velocity.

W3(R) RATED FLOW (m^3/s, gal/min).

W4(R) RATED HEAD (m, ft).

W5(R) RATED TORQUE (N•m, lb_f•ft).

W6(R) MOMENT OF INERTIA (kg•m^2, lb•ft^2). This includes all direct coupled rotating components, including the master for a motor-driven pump.

W7(R) RATED DENSITY (kg/m^3, lb/ft^3). If zero, initial density is used. This is the density used to generate homologous data.

W8(R) RATED PUMP MOTOR TORQUE (N•m, lb_f•ft). If this word is zero, the rated pump motor torque is computed from the initial pump velocity and the pump torque that is computed from the initial pump velocity, initial volume conditions, and the homologous curves. This quantity must be nonzero if the relative pump motor torque table is entered.

W9(R) TF2, FRICTION TORQUE COEFFICIENT (N•m, lb_f•ft). This parameter multiplies the speed ratio (absolute pump speed/rated speed) to the second power. The friction torque factors are summed together.

W10(R) TF0, FRICTION TORQUE COEFFICIENT (N•m, lb_f•ft). This is constant frictional torque.

W11(R) TF1, FRICTION TORQUE COEFFICIENT (N•m, lb_f•ft). This multiplies the speed ratio to the first power.

W12(R) TF3, FRICTION TORQUE COEFFICIENT. (N•m, lb_f•ft). This multiplies the speed ratio to the third power.

A.7.9.11 Card CCC0308, Pump Variable Inertia Card

Pump inertia is given by Word 6 of Card CCC0302 if this card is not entered. If this card is entered, pump inertia is computed from

$$I = I_3 S^3 + I_2 S^2 + I_1 S + I_o \qquad S > W1 \quad ,$$

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•m^2, lb•ft^2).

A.7.9.12 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.

A.7.9.13 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.

A.7.9.14 Cards CCCXX00 through CCCXX99, Single-Phase Homologous Curves

These cards are needed only if W1 of Card CCC0301 is zero. There are sixteen possible sets of homologous curve data to completely describe the single-phase pump operation, that is, a curve for each head and torque for each of the eight possible curve types or regimes of operation. Entering all sixteen curves is not necessary, but an error will occur from an attempt to reference one that has not been entered.

Card numbering is CCC1100 through CCC1199 for the first curve, CCC1200 through CCC1299 for the second curve, through CCC2600 to CCC2699 for the sixteenth curve. Data for each individual curve are input on up to 99 cards, which need not be numbered consecutively.

W1(I) CURVE TYPE. Enter one for a head curve; enter two for a torque curve.

W2(I) CURVE REGIME. See 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.

A.7.9.15 Cards CCCXX00 through CCCXX99, Two-Phase Multiplier Tables

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

W1(I) EXTRAPOLATION INDICATOR. This is not used; enter zero.

W2(R) VOID FRACTION.

W3(R) HEAD OR TORQUE DIFFERENCE MULTIPLIER DEPENDING ON TABLE TYPE.

Additional pairs of data as needed are entered on this or additional cards as needed, up to a limit of 100 pairs. Void fractions must be in increasing order.

A.7.9.16 Cards CCCXX00 through CCCXX99, Two-Phase Difference Tables

These cards are required only if W3 of Card CCC0301 is zero. The two-phase difference tables are homologous curves entered in a similar manner to the single-phase homologous data. Card numbering is CCC4100 through CCC4199 for the first curve, CCC4200 through CCC4299 for the second curve, through CCC5600 to CCC5699 for the sixteenth curve. Data are the same as the data for the single-phase data except that the dependent variable is the difference between single-phase and fully degraded two-phase data.

A.7.9.17 Cards CCC6001 through CCC6099, Relative Pump Motor Torque Data

These cards are required only if W4 of Card CCC0301 is zero. If the pump velocity table is not being used and these cards are present, the torque-
inertia equation is used. When the electrical power is supplied to the pump motor (the pump trip is off), the net torque is computed from the rated pump motor torque times the relative pump motor torque from this table and the torque from the homologous data. If the electrical power is disconnected from the pump (the pump trip is on), the pump motor torque is zero.

W1(R) PUMP VELOCITY (rad/s, rev/min).

W2(R) RELATIVE PUMP MOTOR TORQUE.

Additional pairs as needed are added on this or additional cards, up to a maximum of 100 pairs.

A.7.9.18 Card CCC6100, Time-Dependent Pump Velocity Control Card

This card is required only if W5 of Card CCC0301 is zero. The velocity table, if present, has priority in setting the pump velocity over the pump trip, the pump motor torque data, and the torque-inertia equation.

W1(I) TRIP NUMBER. If the trip number is zero, the pump velocity is always computed from this table using time as the search argument. If the trip number is nonzero, the trip determines which table is to be used. If the trip is off, the pump velocity is set from the trip, the pump motor torque data, and the torque-inertia equation. If the trip is on, the pump velocity is computed from this table. If Word 3 is missing, the search variable in the table is time and the search argument is time minus the trip time.

W2(A) ALPHANUMERIC PART OF VARIABLE REQUEST CODE. This quantity is optional. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. TIME can be selected, but the trip time is not subtracted from the advancement time.

W3(I) NUMERIC PART OF VARIABLE REQUEST CODE. This is assumed to be zero if missing.

A.7.9.19 Cards CCC6101 through CCC6199, Time-Dependent Pump Velocity

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

W1(R) SEARCH VARIABLE. Units depend on the quantity selected for the search variable.

W2(R) PUMP VELOCITY (rad/s, rev/min).

Additional pairs as needed are added on this or additional cards, up to a maximum of 100 pairs. Time values must be in increasing order.

A.7.10 Multiple-Junction Component

A multiple-junction component is indicated by MTPLJUN on Card CCC0000.

The one or more junctions specified by this component can connect volumes in the same manner as several single-junction components except that all the volumes connected by the junctions in the component must be in the same hydrodynamic system. If this restriction is violated, corrective action is to merge the hydrodynamic systems.

A.7.10.1 Card CCC0001, Multiple-Junction Information Card

W1(I) NUMBER OF JUNCTIONS, NJ. This number must be >0 and <100.

W2(I) INITIAL CONDITION CONTROL. This word is optional and, if missing, is assumed to be zero. If zero is entered, the initial conditions on Cards CCC1NNM are velocities; if one is entered, the initial conditions are mass flows.

A.7.10.2 Cards CCC0NNM, Multiple-Junction Geometry Cards

Junctions are described by one or more sets of data, NN being the set number and M being the card number within a set. The junctions are numbered as CCCIINN00, where II is 01 for the first junction described in a set and increments by one for each additional junction. The quantity NN may be 01 through 99, and M may be 1 through 9. Cards are processed by increasing set number NN, and cards within a set by increasing M. Neither NN or M need to be strictly consecutive.

W1(I) FROM CONNECTION CODE TO A COMPONENT. This refers to the component from which the junction coordinate direction originates.

W2(I) TO CONNECTION CODE TO A COMPONENT. This refers to the component at which the junction coordinate direction ends.

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(R) JUNCTION CONTROL FLAGS. This word has the packed format fvcahs.

The digit f specifies CCFL options; f=1 means that the CCFL model will be applied, and f=0 means that the CCFL model will not be applied.

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; c=0 means that the choking model will be applied, and c=1 means that the choking model will not be applied.

The digit a specifies area change options; a=0 means either a smooth area change or no area change, and a=1 means an abrupt area change.

The digit h specifies nonhomogeneous or homogeneous; h=0 specifies the nonhomogeneous (two-velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit printout will show a one.

The digit 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, 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, it is set to 1.0.

W9(I) FROM VOLUME INCREMENT.

W10(I) TO VOLUME INCREMENT. Words 1 and 2 contain the FROM and TO connection codes respectively for the first junction defined by the set. If the set defines more than one junction, connection codes for the following junctions are given by the connection code of the previous junction plus the increments in Words 9 and 10. The increments may be positive, negative, or zero. Junctions are defined up to the limit in Word 12. Words 3 through 8 apply to all junctions defined by the set. If additional sets are entered, Words 1 and 2 apply to the next junction, and increments are applied as with the first set. Word 12 for the second and following sets must be greater than Word 12 of the preceding set, and Word 12 of the last set must equal NJ.

A new set is used whenever a new increment is needed, Words 3 through 8 need to be changed, or a change in junction numbering is desired.

W11(I) Enter zero. This is reserved for future capability.

W12(I) JUNCTION LIMIT. Described above.

A.7.10.3 Cards CCC1NNM, Multiple-Junction Initial Condition Cards

Initial velocities are entered using one or more sets of data. The processing of sets of data is identical to that described in Section A.7.10.2 except that there need be no relationship in the division of junctions within sets between these cards (CCC1NNM) and the multiple-junction geometry cards (CCC0NNM). Likewise, these cards do not affect the numbering of the junctions.

W1(R) INITIAL LIQUID VELOCITY OR MASS FLOW. This quantity is either velocity (M/S, ft/s) or mass flow (kg/s, lb/s), depending on control word 2 of Card CCC0001.

W2(R) INITIAL VAPOR VELOCITY OR MASS FLOW. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control word 2 of Card CCC0001.

W3(I) JUNCTION LIMIT NUMBER.

A.7.10.4 Cards CCC2NNM, Multiple-Junction CCFL Data Cards

These cards are optional. If these cards are input but the junction flag f is set to 0, an input error will occur. The processing of sets of data is identical to that described in Section A.7.10.2 except that there need be no relationship in the division of junctions within sets between these cards (CCC1NNM) and the multiple-junction geometry cards (CCC0NNM). Likewise, these cards do not affect the numbering of the junctions.

W1(R) JUNCTION HYDRAULIC DIAMETER, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and must be ≥ 0. If a zero is entered, the junction diameter is computed from 2.0*(JUNCTION AREA/π)**0.5.

W2(R) FLOODING CORRELATION FORM, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1.

W3(R) GAS INTERCEPT, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be >0.

W4(R) SLOPE, m. This is the slope used in the CCFL correlation and must be >0.

W5(I) JUNCTION LIMIT NUMBER.

A.7.11 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 nitrogen and that the gas and liquid are initially in equilibrium.

A.7.11.1 Cards CCC0101 through CCC0199, Accumulator Volume Geometry Cards

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

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

W3(R) VOLUME OF VOLUME (m^3, ft^3). This is the 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) AXIMUTHAL 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 +90 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). This is 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 (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. Enter <u>pvbfe</u>.

The flag <u>p</u> is not used and should be input as 0.

The flag <u>v</u> is not used and should be input as 0.

The flag <u>b</u> is not used and should be input as 0.

Enter f=0 if wall friction is to be computed, and f=1 if wall friction is not to be computed. The flag e must be zero to specify a nonequilibrium (unequal temperature) calculation.

A.7.11.2 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).

A.7.11.3 Card CCC1101, Accumulator Junction Geometry Card

W1(I) TO CONNECTION CODE TO A COMPONENT. The from connection is not entered, since it is always from the accumulator. The to connection code refers to the component at which the junction coordinate direction ends. See description of W1 for Cards CCC0101 through CCC0109 (Section A.7.4.1).

W2(R) JUNCTION AREA (m^2, ft). This is the average area of the surge line and standpipe.

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 fvcahs.

The accumulator model automatically disables the following terms as long as liquid remains in the accumulator. However, when the accumulator empties of liquid, the model is automatically converted to an active normal volume. The following terms are then enabled and used as defined.

The digit f is not used and should be input as zero.

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; c=0 means that the choking model will be applied, and c=1 means the choking model will not be applied.

The digit a specifies area change options; a=0 means either a smooth area change or no area change, and a=1 is not allowed for an accumulator.

The digit h specifies nonhomogeneous or homogeneous; h=0 specifies the nonhomogeneous (two velocity momentum equations) option; h=2 specifies the homogeneous (single-velocity momentum equation) option. For the homogeneous option (h=2), the major edit will show a one.

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.

A.7.11.4 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). This is the volume of water contained in the tank above the standpipe surge line inlet.

W2(R) LIQUID LEVEL IN TANK (m, ft). This is 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). This is not allowed to be zero.

W6(I) HEAT TRANSFER FLAG. If zero, heat transfer will be calculated. If one, no heat transfer will be calculated.

W7(R) TANK DENSITY (kg/m^3, lb/ft^3). If zero, the density will default to that for carbon steel.

W8(R) TANK VOLUMETRIC HEAT CAPACITY (J/kg•K, Btu/lb•°F). If zero, the heat capacity will default to that for carbon steel.

W9(I) TRIP NUMBER. If zero or if no number is input, then no trip test is performed. If nonzero then this must be a valid trip number, the operations performed are similar to those performed for a trip valve. If the trip is false, then the accumulator is isolated and no flow through the junction can occur. If the trip is true, then the accumulator is not isolated and flow through the junction will occur in the normal manner for an accumulator.

A.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:

CCC 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.

G 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.

X is the card type.

NN is the card number within a card type.

A.8.1 Card 1CCCG000, General Heat Structure Data

This card is required for heat structures.

A.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. Cylindrical geometry must be specified when the gap conductance model is used.

W4(I) STEADY STATE INITIALIZATION FLAG. Use zero if the initial conditions are entered on input cards; use one 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. 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 zero or one 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 a heat structure can have. Storage is allocated for the number indicated, even though a transient may not require that level of subdivision.

A.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.

A.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).

W2(R) GAP CONDUCTANCE REFERENCE VOLUME. This word is required. The pressure of the gas in a fuel pin for the gap conductance model is given by P(t) = P(0)/T(0)*T(t), where P(t) is the pressure in the fuel pin and T(t) is the temperature in the reference volume. P(0) is W1 above, and T(0) is the initial value if the volume is also being defined with these input data or the value from the restart block. The reference volume is usually the volume most closely associated with the nonfuel region in a fuel pin at the top of a stack of fuel pellets.

A.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). This number must be ≥ 0. An appropriate value is 10^{-6} m. If a negative number is entered, it is interpreted as 10^{-6} m. A message is printed, but no errors are set.

W2(R) CLADDING SURFACE ROUGHNESS (m, ft). This number must be either positive or zero. An appropriate value is 2×10^{-6} m. A negative entry is reset to 2×10^{-6} m with no errors.

W3(R) RADIAL DISPLACEMENT DUE TO FISSION GAS INDUCED FUEL SWELLING AND DENSIFICATION (m, ft). This number must be ≥ 0. A negative entry is reset to zero. An appropriate value can be obtained from calculations using FRAPCON-2 or FRAP-T6.

W4(R) RADIAL DISPLACEMENT DUE TO CLADDING CREEPDOWN (m, ft). The value is normally negative. A positive entry is reset to zero. An appropriate value can be obtained from calculations using FRAPCON-2 or FRAP-T6.

W5(I) HEAT STRUCTURE NUMBER.

A.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 A.8.4 through A.8.8 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 are given as a sequence of pairs of numbers in one of two formats to be used in Cards 1CCCG101 - 1CCCG199. If this word is one, 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 a sequential expansion of mesh intervals; i.e., the distance in W1 on Cards 1CCCG101 - 1CCCG199 is used for each interval starting from the leftmost, as yet unspecified, interval to and including the interval number specified in W2.

A.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.

A.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 A-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. If the gap conductance model is used, only one interval can be used for the gap model.

W2(I) INTERVAL NUMBER.

A.8.7 Card 1CCCG300, Fission Product Decay Heat Flag

This card sets the fission product decay heat flag. The code will then treat card 1CCCG301 as a gamma attenuation coefficient card. This card is not needed if fission product decay heat is not used on this heat structure.

W1(A) DKHEAT.

A.8.8 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. If card 1CCCG300 is entered, then the card 1CCCG301 is treated as a gamma attenuation coefficient card.

W1(R) GAMMA ATTENUATION COEFFICIENT. These are values dependent on the heat structure material. A value of 50 is recommended for stainless steel.

W2(I) MESH INTERVAL NUMBER.

A.8.9 Card 1CCCG400, Initial Temperature Flag

This card is optional; 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. If greater than zero, initial temperatures for this heat structure geometry are taken from the heat structure geometry number in this word.

A.8.10 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 do not fit on one card.

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

A.8.11 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 OR GENERAL TABLE. This word specifies the hydrodynamic volume number (of the form CCCNN0000) 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 (of the form NN0000) and W1 of this card 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.

If 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.

If 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.

If 1xxx, the temperature in general Table xxx is used as the left surface temperature.

If 2xxx, the heat flux from Table xxx is used as the left boundary condition.

If 3xxx, a convective boundary condition is used where the heat transfer coefficient as a function of time is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume.

If 4xxx, a convective boundary condition is used where the heat transfer coefficient as a function of surface temperature is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume.

If reflood is specified, the left boundary condition type must be same for all NH heat structures and similarly for the right boundary condition type. The left and right boundary types need not be the same, but neither can be 1000 or 1xxx.

W4(I) SURFACE AREA CODE. If zero, W5 is the left surface area. If one, 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.

A.8.12 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.

A.8.13 Cards 1CCCG701 through 1CCCG799, Source Data Cards

These cards are required for heat structure data. The card format is sequential expansion format, five words per set, describing NH heat structures.

W1(I) SOURCE TYPE. If zero, no source is used. If a positive number <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.

A.8.14 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.

A.8.15 Cards 1CCCG901 through 1CCCG999, Additional Right Boundary Cards

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

A.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.

A.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 are primarily to demonstrate capability. The user should check whether the data are satisfactory. The word DELETE may be entered in RESTART problems to delete a composition.

The next two words are required only if TBL/FCTN is entered for W1.

W2(I) THERMAL CONDUCTIVITY FORMAT FLAG OR GAP MOLE FRACTION FLAG. Enter 1 if a table containing temperature and thermal conductivity is to be entered; enter 2 if functions are to be entered. Enter 3 if 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.

A.9.2 Cards 201MMM01 through 201MMM49, Thermal Conductivity Data or Gap Mole Fraction Data

These cards are required if W1 of Card 201MMM00 contains TBL/FCTN. For a table, enter pairs of temperatures and thermal conductivities or pairs of gas component names and mole fractions according to the specification of W2 of Card 201MMM00. One to 7 pairs of gas names and their mole fractions can be entered. The gas component names that may be entered are: HELIUM, ARGON, KRYPTON, XENON, NITROGEN, HYDROGEN, and OXYGEN. No particular order of the pairs is required. Do not enter any gas component with a zero mole fraction. Normalization of the total mole fraction to one is performed if the sum of the mole fractions entered is not one. The table of gas composition data is applicable to any gap and is required if Card 1CCCG001 is present.

A.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.

A.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).

A.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.

A.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 than the thermal conductivity table or if functions are used for thermal conductivity. If the temperature values are identical, only the volumetric heat capacities need be entered. The number of pairs or single entries 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 ($J/m^3 \cdot K$, $Btu/ft^3 \cdot °F$)

A.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 ($J/m^3 \cdot K$, $Btu/ft^3 \cdot °F$)

W4(R) A1 ($J/m^3 \cdot K^2$, $Btu/ft^3 \cdot °F^2$)

W5(R) A2 ($J/m^3 \cdot K^3$, $Btu/ft^3 \cdot °F^3$)

W6(R) A3 ($J/m^3 \cdot K^4$, $Btu/ft^3 \cdot °F^4$)

W7(R) A4 ($J/m^3 \cdot K^5$, $Btu/ft^3 \cdot °F^5$)

W8(R) A5 (J/m^3, Btu/ft^3)

W9(R) C (K, °F)

A.10. CARDS 202TTTNN, GENERAL TABLE DATA

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

A.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 undesirable units conversion, since no British to SI units conversion is done for REAC-T entries.

The following two, three, or four words are optional and allow trips and factors or 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, and two factors are used if the argument is temperature. The remaining one or two factors are used for the function, two factors being used if temperature is the function.

W2(I) TABLE TRIP NUMBER. This number is optional unless factors are entered. If missing or zero, no trip is used; and the time argument 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.

A.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, $Btu/s{\cdot}ft^2$, if heat flux; $W/m^2{\cdot}K$, $Btu/s{\cdot}ft^2{\cdot}°F$, if heat transfer coefficient; dollars, if reactivity; dimensionless, if normalized area).

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

A.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.

A.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 are 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.

A.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). This is the sum of fission power and fission product and actinide decay power. Watts are used for both SI and British Units.

W3(R) INITIAL REACTIVITY (dollars). This must be ≤ 0.

W4(R) DELAYED NEUTRON FRACTION OVER PROMPT NEUTRON GENERATION TIME (s^{-1}).

W5(R) FISSION PRODUCT YIELD FACTOR. This is usually 1.0 for best-estimate problems, and 1.2 has been used with ANS73 data for conservative mode problems. The factor 1.0 is assumed if this word is not entered.

W6(R) ^{239}U YIELD FACTOR. This is the number of ^{239}U atoms produced per fission times any conservative factor desired. The factor 1.0 is assumed if this word is not entered.

A.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 ^{235}U, and ANS79-3 specifies the 1979 ANS standard data for the three isotopes, ^{235}U, ^{238}U, and ^{239}Pu. 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 ^{235}U, ^{238}U, and ^{239}Pu must be entered in these three words. The sum of the fractions must add to one.

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

A.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}).

A.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}).

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

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

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

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

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

A.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 ≥ 0. If a decay power obtained from the power history exceeds this quantity, the fission power is assumed to be zero.

W2(R) TIME DURATION. Units are as given in next word. This quantity must be ≥ 0.

W3(A) TIME DURATION UNITS. Must be S, MIN, H, DAYS, or WK.

W4-W6(R) POWER FRACTIONS. If ANS79-3 is entered in W1 of Card 30000002, the power fractions for ^{235}U, ^{238}U, and ^{239}Pu must be entered in these words.

A.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.

A.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).

A.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).

A.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 3.9.6 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.

A.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 are entered in a manner similar to Cards 30000701 through 30000799. For each heat structure specified on these cards, input on the heat structure data Cards 1CCCG2NN must define the fueled region as the region over which the volume-average temperature is computed.

Usually, either Word 3 or 4 is zero.

W1(I) HEAT STRUCTURE NUMBER.

W2(I) INCREMENT.

W3(R) WEIGHTING FACTOR FOR DOPPLER FEEDBACK, W_{Fi}. See Section 3.9.6 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.

A.11.13 Cards 30001701 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 A.11.11.

W1(I) HYDRODYNAMIC VOLUME NUMBER.

W2(I) INCREMENT.

W3(R) WEIGHT FACTOR.

A.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 A.11.11.

W1(I) HEAT STRUCTURE NUMBER.

W2(I) INCREMENT.

W3(R) WEIGHT FACTOR.

A.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).

A.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. The coded number has the form ddmmffbb, where the letter pairs represent coordinate numbers of the independent variables of the table. The dd pair refers to moderator density, mm refers to moderator temperature, ff refers to heat structure temperature, and bb refers to boron density. The paired numbers range from 00 to one less than the number of coordinate values for that variable. The 00 pair refers to the first coordinate value. If boron dependence is not included, bb is always 00. All table values must be entered. (A future version may allow gaps which are filled in by interpolation.)

W2(R) TABLE VALUE.

A.12. CARDS 20300000 THROUGH 20499999, 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 Section A.12.5.1 need be entered.

For convenience to the user, a check plot option is provided that will produce plots of input data, such as 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.

A.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.

A.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 SCDAP/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 A-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 20300009, 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.

A.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 INTENSITYN 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 INTENSITYN option.)
COMPLEX	Lettering on the plot is drawn in a high resolution textbook style. (Note: also refer to the INTENSITYN 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 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 $\geq$4, then m=4. This intensity is the default if the intensity option is omitted and the COMPLEX lettering option is activated.

DELETE — This 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 — This is 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 jobs will cancel all plot debug options previously defined. Use of the plot debug option will automatically activate the PLPRINT option for which all plot-related user input and check plot data will be printed. The debug option keywords are listed as follows:

DEBUGR — This will activate 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 — This will activate a debug dump and check plot printout at the third level of input processing (i.e., the "I" level subroutines).

DEBUGP This activates a debug dump of plot-related files at the plot level (i.e., the PLOTMD level subroutines).

DEBUGRI This is a single keyword combining the effects of DEBUGR and DEBUGI.

DEBUGALL This is a single keyword combining the effects of DEBUGR, DEBUGI, and DEBUGP.

DEBUGPR This activates the debug option for plot requests.

DEBUGCR This activates the debug option for plot comparison data table requests.

DEBUGPRCR This is a single keyword combining the effects of DEBUGPR and DEBUGCR.

NODEBUG This cancels all plot debug options currently input. For RESTART or PLOT jobs, cancels all plot debug options previously defined.

A.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. This is the length of the plot axis extremities parallel to the short page axis. (The default of PWIDTH is 6 in.)

W2(R) PHIGHT. This is the length of the plot axis extremities parallel to the long page axis. (The default of PHIGHT is 8 in.)

W3(R) PMAGNF. This is 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. If it is desired to reset these terms to their default values, then each term must be input as zero.

A.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 files for plotting of component tabular data. This option is provided for user convenience to provide plots as a visual aid in checking input data or for graphical presentation of component input data in reports. Only one of the following keywords need be input:

CHK-PLT This activates the check plot option.

DELETE DELETE should be used only for RESTART or PLOT jobs. Input causes deactivation of the check plot option for the current and all following restarts.

DISCARD An equivalent of DELETE.

A.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.

A.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) in Section A-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). This is defined as for the minor edit request variable code described in Section A.4.

W2(I) PARAMETER(1) (required). This is defined as for the minor edit request parameter described in Section A.4.

W3-10(I) PARAMETER(2)-(9) (optional). This is 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 nine 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 203NNN09), 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.

A.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, the independent variable code word may be input with no parameter following, as follows:

W1(A) INDEPENDENT VARIABLE CODE. This is defined as for the minor edit request variable code described in Section A-4. For this format, the parameters will default to those input on the plot request Cards 203NNN00 through 203NNN09.

Second, the independent variable code word may be input followed by only one parameter, as follows:

W1(A) INDEPENDENT VARIABLE CODE. This is defined as for the minor edit request variable code described in Section A-4.

W2(I) PARAMETER(1). This is defined as for the minor edit request parameter described in Section A-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 203NNN000 through 203NNN09.

Third, the independent variable code word may be input followed by several parameters, as follows:

W1(A) INDEPENDENT VARIABLE CODE. This is defined as for the minor edit request variable code described in Section A-4.

W2(I) PARAMETER(1). This is defined as for the minor edit request parameter described in Section A-4.

W3-(N+1)(I) PARAMETER(2)-(N). This is 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 successfully 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, an error will result.

A.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 SCDAP/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 A.12.7.1, 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.

A.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 20300000-20300009). 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 SCDAP/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 SCDAP/RELAP5 units label for the variable being plotted will be appended to the user input title.

A.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 SCDAP/RELAP5 computational results. In order to achieve maximum visual effect the plotted curve of SCDAP/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.

A.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 are to be plotted. Hence, any comparison data point or SCDAP/RELAP5 result point will not be plotted if its corresponding independent variable point lies outside the interval XMIN $\leq$ x $\leq$ XMAX, where XMIN is the minimum of W1(R) or W2(R) and XMAX 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 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 zero, it defaults to one 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 logarithmically (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.

A.12.6.5.2 Card 203NNN41, Dependent Variable Axis Specification. 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 are to be plotted. By input of these two terms, the user is specifying the approximate y-axis extremities for the plot. 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 zero and a grid is specified in the plot options, then IYGRID defaults to one.

W5(A) Y-AXIS TYPE KEYWORDS, LINEAR OR LOG. Defaults to 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.

A.12.6.6 <u>Cards 203NNN50 through 203NNN59, Curve Drawing Specifications</u>

These cards input the specifications for drawing each curve requested in a plot request (Cards 203NNN00 through 203NNN09). 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 are input in the following format.

W1-W2(A) LEGEND LABEL. This 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 203NNN09). If the legend label is entered, it must be composed of sufficient characters for two words. The $ symbol may not be embedded in the character string.

W3(A) CURVE LINE TYPE KEYWORD. This 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. This defines the plot symbol to be drawn at intervals of a specified number of data points. If W4 is omitted or input as zero, a symbol will not be drawn. 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. This defines the number of data point intervals between plot symbols. The plot symbol defined by W4 will be drawn at intervals of W5 data points. If W5 is omitted, it will default to five.

A.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.

A.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.

A.12.7 Cards 204MMMLL, Plot Comparison Data Tables

These cards input tables of data that are to be plotted on the same graphs as SCDAP/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.

A.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 301 through 399 and 203NNN00 through 203NNN09 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. SCDAP/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 204MMM08 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 204MMM20 through 204MMM99 cards for additional explanation. If W3 is omitted or input as " ", it defaults to PAIRS.

W4(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 204MMM20 through

204MMM99 cards for additional explanation. If W4 is omitted or input as " ", it defaults to INDEPFIRST.

A.12.7.2 Cards 204MMM01 through 204MMM08, Dependent Variable Units Conversion

These cards are required if SPECIAL is entered as W2 on Card 204MMM00. Each card inputs a unit conversion coefficient a(K), where the coefficient index K is implied by the card number 204MMM0K and where K ranges from 1 through 8. The units conversion equation is

```
Y(SI) = a(8)* (a(1) + Y*  a(2) + Y*[a(3) + Y*a(4)]
        + a(5)*Y**a(6) + a(7)*ALOG(Y))
```

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.

A.12.7.3 Card 204MMM10, 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 W2 of Card 204MMM00. If the keyword entered is SPECIAL, then the appropriate units coefficient cards 204MMM11 through 204MMM18 must be entered, as described for Cards 204MMM01 through 204MMM08.

A.12.7.4 <u>Cards 204MMM11 through 204MMM18, Independent Variable Units Conversion</u>

These cards are required if SPECIAL is entered as 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 204MMM08.

A.12.7.5 Card 204MMM19, 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 are input in the following format.

W1-W2(A) LEGEND LABEL. This 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 two 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 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. This defines the plot symbol to be drawn at intervals of a specified number of data points. If W4 is omitted or input as zero, a symbol will not be drawn. If the line type keyword input for 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. This defines the number of data point intervals between plot symbols. The plot symbol defined by W4 will be drawn at intervals of W5 data points. If W5 is omitted, it will default to five. However, if the line type keyword input for W3 is NOLINE, then W5 is set to one 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 straight 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.

A.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 W3 and W4 on the 204MMM00 card. For example, if W3 is PAIRS and 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 W3 is SETS and 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.

A.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. 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 CCC ranges from 001 through 999. The card format 205CCCCN allows 9999 control variables, where CCCC ranges from 1 through 9999.

If the self-initialization option is selected, the data cards described in Sections A.13.2, A.13.3.19, and A.13.3.20 must be included. If loop flow control is to be included, the data cards described in Section A.13.3.18 must also be included.

A.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 9999 (4095 also allowed) to select the 205CCCCN format.

A.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 most other computers.

W2(A) CONTROL COMPONENT TYPE. Enter one of the component names, SUM, MULT, DIV, DIFFRENI, DIFFREND, INTEGRAL, FUNCTION, STDFNCTN, DELAY, TRIPUNIT, TRIPDLAY, POWERI, POWERR, POWERX, PROP-INT, LAG, LEAD-LAG, CONSTANT, 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. 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 Volume I.

W4(R) INITIAL VALUE.

W5(I) INITIAL VALUE FLAG. Zero means no initial condition calculation and W4 is used as the initial condition; one means compute initial condition.

W6(I) LIMITER CONTROL. Enter zero or omit this and the following words if no limits on the control variable are to be imposed. Enter 1 if only a minimum limit is to be imposed, 2 if only a maximum limit is to be imposed, and enter 3 if both minimum and maximum limits are to be imposed.

W7(R) MINIMUM OR MAXIMUM VALUE. This word is the minimum or maximum value if only one limit is to be imposed or is the minimum value if both limits are to be imposed.

W8(R) MAXIMUM VALUE. This word is used if both limits are to be imposed.

A.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.

A.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.

A.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

$$Y = S\ V_1\ V_2\ \ldots\ V_J$$

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.

A.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.

A.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 noise into the calculation, it should be avoided if possible. When using control components to solve differential equations, the equations can be arranged such that INTEGRAL components can handle all indicated derivatives except possibly those involving noncontrol variables.

W1(A) ALPHANUMERIC PART OF VARIABLE REQUEST CODE FOR V1.

W2(I) INTEGER PART OF VARIABLE REQUEST CODE FOR V1.

A.13.3.5 Integrating Component

This component is indicated by INTEGRAL in Word 2 of Card 205NNN00 or 205NNNN0. The integrating component is defined by

$$S \int_0^t V_1 dt$$

or, in Laplace notation,

$$Y(s) = \frac{SV_1(s)}{s} \quad .$$

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.

A.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.

A.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

$Y = S*FNCTN(V_1, V_2, \ldots),$

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.

A.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.

A.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.

A.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.

A.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

$$Y = \left(SV_1\right)^{I_1}$$

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.

A.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

$$Y = \left(SV_1\right)^{R_1}$$

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.

A.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

$$Y = \left(SV_1\right)^{V_2} \quad .$$

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(A) ALPHANUMERIC PART OF THE VARIABLE REQUEST CODE FOR V_2.

W4(I) INTEGER PART OF THE VARIABLE REQUEST CODE FOR V_2.

A.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

$$Y = S \quad A_1 V_1 + A_2 \int_0^t V_1 dt$$

or, in Laplace transform notation,

$$Y(s) = S \quad A_1 + \frac{A_2}{s} \quad V_1(s) \quad .$$

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.

A.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,

$$Y(s) = S \frac{1}{1 + A_1 s} V_1(s) .$$

If the control variable is initialized,

$$Y(t_o) = SV_1(t_o) .$$

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.

A.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,

$$Y(s) = S \; \frac{1 + A_1 s}{1 + A_2 s} \; V_1(s) \quad .$$

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.

A.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

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

where I_i is the moment of inertia of component i, ω is rotational velocity, τ_i is torque of component i, f_i is the friction factor of component i, and τ_c is an optional torque from a control component. The summations include the shaft as well as the pump, turbine, and generator components that are connected to the shaft.

The SHAFT control component differs somewhat from other control components. The scale factor on card 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.

A.13.3.17.1 Card 205NNN01 through 205NNN05 or 205NNNN1 through 205NNNN5, Shaft Description Card

W1(I) TORQUE CONTROL VARIABLE NUMBER. If zero, there is no contribution to torque from the control system. If nonzero, the control variable with this number is assumed to be a torque and is added to the torques from the other components attached to the shaft. The torque must be in SI units.

W2(I) SHAFT MOMENT OF INERTIA, I_i (kg•m^2, lb•ft^2).

W3(I) 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.

A.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_1 ($kg \cdot m^2$, $lb \cdot ft^2$).

W4(R) FRICTION FACTOR, f_1 ($N \cdot m \cdot s$, $lb_f \cdot ft \cdot s$).

W5(I) GENERATOR TRIP NUMBER. When the trip is false, the generator is connected to an electrical distribution system and rotational velocity is forced to the synchronous speed. When the trip is true, the generator is not connected to an electrical system and the generator and shaft rotational velocity is computed from the rotational velocity equation.

W6(I) GENERATOR DISCONNECT TRIP NUMBER. If zero, the generator is always connected to the shaft. If nonzero, the generator is connected to the shaft when the trip is false and disconnected when the trip is true.

A.13.3.18 PUMPCTL Component

This component is specified when using the self-initialization option and loop flow control is desired but is not limited to that use. For each PUMPCTL component enter:

W1(A) ALPHANUMERIC NAME OF SETPOINT VARIABLE.

W2(I) PARAMETER PART OF SETPOINT VARIABLE.

W3(A) ALPHANUMERIC NAME OF SENSED VARIABLE.

W4(I) PARAMETER PART OF SENSED VARIABLE.

W5(R) SCALE FACTOR(S) APPLIED TO SENSED AND SETPOINT VALUES, S_1. Must be nonzero.

W6(R) INTEGRAL PART TIME CONSTANT, T_2 (s).

W7(R) PROPORTIONAL PART TIME CONSTANT, T_1 (s).

Standard use of PUMPCTL controller require the following interpretation of the input data. W1 and W2 contain CNTRLVAR and NNN, respectively, where NNN is a CONSTANT-type control element containing the desired (set point) flow rate. W3 is MFLOWJ, and W4 is the junction number at which the flow is to be sensed and compared to the set point. W5 is the S_1 value used to divide the difference between the desired (set point) and sensed flow rate to produce the error signal (E_1). W6 and W7 are the T_2 and T_1 values, respectively. All variables having units must be in SI units.

A.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 but is not limited to that use. For each STEAMCTL component enter:

W1(A) ALPHANUMERIC NAME OF SETPOINT VARIABLE.

W2(I) PARAMETER PART OF SETPOINT VARIABLE.

W3(A) ALPHANUMERIC NAME OF SENSED VARIABLE.

W4(I) PARAMETER PART OF SENSED VARIABLE.

W5(R) SCALE FACTOR(S) APPLIED TO SENSED AND SETPOINT VALUES, S_j. Must be nonzero.

W6(R) INTEGRAL PART TIME CONSTANT, T_4 (s).

W7(R) PROPORTIONAL PART TIME CONSTANT, T_3 (s).

Standard use of the STEAMCTL controller requires the following interpretation of the input data. W1 and W2 would contain CNTRLVAR and NNN, respectively, where NNN is a CONSTANT-type control element. This constant would be the desired (set point) cold leg temperature (for suboptions A and B) or secondary pressure (suboptions C and D). W3 would be TEMPF (for suboptions A and B) or P (for suboptions C and D), and W4 would be the volume number where the temperature (suboptions A and B) or pressure (suboptions C and D) is sensed. W5 is the S_j value used to divide the difference between the desired (set point) 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. All variables having units must be in SI units.

A.13.3.20 FEEDCTL Component

This component is specified when using the self-initialization option to control feedwater flow to a steam generator but is not limited to that use. For each FEEDCTL component enter:

W1(A) ALPHANUMERIC NAME OF FIRST SETPOINT VARIABLE.

W2(I) PARAMETER PART OF FIRST SETPOINT VARIABLE.

W3(A) ALPHANUMERIC NAME OF SENSED VARIABLE TO BE COMPARED WITH FIRST SETPOINT.

W4(I) PARAMETER PART OF SENSED VARIABLE TO BE COMPARED WITH FIRST SETPOINT.

W5(R) SCALE FACTOR APPLIED TO SENSED AND SETPOINT VALUES (FIRST SETPOINT), S_k. Must be nonzero.

W6(A) ALPHANUMERIC PART OF SECOND SETPOINT VARIABLE.

W7(I) PARAMETER PART OF SECOND SETPOINT VARIABLE.

W8(A) ALPHANUMERIC NAME OF SENSED VARIABLE TO BE COMPARED WITH SECOND SETPOINT.

W9(I) PARAMETER PART OF SENSED VARIABLE TO BE COMPARED WITH SECOND SETPOINT.

W10(R) SCALE FACTOR APPLIED TO SENSED AND SETPOINT VALUES (SECOND SETPOINT), S_m. Must be nonzero.

W11(R) INTEGRAL PART TIME CONSTANT, T_6 (s).

W12(R) PROPORTIONAL PART TIME CONSTANT, T_5 (s).

Standard use of the FEEDCTL controller requires the following interpretation of the input data. W1 and W2 contain CNTRLVAR and NNN, respectively, where NNN is a CONSTANT-type control element. This constant would be the desired (set point) steam generator secondary side water level. The latter may be expressed alternatively as a desired secondary coolant mass or as a differential pressure measured between two locations in the steam generator downcomer. W3 and W4 would contain CNTRLVAR and NNN, respectively, where NNN is the number of the control component that describes the summing algorithm to compute the sensed variable (e.g., collapsed water level may be computed by summing the product of VOIDF and volume length over the control volumes in the riser section). W5 is the S_k value used to divide the difference between the desired (set point) and sensed water level to produce the first portion of the error signal (E_3). W6 is MFLOWJ, and W7 is the junction number of the steam exit junction from the steam generator. W8 is MFLOWJ, and W9 is the junction number of the feedwater inlet junction. W10 is the S_m value used to divide the difference between the sensed steam flow and sensed feedwater flow to produce the second portion of the error signal (E_3). W11 and W12 are the T_6 and T_5 values, respectively. All variables having units must be in SI units.

A.14. CARDS 20700000 THROUGH 20799999, FISSION PRODUCT AND AEROSOL TRANSPORT

These cards are required only when the fission product aerosol behavior models are desired when performing a severe accident analysis. These cards are optional and may be entered in NEW or RESTART problems.

A.14.1 Card 20700000, Aerosol Size Bins

W1(I) NUMBER OF BINS OR DELETE FLAG. Zero may be entered in a RESTART problem having a fission product transport model and indicates that the model is to be terminated and all fission product data are to be deleted. No other cards in the range 20700001 through 20799999 may be entered. A positive nonzero quantity may be entered in a RESTART problem with a fission product model to indicate that the current fission product data are to be discarded and a new model entered. A positive nonzero number in a NEW problem or a RESTART without a fission product transport model indicates that the fission product transport model is to be started. The nonzero number is the number of aerosol bins. The number of bins must be > 1 and < 50.

A.14.2 Cards 20700001 through 20700005, Hydrodynamic System Specification

These cards specify the hydrodynamic systems for which the fission product transport calculation is to be made. These cards may be entered in NEW or RESTART problems. A hydrodynamic system is selected by entering one of the volumes in the hydrodynamic system. Only one volume per system may be entered on these cards. A positive volume number indicates that a fission product transport calculation is to be added to the hydrodynamic system. A negative volume number means that the fission product transport model is to be terminated for the hydrodynamic system and the associated data discarded. An input error results if an attempt is made to specify the fission product transport model for a hydrodynamic system already having the model. If in a RESTART, no hydrodynamics systems with fission transport remain, all fission product data are discarded. If Card 20700000 with W1 nonzero is entered, an input error results if no hydrodynamic systems with fission product transport are present.

If volumes are added or deleted in hydrodynamic systems with fission product transport, fission product data corresponding to those volumes are similarly added or deleted. If an entire hydrodynamic system is deleted, the corresponding fission product system is deleted. All fission product systems may be deleted in this manner, but an input error results if this occurs and Card 20700000 with W1 nonzero is entered. If hydrodynamic systems are merged (by junctions connecting them), the fission product systems are similarly merged.

Data may be entered one or more words per card, one or more cards as needed.

W1(I) VOLUME NUMBER OF SELECTED HYDRODYNAMIC SYSTEM. This number is plus or minus, as described above.

A.14.3 Card 20700010, Convergence Criteria

This card may be entered whenever Card 20700000 with W1 nonzero is entered or in any RESTART problem with an existing fission product model. Default values or previously entered values are used if this card is omitted.

W1(R) FIRST CONVERGENCE VALUE (E_1).

W2(R) SECOND CONVERGENCE VALUE (E_2).

A.14.4 Cards 20700011 through 20700018, Species Selection Cards

These cards must be entered whenever Card 20700000 with W1 nonzero is entered and are not entered otherwise. Each word specifies a species to be tracked, and a species may be entered only once. At least one species must be entered, and all species may be entered if desired.

The allowed symbols and species are: I (iodine), CsI (cesium iodide), CSOH (cesium hydroxide), TE (tellurium), HI (hydrogen iodide), HTE (hydrogen telluride), CD (cadmium), AG (silver), UO2 (uranium dioxide), SN (tin) FE (iron), RU (ruthenium), BA (barium), SB (antimony), CS* (user-defined), and I* (user-defined). The symbols are entered, one or more symbols per card, on one or more cards as desired for the desired species.

W1(A) SPECIES SYMBOL.

A.14.5 Cards 2070NNNM, Initial Conditions

Whenever a hydrodynamic volume is associated with the fission product transport model, whether by the specification of a system or by addition of volumes through renodalization, the initial aerosol masses are assumed zero. These cards can be entered in NEW or RESTART problems to set different initial values or to reset values in existing volumes. Since the fission product aerosol masses are zero for undamaged fuel, these cards are generally not needed. Entering data for a volume not involved in a fission product transport calculation is an error.

In the card numbering, nnn ranges from 002 to 999; and each NNN contains the initial conditions for one volume or a range of volumes. The cards are processed in order of increasing NNN. The initial conditions for a volume may be set in one specification and overridden in a subsequent specification. Not all species need to be entered in each specification; and, when not entered, the initial spatial densities remain at the previously set value or the default zero value.

A.14.5.1 Card 2070NNN0

W1(I) INITIAL VOLUME NUMBER

W2(I) FINAL VOLUME NUMBER. Both W1 and W2 must specify hydrodynamic volumes in the problem. These volumes and all volumes with volume numbers between these words are initialized to the aerosol masses on Cards 2070NNN1 to 2070NNN9. All the volumes specified must be part of systems having fission product transport. If this word is omitted or equal to W1, the initial conditions are for the volume specified in W1.

A.14.5.2 <u>Cards 2070NNN1 through 2070NNN9</u>

W1(A) SPECIES SYMBOL. The allowed species are limited to those entered on Cards 20700011 through 20700018.

W2(R) AEROSOL MASS OF SPECIES IN LIQUID FORM (kg, lb).

W3(R) AEROSOL MASS OF SPECIES IN VAPOR FORM (kg, lb)

W4...(R) AEROSOL MASS OF SPECIES IN SPATIAL DENSITIES FOR THE AEROSOLS IN EACH BIN, (kg, lb).

A.14.5.3 <u>Cards 20800NNN</u>

These cards put variables on a restart tape so their history from start of analysis is plotted. These variables do not need to be listed as variables printed in minor edits. All TRAPMELT and SCDAP variables to be plotted must be listed on a 20800NNN card.

Example input:

```
20800001    CADCT 000060201
20800278    GAMMAW 231010000
```

The following cards are for the creep rupture model, which is used in conjunction with the couple debris bed model. None of these cards are read on a RESTART problem.

A.14.6 Card 21000000, Creep Rupture Control Card for COUPLE Wall

This card is optional if the COUPLE model is used but cannot be present if the COUPLE model is not used. All three values may be changed on RESTART.

W1(I)	IMAT	Material index for COUPLE wall: 1 = A-508 Class 2 carbon steel 2 = 316 stainless steel 3 = Inconel 600. If absent on a new problem, IMAT is set at 1.
W2(I)	NCNVOL	Volume number of containment. If there is no containment volume in the problem or if the user wishes not to use the containment pressure in the creep rupture calculations for the COUPLE wall, then the user should use zero for NCNVOL. If absent on a new problem, NCNVOL is set to zero.
W3(R)	PEXT	Pressure outside the COUPLE wall. If NCNVOL is >0, then this input value of PEXT is ignored and PEXT comes from the containment volume. If NCNVOL=0, then PEXT is used for constant outside pressure. If NCNVOL=0 and PEXT is absent on a new problem, then PEXT is set to atmospheric pressure.

A.14.7 Cards 21000021 through 21000029, Creep Rupture Location Elements in COUPLE Wall

One Card 2100002I is read for each COUPLE wall creep rupture calculation location I.

On a restart run, the pressure of any Card 2100002I will replace existing NELEM(I,J)'s for that I; and the creep rupture damage term for location I will be reset to 0.0. Thus, one should not repeat all initial 2100002I cards in a restart run; only those for values of I which the user wishes to replace. On a restart run, one may also add new locations by specifying previously unused values of I.

To remove location I on restart without replacement, specify W1(I) = 0 on Card 2100002I.

Each Card 2100002I lists N (1 to 11) elements of the COUPLE grid which describe location I on the COUPLE wall.

W1(I)	NELEM(,1)	Element 1 in location I.
WN(I)	NELEM(N,1)	Element N in location I.

A.14.8 Cards 21000101 through 21000110, Creep Rupture Locations for RELAP5 Heat Structures

One Card 210001II is read for each creep rupture calculation location II, where the location is at the given heat structure.

On a restart run, the presence of any Card 210001II will replace the data for location II, and the creep rupture damage term for location II will be reset to 0.0. Thus, one should not repeat all initial 210001II cards in a restart run; only those for values of II which the user wishes to replace. On a restart run, one may add new locations by specifying previously unused values of II.

To remove location II on restart without replacement, specify NHS(I) = 0 on Card 210001II.

W1(I)	NHS	Heat structure for which creep rupture calculation is to be done. The format for NHS is CCCG00X, where CCC is the heat structure number and G is its geometry number.
W2(I)	IMATHS	Material index for COUPLE wall: 1 = A-508 Class 1 carbon steel 2 = 316 stainless steel 3 = Inconel 600.
W3(R)	PRIHS	Inner (left) pressure. If > 0.0, this constant pressure is used. If absent or $\leq$ 0.0, pressure is from adjacent volume.
W4(R)	PROHS	Outer (right) pressure. If > 0.0, this constant pressure is used. If absent or $\leq$ 0.0, pressure is from adjacent volume.

A.15. SEVERE ACCIDENT CORE BEHAVIOR INPUT--SCDAP

These cards are required only when performing analysis of a severe accident scenario. The cards are numbered starting with 1 and must be placed in exactly the order called for. If these cards are present, then free-format type Card 108 (Core Slumping Control Card) must be present in the first part of the input file. The description of each input card is followed by an example of proper input. The asterisks indicate a required input for a given card. This portion must be input as SI units only.

Comment cards may be used freely throughout input. Card numbers have been added for a better understanding of the input for the severe accident core behavior models, but they are not to be used in input.

A.15.1 Card 1, Heat Conduction Flag

W1(R) HEAT CONDUCTION TEMPERATURE CONVERGENCE TOLERANCE (K).

W2(I) MAXIMUM NUMBER OF HEAT CONDUCTION ITERATIONS PER TIME STEP.

W3(I) HEAT CONDUCTION SOLUTION FLAG. 0 is for one-dimensional (radial) conduction, 1 is for two-dimensional (axial and radial) conduction, and 2 is for two-dimensional (axial and radial) conduction with fine mesh rezoning.

Example:

```
10.0, 10, 0
```

A.15.2 Card 2, Tolerance

W1(R) RELATIVE TOLERANCE TO CHANGE IN VARIABLE USED FOR BUNDLE TIME STEP DEFINITION. Recommended value; 1.0.

W2(R) ABSOLUTE TOLERANCE TO CHANGE IN VARIABLE USED FOR BUNDLE TIME STEP DEFINITION. Recommended value; 1.0.

Example:

1.0, 1.0

A.15.3 Card 3, Area of Bundle

W1(R) CROSS-SECTIONAL AREA OF BUNDLE (m^2). Sum of flow area and rod cross-sectional area.

Example:

6.016329225E-3

A.15.4 Card 4, Number of Grid Spacers

W1(I) NUMBER OF GRID SPACERS. Maximum of 11, minimum of 1.

Example:

3

A.15.5 Card 5, Elevations of Grid Spacers

W1...(R) ELEVATIONS OF GRID SPACERS (m). Grids must line up with axial node boundaries. If no grid spacers are in the bundle, 1 dummy elevation must be input at some elevation greater than the rod length.

Example:

0.11430, 0.45720, 0.91440

A.15.6 Card 6, Grid Spacer Material Index

W1(I) GRID SPACER MATERIAL INDEX. 0 = zircaloy; 1 = inconel.

Example:

1

A.15.7 Card 7, Number of Components

W1(I) NUMBER OF COMPONENTS TO BE ANALYZED IN THIS RUN. Maximum of 5.

Example:

4

A.15.8 Card 8, Component Type

W1...(I) COMPONENT TYPES. 0 = fuelrod; 1 = control rod; 2 = shroud; 3 = BWR control rod; 6 = CORA.

Shroud input must be last component in analysis.

Example:

0, 0, 1, 2

A.15.9 Card 9, Indicator of Axial Node Spacing

W1(I) INDICATOR OF AXIAL NODE SPACING.

0 = Axial node spacing not identical for each component. (For MODO and MOD1, this option is not available.)

1 = Axial node spacing identical for each component.

Example:

1

[NOTE: If axial node indicator = 1, input next 2 cards. If indicator = 0, axial node spacing will be input with each individual component.]

A.15.10 Card 10, Number of Axial Nodes

W1(I) NUMBER OF AXIAL NODES FOR ALL COMPONENTS.

Example:

8

A.15.11 Card 11, Heights of Axial Nodes

W1...(R) HEIGHTS OF AXIAL NODES FOR ALL COMPONENTS (m). All heights must be the same due to limitations in subroutine ZONE.

Example:

.1143, .1143, .1143, .1143, .1143, .1143, .1143, .1143

A.15.12 Card 12, Reactor Environment

W1(I) REACTOR ENVIRONMENT. 1 = PWR, 2 = BWR, 3 = N reactor, 4 = ATR, 5 = CORA simulator.

W2(R) BURNUP (MW•s/kg).

Example:

1, 0.0

A.15.13 Card 13, Radius of Tungsten Wire

W1(R) RADIUS OF TUNGSTEN WIRE (m). Only used if first value of Card 12 = 5.

Example:

0.0034

A.15.14 Card 14, Criterion for Cohesive Debris

W1(R) CRITERION FOR COHESIVE DEBRIS. Input a dummy value of 0.0064.

Example:

0.0064

A.15.15 Card 15, Parameters in Meltdown Modeling

W1(R) MIXING FACTOR FOR EDDY DIFFUSION HEAT TRANSFER. This input is not used. Recommended value 1.0

W2(I) WETTING MODEL INDICATOR. This input is not used. Recommended value 1.

W3(R) TEMPERATURE FOR FAILURE OF ZrO_2 (K). Recommended temperature 2500.0 K.

W4(R) FRACTION OF CLADDING OXIDATION BEYOND WHICH OXIDE SHELL DOES NOT FAIL.

Example:

1.0, 1, 2500.0, 0.6

A.15.16 Card 16, Power History Types

This card specifies the decay power reduction due to the release of the volatile fission products after fuel disruption. Six different built-in correction relations are provided. The first input quantity, NOKSET, identifies one of the corrections which will be used in the current calculation. The second input quantity is the estimated time interval between reactor shutdown and fuel failure. The model is preliminary in nature; the value of this quantity is not crucial to the overall calculation results. A value of 100.0 is generally used.

W1(I) NDKSET. Indicator of type of power history that fuel rods had before transient.

1 = Generic PWR histories (33800 MWD/tU).

2 = TMI (3250 MWD/tU).

3 = PBF Severe Fuel Damage tests

4 = PBF test other than Severe Fuel Damage tests

5 = Decay power fraction set to 1.0 (full decay power)

6 = Decay power fraction set to 0.0 (no decay power).

NOTE: If shutdown time on Card 32 is greater than problem time, then decay heat correction is not used.

W2(R) *TIME SINCE FAILURE (s).

Example:

3, 100.0

[NOTE: Cards 17 through 41 are input for an individual fuel rod. Input one set for each fuel rod component.]

A.15.17 Card 17, Fuel Rods

W1(I) NUMBER OF RODS IN THIS COMPONENT.

W2(R) PITCH (m). Distance between closest fuel rod centers.

Example:

12, 0.0128

[NOTE: If Card 9, Indicator of Axial Node Spacing, is 0, input the next two cards. If Card 9 is 1, omit the next two cards.]

A.15.18 Card 18, Number of Axial Nodes

W1(I) NUMBER OF AXIAL NODES FOR THIS COMPONENT ONLY. Maximum 10. (Omit this card if the value on Card 9 is 1.)

Example:

8

A.15.19 Card 19, Heights of Axial Nodes .

W1...(R) HEIGHTS OF AXIAL NODES FOR THIS COMPONENT (m). All heights must be the same; limitations are in the subroutine ZONE. (Omit this card if the value on Card 9 is 1.)

Example:

.1143, .1143, .1143, .1143, .1143, .1143, .1143, .1143

A.15.20 Card 20, Volumes Numbers of Hydraulic Volumes

W1...(I) VOLUME NUMBERS OF HYDRAULIC VOLUMES THAT ARE CONNECTED TO AXIAL NODES OF THE CURRENT COMPONENT.

Example:

100010000, 100020000, 100030000, 100040000, 100050000, 100060000, 100070000, 100080000

A.15.21 Card 21, Length and Radius of Rod

W1(R) LENGTH OF ROD (m). Must be the sum of axial node heights.

W2(R) FUEL PELLET RADIUS (m).

W3(R) OUTER CLADDING RADIUS (m).

W4(R) INNER CLADDING RADIUS (m).

If pellet radius is small, then the fission gas release and mechanics models are turned off. If the fission gas release model is turned off, then the PARAGRASS inventory initialization is not printed; if the radius of the pellets is <0.178E-3, then no deformation or fission gas release calculations are done.

SCDAP/RELAP5 assumes that the density of the fuel is 95% of theoretical density and that the fuel pellets have dishes and chambers with a volume equal to 2% of the fuel volume.

Example:

0.9144, 0.004135, 0.004815, 0.004215

A.15.22 Card 22, Plenum Length and Volume

W1(R) PLENUM VOID LENGTH (m). (Plenum volume/cladding inner cross-sectional area).

W2(R) PLENUM VOLUME (m^3). Plenum void volume. Do not include spring volume.

Example:

0.0752, 5.043E-06

A.15.23 Card 23, Radial Mesh Spacing

W1(I) INDICATOR OF RADIAL MESH SPACING.

0 = Mesh not identical for each axial node.

1 = Mesh and temperatures identical for each axial node.

2 = Mesh identical but temperatures vary.

Example:

2

A.15.24 Card 24, Number of Radial Nodes in Rod

W1(I) TOTAL NUMBER OF RADIAL NODES IN ROD. Maximum 6.

Example:

6

A.15.25 Card 25, Radial Mesh Spacing

W1...(R) RADIAL MESH SPACING (m). (This is the radius to each radial node. Begin with radial node 1, which is a pellet center and has a radius of 0.0. End with the radial node at the cladding outer surface.) X(1),X(2),X(3),X(4),...

One each of input radii must exactly equal the fuel pellet radius, the cladding inner radius, and the cladding outer radius, respectively.

Example:

0.0, .001378, .002757, .004135, .004215, .004815

A.15.26 Card 26, Radial Temperature Distribution

W1...(R) RADIAL TEMPERATURE DISTRIBUTION (K). T(1),T(2),T(3),... If the axial distribution is not flat, input one radial distribution per card. (Start the input of radial temperature profile on a new line for each axial node. In each axial node, start with radial node 1.)

Example:

580.0, 579.0, 577.0, 573.0, 567.0, 560.0

A.15.27 Card 27, Masses of Species

W1...(R) MASSES OF SPECIES (kg). The masses of 12 species are read in. Input masses (mass/rod) in the following order (one line of input):

Te, Zr, Sn, Fe, Ru, Zr*, Ba, Sr, Te, Ag, Cs*, I*

(The Sn and Te releases are computed in the code so the input values will have no effect in the computations.)

Example:

0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

A.15.28 Card 28, Masses of PARAGRASS Species

W1...(R) MASSES OF FOUR PARAGRASS SPECIES (kg). Input masses (mass/rod) in the following order (one line of input): xenon, krypton, cesium, iodine.

This card is needed only when the first entry of Card 27 is greater than zero.

Example:

1.0 E-7, 1.0 E-7, 1.0 E-7, 1.0 E-8

A.15.29 Card 29, Power Array Points and Shapes

W1(I) NUMBER OF POINTS IN POWER ARRAY (NPTIM). The maximum value is 20.

W2(I) NUMBER OF POINTS IN PROMPT POWER ARRAY (NPPTIM). This card is input only when the decay heat model is used. The maximum value is 20.

W3(I) NUMBER OF POINTS IN AXIAL POWER DISTRIBUTION (NAXPZ). This number must equal the number of axial nodes.

W4(I) NUMBER OF POINTS IN RADIAL POWER DISTRIBUTION (NRDPR). The maximum value is 2.

W5(I) NUMBER OF AXIAL POWER DISTRIBUTION SHAPES (NSHAPZ). The maximum value is 3.

Example:

17, 0, 8, 2, 3

A.15.30 Card 30, Power Array Time and Elevation

W1(R) TIME FOR WHICH NTH AXIAL SHAPE IS USED (s).

W2(R) AXIAL POWER DISTRIBUTION SHAPE/ELEVATION ARRAY FOR ABOVE TIME. The elevations must match the axial node elevations. Repeat this card if additional shapes are input. A maximum of three shapes can be input. The elevations must exactly equal the elevations of axial nodes.

PARAGRASS will not initialize with an axial power factor of 0.

Example:

360.0, 0.88, 0.0572, 1.32, 0.1715, 1.31, 0.2858, 1.175, 0.4001, 1.11, 0.5144, 0.98, 0.6287, 0.79, 0.7430, 0.43, 0.8573

1440.0, 0.60, 0.0572, 0.95, 0.1715, 1.20, 0.2858, 1.34, 0.4001, 1.34, 0.5144, 1.20, 0.6287, 0.92, 0.7430, 0.53, 0.8573

A.15.31 Card 31, Radial Power Position

W1...(R) RADIAL POWER DISTRIBUTION/POSITION (m). Input pairs of radial power profile/radius.

Example:

1.000, 0.0, 1.000, 2.008E-3, 1.000, 4.135E-3

[NOTE: If there is no decay calculation (Word 2 of Card 29), i.e., NPPTIM = 0, read these cards.]

A.15.32 Card 32, Decay Power

Repeat Card 32 for each point in the power history.

W1(R) PROMPT POWER (W/m^3).

W2(R) FISSION PRODUCT DECAY POWER (W/m^3).

W3(R) ACTINIDE PRODUCT DECAY POWER (W/m^3).

W4(R) TRANSIENT POWER TIME (s). Transient points are interpolated.

Example:

1.68E7,	9.65E5,	1.07E5,	0.,
4.48E6,	2.57E5,	2.85E4,	22.,
4.48E6,	2.57E5,	2.85E4,	60.,
4.76E6,	2.73E5,	3.03E4,	120.,
5.04E6,	2.90E5,	3.21E4,	180.,
5.32E6,	3.06E5,	3.39E4,	240.,
5.60E6,	3.22E5,	3.57E4,	300.,
6.27E6,	3.60E5,	3.99E4,	420.,
6.66E6,	3.38E5,	4.24E4,	540.,
7.50E6,	4.31E5,	4.78E4,	600.,
8.23E6,	4.73E5,	5.24E4,	720.,
9.91E6,	5.69E5,	6.31E4,	840.,
1.27E7,	7.30E5,	8.10E4,	960.,
1.58E7,	9.07E5,	1.01E5,	1080.,
1.90E7,	1.09E6,	1.21E5,	1200.,
2.13E7,	1.22E6,	1.36E5,	1320.,
2.52E7,	1.45E6,	1.61E5,	1440.,

A.15.33 Card 33, Time of Shutdown

W1(R) TIME OF SHUTDOWN (s)

Example:

10000.0

[NOTE: If a decay calculation is performed (Word 2 of Card 29), i.e., NPPTIM > 0, read these cards.]

A.15.34 Card 34, Fuel Characteristics

W1(R) U239 PRODUCTION PER FISSION.

W2(R) FUEL FRACTION OF THEORETICAL DENSITY.

W3(R) U235 ENRICHMENT.

Example:

0.7, 0.95, 0.027

A.15.35 Card 35, Prior Power History/Time

W1(R) PRIOR POWER HISTORY (W/m^3)/TIME (s) PAIRS. Power is assumed to be a series of plateaus, with no interpolation. The last power density in this table is the transient power density until the problem time exceeds the shutdown time.

Example:

1.7E8, 7.E6, 1.5E9, 1.E7, 1.7E8, 1.4E7

A.15.36 Card 36, Prompt Power/Time

W1(R) PROMPT POWER (W/m^3)/TIME (s) PAIRS. The first value of time in this table must equal the shutdown time. Decay and actinide power tables have time points at prompt power time points.

Example:

1.7E8, 0.0, 1.5E8, 10.0

A.15.37 Card 37, Time of Shutdown

W1(R) TIME OF SHUTDOWN (s).

Example:

0.0

[NOTE: The following cards are input for PARAGRASS initialization of the helium and fission product inventory.]

A.15.38 Card 38, Helium Inventory and Internal Gas Pressure

W1(R) HELIUM GAS AS-FABRICATED INVENTORY IN THE ROD (kg). This number is used by SCDAP to calculate transient internal gas pressure for ballooning.

W2(R) INTERNAL GAS PRESSURE PER ROD (N/m^2). This number is used for PARAGRASS initialization. The initial gap gas pressure should correspond with the initial temperature distribution input above.

Example:

3.56E-05, 3.8E+06

[NOTE: If there is no decay calculation (Word 2 of Card 29), NPPTIM = 0, read the following two cards.]

A.15.39 Card 39, Number of Total Power, Prior History/Time Pairs

W1(I) NUMBER OF TOTAL POWER, PRIOR HISTORY,/TIME PAIRS.

Example:

2

A.15.40 Card 40, Total Power, Prior History/Time Pairs

W1...(R) TOTAL POWER, PRIOR HISTORY (W/m^3)/TIME (s) PAIRS. Prior operating history is used by PARAGRASS.

Example:

2.0E+08, 1.5E+07
3.0E+08, 3.0E+07

A.15.41 Card 41, User's Time-Dependent Option Flag

W1(I) USER'S OPTION FLAG. This flag indicates the prior time dependency of both the fuel surface temperature and the fuel hydrostatic pressure. This flag is required for PARAGRASS initialization.

0 = No time dependency, no further input cards are needed.

1 = The following time-dependent input cards must be read.

A.15.42 Card 42, Time, Temperature Pressure Profile

Read if value of 1 is input on Card 41.

W1(R) TIME TO WHICH THE NTH AXIAL SURFACE TEMPERATURE PROFILE AND FUEL AVERAGE HYDROSTATIC PRESSURE ARE USED (s). These times must equal values of time input on Card 40.

W2...(R) CLADDING SURFACE TEMPERATURE FOR EACH AXIAL NODE (K).

W3(R) FUEL HYDROSTATIC PRESSURE (N/m^2). Note that the last card should have a time equal to or greater than the time of the last prior power history input above.

Example:

```
1.0E+07, 700., 710., 712., 713., 714., 716., 718., 720., 2.0E+06
2.0E+07, 650., 653., 653., 655., 656., 660., 661., 663., 2.3E+06
3.0E+07, 660., 660., 666., 667., 667., 668., 669., 670., 2.4E+06
```

[NOTE: Cards 43 through 58 are input for an individual control rod.]

A.15.43 Card 43, Control Rod Component

W1(I) NUMBER OF CONTROL RODS IN THIS COMPONENT.

W2(R) DISTANCE BETWEEN ROD CENTERS (m). Input the same value as for fuel rods.

Example:

4, 0.0128

[NOTE: If the axial node indicator = 0 (Card 10), input the next 2 cards:

A.15.44 Card 44, Number of Axial Nodes

Omit if axial spacing indicator on Card 9 equals 1.

W1(I) NUMBER OF AXIAL NODES FOR THIS COMPONENT.

Example:

8

A.15.45 Card 45, Axial Node Height

Omit if Card 44 is omitted.

W1...(R) HEIGHTS OF AXIAL NODES FOR THIS COMPONENT (m). All heights must be the same due to limitations in the subroutine ZONE.

Example:

.1143, .1143, .1143, .1143, .1143, .1143, .1143, .1143

A.15.46 Card 46, Volume Numbers of Hydraulic Volumes

W1...(I) VOLUME NUMBERS OF HYDRAULIC VOLUMES THAT ARE CONNECTED TO AXIAL NODES OF THE CURRENT COMPONENT.

Example:

100010000, 100020000, 100030000, 100040000, 100050000, 100060000, 100070000, 100080000.

A.15.47 Card 47, Control Rod and Guide Tube

W1(R) CONTROL ROD LENGTH (m).

W2(R) OUTER RADIUS OF STAINLESS STEEL CLADDING (m).

W3(R) INNER RADIUS OF STAINLESS STEEL CLADDING (m).

W4(R) OUTER RADIUS OF ZIRCALOY GUIDE TUBE (m).

W5(R) INNER RADIUS OF ZIRCALOY GUIDE TUBE (m).

Example:

.9144, .4135E-02, .4E-02, .4815E-02, .4215E-02

A.15.48 Card 48, Internal Gas Pressure

W1(R) INTERNAL GAS PRESSURE (N/m^2).

Example:

0.0

A.15.49 Card 49, Flag Indicating Radial Mesh Spacing

W1(I) FLAG INDICATING RADIAL MESH SPACING.

0 = Mesh and temperature distribution are not flat.

1 = Mesh and temperature distribution are flat.

2 = Mesh is flat but temperature is not.

Example:

1

A.15.50 Card 50, Number of Radial Nodes

W1(I) NUMBER OF RADIAL NODES. This number is limited to 2 for a control rod.

Example:

2

A.15.51 Card 51, Radial Mesh

W1...(R) RADIAL MESH (m).

Example:

0.0, .4815E-02

A.15.52 Card 52, Temperature Distribution

W1...(R) TEMPERATURE DISTRIBUTION (K). For each axial node, input the initial radial temperature distribution at that node. See Card 26 for another example.

Example:

.5585E+03, .5585E+03

A.15.53 Card 53, Mass of Tin

W1(R) MASS OF TIN (kg). This is the total for all rods. This input is not used by the code; input 0.0.

Example:

0.0

A.15.54 Card 54, Mass of Silver

WX(R) MASS OF SILVER (kg). This is the total for all rods.

Example:

0.0

[NOTE: Nuclear heat data follow as in a fuel rod, without shutdown time.

A.15.55 Card 55, Power Arrays

W1(I) NUMBER OF POINTS IN POWER ARRAY (NPTIM).

W2(I) NUMBER OF POINTS IN PROMPT POWER ARRAY (NPPTIM).

W3(I) NUMBER OF POINTS IN AXIAL POWER DISTRIBUTION (NAXPZ). This number must equal the number of axial nodes.

W4(I) NUMBER OF POINTS IN RADIAL POWER DISTRIBUTION (NRDPR).

W5(I) NUMBER OF AXIAL POWER DISTRIBUTION SHAPES (NSHAPZ). The maximum number is 3.

Example:

3, 0, 8, 2, 1

A.15.56 Card 56, Axial Power Time and Elevation Array

W1(R) TIME FOR WHICH NTH AXIAL SHAPE IS USED (s).

W2...(R) AXIAL POWER DISTRIBUTION SHAPE/ELEVATION ARRAY FOR ABOVE TIME. Elevations must match the axial node elevations.

Example:

```
1440.0,   1., 0.0572,
          1., 0.1715,
          1., 0.2858,
          1., 0.4001,
          1., 0.5144,
          1., 0.6287,
          1., 0.7430,
          1., 0.8573
```

A.15.57 Card 57, Radial Power Distributions/Positions

W1...(R) RADIAL POWER DISTRIBUTIONS/POSITIONS (m).

Example:

1., 0., 1.0, 4.815E-3

A.15.58 Card 58, Power and Transient Power Time

W1(R) POWER (W/m^3).

W2(R) TRANSIENT POWER TIME (s).

Example:

0., 0.,
0., 700.,
0., 1440.

[NOTE: The following cards are input for a B_4C control rod:]

A.15.59 Card 59, Component Rods

W1(I) NUMBER OF RODS IN THIS COMPONENT.

Example:

13

A.15.60 Card 60, Volume Numbers of Hydraulic Volumes

W1...(I) VOLUME NUMBERS OF HYDRAULIC VOLUMES THAT ARE CONNECTED TO AXIAL NODES OF THE CURRENT COMPONENT.

Example:

100010000, 100020000, 100030000, 100040000
100050000, 100060000, 100070000, 100080000

A.15.61 Card 61, BWR Control Rod Outer Radii

W1...(R) EQUIVALENT OUTER RADII FOR THE SS CLADDING OF A BWR CONTROL ROD AT ALL AXIAL NODES (m).

Example:

2.108E-3, 2.108E-3, 2.108E-3, 2.108E-3
2.108E-3, 2.108E-3, 2.108E-3, 2.108E-3

A.15.62 Card 62, BWR Control Rod Outer Radii for Boron Carbide Absorber

W1...(R) OUTER RADII FOR B_4C ABSORBER OF A BWR CONTROL ROD AT ALL AXIAL NODES.

Example:

1.0E-3, 1.0E-3, 1.0E-3, 1.0E-3
1.0E-3, 1.0E-3, 1.0E-3, 1.0E-3

A.15.63 Card 63, Axial Temperature Distribution for a Boron Carbide Absorber

W1...(R) AXIAL TEMPERATURE DISTRIBUTION FOR B_4C ABSORBER (K).

Example:

558.0, 558.0, 558.0, 558.0
558.0, 558.0, 558.0, 558.0

A.15.64 Card 64, Axial Temperature Distribution for Stainless Steel Cladding

W1...(R) AXIAL TEMPERATURE DISTRIBUTION FOR STAINLESS STEEL CLADDING (K)

Example:

558.0, 558.0, 558.0, 558.0
58.0, 558.0, 558.0, 558.0

[NOTE: Cards 65 through 94 are input data for a shroud.]

A.15.65 Card 65, Number of Shroud Configurations

W1(I) NUMBER OF SHROUD CONFIGURATIONS IN THIS COMPONENT.

Example:

1

A.15.66 Card 66, Shroud Surface

W1(R) PERIMETER OF INNER SURFACE OF SHROUD (m)

W2(R) SHROUD FLOW AREA THICKNESS (m). [(cross-sectional area of bundle) - (number of rods) x $(pitch)^2$]/(shroud inner perimeter)

W3(R) SHROUD HEIGHT (m).

Example:

0.2845, 2.457E-3, 0.9144

A.15.67 Card 67, Radial Criteria

W1(R) RADIAL CRITERIA TO INDICATE WHEN SLAB CAN FRAGMENT AT AN AXIAL NODE. Minimum thickness of α-zircaloy layer before fragmentation. This value is not currently being used; input dummy variable of 1.

W2(I) FLAG FOR SHROUD OUTER SURFACE HEAT TRANSFER BOUNDARY CONDITIONS.

0 = The shroud outer surface heat transfer boundary condition is provided by the hydraulic volumes that are connected to the shroud outer surface (Cards 68 and 69).

1 = The shroud outer surface heat transfer boundary condition is provided by the input heat flux versus time table (Cards 71 and 72).

Example:

1., 0

[NOTE: If the shroud outer surface heat transfer boundary condition indicator = 0, input the next 2 cards.]

A.15.68 Card 68, Number of Axial Nodes

W1(I) NUMBER OF AXIAL NODES FOR THIS COMPONENT.

Example:

8

A.15.69 Card 69, Heights of Axial Nodes

W1...(R) HEIGHTS OF AXIAL NODES FOR THIS COMPONENT (m). All heights must be the same. Limitations are in the subroutine ZONE.

Example:

.1143, .1143, .1143, .1143, .1143, .1143, .1143, .1143

A.15.70 Card 70, Volume Numbers of Hydraulic Volumes

W1...(I) VOLUME NUMBERS OF HYDRAULIC VOLUMES THAT ARE CONNECTED TO THE INNER AXIAL NODES OF CURRENT SHROUD COMPONENT.

Example:

100010000, 100020000, 100030000, 100040000, 100050000, 100060000, 100070000, 100080000.

[NOTE: If the shroud outer surface heat transfer boundary condition indicator = 1, input the next 2 cards.]

A.15.71 Card 71, Heat Fluxes

W1(I) INDICATOR OF DISTRIBUTION SHAPE OF OUTER HEAT FLUX.

0 = Axial varying distribution.

1 = Flat distribution.

W2(I) NUMBER OF TIME-DEPENDENT HEAT FLUXES TO BE READ. The maximum is 20 sets.

Example:

1, 2

A.15.72 Card 72, Heat Transfer Fluxes

W1(R) BEGINNING TIME FOR HEAT TRANSFER FLUXES ON THIS CARD (s).

W2(R) HEAT TRANSFER FLUXES AT THE OUTER SURFACE OF SHROUD ($W/m^2 \cdot s$). Input one time and one heat transfer flux or one axial set of heat transfer coefficients per card.

Example:

0.0, 6000.0
1440.0, 6000.0

[NOTE: If the shroud outer surface heat transfer boundary condition indicator = 0, input the next card.]

A.15.73 Card 73, Volume Numbers of Hydraulic Volumes

W1(I) VOLUME NUMBERS OF HYDRAULIC VOLUMES THAT ARE CONNECTED TO THE OUTER AXIAL NODES OF CURRENT SHROUD COMPONENT.

Example:

200010000, 200020000, 200030000, 200040000, 200050000, 200060000, 200070000, 200080000.

A.15.74 Card 74, Indicator of Radial Node Spacing and Temperature Distributions

W1(I) INDICATOR OF RADIAL NODE SPACING AND TEMPERATURE DISTRIBUTIONS.

0 = Mesh and temperature distributions are not identical for all axial nodes.

1 = Mesh and temperature distributions are identical for all axial nodes.

2 = Temperature distributions not identical for all axial nodes, but radial mesh is identical for each axial node.

Example:

2

A.15.75 Card 75, Material Layers

W1(I) NUMBER OF MATERIAL LAYERS. The maximum is 9, and the minimum is 2.

Example:

6

A.15.76 Card 76, Indices of Materials

W1...(I) INDICES OF MATERIALS IN LAYERS BEGINNING WITH OUTER LAYER FIRST.

1 = Zircaloy. SCDAP always makes the inner layer zircaloy no matter what is input.

2 = ZR-U-O mixture (liquid).

3 = ZR-U-O mixture (refrozen).

4 = Unused; user may specify own properties.

5 = ZrO_2.

6 = Unirradiated fuel, UO_2.

7 = Cracked fuel, UO_2.

8 = Relocated fuel, UO_2.

9 = Steam-gas atmosphere, user may specify own properties.

10 = Unused; user may specify own properties.

11 = Unused; user may specify own properties.

12 = Unused; user may specify own properties.

For use in SLBINP, the shroud input subroutine.

Example:

1, 9, 1, 1, 4, 1

A.15.77 Card 77, Material Layer Radii

W1...(R) RADII OF EACH MATERIAL LAYER ASSUMING OUTER SHROUD = 0.0 (m). There must be a mesh radius specified for the inner and outer surfaces of each zircaloy layer.

Example:

1.524E-3, 4.064E-3, 5.588E-3, 11.951E-3, 19.701E-3, 20.463E-3

A.15.78 Card 78, Oxidation Layer

W1(I) MATERIAL LAYER WHERE OXIDATION WILL OCCUR. (Always input the number of material layers specified on Card 75.)

Example:

6

A.15.79 Card 79, Number of Radial Nodes

W1(I) NUMBER OF RADIAL NODES. The maximum number is 20. A value of 15 to 20 is recommended.

Example:

20

A.15.80 Card 80, Radial Mesh Spacing

W1...(R) RADIAL MESH SPACING (m). The inner liner radius must line up with a mesh point, and there must be a mesh radius specified for the inner and outer surfaces of each zircaloy layer. The radial node on the outside surface of the shroud has a radius of zero.

Example:

0., 4.064E-3, 5.588E-3, 11.951E-3, 19.701E-3, 20.463E-3

[NOTE: The values on Cards 77 and 80 must line up exactly.]

A.15.81 Card 81, Initial Radial Temperature Distribution

W1...(R) INITIAL RADIAL TEMPERATURE DISTRIBUTION (K). Input the temperature of radial node one first (the outside surface of the shroud. For each axial node, start a new line.

Example:

```
518.5, 519.9, 521.3, 521.5, 521.8, 522.0,
518.6, 522.4, 526.1, 526.3, 526.6, 528.0,
518.6, 524.8, 530.9, 531.2, 531.5, 534.0,
518.7, 526.8, 534.9, 535.3, 535.8, 539.0,
518.7, 528.7, 538.8, 539.3, 539.8, 543.8,
518.7, 530.4, 542.1, 542.6, 543.1, 548.0,
518.8, 531.8, 544.9, 545.5, 546.0, 551.4,
518.8, 532.6, 546.3, 546.9, 547.6, 553.2
```

A.15.82 Card 82, Materials Needing User-Specified Properties

W1(I) NUMBER OF DIFFERENT MATERIALS NEEDING USER-SPECIFIED PROPERTIES.

Example:

2

[NOTE: Read in the following cards if the number of new materials > 0.]

A.15.83 Card 83, First Material Index

W1(I) INDEX OF FIRST MATERIAL (1) WHOSE PROPERTIES ARE SPECIFIED BY USER. Index numbers 4, 9, 10, 11, and 12 can be used on Card 76.

Example:

4

A.15.84 Card 84, Specific Heat Capacities

W1...(R) SPECIFIC HEAT CAPACITIES (J/kg•K.). The temperature table is to be used in K. Specify the specific heat for each temperature in the table shown below. Begin with a temperature of 300 K and end with a temperature of 2500 K.

Temperature (K)	TTEMP(1)	300
	TTEMP(2)	550
	TTEMP(3)	700
	TTEMP(4)	873
	TTEMP(5)	1083
	TTEMP(6)	1173
	TTEMP(7)	1248
	TTEMP(8)	1700
	TTEMP(9)	2100
	TTEMP(10)	2500

Example:

0.30E+3, 0.30E+3, 0.30E+3, 0.30E+3, 0.30E+3,
0.30E+3, 0.30E+3, 0.30E+3, 0.30E+3, 0.30E+3

A.15.85 Card 85, Densities

W1...(R) DENSITIES (kg/m^3). Specify the density for each temperature shown on Card 84.

Example:

89.00, 89.00, 89.00, 89.00, 89.00,
89.00, 89.00, 89.00, 89.00, 89.00

A.15.86 Card 86, Thermal Conductivity

W1...(R) THERMAL CONDUCTIVITIES (W/m•K). Specify the thermal conductivity for each temperature shown on Card 84.

Example:

0.800, 0.800, 0.800, 0.800, 0.800,
1.400, 1.400, 1.400, 1.400, 1.400

A.15.87 Card 87, Second Material Index

W1(I) INDEX OF SECOND MATERIAL (2) WHOSE PROPERTIES ARE SPECIFIED BY USER. Index numbers 4, 9, 10, 11, and 12 can be used on Card 76.

Example:

9

A.15.88 Card 88, Specific Heat Capacities

W1...(R) SPECIFIC HEAT CAPACITIES (J/kg•K.). The temperature table is to be used in K. Specify the specific heat for each temperature in the table shown below. Begin with a temperature of 300 K and end with a temperature of 2500 K.

Temperature (K)	TTEMP(1)	300
	TTEMP(2)	550
	TTEMP(3)	700
	TTEMP(4)	873
	TTEMP(5)	1083
	TTEMP(6)	1173
	TTEMP(7)	1248
	TTEMP(8)	1700
	TTEMP(9)	2100
	TTEMP(10)	2500

Example:

6.28E+3, 6.28E+3, 6.28E+3, 6.28E+3, 6.28E+3,
6.28E+3, 6.28E+3, 6.28E+3, 6.28E+3, 6.28E+3

A.15.89 Card 89, Densities

W1...(R) DENSITIES (kg/m^3). Specify the density for each temperature shown on Card 88.

Example:

0.064, 0.064, 0.064, 0.064, 0.064,
0.064, 0.064, 0.064, 0.064, 0.064

A.15.90 Card 90, Thermal Conductivity

W1...(R) THERMAL CONDUCTIVITIES (W/m•K). Specify the thermal conductivity for each temperature shown on Card 88.

Example:

0.15, 0.15, 0.15, 0.15, 0.15,
0.35, 0.38, 0.40, 0.55, 0.65

[NOTE: If the input on Card 82 is >0, use the next card.]

A.15.91 Card 91, Shroud Insulation and Failure

W1(I) IMSHRD - material indicator for shroud insulation.

W2(R) TFSHRD - Time at which shroud fails (s).

W3(R) Multiplier on thermal conductivity for failed shroud.

Example:

4, 1.0E3, 1,0

[NOTE: Nuclear heat data follow as in fuel rod data without shutdown time.]

A.15.92 Card 92, Power Arrays

W1(I) NUMBER OF POINTS IN POWER ARRAY.

W2(I) NUMBER OF POINTS IN PROMPT POWER ARRAY.

W3(I) NUMBER OF POINTS IN AXIAL POWER DISTRIBUTION. This number must equal the number of axial nodes.

W4(I) NUMBER OF POINTS IN RADIAL POWER DISTRIBUTION.

W5(I) NUMBER OF AXIAL POWER DISTRIBUTION SHAPES.

Example:

```
3, 0, 8, 2, 1
```

A.15.93 Card 93, Axial Power Time and Elevation Array

W1(R) TIME FOR WHICH NTH AXIAL SHAPE IS USED (s).

W2(R) AXIAL POWER DISTRIBUTION SHAPE/ELEVATION ARRAY FOR ABOVE TIME. Elevations must match axial node elevations.

Example:

```
1440., 1., 0.0572,
       1., 0.1715,
       1., 0.2858,
       1., 0.4001,
       1., 0.5144,
       1., 0.6287,
       1., 0.7430,
       1., 0.8573
```

A.15.94 Card 94, Radial Power Distribution/Positions

W1...(R) RADIAL POWER DISTRIBUTION/POSITIONS (m).

Example:

1., 0., 1., 20.463E-3

A.15.95 Card 95, Power and Time Data

W1(R) POWER (W/m^3).

W2(R) TIME (s).

Example:

0., 0.
0., 700.
0., 1440.

----End of Shroud Input----

The following input data have been added to the integrated code to give it the capability to model multiple fuel bundles.

----Beginning of input that specifies grouping of SCDAP components----

A.15.96 Card 96, Fuel Bundle Groups

W1(I) NUMBER OF FUEL BUNDLE GROUPS WITH SCDAP COMPONENTS. The number of enclosures for radiation calculations is set equal to the number of fuel bundles with SCDAP components. A fuel bundle typical of that in each bundle group is described. The number of bundles represented by the typical bundle is controlled by input on Card 95.

Example:

1

[NOTE: Read Cards 97 through 105 for each bundle.]

A.15.97 Card 97, View Factors and Path Length Flag

W1(I) FLAG FOR SPECIFYING WHETHER VIEW FACTORS AND PATH LENGTHS ARE TO BE INPUT OR CALCULATED BY CODE.

0 = input by code user

1 = calculated by code

Example:

1

[NOTE: If view factor and path length flag is 0, use Cards 98 through 101.]

A.15.98 Card 98, Bundle Components

W1(I) NUMBER OF DIFFERENT COMPONENTS IN BUNDLE (including shroud).

W1(I) COMPONENT NUMBER WHICH ENCLOSES THE BUNDLE. Input zero if there is no shroud.

Example:

2, 0

A.15.99 Card 99, Numbers of Components in Bundle

W1...(I) NG1, NG2 ... etc., where NG1 is the number of the first component in the bundle. Each differently numbered component must be entered.

Example:

1, 2

A.15.100 Card 100, View Factors

W1...(I) VIEW FACTORS FROM ITH COMPONENT TO JTH COMPONENT. A square matrix (number of components by number of components) is input.

Example:

0.9062	0.0938
0.9311	0.0689

A.15.101 Card 101, Radiation Path Lengths

W1(R) PATH LENGTHS OF RADIATION FROM ITH COMPONENT TO JTH COMPONENT (m). A square matrix (number of components by number of components) is input.

Example:

0.01	0.01
0.01	0.01

[NOTE: If view factor and path length flag is 1, use Cards 102 through 104.]

A.15.102 Card 102, Rows and Columns of Bundle

W1(I) NUMBER OF ROWS OF RODS IN A TYPICAL BUNDLE. The maximum number is 20.

W2(I) NUMBER OF COLUMNS OF RODS IN A TYPICAL BUNDLE. The maximum number is 20.

Example:

3, 3

A.15.103 Card 103, Matrix of Components of the Bundle

W1...(I) MATRIX OF INTEGERS IDENTIFYING THE COMPONENT IN EACH SLOT OF THE BUNDLE. The rows and columns of the matrix correspond to the rows and columns of the bundle. If a rod is missing from an outer row or column, then input 0 for that slot. Component numbers correspond to the order in which the components are input. Maximum size of the input matrix is 20 by 20.

A 0 can be placed anywhere in the peripheral rows or columns.

Example:

1	1	1
1	2	1
1	1	1

A.15.104 Card 104, Pitch of Rods

W1(R) PITCH OF RODS IN BUNDLE (m).

Example:

0.0128

A.15.105 Card 105, Flow Shroud Component Number

W1(I) COMPONENT NUMBER OF FLOW SHROUD THAT SURROUNDS BUNDLE. If the bundle does not have a flow shroud, input 0.

Example:

0

[NOTE: If only one core component with a fuel pellet radius less than 0.2 E-3 m has been defined and the COUPLE model has been turned on (Card 109), then data defining core slumping must be input. Otherwise, it must be omitted. The core slumping data are defined on Cards 106 through 108.]

A.15.1.106 Card 106, User-Defined Core Slumping

W1(R) TIME AT WHICH CORE SLUMPING BEGINS (s).

W2(R) TIME AT WHICH CORE SLUMPING ENDS (s). Core slumping is considered to occur at a uniform rate between the start and end times of slumping.

Example:

```
5.   6.
```

A.15.1.107 Card 107, Mass of Each Material That Slumped

W1(R) MASS OF URANIUM DIOXIDE THAT SLUMPED INTO OR ONTO STRUCTURE MODELED BY COUPLE DURING PERIOD OF CORE SLUMPING (kg).

W2(R) MASS OF METALLIC URANIUM (kg).

W3(R) MASS OF ZIRCALOY (kg).

W4(R) MASS OF OXIDIZED ZIRCALOY (kg).

W5(R) MASS OF BORON CARBIDE (kg).

W6(R) MASS OF STAINLESS STEEL (kg).

W7(R) MASS OF SILVER (kg).

W8(R) MASS OF ALUMINUM (kg).

W9(R) MASS OF CADMIUM (kg).

W10(R) MASS OF LITHIUM (kg).

Example:

0.0 0.0 100. 0.0 0.0 0.0
0.0 0.0 0.0 0.0

A.15.1.108 Characteristics of Slumped Material

W1(R) TEMPERATURE OF SLUMPED MATERIAL (K).

W2(R) RADIUS OF PARTICLES OF SLUMPED MATERIAL (m). If slumped material has no porosity, then input 0.0 for particle radius.

W3(R) POROSITY OF SLUMPED MATERIAL.

W4(R) TOTAL POWER (HEAT GENERATION RATE) IN SLUMPED MATERIAL (W).

Example:

1200. 0.0 0.0 1.3E+5

A.15.109 Card 109, End of SCDAP Input Data

W1...(A) Comment card (needed with COUPLE code calculation).

Example:

End of SCDAP input.

[NOTE: If COUPLE model calculation is *not* to be performed on heatup of debris that slumps into the lower plenum, then no further data are input. If COUPLE model calculation is to be performed, then the COUPLE model data are input here.]

A.16. SEVERE ACCIDENT CORE BEHAVIOR INPUT--COUPLE SUBROUTINE

The COUPLE input data consist of a series of ordered input blocks or input data sections. Those data blocks that do not apply to a particular job may be omitted without affecting other sections of input. Each data block consists of an initial block header card, several data cards, and a block terminator blank card. No units are built into the program, and the user must be careful to be consistent throughout. The input is not freeform and must be properly positioned within the specified columns (spaces) of 80-character records (cards). Integer and exponential types of input data must be right-hand justified. The required type of input data is indicated by A for alphanumeric, I for integer, and R for real. The columns for each piece of input data are specified by the two numbers to the left of the definition of the piece of input data. The type of input data is indicated by the character in parentheses to the right of the column specifier.

A.16.1 Card 1, Header for Title Block

1-5(A) BLOCK HEADER. Since only the first 4 characters, Columns 1 through 4, are actually checked on each block header card for each section, the rest may be used as a comment card.

Always input the following word: TITLE

A.16.2 Card 2, Title Card

1-80(A) FIRST TITLE CARD.

Example:

Modified SFD 1-1 with 4 central control rods

A.16.3 Card 3, Title Card

1-80(A) SECOND TITLE CARD. This is a good place to list the unit set employed.

A.16.4 Card 4, Block Terminator

BLOCK TERMINATOR (blank card)

A.16.5 Card 5, Header for Mesh Generation Block

1-8(A) HEADER FOR MESH GENERATION BLOCK. Always input the following word: AUTOMESH.

A.16.6 Card 6, Mesh Generator Control Card

1-5(I) MAXIMUM VALUE OF I IN MESH. This is the maximum number of nodes in the horizontal direction.

6-10(I) MAXIMUM VALUE OF J IN MESH. This is the maximum number of nodes in the vertical direction.

11-15(I) NUMBER OF MATERIAL BLOCKS TO BE ASSIGNED. This is the number of different material regions specified on Card(s) 9.

16-20(I) GEOMETRIC CODE.

0 = r, z axisymmetric

1 = x, y plane body

21-30(I) MULTIPLIER. This multiplier operates on dimensions that are input on Card(s) 7 and elsewhere in the input. The multiplier allows the COUPLE input to use inches as the unit for length even though the calculations use meters as the unit for length.

A.16.7 Card(s) 7, Line Segment Cards

LINE SEGMENT CARDS. Any reasonable combination of internal and external line segments which represent circular arcs, straight lines, or points in the r, z (or x, y) plane can be used to generate a finite element mesh. The line segments are defined by the location of the end points. Circular line segments are defined by one intermediate point, or the center, in addition to the end points. The line segment cards can be input in any order. Any given (I,J) pair can be input only once.

The elements which may be filled by relocated material must be quadrilateral and not triangular in shape. Two of the sides must be perpendicular to the direction in which material is transported into the element.

1-3(I)	I COORDINATE OF 1ST POINT
4-6(I)	J COORDINATE OF 1ST POINT
7-14(R)	r COORDINATE OF 1ST POINT
15-22(R)	z COORDINATE OF 1ST POINT
23-25(I)	I COORDINATE OF 2ND POINT
26-28(I)	J COORDINATE OF 2ND POINT
29-36(R)	r COORDINATE OF 2ND POINT
37-44(R)	z COORDINATE OF 2ND POINT
45-47(I)	I COORDINATE OF 3RD POINT

If the line segment type (columns 67 to 71) is 0 or 1, then omit the input in columns 48 through 66.

48-50(I) J COORDINATE OF 3RD POINT

51-58(R) r COORDINATE OF 3RD POINT

59-66(R) z COORDINATE OF 3RD POINT

67-71(I) LINE SEGMENT TYPE PARAMETER

0 = Point (Input only 1st I, J, r, z.)

1 = Straight line (Input only 1st and 2nd set of I, J, r, z as end point of line.)

3 = Circular arc with mid-point of arc specified (Input 1st and 3rd sets of I, J, r, z as end points of arc and 2nd set as midpoint on arc.)

4 = Circular arc with center of radius of curvature specified (Input 1st and 2nd sets of I, J, r, z as end points of arc and 3rd set of r, z as coordinates of center of radius of curvature.)

Straight or curved lines segments in the r, z plane must correspond to either a straight line (I or J constant along line) or a stepped diagonal segment [ABS(ΔI)=ABS(ΔJ)] in that I, J plane. Note on a stepped diagonal segment that I is incremented first and then J.

Repeat Card 7 until the finite element mesh has been completely defined by the specification of line segments. In general, a finite-element mesh can be completely defined by inputting a Card 7 for each segment of the surface of the mesh.

A.16.8 <u>Card 8, Line Segment Card Block Terminator</u>

BLOCK TERMINATOR (blank card)

A.16.9 Card(s) 9, Material Block Assignment

MATERIAL BLOCK ASSIGNMENT. A card is needed for each block specified. Each card assigns a material definition number to a block of elements defined by the I, J coordinates.

1-5(I) MATERIAL IDENTIFICATION NUMBER. The COUPLE model considers five different materials. The materials and their identification numbers are:

Material	ID No.
Relocated debris	1
Stainless steel	2
Inconel	3
Carbon steel	4
Null material	6

Each element defined to have relocated debris is considered to contain coolant until the coolant has been displaced by relocated debris that has slumped into the element.

6-10(I) MINIMUM I

11-15(I) MAXIMUM I

16-20(I) MINIMUM J

21-25(I) MAXIMUM J

26-35(R) Always input 0.0.

36-45(R) POROSITY OF MATERIAL IN THESE ELEMENTS.

46-50(I) MATERIAL FLAG. For materials other than material type 1 (relocated material), always input the integer 0. For material type 1, indicate as follows whether relocated material is in the mesh at the start of the analysis.

0 = No material in region.

2 = Material in region.

51-55(I) Always input 0.

56-65(R) SIZE OF PARTICLES IN THESE ELEMENTS (m). If porosity is zero, input zero for particle size.

A.16.10 Card 10, Material Block Terminator

BLOCK TERMINATOR (blank card)

A.16.11 Card 11, Material Block Header

1-8(A) BLOCK HEADER. Always input the following word: MATERIAL.

A.16.12 Card 12, Material Data Information

1-5(I) NUMBER OF DIFFERENT MATERIALS TO BE DEFINED. Materials that do not exist in the finite element mesh can be defined.

A.16.13 Card 13, Emissivity

1-10(R) EMISSIVITY. Emissivity for internal radiation in material with ID No. 1.

A.16.14 Card(s) 14, Material Properties

1-5(I) MATERIAL IDENTIFICATION NUMBER.

11-20(R) DENSITY OF MATERIAL (kg/m^3).

21-52(A) MATERIAL TITLE INFORMATION.

A.16.15 Card(s) 15, Material Multipliers

MATERIAL MULTIPLIERS. These are multipliers on MATPRO-calculated properties for material defined on Card 14.

1-10(R) THERMAL CONDUCTIVITY MULTIPLIER. Always input 1.0.

21-30(R) SPECIFIC HEAT MULTIPLIER. Always input 1.0.

31-45 Blank

(NOTE: Repeat Cards 14 and 15 until each type of material in the mesh has been defined.)

A.16.16 Card 16, Material Block Terminator

BLOCK TERMINATOR (blank card).

A.16.17 Card 17, Time Step Data Block Header

1-4(A) TIME STEP DATA BLOCK HEADER. Always input the following word: STEP.

A.16.18 Card 18, Temperature Control Card

31-40(R) INITIAL TEMPERATURE OF FINITE ELEMENT MESH (K).

41-50(R) RELAXATION PARAMETER IN NUMERICAL SOLUTION. Recommended value is 0.5.

51-60(R) CONVERGENCE PARAMETER IN NUMERICAL SOLUTION. Recommended value is 1.0.

61-70(R) INNER RADIUS OF LOWER HEAD OF VESSEL. Use the same units as the coordinates on Card 7. If a spherical lower head is not being modeled, input 0.0.

A.16.19 Card 19, Description of Lower Head of Vessel

1-10(R) OUTER RADIUS OF REGION IN FINITE ELEMENT MESH THAT CAN FILL WITH SLUMPING MATERIAL. Use the same units as the coordinates on Card 7. If a spherically shaped lower head is being modeled, input 0.0. If a cylindrically shaped lower head is being modeled or plane coordinates are being used, then this input is used. If plane coordinates are being used, this input specifies the inner radius of pipe being modeled in plane geometry.

11-20(R) THICKNESS OF LOWER HEAD OF VESSEL. Use the same units as the coordinates on Card 7. If a spherical lower head is not being modeled, then input the distance from the bottom of the finite element mesh to the surface that supports the slumping material.

21-25(I) SPHERICAL LOWER HEAD MODELING FLAG.

0 = Spherical lower head of vessel is not being modeled.

1 = Spherical lower head of vessel is being modeled.

26-30(I) MAXIMUM NUMBER OF ITERATIONS. Recommended value is 10.

31-40(R) INNER RADIUS OF REGION THAT CAN FILL IN WITH SLUMPING MATERIAL (same units as for Card 7). Omit for the case of spherical lower head. Omit this input for MOD2 version of the code. Omit this input for the case of plane geometry.

41-50(R) DEPTH (THICKNESS) OF PLANE (same units as for Card 7). Omit this input for axisymmetric geometry.

A.16.20 Card 20, Block Terminator

BLOCK TERMINATOR (blank card).

A.16.21 Card 21, Internal Heat Generation Block Header

1-10(A) BLOCK HEADER. Always input the following word: GENERATION.

A.16.22 Card 22, Number of Nodes with Internal Generation

1-5(I) NUMBER OF MATERIALS FOR WHICH INTERNAL GENERATION IS NOT POSSIBLE. If relocated debris is being considered, input the number that is one less than the input in Columns 1 through 5 of Card 12. Otherwise, input the same number.

A.16.23 Card 23, Blank Card

A.16.24 Card 24, Material Numbers with No Internal Generation

1-5(I) FIRST MATERIAL NUMBER.

6-10(I) SECOND MATERIAL NUMBER.

Continue in Col. 11-15, 16-20, etc., until all materials defined in Card 14 have been identified. Although material ID one (relocated debris) must be included on this card, nevertheless internal heat generation is considered for this material.

A.16.25 Card 25, Block Terminator

BLOCK TERMINATOR (blank card).

A.16.26 Card 26, Convection Data Block Header

1-11(A) BLOCK HEADER. Always input the following word: CONVECTSETS.

A.16.27 Card 27, Number of Nodes with Convection

1-5(I) NUMBER OF NODES IN FINITE ELEMENT MESH AT WHICH CONVECTION HEAT TRANSFER CAN OCCUR. Nodes that are specified twice on Card(s) 29 count as two nodes for this input. Nodes that are part of finite elements that receive relocated material should be defined as nodes at which convection heat tranfer occurs. Otherwise, convective heat transfer will not be modeled at the surface of the relocated material.

6-10(I) Input the integer 1.

A.16.28 Card 28, Boundary Conditions at Start of Analysis for Finite Elements that Can Fill with Slumping Debris

1-10(R) Always input 1000.0.

11-20(R) Always input 500.0.

A.16.29 Card(s) 29, Identification of Surfaces with Convective and Radiative Heat Transfer

All convective boundary data should be input for a line of points (that is, I2 equal I1, J2 not equal J1 or I2 not equal I1, J2 equal J1) with the nodal coordinates increasing from the first to the second node. The program will automatically assign values at nodal points intermediate to the first and second defined nodal points. Each line must contain a minimum of two points. Nodes that are on a surface and not listed on Card 29 are treated as being part of an adiabatic surface.

1-5(I) I COORDINATE OF 1ST NODE.

6-10(I) J COORDINATE OF 1ST NODE.

11-15(I) I COORDINATE OF 2ND NODE.

16-20(I) J COORDINATE OF 2ND NODE.

21-30(R) Leave these columns blank.

A.16.30 , Number of Interfacing RELAP5 Volume

Omit for MOD2 of SCDAP/RELAP5.

1-10(I) NUMBER OF RELAP5 VOLUME THAT INTERFACES THESE NODES. Input the full nine-digit number.

Cards 29 and 30 are repeated as many times as necessary to define all the convection boundary data.

A.16.31 Card 31, Block Terminator

BLOCK TERMINATOR (blank card).

A.16.32 Card 32, Initial Temperature Block Header

1-8(A) BLOCK HEADER. Always input the following word: TEMPSETS.

A.16.33 Card 33, Number of Temperature Nodes

5-10(I) NUMBER OF NODES IN MESH AT LOCATIONS THAT MAY BE FILLED WITH SLUMPING DEBRIS. Always input the interger 0.

16-20(I) Always input the integer 0.

21-30(R) Always input 0.0.

A.16.34 Card 34, Block Terminator

BLOCK TERMINATOR (blank card).

A.16.35 Card 35, Plot Control Header

1-5(A) BLOCK HEADER. Always input the following word: PLOTS.

A.16.36 Card 36, Plot Control Card

1-5(I) Always input the integer 1.

6-10(I) Always input the integer 0.

11-15(I) Always input the integer 2.

A.16.37 Card 37, Plot Control Block Terminator

BLOCK TERMINATOR (blank card).

A.16.38 Card 38, Solution Control Header

1-6(A) BLOCK HEADER. Always input the following word: COUPLE.

A.16.39 Card 39, Solution Control Block Terminator

BLOCK TERMINATOR (blank card).

A.16.40 Card 40, Problem Termination Card

1-11(A) PROBLEM TERMINATION CARD. Always input the following words: END OF DATA.

A.17. 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 STRIPS 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.

A.18. SCDAP/RELAP5 OPERATING PROCEDURES

When operating on a CRAY under UNICOS, the SCDAP/RELAP5 program can interpret a command line:

```
selp62.x      -f fort.21        -i input      -o output \
-p plotsl     -r rstplt         -s strips     -w sth2x t
```

The command line above is written with all of the allowed options (prefixed by a minus sign), and each option is followed by its default file name. If an option and its parameter are not entered, the default is used. An option must always be entered with a file name, and an option may not be repeated. The -f option is not operable. The fort.21 file was ftbl on previous versions and is a scratch word addressable file. The word addressable I/O is done by CRAY library subroutines, and these have successfully resisted external open and close statements. This file is small and can fit in most directories. This file should be removed after execution, but no error occurs in subsequent calculations if it is not removed. The file input contains input data, output contains printed output, plotsl contains plotter information, rstplt is the restart plot file, strips is the strip file, and sth2x t is the water property file. New files such as the output file should be empty, since system output routines apparently write over an existing file rather than erasing an old file and then writing.

The command line capability eliminates the need to have all files needed for SCDAP/RELAP5 execution in the same directory or to copy/rename files to match the default names. For example, the command:

```
selp62.x -i myprob -o /tmp/rjw/myprob.o \
-r /tmp/rjw/myprob -w /u2/rjw/selap/sth2x t
```

takes the executable file and input file from the current directory, uses a temporary disk for the output and restart-plot files, and uses a water property file in a different directory.

For other operating systems, the default file names must be used.

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. 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. SUCCES is a code variable that indicates if a time step is successful (SUCCES = 0 means success#ul, 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

```
##################################################################################################################
    jchoke Diagnostic printout, timehy =  0.1030000    , dt =  1.0000000E-03, ncount =      123, help = -1, succes =  1, fail = T

From jchoke    3140000       123  1.03000E-01
Junction void fraction    4.73828E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.63059E+01  6.75187E-01 -2.16011E+04  2.42588E+06          F  2.42588E+06  4.95498E+02  2.44815E+06  2.38379E+06
   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  3.32979E+01  3.36963E+01  1.32997E-02  1.30229E-02  1.84148E+01  1.87992E+01  1.87930E+01

From jchoke    3150000       123  1.03000E-01
Junction void fraction    5.15286E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.87549E+01  3.43229E-01 -1.00798E+04  2.37295E+06          F  2.37295E+06  4.94336E+02  2.38379E+06  2.34259E+06
   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  3.66173E+01  3.55497E+01  1.66629E-02  1.49283E-02  1.99504E+01  2.09160E+01  2.09033E+01

From jchoke    3160000       123  1.03000E-01
Junction void fraction    5.68265E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.61288E+01  4.42173E-02 -1.44034E+04  2.32740E+06          F  2.32740E+06  4.93320E+02  2.34259E+06  2.31119E+06
   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  3.89218E+01  3.72259E+01  1.89954E-02  1.80791E-02  2.18352E+01  2.28338E+01  2.28233E+01

From jchoke    3170000       123  1.03000E-01
Junction void fraction    5.84386E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.66780E+01  2.65696E-02 -1.32665E+04  2.29709E+06          F  2.29709E+06  4.92636E+02  2.31119E+06  2.29314E+06

   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  4.04416E+01  3.77453E+01  2.05582E-02  1.90271E-02  2.27986E+01  2.44274E+01  2.44116E+01

From jchoke    3180000       123  1.03000E-01
Junction void fraction    5.94561E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.73429E+01  1.98141E-02 -1.53705E+04  2.27687E+06          F  2.27687E+06  4.92175E+02  2.29314E+06  2.27872E+06
   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  4.13095E+01  3.86198E+01  2.14531E-02  1.96694E-02  2.40696E+01  2.59999E+01  2.59820E+01

From jchoke    3190000       123  1.03000E-01
Junction void fraction    6.02934E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.83151E+01  1.56393E-02 -1.83410E+04  2.25940E+06          F  2.25940E+06  4.91774E+02  2.27872E+06  2.26848E+06
   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  4.21990E+01  3.93878E+01  2.23547E-02  2.02241E-02  2.56501E+01  2.74732E+01  2.74570E+01

From jchoke    4000000       123  1.03000E-01
Junction void fraction    5.71383E-01flow direction     1.00000E+00
  psmf        psmg        psld        pjun        choke       pres        psat        po-up       po-dn
  3.82144E+01  4.46701E-02 -6.61599E+04  2.20123E+06          T  2.20123E+06  4.90423E+02  2.26848E+06  1.00000E+05
   iq  sounde-up   sonic       quale-up    qualso-up   velfj(i)    velgj(i)    vc
    2  3.97182E+01  3.57772E+01  2.00620E-02  1.77170E-02  9.36377E+01  1.68355E+02  1.67604E+02
Final vel   4000000       123  1.03000E-01  2.83524E+01  3.58526E+01
##################################################################################################################
```

Figure B-1. Diagnostic edit from Edwards Pipe problem with extras.

APPENDIX C

SCDAP/RELAP5 INPUT DECK PREPARATION GUIDELINES

APPENDIX C

SCDAP/RELAP5 INPUT DECK PREPARATION GUIDELINES

C.1 INTRODUCTION

The purpose of this appendix is to provide the SCDAP/RELAP5 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 SCDAP/RELAP5 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 SCDAP/RELAP5 system model can represent a significant and time-consuming effort, it is hoped that the guidelines contained herein will help to facilitate that effort.

C.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 in order to simulate the type of transients to be performed. For example, if a large break is postulated in the pump discharge leg of a pressurized water reactor (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 main steam isolation valves (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--These 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--These 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.

C.3 PLANT DATA ACQUISITION

The type of plant most often modeled by the SCDAP/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 an 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 it 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.

C.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 keyword 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.

C.5 PLANT NODALIZATION

Application of the SCDAP/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 SCDAP/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 SCDAP/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 SCDAP/RELAP5 plant nodalization is presented to provide further insight into the process of establishing a nodalization scheme.

C.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 SCDAP/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 C-5.2, 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:

a. 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.).

b. 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).

c. 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 SCDAP/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 SCDAP/RELAP5 components follows:

o 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

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a. SCDAP/RELAP5 component designation.

single flow path exists between the two volumes. Note that a one-volume PIPE component can generally be used interchangeably with the SNGLVOL component.

- 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.

- 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.

- o 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.

- o 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).

- o 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 that the ANNULUS component must be vertical.

- o 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.

- 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.

- 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 describes the actions of the various types of valves and presents a detailed discussion of the application of each valve type.

- Pump (PUMP)--The PUMP component is used to model pumps. A detailed description of this component is presented in Section 2.3.1.

- Multiple-Junction Component (MTPLJUN)--This hydrodynamic component has been designed to simplify input needed to approximate multi-dimensional flow. Although this component can specify multiple junctions that can connect arbitrary volumes within a system in the same manner as several single-junction components, its primary use is to specify multiple crossflow junctions to connect volumes in different pipe components with a minimum amount of input data. An example of two-dimensional modeling of a reactor core could be three vertically oriented pipe components--one pipe component for the center of the core. the second for a middle annular ring, and the third for the outer annular ring. The pipe component junctions provide the axial connections. One multiple-junction component can specify the crossflow junctions to connect the volumes at the same axial level for all axial levels.

- 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

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.

C.5.2 Plant Nodalization Example

In this section, an example of a SCDAP/RELAP5 plant nodalization is presented. As many types of facilities can be modeled with SCDAP/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 SCDAP/RELAP5 hydrodynamic components used to model segments of the plant, all represent good first a 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

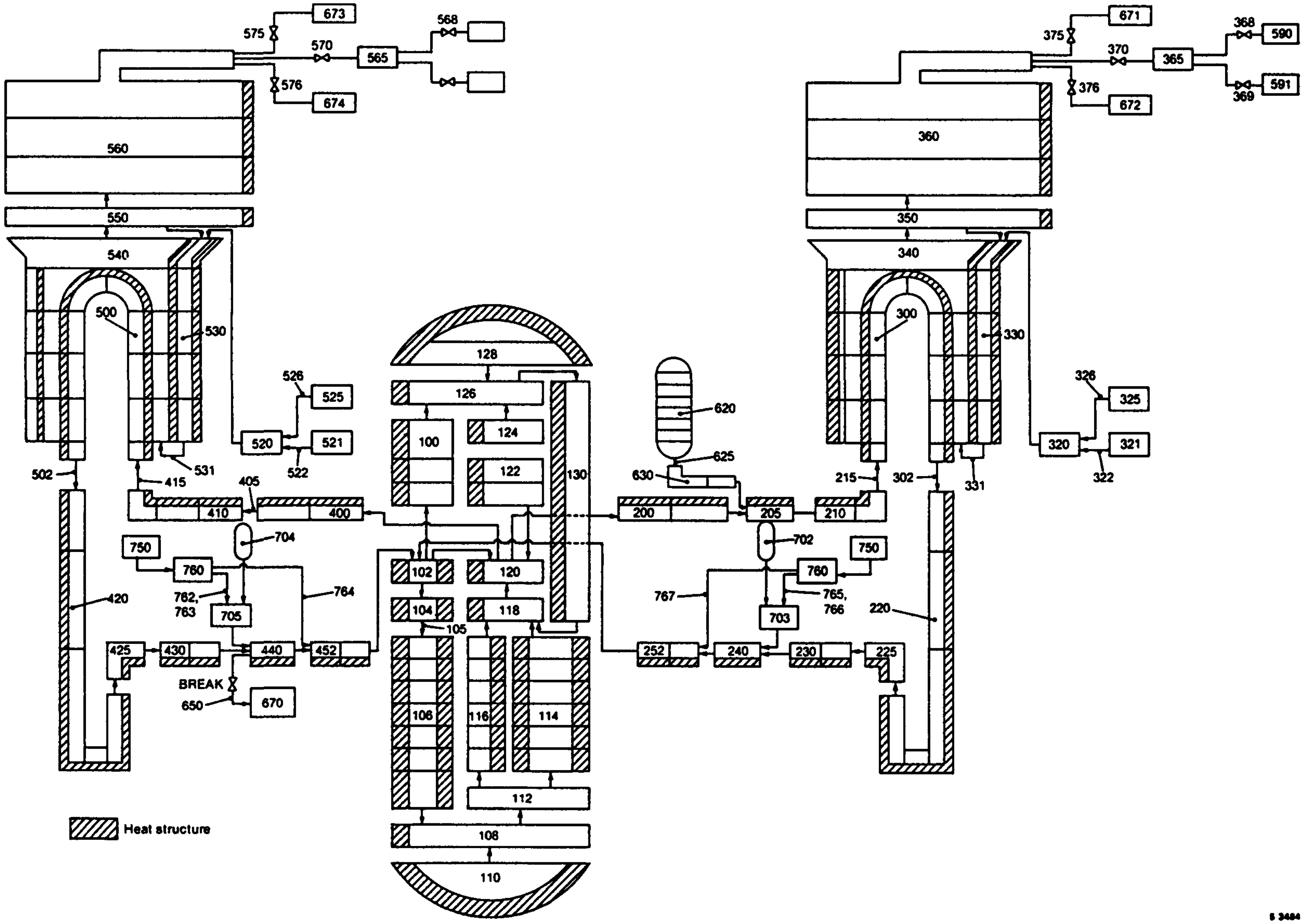

Figure C-1. SCDAP/RELAP5 nodalization diagram for a multiple-loop, pressurized water reactor plant.

TABLE C-1. SCDAP/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

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
210	Intact loop hot leg from surge line segment to steam generator	PIPE	2
215	Junction between hot leg and steam inlet generator 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	--

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
330	Intact loop steam generator downcomer (lower section)	ANNULUS	5
333	Intact loop steam generator downcomer to riser junction	SNGLJUN	--
340	Intact loop steam generator riser up to feed ring	PIPE	5
350	Intact loop steam generator separator	SEPARATR	1
360	Intact loop steam generator steam dome plus steamline to MSIV	PIPE	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

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
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	--
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)	TMDPVOL	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

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
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 generator main steam line 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	--
590 591	Volumes used to control pressure of intact loop steam generator and accept steam from steam dump system	TMDPVOL	--
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

TABLE C-1. (continued)

Component	Component Description	Component Type	Number of Volumes
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	--
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. SCDAP/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 wall3	
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 rod17	
1161	Core baffle assembly	3
1181	Upper core plate and fuel assembly top nozzles	3
1211	Upper core support columns	4
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

TABLE C-2. (continued)

Heat Structure	Heat Structure Description	Number of Mesh Points
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
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

TABLE C-2. (continued)

Heat Structure	Heat Structure Description	Number of Mesh Points
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

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 the 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 one 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 three actual loops in the PWR plant, flow areas and fluid volumes in the model would be three 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 five hydrodynamic volumes,[a] with one of the junctions being located at the point where the pressurizer surge line connects to leg. The downflow portion of the pump suction leg is modeled with three 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 upflow legs. The pump discharge leg

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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.

should be represented with five hydrodynamic volumes, with two of the junctions being located at points where accumulator and emergency core cooling 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 one 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 eight volumes: four up and four down for Westinghouse steam generators; three up, two across, and three down for Combustion Engineering (CE) steam generator; and eight 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, four volumes represent the heated length of the boiler, while for B&W steam generators the boiler region would contain eight volumes. The portion of the secondary above the boiler and below the separator deck in Westinghouse and CE generators is represented with two volumes. The downcomer is represented with six 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 in the downcomer. The steam dome above the separator is modeled with two 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 eight 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 three 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 six 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 eight volumes. Similarly, eight 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 one 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, two to seven mesh intervals (depending on structure thickness) are usually sufficient to adequately describe the various vessel heat structures. The fuel rods should generally be modeled using eight mesh intervals, five for the fuel, one for the gap, and two for the cladding; although for the case involved here a larger number of intervals was used to obtain a more detailed rod response.

C.6 INPUT DECK PREPARATION AND DOCUMENTATION

The preparation of a SCDAP/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 SCDAP/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. 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.

C.7 STEADY-STATE INITIALIZATION

Completion of the basic input data deck preparation as described through Sections C-6 of this Appendix 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 SCDAP/RELAP5 steady-state calculation. The self-initialization option provides a convenient method for achieving the desired steady-state with minimal computer time.

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.

C.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.

C.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.

C.7.1.2 Multi-Loop Models

Ordinarily, a multi-loop model will contain two or more symmetric or asymmetric 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.

C.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.

C.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.

C.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	A-2.1	Problem type and option; used to specify steady-state option
140	A-2.13	Self-initialization control card; used to specify number of each type of generic controller
141-142	A-2.13	Self-initialization pump controller identification cards; used to relate pump controllers to pumps being controlled
143-144	A-2.13	Self-initialization steam flow controller identification cards; used to relate steam flow controllers to valves being controlled
145-146	A-2.13	Self-initialization feedwater controller identification cards cards; used to relate feedwater flow controllers to valves being controlled
147	A-2.13	Pressure and volume control component identification card; used to identify time-dependent volume, its connection point, and pressure level
201-299	A-3.2	Time step control cards; used to specify nearly implicit solution scheme option
205NNN00	A-13.2	Control component type card; one entry for each control component (NNN is the component number); provides characteristics of component
205NNNXX	A-13.3	Control component data cards; one entry for each control component (NNN is the component number); provides data on set point, sensed parameter, and control constants

a. This is not an exhaustive list of all data that will be required (e.g., time-dependent volume data are also needed). However, these data cards are uniquely required for the self-initialization options.

1. The core power can be imposed as a constant boundary condition using a general table. If the point kinetics model is to be used for the ensuing transient analysis, it should also be used for the steady-state calculation. Some means of arriving at a constant power (usually user-selected) must be provided. One option is a reactivity computed by an appropriate control system. A simpler technique is to omit all reactivity feedback information for the steady-state calculation. The resultant power will remain equal to the input power. Feedback information can be entered at restart for the transient simulation.

2. Modeling of the makeup and letdown 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 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; 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 that 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.

C.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 set point 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.

C.7.3.1 PUMPCTL Components

The relationship between primary coolant pump speed and loop flow rate is relatively 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 flow rate and the control variable to be a pump speed. Recalling the control expression as:

$$Y_{1_0}^{n+1} = G_1\left(\frac{E_1}{T_1} + \frac{\int^{t_n} E_1 dt}{T_2}\right) + (Y_1) \qquad \text{(C-1)}$$

TABLE C-4. SUMMARY OF GUIDELINES FOR GENERIC CONTROL COMPONENT CONSTANTS

Constants	Units	Value
PUMPCTL		
$(Y_1)0$	Speed	Initial pump speed
G	--	1.0
S_1	Flow/speed	$\sim Q_R/N_R$
T_1	--	5.0
T_2	--	1.0
STEAMCTL ($T_{control}$)		
$(Y_2)0$	Fractional area (unitless)	Estimated fractional area to accommodate estimated steam flow.
G	--	1.0
S_j	Temperature/fractional area	-1.25
T_3	-	200
T_4	--	6000
STEAMCTL ($P_{control}$)		
S_j	Pressure/fractional	400 (pressure in psia)
All others	--	Same as $T_{control}$ values.
FEEDCTL		
$(Y_3)0$	Flow	Estimated feedwater flow rate
G	--	1.0
S_k	Level/flow	$k\ S_k T_5 \approx \frac{1}{3}\left(\frac{M_{sec}}{\dot{M}_{sec}}\right)$ 100% power[a]
S_m	Flow/flow	$(S_m T_5 \approx (S_k T_5/10$
T_5	--	Arbitrary (see above)
T_6	--	$T_6 \approx T_5$

a. K is the conversion factor to convert level to equivalent mass such that the units of S_k are mass/flow rate.

and that

$$E_1 = \frac{V_1 - V_2}{S_1} \tag{C-2}$$

where Y is in terms of speed and V in terms of flow, it follows that S_1 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:

$$\phi = \frac{Q_R}{N_R} \quad . \tag{C-3}$$

With appropriate modification to obtain consistent units, this value is appropriate for the scale factor S_1. That is,

$$S_1 = 1\phi \tag{C-4}$$

where k is determined by the necessary conversion factors to achieve Y in terms of mass flow rate when V is in terms of speed. This normally requires an assumed coolant density, since Q_R is conventionally expressed as a volumetric flow rate. Note that the sign of S_1 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_1 must be positive; since a positive error (i.e., flow is lower than set point) 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 5 and T_2 at 1.0, when utilizing a maximum time step size of 0.5 s. Ordinarily, the gain (G_1) would be set to unity.

C.3.2 STEAMCTL Component

The thermal response of the primary and secondary coolant systems is relatively sluggish, with the primary lagging the secondary. Consequently, thermal equilibrium in the primary coolant is generally the pacing condition in achieving steady state. (This is true regardless of whether secondary pressure control or cold leg temperature control is chosen.) Moreover, experience has shown that the steam flow controller is the least forgiving in terms of accepting a wide range of control settings with acceptable behavior.

The standard use of the STEAMCTL controller in the cold leg temperature control mode calls for the sensed signal to be a loop volume temperature and the control variable to be a valve setting. Typically, the latter would be expressed as a percent of full-open area. Consequently, the proportionality between the measured and controlled variables is a change in temperature with a change in percent area (actually, fraction of area). There is no straightforward method of determining what this characteristic proportionality should be. However, assuming a gain of unity, a value of S_j on the order of -1.25 has been found to work well. Here it should be noted that the minus sign is consistent with the relationship between the error signal and the control signal (i.e., a positive error signal means that the sensed temperature is low with respect to the set point, requiring a diminished steam flow valve area). The time constants required bear a relationship to the thermal inertia of the system. Experience dictates that values of 200 for T_3 and 6000 for T_4 produce good results. Experience also shows that it is quite important to establish an initial valve area ($Y_2 0$) that is reasonably close to the final value. This can be estimated by calculating the estimated valve area needed to pass the required steam flow, with the latter computed on the basis of an energy balance on the steam generator secondary side. This would be expressed as:

$$M_{sec} = \frac{Q_{core}}{(h_{out} - h_{in})_{sec}} \tag{C-5}$$

The use of the STEAMCTL controller in the secondary pressure control mode alters the meaning and effect of the proportionality constant (S_j). In this case, the units of the constant are pressure difference divided by fractional area. The recommended value for S_j for this mode is 400 when the pressure difference is expressed in psia. The values for G, T_3, and T_4 should be set as indicated above.

C.3.3 FEEDCTL Component

Feedwater control should be slaved to steam flow control so that the two control systems do not counteract each other. In practice, this means that the feedwater should react relatively quickly in response to changes in steam flow. Also, since primary-to-secondary heat transfer is relatively insensitive to secondary level, it is reasonable to allow the feedwater flow control to be dominated by the steam/feed mismatch rather than the level error.

The proportional scale factor for level (or mass) assumes the units of level (or mass) divided by mass flow rate, thereby becoming a de facto time constant for changing level (or mass). If the scale factor, S_k, is to be utilized for level control, then the product of S_k and T_5 should be set such that a change in feedwater flow would eliminate the level error in approximately one-third of the time it takes to completely replace the secondary coolant inventory under full-power conditions. That is,

$$S_k T_5 \approx \frac{1}{3}\left(\frac{m_{sec}}{\dot{m}_{sec}}\right) 100\% \text{ power} \quad . \tag{C-6}$$

The feedwater/steam flow error constant, S_m, should be input so that the product of it and T_5 is approximately 1/10 the magnitude of $S_k T_5$; i.e.,

$$S_k T_5 \approx \frac{S_k T_5}{10} \tag{C-7}$$

This causes the mismatch error to dominate over the level (mass) error in controlling feedwater flow. The above assumes that the overall gain, G, will be set to unity.

The choice for T_5 is somewhat arbitrary, subject to the guideline above and the relationship between T_5 and T_6. Good results have been obtained when these two values are approximately equal.