NUREG/CR-6150, Vol. 3, Rev. 2
INEL-96/0422

SCDAP/RELAP5/MOD 3.3 Code Manual

User's Guide and Input Manual

Idaho National Engineering and Environmental Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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NUREG/CR-6150, Vol. 3, Rev. 2
INEL-96/0422

SCDAP/RELAP5/MOD 3.3 Code Manual

User's Guide and Input Manual

Manuscript Completed: August 2000
Date Published: January 2001

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NRC Job Code W6095

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 and reactor core during severe accidents 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. The coolant system behavior is calculated using a two-phase model allowing for unequal temperatures and velocities of the two phases of the fluid, and the flow of fluid through porous debris and around blockages caused by reactor core damage. The reactor core behavior is calculated using models for the ballooning and oxidation of fuel rods, the meltdown of fuel rods and control rods, fission product release, and debris formation. The code also calculates the heatup and structural damage of the lower head of the reactor vessel resulting from the slumping of reactor core material. 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.

This volume provides guidelines to code users based upon lessons learned during the developmental assessment process. A description of problem control and the installation process is included. Appendix A contains the description of the input requirements.

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EXECUTIVE SUMMARY

The specific features of SCDAP/RELAP5/MOD3.3 are described in this five volume set of manuals covering the theory, use, and assessment of the code for severe accident applications. This set replaces the SCDAP/RELAP5/MOD3.2 Code Manuals, NUREG/CR-6150, Rev. 1.

The SCDAP/RELAP5 computer code is designed to calculate for severe accident situations the overall reactor coolant system (RCS) thermal-hydraulic response, core damage progression, and reactor vessel heatup and damage. The code was developed at the Idaho National Engineering and Environmental Laboratory (INEEL) under the primary sponsorship of the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC). The code is the result of merging the RELAP5 and SCDAP codes. The models in RELAP5 calculate the overall RCS thermal-hydraulics, control system interactions, reactor kinetics, and the transport of noncondensable gases. The RELAP5 code is based on a two-fluid model allowing for unequal temperatures and velocities of the fluids and the flow of fluid through porous debris and around blockages caused by reactor core damage. The models in SCDAP calculate the progression of damage to the reactor core. These models calculate the heatup, oxidation and meltdown of fuel rods and control rods, the ballooning and rupture of fuel rod cladding, the release of fission products from fuel rods, and the disintegration of fuel rods into porous debris and molten material. The SCDAP models also calculate the heatup and structural damage of the reactor vessel lower head resulting from the slumping to the lower head of reactor core material with internal heat generation. Although previous versions of the code have included the analysis of fission product transport and deposition behavior, this capability has been removed from SCDAP/RELAP5, and the analysis of fission product behavior is now performed using the detailed fission product code, VICTORIA[a], in an effort to reduce duplicative model development and assessment.

The SCDAP/RELAP5 code includes many generic component models from which general systems can be simulated. The component models include fuel rods, control rods, pumps, valves, pipes, reactor vessel, electrical fuel rod simulators, jet pumps, turbines, separators, accumulators, and control system components. In addition, special process models are included for effects such as form loss, flow at an abrupt area change, branching, choked flow, boron tracking, and noncondensable gas transport. The code also includes a model for reactor kinetics.

Several new capabilities and improvements in existing capabilities were implemented into the MOD3.3 version of SCDAP/RELAP5. The new capabilities include; (1) an integral diffusion method to calculate oxygen and hydrogen uptake accounting in mechanistic manner for steam starvation and rapid changes in temperature, (2) calculation of the relocation in the circumferential direction of melted metallic cladding retained by the oxidic portion of cladding, (3) calculation of the re-slumping of cladding that previously slumped and froze, (4) calculation of heat transfer in porous debris using correlations specific to porous debris, (5) calculation of flow losses in porous debris locations based on Darcy's Law and applying relative permeabilities and passabilities based on local debris conditions and volume fractions of the liquid and vapor phases of the coolant, (6) calculation of oxidation of both intact and slumped cladding under reflood conditions, (7) calculation of the heatup of the lower core structures and its interaction with slumping core material, (8) calculation of the behavior of jets of core material penetrating into a pool of

a. N. E. Bixler, "VICTORIA2.0: A Mechanistic model for Radionuclide Behavior in a Nuclear Reactor Coolant System Under Severe Accident Conditions," NUREG/CR-6131, SAND93-2301, December 1998.

water, (9) calculation of the permeation of melted core plate material into porous debris in the lower head of reactor vessel and affect of this permeation on lower head heatup, and (10) calculation of heatup of lower head containing melted core material and accounting for whether the melted material is well-mixed or stratified into oxidic and metallic pools. The improvements in existing modeling capabilities include; (1) a semi-mechanistic stress-based model instead of a wholly empirical model for failure of the oxidic portion of cladding retaining melted metallic cladding, and (2) more simplistic but accurate models for calculating position, configuration, and oxidation of melted fuel rod cladding that slumped to a lower location and froze. The MOD3.3 version of the code retains all of the capabilities of the previous version, namely MOD3.2.

This volume, Volume 3, gives detailed descriptions of the input preparation and execution procedures. It also provides code installation procedures, as well as general guidelines on code applications.

ACKNOWLEDGMENTS

Acknowledgments are made to those who made significant contributions to this and earlier versions of SCDAP/RELAP5, B. D. Reagan, D. L. Knudson, F. Griffin, J. L. Rempe and M. Sohal. The authors also acknowledge the former RELAP5 development team, specifically R. A. Riemke and J. Tolli for their contributions to SCDAP/RELAP5.

The SCDAP/RELAP5 Program is indebted to the technical monitor, J. Schaperow and S. Arndt of the U. S. Nuclear Regulatory Commission who was responsible for directing the overall program. Finally, acknowledgment is made of those many code users who have been very helpful in stimulating correction of code deficiencies and suggesting improvements.

1. INTRODUCTION

The SCDAP/RELAP5/MOD3.3 computer code is designed to calculate for severe accident situations the overall reactor coolant system (RCS) thermal-hydraulic response, reactor core and vessel damage progression, and, in combination with VICTORIA,[1] fission product release and transport during severe accidents. The code was developed at the Idaho National Engineering and Environmental Laboratory (INEEL) under the primary sponsorship of the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC).

1.1 General Code Capabilities

The code is the result of merging the RELAP5/MOD3[2] and SCDAP[3] models. The RELAP5 models calculate the overall RCS thermal-hydraulics, control system interactions, reactor kinetics, and transport of noncondensable gases. A model is also included in RELAP5 to calculate flow losses in porous debris. Although previous versions of the code have included the analysis of fission product transport and deposition behavior using models derived from TRAP-MELT, this capability has been replaced through a data link to the detailed fission product code, VICTORIA, as a result of an effort to reduce duplicative model development and assessment. The SCDAP models calculate the heatup and damage progression in the core structures and the lower head of the reactor vessel. The calculations of damage progression include calculations of the meltdown of fuel rods and structures, the fragmentation of embrittled fuel rods, convective and radiative heat transfer in porous debris, the formation of a molten pool of core material, and the slumping of molten material to the lower head.

SCDAP/RELAP5 is capable of modeling a wide range of system configurations from single pipes to different experimental facilities to full-scale reactor systems. The configurations can be modeled using an arbitrary number of fluid control volumes and connecting junctions, heat structures, core components, and system components. Flow areas, volumes, and flow resistances can vary with time through either user-control or models that describe the changes in geometry associated with damage in the core. System structures can be modeled with RELAP5 heat structures, SCDAP core components, or SCDAP debris models. The RELAP5 heat structures are one-dimensional models with slab, cylindrical, or spherical geometries. The SCDAP core components include representative light water reactor (LWR) fuel rods, silver-indium-cadmium (Ag-In-Cd) and B_4C control rods and/or blades, electrically heated fuel rod simulators, and general structures. A two-dimensional, finite element heat conduction model based on the COUPLE[5] code may be used to calculate the heatup of the lower head of the reactor vessel and the slumped material supported by the lower head. This model takes into account the decay heat and internal energy of newly fallen or formed debris and then calculates the transport by conduction of this heat in the radial and axial directions to the wall structures and water surrounding the debris. The most important use of this model is to calculate the heatup of the vessel lower head and the timing of its failure in response to contact with material that has slumped from the core region. Other system components available to the user include pumps, valves, electric heaters, jet pumps, turbines, separators, and accumulators. Models to describe selected processes, such as reactor kinetics, control system response, and tracking noncondensable gases, can be invoked through user control.

The development of the current version of the code was started in the spring of 1998. This version contains a number of new capabilities and improvements in existing models since the last version of the code, SCDAP/RELAP5/MOD3.2 was released. The new capabilities include; (1) an integral diffusion method to calculate oxygen and hydrogen uptake in the fuel cladding, (2) calculation of the relocation in the circumferential direction of melted metallic cladding retained by the oxidic portion of cladding, (3)

calculation of the re-slumping of cladding that previously slumped and froze, (4) calculation of heat transfer in porous debris using correlations specific to porous debris, (5) calculation of flow losses in porous debris based on Darcy's Law and applying relative permeabilities and passabilities based on local debris conditions and volume fractions of the liquid and vapor phases of the coolant, (6) calculation of oxidation of both intact and slumped cladding under reflood conditions, (7) calculation of the heatup of the lower core structure and its interaction with slumping core material, (8) calculation of the behavior of jets of core material penetrating into a pool of water, (9) calculation of the permeation of melted core plate material into porous debris in the lower head of a reactor vessel and the affect of this permeation on lower head heatup, and (10) calculation of heatup of lower head containing melted core material and accounting for whether the melted material is well-mixed or stratified into oxidic and metallic pools. The improvements in existing modeling capabilities include; (1) a semi-mechanistic stress-based model instead of a wholly empirical model for failure of the oxidic portion of cladding retaining melted metallic cladding, (2) more simplistic but accurate models for calculating position, configuration, and oxidation of melted fuel rod cladding that slumped to a lower location and froze. In addition to the above changes, the MOD3.3 version of the code retains all of the capabilities of its previous version, namely MOD3.2. The differences between MOD3.3 and MOD3.2 result in input data for MOD3.2 being slightly different from that for MOD3.2. These differences are described in Section A17.

1.2 Relationship to Other NRC-Sponsored Software

SCDAP/RELAP5 and RELAP5 were developed in parallel and share a common configuration. Both codes share a common source deck. Separate codes are formed only prior to compilation, so changes made to the source deck are automatically reflected in both codes.

The development and application of the code is also related to several other NRC-sponsored software packages. Theoretical work associated with the development of PARAGRASS-VFP[5] has resulted in model improvements for fission product release. A link with PATRAN[6] and ABAQUS[7] provides the user with the means to calculate the details of lower head failure. Animated plant response displays are possible through links to the Nuclear Plant Analyzer (NPA)[8] display software, which gives the user an efficient way of analyzing the large amount of data generated. Detailed plant simulations from accident initiation through release of fission products to the atmosphere are possible by applying SCDAP/RELAP5 results to analyses with VICTORIA[1]code for fission product release and transport, CONTAIN[9] code for containment response and CRAC2[10] or MACCS[11] codes for atmospheric dispersion consequence.

1.3 Quality Assurance

SCDAP/RELAP5 is maintained under a strict code configuration system that provides a historical record of the changes made to the code. Changes are made using an update processor that allows separate identification of improvements made to each successive version of the code. Modifications and improvements to the coding are reviewed and checked as part of a formal quality program for software. In addition, the theory and implementation of code improvements are validated through assessment calculations that compare the code-predicted results to idealized test cases or experimental results.

1.4 Organization of the SCDAP/RELAP5 Manuals

The specific features of SCDAP/RELAP5/MOD3.3 are described in a five-volume set of manuals covering the theory (Volume 2) user's guidelines and input manual (Volume 3), material properties

(Volume 4), and assessment (Volume 5). Although Volume 1 describes (a) the overall code architecture, (b) interfaces between the RELAP5 and SCDAP models, and (c) any system models unique to SCDAP/RELAP5, the code user is referred to the companion set of six volumes which describe the RELAP5 system thermal-hydraulics and associated models.

Volume 1 presents a description of SCDAP/RELAP5/MOD3.3-specific thermal-hydraulic models (relative to RELAP5/MOD3), and interfaces between the thermal-hydraulic models and damage progression models.

Volume 2 contains detailed descriptions of the severe accident models and correlations. It provides the user with the underlying assumptions and simplifications used to generate and implement the basic equations into the code, so an intelligent assessment of the applicability and accuracy of the resulting calculation can be made.

Volume 3 provides the user's guide and code input for the severe accident modeling. User guidelines are produced specifically for the severe accident code. The user should also refer to the RELAP5/MOD3 Code Manual Volume V: User Guidelines for a complete set of guidelines.

Volume 4 describes the material property library, MATPRO. It contains descriptions of the material property subroutines available for severe accident analysis.

Volume 5 documents the assessment of SCDAP/RELAP5/MOD3.3. It summarizes the improvements made to MOD3.3 and the affect of these improvements on code calculations. A presentation is made of the comparisons of MOD3.3 calculations of a wide range of severe fuel damage experiments with the measured results of these experiments and with the calculations of MOD3.2. Also presented are the MOD3.3 and MOD3.2 calculations of the TMI-2 accident and calculations of severe accidents in typical PWRs and BWRs.

1.5 Organization of Volume 3

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 includes 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.

Section 2 of this volume describes the type of core structures that can be modeled with SCDAP/RELAP5. Section 3 provides user guidelines. Section 4 describes nodalization guidelines. Section 5 provides problem control and output editing. Section 6 discusses the installation process, and Section 7 provides references. Appendix A documents the input requirements for SCDAP/RELAP5.

2. CORE STRUCTURES

The core structures represent those portions of the reactor core which are solid at the beginning of the analysis. This may include fuel rods, control rods, flow shrouds, simulator rods, or channel boxes.

2.1 Fuel Rod

The 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 two-dimensional finite difference scheme. The oxidation heat of zircaloy is the dominant heat source after temperatures reach 1,500 K. Cladding deformation is based on mechanical models developed for FRAP-T6[12] and FRAPCON-2.[13] 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[5] model.

2.2 Ag-In-Cd Control Rod

Control rod temperatures are computed using the same heat conduction model as the fuel rods. User-specified nuclear heating, chemical heating caused by 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 relocation 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.

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 caused by 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 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 non-melting models can be used for the structures outside the core as well, since the same material limitations apply.

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 scheme. Cladding deformation is based on mechanical models developed for FRAP-T6 and FRAPCON-2. The melt, flow, and refreezing of liquefied U-O-Zr are also considered.

2.5 BWR Control Blade/Channel Box Model

Analyses of the DF-4 and CORA experiments have shown that the effects of B_4C/stainless steel interactions, as well as stainless steel/zircaloy interactions, must be included to predict control blade relocation accurately. Melting of a control blade begins at the inner surfaces of the absorber rodlets where stainless steel reacts with B_4C. The absorber rodlets fail at a temperature that is lower than the melting temperature of pure stainless steel. Stainless steel from the control blade then relocates downward and forms a blockage between the control blade and channel box, where it reacts with the zircaloy. The zircaloy channel box adjacent to the stainless steel blockage enters into the formation of a eutectic mixture and fails at a temperature that is much lower than the melting of pure zircaloy.

2.6 B_4C Control Rod Model

The B_4C control rod model has been retained in the code because some reactors make use of cylindrical B_4C control rods wherever possible, the use of the control blade channel box model, described in Section 2.5 is recommended.

Control rod temperatures are computed using the same heat conduction model as the fuel rods. User-specified nuclear heating, chemical heating caused by 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 absorber 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 absorber; rather, the material freezes when it reaches a lower elevation where the guide tube temperature is 200 K less than the solidus temperature. 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 relocation of molten B_4C. 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.

3. SCDAP/RELAP5 USER GUIDELINES

3.1 SCDAP/RELAP5 Card Number Input

The SCDAP/RELAP5 input structure has traditionally comprised three different styles--RELAP5 card number, SCDAP unformatted, and COUPLE fixed format. While the SCDAP unformatted input was free-form, it provided no capability for input checking or error recovery during the input process. The COUPLE input scheme required that the input be right-justified within a specified range of columns. This input structure made creation of severe core accident analysis input decks time-consuming, frustrating, and unreliable due to extremely primitive levels of input checking. The input had virtually no error detection, and bad input often ended in floating point exceptions and I/O errors. Resolving input errors often required knowledge of the code structure, use of debugging tools, and use of code debug printout. Since RELAP5-style card-number input provided significantly greater flexibility in input checking, and since users are already familiar with this style of input, all SCDAP/RELAP5 input has been converted to use RELAP5-style card-number input.

Input for SCDAP/RELAP5 is processed on three levels, (a) input echo; (b) individual card, or R-level processing; and (c) initialization, or I-level processing. This input philosophy provides the maximum diagnostic information for each input submittal. During input echoing, the input deck is echoed to the output file; and cards with the same card numbers (replacement cards) are detected. At the R-level processing, the cards are read in and, wherever possible, basic range checking is performed to be sure that the input variables fall within physical limits. At this input level the code is able to provide only primitive input checking, since information is available only about the current card. During the initialization, or I-level processing, more global range checking is performed; and the code is able to verify self-consistency between cards.

As a minimum, all input will be subjected to four comparative checks: (1) physical/code limits, such as a fuel pellet radius greater than the inner cladding radius, (2) consistency of input, such as a radial node omitted at a material interface, (3) number of words on a card, and (4) variable type. A fifth check, for range of normal use, will also occur during input processing wherever applicable. Input violations of physical and/or code limits, consistency of input, number of words on a card, and variable type will result in an input error but will not abort input processing. Wherever possible, input data that has previously been shown to cause a code abort are now tested, and diagnostic messages issued. Rejected input will be identified and reset to a benign value to allow complete input processing. The selected ranges of allowable input are listed with the card input descriptions in Appendix A. This appendix also contains additional information on the type of checks that will be performed.

Sequential expansion, as found in RELAP5, is used wherever possible. In sequential expansion, sets of data used to specify parameters are followed by an integer, which specifies the range over which the parameters should be applied. As an example, if a data set can be applied to each axial node of a component, then the integer would be the final axial node over which the data were to be applied. Utilization of sequential expansion significantly decreases the size of an input deck and is a technique which RELAP5 users have applied for many years. Additional examples are available in Reference 2.

3.2 Input Preparation

Attention to detail in preparing, documenting, and checking the input limits errors and provides a valuable model reference for tracking error corrections and subsequent model improvements. By using

standardized input format and conventions, input errors are easier to detect. The following sections discuss standard procedures for model documentation and quality assurance, input deck arrangement, and conventions.

3.2.1 Input Deck Arrangement

The code accepts data based on the "card number" specified in the first field on each line of input. For a given card number, the code accepts the input parameters specified in the code manual as sequences of floating point, integer, and alphanumeric entries. On any given card, the data entries must appear in the proper sequence and be separated by one or more blanks. The cards may appear in any order, as long as all required cards and data entries are present. If a card number is duplicated in the input listing, the code identifies it as a "replacement card" and uses the information on the last card entered with that number.

As stated above, the input deck cards may appear in any order. In practice, however, arranging the cards in a logical manner is preferred. At the INEEL input decks typically start with the title, job control, and time step control cards. These are followed in sequence by the minor edit requests, trip specifications, hydrodynamic components, heat structures user-input data tables, control variables, and reactor kinetic specifications. An input deck is generally arranged by increasing card numbers when this arrangement is used. Within each of the above groups, data are similarly arranged in order of the card numbers (e.g., the trips are listed in numerical order).

A well-organized input deck includes comment cards that aid interpreting the input from a printed listing. Comments may be inserted through the use of the asterisk (*). On any line, all entries following an asterisk are assumed to be comments. With this format, an analyst will spend a minimum amount of time counting fields and searching through the manual to understand the input.

3.2.2 Model Input Debugging

The input processing routines provide excellent error-checking and error-interpretation capabilities. Input processing error checking is invoked when executing both new- and restart-type problems. All model input errors result in the generation of an informative error message. The presence of one or more input errors results in job termination and a message that the termination was due to input error. As a word of caution, the SCDAP/RELAP5 error-checking functions are primarily intended to check for compliance with the input data requirements. Secondarily, checking is performed for model consistency (e.g., that fuel rod diameter does not exceed pitch). However, the input error-checking function may not uncover basic input errors such as incorrectly specifying a radius of 0.050 m as 0.50 m. Therefore, successful completion of SCDAP/RELAP5 input processing should not be considered a replacement for a quality assurance activity such as a 'workbook', as described in the RELAP5 user guidelines.[2]

An efficient method for debugging a new SCDAP/RELAP5 input deck is described as follows. The complete model is first assembled into a single file and the model is executed in either the transient or steady-state modes as specified on Card 100. Either the INP-CHK or the RUN option may be selected on Card 101. A typical new input deck will likely contain many input errors so the execution will result in generation of a series of error messages. It is common for one actual error to propagate into the generation of multiple error messages. Therefore, the list of error messages generated will in general be much longer than the actual number of errors in the model. The user should read and consider each of the error messages in the order they were generated. This process results in one of the following determinations for each of the error messages: (a) the message clearly indicates an error in the deck and the resolution is clear, (b) the message is found to be caused by the existence of a previous error and is expected to be resolved

when the primary error is corrected, and (c) the reason the message was generated is not clear. In practice, the error messages are very informative and the actual input errors are obvious to the analyst. A significant effort can be expended tracing the source of each error message. Instead, it is more efficient to survey the error messages, correct the obvious errors, and again execute the model. As a rule of thumb, only about one third of the error messages generated are caused by actual errors; the remainder are second-generation messages resulting from the primary errors. This iterative process proceeds rapidly to the removal of all input errors. Experience shows that a large input deck that has been entered with moderate care can be debugged with this process in about five iterations.

The iterative debugging process described in the previous paragraph can be much easier if the output of the debugging runs are reviewed on a terminal by an editor capable of searching for data strings. All input error messages are preceded by a string of eight asterisks (********) and the removal of all errors results in the generation of the message "Input processing completed successfully". The user should be cautioned that even when there are no input error messages (marked by eight asterisks), there may still be input warning messages (marked by eight dollar signs). Although not fatal, these messages may assist in identifying additional errors.

The user should be aware that the input processing is subdivided into several sections of data checking that are performed in sequence. Depending on the nature of the errors found, the job may be terminated at the end of one of the sections before all of the error-checking sections have been executed. In this instance, only error messages for the sections that have been checked will appear. When these errors have been corrected and the checking proceeds to the next section, the number of error messages may increase. In other words, the analyst should realize that in this iterative process the number of error messages may not monotonically decrease.

3.3 Problem Execution

When the input deck has successfully passed input processing, an initial time edit will be generated by the code. If the RUN option is selected, problem execution proceeds from the conditions specified in the initial edit. The initial edit will be identified as zero time for NEW problems and as the time of the restart edit for RESTART problems.

3.3.1 Time Step and Edit Selections

The problem execution is controlled by the options specified on the 201 - 299 time step control cards. These cards specify the time step sizes and output features desired as the problem progresses from one time interval to the next. Card 201 specifies these options and the end time for the first time interval, Card 202 for the second time interval, and so on. Subdividing the problem into time intervals facilitates modifying the execution to suit the expected nature of the problem. For example, consider the case of a modeling action (such as closing a valve or tripping a pump) that is of particular interest and may slow the calculation at a given time (say 10 seconds). For this case, a first execution interval might be selected to end at 9 seconds. The second interval might include a reduced time step, and perhaps increased edit and plot frequencies, from 9 to 15 seconds. After 15 seconds, a third interval would then be used to return the time step and edit options to their original values. Note that execution is terminated if the problem time reaches the end of the last interval specified on the 201 - 299 cards.

For each time interval, minimum and maximum time steps are specified. The code will attempt to execute the problem at the maximum time step. The first time step taken will be at the maximum value. The user is cautioned to use a small maximum time step size when first executing a model for which gross

approximations of initial conditions have been specified. Time step size is automatically reduced based on a number of tests. The material Courant limit may not be violated. Mass, fluid property, quality, and extrapolation errors are monitored in each calculational cell and the time step is reduced if errors exceed internally preset limits. The major edit output indicates the criteria and model region causing time step reduction. This indication can be useful for improving model performance.

The code accomplishes time step reductions by repeated division by two until the errors are within acceptable limits, the minimum time step size is reached, or a failure is encountered. The severe accident subcode, SCDAP, now has the ability to impact the time step selection as well. Phenomena which have more impact during severe accident analysis, such as radiation heat transfer, can apply significant stress to the code. These phenomena can now be used to force SCDAP/RELAP5 to repeat the time advancement with a reduced time increment.

3.4 Plot Variables

One of the primary resources for an analyst using the SCDAP/RELAP5 code is the plot file. Severe accident transients, by the very nature, have parameters which are changing rather dramatically with time, and system 'snapshots', such as are provided by the major edits, reveal only part of the story. The severe accident analyst is encouraged to make extensive use of the ability to plot parameters from the restart/plot file. Specification of the parameters of interest are done by use of '208' cards, and the code user is referred to Appendix A of this report for details on the use of these cards.

3.5 Guidelines for Late Phase Damage Progression

The uncertainties involved in modeling the late phase damage progression make it useful to perform bounding studies on the calculated times of molten pool slumping and failure of the lower head. The areas of modeling with large uncertainty include:

- Strength and configuration of solidified material that supports a pool of molten core material.
- Fragmentation temperature of embrittled fuel rods that are quenched.
- Flow area of break resulting in creep rupture failure in piping system.
- Configuration of slumping molten material.
- Heat transfer coefficient between debris and the lower head of the reactor vessel.

A parameter for each of these areas of modeling can be defined by the code user so that a series of analyses can be performed to bound the possible behavior of the reactor. This section provides guidelines for the range of values of these parameters in order to calculate the range of possible reactor behavior.

An integer parameter is provided on SCDAP input Card 40001100 to provide an estimate of the range of time in which a molten pool slumps to the lower head. If this parameter is set to a value of one, then the molten pool is considered to slump to the lower head whenever material at the periphery of the core has become molten. In this modeling option, solidified material at the periphery of the core is considered to have no strength for supporting a molten pool. This value of the input parameter provides an

estimate of the earliest possible time of molten pool slumping. If the parameter on Card 40001100 is set to a value of zero, then the crust supporting the molten pool is considered to always have the strength necessary for supporting a molten pool. The molten pool does not slump to the lower head until its supporting crust at some point is calculated to melt. This value of the input parameter provides an estimate of the latest possible time for slumping of the molten pool. For both values of the input parameter, if the molten pool is calculated to slump, all of the molten material is calculated to slump. The assumption is applied that the initial point of failure of the crust is eroded to a depth sufficient to allow drainage of the entire molten pool. This assumption and the two types of slumping behavior defined by Card 40001100 are an interim solution until a model is implemented for calculating the structural integrity of the crust

Embrittled fuel rods are considered to fragment when their temperature decreases to a value less than the user-defined fragmentation temperature. The fragmentation temperature is user-defined because the code does not have a mechanistic model for the timing of fragmentation. The most likely time for embrittled fuel rods to fragment is during the period of rapid temperature change that occurs when the mode of heat transfer at the cladding surface changes from film boiling to nucleate boiling. The thermal stresses in the cladding are maximum during this period of time. An upper bound value on fragmentation temperature is estimated to be the temperature at which the mode of heat transfer at the surface of fuel rods being quenched changes from film boiling to transition boiling. The lower bound of the fragmentation temperature is estimated to be the temperature at which the nucleate boiling mode of heat transfer occurs, which is near the saturation temperature of water. Other mechanisms for fuel rod fragmentation may be possible. If the user identifies one of these other mechanisms being in operation, then a fragmentation temperature appropriate for this mechanism should be defined. The user-defined value for fragmentation temperature has no influence on calculated results for the case of severe accidents in which no embrittled fuel rods are cooled below the upper bound value of the fragmentation temperature or in which all of the fuel rods are cooled to temperatures less than the lower bound value of fragmentation temperature. If fuel rods with cladding that is calculated to be embrittled are cooled to a temperature less than the fragmentation temperature, then the fuel rods are considered to disintegrate into porous debris. The upper bound on the calculated extent of core fragmentation is obtained by defining the fragmentation temperature to have its upper bound value. The lower bound on the calculated extent of core fragmentation is obtained by defining the fragmentation temperature to have its lower bound value.

The flow area of a break is defined by the RELAP5 input card for the valve component that represents the break. The break size is estimated to range from 25% to 200% of the flow area of the pipe that broke. Creep rupture calculations must first be requested for each possible location in the reactor piping system at which creep rupture may occur. The locations for which creep rupture is to be performed are defined on RELAP5 Cards 21000110 (no COUPLE) and 21000000 (with COUPLE). Then after the calculations have identified the time and location of the first creep rupture, the calculations are repeated with a break being defined for the location with a creep rupture.

The extent of breakup of material slumping from a molten pool may either be defined by the user or calculated by the code's fuel-coolant interaction model. If the stream of slumping molten material remains as an intact stream, then heat is not transferred from the molten material as it slumps. The molten material is at the same temperature when it impacts the lower head as it was when it was in the molten pool in the core region. In addition, the material that slumps to the lower head is defined to have no porosity. As a result, the lower head of the reactor vessel may heatup rapidly. If the molten material breaks into small droplets as it passes through liquid water, then the molten material is cool when it impacts the lower head. In addition, the material is considered to have open porosity that can be filled with water. The heat transferred from the small droplets of molten material to water may cause a significant increase in pressure in the primary coolant system.

3.6 Noncondensable Model

The noncondensable model is implemented by specifying a noncondensable gas type on control Card 110 and indicating a noncondensable quality on one or more volume initial condition cards. A mixture of noncondensable gases may be specified by indicating more than one gas type on Card 110 and specifying their mass fractions on Card 115. It should be noted that only one noncondensable gas mixture may be used in a problem, although the fractions of each gas type may change in each hydrodynamic volume, and the noncondensable gas must be hydrogen (or include hydrogen in the case of a mixture). This means that if nitrogen is present in one part of the system and hydrogen is present in another, then the system has a mixture of hydrogen and nitrogen, with the mixture consisting of 100% nitrogen and 0% hydrogen in one location and a mixture of 0% nitrogen and 100% hydrogen in another.

The noncondensable model assumes the gas is tracked with the vapor phase. Furthermore, the resulting gas-steam mixture is assumed to be isothermal (i.e., the gas and steam are in thermal equilibrium). A total pressure is calculated for the gas-steam mixture; the partial pressure of steam is available as a standard output variable.

3.7 BWR Channel Box User Guide

This section describes the input data that the user must specify on SCDAP input cards for the BWR control blade and channel box component. Also, information is provided to help the user interpret the printed output.

3.7.1 BWR Blade/Box Cards

The specific SCDAP input cards for the BWR control blade and channel box component are documented in Appendix A. This section provides additional information to help the user prepare data for the input deck. All descriptions in this section refer to the new SCDAP input format with RELAP5-style card numbers (see Section A. 1 of Appendix A).

Hardwired default failure (liquefaction) temperatures are used to account for the effects of eutectic interactions between B_4C/stainless steel and stainless steel/zircaloy. Eutectic interactions are modeled by using failure (liquefaction) temperatures that are less than the melting temperatures of the pure materials.

The metal/water reaction parameters on Card 40003100 affect the B_4C and zircaloy oxidation calculations. The user must specify a maximum fraction of B_4C in each node that can react. This maximum fraction is used by the advanced $B_4C/H_2/H_20$ chemistry package to control the mass of B_4C available for the chemical equilibrium calculations.

The control blade and channel box dimensions specified by the user on Cards 40CC0200 and 40CC0300 are sketched in Figure 3-1. The actual control blade radial dimensions shown in the top of Figure 3-1 are converted by the model into the equivalent slab geometry shown in the bottom of the figure. The equivalent slab thicknesses are calculated so that the cross-sectional area of each layer in the equivalent slab geometry is identical to the cross-sectional area in the actual geometry. The distance between the channel box and the first row of fuel rods (dimension 7 in Figure 3-1) is used in the relocation calculations to determine when the region on the fuel-bundle side of the channel box is blocked.

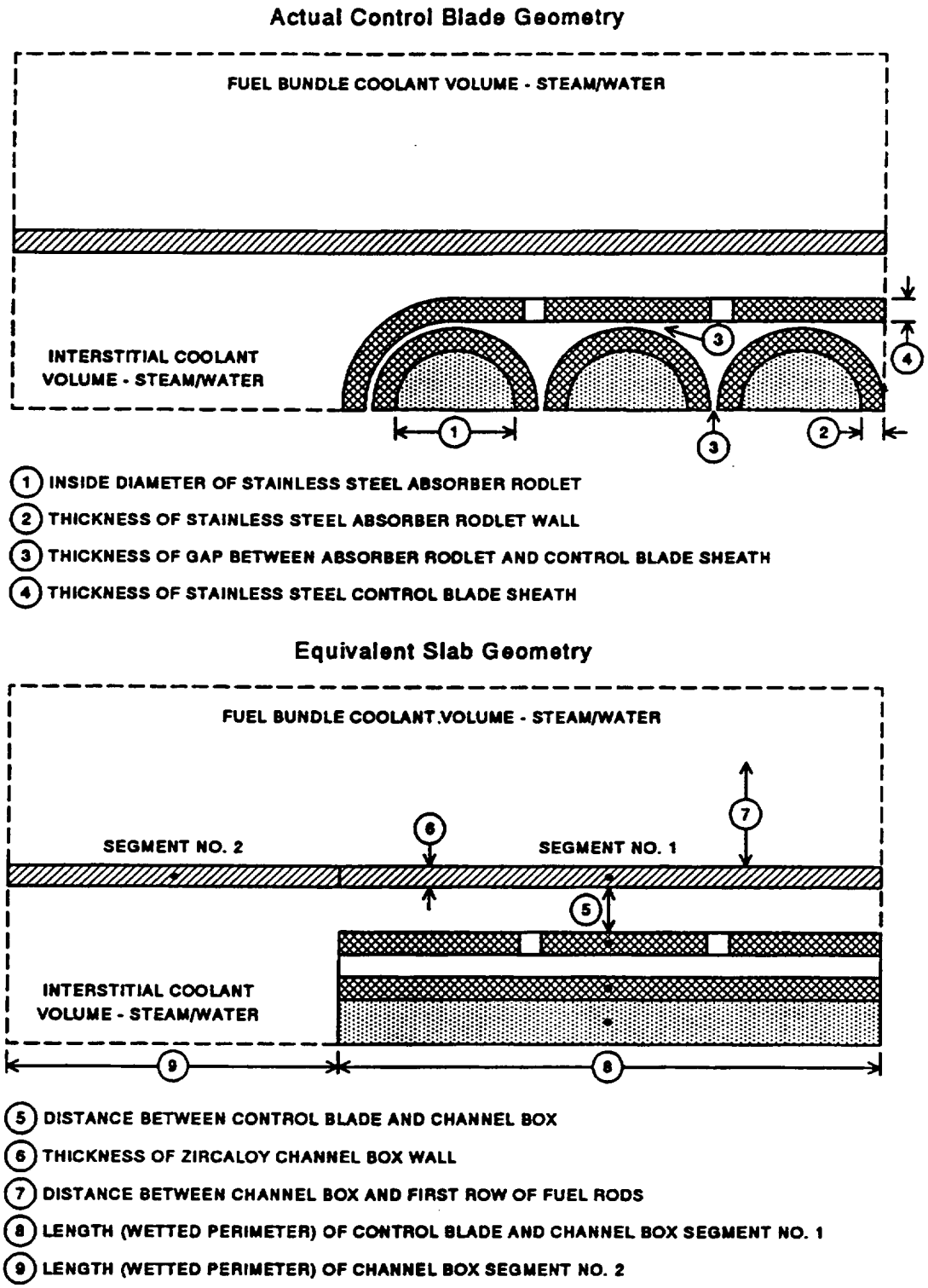


Figure 3-1. BWR control blade and channel box dimensions specified by the user.

As is the case for all other SCDAP components, the internal modeling for the BWR blade/box component is performed using a local set of dimensions that describes the single blade/box structure shown in Figure 3-1. However, the BWR blade/box component can be used to represent many copies of this individual blade/box structure by specifying the value on Card 40CC0100. If a value of 1 is specified on Card 40CC0100, then the component will perform calculations for half of a control blade and two channel box segments with lengths as indicated in Figure 3-1 (dimensions 8 and 9).

The geometric view factors specified on Card 40CC0300 are for radiation between the channel box and the control blade, which is modeled internally by the BWR blade/box component. These geometric view factors must be calculated by the user using the geometry sketched at the bottom of Figure 3-1. The sense of direction is from the channel box to the control blade, i.e., the view factors are based on the areas of the channel box segments.

Initial conditions for the BWR blade/box component are specified on Cards 40CC0500 and 40CC0601 through 40CC0699. The three oxide thicknesses on Card 40CC0500 apply to all axial nodes. The initial stainless steel oxide layer must be specified nonzero because this value is used as a denominator in the stainless steel oxidation calculations. This restriction does not apply to the initial ZrO_2 layers; they may be specified zero. The initial control blade temperatures specified for each axial node on Cards 40CC0601 through 40CC0699 (Word 1) apply to all three radial nodes. The initial channel box temperatures specified for each axial node on Cards 40CC0601 through 40CC0699 (Word 2) apply to both channel box segments.

If fuel rod or electrically-heated simulator rod components can receive molten material from a BWR blade/box component, then this information is specified on Cards 40CC0701 through 40CC0799 and 40CC0801 through 40CC0899. Cards 40CC0701 through 40CC0799 apply to radial spreading from channel box segment No. 1 while Cards 40CC0801 through 40CC0899 apply to segment No. 2. The mass fractions of molten material from channel box segment Nos. 1 and 2 are used to determine how molten material is proportioned between multiple fuel or simulator rod components that are located adjacent to the same channel box segment.

The mass fractions on Cards 40CC0701 through 40CC0799 and 40CC0801 through 40CC0899 can be used to represent radial spreading that occurs initially into the first row of fuel rods and later into the remainder of the fuel bundle. For example, assume the BWR fuel assembly shown in Figure 3-2 is modeled with SCDAP using one BWR blade/box component (No. 1) and three fuel rod components (Nos. 2, 3, and 4). If the following cards are specified for BWR blade/box radial spreading:

*crd.no	comp.no	frac.segl
40010701	2	0.999
40010702	4	0.001
*crd.no	comp.no	frac.seg2
40010801	3	0.999
40010802	4	0.001

then almost all molten material from channel box segment No. 1 (99.9%) will initially be received by fuel rod component No. 2 and almost all molten material from channel box segment No. 2 (99.9%) will initially be received by fuel rod component No. 3. However, the BWR blade/box relocation logic adjusts the mass fractions on Cards 40CC0701 through 40CC0799 and 40CC0801 through 40CC0899 when one of the fuel rods becomes blocked at an axial level by cohesive, rubble, or molten debris. Referring to the above example, after fuel rod component No. 2 becomes blocked at an axial level by debris, the mass fraction on

Card 40010701 (0.999) is changed to 0.0 and the mass fraction on Card 40010702 (0.001) is increased to 1.0. Subsequently, all molten material from channel box segment No. 1 will be received by fuel rod component No. 4.

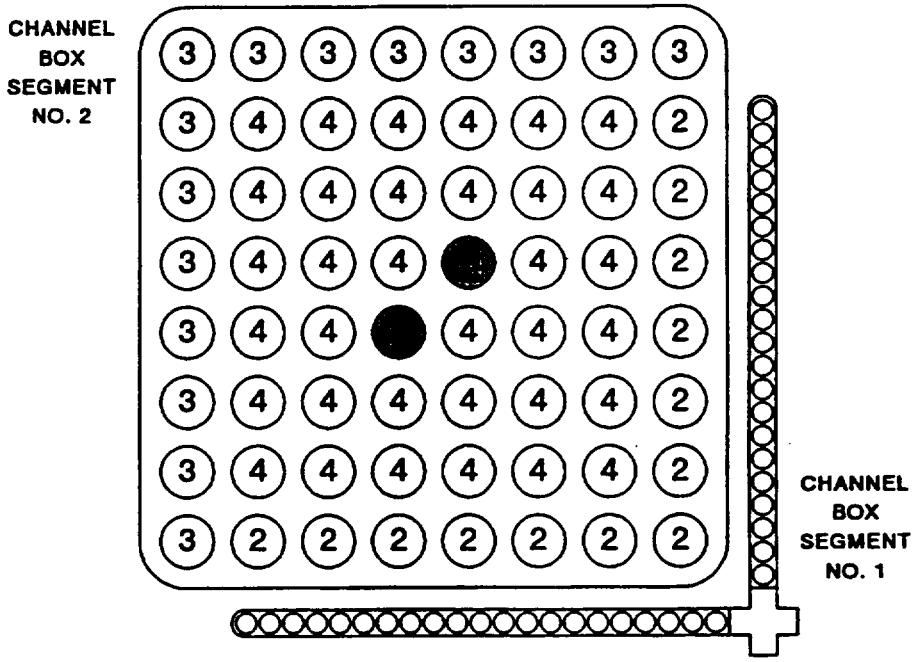


Figure 3-2. Example arrangement of fuel rod components.

3.7.2 Radiation Enclosure Cards

Each BWR blade/box component must be associated with two SCDAP radiation enclosures. One enclosure is for the fuel-bundle side of the channel box and the other is a "dummy" enclosure for the interstitial side of the channel box. Radiation calculations on the fuel-bundle side of the channel box are performed within the SCDAP radiation model using independent surfaces to represent the two channel box segments. The dummy enclosure on the interstitial side of the channel box is not actually used to perform radiation calculations between the channel box and the control blade (these calculations are performed [illegible] BWR blade/box model), but this enclosure is needed to initialize properly the hydrodynamic calculations for the interstitial volume. If the user does not define both SCDAP radiation enclosures for each BWR blade/box component, an error message is printed and execution is terminated after the completion of input processing.

When a BWR blade/box component is included within a radiation enclosure, the view factors and path lengths for that enclosure must be specified by the user on Cards 49NN1001 through 49NN1099 and 49NN1101 through 49NN1199. Because the two segments on the fuel-bundle side of the channel box are treated independently, view factors between channel box segment Nos. 1 and 2 can be calculated and specified, if necessary.

In the radiation enclosure section of an input deck (see the following example), the component number of a BWR blade/box component must be listed three times on Cards 49NN1000. The first two

BWR blade/box entries must be consecutive and are part of a radiation enclosure that represents the fuel-bundle region. These first two entries refer to segment Nos. 1 and 2, respectively, on the fuel-bundle side of the channel box. The third BWR blade/box entry must be on a separate Card 49NN1000 that represents the dummy enclosure for the interstitial side of the channel box. The input cards that define this dummy enclosure must follow the cards that define the fuel-bundle radiation enclosure.

For example, suppose there are two components in a SCDAP input deck and component No. 1 is a fuel rod and component No. 2 is a BWR blade/box. To model radiation between the fuel rods and the two channel box segments, the user must define enclosure No. 3 for the fuel bundle side of the channel box, followed by dummy enclosure No. 4 for the interstitial side of the channel box, using the following format:

```
*crd.no      name          type
49010000     fuel          bundle
*card. no    comp.nos
49011000     1  2  2
*crd.no      view.factor
49011001     0.2818    0.6782    0.0400
49011002     0.9400        0.0   0.0600
49011003     0.2094        0.2267   0.5639
*crd.no      path. length
49011101     0.001         0.005   0.015
49011102     0.005         0.0    0.015
49011103     0.015         0.015   0.010
*crd.no      name          type
49020000     dummy         bundle
*crd.no      comp.nos
49021000     2
*crd.no      view.factor
49021001     1.0
*crd.no      path.length
49021101     0.0
```

Component No. 2 (BWR blade/box) is listed twice on Card 49011000 and once on Card 49021000 of the above example. The view factor and path length arrays for enclosure No. 3 have two sets of entries for component No. 2. The second value on Card 49011001 (0.6782) is the view factor from the fuel rods to channel box segment No. 1. The third value on Card 49011001 (0.0400) is the view factor from the fuel rods to channel box segment No. 2. The third value on Card 49011002 (0.0600) is the view factor from channel box segment No. 1 to channel box segment No. 2. For enclosure No. 2, the view factor on Card 49021001 and the path length on Card 49021101 are dummy values.

3.7.3 Minor Edit Requests

The BWR blade/box variables that can be printed at "Minor Edits" or written to the restart-plot file are described in Appendix A, Section A4.10.5, Table A4-7. Although the variable names are identical to those used for other SCDAP components, these definitions apply only to the BWR blade/box components. These variables are "Expanded Edit/Plot Variables" and are not written to the restart-plot file by default. To write these variables to the restart-plot file, a RELAP5 Card 2080XXXX with the appropriate name and index must be added to the input deck. For all variable names, "Index" is defined as: ii = radial node number, kk = axial node number, and jj = SCDAP component number.

The locations of the BWR blade/box radial nodes for temperature variable CADCT are shown in Figure 3-3. The intact structures of the control blade and the channel box are at radial locations 2-4, 6, and 12. The temperatures defined for radial locations 1 and 14 are average surface temperatures that are used as boundary conditions for the RELAP5 hydrodynamic calculations. The temperatures at the other radial locations (5, 7, 8-11, and 13) have unique values only when those nodes are blocked and filled with relocated material; otherwise they are set equal to the temperature of the adjacent intact structure.

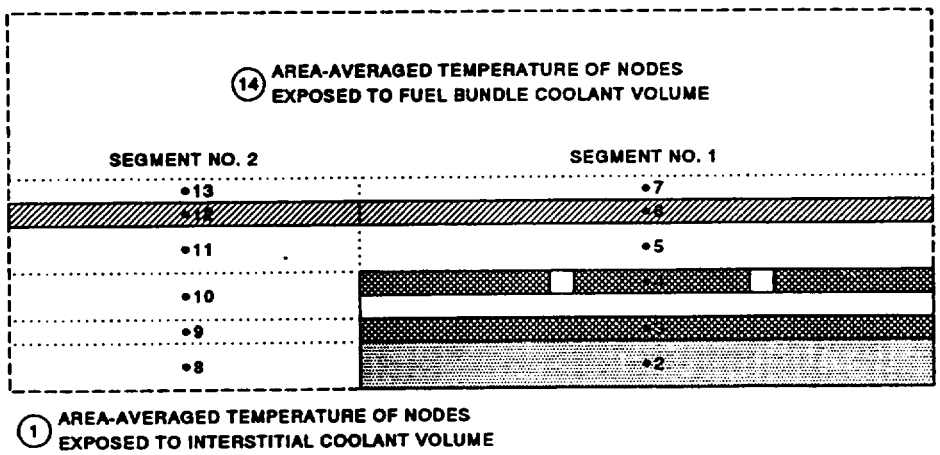


Figure 3-3. Radial node numbers used to print BWR blade/box temperatures at minor edits.

The variable DAMLEV is defined so that it can be used to control gas flow between the interstitial and fuel bundle coolant volumes after the channel box wall has failed. This is accomplished by using RELAP5 servo valve components with valve areas calculated by control system components based upon the values of DAMLEV.

3.7.4 Restart Calculations

A BWR blade/box calculation can be continued from a previous calculation by specifying the problem type on RELAP5 Card 100 as "restart" and the appropriate restart number on RELAP5 Card 103. Information from the restart-plot file is used to initialize the variables for BWR blade/box components.

4. NODALIZATION GUIDELINES

4.1 Core Nodalization Guidelines

Requirements for the nodalization of the reactor core for a severe accident analysis is significantly different from that needed for a comparatively simple hydraulic analysis. Section 3.9 discussed the reasons why a one- or two-channel analysis technique, which has been successful for analysis of thermal-hydraulic phenomena, is not appropriate for the phenomena associated with early phase severe accident conditions.

The nodalization of the core with five radial segments and ten to twenty axial nodes is considered to result in an adequate calculation of the core behavior during late phase damage progression. The nodalization sensitivity study presented in Reference 19 showed that the calculated time of slumping of the molten pool may be 7% later using twenty axial nodes instead of ten axial nodes. The nodalization sensitivity study also showed that if surge line rupture was ignored (high pressure case) the use of three radial segments instead of five resulted in an incorrect calculation of the core location where late phase damage progression began and resulted in a significantly earlier calculated time for the beginning of late phase damage. Each radial core segment should contain one SCDAP component to represent the fuel rods in that segment and one SCDAP component to represent the control rods/control blades. For PWRs, each radial core segment should contain one RELAP5 control volume representing the fluid in that segment. For BWRs, each radial segment should contain two RELAP5 control volumes, one representing the fluid flowing through the fuel assemblies and the other representing the fluid flowing between the fuel assemblies. Each RELAP5 control volume should be divided into as many subvolumes as axial nodes in the SCDAP components, and the subvolumes should overlay the axial segments of the SCDAP components. The reader is referred to the nodalization study documented in Volume 5 of this report for additional details.

4.2 Ex-vessel Example Nodalizations

This section provides example SCDAP/RELAP5 nodalizations for PWRs. The purpose of this section is to provide guidance for ex-vessel nodalization that may be used for analyzing a wide variety of small break LOCAs and operational transients. The user is cautioned that no model is generally applicable for simulating all transient scenarios. Care should be taken so that modeling and nodalization are appropriate for the particular application.

For economic reasons, the numbers of hydrodynamic cells and heat structure mesh points, in general, should be minimized. The computer run time needed to execute a problem simulation is determined almost completely by the number of hydrodynamic cells in the model. The number of heat structures generally increases in tandem with the number of cells. Therefore, a major economic benefit is gained by limiting the number of hydrodynamic cells in a model. Some additional economic benefit may be obtained by minimizing the number of mesh points within the heat structures. Limiting the number of other model features (such as trips and control variables) provides only minimal economic benefits. An additional motivation for employing the largest calculational cells possible, is that when small cells are used, the time step size is reduced as a result of the material Courant limit. The Courant limit, discussed in Reference 2, limits the calculational time step based on the ratio of cell length to fluid velocity.

The process of minimizing model size must always consider the phenomena to be modeled; minimizing must not proceed past the point where important phenomena are excluded from the simulation. This consideration is complicated because the importance of phenomena varies from one region of the model to another and is strongly affected by the transient to be simulated. For example, the important

model regions and simulation phenomena for small and large break loss-of-coolant accidents are dramatically different; therefore, appropriate modeling for these two sequences varies dramatically.

In summary, the modeler should select the minimum number of hydrodynamic cells and heat structure mesh points needed to calculate the important phenomena for the simulated transient. This guidance suggests that a general model (i.e., one that is to be used to simulate many different types of transients) should contain sufficient noding detail for all phenomena anticipated. If the important phenomena are uncertain, a detailed noding scheme should be employed. Conversely, if the important phenomena are well known, nodalization of the noncritical model regions may be simplified. If sufficient time and funds are available, it is recommended that a general model of a reactor system be assembled first. Analysis using the general model will then provide the information needed to determine what model simplifications are appropriate. The following sections provide additional guidance concerning hydrodynamic cell and heat structure sizing. General suggestions for appropriate noding may be inferred from Section 4.

4.2.1 Ex-Vessel Hydrodynamic Cell Size

As discussed above, large hydrodynamic cell sizes should be used for economic reasons. However, in each region of the model, the detail of the calculational cells must be sufficient to allow the simulation of important regional thermal-hydraulic phenomena. As a starting point, cell lengths for ex-vessel hydrodynamic volumes of 1 to 3 m (3 to 10 ft.) are recommended in phenomena-dominating regions (e.g., pressurizer, and steam generator) of a light water reactor model. Cells of much longer lengths are appropriate in less important regions of the model (e.g., the feedwater train and steam lines). The cell sizes presented in these applications may be taken as guideline recommendations for modeling light water reactors. For totally new applications or where the calculation results may be particularly sensitive to the model discretization, a convergence study is recommended to ensure that a proposed nodal layout is adequate.

Good modeling practice includes blending the transition from regions of small cells to regions of large cells. For this blending, it is recommended that the volumes of adjacent cells not differ by more than an order of magnitude.

Other considerations affecting cell size selection are the locations of natural boundaries, flow connections, and instruments within the prototype fluid system. Good modeling practice includes placing junctions at natural fluid system boundaries and at flow loss features (such as support plates, grid spacers, bends, and orifices). Using this practice, the flow loss is placed at the proper location with respect to the fluid volumes. For similar reasons, the placement of junctions at flow connection points is a good practice. Cell size selection should also consider placing model features at prototypical instrument locations (e.g., placing a cell center at the location of a pressure tap or a junction at the location of a flow meter). This practice facilitates the use of the code output because the calculated and measured data are directly comparable without further effort.

4.2.2 Steam Generator Primary Nodalization

The nodalization for the primary side of two types of steam generators are presented, U-tube steam generators (UTSGs) and once-through steam generators (OTSGs).

4.2.2.1 U-Tube Steam Generator Nodalization. Standard nodalization for one of the primary coolant loops is shown in Figure 4-1. Pipe 408 represents the many thousands of steam generator tubes of

a U-tube steam generator. Representing the steam generator tube primaries with an 8-cell pipe component is a nodalization scheme that compromises between calculational fidelity and expense. This scheme has proven is generally useful, however the modeler should individually consider the nodalization requirements for the problem to be modeled. The tube nodalization scheme shown may not be sufficiently detailed to model phenomena associated with reflux cooling and greatly reduced secondary-side levels. Branch 410 represents the steam generator outlet plenum. Modeling of the steam generator secondary region is described in Section 4.2.3.

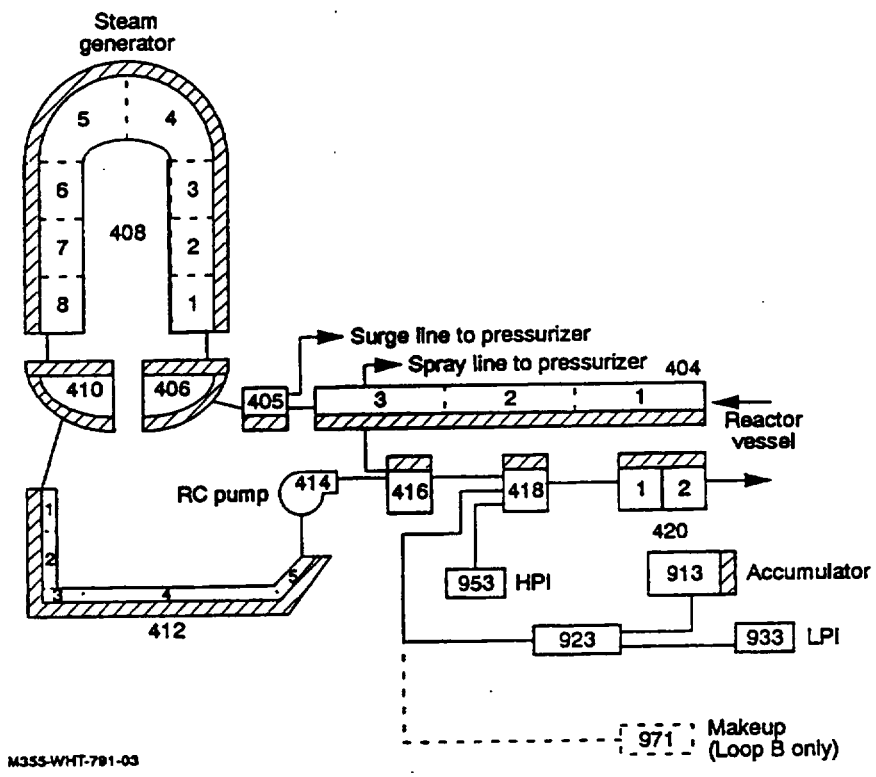


Figure 4-1. Nodalization of primary coolant loops (Loop C shown).

Heat structures are employed to model the hot and cold leg piping walls, the steam generator plena heads, the plena separation plate, the tubesheet, and the steam generator tubes.

4.2.2.2 Once-Through Steam Generators. The OTSG is a counterflow heat exchanger that employs straight tubes. The standard OTSG nodalization is shown in Figure 4-2. Components 116 and 125, represent the OTSG inlet and outlet plena, respectively. Single-sided heat structures represent the significant metal structures (such as the steam generator heads and the tubesheets). Reactor coolant flows downward through the insides of the tubes; 8-cell pipes 120 and 121 represent the tube primaries. Pipe 120 represents 90% of the OTSG tubes, pipe 121 represents the other 10% (the reason for separating the tubes in this manner is discussed below). Two-sided heat structures model the tube walls.

On the secondary side, the downcomer region is modeled with 4-cell pipe 305. Main feedwater enters the downcomer at the upper end of this component. Single-sided heat structures represent the steam

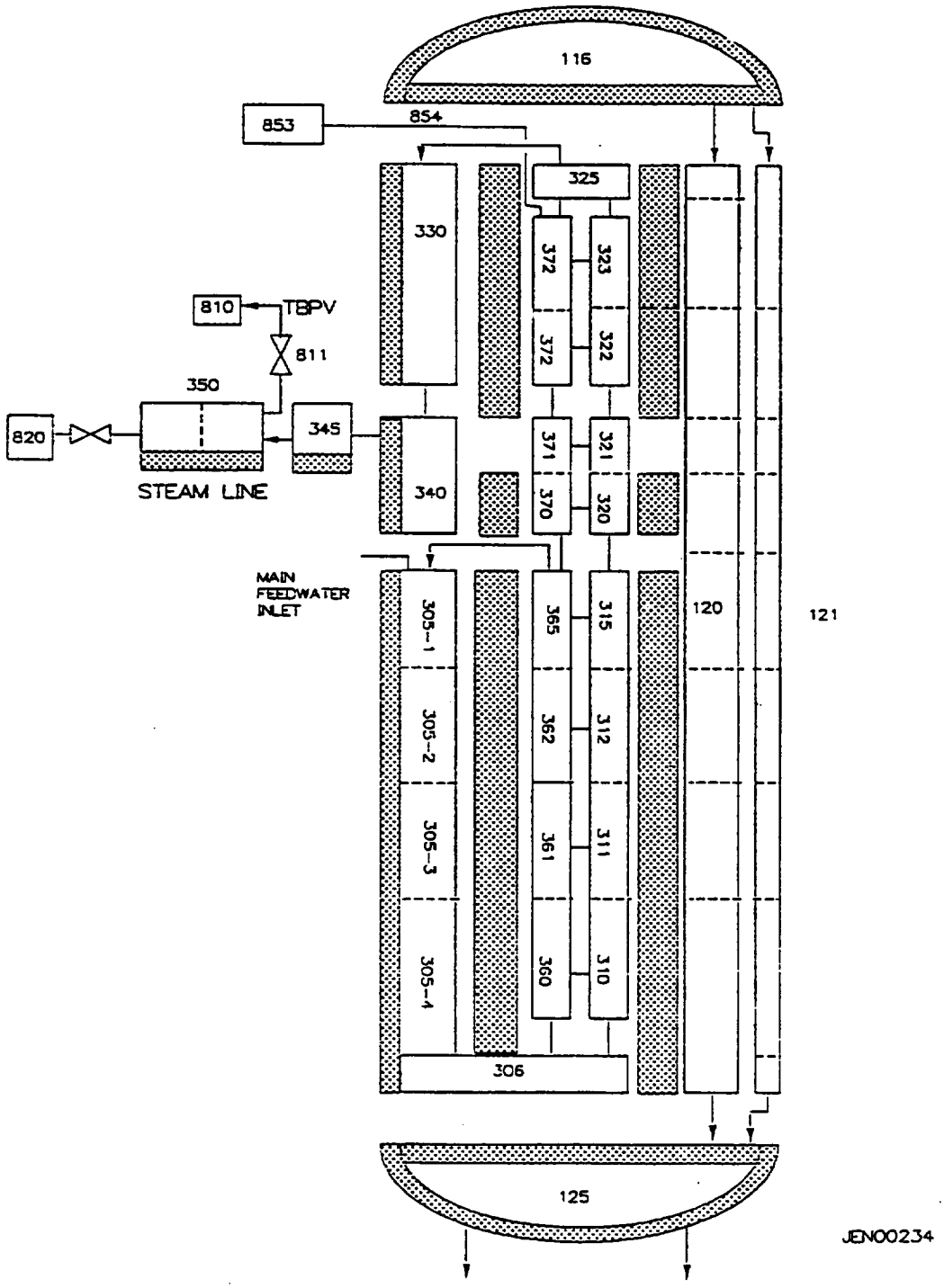


Figure 4-2. Example of once-through steam generator (OTSG) nodalization.

generator shell and the vertical baffle that separates the boiler and downcomer regions. Branch 306 represents the region at the lower tubesheet, where the flow changes direction from downward to upward.

The boiler region is separated into two parallel flow paths, representing 90% and 10% of the flow area. The paths are connected by crossflow junctions. Components 310 through 323 represent the 90% region while components 360 through 372 represent the 10% region. The split boiler region model is recommended to simulate phenomena during periods of emergency feedwater injection. This injection enters the boiler around the circumference of the boiler, near the upper tubesheet (junction 854 in the model) and is directed radially inward, into the tube bundle. Because the OTSG employs over 15,000 tubes, the emergency feedwater wets only a small portion of the tubes around the periphery of the tube bundle. As the emergency feedwater falls downward, it encounters the tube support plates (there are 17 in the OTSG) that tend to spread the injection flow further into the tube bundle. The split boiler nodalization represents a compromise modeling scheme for simulating this behavior. An initial 10% bundle penetration is expected, and the crossflow connections to the 90% region allow simulation of the inward spreading.

At the top of the boiler region, flows from the parallel boiler channels are combined in branch 325 before exiting the steam generator through a steam annulus, modeled with components 330 and 340.

Modeling the behavior of an OTSG is perhaps the most difficult of nuclear thermal-hydraulic system code problems encountered. The difficulty arises for two reasons. First, a complete spectrum of heat transfer phenomena is experienced between the tube wall and the secondary fluid. At the bottom of the tubes, heat transfer is to subcooled liquid. As the flow progresses up the tubes, the liquid is then saturated and boiled away. To preheat the feedwater, a portion of the steam flow is bled into the downcomer through an aspirator near mid-boiler (modeled with the junction between components 365 and 305 in Figure 4-2). Further up the tubes, any remaining droplets are vaporized and the steam is significantly superheated. Second, the OTSG heat removal rate is very sensitive to the secondary-side liquid level. As the level increases, more of the tube surface area experiences effective heat transfer (e.g., boiling) rather than ineffective heat transfer (e.g., convection to steam). Moreover, the sensitivity of OTSG heat removal to level is present during normal operation, while for UTSGs this is a concern only during accidents that involve an extreme depletion of secondary liquid.

The OTSG steam generator nodalization shown in Figure 4-2 has proven adequate for simulating normal operation. The difficulty in obtaining a satisfactory OTSG simulation described above is partly nodalization dependent. Nodalization is by nature discrete, and this causes the steam generator heat removal in the model to be even more sensitive to the secondary level than in the prototype. In the model, as the level moves across cell boundaries, discrete jumps in overall heat transfer are encountered. These changes often cause the model to become unstable, oscillating between two solutions at two different secondary levels. Moving to finer axial noding may remedy the oscillation, however the proximity of the liquid level to cell boundaries often is more important than cell size.

4.2.3 Steam Generator Secondaries

Standard nodalization for a U-tube steam generator secondary is shown in Figure 4-3. In the secondary region, main feedwater enters the steam generator downcomer annulus at branch 258 where it is combined with the recirculation liquid flow returning from the separator (component 278) through downcomer annulus branch 254. The combined flow descends through the downcomer (annulus 262) and enters the boiler (pipe 266). Note that the axial nodalization was made consistent between the tube primary, boiler, and downcomer regions. The use of four axial hydrodynamic cells in the boiler region has proven generally useful. However, finer nodalization of the boiler region may be needed for simulating

phenomena associated with reflux cooling mode and significantly depleted steam generator secondary inventory. The user is advised to carefully consider the nodalization needs for a particular application. Overall steam generator performance is dependent on correctly simulating the recirculation ratio (the boiler flow rate divided by the feedwater/steam flow rate) because it controls the heat transfer process on the outside of the tubes. The flow losses associated with the horizontal baffles in the tube bundle region often are not well-characterized. Therefore, if a satisfactory initial agreement with the desired recirculation ratio is not attained, adjustment of input form losses in the boiler may be justified.

The two-phase mixture exiting the boiler region flows through the mid-steam generator regions (branches 270 and 274) before entering the separator (branch 278). The separator model is idealized and includes three modes of operation that are determined by the separator void fraction. The void fractions defining these modes are input by the user. At low void fractions, the separator model reverts to a normal branch component, allowing carryover of liquid into the steam dome (branch 282). At high void fractions, the separator also reverts to a normal branch component, allowing carryunder of steam through the liquid return path into the downcomer. At intermediate void fractions, an idealized separation process is calculated: all liquid is returned to the downcomer and all vapor is passed to the steam dome.

The modeler should carefully consider the elevation chosen to locate the separator. In the steam generator model, separation will take place based on the void fraction in the separator volume, whose lower and upper elevations are user-specified. In the actual plant, separation is accomplished in two stages (swirl-vane separators and steam dryers) that reside at two different elevations. Therefore, the model is at best a compromise of the actual separation processes. The selections of separator elevation span and void limits determine when recirculation is interrupted as the secondary mixture levels decline. Note that these levels decline significantly when a steam generator's heat load is reduced, such as following a reactor trip. The levels also decline significantly during transients where the secondary inventory is depleted, such as during a secondary side LOCA.

Heat structures are employed in the model to represent the steam generator tubes, the cylindrical shell and spherical head, the cylindrical baffle separating the boiler and downcomer regions, and the internals of the separator and steam dome regions.

It often is difficult to obtain a satisfactory agreement with steam generator full-power conditions. The difficulty arises because the heat transfer coefficient calculated on the outside surface of the steam generator tubes is based on general vertical-pipe correlations rather than correlations that account for the swirling flows present within the tube bundle region. The swirling flow pattern results because horizontal baffles in the boiler direct the flow back and forth across the tube bundle instead of allowing the flow to proceed axially (vertically upward) through the boiler. The effect of this discrepancy is that tube heat transfer is understated by the code, resulting in excessively high calculated primary coolant temperatures (the temperatures increase until the core heat is driven across the tubes). Since the source of the calculated error is understood (i.e., a general heat transfer correlation is not appropriate for this application), it is recommended that the modeler "adjust" the heat transfer on the outside of the tubes to remedy the discrepancy.

The recommended adjustment is to reduce the input heated equivalent diameter on the heat structure cards for the outer tube surface. It is recommended that instead of using the boiler region hydraulic diameter as the heated diameter that the minimum tube-to-tube spacing (the distance from the outside of a tube to the outside of its neighbor) be used. If the modeler decides not to follow this recommendation, it will be necessary to compromise an important parameter (such as using a lower secondary pressure, higher primary temperature, or lower feedwater temperature) to simulate full-power steam generator operation.

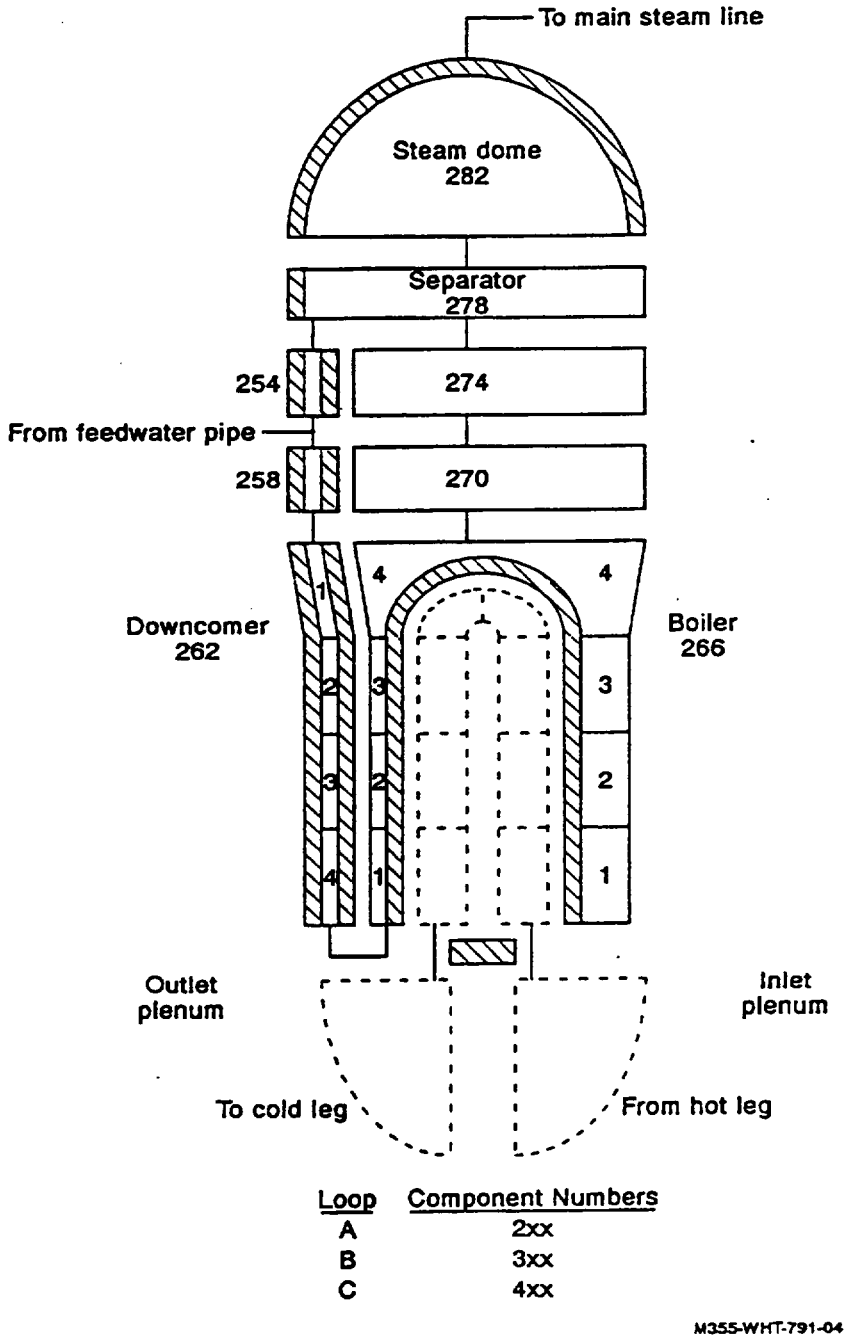


Figure 4-3. Nodalization of secondary side of steam generators.

4.2.4 Primary Coolant Pump

A typical nodalization for the primary coolant pumps is again shown in Figure 4-1. Pipe 412 represents the pump suction cold leg. To ensure proper simulation of behavior in the loop seal region, cell 4 of this pipe is input as horizontal. This orientation allows the formation of horizontally stratified flows at the bottom of the loop seal. It is recommended that at least one horizontal cell be used for simulating loop seal phenomena. Cells 1, 2, 3, and 5 of pipe 412 provide sufficient vertically-oriented calculational cells for simulating the formation of liquid levels in the loop seal region and for simulating countercurrent flow limiting phenomena.

The pump discharge cold leg is modeled with branches 416 and 418 and pipe 420. This nodalization scheme has proven suitable for simulating horizontal stratification of fluid within the cold legs during loss-of-coolant accidents. The nodalization also provides for proper simulation of the fluid temperature distribution in the region; the junction between the branches is located such that the ECC injection site is correctly modeled. The user should remember that SCDAP/RELAP5 provides a one-dimensional representation of the flow and therefore is not capable of resolving thermal stratification of warm and cold liquids within the same pipe. Therefore, although the model may observe the bulk movement of cold ECC liquid toward the core, it is not capable of observing a stream of cold liquid residing in the bottom of the horizontal pipe. The high and low pressure ECC functions are modeled with pairs of time-dependent volumes and junctions. The ECC fluid injection temperature is specified by the time-dependent volume while the injection flow rate is specified as a function of the cold leg pressure by the time-dependent junction. This method allows simulating the head/flow characteristics of the centrifugal ECC pumps. A SCDAP/RELAP5 accumulator component is used to simulate the injection behavior of the nitrogen-charged accumulators. This lumped-parameter component model mechanistically represents the tank and surge pipe hydrodynamics, heat transfer from tank wall and water surface, water surface vaporization to the gas dome, and gas dome condensation.

4.2.5 Pressurizer

Standard INEL nodalization for the pressurizer and its associated systems is shown in Figure 4-4. The pressurizer upper head is modeled with branch 340 and the pressurizer cylindrical body and lower head are modeled with 7-cell pipe 341. Generally, good agreement with experimental and plant data has been attained for slow and fast pressurizer insurges and outsurges with this nodalization. The surge line is modeled with 3-cell pipe 343.

The functions of the two power-operated relief valves (PORVs) are lumped into valve 344 and those of the three code safety valves are lumped into valve 346. The valves open in response to a significant primary coolant system overpressure. Operation of these valves, including their hysteresis effects, is simulated using the methods described in example 2 in Section 5.4.2 of Reference 2. The pressurizer spray system is modeled with single-volumes 335, 337, and 339, and valves 336 and 338. The spray valves open in response to a mild primary coolant system overpressurization. Operation of these valves is simulated using logic similar to the PORV and code safety valves. The flow area of all valves is that necessary for delivering the rated flow capacity at the rated upstream pressure.

Heat structures are used to represent the cylindrical pressurizer shell and its spherical lower and upper heads, and the pressurizer surge line pipe wall. Heat structures are also used to simulate operation of the pressurizer heaters. Heater power is increased in response to an underpressurization of the primary coolant system pressure and is terminated if a low pressurizer level is sensed.

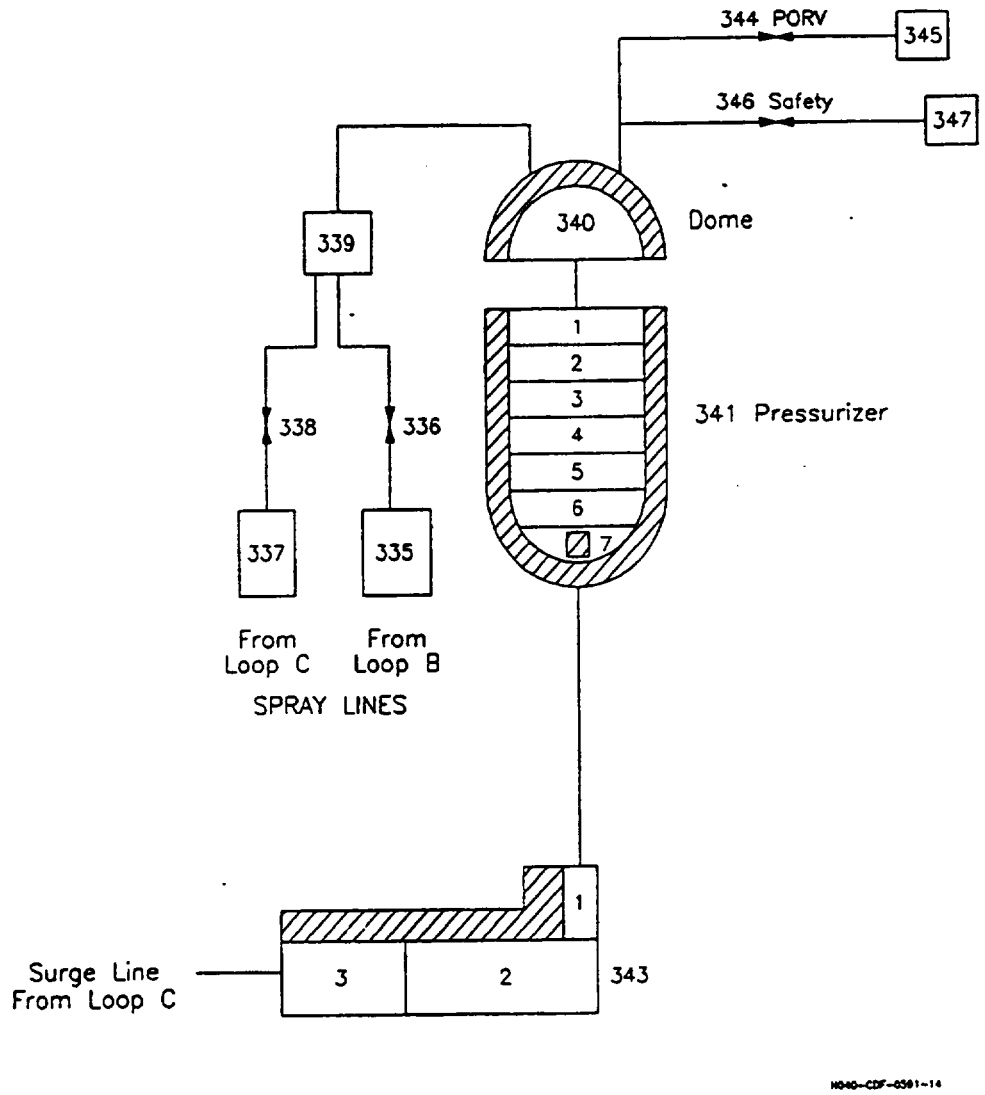


Figure 4-4. Nodalization of pressurizer.

4.3 Break Nodalization

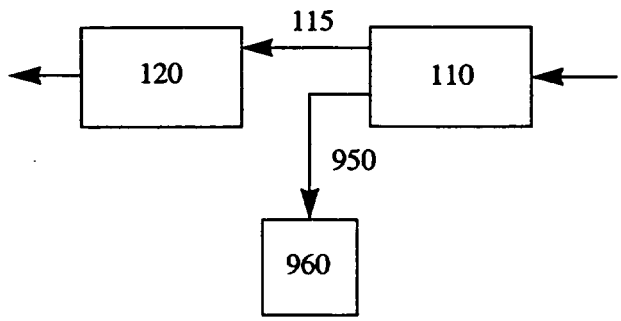
4.3.1 LOCA Modeling

A common code application is simulating a loss-of-coolant accident (LOCA) involving the full or partial rupture of a coolant pipe within an air-filled containment. These applications may involve experimental facility or full-scale plant LOCA simulations.

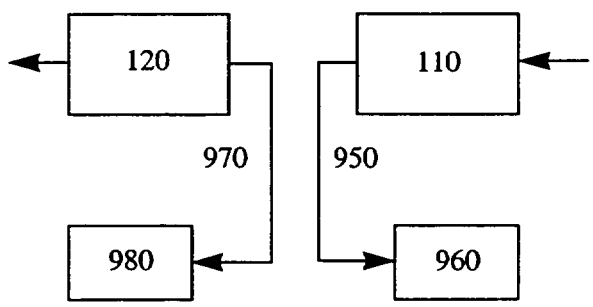
The need to adequately measure the break flow in an experimental facility usually dictates a complex experimental break geometry to provide clearance for instrumentation. The experimental facility break

design often involves a side pipe leading from the broken pipe to a break orifice and valve. This complex design is best modeled in detail (i.e., the geometry upstream and downstream of the break should be modeled directly). Courant limiting considerations will be important in this application because the fluid velocities in the pipe leading to the break will be large. In most analyses of experimental facility LOCAs, benchmarking the break flow path has been necessary to compensate for uncertainties in the break path resistance and the code break flow models. The benchmarking process consists of using experimental data that characterize the break resistance to adjust the model flow losses for an adequate comparison between measured and calculated break flow. The adjustment is typically accomplished by adjusting the discharge coefficients on the break junction.

For full-scale plant applications, the break modeling process typically is more straightforward because the break geometry is simpler. Common LOCA applications for full-scale plants include the opening of circular breaks on the top, side, or bottom of a coolant pipe and the double-ended break of a coolant pipe. For full-scale plants, breaks typically are assumed to open instantly. Figure 4-5 shows a recommended nodalization for modeling small and double-ended breaks in a coolant pipe. In both applications, the broken pipe is simulated with volumes 110 and 120.



Communicative break



Double-ended break

Figure 4-5. Coolant system break modeling.

The small communicative break is simulated by adding single-junction 950 and TMDPVOL 960 to the existing hot leg pipe model. The term "communicative" implies a portion of the normal flow through the pipe continues after the break is opened. Note that the break components may be installed on restart, at

the time of break opening, by including components 950 and 960 in the input stream. Break junction 950 should employ the abrupt area change option, simulating the combined flow losses associated with the sharp-edged area reduction from the pipe to the break plane and the sharp-edged expansion from the break plane to the containment. Junction 950 should employ the choking option and be initialized at a zero flow condition. The junction control flags provide the capability to locate the break on the top, side, or bottom of the pipe.

TMDPVOL 960 simulates the containment into which the break discharges; this implies the containment state is a boundary condition in the calculation. Frequently, a constant-pressure containment assumption is used. If the containment pressure response is known (e.g., as a function of the integrated break flow), then that response may be included in the simulation. For the double-ended break the nodalization includes two break junctions and two TMDPVOLs, as shown in Figure 4-5. Note that two TMDPVOLs are needed because no more than one junction may be attached to a TMDPVOL. As for the small break, the break junctions should employ the abrupt area change and choking options. Care should be used when specifying the initial break conditions. In the example shown, the initial mass flow rate for junction 950 should be positive at the same rate as at the inlet to volume 110; the initial mass flow for junction 970 should be negative and of the same magnitude.

In the above examples, the breaks also could have been implemented by including trip valve components at the break junctions in the original model rather than by adding them on restart. The valves would then be tripped open at the time of the break. Using this technique, the breaks may be opened at any time, not just at a restart point.

The containment condition specification is more important in some applications than in others. For small break applications, the primary coolant system depressurization typically is small, the pressure drop across the break remains large, and the break flow remains both choked and positive (into the containment). The containment conditions specified in this situation are not particularly significant to the simulation. The problem is only moderately sensitive to the containment pressure and is insensitive to its gas species. However, for large breaks, transitions between choked- and friction-dominated flow, and intermittent reverse flow from the containment are likely. In this case, it is important to adequately specify the containment conditions.

For some problems where the response of the containment is particularly important, it may be possible for an approximation of the containment behavior to be included as a part of the model. This can be accomplished by modeling the containment and the actual containment mass and heat balances.

As a final note, the analyst should appreciate that critical break flow simulation represents an area of significant uncertainty. For some problems, this uncertainty may be a controlling factor for the outcome of the simulation. It is therefore recommended that care be taken to independently check code-calculated break flow results either against experimental data in similar geometries or against standard critical flow correlations.

A recommended procedure for correctly specifying the break area and discharge coefficient is linked to the break scenario, the break plane geometry, and whether any data exists for that geometry. Assuming a discharge coefficient of 1.0 is valid, the following generalities are known concerning the SCDAP/RELAP5 critical flow model:

- For subcooled conditions, the SCDAP/RELAP5-calculated flow is too large. Often, it is found that a discharge coefficient of about 0.8 is needed to predict break flow in

representative geometries containing break nozzles with length-to-diameter ratios less than 1.0.

- For low-quality saturated conditions, SCDAP/RELAP5-calculated mass flow rates are too low, often by as much as 20%, even when a discharge coefficient of 1.0 is used.

- Higher-quality saturated conditions at the break plane, such as are approximated by the homogeneous equilibrium model, are well-simulated with SCDAP/RELAP5.

4.3.2 Surge Line Modeling

One of the transient phenomena which is unique to severe accident analysis is failure of the pressurizer surge line. Surge line break modelling differs from most breaks because of the fact that the timing of the failure is not a boundary condition, but is calculated by the SCDAP/RELAP5 code. Modelling of the failure of a surge line can be performed in one of the following two methods.

METHOD 1:

- Model the surge line walls with RELAP5 heat structures.

- Identify surge line heat structures for the creep rupture calculation, on Cards 21000110 and 21000000.

- Specify the 'DCREPH' variable on 208 cards to allow it's use with a logical trip.

- Specify a logical trip to be driven 'true' when any 'DCREPH' variables indicates rupture.

- Model the surge line failure with a valve from the surge line to containment. This valve could be modeled as the communicative break shown in Figure 4-5, with the valve numbered 950. The valve should be initially closed, and open when the trip specified in step 4 is driven 'true'.

METHOD 2:

- Model the surge line walls with RELAP5 heat structures.

- Identify surge line heat structures for the creep rupture calculation on Cards 21000110 and 21000000.

- Perform a calculation to identify the time of the first creep rupture.

- Restart the calculation with a break being defined for the time of creep rupture.

The flow area of the valve which models the surge line rupture is probably plant and transient specific. Creep rupture failure experiments show creep rupture failures to involve longitudinal cracks that had opened to various degrees, from about 1/4 of the axial flow area to an area at least as large as the axial flow area. It should be noted that there is a wide scatter of experimental data in this area. In the model for surge line rupture for the Surry plant,[15] a rupture flow area equal to 1/3 of the pipe axial flow area was judged appropriate. This amounts to a valve diameter of approximately 1/2 of the surge line pipe.

5. PROBLEM CONTROL

Input, output, and auxiliary file names are identified on the command line using flags, as shown in Appendix B. All remaining control parameters are specified within the input deck as documented in Appendix A.

5.1 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. Quantities written in the restart-plot records by default are noted in the input data description. User-specified input can add additional quantities to the restart-plot records.

PLOT and STRIP are output-type runs. PLOT generates plots from data stored on the restart-plot file. The PLOT capability is not now operational but is still documented. The PLOT capability may be dropped from the code since NPA[8] and XMGR5,[16] an INEEL extension of XMGR[17] allow very general and high quality plots of SCDAP/RELAP5 results and associated information. STRIP writes selected information from a restart-plot file onto a new file. The new file consists of records containing time and the user-selected variables in the order selected by the user. Data to be plotted or stripped are limited to that written in the plot records on the restart-plot file.

5.2 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 0 and 15 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 0, the problem has been advanced over one requested time step. Doubling of the time step is allowed only when the step counter is even, and the step counter is halved when the time step is doubled. With no bits set, the time step is doubled whenever possible. At the completion of advancements over a requested time step, the next requested advancement is obtained and may be different from the previous requested time step if data from the next time step control card are used. If necessary, the new requested time step is reduced by halving until the new actual time step is < 1.5 times the last successful time step.

Setting bit one (entering 1, 3, 5, 7, 9, 11, 13, 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 SCDAP/RELAP5 would convert 2 to 3 to maintain compatibility. This is no longer done.

Entering zero is not recommended except for special program testing situations. If bit one is set, care must be taken in selection of the requested time step. Individually, the hydrodynamic and heat conduction advancements are stable; the hydrodynamic time step is controlled to ensure stability, the heat conduction solution with constant thermal properties is stable for all time steps, and the change of thermal properties with temperature has not been a problem. The 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 time step 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.

5.3 Printed Output

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

5.3.1 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 because of input errors.

5.3.2 Major Edits

Major edits are an editing of most of the key quantities being advanced in time. The amount of output depends on the input deck and output options chosen by the code user. Output includes a time step summary, trip information, reactor kinetics information, one to four sections of hydrodynamic volume information, hydrodynamic volume time step control information, one or two sections of hydrodynamic junction information, metal-water reaction information, heat structure/heat transfer information, heat structure temperatures, reflood information, reflood surface temperatures, cladding rupture information, control variable information, and generator pump, turbine, and accumulator 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.

5.3.3 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. The selected quantities are held until 50 time values are stored. The minor edit information is then printed, 50 time values on a page, nine of the selected quantities per page, with time printed in the left most column on each page. Minor edits can print selected quantities at frequent intervals using much less paper than major edits. Appendix A indicates how to request minor edits and what the user-specified quantities represent.

5.4 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.

5.4.1 Temperature Distribution

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.

5.4.2 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 left most radius that is printed applies to the lowest axial node and the right most radius applies to the highest axial node.

5.4.3 Cladding Oxidation

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 left most and the top axial node printed right most. 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.

5.4.4 Meltdown

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 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 then node.

5.4.5 Fission Product and Aerosol Release

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 matrix of numbers. The left most column of numbers applies to the lowest axial node (axial Node 1), and the right most 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[5] 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.[18] 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 left most species is xenon, the second left most 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 is 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.

5.4.6 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.

5.4.7 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.

5.5 Transient Termination

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.

5.5.1 Problem Changes at Restart

The most common use of the restart option is simply to continue a problem after a normal termination. If the problem terminated because of approaching the CPU time limit, the problem can be restarted with no changes to information obtained from the restart file. If the problem stopped because the advancement time 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 INEEL. 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. The user can also specify that the previously defined trips remain but that specific trips be deleted, be reset to false, be redefined, or that new trips be added.

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

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

Heat structures, general tables, and material properties can also be deleted, changed, or added. If these are changed, all of the cards for heat structures, general tables, and material properties must be entered.

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, many modeling features in SCDAP/RELAP5 can be added, deleted, or changed at restart.

6. INSTALLATION

The SCDAP/RELAP5 computer program should execute on a wide variety of scientific computers with minimal modifications. In particular, the code should execute on all computers using 64 bits for both floating point and integer arithmetic. It should also execute on 32-bit computers that have 32-bit integer arithmetic but provide 64-bit floating point arithmetic through double precision operations.

Even with the use of the Unix operating system on many computers, it still is not possible to easily write installation scripts for all Unix machines since there are vendors who continue to implement non-standard commands in order to differentiate themselves from other vendors. The approach taken with SCDAP/RELAP5 is to establish a single script, which is capable of generating all the machine-dependent files at the time of installation. Options are provided for several machines and have been tested on several computers, although it should be noted that operating systems and computing platforms are notorious for rapid change. After the machine-dependent files are generated, installation and maintenance instructions should be common to all machines, and consist primarily of utilizing the '*make*' utility.

6.1 Transmittal Files

The transmittal now consists of two files, and six directories. The files are:

2. ReadMe - last minute installation changes,
3. configure - a script to build the machine dependent installation files.

The directories are:

4. aux - a collection of files auxiliary to the installation,
5. envrl - the environmental library source files.
6. matpro - the materials property library source files.
7. relap - the RELAP5 library source files.
8. scdap - the SCDAP/COUPLE library source files.
9. run - sample problems.

There may be a third text file 'input.chng' with a brief description of the input changes that have occurred within each version. This is not intended as a replacement for the input description in Appendix A, but should alert you to significant changes. Note that this file is not required for the installation and may not exist.

6.2 Benchmark Problems

A set of standard input decks are transmitted with each transmittal, which allow the code user to exercise the code as it is installed on their site, and compare results with results generated with the same input decks by the code developers. In the follow sections, the objective of each test problem will be identified, and the approach, boundary conditions, and success criterion will be described.

6.2.1 Boiloff Problem

The 'boiloff' problem is a recent addition to the suite of standard test decks, and is intended to test

the interface between the heat transfer package and the severe accident models. The approach is to define two completely separate, but identical hydraulic systems. Each of these systems consist of a pipe, with eight volumes, and a time-dependent volume acting as inlet and outlet, as shown in Figure 6-1. These volumes allow the user to define inlet and outlet hydrodynamic conditions. This problem is initiated with the pipe filled with water, experiences a standard boiloff, and then undergoes super heated steam boundary conditions. A time-dependent junction in used to connect the source volume to the pipe so that flow conditions through the pipe may be specified as a function of time. Connected to each pipe are either a RELAP5 heat structure or a SCDAP fuel rod, experiencing the same power history. The intent is to provide identical boundary conditions for each type of structure, and then to examine the differences in the calculated behavior of the SCDAP and RELAP heat structures.

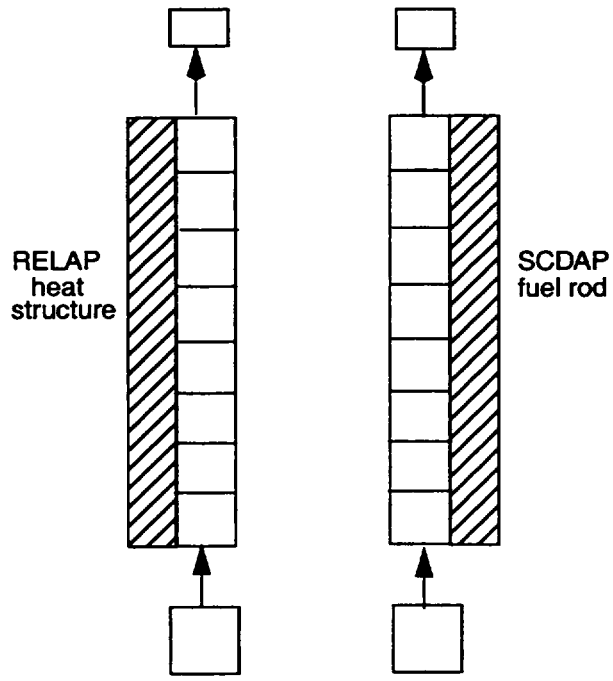


Figure 6-1. Boiloff nodalization diagram.

In the transmitted input deck, two control variables CNTRLVAR-110 and CNTRLVAR-111 may be compared to assess the effectiveness of the implementation. CNTRLVAR-110 sums the total heat which is added to the pipe by the RELAP heat structure and CNTRLVAR-111 sums the total heat which is added to the pipe by the SCDAP fuel rod. This problem is considered successful, if the control variables are similar, although there will be an increasing deviation as the cladding temperature increases, since the RELAP heat structure does not model cladding oxidation.

6.2.2 Simple Cheap Problem

Simple Cheap Problem #2 (SCP2) is intended to exercise the SCDAP fuel rod model by modeling the response of a 32 rod bundle through a very rapid transient to meltdown. The approach, just as in the previous problem, is to define a pipe with time-dependent volumes at each end, and a time-dependent junction at the source volume, as shown in Figure 6-2. The time-dependent volumes are used to specify inlet and outlet hydrodynamic conditions, and the time-dependent junction is used to specify time-dependent flow rates.

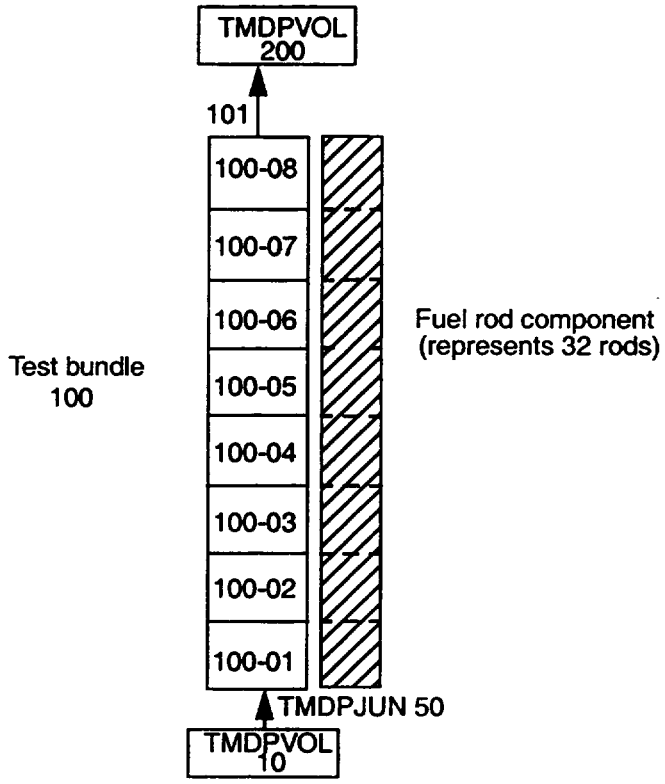


Figure 6-2. Nodalization diagram for Simple Cheap Problem #2.

In this problem, the pipe is initialized with steam and a steam flow comparable to that experienced during the PBF SFD 1-4 experiment is maintained. The fuel rod is expected to experience intense oxidation, cladding melting, and significant relocation. This problem is considered successful if it runs to completion without error, and without generating non-physical results.

6.2.2.1 Simple Cheap Problem Restart

An additional input deck is added to the suite, in order to allow a restart of the SCP2 run. This deck should perform a restart approximately 50 s prior to the end of SCP2, and run to the same end time. The problem is considered successful if identical results are obtained.

6.2.3 Simple Cheap Vessel Problem

The Simple Cheap Vessel Problem is the most rigorous of the benchmark problems, in that the core

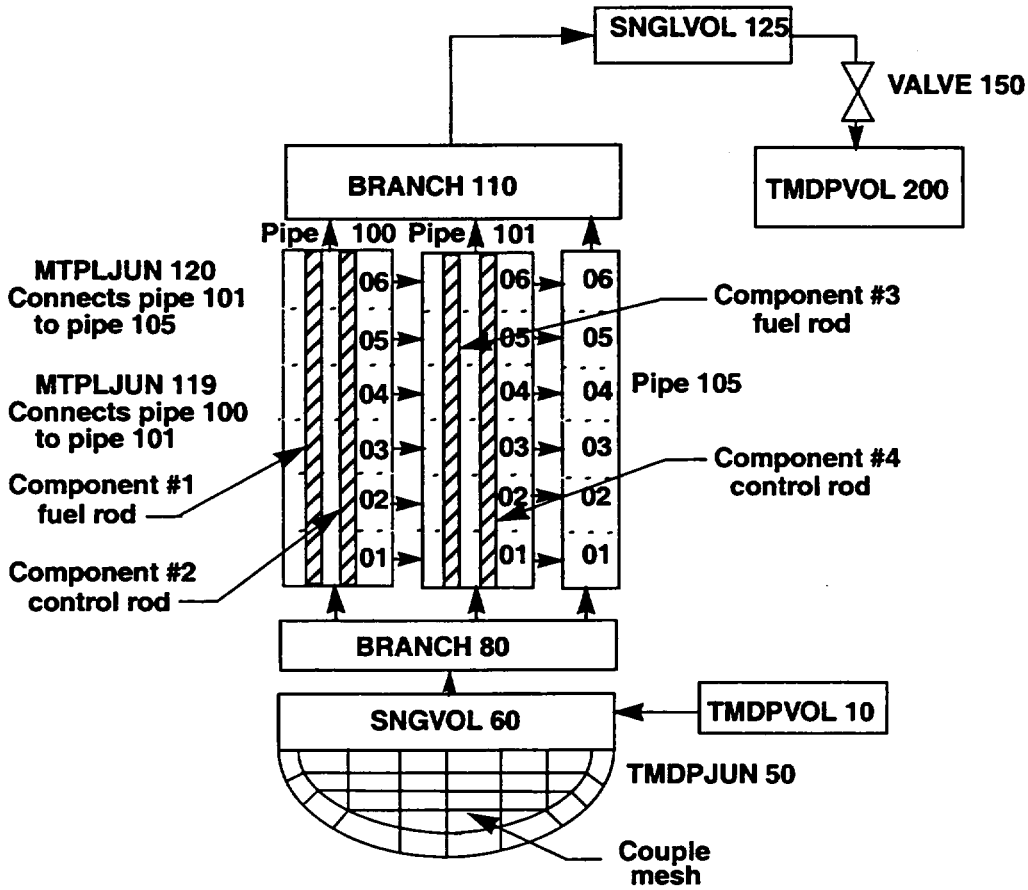


Figure 6-3. Nodalization diagram for Simple Cheap Vessel Problem.

is modeled with two groups of fuel rod and two groups of Ag/In/Cd control rod components, and a COUPLE mesh has been added, as shown in Figure 6-3. Each group of fuel rods represents 18,408 rods and each group of control rods represents 118 rods. These groups of fuel and control rods are representative of an entire reactor core. This problem is intended to test the meltdown of the core, and the transfer of core molten material to the lower head.

The core volumes are initialized with steam, and allowed to heat up, meltdown, and relocate to the lower head. This problem is considered successful if it runs to completion without error, and without generating non-physical results.

6.3 Installation Procedures

The installation of SCDAP/RELAP5/MOD3.3 has been moved entirely to a 'make' based installation. This means that the code user may use the same procedure for modifying subroutines, or installing error corrections, as the original installation uses. The installation does not destroy or change any transmittal files.

The procedure for installing SCDAP/RELAP5 with links to the 'Nuclear Plant Analyzer' (NPA) are as follows. The NPA utility should be installed prior to the installation of SCDAP/RELAP5. Once this has been accomplished, an environmental variable is set to point to the directory which contains the NPA libraries, and the installation scripts will then activate the NPA link. To specify the source of the NPA libraries, execute the following command before initiating the SCDAP/RELAP5 installation.

setenv NPA directory_containing_NPA_libraries

Once the transmittal files have been transferred to the machine they will be installed on, execute the 'configure' script to setup the installation. This will determine the hardware type, and setup the machine specific files. Once the setup is complete, this script will exit WITHOUT BUILDING THE CODE! The user should never have to re-execute this script, unless of course he or she wishes to setup the installation from scratch again.

There will now be a 'Makefile' in each of the source directories, and in the installation base directory. The user may type 'make' to build the SCDAP/RELAP5 code, and the executable 'relap5.x' will be created in the base directory (Note: this is a different location that the standard RELAP5 installation!).

After the code is installed, the user may run the sample problems by changing to the 'run' subdirectory, and executing the 'runx' script.

The installation process does not destroy or modify any transmittal files. After the code has been installed, the user may execute the command 'make clean' from the base directory to uninstall all generated files, and recover the as-transmitted code.

6.4 Utility Routines

This section describes several utility routines and scripts used in installation and maintenance.

6.4.1 C PreProcessor

The C PreProcessor (CPP) is a system utility used during the SCDAP/RELAP5 installation to address machine differences, and to invoke or disable specific development options. This utility makes use of lines within the source, which have the format #if [n]def,name and #endif. If a specific installation option has been defined or undefined, CPP will either remove the marked source or leave them as active source lines. The define variables for CPP are defined within a file named 'define' in the base directory.

Appropriate 'define' statements are automatically generated during the installation. However, if the code user has a need to understand these options they are as follows:

bufr If the bufr option is defined, buffer in and buffer out statements are used to read and write

the rstplt file and the unformatted form of the strip file. The software must also support a record concept and the length function that returns the size of a record read. The bufr defined option is recommended for CRAY-1, CRAY-XMP, and CDC-NOS-VE machines. It is not recommended for the CRAY-2 machine. When the bufr option is undefined, unformatted read and write statements are used. These are standard Fortran statements that can be used with any machine, but may be slower than the buffer in and buffer out statements. In the typical read or write statement, write (rstplt) len, a(i),i=1,len), the implied do loop was not treated as a block write.

cdccra — This option is defined for CDC-NOS-VE machines or CRAY machines.

cray — This option is defined for CRAY machines.

fourbyt — When the bufr option is undefined, this option selects whether the reads and writes of restart information uses eight or four byte words. This option should be undefined when bufr is defined or when bufr is undefined but the machine uses 64 bits for both integer and floating point data. Thus CRAY and CDC-NOS-VE should have fourbyt undefined. The RELAP5 portion of the code writes restart records that are multiples of eight byte words and the fourbyt option may be undefined on many 32-bit machines. The RELAP5 code is executed on IBM, Dec station, and Vax machines with fourbyt undefined. The SCDAP portion does require the fourbyt option on 32-bit machines. The safest option for 32-bit machines is to define fourbyt. Compilers should treat the reads and writes as block operations and there should be no difference in execution time.

hp — This option is defined for HP machines.

ibm — This option is defined for IBM mainframe machines.

ibmrisc — This option is defined for IBMRisc machines.

impnon — Many compilers allow an implicit none statement. This statement when entered in a routine removes all implicit typing of variables and requires each variable and function to be typed. Multiple explicit typing is also considered an error. Additionally, the Cray compiler requires subroutine names called in a routine to appear in external statements. This provides an automatic level of checking by the compiler to avoid inadvertent multiple use of variable names during code development. All comdecks defining common blocks or dynamic blocks have explicit typing. Some subroutines have been modified such that all local variables are explicitly typed. When impnon is defined, an implicit none statement is activated in those subroutines. Eventually, all routines will be explicitly typed. Although most important for code developers, impnon is recommended to be defined for all systems allowing implicit none statements. The IBM mainframe compiler does not allow implicit none and impnon should be undefined for that machine.

in32 — This option is defined for 32-bit machines, that is, machines that can perform 64-bit floating point computations but only 32-bit integer operations. This option is needed for Decstation, HP, IBM, IBMRisc, Masscomp, Macintosh, and Vax computers.

npa — This option should be defined when linkage to the Nuclear Plant Analyzer (NPA) is desired. This option should be undefined unless the NPA system has been installed.

selap — This option selects between the RELAP5 code and the SCDAP/RELAP5 code. This option when undefined selects the RELAP5 code and when defined selects the SCDAP/RELAP5 code. Some RELAP5 only transmittals will have all SCDAP subroutines removed and some will also have all interface coding removed. For SCDAP/RELAP5 transmittals, this option when undefined selects only the RELAP5 capability, and when defined selects the integrated SCDAP/RELAP5 capability. The SCDAP/RELAP5 code when given RELAP5 only input data generates the same results as if the RELAP5 only code was installed.

unicos — This option is defined for the CRAY computers operating under Unicos.

6.4.2 CNV32 Program

The source for the CNV32 program is aux/cnv32.f. This program converts the source file, which is oriented to a 64-bit machine to a 32-bit machine version. Changes which are made include: real statements without a length designation are changed to real*8; selected integer and logical variable references with subscripts have 1 or 2 added as the first subscript so that they occupy the same space as real*8 floating point variables; and single-precision floating point literals are changed to double precision literals.

The *cnv32* program reads a file, mlist, which contains a list of integer and logical global variables that must be converted to occupy the same space as real*8 variables. Local variables needing the conversion are indicated by a list of "*in32 name" statements and terminated "*in32end" in the source. The mlist file needed for processing of the selap file is packed in the file goodies. No mlist file is needed for processing the envrl and matpro files.

6.5 Make Utility

The *make* program is a Unix utility used to maintain programs. It generates "targets" using an input file describing dependencies between files and rules for generating files from other files. The input files are generally called makefiles and the appropriate makefiles are generated during the installation. Except for the list of files to be processed, the makefiles are very similar.

The file which is generated by each make operation is, by default, a library. The makefile identifies the source files which must be processed to create or update the library, and defines the rules for creating the library file. The *make* program checks the last modification date of each source file and compares that date to the creation time of the file generated by the compiler. If the library file does not exist, or one or more source files are newer than the library file, the appropriate source files are automatically processed. Similarly, the makefiles identify which of the source files use each include (.H) files. This means that when an include file is modified, and make is executed, then each source file which references that include file will be recompiled and saved in the library files.

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SCDAP/RELAP5/MOD3.3

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A1. INTRODUCTION

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

A1.1 Control Format

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

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

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

A1.2 Data Deck Organization

A SCDAP/RELAP5 problem input deck 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 caret (^) located under the character causing the error and a message giving the card column of the error are printed. An error flag is set such that input processing continues, but the SCDAP/RELAP5 problem is terminated at the end of input processing. A standard SCDAP/RELAP5 error message (error message preceded by ********) is printed if a card error is found. Usually a card error will cause additional error comments to be printed during further input processing when the program attempts to process the erroneous data.

A1.3 Title Card

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

A1.4 Comment Cards

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

A1.5 Data Cards

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

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

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

A numeric field must begin with either a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or blank (with one exception subsequently noted) terminates the numeric field. The numeric field has a number part and optionally an exponent part. A numeric field without a decimal point or an exponent is an integer field; a number with either a decimal point, an exponent, or both is a real field. A real number without a decimal point (i.e., with an exponent) is assumed to have a decimal point immediately in front of the first digit. The exponent part denotes the power of 10 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 10. These rules for real numbers are identical to those for entering data in FORTRAN E or F fields, except that no blanks (with one exception) are allowed between characters to allow real data written by FORTRAN programs to be read. The exception is that a blank following an E or D denoting an exponent is treated as a plus sign. Acceptable ways of entering real numbers, all corresponding to the quantity 12.45, are illustrated by the following six fields:

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

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

Most computers (e.g., Workstations, CRAY, Cyber 205, and IBM) hold only eight characters per word. All alphanumeric words required by SCDAP/RELAP5, such as component types, system names, 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.

A1.6 Continuation Cards

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

A1.7 Terminator Cards

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

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

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

A1.8 Sequential Expansion Format

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

0010101 0.01,10

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

A1.9 Upper/Lower Case Sensitivity

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

A1.10 Data Card Requirements

In the following description of the data cards, the card number is given with a descriptive title of the data contained on the card. Next, an explanation is given of any variable data 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.

A1.11 Input Error Trapping

Comparative checks will occur during input processing for variable type, number of words on a card, range of normal use, and physical/code limits Further checks will also be performed for consistency of input. For example, one consistency check will examine radial node placement and verify that radial nodes have been placed at material interfaces.

Input violations of variable type, number of words, physical limit, and consistency of input will result in an input error, but will not abort input processing. Error messages will be printed in the output file flagged with the character string "********". If the input is outside the range of normal use, a warning message will be printed in the output file and marked with the character string "$$$$$$$$."

To assist the user during deck building and input processing, selected ranges of allowable input will be identified with the card input descriptions. The range for a given input variable will be identified in the following manner:

Normal type - issue warning if out of range

$\underline{0.0\ \text{m}} < x \leq 2.0\ \text{m}$

Underline - input error if out of range

A2. MISCELLANEOUS CONTROL CARDS

A2.1 Card 1, Developmental Model Control

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

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

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

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

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

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

W1-90(I) Zero or an available option number as described above.

Option 2. Apply transient natural circulation model in calculation of heat transfer from interior to boundary of molten pool.

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

Option 36. Limit increase in metastable temperature by time step reduction.

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

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

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

Option 53. Invokes the modified Henry-Fauske critical flow model.

Option 54. This option changes the voidf limit in EQFINL from 1.0E-9 to 1.0E-9*(rhof/rhof). When this option is activated, it reduces the mass loss in low pressure cases many orders of magnitude.

Option 55. This option is a collection of modeling improvements designed to minimize numerical sources of oscillations for low pressure two-phase flow simulations. Specifically, this option affects interfacial heat transfer for annular-mist, mist pre-CHF, and mist post-CHF flow regimes. The liquid-side interfacial heat transfer coefficient has been modified to replace "ad hoc" correlations with more physical models.

Option 57. This option modifies the phasic partitioning of the wall friction so that all of the wall friction is applied to the liquid film in the annular-mist flow regime. This option is necessary to compute realistic values of the liquid film thickness.

Option 58. This option changes the smoothing used for the bubbly flow interfacial heat transfer coefficient between the liquid superheat and subcooled regions.

Option 61. This option further modifies constitutive relationships to reduce numerical oscillations at low pressure. Specifically this option affects vertical stratification.

Option 65. This option changes the subcooled boiling model by modifying the fraction of nucleate boiling heat flux that generates vapor when the bulk liquid is subcooled. The modification minimizes the "on/off" behavior associated with low-pressure/low-flow conditions.

Option 66. This option implements donor/acceptor differencing in vertical stratification volumes.

Option 67. This option implements velocity squared instead of velocity * velocity-donored for momentum flux.

Option 68. This option implements velocity - j times (velocity - L - velocity - K) instead of velocity * velocity-donored for momentum flux.

Option 69. This option uses a momentum flux with a donored velocity calculated using the actual donored void fraction in the numerator instead of a floored value.

A2.2 Card 100, Problem Type and Option

This card is always required.

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

NEW specifies a new simulation problem. RESTART specifies continuation from some point in a previous problem using information from the RSTPLT file. The PLOT capability is not now functional. PLOT specifies plotting results from a previous simulation run using the RSTPLT file. REEDIT has not been implemented. STRIP specifies that data are to be extracted (stripped) from the RSTPLT file, and only the data specified are written to the STRIP file. CMPCOMS specifies that a comparison is to be made between dump records on two files written in one or two previous runs.

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

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

STRIP Record 2. (A10,3I10).

STRIP Record 3. (8A10).

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

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

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

A2.3 Card 101, Input Check or Run Option

This card is optional for all types.

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

A2.4 Card 102, Units Selection

This card is optional for all problem types. If the card is omitted, SI units are assumed for both input and output. If the card is used, enter either SI or BRITISH for each word. SI units used are the basic units, kg, m, s, and the basic combined units such as Pa = $kg \cdot m/s^2 \cdot m^2$. 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. Thermal conductivity and heat transfer units use s, not h.

W1(A) Input units.

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

A2.5 Card 103, Restart Input File Control Card

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

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

Some cautions should be observed when the problem advancement time is changed by changing the problem option from STDY-ST to TRANSNT, or vice versa, or the problem advancement time is reset through W1 on Card 200. Either or both of these could be specified at restart. When the advancement time is changed, the user is responsible for ensuring that models involving problem time will operate as intended. Affected models include trips using advancement time, control systems using time as an operand (does not include differentiation or integration with respect to time), and table lookup and interpolation using time as the independent variable. If necessary, trips, control systems, general tables, time-dependent volumes, junctions, and pump speed tables can all be reentered at restart. With normal modeling practices, little use of modeling features involving advancement time is needed for runs to steady-state and accordingly little effort should be needed in switching from STDY-ST to TRANSNT. Because of the frequent use of time in logic to initiate failures, as part of safety systems, and used in establishing the delay times allowed in most table lookup and interpolation tables, required changes to a transient run may be extensive.

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

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

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

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

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

W2(A) Restart plot file name. This optional alphanumeric entry can be used to enter the file name of the restart plot file. Up to forty characters may be entered as one alphanumeric field. The default file name for the restart plot file is rstplt. This default may be overridden on Unix machines by using the -r option on the command line. Either the default name, the name from the command field, or the name from this field on a previous case may be overridden by this field. This information can be entered only on NEW problems; in RESTART problems, this information may be entered on the 103 card.

A2.7 Card 105, CPU Time Remaining and Diagnostic Edit 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, Word 3 of this card may be entered as the CPU time allocated. An alternative CPU remaining time is computed by decrementing this quantity by the CPU used as measured by the program. If Word 3 is omitted or zero, the alternative CPU remaining time is assumed infinite. At the end of each time step, the CPU time remaining for the job is determined from the minimum of the system (if available) and alternative CPU remaining times. If the remaining CPU time is less than Word 1, the transient is immediately terminated. The advancement may not be at the end of a requested time step due to time step reduction; the hydrodynamic, heat conduction, and reactor kinetics may not be advanced to the same point; or the advancement may not be successful and the advancement is scheduled to be repeated with reduced time step. Major edits, minor edits, plot edits, and a restart record are forced. The transient can be restarted from this point as if the problem had not been interrupted. The transient is also terminated after successful advancement over a requested time step and the CPU time is less than Word 2. Word 2 should be larger than Word 1. The default values for Words 1 and 2 are 1.0 and 2.0 seconds. The default values are used if the card is not supplied or the entered numbers are less than default values. Word 2 is also forced to be 1.0

second larger than Word 1. The time values must include time for the final minor and major edits (very little time required), plotting, and any other processing that is to follow termination of SCDAP execution. This card is optional, but we strongly recommend its use with Word 3 nonzero on systems that do not provide a system CPU limit.

Card 105 also controls the diagnostic edit printout through the use of Words 4 and 5. If these words are missing or zero, no debug options are in effect. If Word 4 is greater than zero, then Word 4 is the attempted advancement count number to start a diagnostic edit, and Word 5 is the attempted advancement count number to stop the diagnostic edit as well as the calculation. If Word 4 is -1, a dump file is written on the file specified by the -A option on the command line at the completion of the advancement given in Word 5. Entering 0 in Word 5 writes the dump file just before the start of transient advancement. The problem is terminated after writing the dump file. If Word 4 is -2, a dump file is written on the file given by the -A option after the advancement given in Word 5; the time advancement is then repeated and a dump file following the repeated advancement is written on the file given by the -B option. The problem is terminated after writing the second dump file. Word 5 must be greater than 0 when Word 4 is -2. The default file names are -A dumpfil1 and -B dumpfil2.

W1(R) CPU remaining limit 1 (s).

W2(R) CPU remaining limit 2 (s).

W3(R) CPU time allocated (s). This quantity is optional.

W4(I) Debug control word as described above.

W5(I) Debug control word as described above.

If the program is compiled with compile time option CTSS defined, entering Word 1 as 0.0 will cause no testing for CPU termination; and normal CTSS termination at the end of CPU time can occur. In this case, the problem can be restarted from the drop file.

A2.8 Card 110, Noncondensable Gas Species

This card is required for all calculations that use noncondensable gas. Hydrogen must be included for SCDAP/RELAP5 problems. Nitrogen must be included for any problem having accumulators. This card cannot be entered on a RESTART problem.

W1-WN(A) Noncondensable gas type. Enter any number N of words (maximum 5) of the following noncondensable gas types: argon, helium, hydrogen, nitrogen, xenon, krypton, air or sf6.

A2.9 Cards 115 and 116, Noncondensable Mass Fractions

Card 115 is related to Card 110 and similarly Card 116 is related to Card 111. Card 115 is required if Card 110 is entered unless only one species is entered on Card 110 and then the mass fraction is set to 1.0. The number of words on Card 115 must equal the number of words on Card 110. A similar requirement holds for Card 116. The sum of the mass fractions on each card must sum to one. The mass fractions on these cards are default values and are used for initial conditions of active volumes and for values of time-

dependent volumes unless mass fractions are entered in the hydrodynamic component data. These cards cannot be entered on a RESTART problem.

A2.9.1 Card 115, Noncondensable Gas Mass Fractions

W1-W2(R) Mass fraction for each noncondensable gas type.

A2.10 Cards 120 through 129, Hydrodynamic System Control Cards

Independent hydrodynamic systems can be described by the hydrodynamic component input. The term independent hydrodynamic systems means that there is no possibility of flow between the independent systems. A typical example would be the primary and secondary systems in a reactor where heat flows from the primary system to the secondary system in the steam generator but there is no fluid connection. If a tube rupture was 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 for each system. If not entered for a system, that system contains H_2O as the fluid unless a different fluid is specified in hydrodynamic component data and the lowest numbered volume in each system is the reference volume. Additionally, the reference volume has a default elevation of zero for fixed problems. These cards should not be entered in a RESTART problem.

W1(I) Reference volume number of the system. This must be a volume in the hydrodynamic system.

W2(R) Reference elevation of the volume center relative to a fixed z-axis for the system (m, ft).

W3(A) Fluid type for the system. Enter H2O or D2O.

W4(A) Optional alphanumeric name of system used in output editing. *NONE* is used if this is word not entered.

W5(I) System information flag. This word has the packed format g. This word is optional. If this word is not entered, g = 0 is used.

The digit g specifies whether noncondensable gas is present for this system. g = 0 specifies that noncondensable gas is present for this system. g = 1 specifies that noncondensable gas is not present for this system. If g = 1 (no noncondensable) in a system and if the digit t = 4, 5, or 6 in the hydrodynamic volume component control word εbt (see Section A7 of this Appendix A), an input error will result.

W6-9(A) Thermodynamic property file name of the system. This optional alphanumeric entry can be used to enter the file name of the thermodynamic property file of the system. Up to thirty-two characters may be entered as one alphanumeric field. (The code internally treats the field as up to four eight-character words.) The default file name for the thermodynamic property file is tpfh20 for H2O and typfd2o for D2O.

A2.11 Cards 140 through 147, Self-Initialization Option Control Cards

These cards are optional, are not needed, and are only used as a cross-check on the controllers specified in Section A14. Data supplied on these cards are used to invoke the self-initialization option. These data describe which and how many of each controller will be used. To retain generality and flexibility, the self-initialization option does not require that the steady-state and nearly-implicit solution scheme options be concurrently turned on. However, this is the recommended procedure. These latter options are invoked through input data Cards 100 and 201 through 299. In addition to the data cards described below, the user must furnish data on the controllers to be used, as described in Section A14.

A2.11.1 Card 140, Self-Initialization Control Card

This card specifies the number and type of controllers desired.

W1(I) Number of pump controllers.

W2(I) Number of steam flow controllers.

W3(I) Number of feedwater controllers.

A2.11.2 Cards 141 through 142, Self-Initialization Pump Controller and Identification Cards

These cards establish the relationship between the pump number and the number of the pump controller. For each pump so referenced, the user must use the time-dependent pump velocity option. For pump component Card CCC6100, Words 2 and 3 must be the alphanumeric and numeric parts for the pump controller. The time-dependent pump velocity data (pump component Cards CCC6100 through CCC6199) should be input so that the search variable and pump velocity are related by a straight line through the origin with a slope of 1.

W1(I) Component number of pump number 1.

W2(I) Controller identification number for pump number 1.

W3(I) Component number of pump number 2.

W4(I) Controller identification number for pump number 2.

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

A2.11.3 Cards 143 through 144, Self-Initialization Steam Flow Controller Identification Cards

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

W1(I) Component number of steam flow control valve number 1.

W2(I) Controller number of steam flow controller for steam flow control valve number 1.

W3(I) Component number of steam flow control valve number 2.

W4(I) Controller number of steam flow controller for steam flow control valve number 2.

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

A2.11.4 Cards 145 and 146, Self-Initialization Feedwater Controller Identification Cards

These cards establish the relationship between the feedwater valve number and the feedwater controller number.

W1(I) Component number of feedwater valve number 1.

W2(I) Controller id number of the feedwater controller for feedwater valve number 1.

W3(I) Component number of feedwater valve number 2.

W4(I) Controller id number of the feedwater controller for feedwater valve number 2.

A maximum of six control valve/controller pairs may be entered. Note that in the above it is assumed that a valve component is the control junction. 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 is allowed, or a diagnostic error will result, such as a time-dependent junction with the controller output used as the independent variable in place of time.

A2.11.5 Card 147, Pressure and Volume Control Component Identification Card

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

W1(I) Component number of time-dependent volume that replace the pressurizer.

W2(I) Component number to which the above time-dependent volume is connected. CAUTION: Only a single-junction is allowed or an error will result.

W3(R) Desired steady-state pressure.

A3. CARDS 200 THROUGH 299, TIME STEP CONTROL CARDS

A3.1 Card 200, Initial Time Value

This card is optional. See the description of each word on this card for the default values if this card is not entered.

W1(R) Initial time. If not entered, the simulation time at the start of the advancements is zero for a NEW problem, the advancement time at the point of restart for a RESTART problem, or zero for a RESTART problem in which the problem option switches from STDY-ST to TRANSNT or vice versa. If this card is entered, the simulation time is set to the entered value, which must be greater than or equal to zero. Setting the simulation time with this entry can be done on any NEW or RESTART problem but with most applications should only be used in NEW or RESTART problems that switch from the STDY-ST or TRANSNT options. See the cautions discussed in Section A2.5 for this capability. When needing to enter W2 but do not wish to enter a new initial time, enter -1.0, which is a flag to ignore this word.

W2(I) Control variable number for user-controlled time step. This word is optional. A nonzero number specifies a control variable whose value is used for user-specified time step control. The time step will be determined from the maximum of the value of the control variable and the current minimum time step entered on Cards 201 through 209. The time step will be equal to or less than this value and depends on the current requested time step, the mass error and other error checks, the Courant limit, and the time step reduction options.

A3.2 Cards 201 through 299, Time Step Control

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

W1(R) Time end for this set (s). This quantity must increase with increasing card numbers.

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) Control option (see Section 5.2 for a discussion of this input). This word has the packed format ssdtt. It is not necessary to input leading zeros.

The digits ss, that represent a number from 0 through 15, are used to control the printed content of the major edits. The number is treated as a four-bit binary number. If no bits are set (i.e., the number is 0), all the standard major printed output is given. If the first bit from the right is set (i.e., ss = 1 if the other bits are not set), the heat structure temperature block

is omitted. If the second bit from the right is set (i.e., ss = 2 if the other bits are not set), the second portion of the junction block is omitted. If the third bit from the right is set (i.e., ss = 4 if the other bits are not set), the third and fourth portions of the volume block are omitted. If the fourth bit from the right is set (i.e., ss = 8 if the other bits are not set), the statistics block is omitted.

The digit d, which represents a number from 0 through 7, can be used to obtain extra output at every hydrodynamic time step. The number is treated as a three-bit binary number. If no bits are set (i.e., the number is 0), the standard output at the requested frequency using the maximum time step is obtained (see Words 5 and 6 of this card). If the number is nonzero, output is obtained at each successful time step; and the bits indicate which output is obtained. If the first bit from the right is set (i.e., d = 1 if the other bits are not set), major edits are obtained every successful time step. If the second bit from the right is set (i.e., d = 2 if the other bits are not set), minor edits are obtained every successful time step. If the third bit from the right is set (i.e., d = 4 if the other bits are not set), plot records are written every successful time step. These options should be used carefully, since considerable output can be generated.

The digits tt, that represent a number from 0 through 31, are used to control the time step. The number is treated as a four-bit binary number. The effect of no bits being set (i.e., 0 being entered, and the effect of each bit are first described followed by the recommended combination of bits.

If no bits are set (i.e., the number is 0), no error estimate time step control is used, and the maximum time step is attempted for both hydrodynamic and heat structure advancement. The hydrodynamic time step, however, is reduced to the material Courant limit and further to the minimum time step for cases such as water property failures. If the first bit from the right is set (i.e., tt = 1 if the other bits are not set), the hydrodynamics advancement, in addition to the time step control when no bits are set, uses a mass error analysis to control the time step between the minimum and maximum time step. If the second bit from the right is set (i.e., tt = 2 if the other bits are not set), the heat conduction/transfer time step is the same as the hydrodynamic time step; if the second bit from the right is not set, the heat conduction/transfer time step uses the maximum time step. If the third bit from the right is set (i.e., tt = 4 if the other bits are not set), the heat conduction/transfer and hydrodynamics are coupled implicitly; if the third bit from the right is not set, the heat conduction/transfer and hydrodynamic advancements are done separately and the information between the models is coupled explicitly. If the fourth bit from the right is set (i.e., tt = 8 if the other bits are not set), the nearly-implicit scheme is used to advance the hydrodynamics; if the fourth bit from the right is not set, the semi-implicit scheme is used to advance the hydrodynamics. If the fifth bit from the right is set (i. e., tt = 16 if the other bits are not set), the test for convergence of a steady-state calculation is not made; if the fifth bit from the right is not set, the test for convergence of a steady-state calculation is made.

We recommend not using tt equal to 0 except for special testing situations. The use of tt equal to 1 is possible if the maximum time step is kept sufficiently small to ensure that the explicit connection between the heat conduction/transfer and hydrodynamic calculations remains stable. If there is any doubt, use tt equal to or greater than 3 (sets first bit and second bit). Using tt equal to 3 or 11 specifies the semi-implicit or the nearly-implicit advancement scheme, respectively, with both schemes using time step control, the heat conduction and hydrodynamics use the same time step, and the heat conduction/transfer

and hydrodynamics are advanced separately. Using tt equal to 7 or 15 specifies the same features as tt equal to 3 or 11 and, in addition, specifies the implicit advancement of the heat conduction/transfer with the hydrodynamics. We recommend the nearly-implicit scheme during a steady-state and/or self-initialization case problem where the time step is limited by the material Courant limit. The nearly-implicit scheme can also be used during slower phases of a transient problem, though we advise the user that the answers may change somewhat from the semi-implicit scheme answers (depending on the time step size). (The nearly-implicit advancement scheme is still under development; most of the verification and assessment for the code has been done with the semi-implicit advancement scheme.) We did not recommend use of the implicit coupling of the heat conduction/transfer and hydrodynamics in prior versions since the implicit coupling was only partially implemented. With the implicit coupling now complete, we encourage the use of tt equal to 7 or 15. Users should be cautioned that the implicit coupling is a recent addition to SCDAP/RELAP5 and is still under assessment. When using the implicit coupling, the heat conduction time step must be the same as the hydrodynamic time step. This requirement is currently not enforced by the coding. In steady-state calculations, setting the fifth bit (adding 16) for the early part of the run can ensure the calculation runs to a user-specified time, then, setting the fifth bit off can allow the steady-state convergence to test control the termination of the problem.

W5(I) Minor edit and plot frequency. This is the number of maximum or requested time advances per minor edit and write of plot information.

W6(I) Major edit frequency. This is the number of requested time advances per major edit.

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

A4. CARDS 301 THROUGH 399, MINOR EDIT REQUESTS

These cards are optional for NEW and RESTART problems, required for a REEDIT problem, and not allowed for PLOT and STRIP problems. If these cards are not present, no minor edits are printed. If these cards are present, minor edits are generated and the order of the printed quantities is given by the card number of the request card. One request is entered per card, and the card numbers need not be consecutive. For RESTART problems, if these cards are entered, all the cards from the previous problem are deleted.

W1(A) Variable code (alphanumeric).

W2(I) Parameter (numeric).

Words 1 and 2 form the variable request code pair. The quantities that can be edited and the input required are listed below. For convenience, quantities that can be used in plotting requests, in trip specifications, as search variables in tables, and as operands in control statements are listed. Units for the quantities are also given. Interactive input variables described in Section A6. can be used in batch or interactive jobs in the same manner as the variables listed below. The parameter for interactive input variables is 1000000000. Quantities compared in variable trips must have the same units, and input to tables specified by variable request codes must have the specified units. The quantities are listed in alphabetical order within each section.

The underlined quantities without an asterisk in Section A4.1 through Section A4.8 are always written to the restart-plot file (RSTPLT). Underlined quantities followed by an asterisk have only some of the quantities written to the restart-plot file and the text will indicate which quantities are written. The quantities that are not underlined or some of the quantities underlined that are followed with an asterisk are written to the restart-plot file only if requested on a 208XXXX card as described in Section A4.9.

A4.1 General Quantities

Code	Quantity
COUNT	The current attempted advancement count number. The parameter is 0.
CPUTIME	The current CPU time for this problem (s). The parameter is zero.
DT	The current time step (s). The parameter is 0.
DTCRNT	The current Courant time step (s). The parameter is 0.
EMASS	Estimate of mass error in all the systems (kg, lb). The parameter is 0.
ERRMAX	The current estimate of the truncation mass error fraction. The parameter is 0. This is the maximum of the two types of computed mass error (ε_m or ε_{rms}).
NULL	Specifies null field. Allowed only on trip cards. The parameter is 0.
SYSTMS	Total mass of steam, water, and noncondensable in system n (kg, lb). Parameter is system number n.

STDTRN Steady-state/transient flag. The parameter is 0. For steady-state, the value is 0.0. For transient, the value is 1.0.

SYSMER Estimate of mass error in system n (kg, lb). Parameter is system number n.

TESTDA An array testda, of twenty quantities, [real testda(20)] has been defined for the convenience of program developers. This entry with a parameter ranging from 1 through 20 selects testda(parameter). The testda array is initially set to zero, and programming must be inserted to set testda values. The usual purpose of this capability is to allow a simple method for debug information to be printed in minor edits or to be plotted.

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

TIMEOF Time of trip occurring (s). The parameter is the trip number. This request is allowed only on trip cards.

TMASS Total mass of water, steam, and noncondensables in all the systems (kg, lb). The parameter is 0.

A4.2 Component Quantities

The quantities listed below are unique to certain components; for example, a pump velocity can only be requested for a pump component. The parameter is the component number, i.e., the three-digit number CCC used in the input cards.

Code	Quantity
ACPGTG	Accumulator vapor specific heat, C_p, at vapor temperature (J/kg · K, Btu/lb · °F).
ACPNIT	Accumulator noncondensable specific heat, C_p, at vapor temperature (J/kg · K, Btu/lb · °F).
ACQTANK	Total energy transport to the gas by heat and mass transfer in the accumulator (W, Btu/s).
ACRHON	Accumulator noncondensable density (kg/m^3, lb/ft^3).
ACTTANK	Mean accumulator tank wall metal temperature (K, °F).
ACVDM	Gas volume in the accumulator tank, standpipe, and surge line (m^3, ft^3).
ACVGTG	Accumulator vapor specific heat, C_v, at vapor temperature (J/kg · K, Btu/lb · °F).
ACVLIQ	Liquid volume in the accumulator tank, standpipe, and surge line (m^3, ft^3).
AHFGTF	Accumulator heat of vaporization at liquid temperature (J/kg, Btu/lb).

AHFGTG	Accumulator heat of vaporization at vapor temperature (J/kg, Btu/lb).
AHFTG	Accumulator liquid enthalpy at vapor temperature (J/kg, Btu/lb).
AHGTF	Accumulator vapor enthalpy at liquid temperature (J/kg, Btu/lb).
AVGTG	Accumulator specific volume at vapor temperature (m^3/kg, ft^3/lb).
AVISCN	Accumulator noncondensable viscosity (kg/m · s, lb/ft · s).
BETAV	Accumulator steam saturation coefficient of expansion (K^{-1},$^oF^{-1}$).
CDIM	GE mechanistic dryer critical inlet moisture quality.
DIM	GE mechanistic inlet moisture quality.
DMGDT	Accumulator/time rate of change in dome vapor mass (kg/s, lb/s).
GDRY	GE mechanistic separator capacity factor.
OMEGA	Inertial valve disk angular velocity (rad/s, rev/min).
PMPHEAD	Pump head in the pump component (Pa, lb_f/in^2).
PMPMT	Pump motor torque (N · m, lb_f · ft).
PMPNRT	Calculated pump inertia (kg · m^2, lb · ft^2).
PMPTRQ	Pump torque in the pump component (N · m, lb_f · ft).
PMPVEL	Pump velocity in the pump component (rad/s, rev/min).
THETA	Inertial valve disk angular position (deg).
TURETA	The efficiency of the turbine component.
TURPOW	The power developed in the turbine component (W, Btu/s).
TURTRQ	The torque developed in the turbine component (N · m, lb_f · ft).
TURVEL	The rotational velocity of the turbine component (rad/s, rev/min).
VLVAREA	This is the ratio of the current valve physical area to the junction area. The junction area is the fully open valve physical area for the smooth area option and the minimum of the two connecting volumes for the abrupt area change.

VLVSTEM This is the ratio of the current valve stem position to the fully open valve stem position for the motor and servo valves when the normalized stem position option is used. For the motor and servo valves when the normalized area option is used and for all the other valves, this is the ratio of the current valve physical area to the fully open valve physical area.

XCO GE mechanistic separator liquid carryover quality.

XCU GE mechanistic separator vapor carryunder quality.

XI GE mechanistic separator inlet quality.

A4.3 Volume Quantities

For most of the following variable codes, the parameter is the volume number, i.e., the nine-digit number CCCNN0000 printed in the major edit. The parameter is CCC010000 for a single-volume; CCC010000 for a time-dependent volume; CCCNN0000 for a volume in a pipe component ($01 \leq NN \leq 99$); CCC010000 for the volume in a branch, separator, jetmixer, turbine, or ECC mixer component; CCC010000 for the volume in a pump component; and CCC010000 for the volume in an accumulator component. Some of the quantities are associated with the coordinate directions in the volume and these quantities are computed for each coordinate direction in use. The parameter for the coordinate direction-related quantities is the volume number plus F, where F is described below. The quantities requiring the volume number plus F are so identified.

Every volume has at least one coordinate direction, and some volumes may have up to three orthogonal coordinate directions. Each coordinate has an inlet face and an outlet face. Faces are numbered 1 through 6, where faces 1 and 2 are the inlet and outlet faces associated with coordinate 1 (or x), respectively, faces 3 and 4 are inlet and outlet faces associated with coordinate 2 (or y), and faces 5 and 6 are inlet and outlet faces associated with coordinate 3 (or z). All volumes use coordinate 1. The quantity F is to be added to the volume number to form the parameter used with coordinate direction related quantities is 0 or the face number. When F is 0 (i.e., just the volume number), 1, or 2, the volume velocity is for coordinate 1. When F is 3 or 4, the volume velocity is for coordinate 2; and when F is 5 or 6, the volume velocity is for coordinate 3. The underlined quantities followed by an asterisk in the list below, the coordinate-dependent quantities for coordinate 1 are automatically written to the restart-plot records using the parameter with F equal to 0. The other coordinate-dependent quantities can be written to the plot records using the 2080XXXX card series described in Section A4.9. Input checks are made to ensure the parameter specifies a volume coordinate direction that is in use.

Code	Quantity
AVOL	Area of the volume (m^2, ft^2); the parameter is the volume number plus F.
BETAFF	Liquid isobaric coefficient of the thermal expansion, β_f, bulk conditions (K^{-1}, $^oF^{-1}$).
BETAGG	Vapor isobaric coefficient of the thermal expansion, β_f, bulk conditions (K^{-1}, $^oF^{-1}$).
BORON	Spatial boron density, ρ_b (kg/m^3, lb/ft^3). This is volume liquid fraction (α_f) times the

liquid density (ρ_f) times the boron concentration (C_b). Boron concentration is used for hydrodynamic input, and boron density is used for minor edits and plots.

CSUBPF Liquid specific heat, C_{pf}, bulk conditions (J/kg · K, Btu/lb · °F).

CSUBPG Vapor specific heat C_{pg}, bulk conditions (J/kg · K, Btu/lb · °F).

DRFDP Partial derivative of ρ_f with respect to pressure (s^2/m^2, s^2/ft^2).

DRFDUF Partial derivative of ρ_f with respect to U_f ($kg \cdot s^2/m^5$, $lb \cdot s^2/ft^2$).

DRGDP Partial derivative of ρ_g with respect to pressure (s^2/m^2, s^2/ft^2).

DRGDUG Partial derivative of ρ_g with respect to U_g ($kg \cdot s^2/m^5$, $lb \cdot s^2/ft^2$).

DRGDXA Partial derivative of ρ_g with respect to X_n (kg/m^3, lb/ft^3).

DSNDDP Steam specific enthalpy at bulk conditions using partial pressure of steam (J/kg, Btu/lb).

DTDP Partial derivative of T_s with respect to pressure (K/Pa, $in^2 \cdot {}^oF/lb_f$).

DTDUG Partial derivative of T_s with respect to U_g ($s^2 \cdot K/m^2$, $s^2 \cdot {}^oF/ft^2$).

DTDXA Partial derivative of T_s with respect to X_n (K, °F).

DTFDT Partial derivative of T_f with respect to pressure (K/Pa, $in^2 \cdot {}^oF/lb_f$).

DTFDUF Partial derivative of T_f with respect to U_f ($s^2 \cdot K/m^2$, $s^2 \cdot {}^oF/ft^2$).

DTGDP Partial derivative of T_g with respect to pressure (K/Pa, $in^2 \cdot {}^oF/lb_f$).

DTDUG Partial derivative of T_g with respect to U_g ($s^2 \cdot K/m^2$, $s^2 \cdot {}^oF/ft^2$).

DTGDXA Partial derivative of T_g with respect to X_n (K, °F).

FLOREG Flow regime number; the parameter is the volume number plus °F.

FWALF Liquid wall frictional drag coefficient ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$); the parameter is the volume number plus °F.

FWALG Vapor wall frictional drag coefficient ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$); the parameter is the volume

number plus °F.

GAMMAC For explicit coupling of heat conduction/transfer and hydrodynamics, this is 0. For implicit coupling of heat conduction/transfer and hydrodynamics, this is the mass transfer rate per unit volume at the vapor./liquid interface in the boundary layer near the wall for condensation ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).

GAMMAI Mass transfer rate per unit volume at the vapor/liquid interface in the bulk fluid for vapor generation/condensation ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).

GAMMAW For explicit coupling of heat conduction/transfer and hydrodynamics, this is the mass transfer rate per unit volume at the vapor/liquid interface in the boundary layer near the wall for vapor generation/condensation ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$). For implicit coupling of heat conduction/transfer and hydrodynamics, this is the mass transfer rate per unit volume at the vapor/liquid interface in the boundary layer near the wall for vapor generation ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).

HGF Direct heating heat transfer coefficient per unit volume ($W/m^3 \cdot K$, $Btu/s \cdot ft^3 \cdot °F$).

HIF Liquid side interfacial heat transfer coefficient per unit volume ($W/m^3 \cdot K$, $Btu/s \cdot ft^3 \cdot °F$).

HIG Vapor side interfacial heat transfer coefficient per unit volume ($W/m^3 \cdot K$, $Btu/s \cdot ft^3 \cdot °F$).

HVMIX Enthalpy of the liquid and vapor (J/kg, Btu/lb).

P Volume pressure (Pa, lb_f/in^2).

PECLTV Peclet number.

PPS Steam partial pressure (Pa, lb_f/in^2).

Q Total volume heat source from the wall and direct moderator heating to liquid and vapor (W, Btu/s). This variable request is the same as Q.wall.tot. in the major edits.

QUALA Volume noncondensable mass fraction.

QUALE Volume equilibrium quality. This quality uses phasic enthalpies and mixture quality, with the mixture enthalpy calculated using the flow quality.

QUALS Volume static quality.

QWG Volume heat source from the wall and direct moderator heating to vapor (W, Btu/s). This variable request is the same as Qwg.wall.gas in the major edits.

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

RHOF	Liquid density (kg/m^3, lb/ft^3).
RHOG	Vapor density (kg/m^3, lb/ft^3).
RHOM	Total density for the mass error check (kg/m^3, lb/ft^3).
SATHF	Liquid specific enthalpy at saturation conditions using partial pressure of steam (J/kg, Btu/lb).
SATHG	Steam specific enthalpy at saturation conditions using partial pressure of steam (J/kg, Btu/lb).
SATTEMP	Volume saturation temperature based on the partial pressure of steam (K, °F).
SIGMA	Surface tension (N/m, lb_f/ft).
SOUNDE	Volume sonic velocity (m/s, ft/s).
TEMPF	Volume liquid temperature (K, °F).
TEMPG	Volume vapor temperature (K, °F).
THCONF	Liquid thermal conductivity (W/m · K, Btu/s · ft · °F).
THCONG	Vapor thermal conductivity (W/m · K, Btu/s · ft · °F).
TSATT	Saturation temperature corresponding to total pressure (K,°F).
UF	Liquid specific internal energy (J/kg, Btu/lb).
UG	Vapor specific internal energy (J/kg, Btu/lb).
VAPGEN	Total mass transfer rate per unit volume at the vapor/liquid interface in the bulk fluid for vapor generation/condensation and in the boundary layer near the wall for vapor generation/condensation ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).
VELF*	Volume-oriented liquid velocity (m/s, ft/s). The parameter is the volume number plus °F.
VELG*	Volume-oriented vapor velocity (m/s, ft/s). The parameter is the volume number plus °F.
VISCF	Liquid viscosity (kg/m · s, lb/ft · s).
VISCF	Vapor viscosity (kg/m · s, lb/ft · s).
VOIDF	Volume liquid fraction.

VOIDG	Volume vapor fraction (void fraction).
VOIDLA	Void above the level.
VOIDLB	Void below the level.
VOLLEV	Location of the level inside the volume (m, ft).
VVOL	Volume of the volume (m^3, ft^3).

A4.4 Junction Quantities

For the following variable request codes, the parameter is the junction number, i.e., the nine-digit number CCCNN0000 printed in the major edit. The parameter is CCC000000 for a single-junction; CCC000000 for a time-dependent junction; CCCMM0000 for a junction in a pipe component ($01 \leq MM \leq 99$); CCCMM0000 for a junction in a branch, separator, jetmixer, turbine, or ECC mixer component ($01 \leq MM \leq 9$); CCC000000 for a valve junction; CCC010000 for the inlet junction in a pump component; CCC020000 for the outlet junction in a pump component; CCCIINN00 for a junction in the multiple-junction component ($01 \leq II \leq 99$, $01 \leq NN \leq 99$); and CCC010000 for the junction in an accumulator component.

Code	Quantity
C0J	Junction distribution coefficient. The 0 in C0J is the number zero and not the upper case letter O.
CHOKEF	Junction choking flag. The value is 0 if the flow is not choked, and is 1 if the flow is choked.
FIJ	Interphase friction ($N \cdot s^2/m^5$, $lb_f \cdot s^2/ft^5$).
FJUNFT	Total form loss coefficient for irreversible losses, forward.
FJUNRT	Total form loss coefficient for irreversible losses, reverse.
FLORGJ	Junction flow regime number.
FORMFJ	Liquid form loss factor (dimensionless).
FORMGJ	Vapor form loss factor (dimensionless).
FWALFJ	Non-dimensional liquid wall friction coefficient.
FWALGJ	Non-dimensional vapor wall friction coefficient
IREGJ	Vertical bubbly/slug flow junction flow regime number.

MFLOWJ	Combined liquid and vapor flow rate (kg/s, lb/s).
QUALAJ	Junction noncondensable mass fraction.
RHOFJ	Junction liquid density (kg/m^3, lb/ft^3).
RHOGJ	Junction vapor density (kg/m^3, lb/ft^3).
SONICJ	Junction sound speed (m/s, ft/s). This speed is based on the physical junction area. It does not include the effects of the throat ratio and the discharge coefficients.
UFJ	Junction liquid specific internal energy (J/kg, Btu/lb).
UGJ	Junction vapor specific internal energy (J/kg, Btu/lb).
VELFJ	Junction liquid velocity (m/s, ft/s). This velocity is based on the junction area, A_j.
VELGJ	Junction vapor velocity (m/s, ft/s). This velocity is based on the junction area, A_j.
VGJJ	Vapor drift velocity (m/s, ft/s).
VOIDFJ	Junction liquid fraction.
VOIDGJ	Junction vapor fraction (void fraction).
VOIDJ	Junction vapor fraction (void fraction) used in the interphase drag.
XEJ	Junction equilibrium quality.

A4.5 Heat Structure Quantities

For the request code, HTVAT, the parameter is the seven-digit heat structure number CCCG0NN. For the remaining codes, the parameter is the seven-digit heat structure number CCCG0NN with a two-digit number appended. For codes other than HTTEMP and HTVAT, the appended number is 00 for the left boundary and 01 for the right boundary. For HTTEMP, the appended number is the mesh point number. For HTVAT, omit the two appended digits and use only the seven digit number. Only the left and right surface temperatures are written by default in plot records on the RSTPLT file, and, thus plot requests in plot-type problems and strip requests are limited to those temperatures unless the interior temperatures are forced to the RSTPLT file through 2080XXXX cards.

Code	Quantity
HTCHF	Critical heat flux (W/m^2, $Btu/s \cdot ft^2$).
HTGAMW	Wall vapor generation rate per unit volume ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$). The parameter is the heat structure geometry number CCCG0NN with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).

HTHTC — Heat transfer coefficient ($W/m^2 \cdot K$, $Btu/s\text{-}ft^2 \cdot {}^oF$).

HTMODE — Boundary heat transfer mode number (unitless). The mode number indicates which heat transfer regime is currently in effect. The parameter is the seven-digit heat structure geometry number, CCCG0NN, with a two-digit number appended. The two-digit appended number, 00, specifies the left boundary, and 01 specifies the right boundary. This same quantity is valid for the reflood heat structures.

HTRG — Heat flux to vapor phase (W/m^2, $Btu/s \cdot ft^2$). The parameter is the heat structure geometry number, CCCG0NN, with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).

HTRNR — Heat flux (W/m^2, $Btu/s \cdot ft^2$).

HTTEMP* — Mesh point temperature (K, ^oF). The parameter is the heat structure geometry number CCCG0NN with a two-digit number appended (mesh point number). The surface temperatures are written to the plot record but interior mesh point temperatures must be requested through the 2080XXXX cards.

HTVAT — Volume-averaged temperature in the heat structure (K, ^oF).

PECL — Liquid Peclet number for the heat structures. The parameter is the heat structure geometry number CCCG00NN with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).

STANT — Stanton number. The parameter is the heat structure geometry number CCCG00NN with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).

A4.6 Reflood-Related Quantities

For the following variable codes, the parameter is the heat structure geometry number, i.e., the four-digit number CCCG printed in the major edit.

Code	Quantity
QFBOT	Elevation of bottom quench front (m, ft).
QFTOP	Elevation of top quench front (m, ft).
TCHFQF	Temperature at the critical heat flux (K, ^oF).
TREWET	Rewet or minimum film boiling temperature (K, ^oF).
FINES	Total number of axial mesh points for this CCGN.

A4.7 Reactor Kinetic Quantities

The parameter is zero for the following reactor kinetic quantities.

Code	Quantity

The following list is for point kinetics variables.

RKPOWA	Reactor power from decay of actinides (W).
RKFIPOW	Reactor power from fission (W).
RKGAPOW	Reactor power from decay of fission products and actinides (W).
RKREAC	Reactivity (dollars).
RKRECPER	Reciprocal period (s^{-1}).
RKTPOW	Total reactor power, i.e., sum of fission and decay powers (W).

A4.8 Control System Quantities

The parameter is the control component number; i.e., the three-digit number, CCC, or the four-digit number, CCCC, used in the input cards.

CNTRLVAR	Control component number. These quantities are assumed dimensionless except for a SHAFT component.

A4.9 Cards 2080XXXX, 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 Section A4.9.1 through Section A4.11.

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 that the user wants to have written on the restart-plot file. The user can specify that between 1 and 9999 of these variables be written to the restart-plot file.

The 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 Section A4.1 through Section A4.8), since they are always written to the RSTPLT file. The field XXXX need not be consecutive.

W1(A) Variable request code. See Section A4.9.1 through Section A4.11 for the valid request code.

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

A4.9.1 General Quantities

Code	Quantity
COUNT	The current attempted advancement count number. The parameter is 0.
DT	The current time step (s). The parameter is 0.
DTCRNT	The current Courant time step (s). The parameter is 0.
ERRMAX	The current estimate of the truncation mass error. The parameter is 0.
STDTRN	Steady-state/transient flag. The parameter is 0. For steady-state, the value is 0.0. For transient, the value is 1.0.
TESTDA	An array testda of twenty quantities, [real testda(20)] has been defined for the convenience of program developers. This entry with a parameter ranging from 1 through 20 selects testda(parameter). The testda array is initially set to zero and programming must be inserted to set testda values. The usual purpose of this capability is to allow a simple method for debug information to be printed in minor edits or to be plotted.

A4.9.2 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 CCC used in the input cards.

Code	Component Type	Quantity
ACPGTG	Accumulator	Vapor specific heat, C_p, at vapor temperature (J/kg · K, Btu/lb · °F).
ACPNIT	Accumulator	Noncondensable specific heat, C_p, at vapor temperature (J/kg · K, Btu/lb· °F).
ACVGTG	Accumulator	Vapor specific heat, C_v, at vapor temperature (J/kg · K, Btu/lb · °F).
AHFTG	Accumulator	Liquid enthalpy at vapor temperature (J/kg, Btu/lb).
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).
AHGTF	Accumulator	Vapor enthalpy at liquid temperature (J/kg, Btu/lb).
AVISCN	Accumulator	Noncondensable viscosity (kg/m · s, lb/ft · s).
BETAV	Accumulator	Steam saturation coefficient of expansion (K^{-1}, $^oF^{-1}$).
DMGDT	Accumulator	Time rate of change in dome vapor mass (kg/s, lb/s).
OMEGA	Inertial Valve	Valve disk angular velocity (rad/s, rev/min).
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).

A4.9.3 Volume-Related Quantities

For the following variable codes, the parameter is the volume number or the volume number plus F. See Section A4.3 for discussion of F. Quantities requiring the volume number plus F are so noted.

Code	Quantity
AHTCOFG	Heat transfer coefficient between slab and vapor (W/m^2 · K, Btu/s•ft^2 · ^oF).
AVOL	Area of the volume (m^2, ft^2). The parameter is the volume number plus ^oF.
BETAFF	Liquid isobaric coefficient of the thermal expansion (K^{-1}, $^oF^{-1}$).
BETAGG	Vapor isobaric coefficient of the thermal expansion (K^{-1}, $^oF^{-1}$).
CSUBPF	Liquid specific heat, C_p, bulk conditions (J/kg · K, Btu/lb · ^oF).
CSUBPG	Vapor specific heat, C_p, bulk conditions (J/kg · K, Btu/lb · ^oF).
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).

DSNDDP	Partial derivative of SOUNDE with respect to pressure ($m^2 \cdot s/kg$, ft^2-s/lb).
DTDP	Partial derivative of T_{sat} with respect to pressure (K/Pa, $in^2 \cdot {}^oF/lb_f$).
DTDUG	Partial derivative of T_{sat} with respect to U_g ($s^2 \cdot K/m^2$, $s^2 \cdot {}^oF/ft^2$).
DTDXA	Partial derivative of T_{sat} with respect to X_n (K, ^oF).
DTFDP	Partial derivative of T_f with respect to pressure (K/Pa, $in^2 \cdot {}^oF/lb_f$).
DTFDUF	Partial derivative of T_f with respect to U_f ($s^2 \cdot K/m^2$, $s^2 \cdot {}^oF/ft^2$).
DTGDP	Partial derivative of T_g with respect to pressure (K/Pa, $in^2 \cdot {}^oF/lb_f$).
DTGDUG	Partial derivative of T_g with respect to U_g ($s^2 \cdot K/m^2$, $s^2 \cdot {}^oF/ft^2$).
DTGDXA	Partial derivative of T_g with respect to X_n (K, ^oF).
FLOREG	Flow regime number. The parameter is the volume number plus ^oF.
FWALF	Liquid wall frictional drag coefficient ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$). The parameter is the volume number plus ^oF.
FWALG	Vapor wall frictional drag coefficient ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$). The parameter is the volume number plus ^oF.
GAMMAW	Vapor generation rate at the wall per unit volume ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$).
HIF	Liquid side interfacial heat transfer coefficient per unit volume ($W/m^3 \cdot K$, Btu/ $s \cdot ft^3 \cdot {}^oF$).
HIG	Vapor side interfacial heat transfer coefficient per unit volume ($W/m^3 \cdot K$, $Btu/s \cdot ft^3 \cdot {}^oF$).
HVMIX	Enthalpy of the liquid and vapor (J/kg, Btu/lb).
PECLTV	Peclet number.
PPS	Vapor partial pressure (Pa, lb_f/in^2).
RGDXA	Partial derivative of RHOG with respect to X_n (kg/m^3, lb/ft^3).

RHOM	Total density for the mass error check (kg/m^3, lb/ft^3).
SATHF	Liquid specific enthalpy at saturation conditions (J/kg, Btu/lb).
SATHG	Vapor specific enthalpy at saturation conditions (J/kg, Btu/lb).
VISCF	Liquid viscosity (kg/m · s, lb/ft · s).
VISCG	Vapor viscosity (kg/m · s, lb/ft · s).
SIGMA	Surface tension (J/m^2, Btu/ft^2).
THCONF	Liquid thermal conductivity (W/m · K, Btu/s · ft · °F).
THCONG	Vapor thermal conductivity (W/m · K, Btu/s · ft · °F).
TSATT	Saturation temperature corresponding to total pressure (K, °F).
VELF	Volume-oriented liquid velocity (m/s, ft/s). The parameter is the volume number plus °F.
VELG	Volume-oriented vapor velocity (m/s, ft/s). The parameter is the volume number plus °F.
VVOL	Volume of the volume (m^3, ft^3).

A4.9.4 Junction-Related Quantities

For the following variable codes, the parameter is the junction number, i.e. the nine-digit number CCCNN0000 printed in the major edit.

Code	Quantity
COJ	Junction distribution coefficient.
FIJ	Interphase friction ($N \cdot s^2/m^5$, $lb_f \cdot s^2/ft^5$).
FLORGJ	Junction flow regime number.
FORMFJ	Liquid form loss factor (dimensionless).
FORMGJ	Vapor form loss factor (dimensionless).
IREGJ	Vertical bubbly/slug flow junction flow regime number.
SONICJ	Junction sound speed (m/s, ft/s).

VGJJ	Vapor drift velocity (m/s, ft/s).
VOIDJ	Junction vapor fraction (void fraction) used in the interphase drag.
XEJ	Junction equilibrium quality.

A4.9.5 Heat Structure-Related Quantities

Code	Quantity
HTGAMW	Wall vapor generation rate per unit volume ($kg/m^3 \cdot s$, $lb/ft^3 \cdot s$). The parameter is the heat structure geometry number CCCG0NN with a two-digit number appended (00 for the left boundary, and 01 for the right boundary).
HTMODE	Boundary heat transfer mode number (unitless). The mode number indicates which heat transfer regime is currently in effect. The parameter is the seven-digit heat structure geometry number CCCG0NN with a two-digit number appended. The two-digit appended Number 00 specifies the left boundary, and 01 specifies the right boundary. This same quantity is valid for the reflood heat structures.
HTRG	Heat flux to vapor phase (W/m^2, $Btu/s \cdot ft^2$). The parameter is the heat structure geometry number CCCG0NN with a two-digit number appended (00 for left boundary, and 01 for right boundary).

A4.9.6 Reflood-Related Quantities

For the following variable codes, the parameter is the heat structure geometry number, i.e., the seven-digit number CCCG0NN.

Code	Quantity
QFCHFN	Critical heat flux (W/m^2, $Btu/s \cdot ft^2$).
QFHTCN	Critical heat transfer coefficient ($W/m^2 \cdot K$, $Btu/s.\ ft^2 \cdot {}^oF$).
TCHFQF	Temperature corresponding to QFCHFN (K, ^oF).
TREWET	Rewet temperature (K, ^oF).
ZTRWT	Position of CHF point (m, ft).

A4.9.7 Reactor Kinetic-Related Quantities

These variables are from the one-dimensional space-dependent kinetic model. The parameter is defined in the definition of the quantity.

Code	Parameter	Quantity
RKOBK1	ll	Buckling in fast neutron group in Axial Level ll (cm^{-2}).
RKOBK2	ll	Total buckling in thermal neutron group in Axial Level ll (cm^{-2}).
RKOBTB	ll	Bias thermal buckling in Axial Level ll (cm^{-2}).
RKOCRPSN	cc	Insertion depth of control rod cc (m, ft)
RKOD1	ll	Diffusion coefficient in fast neutron group in Axial Level ll (cm).
RKOD2	ll	Diffusion coefficient in thermal neutron group in Axial Level ll (cm).
RKOLVCFR	ll	Control fraction in Axial Level ll.
RKOLVFIP	ll	Fission power in Axial Level ll (W).
RKOLVGAP	ll	Total decay power in Axial Level ll (W).
RKOLVPWA	ll	Actinide decay power in Axial Level ll (W).
RKOLVPWK	ll	Fission product decay power in Axial Level ll (W).
RKOPHI1	ll	Neutron flux in fast neutron group in Axial Level ll (n/cm^2-s).
RKOPHI2	ll	Neutron flux in thermal neutron group in Axial Level ll (n/cm^2-s).
RKOPOWA	0	Total reactor actinide decay power (W).
RKOPOWK	0	Total fission product decay power (W).
RKOSIGA1	ll	Macroscopic absorption cross-section in fast neutron group in Axial Level ll (cm^{-1}).
RKOSIGA2	ll	Macroscopic absorption cross-section in thermal neutron group in Axial Level ll (cm^{-1}).
RKOSIGR	ll	Macroscopic removal cross-section in fast neutron group in Axial Level ll (cm^{-1}).
RKOSIGF1	ll	Macroscopic fission cross-section in fast neutron group in Axial Level ll (cm^{-1}).
RKOSIGF2	ll	Macroscopic fission cross-section in thermal neutron group in Axial Level ll (cm^{-1}).

RKOZNALP	zz	Average void fraction in zone zz. Only valid if RAMONA feedback selected.
RKOZNBOR	zzvv	Average poison density in volume region vv of zone zz If RAMONA feedback is selected, vv is omitted (kg/m^3, lb/ft^3).
RKOZNDEN	zzvv	Average fluid density in volume region vv of zone zz. Only valid if HWR feedback selected (kg/m^3, lbm/ft^3).
RKOZNFIP	zz	Total fission power in zone zz (W).
RKOZNGAP	zz	Total decay power in zone zz (W).
RKOZNPWA	zz	Total actinide decay power in zone zz (W).
RKOZNPWK	zz	Total fission product decay power in zone zz (W).
RKOZNTF	zzss	Average structure temperature in structure region ss of zone zz. If RAMONA feedback is selected, ss is omitted (K, °F).
RKOZNTM	zzvv	Average fluid temperature in volume region vv of zone zz. If RAMONA feedback is used, vv is omitted (K, °F).
RKOZNTPW	zz	Total reactor power in zone zz (W).

A4.10 SCDAP Quantities

A4.10.1 SCDAP Bundle Quantities

Table A4-1 describes variables that characterize the response of the bundle. The index is required for input, but is ignored. The underlined variables are default variables that are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Section A-15. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

Table A4-1. Variables that characterize the response of fuel bundles and reactor core .

Code	Index	Quantity
BGNHG	0	Core or test fuel bundle nuclear heat generation (W).
BGMCT	0	Core or test fuel bundle maximum surface temperature (K).
BGTFPRN	0	Core cumulative noncondensable fission product release (kg).
BGTFPRS	0	Core cumulative soluble fission product release (kg).
BGTH	0	Core total hydrogen generation rate (kg/s).
BGTHQ	0	Core total oxidation heat generation (W).

Table A4-1. Variables that characterize the response of fuel bundles and reactor core (continued).

Code	Index	Quantity
BGTHQU	0	Core oxidation heat generation due to uranium oxidation (W).
BGTHU	0	Core hydrogen generation rate due to uranium oxidation (kg/s).
CRUCB	0	Indicator of whether crust supporting molten pool has failed: 0.0 = no, 1.0 = yes.
FPMASR	1 - Xe 2 - Kr 3 - Cs 4 - I 5 - Te	Cumulative mass released (kg, lb).
FPFRCR		Fractional mass released (unitless).
REPOOL	0	Equivalent radius of the molten pool of core material (m).
SHQIN	0	Total heat flowing through the inside surface of the flow shroud (W). Available only if the shroud component is input.
SHQOUT	0	Total heat flowing through the outside surface of the flow shroud (W). Available only if the shroud component is input.
TCORAV	0	Average temperature of reactor core (K).

A4.10.2 SCDAP Component Quantities

Table A4-2 describes the variables that characterize the response of each component. The index, jj, is the component number of interest. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Section A15. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

Table A4-2. Variables that characterize the response of each component.

Code	Index	Quantity
PGAS	jj	Gas pressure inside component jj (MPa).
ZBTCOH	jj	Elevation of the bottom surface of the cohesive debris bed for component jj (m).
ZBTRUB	jj	Elevation of the bottom of the rubble debris bed for component jj (m).
ZTPCOH	jj	Elevation of the top surface of the cohesive debris bed for component jj (m).
ZTPRUB	jj	Elevation of the top of the rubble debris bed for component jj (m).

A4.10.3 SCDAP Axial Dependent Quantities

Table A4-3 describes the variables that characterize the response of each axial node of each component. The index, kkjj, is the axial node, kk, and the component number, jj, of interest. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Section A15. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

Table A4-3. Variables that characterize the response of each axial node of each component.

Code	Index	Quantity
BRCHV	kkjj	Indicator of whether double-sided oxidation is taking place at axial node kk of component jj: 0.0 = no, 1.0 = yes.
GGIVY	nnjj	Mass of nn-th species of fission product released from SCDAP component jj (kg).
DAMLEV	kkjj	Level of damage at axial node kk of component jj (unitless). See Table A4-6.
DZFRCQ	kkjj	Height of cohesive debris at axial node kk of component jj (m).
EFFOXD	kkjj	Effective oxide thickness at axial node kk of component jj. SCDAP/RELAP5 now uses two oxide thicknesses: the first is the physical oxide thickness, OXDEO, and the second is an effective thickness, used to calculate the oxidation rate.
H2OXD2	kkjj	Hydrogen production rate at axial node kk of component jj (kg/s).
HFIXF	kkjj	Convective heat transfer coefficient for liquid phase at axial node k of component jj ($W/m^2 \cdot K$).
HFIXG	kkjj	Convective heat transfer coefficient for vapor phase at axcial node k of component jj ($W/m^2 \cdot K$).
HOOP	kkjj	Cladding hoop strain of component jj at axial node kk.
OXDEO	kkjj	Oxide thickness of the cladding at axial node kk of component jj (m).
QFLUX0	kkjj	Total heat flux at axial node kk of component jj (W/m^2).
QSCD	kkjj	Heat transferred from SCDAP component jj at axial node kk to fluid at this location (W).
QWGSCD	kkjj	Heat transferred to vapor phase of fluid from SCDAP component jj at axial node kk (W).
RCI	kkjj	Inside radius of the cladding at axial node kk of component jj (m).
RCO	kkjj	Outside radius of the cladding (not including the crust of solidified material) at axial node kk of component jj (m).

Table A4-3. Variables that characterize the response of each axial node of each component. (continued)

Code	Index	Quantity
RNALF	kkjj	Inner radius of the alpha oxide layer at axial node kk of component jj (m).
RNOXD	kkjj	Inner radius of the oxide layer at axial node kk of component jj (m).
ROCRST	kkjj	Outside radius of cladding (including the crust of the solidified material) of component jj at axial node kk (m).
RPEL	kkjj	Radius of fuel pellet of component jj at axial node kk (m).
RULIQ	kkjj	Outside radius of the solid part of the fuel pellet at axial node kk of component jj (m).
SCDCHF	kkjj	Critical heat flux at surface of SCDAP component jj at axial node kk (W/m^2).
WFROSR	kkjj	Mass of stainless steel resolidified at axial node kk of component jj per individual rod (kg).
WFROUO	kkjj	Mass of UO_2 resolidified at axial node kk of component jj (kg).
WFROZR	kkjj	Mass of zircaloy resolidified at axial node kk of component jj (kg).
WREMSR	kkjj	Mass of stainless steel remaining at axial node kk of component jj (kg).
WREMUO	kkjj	Mass of removed fuel of component jj at axial node kk (kg).
WREMZR	kkjj	Mass of removed cladding of component jj at axial node kk (kg).

A4.10.4 SCDAP General

The subfields of the index are explained for each variable in Table A4-4. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Section A15. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

Table A4-4. Variables that characterize temperature and creep rupture.

Code	Index	Quantity
CADCT[a]	iikkjj	Temperature of radial node number ii, axial node number kk, and component number jj (K).
DCREPC	ii	Fraction of life expended for ii-th COUPLE heat structure identified for creep rupture calculation.

Table A4-4. Variables that characterize temperature and creep rupture. (continued)

Code	Index	Quantity
DCREPH	ii	Fraction of life expended for ii-th RELAP5 heat structure identified for creep rupture calculation.

a. The component surface and centerline temperatures are always written to the restart/plot file at each minor edit frequency. A 208 card is required to save the temperature at any other radial node for plotting.

Table A4-5. Fission product species.

Index	Specie	Index	Specie
1	I		
2	CsI	10	Sn
3	CsOH	11	Fe
4	Te	12	Ru
5	HI	13	Ba
6	HTe	14	Sb
7	CD	15	Zn
8	Ag	16	Xe
9	UO2	17	Kr

Table A4-6. Damage state.

DAMLEV	Damage state
0.0	Intact geometry
0.1	Rupture due to ballooning
0.2	Rubble (fragmented)
0.4	Cohesive debris
1.0	Molten pool

A4.10.5 SCDAP Quantities for BWR Blade/Box Component

The expanded edit/plot variables defined for the BWR blade/box component are listed in Table A4-7. Although the variable names are identical to those used for other SCDAP components, the definitions listed below apply only to BWR blade/box components. The subfields of the index are ii for the radial

node number, kk for the axial node number, and jj for the component number.

Table A4-7. Edit/plot variables defined for the BWR blade/box component.

Code	Index	Quantity
CADCT	iikkjj	Temperatures (K) at radial node ii and axial node kk of component jj. For a BWR blade/box component, valid values of radial node ii are 1 - 14.
DAMLEV	kkjj	Level of damage (unitless) at axial node kk of component jj. For a BWR blade/box component, this indicates when the channel box wall has failed and a flow path has opened between the interstitial and fuel bundle coolant volumes. 0.0 = Both channel box segments intact. 0.1 = Channel box segment 1 gone. 0.2 = Channel box segment 2 gone. 0.3 = Both channel box segments gone.
H2OXD2	kkjj	Total hydrogen production rate (kg/s) at axial node kk of component jj. For a BWR blade/box component, this is the total hydrogen from the control blade and both sides of the channel box.
OXDEO	kkjj	Frozen crust thickness (m) on the interstitial side of channel box segment 2 at axial node kk of component jj.
RCI	kkjj	Equivalent thickness (m) of the intact control blade sheath at axial node kk of component jj.
RCO	kkjj	Frozen crust thickness (m) on the control blade at axial node kk of component jj.
ROCRST	kkjj	Thickness (m) of the intact channel box segment 1 at axial node kk of component jj.
RPEL	kkjj	Thickness (m) of the intact channel box segment 2 at axial node kk of component jj.
RULIQ	kkjj	Equivalent thickness (m) of the intact absorber rodlet (B_4C and stainless steel) at axial node kk of component jj.
WREMUO	kkjj	Frozen crust thickness (m) on the fuel bundle side of channel box segment 2 at axial node kk of component jj.
WREMZR	kkjj	Frozen crust thickness (m) on the fuel bundle side of channel box segment 1 at axial node kk of component jj.

A4.11 COUPLE Quantities

A4.11.1 Element or Node Specific Parameters

Table A4-8 describes quantities which are specific to a single node or element, and may be requested or plotted. The underlined variables that are default written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in

Section A4-15. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

Table A4-8. COUPLE node quantities.

Code	Index	Quantity
AFBULK	jjkk	Indicator of type of material in element jj of COUPLE mesh kk. See Table A4-10.
EVHTC	jj	Ex-vessel heat transfer coefficient at convection heat transfer node jj.
FPDEB	iijjkk	Fission product ii in element jj in COUPLE mesh number kk.
FRACML	jjkk	Fraction of COUPLE element jj in COUPLE mesh number kk that has melted.
GAPHTC	jjkk	Heat transfer coefficient for jj-th finite element (gap element) of mesh number kk (W/m2 · K).
MPHTC	jjkk	Heat transfer coefficient at liquid-solid interface for node jj of mesh number kk ($W/m^2 \cdot K$).
PORE	jjkk	Porosity of debris in element jj of COUPLE mesh kk
POWDB	jjkk	Power in element jj of COUPLE mesh kk (W/m^3).
TMLTEL	jjkk	Melting temperature of material in element kk of COUPLE mesh kk (K).
TMPCOU	jjkk	Debris bed temperature at node jj in COUPLE mesh number kk (K).
TOTHTC	jjkk	Convective heat transfer coefficient at node jj of COUPLE mesh kk ($W/m^2 \cdot K$).

A4.11.2 COUPLE Mesh Quantities

Table A4-9 defines COUPLE quantities which are characteristic of an entire mesh. The underlined variables are default variables which are written to the plot file for every analysis, while 208 cards are required to save non-underlined variables for plotting, as documented in Section A15. It should be noted that if the default variables are requested on a 208 card, they will be written to the plot file twice.

Table A4-9. COUPLE mesh quantities.

Code	Index	Quantity
CSENRG	kk	Total internal energy in structural material that supports debris (J).
DEBQUP	kk	Total rate of heat transfer by convection from top surface of debris (W).
DENRGY	kk	Total internal energy of debris (J).

Table A4-9. COUPLE mesh quantities. (continued)

Code	Index	Quantity
HGTDEB	kk	Debris bed height in COUPLE mesh kk (m).
INTPOW	kk	Integral with respect to time of total power in debris (J).
INTQ	kk	Integral with respect to time of total transfer from debris and structural material to fluid at boundaries of debris and structural material (J).
LIQAVG	kk	Average liquefied debris temperature (K).
LIQAG	kk	Mass of liquefied silver in mesh kk (kg).
LIQFE	kk	Mass of liquefied steel in mesh kk (kg).
LIQUO2	kk	Mass of liquefied UO_2 in mesh kk (kg).
LIQZO2	kk	Mass of liquefied ZrO_2 in mesh kk (kg).
LIQZR	kk	Mass of liquefied zirconium in mesh kk (kg).
MASLIQ	kk	Liquefied mass in mesh kk (kg).
MASSAG	kk	Total mass of silver in mesh kk (kg).
MASSAL	kk	Total mass of aluminum in mesh kk (kg).
MASB4C	kk	Total mass of B_4C in mesh kk (kg).
MASSCD	kk	Total mass of cadmium in mesh kk (kg).
MASSFE	kk	Total mass of stainless steel in mesh kk (kg).
MASSLI	kk	Total mass of lithium in mesh kk (kg).
MASSU	kk	Total mass of metallic uranium in mesh kk (kg).
MASUO2	kk	Total mass of uranium dioxide (UO_2) in mesh kk (kg).
MASSZR	kk	Total mass of zircaloy in mesh kk (kg).
MASZO2	kk	Total mass of zirconium oxide in mesh kk (kg).
MPPDEN	kk	Molten pool power density (W/m^3)
PDBTOT	kk	Total power in material that has slumped to lower head (W).
TMPDAV	kk	Average debris temperature in COUPLE mesh number kk (K).
TMPDMX	kk	Maximum debris bed temperature in COUPLE mesh number kk (K).
TWALMX	kk	Maximum temperature of structural material in COUPLE mesh kk (K)

Table A4-10. COUPLE material indicator.

AFBULK	Type of material
0.3	Mostly Ag-In-Cd
0.4	Mostly stainless steel
0.5	Mostly Zr
0.6	Mostly ZrO_2
0.7	More than 50% UO_2
1.0	More than 70% UO_2

A5. CARDS 400 THROUGH 799 OR 20600000 THROUGH 20620000, TRIP INPUT DATA

These cards are optional for NEW and RESTART type problems and are not used for other problem types. Two different card series are available for entering trip data, but only one series type may be used in a problem. Cards 401 through 799 allow 199 variable trips and 199 logical trips. Cards 20600010 through 20620000 allow 1,000 variable trips and 1,000 logical trips.

A5.1 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.

A5.2 Card 20600000, Trip Card Series Type

This card, if omitted, selects Cards 401 through 599 for variable trips and 601 through 799 for logical trips. For this case, the trip numbers are equal to the card numbers.

If this card is entered, card numbers 206NNNN0 are used for entering trip data and NNNN is the trip number. Trip numbers (NNNN) 1 to 1,000 are variable trips, and 1,001 to 2,000 are logical trips. Trip numbers do not have to be consecutive.

W1(A) Expanded. Any other entry is an error.

A5.3 Cards 401 through 599 or 20600010 through 20610000, Variable Trip Cards

Each card defines a logical statement or trip condition concerned with the quantities being advanced in time. A trip is false or not set if the trip condition is not met, and true if it is met. On restart, new trips can be introduced, old trips can be deleted, and a new trip with the same number as an old trip replaces the old trip.

The variable codes and parameters are the same as described for minor edits, Section A4. NULL is allowed for the right side when only a comparison to the constant is desired. The variable code TIMEOF, with the parameter set to the trip number, indicates the time at which the trip was last set. If the trip goes false, TIMEOF is set to -1.0.

W1(A) Variable code. On RESTART problems, this word can also contain DISCARD or RESET. DISCARD deletes the trip; RESET sets the trip to false. If DISCARD or RESET are entered, no further words are entered on the card.

W2(I) Parameter.

W3(A) Relationship. This may be either EQ, NE, GT, GE, LT, or 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 at each time advancement.

W8(R) Timeof quantity (s). This word is optional. If it is not entered, the trip is initialized as false and the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized as false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true. TIMEOF must not be greater than zero for NEW problems and must not be greater than the time of restart for RESTART problems.

The logical statement is "Does the quantity given by Words 1 and 2 have the relationship given by Word 3 with the quantity given by Words 4 and 5 plus Word 6?" If the relationship is false, the trip is false or not set. If the relationship is true, the trip is true or set. The TIMEOF variable is -1.0 if the trip is false. If the trip is true, this variable is the time the trip was last set true. A latched trip is never reset, so the trip time never changes once it changes from -1.0. For the nonlatched trips, the trip time when set remains constant until the trip condition becomes false and then the trip time is -1.0 again. If the trip condition becomes true again, the process is repeated. For trips such as a time test, L should be used to eliminate repeated testing, although no error or difference in results will occur if N is used.

A5.4 Cards 601 through 799 or 20610010 through 20620000, Logical Trip Cards

If these cards are entered, at least one of the variable trip cards must have been entered. Each card defines a logical relationship with the trips defined on these cards or on the variable trip cards.

W1(I) Trip number. The absolute value of this number must be one of the trip numbers defined by the variable or logical trip cards. A negative trip number indicates that the complement of the trip is to be used in the test.

W2(A) Operator. The operator may be AND, OR, or XOR. For RESTART problems, this quantity may also contain DISCARD or RESET. DISCARD deletes the trip and RESET sets the trip to false. If DISCARD or RESET are entered, no further words are entered on the card and Word 1 (W1) may be zero.

W3(I) Trip number. This is similar to Word 1 (W1).

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

W5(R) Timeof quantity (s). This word is optional. If not entered, the trip is initialized as false and the associated TIMEOF quantity is set to -1.0. If -1.0 is entered, the trip is initialized as

false. If zero or a positive number is entered for TIMEOF, the trip is initialized as true. TIMEOF must not be greater than zero for NEW problems and must not be greater than the time of restart for RESTART problems.

The trip condition is given by the result of the logical expression:

CONDITION OF TRIP IN W1 OPERATOR CONDITION OF TRIP IN W3.

A5.5 Card 600, Trip Stop Advancement Card

This card can be entered in NEW and RESTART problems. One or two trip numbers may be entered. If either of the indicated trips are true, the problem advancement is terminated. These trips are tested only at the end of a requested advancement. If the trips can cycle true and false, they should be latched-type trips to ensure being true at the test time.

W1(I) Trip number.

W2(I) Trip number. A second trip number need not be entered.

A6. CARDS 801 THROUGH 999, INTERACTIVE INPUT DATA

An interactive and color display capability exists when the code is interfaced with Nuclear Plant Analyzer (NPA) software. This capability allows a user to view selected results on a color graphics terminal and to modify user-defined input quantities. A user can view 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 computer terminal if the job is being run interactively. The card input defines input variable names and initial values. These variables are completely independent from the Fortran variable names used in the SCDAP/RELAP5 coding even if they are spelled the same. These user-defined variables can appear wherever variables listed in Section A4. can be used. Thus, the user-defined variables can be used in trips, control variable statements, search arguments for some tables, edited in minor edits, and plotted. With appropriate input, an interactive user can effect changes similar to those made by a reactor operator, such as opening/closing/ repositioning valves or setting new operating points in controllers. When entering these user-defined variables, the variable name is the alphanumeric part of the request code and 1000000000 is the numeric part.

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

W2(R) Initial value. This is not needed if DELETE is entered in Word 1.

In interactive execution, the initial value is used until changed by a terminal entry. The value can be changed at any time and as often as needed. One or more variables can be changed by entering the variable name and value pairs on the computer terminal. An example is VLV1 = 0 VLV2,1 VLV3,0, POWER = 3050.+6, where VLV1, VLV2, VLV3, and POWER are user-defined variable names. The format is identical to data input on cards. An equal sign is treated as a terminating comma. The values should be floating-point quantities, but integers are converted to floating point values. The NPA interface also allows other more convenient methods for entering new values during the simulation.

W3(R) Conversion factor. Word 2 or any terminal-entered replacement value is entered in user-defined units. These quantities should be converted to SI units if they are to be involved in comparisons or computations with quantities advanced in time. User units can be used only if these input interactive variables are used with control variables defined in compatible units. This word, if nonzero, is the conversion factor. If this word is positive, the conversion is:

$$V(\text{converted}) = V(\text{input}) \bullet W3 \ .$$

If negative,

V(converted) = V(input)/1.8 - W3.

For temperature conversion from °F to K, Word 3 should be -255.3722222. If this word is missing, the conversion factor defaults to 1.0. If this word is zero, the next two words must contain a variable request code; and the conversion factor appropriate for this quantity is supplied by the code. If SI units are in use, the supplied conversion factor is 1.0. If British units are in use, the appropriate conversion factor is supplied.

A7. CARDS CCCXXNN, HYDRODYNAMIC COMPONENTS

These cards are required for NEW type problems and may be entered for RESTART problems. Hydrodynamic systems are described in a NEW problem. In a RESTART problem, the hydrodynamic systems may be modified by deleting, adding, or replacing components. The resultant problem must describe at least two volumes and one junction. The hydrodynamic card numbers are divided into fields, where CCC is the component number (the component numbers need not be consecutive), XX is the card type, and NN is the card number within type. When a range is indicated, the numbers need not be consecutive.

A7.1 Card CCC0000, Component Name and Type

This card is required for each component.

W1(A) Component name. Use a name descriptive of the component's use in system. A limit of 8 characters is allowed for some computers, e.g., workstations, CRAY, Cyber-205, and IBM computers.

W2(A) Component type. Enter one of the following component types, SNGLVOL, TMDPVOL, SNGLJUN, TMDPJUN, PIPE, ANNULUS, BRANCH, SEPARATR, JETMIXER, TURBINE, ECCMIX, VALVE, PUMP, ACCUM, or the command DELETE. The command DELETE is allowed only in RESTART problems, and the component number must be an existing component at the time of restart. The DELETE command deletes the component.

The remaining cards for each component depend on the type of component.

A7.2 Single-Volume Component

A single-volume component is indicated by SNGLVOL for Word 2 on Card CCC0000. The junction connection code determines the placement of the volume within the system. More than one junction may be connected to an inlet or outlet If an end has no junctions, that end is considered a closed end. Normally, only a branch has more than one junction connected to a volume end. For major edits, minor edits, and plot variables, the volume in the single-volume component number is CCC010000.

A7.2.1 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 x-

direction length within a relative error of 0.000001. The same relative error check is done for the y- and z-directions.

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. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign.When the absolute value of the elevation angle determined by the ratio of the elevation change (this Word 6) and the volume length (Word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used. When the ratio is greater than 45 degrees, the vertical flow regime map is used.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed from $4.0 \bullet \frac{\text{volume flow area}}{\text{wetted perimeter}}$. If zero, the hydraulic diameter is computed from $2.0 \bullet \left(\frac{\text{volume flow area}}{\pi}\right)^{0.5}$. A check is made to ensure the pipe roughness is less than half the hydraulic diameter. See Word 1 for volume flow area.

W9(I) Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag.

The digit t specifies whether the thermal front tracking model is to be used; t = 0 specifies that the front tracking model is not to be used for the volume, and t = 1 specifies that the front tracking is to be used for the volume.

The digit l specifies whether the mixture level tracking model is to be used; l = 0 specifies that the level model not be used for the volume, and l = 1 specifies that the level model be used for the volume.

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

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

The digit b specifies the interphase friction that is used. b = 0 means that the pipe interphase friction model will be applied, b = 1 means that the rod bundle interphase friction model will be applied.

The digit f specifies whether wall friction is to be computed. f = 0 specifies that wall friction effects are to be computed along the x-coordinate of the volume, and f = 1 specifies that wall friction effects are not to be computed along the x-coordinate.

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

A7.2.2 Card CCC0141, Additional Laminar Wall Friction Card

This card is optional. If this card is not entered, the default values are 1.0 for the shape factor and 0.0 for the viscosity ratio exponent. Two, four, or six quantities may be entered on the card, and the data not entered are set to default values.

W1(R) Shape factor for x-coordinate.

W2(R) Viscosity ratio exponent for x-coordinate.

A7.2.3 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. It is not necessary to input leading zeros.

The digit ε specifies the fluid. ε = 0 is the default fluid, ε = 1 specifies H_2O and ε = 2 specifies D_2O. 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 H_2O is assumed as the fluid.

The digit b specifies whether boron is present or not. The digit b = 0 specifies that the volume fluid does not contain boron; b = 1 specifies that a boron concentration in mass of boron per mass of liquid (which may be zero) is being entered after the other required thermodynamic information.

The digit t specifies how the following words are to be used to determine the initial thermodynamic state. Entering t = 0 through 3 specifies only one component (steam/water). Entering t = 4 through 6 allows the specification of two components (steam/water and noncondensable gas).

With options t equal to 4 through 6, names of the components of the noncondensable gas must be entered on Card 110, and mass fractions of the components are entered on Card 115.

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 internal energies used to define the thermodynamic state.

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

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

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

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for static quality are:

1.0E-9 ≤ static quality ≤ 0.99999999, two-phase conditions, and static quality < 1.0 E-9 or quality > 0.99999999, single-phase. The static quality is given by $M_g/(M_g + M_f)$, where $M_g = M_s + M_n$.

Noncondensable options are:

If t = 4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and static quality in equilibrium condition. Using this input option with static quality 0.0 and ≤ 1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting static quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Static quality is reset to 1.0 using this dry noncondensable option.

If t = 5, the next three words are interpreted as temperature (K, °F), static quality, and noncondensable quality in equilibrium condition. Both the equilibrium and noncondensable qualities are restricted to be between 1.0 E-9 and 0.99999999. Little experience has been obtained using this option, and it has not been checked out.

If t = 6, the next five words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction,

and noncondensable quality. These quantities will be interpreted as nonequilibrium conditions depending on the internal energies used to define the thermodynamic state. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing (t = 0). If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must also be greater than 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy.

W2-W6(R) Quantities as described under Word 1 (W1). Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, boron concentration (mass of boron per mass liquid) follows the last required word for thermodynamic conditions.

A7.3 Time-Dependent Volume Component

This component is indicated by TMDPVOL for Word 2 on Card CCC0000. For major edits, minor edits, and plot variables, the volume in the time-dependent volume component is numbered as CCC010000.

A7.3.1 Cards CCC0101 through CCC0109, Time-Dependent Volume Geometry Cards

This card (or cards) is required for a time-dependent volume component. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R) Volume flow area (m^2, ft^2). When a time-dependent volume is used to model a pressure boundary condition (i.e., the time-dependent volume is connected to the system through a normal junction), it is generally recommended that the cross-sectional area of the time-dependent volume be large compared to the area of the normal junction.

W2(R) Length of volume (m, ft). After initialization, the length is set to zero.

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. After initialization, the volume is set to zero.

W4(R) Azimuthal angle (degrees). The absolute value of this angle must be $\leq$ 360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R) Inclination angle (degrees). The absolute value of this angle must be $\leq$ 90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. As with the other components, this Word 6 is compared to the volume length (Word 2) to determine if the horizontal or vertical flow regime map is used. This is not important for this component, since the correlations that depend on the flow regime maps are not needed. The volume conditions are prescribed through input Cards CCC0201 through CCC0299. After initialization, the elevation change is set to zero.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed for $4.0\left(\frac{\text{volume flow area}}{\text{wetted perimeter}}\right)^{0.5}$. A check is made to ensure the pipe roughness is less than half the hydraulic diameter.

W9(I) Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag. The y- and z-coordinate data (wall friction flag f) are not read in for the time-dependent component because the wall friction is not used for time-dependent volumes.

The digit t is not used and should be input as zero (t = 0). The thermal stratification model is not used in a time-dependent volume.

The digit l is not used and should be input as zero (l = 0). The level tracking model is not used in a time-dependent volume.

The digit p is not used and should be input as zero (p = 0). The major edit will show p = 1.

The digit v is not used and should be input as zero (v = 0). The major edit will show v = 1.

The digit b specifies the interphase friction that is used. b = 0 means that the pipe interphase friction model will be applied, and b = 1 means that the rod bundle interphase friction model will be applied. The interphase friction models are not used for time-dependent volumes, so either b = 0 or b = 1 can be inputted and the output will show the digit entered.

The digit f specifies whether wall friction is to be computed. f = 0 specifies that wall friction effects are to be computed for the volume, and f = 1 specifies that wall friction effects are not to be computed for the volume. The wall friction model is not used for time-dependent volumes, so either f = 0 or f = 1 can be inputted and the output will show the digit entered.

The digit e specifies if nonequilibrium or equilibrium is to be used. e = 0 specifies that a

nonequilibrium (unequal temperature) calculation is to be used, and $\underline{e} = 1$ specifies that an equilibrium (equal temperature) calculation is to be used. Equilibrium volumes should not be connected to nonequilibrium volumes. The equilibrium option is provided only for comparison to other codes. The nonequilibrium and equilibrium options are not used for time-dependent volumes, so either $\underline{e} = 0$ or $\underline{e} = 1$ can be used.

A7.3.2 Card CCC0200, Time-Dependent Volume Data Control Word

This card is required for a time-dependent volume.

W1(I) Control word for time-dependent data on the CCC02NN cards. This word has the packed format $\underline{\varepsilon}\underline{bt}$. It is not necessary to input leading zeros.

The digit $\underline{\varepsilon}$ specifies the fluid. $\underline{\varepsilon} = 0$ is the default fluid, $\underline{\varepsilon} = 1$ specifies H_2O, and $\underline{\varepsilon} = 2$ specifies D_2O. The default fluid is that set for the hydrodynamic system by Cards 120 through 129 or this control word in another volume in this hydrodynamic system. The fluid type set on Cards 120 through 129 or these control words within the hydrodynamic system must be consistent (i.e., not specify different fluids). If Cards 120 through 129 are not entered and all control words use the default $\underline{\varepsilon} = 0$, then H_2O is assumed as the fluid.

The digit $\underline{b}$ specifies whether boron is present or not. The digit $\underline{b} = 0$ specifies that the volume fluid does not contain boron; $\underline{b} = 1$ specifies that a boron concentration in mass of boron per mass of liquid water (which may be zero) is being entered after the other required thermodynamic information.

The digit $\underline{t}$ specifies how the words of the time-dependent volume data in Cards CCC0201 through CCC0209 are to be used to determine the initial thermodynamic state. Entering $\underline{t}$ equal to 0 through 3 specifies one component (steam/water). Entering $\underline{t}$ equal to 4 through 6 allows the specification of two components (steam/water and noncondensable gas).

With options 4 through 6, names of the components of the noncondensable gas must be entered on Card 110, and mass fractions of the components are entered on 115. Entering $\underline{t} = 7$ specifies three components, liquid/steam, noncondensable gas, and a molten metal. Option 7 requires Card 110 and Card CCC0301 or Card 115 similarly to options 4 through 6. In addition, option 7 requires Card 111 defining components of the metal. The mass fractions are defined by Card CCC0302 if entered or from Card 116.

If $\underline{t} = 0$, the second, third, fourth, and fifth words of the time-dependent volume data on Cards CCC0201 through CCC0299 are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If $\underline{t} = 1$, the second and third words of the time-dependent volume data on Cards CCC0201 through CCC0299 are interpreted as temperature (K, °F) and static quality in equilibrium condition. Enter only the minimum number of words required. If entered, boron

concentration follows the last required word for thermodynamic conditions.

If $\underline{t} = 2$, the second and third words of the time-dependent volume data on Cards CCC0201 through CCC0299 are interpreted as pressure (Pa, lb_f/in^2) and static quality in equilibrium condition. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If $\underline{t} = 3$, the second and third words of the time-dependent volume data on Cards CCC0201 through CCC0299 are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium conditions. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for static quality are:

1.0E-9 $\leq$ static quality $\leq$ 0.99999999, two-phase conditions, and static quality < 1.0E-9 or static quality > 0.99999999, single-phase. The static quality is given by $M_g/(M_g + M_f)$, where $M_g = M_s + M_n$.

Noncondensable options are:

If $\underline{t} = 4$, the second, third, and fourth words of the time-dependent data on Cards CCC0201 through CCC0299 are interpreted as pressure (Pa, $lb_f/in.^2$), temperature (K, °F), and static quality in equilibrium condition. Using this input option with static quality > 0.0 and $\leq$ 1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting static quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Static quality is reset to 1.0 using this dry noncondensable option. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If $\underline{t} = 5$, the second, third, and fourth words of the time-dependent data on Cards CCC0201 through CCC0299 are interpreted as temperature (K, °F), static quality, and noncondensable quality in equilibrium condition. Both the static and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions. Little experience has been obtained using this option, and it has not been checked out.

If $\underline{t} = 6$, the second, third, fourth, fifth, and sixth words of the time-dependent data on Cards CCC0201 through CCC0299 are interpreted as pressure (Pa, $lb_f/in.^2$), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing (t = 0). If noncondensables are present (noncondensable quality greater

than 0.0), then the vapor void fraction must also be greater than 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor specific internal energy. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions.

If $\underline{t}$ = 7, the next seven words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, noncondensable quality, metal internal energy (J/kg, Btu/lb), and metal void fraction The sum of the vapor void fraction and the metal void fraction must be greater than or equal to zero and less than or equal to one. The noncondensable quality must be greater than or equal to zero and less than or equal to one. Enter only the minimum number of words required. If entered, boron concentration (mass of boron per mass of liquid) follows the last required word for thermodynamic conditions.

W2(I) Table trip number. This word is optional. If missing or zero and Word 3 is missing, no trip is used and the time argument is the advancement time. If nonzero and Word 3 is missing, this number is the trip number and the time argument is -1.0 if the trip is false and the advancement time minus the trip time if the trip is true.

W3(A) Alphanumeric part of variable request code. This quantity is optional. If not present, time is the search argument. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. If the trip number is zero, the specified argument is used. If the trip number is nonzero, -1.0E + 75 is used if the trip is false and the specified argument is used if the trip is true. TIME can be selected, but note that the trip logic is different than if this word were omitted.

W4(I) Numeric part of variable request code. This is assumed zero if missing.

A7.3.3 Cards CCC0201 through CCC0299, Time-Dependent Volume Data Cards

These cards are required for time-dependent volume components. A set of data is made up of the search variable (e.g., time) followed by the required data indicated by control Word 1 in Card CCC0200. The card numbers need not be consecutive, but the value of the search variable in a succeeding set must be equal to or greater than the value in the previous set. One or more sets of data, up to 5,000 sets are allowed. Enter only the minimum number of words required. If entered, boron concentration follows the last required word for thermodynamic conditions. Linear interpolation is used if the search argument lies between the search variable entries. End-point values are used if the argument lies outside the table values. Only one set is needed if constant values are desired, and computer time is reduced when only one set is entered. Step changes can be accommodated by entering the two adjacent sets with the same search variable values or an extremely small difference between them. Given two identical argument values, the set selected will be the closest to the previous argument value. Sets may be entered one or more per card and may be split across cards. The total number of words must be a multiple of the set size.

Inputting time-dependent volume tables where the search variable is a thermodynamic variable from some other component can run into difficulties if the component numbering is such that the time-dependent volume is initialized before the component providing the needed search variable. A 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.

W1(R) Search variable (e.g., time).

W2-W7(R) Quantities as described under Word 1 in Card 200. Depending on the control word, two through five quantities may be required. If entered, boron concentration (parts of boron per parts of liquid) follows the last required word for thermodynamic conditions.

As described above, sets may be entered one or more per card.

A7.4 Single-Junction Component

A single-junction component is indicated by SNGLJUN for Word 2 on Card CCC0000. For major edits, minor edits, and plot variables, the junction in the single-junction component is numbered CCC000000.

A7.4.1 Cards CCC0101 through CCC0109, Single-Junction Geometry Cards

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

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. An old or an expanded format can be used to connect volumes. In the old format, use CCC000000 if the connection is to the inlet side of the component and use CCC010000 if the connection is to the outlet side of the component. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces, respectively, for the volume's coordinate direction. The number N equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; N equal to 5 and 6 would do the same for the third coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m^2, ft^2). If zero, the area is set to the minimum volume flow area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.

W4(R) Reynolds number independent forward flow energy loss coefficient, A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified (see Section A7.4.3). The interpretation and use of the coefficient depends on whether the smooth or

abrupt area change option is specified or grid spacers are modeled.

W5(R) Reynolds number independent reverse flow energy loss coefficient A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified (see Section A7.4.3). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change is specified or grid spacers are modeled.

W6(I) Junction control flags. This word has the packed format jefvcahs. It is not necessary to input leading zeros.

The digit j specifies that this junction is a jet junction. Pool surface condensation is enhanced in the volume above the junction when this model is activated. This junction must be underneath the to volume.

The digit e specifies the modified PV term in the energy equations. e = 0 means that the modified PV term will not be applied, and e = 1 means that it will be applied.

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

The digit v specifies horizontal stratification entrainment/pullthrough options. This model is for junctions connected to a horizontal volume. v = 0 means the model is not applied; v = 1 means an upward-oriented junction; v = 2 means a downward-oriented junction; and v = 3 means a centrally (side) located junction.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, a = 1 means full abrupt area change model, (K_{loss}, area apportioning at branch, restricted junction area, and extra interphase drag), and a = 2 means a partial abrupt area change model (no K_{loss}, but includes area apportioning at branch, restricted junction area, and extra interphase drag).

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

The digit s specifies momentum flux options. s = 0 uses momentum flux in both the to volume and the from volume. s = 1 uses momentum flux in the from volume, but not in the to volume. s = 2 uses momentum flux in the to volume, but not in the from volume. s = 3 does not use momentum flux in either the to or the from volume.

W7(R) Subcooled discharge coefficient. This quantity is applied only to subcooled liquid choked flow calculations. The quantity must be > 0.0 and ≤ 2.0. If W7, W8, and W9 are missing, then W7, W8, and W9 are set to 1.0.

W8(R) Two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be > 0.0 and ≤ 2.0. If W7 is entered, and W8, and W9 are missing, then W8, and W9 are set to 1.0.

W9(R) Superheated discharge coefficient. This quantity is applied only to superheated vapor choked flow calculations. The quantity must be > 0.0 and ≤ 2.0. If W7 and W8 are entered, and W9 is missing, then W9 is set to 1.0.

A7.4.2 Card CCC0110, Single-Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., f = 0 in Word 6 of Cards CCC0101 through CCC0109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., f = 1 in Word 6 of Cards CCC0101 through CCC0109), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R) Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥ 0. This number should be computed from $4.0 \bullet \left(\frac{\text{junction area}}{\text{wetted perimeter}}\right)$. If zero is entered or if the default is used, the junction diameter is computed from $2.0 \bullet \left(\frac{\text{junction area}}{\pi}\right)^{0.5}$. See Word 3 of Cards CCC0101 through CCC0109 for the junction area.

W2(R) Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R) Gas intercept, C. This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R) Slope, m. This quantity is the slope used in the CCFL correlation and must be > 0. The default value is 1.

A7.4.3 Card CCC0111, Single-Junction Form Loss Data Card

These cards are optional. (The user-specified form loss coefficients are given in Words 1 and 2 of Cards CCC0101 through CCC0109 if these cards are not entered.) If these cards are entered, the form loss coefficients depend on the flow conditions and are calculated from

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_R = A_R + B_R Re^{-C_R}$$

where K_F and K_R are the forward and reverse form loss coefficients. A_F, A_R, B_F, B_R, C_F and C_R are user-specified constants; A_F and A_R are Words 4 and 5 of Cards CCC0101 through CCC0109; B_F, B_R, C_F and C_R are Words 1, 2, 3, and 4 of this card, (CCC0111); and Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculations, then enter all four words for the appropriate expression.

W1(R) B_F (≥ 0). This quantity must be greater than or equal to zero.

W2(R) C_F (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_R (≥ 0). This quantity must be greater than or equal to zero.

W4(R) C_R (≥ 0). This quantity must be greater than or equal to zero.

A7.4.4 Card CCC0201, Single-Junction Initial Conditions

This card is required for single-junction components.

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

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

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

W4(R) Interface velocity (m/s, ft/s). Enter zero.

A7.5 Time-Dependent Junction Component

This component is indicated by TMDPJUN for Word 2 on Card CCC0000. For major edits, minor edits, and plot variables, the junction in the time-dependent junction component is numbered as CCC000000.

A7.5.1 Card CCC0101, Time-Dependent Junction Geometry Card

This card is required for time-dependent junction components.

W1(I) <u>From</u> connection code to a component. This refers to the component from which the junction coordinate direction originates. An old or an expanded format can be used to connect volumes. In the old format, use CCC000000 if the connection is to the inlet side of the component and use CCC010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces, respectively, or the volume's coordinate direction. The number N

equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; N equal to 5 and 6 would do the same for the third coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

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

A7.5.2 Card CCC0200, Time-Dependent Junction Data Control Card

This card is optional. If this card is missing, the second and third words of the time-dependent data are assumed to be velocities.

W1(I) Control word. If zero, the second and third words of the time-dependent junction data in Cards CCC0201 through CCC0299 are velocities. If one, the second and third words of the time-dependent junction data in Cards CCC0201 through CCC0299 are mass flows. In both cases, the fourth word is interface velocity and should be entered as zero.

W2(I) Table trip number. This word is optional. If missing or zero and Word 3 is missing, no trip is used and the time argument is the advancement time. If nonzero and Word 3 is missing, this number is the trip number and the time argument is -1.0 if the trip is false and the advancement time minus the trip time if the trip is true.

W3(A) Alphanumeric part of variable request code. This quantity is optional. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. If the trip number is zero, the specified argument is always used. If the trip number is nonzero, -1.0E75 is used if the trip is false, and the specified argument is used if the trip is true. TIME can be selected, but note that the trip logic is different than if this word is omitted. The variable MFLOWJ should not be used as a search variable; a user-initialized control variable that uses MFLOWJ should be used instead.

W4(I) Numeric part of variable request code. This is assumed zero if missing.

A7.5.3 Cards CCC0201 through CCC0299, Time-Dependent Junction Data Cards

These cards are required for time-dependent junction components. A set of data consists of the search variable (e.g., time) followed by the required data indicated by control Word 1 on Card CCC0200. The card numbers need not be consecutive, but the value of the search variable in a succeeding set must be equal to or greater than the value in the previous set. One or more sets of data up to 5,000 sets may be entered. Zero may be entered for a velocity or flow if the phase or material is not present. The interpolation and card formats for the time-dependent data are identical to that in Section A7.3.3.

When doing a single-phase problem and entering velocities here, the same value should be entered for both liquid and vapor velocities. If entering mass flows, the correct value should be entered for either liquid or vapor (whichever single-phase is being modeled) and the other entry should be zero.

If the user wants to specify the vapor void fraction as a function of time in the time-dependent volume, and the total mass flow as a function of time in the time-dependent junction, then both the phasic (gas and liquid) mass flow rates must be calculated and entered on these cards.

W1(R) Search variable (e.g., time).

W2(R) Liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on the control Word 1 on Card CCC0200.

W3(R) Vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control Word 1 on Card CCC0200.

W4(R) Interface velocity (m/s, ft/s). Enter zero.

As described above, sets may be entered one or more per card.

A7.6 Pipe, Annulus Component

A pipe component is indicated by PIPE, an annulus component is indicated by ANNULUS for Word 2 on Card CCC0000. The PIPE and ANNULUS components are similar, except that the ANNULUS component must be vertical and all the water is in the film (i.e., no drops) when in the annular-mist flow regime. The remaining input for both components is identical. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. For major edits, minor edits, and plot variables, the volumes in the pipe or annulus component are numbered as CCCNN0000, where NNN is the volume number (greater than 00 and less than 100). The junction in the pipe or annulus component are numbered as CCCMM0000, where MM is the junction number (greater than 00 and less than 99).

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

The volumes in a pipe or annulus are usually considered one-dimensional components and flow in the volumes is along the x-coordinate. Crossflow junctions can connect to any of the pipe or annulus volumes in the y- and z-coordinate directions using a form of the momentum equation that does or does not include momentum flux terms. It is also possible to include or not include the momentum flux terms in internal pipe or annulus junctions.

A7.6.1 Card CCC0001, Pipe, Annulus Information Card

This card is required for pipe components.

W1(I) Number of volumes, nv. The number nv must be greater than zero and less than 100. The number of associated junctions internal to the pipe or annulus is nv-1. The outer junctions are described by other components.

A7.6.2 Cards CCC0101 through CCC0199, Pipe, Annulus X-Coordinate Volume Flow Areas

The format is two words per set in sequential expansion format for nv sets These cards are required, and the card numbers need not be consecutive. The words for one set are:

W1(R) Volume flow area (m^2, ft^2).

W2(I) Volume number.

A7.6.3 Cards CCC0201 through CCC0299, Pipe, Annulus Junction Flow Areas

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

W1(R) Internal junction flow area (m^2, ft^2). If cards are missing or a word is zero, the junction flow area is set to the minimum area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or less than the minimum of the adjacent volume areas. There is no restriction for smooth area changes.

W2(I) Junction number.

A7.6.4 Cards CCC0301 through CCC0399, Pipe, Annulus X-Coordinate Volume Lengths

These cards are required for pipe or annulus components. The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R) Pipe or annulus volume length (m, ft).

W2(I) Volume number.

A7.6.5 Cards CCC0401 through CCC0499, Pipe, Annulus Volume Volumes

The format is two words per set in sequential expansion format for nv sets. Card numbers need not be consecutive.

W1(R) Volume (m^3, ft^3). If these cards are missing, volumes equal to zero are assumed. The code requires that each volume equal the x-direction flow area times the x-direction length. If activated, the code also requires each volume equal the y-direction flow area times the y-direction length, and each volume equal the z-direction flow area times the z-direction length. For any volume, at least two of the three quantities, x-direction area, the x-direction 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 x-direction area times the x-direction length within a relative error of 0.000001. The same relative error check is done for the y-and z-directions. If both the y-direction area and y-direction length are not entered or are zero, the y-direction length is computed from $2.0 \bullet \left(\frac{\text{x-direction flow area}}{\pi}\right)$ and the y-direction flow area is computed from

$\frac{\text{volume of volume}}{\text{y} - \text{direction length}}$. The same is true for the z-direction.

W2(I) Volume number.

A7.6.6 Cards CCC0501 through CCC0599, Pipe, Annulus Volume Azimuthal Angles

These cards are optional, and, if not entered, the angles are set to zero. The format is two words per set in sequential expansion format for nv sets, and card numbers need not be consecutive.

W1(R) Azimuthal angle (degrees). The absolute value of the angle must be $\leq$ 360 degrees.

W2(I) Volume number.

A7.6.7 Cards CCC0601 through CCC0699, Pipe, Annulus Volume Vertical Angles

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

W1(R) Vertical angle (degrees). The absolute value of the angle must be $\leq$ 90 degrees. This angle is used in the interphase drag calculation.

W2(I) Volume number.

A7.6.8 Cards CCC0701 through CCC0799, Pipe, Annulus X-Coordinate (Elevation) Changes

These cards are optional. If these cards are missing, the coordinate changes or elevation changes are computed from the x-coordinate volume length and a rotation matrix computed from the angle information. If these cards are entered, the entered data becomes the x-coordinate change or elevation change data. Two formats entering one or three coordinate changes per volume are provided. The card format is two or four words per set in sequential expansion format up to nv sets, and card numbers need not be consecutive.

One coordinate change per volume format:

W1(R) Elevation change. That is the coordinate change along fixed z-axis because of the traverse from inlet to outlet along the local x-coordinate, Δ_{zx} (m, ft). A positive value is an increase in elevation. The magnitude must be equal to or less than the volume length. When the absolute value of the elevation angle determined by the ratio of the elevation change (this Word 6) and the volume length (Word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used; when the ratio is greater than 45 degrees, the vertical flow regime map is used.

W2(I) Volume number.

A7.6.9 Cards CCC0801 through CCC0899, Pipe, Annulus Volume X-Coordinate Friction Data

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

W1(R) Wall roughness (m, ft).

W2(R) Hydraulic diameter (m, ft). This should be computed from $4.0 \bullet \left(\frac{\text{volume flow area}}{\text{wetted perimeter}}\right)$. If zero, the hydraulic diameter is computed from $2.0 \bullet \left(\frac{\text{volume flow area}}{\pi}\right)^{0.5}$. A check is made to ensure that the roughness is less than half the hydraulic diameter. See Word 1 on Cards CCC0101 through CCC0109 for the volume flow area.

W3(I) Volume number.

A7.6.10 Cards CCC0901 through CCC0999, Pipe, Annulus Junction Loss Coefficients

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

W1(R) Reynolds number independent forward flow energy loss coefficient, A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. Note: a variable loss coefficient may be specified (see Section A7.6.18). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W2(R) Reynolds number independent reverse flow energy loss coefficient, A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. Note: a variable loss coefficient may be specified (see Section A7.6.18). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W3(I) Junction number.

A7.6.11 Cards CCC1001 through CCC1099, Pipe, Annulus Volume X-Coordinate Control Flags

These cards are required for pipe or annulus 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 tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction.

At present, the f flag is the only coordinate direction oriented flag. These words enter the scaler oriented flags and the x-coordinate flags for each volume in the pipe or annulus.

The digit t specifies whether the thermal front tracking model is to be used; t = 0 specifies that the front tracking model is not to be used for the volume, and t = 1 specifies that the front tracking model is to be used for the volume. The thermal front tracking model can only be applied to vertically-oriented components.

The digit l specifies whether the mixture level tracking model is to be used; l = 0 specifies that the level model not be used for the volume, and l = 1 specifies that the level model be used for the volume. The mixture level tracking model can only be applied to vertically-oriented components.

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

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

The digit b specifies the interphase friction that is used. b = 0 means that the pipe interphase friction model will be applied, b = 1 means that the rod bundle interphase friction model will be applied.

The digit f specifies whether wall friction is to be computed. f = 0 specifies that wall friction effects are to be computed along the x-coordinate of the volume, and f = 1 specifies that wall friction effects are not to be computed along the x-coordinate.

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

W2(I) Volume number.

A7.6.12 Cards CCC1101 through CCC1199, Pipe, Annulus Junction Control Flags

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

W1(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equation. e = 0 means that the modified PV term will not be applied, and e = 1 means that it will be applied.

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

The digit v is not used and should be input as zero (v = 0). The horizontal stratification entrainment/pullthrough model cannot be used.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, and a = 1 means full abrupt area change model (K_{loss} area apportioning at branch, restricted junction area, and extra interphase drag), and a = 2 means a partial abrupt area change model (no K_{loss} but includes area apportioning at branch, restricted junction area, and extra interphase drag).

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 = 1 or 2), the major edit printout will show a one.

The digit s specifies momentum flux options. s = 0 uses momentum flux in both the to volume and the from volume. s = 1 uses momentum flux in the from volume, but not in the to volume. s = 2 uses momentum flux in the to volume but not in the from volume. s = 3 does not use momentum flux either the to or the from volume. For the case of a pipe or annulus, the option s = 0 is the usual recommendation (momentum flux in both volumes). The other options s = 1, 2, and 3 are included to allow consistency for this flag for other components (single-junction, branch junction, etc.).

W2(I) Junction number.

A7.6.13 Cards CCC1201 through CCC1299, Pipe, Annulus Volume Initial Conditions

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

W1(I) Control word. This word has the packed format εbt. It is not necessary to input leading zeros.

The digit ε specifies the fluid. ε = 0 is the default fluid, ε = 1 specifies H_2O and ε = 2 specifies D_2O. 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 H_2O is assumed as the fluid.

The digit b specifies whether boron is present or not. b = 0 specifies that the volume liquid does not contain boron; b = 1 specifies that a boron concentration in mass of boron per mass of liquid (which may be zero) is being entered after the other required

thermodynamic information.

The digit t specifies how the following words are to be used to determine the initial thermodynamic state. Entering t equal to 0 through 3 specifies one component (steam/water). Entering t equal to 4 through 6 allows the specification of two components (steam/water and noncondensable gas).

With options t equal to 4 through 6, names of the components of the noncondensable gas must be entered on Card 110, and mass fractions of the components are entered on Card 115.

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 internal energies used to define the thermodynamic state. W6 should be 0.0.

If t = 1, the next two words are interpreted as temperature (K, °F) and static quality in equilibrium condition. W4, W5, and W6 should be 0.0.

If t = 2, the next two words are interpreted as pressure (Pa, lb_f/in^2) and static quality in equilibrium condition. W4, W5, and W6 should be 0.0.

If t = 3, the next two words are interpreted as pressure (Pa, lb_f/in^2) and temperature (K, °F) in equilibrium condition. W4, W5, and W6 should be 0.0.

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for static quality are:

1.0E-9 $\leq$ static quality $\leq$ 0.99999999, two-phase conditions, and static quality < 1.0E-9 or static quality > 0.99999999, single-phase. The static quality is given by $M_g/(M_g + M_f)$, where $M_g = M_s + M_n$.

Noncondensable options are:

If t = 4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and static quality in equilibrium condition. Using this input option with static quality > 0.0 and $\leq$ 1.0, saturated noncondensables will result. W5 and W6 should be 0.0. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting static quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Static quality is reset to 1.0 using this dry noncondensable option.

If t = 5, the next three words are interpreted as temperature (K, °F), static quality, and noncondensable quality in equilibrium condition. Both the static and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. W5 and W6 should be 0.0. Little experience has been obtained using this option, and it has not been checked out.

If $\underline{t} = 6$, 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 noncondensable quality. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing ($\underline{t} = 0$). If noncondensables are present (noncondensable quality > 0.0), then the vapor void fraction must also be greater than 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor-specific internal energy.

W2-W6(R) Quantities as described under Word 1. Five quantities must be entered, and zeros should be entered for unused quantities. If any control word (Word1) indicates that boron is present, Cards CCC2001 through CCC2099 must be entered to define the initial boron concentrations. Boron concentrations are not entered in Words 2 through 6.

W7(I) Volume number.

A7.6.14 Cards CCC2001 through CCC2099, Pipe, Annulus Initial Boron Concentrations

These cards are required only if boron is specified in one of the control words (Word 1) in Cards CCC1201 through CCC1299. The card format is two words per set in sequential expansion format for nv sets. Boron concentrations must be entered for each volume, and zero should be entered for those volumes whose associated control word did not specify boron.

W1(R) Boron concentration (mass of boron per mass of liquid).

W2(I) Volume number.

A7.6.15 Card CCC1300, Pipe, Annulus Junction Conditions Control Words

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

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

A7.6.16 Cards CCC1301 through CCC1399, Pipe, Annulus Junction Initial Conditions

W1(R) Initial liquid velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R) Initial vapor velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s.

W3(R) Interface velocity (m/s, ft/s). Enter zero.

W4(I) Junction number.

A7.6.17 Cards CCC1401 through CCC1499, Pipe, Annulus Junction Diameter and CCFL Data Cards

These cards are optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., f = 0 in Word 1 of Cards CCC1101 through CCC1199), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model, (i.e., f = 1 in Word 1 of Cards CCC1101 through CCC1199), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R) Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag and must be ≥ 0. The number should be computed from $4.0 \bullet \left(\frac{\text{junction area}}{\text{wetted perimeter}}\right)$. If a zero is entered or if the default is used, the junction diameter is computed from $2.0 \bullet \left(\frac{\text{junction area}}{\pi}\right)^{0.5}$. See Word 1 of Cards CCC0201 through CCC0299 for the junction area.

W2(R) Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R) Gas intercept, C This quantity is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value is 1.

W4(R) Slope, M. This quantity is the slope used in the CCFL correlation and must be > 0. The default value is 1.

W5(I) Junction number.

A7.6.18 Cards CCC3001 through CCC3099, Pipe, Annulus Junction Form Loss Data Card

These cards are optional. (The user-specified form loss coefficients are given in Words 1 and 2 of Cards CCC0901 through CCC0999 if these cards are not entered.) If these cards are entered, the form loss coefficients depend on the flow conditions and are calculated from

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_R = A_R + B_R Re^{-C_R}$$

where K_F and K_R are the forward and reverse form loss coefficients; A_F, A_R, B_F, B_R, C_F and C_R are user-specified constants; A_F and A_R are the Words 1 and 2 of Cards CCC0901 through CCC0999; B_F, B_R, C_F

and C_R are Words 1, 2, 3, and 4 of these cards (CCC3001 through CCC3099); Re is the Reynolds number based on mixture fluid properties. If these cards are being used for the form loss coefficients, then enter all five words for the appropriate expression.

W1(R) B_F (≥ 0). This quantity must be greater than or equal to zero.

W2(R) C_F (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_R (≥ 0). This quantity must be greater than or equal to zero.

W4(R) C_R (≥ 0). This quantity must be greater than or equal to zero.

W5(I) Junction number.

A7.7 Branch, Separator, Jetmixer, Turbine, Or ECC Mixer Component

A branch component is indicated by BRANCH, a steam separator is indicated by SEPARATR, a jetmixer is indicated by JETMIXER, a turbine is indicated by TURBINE, and an ECC mixer is indicated by ECCMIX for Word 2 on Card CCC0000. In junction references using the old format, the code for the component inlet is CCC000000 and the code for the component outlet is CCC010000. In the junction references using the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N is the face number. More than one junction may be connected to the inlet or outlet. If an end has no junctions, that end is considered a closed end. Normally, only a branch has more than one junction connected to a volume end. Multiple junctions may connect to the ends of pipes and single-volumes except that a warning message is issued even though the connections are handled correctly. Limiting multiple connections to branch components allows the warning message to indicate probable input error. If more than one junction is connected on one end of a branch, each junction should be modeled as an abrupt area change. For major edits, minor edits, and plot variables, the volume in the branch component is numbered as CCC010000. The junctions associated with the branch component are numbered as CCCMM0000, where MM is the junction number (greater than 00 and less than 10).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. The number of junctions nj defined below must be three, and no junctions in other components may connect to this component. The variable 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 <u>from</u> part of the vapor outlet junction must refer to outlet of the separator (old format is CCC010000, and expanded format is CCC010002), and the <u>from</u> part of the liquid fall back must refer to the inlet of the separator (old format is CCC000000, and expanded format is CCC010001). To include the direct path from a steam generator downcomer to the steam dome, a bypass volume is recommended. The smooth or abrupt junction option can be used for the three junctions. Appropriate user-input energy loss coefficients may be needed to match a known pressure drop across the separator. We 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 (<u>f</u> = 0) for all three junctions. The horizontal stratification flag is not used for separator junctions and should be set to zero (<u>v</u> = 0). The rod bundle interphase friction flag must be turned off (<u>b</u> = 0) in the separator volume. The vertical stratification model flag is not used in the separator volume and should be set to zero (<u>v</u> = 0). The water packing scheme flag is not used in the

separator volume and should be set to zero (p = 0).

A jetmixer component is a specialized branch using three junctions numbered in the same manner as the separator. For the junctions, N = 1 represents the drive, N = 2 represents the suction, and N = 3 represents the discharge. The to part of the drive and suction junctions must refer to the inlet end of the jetmixer (old format is CCC000000, and the expanded format is CCC010001), and the from part of the discharge junction must refer to the outlet end of the jetmixer (old format is CCC010000, and expanded format is CCC010002). To model a jet pump properly, the junction flow areas of the drive and suction should equal the volume flow area. The CCFL flag must be turned off (f = 0) for all three junctions. The horizontal stratification entrainment/pullthrough flag is not used for jetmixer junctions and should be set to zero (v = 0). The rod bundle interphase friction flag must be turned off (b = 0) in the jetmixer volume. The vertical stratification model flag is not used in the jetmixer volume and should be set to zero (v = 0). The water packing scheme flag is not used in the jetmixer volume and should be set to zero (p = 0).

A turbine component is a specialized branch with additional input to describe the turbine characteristics. A simple turbine might use only one turbine component. A multistage turbine with steam extraction points might require several turbine components. The number of junctions, 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 should be crossflow. The primary steam inlet junction (N = 1) is a normal junction, and the steam extraction line (N = 2) should be 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 (old format is CCC000000, and expanded format is CCC0100001). A restriction currently exists such that the volume and junction upstream (usual flow) must be the numerically preceding volume and junction. For the first turbine, there must be an artificial turbine component preceding it (i.e., constant efficiency, with efficiency = 0, turbine with h = 0). The volume and junction upstream of the artificial turbine need not be the numerically preceding volume and junction. The inertia and the friction of this artificial turbine should be entered somewhat less than that of the normal turbines. The horizontal stratification entrainment/pullthrough flag must be turned off (v = 0). If several turbine components are in series, the choking flag should be left on (c = 0) for the first component but turned off for the other components (c = 1). The smooth junction option (a = 0) should be used at both inlet and outlet junctions. The inlet and outlet junctions must be input as homogeneous junctions (h = 1 or 2). If a steam extraction (bleed) junction is present, it must be a crossflow junction. The CCFL flag must be turned off (f = 0) for both junctions. The rod bundle interphase friction flag must be turned off (b = 0) in the turbine volume. The vertical stratification model flag is not used in the turbine volume and should be set to zero (v = 0). The water packing scheme flag is not used in the turbine volume and should be set to zero (p = 0).

An ECC mixer (ECCMIX) component is a specialized branch that requires three junctions with a certain numbering order. The physical extent of the ECC mixer is a length of the cold leg, or any other horizontal pipe, centered around the position of the ECC injection location. The length of this pipe segment should be equal to three times the inside diameter of the pipe (if the physical arrangement of the system permits). Junction number one (the lowest numbered junction) must be the ECC connection. This is, in some respects, similar to the drive junction of a jetmixer component. Junction number two (the junction with higher number than the first one) should be the one that is the flow inlet to this component in normal operation. The geometrical angle between the axis of junctions one and two is one of the necessary inputs, as will be specified later. The third, or discharge, junction is the normal outlet of flow through this pipe segment. The to part of junctions one and two must refer to the inlet end of the ECC mixer (old format CCC00000, and expanded format is CCC010001), and the from part of the discharge junction must refer to the outlet end of the ECC mixer (old format CCC010000, and expanded format is CCC010002).

Two or more ECCMIX components may be considered in modeling some piping. These may be connected in tandem and require at least one normal volume between them.

The component identification word on Card CCC0000 should be ECCMIX for the ECC mixer. This word directs the code to use a specific flow regime map and a specific interfacial heat transfer package for steam condensation.

A7.7.1 Card CCC0001, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Information Card

This card is required for branch, separator, jetmixer, turbine, or ECC mixer components.

W1(I) Number of junctions, nj. The variable nj is the number of junctions described in the input data for this component and must be equal to or greater than zero and less than ten. This number must be 3 for SEPARATR, JETMIXER, and ECCMIX components and must be 1 or 2 for TURBINE components. For BRANCH components, not all junctions connecting to the branch need to be described with this component input, and nj is not necessarily the total number of junctions connecting to the branch. Junctions described in single-junctions, time-dependent junctions, pumps, separators, jetmixers, and other branches can be connected to this branch.

W2(I) Initial condition control. This word is optional and, if missing, the junction initial velocities in the first and second words on Cards CCCN201 are assumed to be velocities. If zero, velocities are assumed; if nonzero, mass flows are assumed.

A7.7.2 Card CCC0002, Separator Component Options Card

This card is an optional card for a separator component. The first word specifies the separator option while the second word specifies the number of actual separator components by this RELAP5 SEPARATR component. The second word is needed if the user uses the General Electric separator options.

W1(I) Separator option, ISEPST. A value of 0 specifies the simple separator contained in previous versions of RELAP5 (default), a value of 1 specifies the General Electric dryer model, a value of 2 specifies a General Electric two-stage separator, and a value of 3 specifies a three-stage General Electric separator.

W2(I) Number of separator components represented by this RELAP5 component. The number is needed only if Word 1 has a value of two or three.

A7.7.3 Cards CCC0101 through CCC0109, Branch, Separator, Jetmixer, Turbine, or ECC Mixer X-Coordinate Volume Data

This card (or cards) is required for branch, separator, jetmixer, turbine, and ECC mixer components. The nine words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R) Volume flow area (m^2, ft^2).

W2(R) Length of volume (m, ft).

W3(R) Volume of volume (m^3, ft^3). The code requires that the volume equals the volume flow area times the length (W3 = W1•W2). At least two of the three quantities, W1, W2, and W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the x-direction area times the x-direction length within a relative error of 0.000001. The same relative error check is done for the y- and z-directions.

W4(R) Azimuthal angle (degrees). The absolute value of this angle must be $\leq$ 360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R) Inclination angle (degrees). The absolute value of this angle must be $\leq$ 90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward inclination, i.e., the inlet is at the lowest elevation. This angle is used in the interphase drag calculation. For ECCMIX, the allowable inclination angle is less than $\pm$ 15 degrees. Any other value will be considered an input error.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than or equal to the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. When the absolute value of the elevation angle determined by the ratio of the elevation change (this Word 6) and the volume length (Word 2) is less than or equal to 45 degrees, the horizontal flow regime map is used. When the ratio is greater than 45 degrees, the vertical flow regime map is used. For ECCMIX, the ECC mixer flow regimes are used.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed for $4.0\left(\frac{\text{volume flow area}}{\text{wetted perimeter}}\right)^{0.5}$. If zero, the hydraulic diameter is computed from $2.0 \bullet \left(\frac{\text{volume flow area}}{\pi}\right)^{0.5}$. A check is made to ensure the pipe roughness is less than half the hydraulic diameter. See Word 1 for the volume flow area.

W9(I) Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag.

The digit t specifies whether the thermal front tracking model is to be used; t = 0 specifies that the front tracking model is not to be used for the volume, and t = 1 specifies that the front tracking model is to be used for the volume. This model is not used for SEPARATR, JETMIXER, TURBINE, or ECCMIX components and the flag if entered is considered an input error.

The digit l specifies whether the mixture level tracking model is to be used; l = 0 specifies that the level model not be used for the volume, and l = 1 specifies that the level model be used for the volume. This model is not used for SEPARATR, METMIXER, TURBINE, or ECCMIX components and the flag if entered as 1 is considered an input error.

The digit p specifies whether the water packing scheme is to be used. p = 0 specifies that the water packing scheme is to be used for the volume, and p = 1 specifies that the water packing scheme is not to be used for the volume. The water packing scheme is recommended when modeling a pressurizer. This digit is used for the BRANCH and ECCMIX components. For the SEPARATR, JETMIXER, and TURBINE components, the water packing scheme is not allowed, the digit is not used and may be input as 0 or 1. The major edit will show p = 1.

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

The digit b specifies the interphase friction that is used. b = 0 means that the pipe interphase friction model will be applied, b = 1 means that the rod bundle interphase friction model will be applied. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, TURBINE, and ECCMIX, the rod bundle interphase friction is not allowed, the digit is not used, and must be input as 0.

The digit f specifies whether wall friction is to be computed. f = 0 specifies that wall friction effects are to be computed along the x-coordinate direction in the volume, and f = 1 specifies that wall friction effects are not to be computed along the x-coordinate. For a SEPARATR component, either 0 or 1 may be entered; the code will set f = 1 and no wall friction will be calculated. The digit f must be entered as 1 for a TURBINE component.

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

A7.7.4 Card CCC0131, Additional Laminar Wall Friction Card

This card is optional except for a TURBINE component. If this card is not entered, the default values are 1.0 for the shape factor and 0.0 for the viscosity ratio exponent. Two, four, or six quantities may be entered on the card, and the data not entered are set to default values.

W1(R) Shape factor for x-coordinate.

W2(R) Viscosity ratio exponent for x-coordinate.

W3(R) Shape factor for y-coordinate.

W4(R) Viscosity ratio exponent for y-coordinate.

W5(R) Shape factor for z-coordinate.

W6(R) Viscosity ratio exponent for z-coordinate.

A7.7.5 Card CCC0200, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Volume Initial Conditions

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

W1(I) Control word. This word has the packed format $\underline{\varepsilon}\underline{b}\underline{t}$. It is not necessary to input leading zeros.

The digit $\underline{\varepsilon}$ specifies the fluid; $\underline{\varepsilon} = 0$ is the default fluid, $\underline{\varepsilon} = 1$ specifies H_2O and $\underline{\varepsilon} = 2$ specifies D_2O. 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. $\underline{b} = 0$ specifies that the volume fluid does not contain boron, and $\underline{b} = 1$ specifies that a boron concentration in mass of boron per mass of liquid (which may be zero) is being entered after the other required thermodynamic information.

The digit $\underline{t}$ specifies how the following words are to be used to determine the initial thermodynamic state. $\underline{t} = 0$ through 3 specifies one component (steam/water); $\underline{t} = 4$ through 6 allows the specification of two components (steam/water and noncondensable gas).

With options $\underline{t}$ equal to 4 through 6, names of the components of the noncondensable gas must be entered on Card 110, and mass fractions of the components are entered on Card 115.

If $\underline{t} = 0$, the next four words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state.

If $\underline{t} = 1$, the next two words are interpreted as temperature (K, ^oF) and static quality in equilibrium condition.

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

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for static quality are:

1.0E-9 ≤ static quality ≤ 0.99999999, two-phase conditions, and static quality < 1.0E-9 or static quality > 0.99999999, single-phase. The static quality is given by $M_g/(M_g + M_f)$, where $M_g = M_s + M_n$.

Noncondensable options are:

If $\underline{t}$ = 4, the next three words are interpreted as pressure (Pa, $lb_f/in.^2$), temperature (K, °F), and static quality in equilibrium condition. Using this input option with static quality > 0.0 and ≤ 1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting static quality to 0.0 is used as a flag that will initialize the volume to all noncondensable (dry noncondensable) with no temperature restrictions. Static quality is reset to 1.0 using this dry noncondensable option.

If $\underline{t}$ = 5, the next three words are interpreted as temperature (K, °F), equilibrium quality, and noncondensable quality. Both the equilibrium and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. Little experience has been obtained using this option, and it has not been checked out.

If $\underline{t}$ = 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 noncondensable quality. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing ($\underline{t}$ = 0). If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must also be greater than 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor-specific internal energy.

W2-W6(R) Quantities as described under Word 1. Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, boron concentration (mass of boron per mass of liquid) follows the last required word for thermodynamic conditions.

A7.7.6 Cards CCCN101 through CCCN109, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Geometry Card

These cards are required if nj is greater than zero. Cards with N equal to 1 through 9 are entered, one for each junction. The variable N equal to 1, 2, and 3 must be used for SEPARATR, JETMIXER, and ECCMIX components. For a BRANCH component, N need not be consecutive, but nj cards must be entered. The card format for Words 1 through 6 is listed below and is identical to Words 1 through 6 on Card CCC0101 of the Single-Junction Geometry Card, except that N instead of 0 is used in the fourth digit. Word 7 is not used for JETMIXER and TURBINE components. Word 7 is defined for SEPARATR and ECCMIX components. Words 7, 8, and 9 are defined BRANCH components.

W1(I) From connection code to a component. This refers to the component from which the junction coordinate direction originates. An old or expanded format can be used to connect volumes. In the old format, use CCC000000 if the connections to the inlet side of the component and use CCC010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number N equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; N equal to 5 and 6 would do the same for the third coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

W2(I) To connection code to a component. This refers to the component at which the junction coordinate direction ends. See the description for W1 above.

W3(R) Junction area (m^2, ft^2). If zero, the area is set to the minimum volume area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.

W4(R) Reynolds number independent forward flow energy loss coefficient, A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. A variable loss coefficient may be specified (see Section A7.7.8). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W5(R) Reynolds number independent reverse flow energy loss coefficient A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. A variable loss coefficient may be specified (see Section A7.7.8). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W6(I) Junction control flags. This word has the packed format efvcahs.

The digit e specifies the modified PV term in the energy equations. e = 0 means that the modified PV term will not be applied, and e = 1 means that it will be applied. This digit is only for the BRANCH component. For the SEPARATR, JETMIXER, TURBINE, and

ECCMIX components, this digit is not used and should be set to 0. The major edit output will show e = 0.

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

The digit v specifies horizontal stratification entrainment/pullthrough options. This model is for junctions connected to a horizontal volume. v = 0 means the model is not applied; v = 1 means an upward oriented junction; v = 2 means a downward oriented junction; and v = 3 means a centrally (side) located junction. This digit is only used for the BRANCH component. For the SEPARATR, JETMIXER, TURBINE, and ECCMIX components, the horizontal stratification entrainment/pullthrough model is not allowed, this digit is not used and should be set to 0.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, a = 1 means full abrupt area change model (K_{loss}, area apportioning at branch, restricted junction area, and extra interphase drag), and a = 2 means a partial abrupt area change (no K_{loss}, but includes area apportioning at branch, restricted junction area, and extra interphase drag).

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

The digit s specifies momentum flux options. This digit is used for the BRANCH, SEPARATR, and TURBINE components. s = 0 uses momentum flux in both the to and the from volume. s = 1 uses momentum flux in the from volume, but not in the to volume. s = 2 uses momentum flux in the to volume, but not in the from volume. s = 3 does not use momentum flux in either the to or the from volume. For the JETMIXER and ECCMIX components, this digit is not used and should be input as 0.

W7(R) Void fraction limit (for SEPARATR).

Angle (for ECCMIX), and subcooled discharge coefficient (for BRANCH). This word is needed only for a SEPARATR or an ECCMIX component.

For SEPARATR, this word is void fraction limit. For the vapor exit junction (N = 1), this quantity (VOVER) is the vapor void fraction above which flow out of the vapor outlet is pure vapor. If the word is missing, a default value of 0.5 is used. For the liquid fall back junction (N = 2), this quantity (VUNDER) is the liquid void fraction above which flow out of the liquid fall back is pure liquid. If the word is missing, a default value of 0.15 is used. For the separator inlet, this word is not used.

For ECCMIX, this word is angle and is the angle between the axis of the ECC injection line and the main pipe (or the angle between Junctions 1 and 2). This angle must be between 0 and 180 degrees. If missing, a 90-degree connection for the ECC pipe is assumed.

For BRANCH, this word is subcooled discharge coefficient. This quantity is applied only to subcooled choked flow calculations. The quantity must be > 0 and ≤ 2.0. If W7, W8, and W9 are missing, then W7, W8, and W9 are set to 1.0.

W8(R) For BRANCH, this word is two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be > 0 and ≤ 2.0. If W7 is entered and W8 and W9 are missing, then W8, and W9 are set to 1.0.

W9(R) For BRANCH, this word is superheated discharge coefficient. This quantity is applied only to superheated choked flow calculations. The quantity must be > 0 and ≤ 2.0. If W7 and W8 are entered and W9 is missing, then W9 is set to 1.0.

A7.7.7 Cards CCCN110 Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Diameter And CCFL Data Cards

These cards are optional. The value N should follow the same approach as used in Cards CCCN101 through CCCN109. (The defaults indicated for each word are used if the card is not entered.) If these cards are being used to specify only the junction hydraulic diameter for the interphase drag calculations (i.e., f = 0 in Word 6 of Cards CCCN101 through CCCN109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If these cards are being used for the CCFL model (i.e., f = 1 in Word 6 of Cards CCCN101 through CCCN109), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R) Junction hydraulic diameter, D_j (m, ft). This quantity is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag calculation. This number must be ≥ 0. This number should be computed from $4.0 \bullet \left(\frac{\text{junction area}}{\text{wetted perimeter}}\right)^{0.5}$. If a zero is entered or if the default is used, the junction diameter is computed from $2.0 \bullet \left(\frac{\text{junction area}}{\pi}\right)^{0.5}$ of the respective junction. See Word 3 of Cards CCCN101 through CCCN109 for the junction area.

W2(R) Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

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

W4(R) Slope, m. This quantity is the slope used in the CCFL correlation and must be > 0. The default value is 1.

A7.7.8 Cards CCCN112, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Form Loss Data Card

These cards are optional. The values of N should follow the same approach as used in Cards CCCN101 through CCCN109. (The user-specified form loss coefficients are given in Words 4 and 5 of Cards CCCN101 through CCCN109 if these cards are not entered.) If these cards are entered, the form loss coefficients depend on the flow conditions and are calculated from;

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_R = A_R + B_R Re^{-C_R}$$

where K_F and K_R are the forward and reverse form loss coefficients. A_F, A_R, B_F, B_R, C_F, and C_R are user-specified constants; A_F and A_R are the Words 4 and 5 of Cards CCCN101 through CCCN109; B_F, B_R, C_F, and C_R are Words 1, 2, 3, and 4 of these cards (CCCN112); and Re is the Reynolds number based on mixture fluid properties. If these cards are being used for the form loss calculations, then enter all four words for the appropriate expression.

W1(R) B_F (≥ 0). This quantity must be greater than or equal to zero.

W2 (R) C_F (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_R (≥ 0). This quantity must be greater than or equal to zero.

W4(R) C_R (≥ 0). This quantity must be greater than or equal to zero.

A7.7.9 Cards CCCN201, Branch, Separator, Jetmixer, Turbine, or ECC Mixer Junction Initial Conditions

These cards are required depending on the value of NJ as described for Cards CCCN101 through CCCN109. The values of N should follow the same approach as used in Cards CCCN101 through CCCN109. A 90% extraction limit during input processing is tested for the vapor at the vapor outlet junction and for the liquid at the liquid fall back junction. If greater than 90%, an input error occurs.

W1(R) Initial liquid or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W2(R) Initial vapor velocity or mass flow (velocity in m/s, ft/s or mass flow in kg/s, lb/s).

W3(R) Interface velocity (m/s, ft/s). Enter zero.

A7.7.10 Card CCC0300, Turbine/Shaft Geometry Card

This card is used only for TURBINE components.

W1(R) Turbine stage shaft speed, ω (rad/s, rev/min). This speed should equal the shaft speed used

in the SHAFT component.

W2(R) Inertia of rotating stages in stage group, I_i. (kg• m^2, lb•ft^2).

W3(R) Shaft friction coefficient, f_i (N•m•s, lb•ft•s). The frictional torque equals $f_i\omega$. This fractional torque is used by the SHAFT component.

W4(I) Shaft component number to which the turbine stage is connected.

W5(I) Disconnect trip number. If trip is zero, the turbine is always connected to the shaft. If nonzero, the turbine is connected to the shaft when the trip is false and disconnected when the trip is true.

W6(I) Drain flag. At the present time, this is not used and can be neglected or set to zero.

A7.7.11 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_o at the maximum efficiency design point.

W3(R) Design reaction fraction, r. This is the fraction of the enthalpy decrease that takes place in the rotating blade system.

W4(R) Mean stage radius, r (m, ft).

A7.7.12 Card CCC0500, GE Separator Data

This card is optional for the GE separator. If this card is missing and the GE separator has been specified on Card CCC0002, the default values will be used. If the card is present, all eight values must be specified.

W1(R) Radius of larger pickoff ring at first stage of a two-stage separator (m, ft). Default = 0.0857208 m.

W2(R) Standpipe flow area (m^2, ft^2). Default = 0.018637 m^2.

W3(R) Separator nozzle exit area (m^2, ft^2). Default = 0.01441 m^2.

W4(R) Radius of separator hub at inlet (m, ft). Default = 0.0809585 m.

W5(R) Swirl vane angle relative to the horizontal (deg). Default = 48 deg.

W6(R) Liquid carryover coefficient for upper separating stages. Default = 0.009 for two-stage separator and 0.110 for three-stage separator.

W7(R) Vapor carryunder coefficient for upper separating stages. Default = 0.0004.

W8(R) Axial distance between exit of first stage discharge passage and swirl vanes (m, ft). Default = 0.2127 m for two-stage separator and 0.45083 m for three-stage separator.

A7.7.13 Card CCC0501, GE Separator First Stage Data

This card is optional for the GE separator. If this card is missing and the GE separator has been specified on Card CCC0002, the default values will be used. If the card is present, all nine values must be specified.

W1(R) Liquid film void profile coefficient. Default = 110.0

W2(R) Vapor core void profile coefficient. Default = 0.5.

W3(R) Separator wall inner radius (m, ft). Default = 0.10794 m.

W4(R) Pickoff ring inner radius (m, ft). Default = 0.069875 m for two-stage separator and 0.0857208 m for three-stage separator.

W5(R) Discharge passage flow area (m^2, ft^2). Default = 0.0415776 m^2 for two-stage separator and 0.0096265 m^2 for three-stage separator.

W6(R) Discharge passage hydraulic diameter (m, ft). Default = 0.045558 m for two-stage separator and 0.025399 m for three-stage separator.

W7(R) Separating barrel length (m, ft). Default = 0.877845 m for two-stage separator and 1.0699 m for three-stage separator.

W8(R) Discharge passage loss coefficient. Default = 10.0 for two-stage separator and 2.5 for three-stage separator.

W9(R) Discharge passage effective $\frac{L}{D}$ coefficient. Default = 450.0 for two-stage separator and 53.44 for three-stage separator.

A7.7.14 Card CCC0502, GE Separator Second Stage Data

This card is optional for the GE separator. If this card is missing and the GE separator has been specified on Card CCC0002, the default values will be used. If the card is present, all nine values must be specified.

W1(R) Liquid film void profile coefficient. Default = 20.0

W2(R) Vapor core void profile coefficient. Default = 0.25.

W3(R) Separator wall inner radius (m, ft). Default = 0.06985 m for two-stage separator and 0.10794 m for three-stage separator.

W4(R) Pickoff ring inner radius (m, ft). Default = 0.06032 m for two-stage separator and 0.0952453 m for three-stage separator.

W5(R) Discharge passage flow area (m^2, ft^2). Default = 0.0029133 m^2 for two-stage separator and 0.0096265 m^2 for three-stage separator.

W6(R) Discharge passage hydraulic diameter (m, ft). Default = 0.0121699 m for two-stage separator and 0.025399 m for three-stage separator.

W7(R) Separating barrel length (m, ft). Default = 0.16255 m for two-stage separator and 0.384156 m for three-stage separator.

W8(R) Discharge passage loss coefficient. Default = 0.5 for two-stage separator and 1.429 for three-stage separator.

W9(R) Discharge passage effective $\frac{L}{D}$ coefficient. Default = 95.85 for two-stage separator and 194.64 for three-stage separator.

A7.7.15 Card CCC0503, GE Separator Third Stage Data

This card is optional for the GE separator. If this card is missing and the GE three-stage separator has been specified on Card CCC0002, the default values will be used. If the card is present, all nine values must be specified.

W1(R) Liquid film void profile coefficient. Default = 20.0

W2(R) Vapor core void profile coefficient. Default = 0.55.

W3(R) Separator wall inner radius (m, ft). Default = 0.10794 m.

W4(R) Pickoff ring inner radius (m, ft). Default = 0.0984201 m.

W5(R) Discharge passage flow area (m^2, ft^2). Default = 0.0096265 m^2.

W6(R) Discharge passage hydraulic diameter (m, ft). Default = 0.025399 m.

W7(R) Separating barrel length (m, ft). Default = 0.384156 m.

W8(R) Discharge passage loss coefficient. Default = 2.563.

W9(R) Discharge passage effective $\frac{L}{D}$ coefficient. Default = 424.96.

A7.7.16 Card CCC0600, GE Dryer Data

This card is optional for the GE dryer. If this card is missing and the GE dryer has been specified on Card CCC0002, the default values will be used. If the card is present, all three values must be specified.

W1(R) Vapor velocity at dryer inlet below which there is 0% liquid carryover (m/s, ft/s). Default = 1.5 m/s.

W2(R) Vapor velocity at dryer inlet above which there is 100% carryover (m/s, ft/s). Default = 6.0 m/s.

W3(R) Range of dryer inlet quality where dryer carryover changes from 0 to 100% when dryer inlet vapor velocity is between lower and upper values. Default = 0.05.

A7.8 Valve Junction Component

A valve junction component is indicated by VALVE for Word 2 on Card CCC0000. For major edits, minor edits, and plot variables, the junction in the valve junction component is numbered CCC000000.

A7.8.1 Cards CCC0101 through CCC0109, Valve Junction Geometry Cards

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

W1(I) <u>From</u> connection code to a component. This refers to the component from which the junction coordinate direction originates. An old or expanded format can be used to connect volumes. In the old format, use CCC000000 if the connection is the inlet side of the component, and CCC010000 if the connection is the outlet side of the volume. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number N equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; N equal to 5 and 6 would do the same for the third coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

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). This quantity is the full open area of the valve except in the case of a relief valve. For valves other than relief valves, if this area is input as zero, the area is set to the minimum area of adjoining volumes. If nonzero, this area is used. For relief valves, this term is the valve inlet throat area. If this term is input as zero, it will default to the area calculated from the inlet diameter term input on Cards CCC0301 through CCC0309, in which case the inlet diameter term cannot be input as zero. If both this area and the inlet

diameter are input as nonzero, this area will be used but must agree with the area calculated from the inlet diameter within 10^{-5} m^2. However, if this area is input as nonzero and the inlet diameter is input as zero, the inlet diameter will default to the diameter calculated from this area. When an abrupt area change model is specified, the area must be less than or equal to the minimum of the adjoining volume areas.

W4(R) Reynolds number independent forward flow energy loss coefficient, A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. A variable loss coefficient may be specified (see Section A7.8.3). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W5(R) Reynolds number independent reverse flow energy loss coefficient, A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. A variable loss coefficient may be specified (see Section A7.8.3). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W6(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equations. e = 0 means that the modified PV term will not be applied, and e = 1 means that it will be applied.

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

The digit v specifies horizontal stratification entrainment/pullthrough options. This model is for junctions connected to a horizontal volume. v = 0 means the model is not applied, v = 1 means an upward-oriented junction; v = 2 means a downward-oriented junction; and v = 3 means a centrally (side) located junction.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, and a = 1 means full abrupt area change model (K_{loss}, area apportioning at branch, restricted junction area, and extra interphase drag), and a = 2 means a partial abrupt area change model (no K_{loss}, but includes area apportioning at branch, restricted junction area, and extra interphase drag). All options 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 one of the abrupt area change options must be input. For all other valves, one of the abrupt area change options must be input.

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

The digit s specifies momentum flux options. s = 0 uses momentum flux in both the to volume and the from volume. s = 1 uses momentum flux in the from volume, but not in the to volume. s = 2 uses momentum flux in the to volume but not in the from volume; s = 3 does not use momentum flux in either the to or the from volume.

W7(R) Subcooled discharge coefficient. This quantity is applied only to subcooled choked flow calculations. The quantity must be > 0 and ≤ 2.0. If W7, W8, and W9 are missing, then W7, W8, and W9 are set to 1.0.

W8(R) Two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be > 0 or ≤ 2.0. If W7 is entered, and W8 and W9 are missing, then W8 and W9 are set to 1.0

W9(R) Superheated discharge coefficient. This quantity is applied only to superheated choked flow calculations. The quantity must be > 0 and ≤ 2.0. If W7 and W8 are entered, and W9 is missing, then W9 is set to 1.0.

A7.8.2 Card CCC0110, Valve Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify the junction hydraulic diameter for the interphase drag calculation (i.e., f = 0 in Word 6 of Cards CCC0101 through CCC0109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., f = 1 in Word 6 of Cards CCC0101 through CCC0109), then enter all four words for the appropriate CCFL model if values different from the default values are used.

W1(R) Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag calculation and must be ≥ 0. This number should be computed from $4.0 \bullet \left(\frac{\text{junction area}}{\text{wetted perimeter}}\right)$. If a zero is entered or if the default is used, the junction diameter is computed from $2.0 \bullet \left(\frac{\text{junction area}}{\pi}\right)^{0.5}$. See Word 3 of Cards CCC0101 through CCC0109 for the junction area.

W2(R) Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R) Gas intercept, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value of f is 1.

W4(R) Slope, m. This is the slope used in the CCFL correlation and must be > 0. The default value is 1.

A7.8.3 Card CCC0111, Valve Junction Form Loss Data Card

This card is optional. The user-specified form loss coefficients are given in Words 4 and 5 of Card CCC0101 if this card is not entered. If this card is entered, the form loss coefficients depend on the flow conditions and are calculated from;

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_R = A_R + B_R Re^{-C_R}$$

where K_F and K_R are the forward and reverse form loss coefficients; A_F, A_R, B_F, B_R, C_F, and C_R are user-specified constants; A_F and A_R are the Words 4 and 5 of Cards CCC0101 through CCC0109; B_F, B_R, C_F, and C_R are Words 1, 2, 3, and 4 of this Card (CCC0111); and Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculations, then enter all four words for the appropriate expression.

W1(R) B_F (≥ 0). This quantity must be greater than or equal to zero.

W2(R) C_F (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_R (≥ 0). This quantity must be greater than or equal to zero.

W4(R) C_R (≥ 0). This quantity must be greater than or equal to zero.

A7.8.4 Card CCC0201, Valve Junction Initial Conditions

This card is required for valve junction components.

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

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

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

W4(R) Interface velocity (m/s, ft/s). Enter zero.

A7.8.5 Card CCC0300, Valve Type Card

This card is required to specify the valve type.

W1(A) Valve type. This word must contain one of the following: CHKVLV for a check valve, TRPVLV for a trip valve, INRVLV for an inertial swing check valve, MTRVLV for a motor valve, SRVVLV for a servo valve, or RLFVLV for a relief valve.

A7.8.6 Cards CCC0301 through CCC0399, Valve Data and Initial Conditions

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

A7.8.6.1 Check Valve. *This behaves as an 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). It is recommended that 0 be used for most calculations, as it is more stable (i.e., less noisy and less oscillations) than +1 or -1.

W2(I) Check valve initial position. The valve is initially open if zero, closed if one.

W3(R) Closing back pressure (Pa, lb_f/in^2).

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

A7.8.6.2 Trip Valve. This behaves as an 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.

A7.8.6.3 Inertial Valve. This behaves realistically in that the valve area varies considering the hydrodynamic forces and the flapper inertia, momentum, and angular acceleration. The abrupt area change model must be specified.

W1(I) Latch option. The valve can open and close repeatedly if the latch option is zero. When W1 = 1, the valve either opens or closes only once if the initial angle is between the maximum and minimum. If the flapper starts at either the maximum or minimum angle it will not move. When W1 = W2, the flapper will latch only at the maximum position. If it starts at the maximum, it will not move.

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 6 and 7.

W6(R) Minimum flapper angle (degrees). This must be greater than or equal to zero.

W7(R) Maximum flapper angle (degrees).

W8(R) Moment of inertia of valve flapper ($kg \cdot m^2$, $lb \cdot ft^2$).

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).

A7.8.6.4 Motor Valve. This behaves realistically in that the valve area varies as a function of time by either of two models specified by the user. The user must also select the model for valve hydrodynamic losses by specifying either the smooth or the abrupt area change model. If the smooth area change model is selected, a table of flow coefficients must also be input as described in Cards CCC0400 through CCC0499, CSUBV Table Section A7.8.7. If the abrupt area change model is selected, a flow coefficient table cannot be input.

W1(I) Open trip number.

W2(I) Close trip number. Both the open and close trip numbers must be valid trips. When both trips are false, the valve remains at its current position. When one of the trips is true, the valve opens or closes depending on which trip is true. The transient will be terminated if both trips are true at the same time.

W3(R) Valve change rate (s^{-1}). If Word 5 is not entered, this quantity is the rate of change of the normalized valve area as the valve opens or closes. If Word 5 is entered, this quantity is the rate of change of the normalized valve stem position. This word must be greater than zero.

W4(R) Initial position. This number is the initial normalized valve area or the initial normalized stem position depending on Word 5. This quantity must be between 0.0 and 1.0.

W5(I) Valve table number. If this word is omitted or input as zero, the valve area is determined by the valve change rate and the trips. If this word is input as nonzero, the valve stem position is determined by the valve change rate and the trips; and the valve area is determined from a general table containing normalized valve area versus normalized stem position.

Input for general tables is discussed in Cards 202TTTNN, General Table Data, Section A11. For this case, the normalized stem position is input as the <u>argument value</u> and the normalized valve area is input as the <u>function value</u>.

A7.8.6.5 Servo Valve. This behaves as described for a motor valve except that the valve flow area or stem position is calculated by a control system. Input for control systems is discussed in Section A.1.

Input specifying the hydrodynamic losses for servo valves is also identical to that for motor valves.

W1(I) Control variable number. The value of the indicated control variable is either the normalized valve area or the normalized stem position, depending on whether Word 2 is entered. The control variable is also the search argument for the CSUBV table if it is entered.

W2(I) Valve table number. If this word is not entered, the control variable value is the normalized flow area. If it is entered, the control variable value is the normalized stem position; and the general table indicated by this word contains a table of normalized area versus normalized stem position. Input for the general table is identical to that for a motor valve.

A7.8.6.6 Relief Valve. The valve area varies considering the hydrodynamic forces and the valve mass, momentum, and acceleration. The abrupt area change model must be specified. The junction area input by Cards CCC0101 through CCC0199 is the valve inlet area.

W1(I) Valve initial condition. The valve is initially closed if zero, open if one.

W2(R) Inlet diameter (m, ft). This is the inside diameter of the valve inlet. If this term is input as zero, it will default to the diameter calculated from the junction area input on Cards CCC0101 through CCC0109. If both this diameter and the junction area are input as nonzero, care must be taken that these terms are input with enough significant digits so that the areas agree within 10^{-5} m^2. If the junction area is input as zero, then this diameter must be input as nonzero.

W3(R) Valve seat diameter (m, ft). Nonzero input is required. This term is the outside diameter of the valve seat, including the minimum diameter of the inner adjustment ring. This term must also be greater than or equal to the inlet diameter.

W4(R) Valve piston diameter (m, ft). If input as zero, the default is to the valve seat diameter.

W5(R) Valve lift (m, ft). Nonzero input is required. This is the distance the valve piston rises above the valve seat at the fully open position.

W6(R) Maximum outside diameter of the inner adjustment ring (m, ft). If this input is zero, it will default to the valve seat diameter; in which case W7, 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, is allowed. Also refer to the warning stated for W9.

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 preceding is defaulted or input equal to the valve seat diameter. If the shoulder is below the seat, this distance is negative. Also refer to the warning stated for W9.

W8(R) Minimum inside diameter of the outer adjustment ring (m, ft). If this input is zero [illegible] default to the valve piston diameter, in which case W9 must be input as posi[illegible]d

nonzero. If this input is nonzero, the value must be greater than or equal to the valve piston diameter. Input of a negative W9 is allowed only if this diameter is greater than the valve piston diameter. Also refer to the warning stated for W9.

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 preceding must be greater than the valve piston diameter. If the bottom edge is below the valve seat, this distance is negative. WARNING: Input of this term and terms W6, W7, and W8 preceding must be done with care to ensure that the resultant gap between the adjustment rings is positive and nonzero; otherwise, an input error will result.

W10(R) Bellows average diameter (m, ft). If this term is input as zero, it will default to the valve piston diameter, resulting in a model not containing a bellows for which the valve bonnet region is vented to the atmosphere.

W11(R) Valve spring constant (N/m, lb_f/ft). Positive, nonzero input is required.

W12(R) Valve setpoint pressure (Pa, lb_f/in^2). Positive input is required.

W13(R) Valve piston, rod, spring, bellows mass (kg, lb). Nonzero input is required.

W14(R) Valve damping coefficient (N•s/m, lb_f• s/ft).

W15(R) Bellows inside pressure (Pa, lb_f/in^2). Defaults to standard atmospheric pressure if omitted or input as zero.

W16(R) Initial stem position. This is the fraction of total lift and is required if W1 is input as one. Total lift is input as W5.

W17(R) Initial valve piston velocity (m/s, ft/s). This must be zero or omitted if W1 is input as zero.

A7.8.7 Cards CCC0400 through CCC0499, Valve CSUBV Table

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

The CSUBV table contains forward and reverse flow coefficients as a function of normalized flow area or normalized stem position.

A7.8.7.1 Card CCC0400, Factors. This card is optional. The factors apply to the flow area or the stem position and the flow coefficient entries in the CSUBV table.

W1(R) Normalized flow area or normalized stem position.

W2(R) Flow coefficient factor.

A7.8.7.2 Cards CCC0401 through CCC0499, Table Entries. The table is entered by using three-word sets. W1 is the flow area or stem position and must be normalized. The factor W1 on Card CCC0400 can be used to normalize the flow area or stem position. In either case, the implication is that if the valve is fully closed, the normalized term is zero. If the valve is fully open, the normalized term is one. Any value may be input that is between zero and one. The forward and reverse flow coefficients are W2 and W3, respectively. The code internally converts flow coefficients to energy loss coefficients by the formula $k = 2 \bullet A_j^2/(\rho \bullet CSUBV^2)$, where ρ is density of water at 60 °F (288.71 K), A_j is the full open valve area, and CSUBV is the flow coefficient. On Card CCC0400, W2 may be used to modify the definition of CSUBV. A smooth area change must be specified in W6 on Card CCC0101 to use the CSUBV table. CSUBV is entered in British units only.

W1(R) Normalized flow area or normalized stem position.

W2(R) Forward CSUBV $\{gal/[min \bullet (lb_f/in^2)^{0.5}]\}$. 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 $\{gal/[min \bullet (lb_f/in^2)^{0.5}]\}$.

A7.9 Pump Component

A pump component is indicated by PUMP on for Word 2 on Card CCC0000. A pump consists of one volume and two junctions, one attached to each end of the volume. For major edits, minor edits, and plot variables, the volume in the pump component is numbered CCC010000. The pump junctions are numbered CCC010000 for the inlet junction and CCC020000 for the outlet junction.

A7.9.1 Cards CCC0101 through CCC0107, Pump Volume Geometry Cards

This card (or cards) is required for a pump component. The seven words can be entered on one or more cards, and the card numbers need not be consecutive.

W1(R) Volume flow area (m^2, ft^2).

W2(R) Length of volume (m, ft).

W3(R) Volume of volume (m^3, ft^3). The program requires that the volume equals the volume flow area times the length (W3 = W1•W2). At least two of the three quantities, W1, W2, W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. If none of the words are zero, the volume must equal the area times the length within a relative error of 0.000001.

W4(R) Azimuthal angle (degrees). The absolute value of this angle must be ≤ 360 degrees. This quantity is not used in the calculation but is specified for possible automated drawing of nodalization diagrams.

W5(R) Inclination angle (degrees). The absolute value of this angle must be ≤ 90 degrees. The angle 0 degrees is horizontal, and positive angles have an upward direction, i.e., the outlet is at a higher elevation than the inlet. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be equal to or less than the volume length. If the vertical angle orientation is zero, this quantity must be zero. If the vertical angle is nonzero, this quantity must also be nonzero and have the same sign. For this component, this Word 6 is not compared to the volume length (Word 2) to decide if the horizontal or vertical flow regime is used. Rather, the pump flow regime map is used

W7(I) Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag. The pump component forces all volume flags except for the e digit, and y- and z-coordinate flags are not read. The effective format is 000000e.

The digit t is not used and must be input as zero (t = 0). Thermal stratification is not used in a pump component.

The digit l is not used and must be entered as zero (l = 0). Level tracking is not used in a pump component.

The digit p is not used and should be input as 0 (p = 0). The major edit output will show p = 1. The water packing scheme is not used.

The digit v is not used and should be input as 0 (v = 0). The major edit output will show v = 1. The vertical stratification model is not used.

The digit b is not used and should be input as 0 (b = 0). The major edit will show b = 0. The rod bundle interphase friction is not used.

The digit f that normally specifies whether wall friction is to be computed is not used and a 0 must be entered. No wall friction is computed for a pump, since it is included in the homologous pump data. The major edit output will show f = 1, which indicates that no friction flag is set.

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

A7.9.2 Card CCC0108, Pump Inlet (Suction) Junction Card

This card is required for a pump component.

W1(I) Volume code of connecting volume on inlet side. This refers to the component from which the junction coordinate direction originates. An old or expanded format can be used to connect volumes. In the old format, use CCC000000 if the connection is to the inlet side

of the component and use CCC010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number N equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; N equal to 5 and 6 would do the same for the third coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

With the old format, connections are possible only to the inlet or crossflow faces of the first pipe volume or to the outlet or crossflow faces of the last pipe volume. With the expanded format, connections can be made to any face of any pipe volume. Output edits use the expanded format regardless of the input format.

W2(R) Junction area (m^2, ft^2). If zero, the area is set to the minimum of the volume areas of adjacent volumes. If an abrupt area change, the area must be equal to or less than the minimum of the adjacent volume areas. If a smooth area change, no restrictions exist. Note: a variable loss coefficient may be specified. See Section A7.9.6.

W3(R) Reynolds number independent forward flow energy loss coefficient A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. A variable loss coefficient may be specified (see Section A7.9.6). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W4(R) Reynolds number independent reverse flow energy loss coefficient, A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. A variable loss coefficient may be specified (see Section A7.9.6). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W5(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e is not used and should be input as zero (e = 0).

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

The digit v is not used and should be input as zero (v = 0). The horizontal stratification entrainment/pullthrough model is not used.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, a = 1 means full abrupt area change model (K_{loss}, area apportioning at

branch, restricted junction area, and extra interphase drag), and a = 2 means a partial abrupt area change (no K_{loss}, but includes area apportioning at branch, restricted junction area, and extra interphase drag).

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 (s = 0).

A7.9.3 Card CCC0109, Pump Outlet (Discharge) Junction Card

This card is required for a pump component. The format for this card is identical to Card CCC0108 except data are for the outlet junction.

A7.9.4 Card CCC0110, Pump Inlet (Suction) Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to specify only the junction hydraulic diameter for the interphase drag calculation i.e., f = 0 in Word 5 of Card CCC0108), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If the card is being used for the CCFL model (i.e., f = 1 in Word 5 of Card CCC0108), then enter all four words for the appropriate CCFL model if values different from the default values are desired.

W1(R) Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag calculation and must be ≥ 0. This number should be computed from $4.0 \bullet \left(\frac{\text{junction area}}{\text{wetted perimeter}}\right)$. If a zero is entered or the default is used, the junction diameter is computed from $2.0 \bullet \left(\frac{\text{junction area}}{\pi}\right)^{0.5}$. See Word 2 of Card CCC0108 for the junction area.

W2(R) Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

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

W4(R) Slope, m. This is the slope used in the CCFL correlation and must be > 0. The default value is 1.

A7.9.5 Card CCC0111, Pump Outlet (Discharge) Junction Diameter and CCFL Data Card

This card is optional. The defaults indicated for each word are used if the card is not entered. If this card is being used to just specify the junction hydraulic diameter for the interphase drag calculation (i.e., f = 0 in Word 5 of Card CCC0109), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If the card is being used for the CCFL model (i.e., f = 1 in Word 5 of Card CCC0109), then enter all four words for the appropriate CCFL model if values different from the default values are desired. The format for this card is identical to Card CCC0110 except that data are for the outlet junction.

A7.9.6 Card CCC0112, Pump Inlet (Suction) Junction Form Loss Data Card

This card is optional. The user-specified form loss coefficients are given in Words 3 and 4 of Card CCC0108 if this card is not entered. If this card is entered, the form loss coefficients depend on the flow conditions and are calculated from

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_R = A_R + B_R Re^{-C_R}$$

where K_F and K_R are the forward and reverse form loss coefficients; A_F, A_R, B_F, B_R, C_F, and C_R are user-specified constants; A_F and A_R are the Words 3 and 4 of Card CCC0108; B_F, B_R, C_F, and C_R are Words 1, 2, 3, and 4 of this Card (CCC0112); and Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculations, then enter all four words for the appropriate expression.

W1(R) B_F (≥ 0). This quantity must be greater than or equal to zero.

W2(R) C_F (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_R (≥ 0). This quantity must be greater than or equal to zero.

W4(R) C_R (≥ 0). This quantity must be greater than or equal to zero.

A7.9.7 Card CCC0113, Pump Outlet (Discharge) Junction Form Loss Data Card

This card is optional. The user-specified form loss coefficients are given in Words 3 and 4 of Card CCC0109 if this card is not entered. If this card is entered, the form loss coefficients depend on the flow conditions and are calculated from

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_R = A_R + B_R Re^{-C_R}$$

where K_F and K_R are the forward and reverse form loss coefficients. A_F, A_R, B_F, B_R, C_F, and C_R are user-specified constants. A_F and A_R are Words 3 and 4 of Card CCC0109; B_F, B_R, C_F, and C_R are Words 1, 2, 3, and 4 of this Card (CCC0113); and Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculations, then enter all four words for the appropriate expression. The format of this card is identical to Card CCC0112 except data are for the outlet junction.

A7.9.8 Card CCC0200, Pump Volume Initial Conditions

This card is required for a pump component.

W1(I) Control word. This word has the packed format $\underline{\varepsilon bt}$. It is not necessary to input leading zeros.

The digit $\underline{\varepsilon}$ specifies the fluid; $\underline{\varepsilon} = 0$ is the default fluid, $\underline{\varepsilon} = 1$ specifies H_2O and $\underline{\varepsilon} = 2$ specifies D_2O. 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 H_2o is assumed to be the fluid.

The digit $\underline{b}$ specifies whether boron is present. $\underline{b} = 0$ specifies that the volume fluid does not contain boron; $\underline{b} = 1$ specifies that a boron concentration in mass of boron per mass of liquid (which may be zero) is being entered after the other required thermodynamic information.

The digit $\underline{t}$ specifies how the following words are to be used to determine the initial thermodynamic state. $\underline{t} = 0$ through 3 specifies one component (steam/water). Entering $\underline{t} = 4$ through 6 allows the specification of two components (steam/water and noncondensable gas).

With options $\underline{t}$ equal to 4 through 6, names of the components of the noncondensable gas must be entered on Card 110, and mass fractions of the components are entered on Card 115.

If $\underline{t} = 0$, the next four words are interpreted as pressure (Pa, lb_f/in^2), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), and vapor void fraction. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state.

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

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

The following options are used for input of noncondensable states only. In all cases, the criteria used for determining the range of values for static quality are:

1.0E-9 ≤ static quality ≤ 0.99999999, two-phase conditions, and static quality < 1.0E-9 or static quality > 0.99999999, single-phase.

Noncondensable options are as follows:

If t = 4, the next three words are interpreted as pressure (Pa, lb_f/in^2), temperature (K, °F), and static quality in equilibrium condition. Using this input option with static quality > 0.0 and ≤ 1.0, saturated noncondensables will result. Also, the temperature is restricted to be less than the saturation temperature at the input pressure. Setting static quality to 0.0 is used as a flag that will initialize the volume to all noncondensables (dry noncondensable) with no temperature restrictions. Static quality is reset to 1.0 using this dry noncondensable option.

If t = 5, the next three words are interpreted as temperature (K, °F), static quality, and noncondensable quality in equilibrium condition. Both the static and noncondensable qualities are restricted to be between 1.0E-9 and 0.99999999. Little experience has been obtained using this option, and it has not been checked out.

If t = 6, the next five words are interpreted as pressure (Pa, $lb_f/in.^2$), liquid specific internal energy (J/kg, Btu/lb), vapor specific internal energy (J/kg, Btu/lb), vapor void fraction, and noncondensable quality. These quantities will be interpreted as nonequilibrium or equilibrium conditions depending on the internal energies used to define the thermodynamic state. The combinations of vapor void fraction and noncondensable quality must be thermodynamically consistent. If noncondensable quality is set to 0.0, noncondensables are not present and the input processing branches to that type of processing (t = 0). If noncondensables are present (noncondensable quality greater than 0.0), then the vapor void fraction must also be greater than 0.0. If the noncondensable quality is set to 1.0 (pure noncondensable), then vapor void fraction must also be 1.0. When both the vapor void fraction and the noncondensable quality are set to 1.0, the volume temperature is calculated from the noncondensable energy equation using the input vapor-specific internal energy.

W2-W6(R) Quantities as described under Word 1. Depending on the control word, two through five quantities may be required. Enter only the minimum number required. If entered, boron concentration (mass of boron per mass of liquid) follows the last required word for thermodynamic conditions.

A7.9.9 Card CCC0201, Pump Inlet (Suction) Junction Initial Conditions

This card is required for a pump component.

W1(I) Control word. If zero, the next two words are velocities; if one, the next two words are mass flow rates.

W2(R) Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s).

W3(R) Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s).

W4(R) Initial interface velocity (m/s, ft/s). Enter zero.

A7.9.10 Card CCC0202, Pump Outlet (Discharge) Junction Initial Conditions

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

A7.9.11 Card CCC0301, Pump Index and Option Card

This card is required for a pump component.

W1(I) Pump table data indicator. If zero, single-phase homologous tables are entered with this component. A positive nonzero number indicates that the single-phase tables are to be obtained from the pump component with this number. If -1, use built-in data for the Bingham pump. If -2, use built-in data for the Westinghouse pump.

W2(I) Two-phase index. Enter -1 if the two-phase option is not to be used. Enter zero if the two-phase option is desired and two-phase multiplier tables are entered with this component. Enter nonzero if the two-phase option is desired and the two-phase multiplier table data are to be obtained from the pump component with the number entered. There are no built-in data for the two-phase multiplier table.

W3(I) Two-phase difference table index. Enter -3 if the two-phase difference table is not needed (i.e., if W2 is -1). Enter zero if a table is entered with this component. Enter a positive nonzero number if the table is to be obtained from pump component with this number. Enter -1 for built-in data for the Bingham pump. Enter -2 for built-in data for the Westinghouse pump.

W4(I) Pump motor torque table index. If -1, no table is used. If zero, a table is entered for this component. If nonzero, use the table from the component with this number.

W5(I) Time-dependent pump velocity index. If -1, no time-dependent pump rotational velocity table is used and the pump velocity is always determined by the torque-inertia equation. If zero, a table is entered with this component. If nonzero, the table from the pump component with this number is used. A pump velocity table cannot be used when the pump is connected to a shaft control component.

W6(I) Pump trip number. When the trip is off, electrical power is supplied to the pump motor; when the trip is on, electrical power is disconnected from the pump motor. The pump velocity depends on the pump velocity table and associated trip, the pump motor torque data and associated trip. If the pump velocity table is being used, the pump velocity is always computed from that table. If the pump velocity table is not being used, the pump velocity depends on the pump motor torque data and this trip. If the trip is off and no pump motor torque data are present, the pump velocity is the same as for the previous time

step. This will be the initial pump velocity if the pump trip has never been set. Usually the pump trip is a latched trip, but that is not necessary. If the trip is off and a pump motor torque table is present, the pump velocity is given by the torque-inertia equation where the net torque is given by the pump motor torque data and the homologous torque data. If the trip is on, the torque-inertia equation is used and the pump motor torque is set to zero. If the pump trip number is zero, no trip is tested and the pump trip is assumed to always be off.

W7(I) Reverse indicator. If zero, no reverse is allowed; if one, reverse is allowed.

A7.9.12 Cards CCC0302 through CCC0304, Pump Description Card

This card (or cards) is required for a pump component.

W1(R) Rated pump velocity (rad/s, rev/min).

W2(R) Ratio of initial pump velocity to rated pump velocity. Used for calculating initial pump velocity.

W3(R) Rated flow (m^3/s, gal/min).

W4(R) Rated head (m, ft).

W5(R) Rated torque (N•m, lb_f•ft).

W6(R) Moment of inertia (kg•m^2, lb•ft^2). This includes all direct coupled rotating components, including the master for a motor driven pump.

W7(R) Rated density (kg/m^3, lb/ft^3). If zero, initial density is used. This is the density used to generate homologous data.

W8(R) Rated pump motor torque (N•m, lb_f•ft). If this word is zero, the rated pump motor torque is computed from the initial pump velocity and the pump torque that is computed from the initial pump velocity, initial volume conditions, and the homologous curves. This quantity must be nonzero if the relative pump motor torque table is entered.

W9(R) TF2, friction torque coefficient (N• m, b_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, b_f•ft). This is constant frictional torque.

W11(R) TF1, friction torque coefficient (N•m, lb_f•ft). This multiplies the speed ratio to the first power.

W12(R) TF3, friction torque coefficient (N•m, lb_f•ft). This multiplies the speed ratio to the third power.

A7.9.13 Card CCC0308, Pump Variable Inertia Card

Pump inertia is given by Word 6 of Card CCC0302 if this card is not entered. If this card is entered, pump inertia is computed from

$$I = I_3S^3 + I_2S^2 + I_1S^1 + I_0$$

where S is the relative pump speed defined as the absolute value of the pump rotational velocity divided by the rated rotational velocity.

W1(R) Relative speed at which to use the cubic expression for inertia. When the relative speed is less than this quantity, the inertia from Word 6 of Card CCC0302 is used.

W2-W5(R) I_3, I_2, I_1, I_0 ($kg \cdot m^2$, $lb \cdot ft^2$).

A7.9.14 Card CCC0309, Pump-Shaft Connection Card

If this card is entered, the pump is connected to a SHAFT component. The pump may still be driven by a pump motor that can be described in this component, by a turbine also connected to the SHAFT component, or from torque computed by the control system and applied to the SHAFT component. The pump speed table may not be entered if this card is entered.

W1(I) Control component number of the shaft component.

W2(I) Pump disconnect trip. If this quantity is omitted or zero, the pump is always connected to the SHAFT. If nonzero, the pump is connected to the shaft when the trip is false and disconnected when the trip is true.

A7.9.15 Card CCC0310, Pump Stop Data Card

If this card is omitted, the pump will not be stopped by the program.

W1(R) Elapsed problem time for pump stop (s).

W2(R) Maximum forward velocity for pump stop (rad/s, rev/min).

W3(R) Maximum reverse velocity for pump stop (rad/s, rev/min). Reverse velocity is a negative number.

A7.9.16 Cards CCCXX00 through CCCXX99, Single-Phase Homologous Curves

These cards are needed only if W1 of Card CCC0301 is zero. There are sixteen possible sets of homologous curve data to completely describe the single-phase pump operation, that is, a curve for each head and torque for each of the eight possible curve types or regimes of operation. Entering all sixteen curves is not necessary, but an error will occur from an attempt to reference one that has not been entered.

Card numbering is CCC1100 through CCC1199 for the first curve, CCC1200 through CCC1299 for

the second curve, through CCC2600 to CCC2699 for the sixteenth curve. Data for each individual curve are input on up to 99 cards, which need not be numbered consecutively.

W1(I) Curve type Enter one for a head curve; enter two for a torque curve.

W2(I) Curve regime. The possible integer numbers and the corresponding homologous curve octants are: 1 (HAN or BAN), 2 (HVN or BVN), 3 (HAD or BAD), 4 (HVD or BVD), 5 (HAT or BAT), 6 (HVT or BVT), 7 (HAR or BAR), and 8 (HVR or BVR).

W3(R) Independent variable. Values for each curve range from -1.0 to 0.0 or from 0.0 to 1.0 inclusive. The variable is v/a for W2(I) = 1, 3, 5, or 7 and a/v for W2(I) = 2, 4, 6, or 8. If the tabular data do not span the entire range of the independent variable, end point values are used for data outside the table. This usually leads to incorrect pump performance data. Thus entering data to cover the complete range is recommended.

W4(R) Dependent variable. The variable is h/a^2 or b/a^2 for W2(I) = 1, 3, 5, or 7 and h/v^2 or b/v^2 for W2(I) = 2, 4, 6, or 8.

Additional pairs as needed are entered on this or following cards, up to a limit of 100 pairs.

A7.9.17 Cards CCCXX00 through CCCXX99, Two-Phase Multiplier Tables

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

W1(I) Extrapolation indicator. This is not used, enter zero.

W2(R) Void fraction.

W3(R) Head or torque difference multiplier depending on table type.

Additional pairs of data are entered on this or additional cards, as needed, up to a limit of 100 pairs. Void fractions must be in increasing order.

A7.9.18 Cards CCCXX00 through CCCXX99, Two-Phase Difference Tables

These cards are required only if W3 of Card CCC0301 is zero. The two-phase difference tables are homologous curves entered in a similar manner to the single-phase homologous data. Card numbering is CCC4100 through CCC4199 for the first curve, CCC4200 through CCC4299 for the second curve, through CCC5600 to CCC5699 for the sixteenth curve. Data are the same as the data for the single-phase data except that the dependent variable is the difference between single-phase and fully degraded two-phase data.

A7.9.19 Cards CCC6001 through CCC6099, Relative Pump Motor Torque Data

These cards are required only if W4 of Card CCC0301 is zero. If the pump velocity table is not being used and these cards are present, the torque-inertia equation is used. When the electrical power is supplied to the pump motor (the pump trip is off), the net torque is computed from the rated pump motor torque

times the relative pump motor torque from this table and the torque from the homologous data. If the electrical power is disconnected from the pump (the pump trip is on), the pump motor torque is zero.

W1(R) Pump velocity (rad/s, rev/min).

W2(R) Relative pump motor torque.

Additional pairs as needed are added on this or additional cards, up to a maximum of 100 pairs.

A7.9.20 Card CCC6100, Time-Dependent Pump Velocity Control Card

This card is required only if W5 of Card CCC0301 is zero. The velocity table, if present, has priority in setting the pump velocity over the pump trip, the pump motor torque data, and the torque-inertia equation.

W1(I) Trip number. If the trip number is zero, the pump velocity is always computed from the velocity 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 the velocity table. If Word 3 is missing, the search variable in the table is time and the search argument is time minus the trip time. If this word is used, it takes precedence over the trip number used in Word 6 of the CCC0301 card.

W2(A) Alphanumeric part of variable request code. This quantity is optional. If present, this word and the next are a variable request code that specifies the search argument for the table lookup and interpolation. TIME can be selected, but the trip time is not subtracted from the advancement time.

W3(I) Numeric part of variable request code. This is assumed to be zero if missing.

A7.9.21 Cards CCC6101 through CCC6199, Time-Dependent Pump Velocity

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

W1(R) Search variable. Units depend on the quantity selected for the search variable.

W2(R) Pump velocity (rad/s, rev/min).

Additional pairs, as needed, are added on this or additional cards, up to a maximum of 100 pairs. Time values must be in increasing order.

A7.10 Multiple Junction Component

A multiple junction component is indicated by MTPLJUN for Word 2 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 volumes connected by the junctions in the component

must be in the same hydrodynamic system. If this restriction is violated, corrective action is to merge the hydrodynamic systems. For major edits, minor edits, and plot variables, the junctions in the multiple junction component are numbered CCCIINN00, where NN is the set number and II is the junction number within the set. The quantity NN may be 01 through 99; II is 01 for the first junction described in a set and incremented by one for each additional junction ($01 \leq II \leq 99$).

A7.10.1 Card CCC0001, Multiple Junction Information Card

W1(I) Number of junctions, nj. This number must be > 0 and < 100.

W2(I) Initial condition control. This word is optional and, if missing, is assumed to be zero. If zero is entered, the initial conditions on Cards CCC1NNM are velocities; if one is entered, the initial conditions are mass flows.

A7.10.2 Cards CCC0NNM, Multiple Junction Geometry Card

Junctions are described by one or more sets of data; NN being the set number and M being the card number within a set. The junctions are numbered as CCCIINN00, where II is 01 for the first junction described in a set and increments by one for each additional junction. The quantity NN may be 01 through 99, and M may be 1 through 9. Cards are processed by increasing set number NN, and cards within a set by increasing M. Neither NN or M need be strictly consecutive.

W1(I) <u>From</u> connection code to a component. This refers to the component from which the junction coordinate direction originates. An old or an expanded format can be used to connect volumes. In the old format, use CCC000000 if the connection is to the inlet side of the component and use CCC010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number N equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction; N equal to 5 and 6 would do the same for the third coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

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) Reynolds number independent forward flow energy loss coefficient A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. A variable loss coefficient may be specified (see Section A7.10.5). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W5(R) Reynolds number independent reverse flow energy loss coefficient, A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. A variable loss coefficient may be specified (see Section A7.10.5). The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W6(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The digit e specifies the modified PV term in the energy equations. e = 0 means that the modified PV term will not be applied, and e = 1 means that it will be applied.

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

The digit v is not used and should be input as zero (v = 0). The horizontal stratification entrainment/pullthrough model is not used.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, and a = 1 means full abrupt area change model (K_{loss}, area apportioning at branch, restricted junction area, and extra interphase drag), and a = 2 means a partial abrupt area change (no K_{loss}, but includes area apportioning at branch, restricted junction area, and extra interphase drag).

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

The digit s specifies momentum flux options. s = 0 uses momentum flux in both the to and from volume. s = 1 uses momentum flux in the from volume, but not in the to volume. s = 2 uses momentum flux in the to volume, but not in the from volume. s = 3 does not use momentum flux in either the to volume or the from volume.

W7(R) Subcooled discharge coefficient. This quantity is applied only to subcooled liquid choked flow calculations. The quantity must be > 0 and ≤ 2.0.

W8(R) Two-phase discharge coefficient. This quantity is applied only to two-phase choked flow calculations. The quantity must be > 0 and ≤ 2.0.

W9(R) Superheated discharge coefficient. This quantity is applied only to superheated vapor choked flow calculations. The geometry must be > 0 and ≤ 2.0.

W10(I) From volume increment. Words 1 and 2 contain the from and to connection codes respectively for the first junction defined by the set. If the set defines more than one

junction, connection codes for the following junctions are given by the connection code of the previous junction plus the increments in Words 10 and 11. The increments may be positive, negative, or zero. Junctions are defined up to the limit in Word 13. Words 3 through 9 apply to all junctions defined by the set. If additional sets are entered, Words 1 and 2 apply to the next junction, and increments are applied as with the first set. Word 13 for the second and following sets must be greater than Word 13 of the preceding set, and Word 13 of the last set must equal nj. A new set is used whenever a new increment is needed, Words 3 through 9 need to be changed, or a change in junction numbering is desired.

W11(I) To volume increment. See description for Word 10.

W12(I) Enter zero. This is reserved for future capability.

W13(I) Junction limit. Described above.

A7.10.3 Cards CCC1NNM, Multiple Junction Initial Condition Cards

Initial velocities are entered using one or more sets of data. The processing of sets of data is identical to that described in Section A7.10.2 except that there need be no relationship in the division of junctions within sets between these cards (CCC1NNM) and the multiple junction geometry cards (CCC0NNM). Likewise, these cards do not affect the numbering of the junctions.

W1(R) Initial liquid velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control Word 2 of Card CCC0001.

W2(R) Initial vapor velocity or mass flow. This quantity is either velocity (m/s, ft/s) or mass flow (kg/s, lb/s), depending on control Word 2 of Card CCC0001.

W3(I) Junction limit number.

A7.10.4 Cards CCC2NNM, Multiple Junction Diameter and CCFL Data Cards

These cards are optional. The defaults indicated for each word are used if the card is not entered. If the card is being used to specify only the junction hydraulic diameter for the interphase drag calculation (i.e., $\underline{f} = 0$ in Word 6 of Cards CCC0NNM), then the diameter should be entered in Word 1 and any allowable values should be entered in Words 2 through 4 (will not be used). If this card is being used for the CCFL model (i.e., $\underline{f} = 1$ in Word 6 of Cards CCC0NNM), then enter all four words for the appropriate CCFL model if values different from the default values are desired. The processing of sets of data is identical to that described in Section A7.10.2 except that there need be no relationship in the division of junctions within sets between these cards (CCC1NNM) and the multiple junction geometry cards (CCC0NNM). Likewise, these cards do not affect the numbering of the junctions.

W1(R) Junction hydraulic diameter, D_j (m, ft). This is the junction hydraulic diameter used in the CCFL correlation equation and interphase drag calculation and must be ≥ 0. This number should be computed from $4.0 \bullet \left(\frac{\text{junction area}}{\text{wetted perimeter}}\right)$. If a zero is entered or if the default

is used, the junction diameter is computed from $2.0 \bullet \left(\frac{\text{junction area}}{\pi}\right)^{0.5}$. See Word 3 of Card CCC0NNMM for junction area.

W2(R) Flooding correlation form, β. If zero, the Wallis CCFL form is used. If one, the Kutateladze CCFL form is used. If between zero and one, Bankoff weighting between the Wallis and Kutateladze CCFL forms is used. This number must be ≥ 0 and ≤ 1. The default value is 0 (Wallis form).

W3(R) Gas intercept, c. This is the gas intercept used in the CCFL correlation (when $H_f^{1/2} = 0$) and must be > 0. The default value of f is 1.

W4(R) Slope, m. This is the slope used in the CCFL correlation and must be > 0. The default value is 1.

W5(I) Junction limit number.

A7.10.5 Card CCC3NNM, Multiple Junction Form Loss Data Card

These cards are optional. The user-specified form loss coefficients are given in Words 4 and 5 of Card CCC0NNM if these cards are not entered. If this card is entered, the form loss coefficients depend on the flow conditions and are calculated from

$$K_F = A_F + B_F Re^{-C_F}$$

$$K_r = A_r + B_r Re^{-C_r}$$

where K_F and K_R are the forward and reverse form loss coefficients; A_F, A_R, B_F, B_R, C_F, and C_R are user-specified constants; A_F and A_R are the Words 4 and 5 of Cards CCC0NNM; B_F, B_R, C_F, and C_R are Words 1, 2, 3, and 4 of these Cards (CCC3NNM); and Re is the Reynolds number based on mixture fluid properties. If this card is being used for the form loss calculations, then enter all five words for the appropriate expression.

W1(R) B_F (≥ 0). This quantity must be greater than or equal to zero.

W2(R) C_F (≥ 0). This quantity must be greater than or equal to zero.

W3(R) B_R (≥ 0). This quantity must be greater than or equal to zero.

W4(R) C_R (≥ 0). This quantity must be greater than or equal to zero.

W5(I) Junction limit number.

A7.11 Accumulator Component

An accumulator component is indicated by ACCUM for Word 2 on Card CCC0000. For major edits, minor edits, and plot variables, the volume in the accumulator component is numbered CCC010000, and the junction in the accumulator component is numbered CCC010000.

An accumulator is a lumped parameter component treated by special numerical techniques that model both the tank and surgeline until the accumulator is emptied of liquid. When the last of the liquid leaves the accumulator, the code automatically resets the accumulator to an equivalent single-volume with an outlet junction and proceeds with calculations using the normal hydrodynamic solution algorithm.

In the following input requirements, it is assumed that the component is an accumulator in which liquid completely fills the surgeline but may or may not occupy the tank. It is further assumed that the accumulator is not initially in the injection mode. Hence, the initial pressure must be input lower than the injection point pressure, including elevation head effects; and junction initial conditions may not be input (i.e., initial hydrodynamic velocities are set to zero in the code). It is further assumed that the noncondensable gas in the accumulator is nitrogen and that the gas and liquid are initially in equilibrium. No other junctions (except the accumulator junction) should be connected to the accumulator volume. The geometry of the tank may be cylindrical or spherical. The standpipe/surgeline inlet refers to the end of the pipe inside the tank itself.

A7.11.1 Cards CCC0101 through CCC0199, Accumulator Volume Geometry Cards

W1(R) Volume flow area (m^2, ft^2). This is the flow area of a cylindrical tank, or the maximum flow area of a spherical tank. In the case of a spherical tank, the flow area and the tank radius are related by the formula $A = \pi R^2$.

W2(R) Length of volume (m, ft). This is the length of the tank above the standpipe/surgeline inlet, where this inlet refers to the end of the pipe inside the tank itself

W3(R) Volume of volume (m^3, ft^3). This is the volume of the tank above the standpipe/surgeline inlet, where this inlet refers to the end of the pipe inside the tank itself. The code requires the volume, volume flow area, and length to be consistent. For a cylindrical tank, W3 = W1 • W2, and at least two of the three quantities, W1, W2, or W3, must be nonzero. If one of the quantities is zero, it will be computed from the other two. For a spherical tank, W1 and W2 must be nonzero. If W3 is zero, it will be computed from the other two. If none of the words are zero, they must satisfy the consistency condition within a relative error $\pm$ 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). Only +90 or -90 degrees is allowed. The accumulator is assumed to be a vertical tank with the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank itself) at the bottom. This angle is used in the interphase drag calculation.

W6(R) Elevation change (m, ft). This is the elevation change from the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank itself) to the top of the tank. A positive value is an increase in elevation. The absolute value of this quantity must be nonzero, less than or equal to the volume length, and have the same sign as the angle for vertical orientation. As with other components, this Word 6 is compared to the volume length (Word 2) to decide if the horizontal or vertical flow regime map is used. This is not important for this component, since the correlations that depend on the flow regime map are not needed for this component. The volume conditions are determined from the accumulator's special model.

W7(R) Wall roughness (m, ft).

W8(R) Hydraulic diameter (m, ft). This should be computed from $4.0 \bullet \left(\frac{\text{volume flow area}}{\text{wetted perimeter}}\right)$. If zero, the hydraulic diameter of the tank is computed from $2.0 \bullet \left(\frac{\text{volume flow area}}{\pi}\right)^{0.5}$ A check is made that the pipe roughness is less than half the hydraulic diameter of the tank. See Word 1 for the volume flow area.

W9(I) Volume control flags. This word has the packed format tlpvbfe. It is not necessary to input leading zeros. Volume flags consist of scaler oriented and coordinate direction oriented flags. Only one value for a scaler oriented flag is entered per volume but up to three coordinate oriented flags can be entered for a volume, one for each coordinate direction. At present, the f flag is the only coordinate direction oriented flag. This word enters the scaler oriented flags and the x-coordinate flag. The accumulator component forces all volume flags except for the f digit and y- and z-coordinate flags are not read. The effective format is 00110f0 where 0 and 1 indicate fields as set by the accumulator component. The user must enter 0 in the digits marked with 0 and may enter 0 or 1 in the digits marked with 1.

The t flag is not used and must be input as zero (t = 0). The thermal stratification is not used for an accumulator component.

The l flag is not used and must be input as zero (l = 0). The level tracking model is not used for an accumulator component.

The flag p is not used and may be input as zero or one (p = 0 or 1). The water packing scheme is not used.

The flag v is not used and may be input as zero or one (v = 0 or 1). The major edit will show v = 1. The vertical stratification model is not used.

The flag b is not used and must be input as zero (b = 0). The rod bundle interphase friction model is not used.

The flag f specifies wall friction. Enter f = 0 if wall friction is to be computed, and enter f = 1 if wall friction is not to be computed.

The flag e must be specified zero, since only a nonequilibrium (unequal temperature) calculation is allowed.

W10(I) Geometry flag (optional). To specify a cylindrical tank, set the flag equal to 0 (default); to specify a spherical tank, set the flag equal to 1.

A7.11.2 Card CCC0200, Accumulator Tank Initial Thermodynamics Conditions

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

W2(R) Temperature (K, °F).

W3(R) Boron concentration (mass of boron per mass of liquid). This word is optional.

A7.11.3 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 from which the junction coordinate direction originates. An old or an expanded format can be used to connect volumes. In the old format, use CCC000000 if the connection is to the inlet side of the component and use CCC010000 if the connection is to the outlet side of the volume. In the expanded format, the connection code is CCCVV000N, where CCC is the component number, VV is the volume number, and N indicates the face number. A nonzero N specifies the expanded format. The number N equal to 1 and 2 specifies the inlet and outlet faces respectively for the volume's coordinate direction. The number N equal to 3 through 6 specifies crossflow. The number N equal to 3 and 4 would specify inlet and outlet faces for the second coordinate direction. For connecting to a time-dependent volume using the expanded format, only the number N equal to 1 or 2 is allowed.

W2(R) Junction area (m^2, ft). This is the average area of the surgeline and standpipe.

W3(R) Reynolds number independent forward flow energy loss coefficient, A_F. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is positive or zero. The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W4(R) Reynolds number independent reverse flow energy loss coefficient, A_R. This quantity will be used in each of the phasic momentum equations when the junction velocity of that phase is negative. The interpretation and use of the coefficient depends on whether the smooth or abrupt area change option is specified or grid spacers are modeled.

W5(I) Junction control flags. This word has the packed format efvcahs. It is not necessary to input leading zeros.

The accumulator model automatically disables the following terms as long as liquid remains in the accumulator. However, when the accumulator empties of liquid, the model is automatically converted to an active normal volume. The following terms are then enabled and used as defined.

The digit e is not used and should be input as zero (e = 0). The modified energy model is not used.

The digit f is not used and should be input as zero (f = 0). The major edit output will show f = 0. The CCFL model is not used.

The digit v is not used and should be input as zero (v = 0). The horizontal stratification entrainment/pullthrough model is not used.

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

The digit a specifies area change options. a = 0 means either a smooth area change or no area change, and a = 1 and a = 2 are not allowed for an accumulator.

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

The digit s specifies momentum flux options. s = 0 uses momentum flux in both the to volume and the from volume. s = 1 uses momentum flux in the from volume, but not in the to volume s = 2 or 3 is not allowed for an accumulator.

A7.11.4 Card CCC2200, Accumulator Tank Initial Fill Conditions, Standpipe/Surgeline Length/Elevation, and Tank Wall Heat Transfer Terms

W1(R) Liquid volume in tank (m^3, ft^3). This is the volume of water contained in the tank above the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank).

W2(R) Liquid level in tank (m, ft). This is the liquid level of water contained in the tank above the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank) entrance. For a cylindrical tank, either W1 or W2 must be specified as nonzero. For a spherical tank, W2 must be specified as nonzero. If one of the words is zero, it is computed from the other two.

W3(R) Length of surgeline and standpipe (m, ft). If input as zero, then the surgeline and standpipe are not modeled.

W4(R) Elevation drop of surgeline and standpipe (m, ft). This is the elevation drop from the standpipe/surgeline inlet (where this inlet refers to the end of the pipe inside the tank) entrance to the injection point. A positive number denotes a decrease in elevation.

W5(R) Tank wall thickness (m, ft). This is not allowed to be zero.

W6(I) Heat transfer flag. If zero, heat transfer will be calculated. If one, no heat transfer will be calculated.

W7(R) Tank density (kg/m^3, lb/ft^3). If zero, the density will default to that for carbon steel.

W8(R) Tank volumetric heat capacity (J/kg•K, Btu/lb•°F). If zero, the heat capacity will default to that for carbon steel.

W9(I) Trip number. If zero or if no number is input, then no trip test is performed. If nonzero then this must be a valid trip number, the operations performed are similar to those performed for a trip valve. If the trip is false, then the accumulator is isolated and no flow through the junction can occur. If the trip is true, then the accumulator is not isolated and flow through the junction will occur in the normal manner for an accumulator.

The digit p specifies whether the water packing scheme is to be used. p = 0 specifies that the water packing scheme is to be used for that volume, and p = 1 specifies that the water packing scheme is not to be used.

The digit v specifies whether the vertical stratification model is to be used. v = 0 specifies that the vertical stratification model is to be used, and v = 1 specifies that the vertical stratification model is not to be used.

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

The digit f specifies whether wall friction is to be computed. f = 0 means that wall friction effects are to be computed for the volume, and f = 1 specifies that wall friction effects are not to be computed.

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.

A8. CARDS 1CCCGXNN, HEAT STRUCTURE INPUT

These cards are used in NEW and RESTART type problems and are required only if heat structures are described. The heat structure card numbers are divided into fields where:

CCC is a heat structure number. The heat structure numbers need not be consecutive. We suggest, but the system does not require, that if heat structures and hydrodynamic volumes are related, they be given the same number.

G is a geometry number. The combination CCCG is a heat structure geometry combination referenced in the heat structure input data. The G digit is provided to differentiate between different types of heat structures (such as fuel pins and core barrel) that might be associated with the same hydrodynamic volume.

X is the card type.

NN is the card number within a card type.

A8.1 Card 1CCCG000, General Heat Structure Data

This card is required for heat structures. Use eight words for new data input or one word for deleting a heat structure.

A8.1.1 General Heat Structure Data Card

W1(I) Number of axial heat structures with this geometry, nh. This number must be > 0 and < 100.

W2(I) Number of radial mesh points for this geometry, np. This number must be < 100. Enter > 1 if no reflood is specified, and > 2 if reflood or metal water reaction is specified.

W3(I) Geometry type. Enter 1 for rectangular, 2 for cylindrical, and 3 for spherical. Spherical geometry is not allowed if reflood is specified. Cylindrical geometry must be specified when the gap conductance model is used.

W4(I) Steady-state initialization flag. Use zero if the desired initial condition temperatures are entered on input cards 1CCCG401 through 1CCCG499; use one if a steady-state initial condition temperatures are to be calculated by the code. If option one is chosen, the user is still required to enter temperatures on cards 1CCCG402 through 1CCCG499. In this case, the temperatures are used as starting points for the steady-state solutions. The user should therefore enter temperatures either below or above the minimum film boiling point to assure the respective pre-DNB or post-DNB steady-state condition is calculated. This is because the boiling curve is multi-valued.

W5(R) Left boundary coordinate (m, ft).

W6(I) Reflood condition flag. This quantity is optional if no reflood calculation is to be performed. This quantity may be 0, 1, 2, or a trip number. If zero, no reflood calculation is

to be performed. If nonzero, all the heat structures in this heat structure/geometry are assumed to form a two-dimensional representation of a fuel pin. The radial mesh is defined on Card 1CCCG1NN. Each heat structure represents an axial level of the fuel pin, with the first heat structure being the bottom level. Each heat structure should be connected to a hydrodynamic volume representing the same axial section of the coolant channel. The length of the axial mesh in the fuel pin is given by the height of the connected hydrodynamic volume. If the heat structure is fuel pins or heat exchange tubes, the length factor (Word 5 on Cards 1CCCG501 through 1CCCG509) is the product of the hydrodynamic volume length and the number of pins or tubes. The heat structures represent the temperatures at the midpoint of the axial mesh. Once the reflood calculation is initiated, additional mesh lines are introduced at each end of the fuel pin and between the heat structures. Once the reflood calculation is initiated, it remains activated; and the two-dimensional heat conduction calculation uses a minimum of 2*nh + 1 axial mesh nodes. Additional mesh lines are introduced and later eliminated as needed to follow the quench front. If 1 is entered, the reflood calculation is initiated in this heat structure geometry when the average pressure in the connected hydrodynamic volumes is less than 1.2×10^6 Pa, and the average void fraction in the interconnected hydrodynamic volumes is greater than 0.9 (i.e., nearly empty). If 2 is entered, the reflood calculation is initiated in this heat structure geometry when the average pressure in the connected hydrodynamic volumes is less than 1.2×10^6 Pa and the average void fraction in the interconnected hydrodynamic volumes is greater than 0.1 (i.e., dryout begins). If a trip number is entered, the reflood calculation is initiated when the trip is set true. When using the expanded trip number format, 1 and 2 are possible trip numbers. A 1 or 2 entered in this word is not treated as a trip number.

W7(I) Boundary volume indicator. Enter zero or one to indicate that reflood heat transfer applies to the left or right boundary, respectively.

W8(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.

A8.1.2 Heat Structure Delete Card

This card is entered only for RESTART problems. If entered, all heat structures associated with the heat structure geometry number CCCG are deleted.

W1(A) Enter DELETE.

A8.2 Card 1CCCG001, Gap Conductance Model Initial Gap Pressure Data

This card is needed only if the gap conductance model is to be used. If the card is entered, W1 of Card 1CCCG100 must be zero, Cards 1CCCG011 through 1CCCG099, and Cards 1CCCG201 through 1CCCG299 are required. W2 of Card 201MMM00 must be 3, and a table of the gas component name and mole fraction must be specified in the gap material data (Cards 201MMM01 through 201MMM49 described in Section A10.2).

W1(R) Initial gap internal pressure (Pa, lb_f/in^2).

W2(I) Gap conductance reference volume. This word is required. The pressure of the gas in a fuel pin for the gap conductance model is given by P(t) = P(O)/T(O)*T(t), where P(t) is the pressure in the fuel pin and T(t) is the temperature in the reference volume. P(O) is W1 above, and T(O) is the initial temperature 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.

A8.3 Card 1CCCG003, Metal-Water Reaction Control Card

CCCG is a heat structure geometry number. If this card is not present, no metal-water reaction will be calculated. The initial oxide thickness is assumed to be zero on the inner surface. It remains zero unless cladding rupture occurs.

W1(R) Initial oxide thickness on cladding's outer surface.

A8.4 Card 1CCCG004, Fuel Cladding Deformation Model Control Card

CCCG is a heat structure geometry number. If this card is not present, no deformation calculations will be done. If this card is present, then Card 1CCCG001 must also be present.

W1(I) Form loss factor flag. Enter 0 if no additional form loss factors are to be calculated after a rod ruptures. Enter 1 if additional form loss factors are to be calculated. Either a 0 or a 1 must be entered.

A8.5 Cards 1CCCG011 through 1CCCG099, Gap Deformation Data

These cards are required for the gap conductance model only. The card format is sequential, 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. A negative entry is reset to 10^{-6} m with no errors.

W2(R) Cladding surface roughness (m, ft). This number must be either positive or zero. An appropriate value is 2×10^{-6} m. A negative entry is reset to 2×10^{-6} m with no errors.

W3(R) Radial displacement due to fission gas-induced fuel swelling and densification (m, ft). This number must be ≥ 0. A negative entry is reset to zero. An appropriate value can be obtained from calculations using FRAPCON-2 or FRAP-T6.

W4(R) Radial displacement due to cladding creepdown (m, ft). The value is normally negative. A positive entry is reset to zero. An appropriate value can be obtained from calculations using FRAPCON-2 or FRAP-T6.

W5(I) Heat structure number.

A8.6 Card 1CCCG100, Heat Structure Mesh Flags

This card is required for heat structure input.

W1(I) Mesh location flag. If zero, geometry data including mesh interval data, composition data, and source distribution data, are entered with this heat structure input. If nonzero, that information is taken from the geometry data from the heat structure geometry (CCCG) number in this word. If this word is nonzero, the remaining geometry information described in Section A8.7 through Section A8.9 is not entered.

W2(I) Mesh format flag. This word is needed only if Word 1 is zero, though no error occurs if it is present when Word 1 is nonzero. The mesh interval data are given as a sequence of pairs of numbers in one of two formats to be used in Cards 1CCCG101 through 1CCCG199. If this word is 1 (format 1 on Cards 1CCCG101 through 1CCCG199), the pairs of numbers contain the number of intervals in this region and the right boundary coordinate. For the first pair, the left coordinate of the region is the left boundary coordinate previously entered in Word 5 of Card 1CCCG000; for succeeding pairs, the left coordinate is the right coordinate of the previous pair. If this word is 2 (format 2 on Cards 1CCCG101 through 1CCCG199), the format is a sequential expansion of mesh intervals; i.e., the distance in Word 1 on Cards 1CCCG101 through 1CCCG199 is used for each interval starting from the leftmost, as yet unspecified, interval to and including the interval number specified in Word 2.

A8.7 Cards 1CCCG101 through 1CCCG199, Heat Structure Mesh Interval Data (Radial)

These cards are required if Word 1 of Card 1CCCG100 is zero. In Format 1, the sum of the numbers of intervals must be np-1. In Format 2, the sequential expansion must be for np-1 intervals. The card numbers need not be sequential.

A8.7.1 Format 1

W1(I) Number of intervals. Enter the number of intervals, not the interval number.

W2(R) Right coordinate (m, ft).

A8.7.2 Format 2

W1(R) Mesh interval (m, ft.).

W2(I) Interval number.

A8.8 Cards 1CCCG201 through 1CCCG299, Heat Structure Composition Data (Radial)

These cards are required if Word 1 of Card 1CCCG100 is zero and must not be entered otherwise. The card format is two numbers per set in sequential expansion format for np-1 intervals. The card

numbers need not be in sequential order.

W1(I) Composition number. The absolute value of this quantity is the composition number, and it must be identical to the subfield MMM used in Heat Structure Thermal Property Data, Section A-10. The sign indicates whether the region over which this composition is applied is to be included or excluded from the volume averaged temperature computation. If positive, the region is included; if negative, the region is not included. The option to exclude regions from the volume averaged temperature integration is to limit the integration to fuel regions only for use in reactivity feedback calculations. Gap and cladding regions should not be included in this case. If the gap conductance model is used, only one interval can be used for the gap model.

W2(I) Interval number.

A8.9 Cards 1CCCG301 through 1CCCG399, Heat Structure Source Distribution Data (Radial)

These cards are required if Word 1 of Card 1CCCG100 is zero and must not be entered otherwise. The card format is two numbers per set in sequential expansion format for np-1 intervals. The card numbers need not be in sequential order. Radial power peaking factors are entered here.

W1(R) Source value. These are relative values only and can be scaled by any factor without changing the results. By entering different values for the various mesh intervals, a characteristic shape of a power curve can be described.

W2(I) Mesh interval number.

A8.10 Card 1CCCG400, Initial Temperature Flag

This card is optional; if missing, Word 1 is assumed to be zero.

W1(I) Initial temperature flag. If this word is zero or -1, initial temperatures are entered with the input data for this heat structure geometry. If greater than zero, initial temperatures for this heat structure geometry are taken from the heat structure geometry number in this word.

A8.11 Cards 1CCCG401 through 1CCCG499, Initial Temperature Data

These cards are required if Word 1 on Card 1CCCG400 is zero or -1.

A8.11.1 Format 1 (Word 1 on Card 1CCCG400 = 0)

If Word 1 is zero, one temperature distribution is entered, and the same distribution is applied to all of the nh heat structures. The card format is two numbers per set in sequential expansion format for np mesh points.

W1(R) Temperature (K, °F).

W2(I) Mesh point number.

A8.11.2 Format 2 (Word 1 on Card 1CCCG400 = -1)

If W1 of Card 1CCCG400 is -1, a separate temperature distribution must be entered for each of the nh heat structures. The distribution for the first heat structure is entered on Card 1CCCG401, the distribution for the second heat structure is entered on Card 1CCCG402, and the remaining distributions are entered on consecutive card numbers. Continuation cards can be used if the data does not fit on one card.

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

A8.12 Cards 1CCCG501 through 1CCCG599, Left Boundary Condition Cards

These cards are required. The boundary condition data for the heat structures with this geometry are entered in a slightly modified form of sequential expansion using six quantities per set for the number of heat structures with this geometry (nh sets). The modification deals with Words 1 and 2.

W1(I) Boundary volume number or general table. This word specifies the hydrodynamic volume number (of the form CCCNN000F) or general table associated with the left surface of this heat structure. These are used to specify the sink temperature. If zero, no volume or general table is associated with the left surface of this heat structure, and a symmetry or insulated boundary condition is used (i.e., a zero temperature gradient at the boundary), or a temperature of zero is used for a surface temperature or a sink temperature in boundary conditions. A boundary volume number is entered as a positive number. If F is 0 or 4, the volume coordinate associated values such as average volume velocity are taken from the x-coordinate; if F is 2 or 1, volume coordinate associated values are taken from the y- or z-axes, respectively. These numbers define the flow direction parallel with tube bundles. Any flow in other directions is vectorally added to give the crossflow mass flux. Specifying a volume coordinate not in use is an input error. A general table is entered as a negative number (-1 through -999).

W2(I) Increment. This word and Word 1 of this card are treated differently from the standard sequential expansion. Word 1 of the first set applies to the first heat structure of the heat structure geometry set. The increment is (normally 10,000) is added to Word 1, which results in the hydraulic cell number associated with heat structure 2; etc. The increment is applied up to the limit in Word 6 of a set. Word 1 of the next set applies to the next heat structure, and increments are applied as for the first set. The increment may be zero or nonzero, positive or negative. If Word 1 is zero, this word should be zero.

W3(I) Boundary condition type.

If 0, a symmetry or insulated boundary condition is used (i.e., a zero temperature gradient is used at the boundary). The boundary volume must be 0.

If 1 or 1nn, a convective boundary condition where the heat transfer coefficient obtained from Heat Transfer Package 1 is used. The allowed values of NN are shown in Table A8-1. The sink temperature is the temperature of the boundary volume. Word 1 must specify a boundary volume with this boundary condition type. The boundary volume cannot be a time-dependent volume.

There are several numbers allowed for Word 3 to activate convective boundary conditions for nonstandard geometries. A 1, 100, or 101 give the default values. The numbers 1, 100, and 101 use the same correlations. The number 101 is recommended; the numbers 1 and 100 are allowed so that the code is backwards compatible with previous input decks. The default convection and boiling correlations were derived mainly based on data from internal vertical pipe flow. Other possible input values are shown in Table A8-1. When modeling a vertical bundle, the rod or tube pitch-to-diameter ratio should be input on the 901 card. This has the effect of increasing the convective part of heat transfer such that users can input the true hydraulic diameter and get reasonable predictions.

Table A8-1. Card 501 and 601 Word 3 convection boundary type.

Word 3	Geometry type
1, 100, 101	Default
110	Vertical bundle without crossflow (set P/D on 801/901 card)
111	Vertical bundle with crossflow (set P/D on 801/901 card)
130	Flat plate above fluid
134	Horizontal bundle

If 1,000, the temperature of the boundary volume or the temperature from the general table (as specified in Word 1) is used as the left surface temperature. If Word 1 is zero, the surface temperature is set to zero.

If 1xxx, the temperature in general Table xxx is used as the left surface temperature.

If 2xxx, the heat flux from Table xxx is used as the left boundary condition.

If 3xxx, a convective boundary condition is used where the heat transfer coefficient as a function of time is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume or from the table specified in Word 1. If Word 1 is zero, the sink temperature is set to zero.

If 4xxx, a convective boundary condition is used where the heat transfer coefficient as a function of surface temperature is obtained from general Table xxx. The sink temperature is the temperature of the boundary volume or from the table specified in Word 1. If Word 1 is zero, the sink temperature is set to zero.

If reflood is specified, the left boundary condition type must be the 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 1,000 or 1xxx.

W4(I) Surface area code. If zero, Word 5 is the left surface area. If one, Word 5 is: (a) the surface area in rectangular geometry; (b) the cylinder height or equivalent in cylindrical geometry; or (c) the fraction of a sphere (0.5 is a hemisphere) in spherical geometry.

W5(R) Surface area or factor. As indicated in Word 4, this word contains the surface area (m^2, ft^2) or a geometry dependent multiplier (m^2, ft^2) for rectangular; (m, ft) for cylindrical; or

dimensionless for spherical geometries. If the symmetry boundary condition is specified (Word 3 = 0), this word must still be entered nonzero.

W6(I) Heat structure number.

A8.13 Cards 1CCCG601 through 1CCCG699, Right Boundary Condition Cards

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

A8.14 Cards 1CCCG701 through 1CCCG799, Source Data Cards

These cards are required for heat structure data. The card format is sequential expansion format, five words per set, describing nh heat structures.

W1(I) Source type. If zero, no source is used. If a positive number is less than 1,000, power from the general table with this number is used as the source. If 100,000 through 1999949, the number has the form 1zzzzt and the source is taken from a reactor kinetics calculation. The field zzzz must be 0000 for point reactor kinetics and is the zone number for nodal reactor kinetics. The zone number specified must be in use in the nodal kinetics model. The field t = 0 specifies total reactor power, t = 1 specifies total decay power, t = 2 specifies fission power, t = 3 specifies fission product decay power, and t = 4 specifies actinide decay power. If 10,001 through 14,095, the source is the control variable whose number is this quantity minus 10,000.

W2(R) Internal source multiplier. Axial peaking factors may be entered here. These values are multiplied by the power in the general table number in Word 1 to obtain the total power generated in this heat structure. These factors are not relative factors

W3(R) Direct moderator heating multiplier for left boundary volume.

W4(R) Direct moderator heating multiplier for right boundary.

W5(I) Heat structure number.

A8.15 Card 1CCCG800, Additional Left Boundary Option

W1(I) If this card is not entered or if this word is zero, the nine-word format is used on Cards 1CCCG801 through 1CCCG899. If this word is one, the twelve-word format is used on the cards. If this word is two, the thirteen-word format is used on the cards (needed for PG-CHF correlation).

A8.16 Cards 1CCCG801 through 1CCCG899, Additional Left Boundary Cards

These cards are required whenever the left boundary communicates energy with the left hand fluid volume. The cards are in sequential expansion format, nine words per set, describing nh heat structures.

Sequential expansion would only be used where the critical heat flux value was not of importance, since the length would be the same for all heat structures in the expansion. Words 2 through 8 are used for the CHF correlation.

Nine-word format:

W1(R) Heat transfer hydraulic diameter (i.e., heated equivalent diameter) (m, ft). This is $4\left(\frac{\text{flow area}}{\text{heated perimeter}}\right)$ and is recommended to be greater than or equal to the volume hydraulic diameter since (heated perimeter $\leq$ (wetted perimeter). It is possible to input this diameter to be less than the volume hydraulic diameter. If Word 1 equals 0.0, the volume hydraulic diameter is used. See Section 3.5 of Volume II of the RELAP5 manual for further guidelines.

W2(R) Heated length forward (m, ft). Distance is from the heated inlet to the center of this slab. This quantity will be used when the liquid volume velocity is positive or zero. This is used to get the hydraulic entrance length effect. This is used only for the CHF correlation. It must be > 0. To ignore the length effect, put in a large number (i.e., $\geq$ 10.0).

W3(R) Heated length reverse (m, ft). Distance is from the heated outlet to the center of this slab. This quantity will be used when the liquid volume velocity is negative. This is used to get the hydraulic entrance length effect. This is used only for the CHF correlation. It must be > 0. To ignore the length effect, put in a large number (i.e., $\geq$ 10.0).

W4(R) Grid spacer length forward (m, ft). Distance is from the center of this slab to the nearest grid or obstruction upstream. This quantity will be used when the liquid volume velocity is positive or zero. This is used to get the boundary layer disturbance and atomization effect of a grid spacer in rod bundles. This is used only for the CHF correlation. If the grid K loss (Word 6) is zero, Word 4 is not used.

W5(R) Grid spacer length reverse (m, ft). Distance is from the center of the slab to the nearest grid or obstruction downstream. This quantity will be used when the liquid volume velocity is negative. This is used to get the boundary layer disturbance and atomization effect of a grid spacer in rod bundles. This is used only for the CHF correlation. If the grid K loss (Word 7) is zero, Word 5 is not used.

W6(R) Grid loss coefficient forward. Used for forward flow in rod bundles. This quantity is used when the liquid volume velocity is positive or zero. This is used only for the CHF calculation.

W7(R) Grid loss coefficient reverse. Used for reverse flow in rod bundles. This quantity is used when the liquid volume velocity is negative. This is used only for the CHF correlation.

W8(R) Local boiling factor. Enter 1.0 if there is no power source in the heat structure or if the local equilibrium quality is negative (i.e., liquid is subcooled and void is zero). This is the local heat flux/average heat flux from start of boiling. If the power profile is not flat, a steady-state run may help determine this number. This number must be greater than 0.0.

W9(R) Heat structure number.

Twelve-word format (Word 1 = 1 on Card 1CCCG800). The first eight words of this format are identical to the nine-word format.

W9(R) Natural circulation length (m, ft). This should be the height of a hydraulic natural convection cell. For a heated vertical plate, this is the total height of the plate. For inside a horizontal tube, this should be the inside tube diameter. For the outer surface of vertical or horizontal bundles, it is suggested to use the heated bundle height in the vertical direction. When using the nine-word format, this quantity is set to Word 1, the heat transfer hydraulic diameter (i.e., heated equivalent diameter).

W10(R) Rod or tube pitch-to-diameter ratio. The minimum allowed value is 1.1. The maximum allowed value is 1.6. When using the nine-word format, this quantity is set to 1.1.

W11(R) Fouling factor. This factor is applied to the heat transfer correlations and may be used to represent fouling or to run sensitivity studies. This quantity must be a positive nonzero number. When using the nine-word format, this quantity is set to 1.0.

W12(I) Heat structure number.

Thirteen-word format (Word 1 = 2 on Card 1CCCG800). Set Word 1 = 0. Words 9, 10, and 11 of this format are identical to Words 9, 10, and 11 of the twelve-word format.

W2(R) Reduced heated length forward (m, ft). This is the product ($y \bullet T_a$). The first term is the distance from the heated channel inlet to the point of the predicted CHFR when the liquid volume velocity is positive or zero. The second term is the ratio of average heat flux from the heated channel inlet to the axial coordinate y (m, ft), i.e., at the point of the predicted CHFR, to local heat flux q at y. Word 2 should be determined as follows:

$$y \bullet T_a = \frac{1.}{q(y)} \int_0^y q(z)dz \quad .$$

W3(R) Reduced heated length reverse (m, ft). This is the product ($y \bullet T_a$). The first term is the distance from the heated channel outlet to the point of the predicted CHFR when the liquid volume velocity is negative. The second term is the ratio of average heat flux from the heated channel outlet to the axial coordinate y (m, ft), i.e., at the point of the predicted CHFR, to local heat flux q at y. Word 3 should be determined as follows:

$$y \bullet T_a = \frac{1.}{q(y)} \int_0^y q(z)dz \quad .$$

W4(R) Grid spacer factor forward. This should be input as follows:

If Word 12 = 11, 12, 21, 22, 31, 32, 41, or 42, i.e., CHFR for the tube or the internally heated annulus, then Word 4 must be input as W4 = 1.0.

If Word 12 = 13, 23, 33, or 43, i.e., CHFR for the rod bundle with <u>vaneless</u> grid spacers, then Word 4 should be input as W4 = $1.0/\overline{R}$, if the statistical evaluation data for the rod

bundles are available ($\overline{R}$ is the mean of variable R. R is the statistical random variable representing CHFR, i.e., predicted CHF to measured CHF ratio), or as W4 = 1.0, if the statistical evaluation data for the rod bundle are not available.

If Word 12 = 14, 24, 34, or 44, i.e., CHFR for the rod bundle with vane grid spacers, then Word 4 should be input as: W4 could be determined from statistical evaluation data of specific fuel design.

If Word 12 = 15, then W4 should be input as W4 = 1.0.

W5(R) Grid spacer factor reverse. This should be input as follows:

If Word 12 = 11, 12, 21, 22, 31, 32, 41, or 42, i.e., CHFR for the tube or the internally heated annulus, then Word 5 must be input as W5 = 1.0.

If Word 12 = 13, 23, 33, or 43, i.e., CHFR for the rod bundle with vaneless grid spacers, then Word 5 must be input either as W5 = 1. / $\overline{R}$, if the statistical evaluation data for the rod bundle are available ($\overline{R}$ is the mean of variable R. R is the statistical random variable representing CHFR, i.e., predicted CHF to measured CHF ratio), or as W5 = 1.0, if the statistical evaluation data for the rod bundle are not available.

If Word 12 = 14, 24, 34, or 44, i.e., CHFR for the rod bundle with vane grid spacers, then Word 5 should be input as: 1.0.

W5 could be determined from statistical evaluation data of specific fuel design. If Word 12 = 15, then W5 should be input as W5 = 1.0.

W6(R) Factor of the radial heat flux distribution. This should be input as:

$$T_r = q\frac{\sum_i r_i}{\sum_i r_i q_i} .$$

This is the ratio of local heat flux on referred perimeter to average heat flux on perimeters pertaining to the subchannel (or the annulus).

W7(I) Heated channel upstream hydrodynamic volume number. This refers to the hydrodynamic components which represents the inlet for the heated channel. This is to get the heated channel inlet quality in the case of forward flow direction.

W8(I) Heated channel downstream hydrodynamic volume number. This refers to the hydrodynamic component which represents the outlet for the heated channel. It applies when the flow reverses.

W12(I) CHFR correlation option. This is input in mn format. The first digit specifies the CHFR correlation form.

If m = 1, then the basic form of PG CHFR correlation is used.

If m = 2, then the flux form of the PG CHFR correlation is used.

If m = 3, then the geometry form of PG CHFR correlation is used.

If m = 4, then the power form of PG CHFR correlation is used.

The second digit specifies the geometry of the heated structure. If this is the rod bundle, it specifies if and how the statistical evaluation data are applied for the grid spacer factor (see Word 4 and Word 5).

If n = 1, then this is the tube,

If n = 2, then this is the internally heated annulus.

If n = 3, then this is the rod bundle. The use of an isolated subchannel model is recommended. This is used if the applicable PG CHFR correlation statistical evaluation data are not available.

If n = 4, then this is the rod bundle. The use of an isolated subchannel model is recommended. An extended use of the PG CHFR statistical evaluation data is enabled.

If n = 5, then this is the rod bundle. This is only used in combination with m = 1. Applicable for a subchannel code respecting lateral mixing.

W13(I) Heat structure number.

A8.17 Card 1CCCG900, Additional Right Boundary Option

This card is the same as Card 1CCCG800 but applies to the right boundary.

A8.18 Cards 1CCCG901 through 1CCCG999, Additional Right Boundary Cards

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

A9. CARD 60000000, RADIATION MODEL CONTROL CARD

Any heat structure may radiate to any other heat structure or set of heat structures in a user-defined enclosure. An enclosure is a set of heat structures that communicate via thermal radiation. The calculation ignores fluid in the enclosure.

W1(I) Number of sets of radiation enclosures, nset. This word must be less than 100 and greater than 0 for radiation to be on.

A9.1 Card 6SS00000, Radiation Set Card

SS is the set number. One of these cards must be input for each radiating set. The first word is required, the other three are optional.

W1(I) Number of radiating heat slabs, nrh. This word is the number of radiating heat slabs (surfaces) that participate in radiation heat transfer in set SS. The maximum is 99.

W2(R) Minimum temperature, trmin (K, °F). This word is the minimum temperature of all surfaces in a radiation enclosure below which radiation will no longer be calculated. The default value is 900 K.

W3(R) Minimum void fraction, voidmm. This word is the minimum void fraction below which radiation will no longer be calculated. The default value is 0.75. Each volume connected to any of the radiating surfaces in the set is checked and if any have a void fraction greater than Word 3, radiation stays on in the enclosure set.

W4(I) View factor set, refset. If input, this is the number of the set (SS) from which view factors are to be obtained. If no number is found here, the view factors must be input for this set.

A9.2 Cards 6SSNN001 through 6SSNN099, Radiation Heat Structure Data

For these cards, SS must take on every value from 1 to nset (Word 1 in Card 60000000) and NN must take on every value from 1 to nrh (Word 1 on Card 6SS00000) for each SS. Data are entered for each conductor surface that participates in radiation heat transfer.

W1(I) Heat structure geometry level, jrh. This word is CCCG0ZZ, where CCCG is the heat structure geometry combination of nh and ZZ is the axial level number participating in radiation.

W2(I) Surface flag, jlr. For this word, 0 = left surface, and 1 = right surface of NN.

W3(R) Emissivity of surface NN.

A9.3 Cards 6SSNN101 through 6SNN199, Radiation View Factors

There are nrh•nrh values in each set. SS is the set number (from 1 to nset). NN is the surface number (from 1 to nrh). For a given NN, the sum of the view factors must be 1.0 and the view factor times the surface area must equal the view factor times the area of the receiving surface.

W1(R) View factor, vfij. View factor from surface NN to surface Word 2.

W2(I) Radiation surface number to which NN radiates. Repeat the above two words until view factors to all nrh (Word 1 on Card 6SS00000) surfaces from all surfaces are entered. Sequential expansion is used.

A10. CARDS 201MMMNN, HEAT STRUCTURE THERMAL PROPERTY DATA

These cards are used in NEW or RESTART problems. These cards are required if Cards 1CCCGXNN, Heat Structure Input Cards, Section A8., 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 properties may be deleted, new compositions may be added, or data may be modified by entering new data for an existing composition.

A10.1 Card 201MMM00, Composition Type and Data Format

This card is required.

W1(A) Material type. Thermal properties for four materials are stored within the program: carbon steel (C-STEEL), stainless steel (S-STEEL), uranium dioxide (UO_2), and zirconium (ZR). These properties are selected by entering the name in parentheses for this word. If a user-supplied table or function is to be used, enter TBL/FCTN for this word. At present, the data are primarily to demonstrate capability. The user should check whether the data are satisfactory. The word DELETE may be entered in RESTART problems to delete a composition.

The next two words are required only if TBL/FCTN is entered for Word 1.

W2(I) Thermal conductivity format flag or gap mole fraction flag. Enter 1 if a table containing temperature and thermal conductivity is to be entered; enter 2 if functions are to be entered. Enter 3 if the gap conductance model is used, and thus a table containing gas component names and mole fractions is to be entered.

W3(I) Volumetric heat capacity flag. Enter 1 if a table containing temperature and volumetric heat capacity is to be entered; enter -1 if a table containing only volumetric heat capacities is to be entered and the temperature values are identical to the thermal conductivity table; enter 2 if functions are to be entered.

A10.2 Cards 201MMM01 through 201MMM49, Thermal Conductivity Data or Gap Mole Fraction Data

These cards are required if W1 of Card 201MMM00 contains TBL/FCTN. For a table, enter pairs of temperatures and thermal conductivities or pairs of gas component names and mole fractions according to the specification of Word 2 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.

A10.2.1 Table Format

If only one word is entered, that word contains the thermal conductivity that is assumed constant. Otherwise, pairs of temperatures and thermal conductivities are entered. The number of pairs is limited to 100. The temperatures must be in increasing order. The end-point temperatures must bracket the expected temperatures during a transient. That is, if the temperature is outside the bracketed range, a failure will occur and a diagnostic edit will be printed.

W1(R) Temperature (K, °F) or gas name.

W2(R) Thermal conductivity (W/m•K, Btu/s•ft•°F) or mole fraction.

A10.2.2 Functional Format

In the functional format, sets of nine quantities are entered, each set containing one function and its range of application. The function is

k = A0 + A1*TX + A2*TX**2 + A3*TX**3 + A4*TX**4 + A5*TX**(-1)

where TX = T - C, T is the temperature argument, and C is a constant. Each function has a lower and upper limit of application. The first function entered must be for the lowest temperature range. The lower limit of each following function must equal the upper bound of the previous function.

W1(R) Lower limit temperature (K, °F).

W2(R) Upper limit temperature (K, °F).

W3(R) A0 (W/m•K, Btu/s•ft• °F).

W4(R) A1 (W/m•K^2, Btu/s•ft• $°F^2$).

W5(R) A2 (W/m•K^3, Btu/s•ft• $°F^3$).

W6(R) A3 (W/m•K^4, Btu/s•ft• $°F^4$).

W7(R) A4 (W/m•K^5, Btu/s•ft• $°F^5$).

W8(R) A5 (W/m, Btu/s•ft).

W9(R) C (K, °F).

A10.3 Cards 201MMM51 through 201MMM99, Volumetric Heat Capacity Data

These cards are required if Word 1 of Card 201MMM00 contains TBL/FCTN. The card numbers need not be consecutive.

A10.3.1 Table Format

If only one word is entered, that word contains the volumetric heat capacity that is assumed constant. Pairs of 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.

W1(R) Temperature (K, °F). If only volumetric heat capacities are being entered, this word is not entered.

W2(R) Volumetric heat capacity ($J/m^3 \cdot {}^oK$, $Btu/ft^3 \cdot {}^oF$). This is ρC_p, where ρ is density (kg/m^3, lb/ft^3) and C_p is specific heat capacity ($J/kg \cdot K$, $Btu/lb \cdot {}^oF$).

A10.3.2 Functional Format

In the functional format, sets of nine quantities are entered, each set containing one function and its range of application. The function is

$$c\rho = A0 + A1*TX + A2*TX**2 + A3*TX**3 + A4*TX**4 + A5*TX**(-1)$$

where TX = T - C, and T is the temperature argument. Each function has a lower and upper limit of application. The first function entered must be for the lowest temperature range. The lower limit of each following function must equal the upper bound of the previous function.

W1(R) Lower limit temperature (K, °F).

W2(R) Upper limit temperature (K, °F).

W3(R) A0 (J/m^3 K, $Btu/ft^3 \cdot {}^oF$).

W4(R) A1 (J/m^3 K^2, $Btu/ft^3 \cdot {}^oF^2$).

W5(R) A2 (J/m^3 K^3, $Btu/ft^3 \cdot {}^oF^3$).

W6(R) A3 J/m^3 K^4, $Btu/ft^3 \cdot {}^oF^4$).

W7(R) A4 ($J/m^3 K^5$, $Btu/ft^3 \cdot {}^oF^5$).

W8(R) A5 (J/m^3, Btu/ft^3).

W9(R) C (K, ^oF).

A11. CARDS 202TTTNN, GENERAL TABLE DATA

These cards are used only in NEW or RESTART type problems and are required only if any input references general tables. TTT is the table number, and table references such as for power, heat transfer coefficients, and temperatures refer to this number. Data must be entered for each table referenced, but TTT need not be consecutive. Tables entered but not referenced are stored, and this is not considered an error. During RESTART, general tables may be added, existing tables may be deleted, or existing tables may be modified by entering new data.

A11.1 Card 202TTT00, Table Type and Multiplier Data

W1(A) TABLE TYPE. Enter POWER for power versus time; enter HTRNRATE for heat flux versus time; enter HTC-T for heat transfer coefficient versus time; enter HTC-TEMP for heat transfer coefficient versus temperature; enter TEMP for temperature versus time; enter REAC-T for reactivity versus time; enter NORMAREA for normalized area versus normalized stem position. In RESTART problems, DELETE can be entered to delete general table TTT. When a general table is used to define a FUNCTION type control system variable, table type REAC-T can be used to prevent undesirable units conversion, since no British to SI units conversion is done for REAC-T entries.

The following two, three, or four words are optional and allow trips and factors or units changes to be applied to the table entries. If the factors are omitted, the data are used as entered. One multiplier is used for time, power, heat 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 in the following table is the time supplied to the table for interpolation. If nonzero, the number is the trip number, and the time argument in the following table is -1.0 if the trip is false and the time supplied to the table minus the trip time if the trip is true. This field may be omitted if no factors are entered. This number must be zero or blank for tables that are not a function of time.

W3-W5(R) Factors. As described above, enter factors such that when applied to the table values entered, the resultant values have the appropriate units. For the NORMAREA table, the resultant values for both the normalized length and area must be ≥ 0 and ≤ 1.0.

A11.2 Cards 202TTT01 through 202TTT99, General Table Data

The card numbers need not be consecutive. The units given are the units required after the factors on Card 202TTT00 have been applied. Pairs of numbers are entered; the limit on the number of pairs is 99.

W1(R) Argument value (s, if time; K, °F, if temperature; dimensionless, if normalized stem position).

W2(R) Function value (W, MW, if power; K, °F, if temperature; W/m^2, $Btu/s \cdot ft^2$, if heat flux; $W/m^2 \cdot K$, $Btu/sft^2 \cdot °F$, if heat transfer coefficient; dollars, if reactivity; dimensionless, if normalized area).

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

A12. CARDS 30000000 THROUGH 30399999, REACTOR KINETICS INPUT

These cards are required if a space-independent (point) reactor kinetics or a nodal reactor kinetics calculation is desired. These cards may be entered in a NEW problem or on a RESTART. [If no reactor kinetics data are present in a RESTART problem, the data will be added; if reactor kinetics data are already present, the data are deleted and replaced by the new data.] A complete set of reactor kinetics data must always be entered. Initial conditions are computed the same, for NEW, or RESTART problems; the initial conditions can be obtained from assuming infinite operating time at the input power or from an input power history.

A12.1 Card 30000000, Reactor Kinetics Type Card

This card is required.

W1(A) Kinetics type. Enter POINT or DELETE. Enter POINT for the point reactor kinetics option. Enter DELETE in a restart problem if reactor kinetics is to be deleted. No other data are needed if reactor kinetics is being deleted.

W2(A) Feedback type. Enter SEPARABL, TABLE3, TABLE4, TABLE3A, or TABLE4A. If Word 2 is not entered, a default value is assumed. If the reactor kinetics type is POINT, the default is SEPARABL. If SEPARABL is entered, reactor kinetics feedback due to moderator density, void fraction weighted moderator temperature, and fuel temperature is assumed to be separable, and feedback data are entered on Cards 30000501 through 30000899. If TABLE3, TABLE4, TABLE3A, or TABLE4A is entered, reactivity is obtained from a table defining reactivity as a function of three or four variables using Cards 30001001 through 30002999. If TABLE3 or TABLE4 are entered, the variables are moderator density, void fraction weighted moderator temperature, fuel temperature, and boron density. If TABLE3A or TABLE4A is entered, the variables are void fraction, liquid moderator temperature, volume average fuel temperature, and boron concentration. If TABLE3 or TABLE3A is entered, the first three of the variables in one of the sets defined above are used, and if TABLE4 or TABLE4A is entered, all four variables are used.

A12.2 Card 30000001, Reactor Kinetics Information Card

W1(A) Fission product decay type. Enter NO-GAMMA for no fission product decay calculations, GAMMA for standard fission product decay calculations, or GAMMA-AC for fission product decay plus actinide decay calculations.

W2(R) Total reactor power (W). This is the sum of fission power, fission product decay power, and actinide decay power. Watts are used for both SI and British units. This must be > 0.0.

W3(R) Initial reactivity (dollars). This quantity must be ≤ 0.0.

W4(R) Delayed neutron fraction over prompt neutron generation time (s^{-1}).

W5(R) Fission product yield factor. This is usually 1.0 for best-estimate problems, and 1.2 has

been used with ANS73 data for conservative mode problems. The factor 1.0 is assumed if this word is not entered.

W6(R) ^{239}U yield factor. This is the number of ^{239}U atoms produced per fission times any conservative factor desired. The factor 1.0 is assumed if this word is not entered.

W7(R) Fissions per initial fissile atom, ψ. Used in factor [$G(t) = 1.0 + (3.24 \cdot 10^{-6} + 5.23 \cdot 10^{-10} t) T^{0.4} \psi$] to account for neutron capture in fission products when using ANS79-1 or ANS79-3 option. Entering this quantity as a nonzero includes the G factor as part of the decay heat. The factor is not included if this quantity is not entered or is entered as zero. Entering this word as a positive quantity indicates that the equation is to be used for shutdown time up to 10^4 seconds, and the table is to be used from that time on. Entering this word as a negative number indicates that the table is to be used for all shutdown times. Note that there is a discontinuity in G(t) when switching between an equation and the table. The standard indicates that the table can be used for all shutdown times and that would result in a higher neutron absorption capture effect. The magnitude of this quantity if nonzero must be ≥ 1.0 and ≤ 3.0.

W8(R) Reactor operating time T. This quantity is the T in the expression given in Word 7 above. The unit for this quantity is given in the next word. If not entered or entered as zero, this quantity defaults to 52 wk. This quantity is used only if the power history data in Section A12.7 are not entered. When the power history data are entered, the reactor operating time is obtained from that data. When the power history data are not entered, an infinite operating time is assumed in initializing the decay heat variables, and if the equation form of G(T) is being used, the quantity in this word is used with the shutdown period t set to zero to determine the G factor at the start of the simulation. The limit for this quantity is $1.2614 \cdot 10^8$ seconds.

W9(A) Units for Word 8 above. Must be sec, min, hr, day, wk.

A12.3 Card 30000002, Fission Product Decay Information

This card is entered for POINT problems if Word 1 of Card 30000001 contains GAMMA or GAMMA-AC. If this card is not entered, the proposed 1973 ANS standard fission product data are used if default data are used.

W1(A) Fission product type. Enter ANS73, ANS79-1, or ANS79-3. If default fission product data are used, ANS73 specifies the proposed 1973 ANS standard data, ANS79-1 specifies the 1979 standard data for ^{235}U, and ANS79-3 specifies the 1979 ANS standard data for the three isotopes, ^{235}U, ^{238}U, and ^{239}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 decay heat groups for each isotope be entered.

W2(R) Energy release per fission (MeV/fission). If not entered or zero, the default value of 200 MeV/fission is used.

W3-W5(R) If ANS79-3 is specified in Word 1. 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 Word 1 and default data are not being used, the number of decay groups for ^{235}U, ^{238}U, and ^{239}Pu must be entered in these words. The number of groups for each isotope must be ≤ 50.

A12.4 Cards 30000101 through 30000199, Delayed Neutron Constants

If these cards are missing, constants for the six generally accepted delayed neutron groups are supplied. Otherwise, two numbers for each delay group are entered, one or more pairs per card. Card numbers need not be consecutive. The number of pairs on these cards defines the number of delay groups. Up to 50 delay groups may be entered.

W1(R) Delayed neutron precursor yield ratio.

W2(R) Delayed neutron decay constant (s^{-1}).

A12.5 Cards 30000201 through 30000299, Fission Product Decay Constants

These cards are not needed if Word 1 of Card 30000001 is NO-GAMMA. If this word is GAMMA or GAMMA-AC, data from these cards or default data are used to define fission product decay. If the cards are missing, data as defined in Word 1 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 Word 5 of Card 30000001 is applied to the yield fractions.

W1(R) Fission product yield fraction (MeV).

W2(R) Fission product decay constant (s^{-1}).

A12.6 Cards 30000301 through 30000399, Actinide Decay Constants

These cards are not needed unless Word 1 of Card 30000001 is GAMMA-AC. If GAMMA-AC is entered, data from these cards or default data are used to define actinide decay. If the cards are missing, default data are supplied.

W1(R) Energy yield from ^{239}U decay (MeV).

W2(R) Decay constant of ^{239}U (s^{-1}).

W3(R) Energy yield from ^{239}Np (MeV).

W4(R) Decay constant of ^{239}Np (s^{-1}).

A12.7 Cards 30000401 through 30000499, Power History Data

If these cards are not present, initial conditions for fission product and actinide groups are for steady-state operation at the power given in Word 2 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 sec, min, hr, day, or wk.

W4-W6(R) Power fractions. If ANS79-3 is entered in Word 1 of Card 30000002, the power fractions for ^{235}U, ^{238}U, and ^{239}Pu must be entered in these words.

A12.8 Feedback Input

Feedback information for point kinetics information are entered on the following cards. For steady-state computations in which constant power is desired, these cards can be omitted and the feedback reactivity will be zero.

A12.8.1 Cards 30000011 through 30000020, Reactivity Curve or Control Variable Numbers

Reactivity (or scram) curves from the general tables (Cards 202TTTNN) or control variables that contribute to reactivity feedback are specified on these cards. These cards are not used if there are no references to reactivity contributions from general tables or control variables. Tables and control variables referenced must be defined. No error is indicated if reactivity curves are defined but not referenced on this card, but memory space is wasted. Curve numbers, which are the TTT of the general table card number or control variable number code, are entered one or more per card. Card numbers need not be consecutive.

W1(I) Table or control variable number. Up to 20 numbers may be entered. Numbers from 1 through 999 indicate general table numbers. Numbers > 10,000 indicate the control variable whose number is the entered number minus 10,000.

A12.8.2 Cards 30000501 through 30000599, Density Reactivity Table

This table is required if the SEPARABL option is being used and if Cards 30000701 through 30000799 are entered. One or more pairs of numbers are entered to define reactivity as a function of moderator density. Data are entered one or more pairs per card, and card numbers need not be consecutive. Up to 100 pairs may be entered. The table uses linear interpolation for segments between table search argument values. For search arguments beyond the range of entered data, the end-point values are used.

W1(R) Moderator density (kg/m^3, lb/ft^3).

W2(R) Reactivity (dollars).

A12.8.3 Cards 30000601 through 30000699, Doppler Reactivity Table

This table is required if the SEPARABL option is being used and if Cards 30000801 through 30000899 are entered. One or more pairs of numbers are entered to define Doppler reactivity as a function of volume-averaged fuel temperature. Heat structure composition data Cards 1CCCG201 through 1CCCG209 need to exclude the gap and the cladding for the volume-average fuel temperatures. Data are entered one or more pairs per card, and card numbers need not be consecutive. Up to 100 pairs may be entered. The table uses linear interpolation for segments between table search argument values. For search arguments beyond the range of entered data, the end-point values are used.

W1(R) Temperature (K, °F).

W2(R) Reactivity (dollars).

A12.8.4 Cards 30000701 through 30000799, Volume Weighting Factors

These cards are used only if the SEPARABL option is being used and are omitted if no reactor kinetics feedback from hydrodynamics is present. Each card contains the input for reactivity feedback due to conditions in one or more hydrodynamic volumes. Words 1 and 2 are a volume number and an increment. 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, $W_{\rho i}$.

W4(R) Water temperature coefficient, a_{Wi} (dollars/K, dollars/°F). The weighting factor in Word 3 is not applied to this quantity.

A12.8.5 Cards 30000801 through 30000899, Heat Structure or SCDAP Component Weighting Factors

These cards are used only if the SEPARABL option is being used and are omitted if no reactor kinetics feedback from heat structures or SCDAP components are present. Each card contains the input for reactivity feedback due to conditions in one or more heat structures or SCDAP components representing fueled portions of the reactor. Data are entered in a manner similar to Cards 30000701 through 30000799.

For each heat structure specified on these cards, input on the heat structure data Cards 1CCCG2NN must define the fueled region as the region over which the volume-average temperature is computed.

Usually, either Word 3 or 4 is zero.

W1(I) Heat structure number or SCDAP component iijj. ii equals the axial node, and jj equals the component number.

W2(I) Increment.

W3(R) Weighting factor for doppler feedback, W_{Fi}.

W4(R) Fuel temperature coefficient, a_{Fi} (dollars/K, dollars/°F). The weighting factor in Word 3 is not applied to this quantity.

A12.8.6 Cards 30001701 through 30001799, Volume Weighting Factors

These cards are used only if the TABLE3, TABLE3A, TABLE4, or TABLE4A option is not being used. Each card contains the weighting factor for reactivity feedback due to moderator density (void fraction), void weighted moderator temperature (liquid moderator temperature), and spatial boron density (boron concentration) in one or more hydrodynamic volumes. The quantities preceding the quantities within parentheses are used if TABLE3 or TABLE4 has been entered; the quantities within the parentheses are used if TABLE3A or TABLE4A has been entered The same factor is assumed to apply to all three effects, so only one factor is entered for each value. At least three quantities must be entered on each card. The use of the increment field is similar to that in Section A12.8.5.

W1(I) Hydrodynamic volume number.

W2(I) Increment.

W3(R) Weight factor, $W_{\rho i}$.

A12.8.7 Cards 30001801 through 30001899, Heat Structure or SCDAP Component Weighting Factors

These cards are used only if the TABLE3, TABLE3A, TABLE4, or TABLE4A option is being used. Each card contains the weighting factor for reactivity feedback due to temperature in one or more heat structures or SCDAP components. At least three quantities must be entered on each card. The use of the increment field is similar to that in Section A12.8.5.

W1(I) Heat structure number or SCDAP component iijj. ii is the axial node, and jj is the component number.

W2(I) Increment.

W3(R) Weight factor, W_{Fi}.

A12.8.8 Cards 300019C1 through 300019C9, Feedback Table Coordinate Data

If the TABLE3 or TABLE3A option is being used, the feedback table is a function of three variables: moderator density or void fraction (C = 1), void weighted moderator temperature or liquid moderator temperature (C = 2), and fuel temperature (C = 3). If the TABLE4 or TABLE4A option is being used, the

feedback table is a function of four variables: the three above and spatial boron density or boron concentration (C = 4). Which variables are used depend on the feedback option used (see Word 2, Card 30000000 in Section 12.1). These cards define the coordinates of the table, and table values are entered (on another card set) for each point defined by all combinations of the coordinate values. The table size is the product of the number of coordinate values entered for each variable. At least two coordinate points must be entered, and up to twenty points may be entered for each variable. The table uses multi-dimensional interpolation for values between table coordinate values. For values beyond the range of the entered coordinate values, the end-point coordinate values are used. 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 spatial boron densities; K, °F for moderator and heat structure temperatures; void fractions and boron concentrations are dimensionless).

A12.8.9 Cards 30002001 through 30002999, Feedback Table Data

Values defining the table are entered in pairs. The first is a coded number defining the position of the table entry. The second number is the table entry. One or more pairs may be entered on one or more cards as needed. Card numbers need not be consecutive. There is no required ordering for the coded number, but a coded number may be entered only once.

W1(I) Coded number. The coded number has the form ddmmffbb, where the letter pairs represent coordinate numbers of the independent variables of the table. The dd pair refers to moderator density or void fraction, mm refers to void weighted moderator temperature or liquid moderator temperature, ff refers to heat structure temperature, and bb refers to spatial boron density or boron concentration. The paired numbers range from 00 to one less than the number of coordinate values for that variable. The 00 pair refers to the first coordinate value. If boron dependence is not included, bb is always 00. All table values must be entered. (A future version may allow gaps that are filled in by interpolation.)

W2(R) Table value.

A13. CARDS 20300000 THROUGH 20499999, PLOT REQUEST INPUT DATA

The plotting capability is not currently active. Besides not being converted to machine-dependent form from the original CDC-7600 version, a proprietary plotting package was required. Most users use the strip option to write an ASCII coded file containing data to be plotted and interface this file to plotting routines available within their organizations.

A14. CARDS 205CCCNN OR 205CCCCN, CONTROL SYSTEM INPUT DATA

These cards are used in NEW and RESTART problems if a control system is desired. They are also used to define the generic control components employed with the self-initialization option. Input can also be used to compute additional quantities from the normally computed quantities. These additional quantities can then be output in major and minor edits and plots.

Two different card types are available for entering control system data, but only one type can be used in a problem. The digits CCC or CCCC form the control variable number (i.e., control component number). The card format 205CCCNN allows 999 control variables, where CCC ranges from 001 through 999. The card format 205CCCCN allows 9,999 control variables, where CCCC ranges from 1 through 9,999.

If the self-initialization option is selected, the data cards described in Section A14.2, Section A14.3.20, and Section A14.3.21 must be included. If loop flow control is to be included, the data cards described in Section A14.3.19 must also be included.

A14.1 Card 20500000, Control Variable Card Type

If this card is omitted, Card 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 9,999 (4,095 also allowed) to select the 205CCCCN format.

A14.2 Card 205CCC00 or 205CCCC0, Control Component Type Card

One card must be entered for each of the generic control components when using the self-initialization option.

W1(A) Alphanumeric name. Enter a name descriptive of the component. This name will appear in the printed output along with the component number. A limit of 10 characters is allowed for CDC 7600 computers, and a limit of 8 characters is allowed for most other computers.

W2(A) Control component type. Enter one of the component names, SUM, MULT, DIV, DIFFRENI, DIFFREND, INTEGRAL, FUNCTION, STDFNCTN, DELAY, TRIPUNIT, TRIPDLAY, POWERI, POWERR, POWERX, PROP-INT, LAG, LEAD-LAG, CONSTANT, SHAFT, PUMPCTL, STEAMCTL, or FEEDCTL, or the command, DELETE. If DELETE is entered, enter any alphanumeric word in Word 1 and zeros in the remaining words. No other cards are needed when deleting a component.

W3(R) Scaling factor. For a CONSTANT component, this quantity is the constant value. No additional words are entered on this card, and Cards 205CCC01 through 205CCC09 or 205CCCC1 through 205CCCC9 are not entered. For the PUMPCTL, STEAMCTL, or FEEDCTL components, this is the gain multiplier (G) for the output signal.

W4(R) Initial value.

W5(I) Initial value flag. Zero means no initial condition calculation and Word 4 is used as the initial condition; one means compute initial condition.

W6(I) Limiter control. Enter zero or omit this and the following words if no limits on the control variable are to be imposed. Enter 1 if only a minimum limit is to be imposed, 2 if only a maximum limit is to be imposed, and enter 3 if both minimum and maximum limits are to be imposed.

W7(R) Minimum or maximum value. This word is the minimum or maximum value if only one limit is to be imposed or is the minimum value if both limits are to be imposed.

W8(R) Maximum value. This word is used if both limits are to be imposed.

A14.3 Cards 205CCC01 through 205CCC98 or 205CCCC1 through 205CCCC8, Control Component Data Cards

The format of these cards depends on the control component type. An equation is used to describe the processing by each component. The symbol Y represents the control variable defined by the component. The symbols A_j, j = 1,2,...J, represent constants defined by the control component input data. The variables V_j, j = 1,2,...J, represent any of the variables listed in the minor edit input description. Besides hydrodynamic component data, heat structure data, reactor kinetic data, etc., any of the control variables including the variable being defined may be specified. The symbol S is the scale factor (or G, the gain multiplier, for self-initialization control components) on Card 205CCC00 or 205CCCC0. The variables V_j use the code's internal units (SI). To use British units, the user must convert from SI to British using the scale factor S (or the gain multiplier G) and the constants A_j.

A14.3.1 Sum-Difference Component

This component is indicated by SUM in Word 2 of Card 205CCC00 or 205CCCC0. The sum-difference component is defined by

$$Y = S(A_0 + A_1V_1 + A_2V_2 + ... + A_jV_j)$$

W1(R) Constant A_0.

W2(R) Constant A_1.

W3(A) Alphanumeric name of variable request code for V_1.

W4(I) Integer name of the variable request code for V_1. At least four words that define a constant and one product term must be entered. Additional sets of three words corresponding to Words 2 through 4 can be entered for additional product terms up to 20 product terms. One or more cards may be used as desired. Card numbers need not be strictly consecutive. The sign of A_j determines addition or subtraction of the product terms.

A14.3.2 Multiplier Component

This component is indicated by MULT in Word 2 of Card 205CCC00 or 205CCCC0. The multiplier component is defined by

$$Y = SV_1V_2...V_j$$

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1. At least two words must be entered. Additional pairs of words can be entered on this or additional cards to define additional factors. Card numbers need not be strictly consecutive.

A14.3.3 Divide Component

This component is indicated by DIV in Word 2 of Card 205CCC00 or 205CCCC0. The divide component is defined by

$$Y = \frac{S}{V_1} \text{ or } Y = \frac{SV_2}{V_1}.$$

Specifying two words on the card indicates the first form, and specifying four words on the card indicates the second form. Execution will terminate if a divide by zero is attempted.

W1(A) Alphanumeric name of the variable request code V_1.

W2(I) Integer name of the variable request code for V_1.

W3(A) Alphanumeric name of the variable request code for V_2.

W4(I) Integer name of the variable request code for V_2.

A14.3.4 Differentiating Components

These components are indicated by DIFFRENI or DIFFREND in Word 2 of Card 205CCC00 or 205CCCC0. The differentiating component is defined by

$$Y = S\frac{dV_1}{dt} \quad . \qquad \text{(A14-1)}$$

This is evaluated by

$$Y = \frac{2S}{\Delta t}(V_1 - V_{10}) - Y_o \qquad \text{(DIFFRENI)}$$

$$Y = S\frac{(V_1 - V_{10})}{\Delta t} \qquad \text{(DIFFREND)},$$

where Δt is the time step, and V_{10} and Y_o are values at the beginning of the time step. The numerical approximations for the DIFFRENI and INTEGRAL components are exact inverses of each other. However, an exact initial value is required to use the DIFFRENI component, and erroneous results are obtained if an exact initial value is not furnished The DIFFREND component uses a simple difference approximation that is less accurate, 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 name of variable request code for V_1.

W2(I) Integer name of variable request code for V_1.

A14.3.5 Integrating Component

This component is indicated by INTEGRAL in Word 2 of Card 205CCC00 or 205CCCC0. The integrating component is defined by

$$Y = S\int_0^t V_1 dt \qquad \text{(A14-2)}$$

or, in Laplace notation,

$$Y(s) = \frac{SV_1(s)}{s} \ . \qquad \text{(A14-3)}$$

This is evaluated by

$$Y = Y_o + S*(V_1 + V_{10})\frac{\Delta t}{2}$$

where Δt is the time step and Y_o and V_{10} are the values at the beginning of the time step.

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1.

A14.3.6 Functional Component

This component is indicated by FUNCTION in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = S[\text{FUNCTION}\ (V_1)] \tag{A14-4}$$

where FUNCTION is defined by a general table. This allows the use of any function conveniently defined by a table lookup and linear interpolation procedure. The function component can also be used to set limiting values.

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1.

W3(I) General table number of the function.

A14.3.7 Standard Function Component

This component is indicated by STDFNCTN in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = S[\text{FNCTN}\ (V_1, V_2, \ldots)] \tag{A14-5}$$

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 20 arguments. If the control variable being defined also appears in the argument list of MIN or MAX, the old time value is used in the comparison.

W1(A) FNCTN.

W2(A) Alphanumeric name of the variable request code for V_1.

W3(I) Integer name of the variable request code for V_1.

A14.3.8 Delay Component

This component is indicated by DELAY in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = SV_1\ (t - t_d) \tag{A14-6}$$

where t is time and t_d is the delay time.

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1.

W3(R) Delay time, t_d (s).

W4(I) Number of hold positions. This quantity, h, must be > 0 and ≤ 100. This quantity determines the length of the table used to store past values of the quantity V_1. The maximum number of time-function pairs that can be stored is h + 2. The delay table time increment, d_{TM}, is $d_{TM} = \frac{t_d}{h}$. 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_dT or d_{TM} relative to the time steps on Cards 2nn. When a change in advancement time is made at a restart, the time values in this table are changed to have time values as if the problem in the restart had run to the new advancement time.

A14.3.9 Unit Trip Component

This component is indicated by TRIPUNIT in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = S*U\ (\pm T_1), \tag{A14-7}$$

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.

A14.3.10 Trip Delay Component

This component is indicated by TRIPDLAY in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = S\ T_{rptim}(T_1), \tag{A14-8}$$

where T_{rptim} is the time the trip last turned true. If the trip is false, the value is -1.0; if the trip is true, the value is zero or a positive number.

W1(I) Trip number, T_1.

A14.3.11 Integer Power Component

This component is indicated by POWERI in Word2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = (SV1)_I^I. \tag{A14-9}$$

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1.

W3(I) I.

A14.3.12 Real Power Component

This component is indicated by POWERR in Word 2 of Card 205CCCc00 or 205CCCC0. The component is defined by

$$Y = SV_1^R. \tag{A14-10}$$

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1.

W3(R) R.

A14.3.13 Variable Power Component

This component is indicated by POWERX in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = SV_1^{V_2}. \tag{A14-11}$$

W1(A) Alphanumeric name of the variable request code for V_1.

W2(I) Integer name of the variable request code for V_1.

W3(A) Alphanumeric name of the variable request code for V_2.

W4(I) Integer name of the variable request code for V_2.

A14.3.14 Proportional-Integral Component

This component is indicated by PROP-INT in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = S[A_1V_1 + A_2\int_0^t V_1 dt] \tag{A14-12}$$

or in Laplace transform notation,

$$Y(s) = S\left[A_1 + \frac{A_2}{s}\right]V_1(s). \tag{A14-13}$$

If the control variable is initialized,

$$Y(t_o) = SA_1V_1(t_o). \tag{A14-14}$$

If it is desired that the output quantity Y remain constant as long as the input quantity remains constant, V_1 must initially be zero regardless of the initialization flag.

W1(R) A_1.

W2(R) A_2.

W3(A) Alphanumeric name of the variable request code for V_1.

W4(I) Integer name of the variable request code for V_1.

A14.3.15 Lag Component

This component is indicated by LAG in Word 2 of Card 205CCC00 or 205CCCC0. This component is defined by

$$Y = \int_0^t \left(\frac{SV_1 - Y}{A_1}\right)dt \tag{A14-15}$$

or, in Laplace transform notation,

$$Y(s) = \frac{S}{1 + A_1 s} V_1(s). \tag{A14-16}$$

If the control variable is initialized,

$$Y(t_0) = SV_1(t_0) \ . \tag{A14-17}$$

If the initialization flag is set on and if the initial values of Y and V_1 satisfy a specified relationship, Y remains constant as long as V_1 retains its initial value.

W1(R) Lag time, A_1 (s).

W2(A) Alphanumeric name of the variable request code for V_1.

W3(I) Integer name of the variable request code for V_1.

A14.3.16 Lead-Lag Component

This component is indicated by LEAD-LAG in Word 2 of Card 205CCC00 or 205CCCC0. The component is defined by

$$Y = \frac{A_1 S V_1}{A_2} + \int_0^t \left(\frac{SV_1 - Y}{A_2} \right) dt \tag{A14-18}$$

or, in Laplace transform notation,

$$Y(s) = S \frac{1 + A_1 s}{1 + A_2 s} V_1(s). \tag{A14-19}$$

If the control variable is initialized,

$$Y(t_o) = SV_1(t_o). \tag{A14-20}$$

If the initialization flag is set on and if the initial values of Y and V_1 satisfy a specified relationship, Y remains constant as long as V_1 retains its initial value.

W1(R) Lead time, A_1 (s).

W2(R) Lag time, A_2 (s).

W3(A) Alphanumeric name of the variable request code for V_1.

W4(I) Integer name of the variable request code for V_1.

A14.3.17 Constant Component

Cards 205CCC01 through 205CCC09 or 205CCCC1 through 205CCCC9 are not entered. The quantity in Word 3 of Card 205CCC00 or 205CCCC0 is the constant value used for this component.

A14.3.18 Shaft Component

This component is indicated by SHAFT in Word 2 of Card 205CCC00 or 205CCCC0. A GENERATR component may optionally be associated with a SHAFT component. The SHAFT component advances the rotational velocity equation

$$\sum_i I_i \frac{d\omega}{dt} = \sum_i \tau_i - \sum_i f_i \omega + \tau_c \qquad \text{(A14-21)}$$

where I_i is the moment of inertia of component i, ω is rotational velocity, τ_i is torque of component i, f_i is the friction factor of component i, and τ_c is an optional torque from a control component. The summations include the shaft as well as the pump, turbine, and generator components that are connected to the shaft.

The SHAFT control component differs somewhat from other control components. The scale factor on Card 205CCC00 or 205CCCC0 must be 1.0. The initial value and optional minimum and maximum values have units (rad/s, rev/min), and British-SI units conversion are applied to these quantities. The output of the SHAFT in minor and major edits is in the requested units. Card number ranges are restricted so that both data to complete the SHAFT component description and optional data to describe a generator can be entered. Units conversion is applied to the following cards.

A14.3.18.1 Card 205CCC01 through 205CCC05 or 205CCC1 through 205CCCC5, Shaft Description Card.

W1(I) Torque control variable number. If zero, there is no contribution to torque from the control system. If nonzero, the control variable with this number is assumed to be a torque and is added to the torques from the other components attached to the shaft. The torque must be in SI units.

W2(R) Shaft moment of inertia, I_i ($kg \cdot m^2$, $lb \cdot ft^2$).

W3(R) Friction factor for the shaft, f_i ($N \cdot m \cdot s$, $lb_f \cdot ft \cdot s$).

W4(A) Type of attached component. Enter either TURBINE, PUMP, or GENERATR.

W5(I) Component number. This is the hydrodynamic component number for a TURBINE or PUMP, or the control variable number for this SHAFT component if GENERATR.

Additional two-word pairs may be entered to attach additional components to the shaft, up to a total of 10 components. Only one generator, the one defined as part of this SHAFT component, may be attached.

A14.3.18.2 Card 205CCC06 or 205CCCC6, Generator Description Card. Each SHAFT component may optionally define an associated GENERATR component.

W1(R) Initial rotational velocity (rad/s, rev/min).

W2(R) Synchronous rotational velocity (rad/s, rev/min).

W3(R) Moment of inertia, I_i ($kg \cdot m^2$, $lb \cdot ft^2$).

W4(R) Friction factor, f_i ($N \cdot m \cdot s$, $lb_f \cdot ft \cdot s$).

W5(I) Generator trip number. When the trip is false, the generator is connected to an electrical distribution system and rotational velocity is forced to the synchronous speed. When the trip is true, the generator is not connected to an electrical system and the generator and shaft rotational velocity is computed from the rotational velocity equation.

W6(I) Generator disconnect trip number. If zero, the generator is always connected to the shaft. If nonzero, the generator is connected to the shaft when the trip is false and disconnected when the trip is true.

A14.3.19 PUMPCTL Component

This component is specified when using the self-initialization option and loop flow control is desired but is not limited to that use. For each PUMPCTL component enter:

W1(A) Alphanumeric name of setpoint variable.

W2(I) Parameter part of setpoint variable.

W3(A) Alphanumeric name of sensed variable.

W4(I) Parameter part of sensed variable.

W5(R) Scale factor(s) applied to sensed and setpoint values, S_i. Must be nonzero.

W6(R) Integral name time constant, T_2 (s).

W7(R) Proportional part-time constant, T_1 (s).

Standard use of PUMPCTL controller require the following interpretation of the input data. Word 1 and Word 2 contain CNTRLVAR and CCC (or CCCC), respectively, where CCC (or CCCC) is a CONSTANT type control element containing the desired (setpoint) flow rate. Word 3 is MFLOWJ, and Word 4 is the junction number at which the flow is to be sensed and compared to the setpoint. Word 5 is

the S_i value used to divide the difference between the desired (setpoint) and sensed flow rate to produce the error signal E_1. E_1 must be initially zero if it is intended to have the controller output remain constant as long as the input quantities remain constant. Word 6 and Word 7 are the T_2 and T_1 values, respectively. All variables having units must be in SI units.

A14.3.20 STEAMCTL Component

This component is specified when using the self-initialization option to control steam flow from one or more steam generators but 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 name 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. Word 1 and Word 2 would contain CNTRLVAR and CCC (or CCCC), respectively, where CCC (or CCCC) is a CONSTANT type control element. This constant would be the desired (setpoint) cold leg temperature (for suboptions A and B) or secondary pressure (suboptions C and D). Word 3 would be TEMPF (for suboptions A and B) or P (for suboptions C and D), and Word 4 would be the volume number where the temperature (suboptions A and B) or pressure (suboptions C and D) is sensed. Word 5 is the S_j value used to divide the difference between the desired (setpoint) and sensed temperature (suboptions A and B) or pressure (suboptions C and D) to produce the error signal E_2. E_2 must be initially zero if it is intended to have the controller output remain constant as long as the input quantities remain constant. Word 6 and Word 7 are the T_4 and T_3 values, respectively. All variables having units must be in SI units.

A14.3.21 FEEDCTL Component

This component is specified when using the self-initialization option to control feedwater flow to a steam generator but is not limited to that use. For each FEEDCTL component enter:

W1(A) Alphanumeric name of first setpoint variable.

W2(I) Parameter part of first setpoint variable.

W3(A) Alphanumeric name of sensed variable to be compared with first setpoint.

W4(I) Parameter part of sensed variable to be compared with first setpoint.

W5(R) Scale factor applied to sensed and setpoint values (first setpoint), S_k. Must be nonzero.

W6(A) Alphanumeric name of second setpoint variable.

W7(I) Parameter part of second setpoint variable.

W8(A) Alphanumeric name of sensed variable to be compared with second setpoint.

W9(I) Parameter part of sensed variable to be compared with second setpoint.

W10(R) Scale factor applied to sensed and setpoint values (second setpoint), S_m. Must be nonzero.

W11(R) Integral name time constant, T_6 (s).

W12(R) Proportional part-time constant, T_5 (s).

Standard use of the FEEDCTL controller requires the following interpretation of the input data. Word 1 and Word 2 contain CNTRLVAR and CCC (or CCCC), respectively, where CCC (or CCCC) is a CONSTANT type control element. This constant would be the desired (setpoint) steam generator secondary side water level. The latter may be expressed alternatively as a desired secondary coolant mass or as a differential pressure measured between two locations in the steam generator downcomer. Word 3 and Word 4 would contain CNTRLVAR and CCC (or CCCC), respectively, where CCC (or CCCC) is the number of the control component that describes the summing algorithm to compute the sensed variable (e.g., collapsed water level may be computed by summing the product of VOIDF and volume length over the control volumes in the riser section). Word 5 is the S_k value used to divide the difference between the desired (setpoint) and sensed water level to produce the first portion of the error signal E_3. Word 6 is MFLOWJ, and Word 7 is the junction number of the steam exit junction from the steam generator. Word 8 is MFLOWJ, and Word 9 is the junction number of the feedwater inlet junction. Word 10 is the S_m value used to divide the difference between the sensed steam flow and sensed feedwater flow to produce the second portion of the error signal E_3. E_3 must be initially zero if it is intended to have the controller output remain constant as long as the input quantities remain constant. Word 11 and Word 12 are the T_6 and T_5 values, respectively. All variables having units must be in SI units.

A15. ADDITIONAL PLOT VARIABLES

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. Some SCDAP variables are written to the plot file by default, others must be listed on a 20800NNN card to be plotted. Refer to "SCDAP Quantities" on page A4-18.

A15.1 Cards 20800NNN, Additional Plot Variables

These cards consist of the card number, followed by the variable name as specified in Section A4., Minor Edit Requests.

Example input:

```
20800001    CADCT 000060201.

20800278    GAMMAW 231010000.
```

A16. CREEP RUPTURE

The following cards are used to activate the creep rupture model. The temperature for this model may either come from a SCDAP/RELAP5 heat structure, or from the COUPLE debris bed model. Card 21000000 and cards 21000001 through 21000009 are used to link the creep rupture model to the COUPLE debris bed, while cards 21000101 through 21000110 link the model to a SCDAP/RELAP5 heat structure. Either or both types of cards may be entered.

These cards are optional for either a NEW or RESTART problem. If the creep rupture model is linked to a COUPLE debris bed, then the COUPLE debris bed model must be activated.

A16.1 CARD 21000000, COUPLE Creep Rupture Control

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 (default).

2 = 316 stainless steel.

3 = Inconel 600.

W2(I) Containment volume. If specified as non-zero this volume is used as the containment volume. Default is zero.

W3(R) External pressure (Pa, lb_f/in^2). If W2 is > 0, then this value is ignored and the external pressure is taken from the containment volume, otherwise this value is the constant external pressure. Default is atmospheric pressure.

A16.2 Cards 21000001 through 21000009, Creep Rupture at COUPLE Wall

Creep rupture may be modeled at a maximum of nine COUPLE locations (defined by parameter nrlcmx). At each creep rupture location, a maximum of eleven COUPLE mesh points may be used to define the temperature for the creep rupture model. The temperature at each mesh points is used to produce an average temperature, which is then used as the single temperature of that creep rupture location.

One Card 2100000I is read for each COUPLE wall creep rupture calculation for location I, and the specification of all mesh points for that location must be contained on that card.

If entered on a restart run, any Card 2100000I will cause the mesh points identifying the average temperature of location i to be replaced for that I. The creep rupture damage term for location I will also be reset to 0.0 at the time of restart. Therefore the user should not re-enter any creep rupture locations which the user does not wish 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 on Card

2100000I as 0.

Each Card 2100000I lists N (1 to 11) elements of the COUPLE grid, which describe location I on the COUPLE wall.

W1(I) ELEMENT 1.

WN(I) ELEMENT N.

A16.3 Cards 21000101 through 21000110, Creep Rupture at Heat Structures

Creep rupture may be modeled at up to ten SCDAP/RELAP5 heat structures. A COUPLE mesh need not be entered to model creep at a heat structure.

These cards are optional for either NEW or RESTART calculations. One Card 210001II is read for each creep rupture calculation location II, where the location is at the given heat structure.

If entered on a restart run, any Card 210001II will cause the mesh points identifying the average temperature of location II to be replaced. The creep rupture damage term for location II will also be reset to 0.0 at the time of restart. Therefore the user should not re-enter any creep rupture locations which the user does not wish to replace. On a restart run, one may also add new locations by specifying previously unused values of II. To remove location II on restart without replacement, specify W1 on Card 210001II as 0.

W1(I) Heat structure number. The heat structure for which creep rupture failure calculation is to be done. The format is CCCG00X, where CCC is the heat structure number and G is its geometry.

W2(I) Material index.

1 = A-508 Class 1 carbon steel.

2 = 316 stainless steel.

3 = Inconel 600.

W3(R) Inner (left) pressure (Pa, lb_f/in^2). If non-zero, this constant pressure is used. If zero, pressure is from adjacent volume. Default is zero.

W4(R) Outer (left) pressure (Pa, lb_f/in^2). If non-zero, this constant pressure is used. If zero, pressure is from adjacent volume. Default is zero.

A17. INPUT FOR MODELING REACTOR CORE

The presence of cards described in this section activates the SCDAP (Severe Core Damage Analysis) portion of the code. Each card number begins with the digit '4'.

Comparative checks will occur during input processing for variable type, number of words on a card, range of normal use, and physical/code limits. Further checks will also be performed for consistency of input. For example, one consistency check will examine radial node placement and verify that radial nodes have been placed at material interfaces.

Input violations of variable type, number of words, physical limit, and consistency of input will result in an input error, but will not abort input processing. Error messages will be printed in the output file flagged with the character string "********". If the input is outside the range of normal use, a warning message will be printed in the output file and marked with the character string "$$$$$$$$."

To assist the user during deck building and input processing, selected ranges of allowable input will be identified with the card input descriptions. The range for a given input variable will be identified in the following manner:

Normal type - issue warning if out of range

$\underline{0.0m} < x \leq 2.0m$

Underline - input error if out of range

A few input cards for MOD3.3 are different from those for MOD3.2. The new input cards for MOD3.3 or input cards for MOD3.2 modified for MOD3.3 are identified in Table A17-1.

Table A17-1. New input cards for MOD3.3 and MOD3.2 input cards modified for MOD3.3

New or modified input cards	Status
40000300	modified
40000310	modified
40000320	modified
40000330	modified
400001500	new
50005000	new
50006000	new
50007000	new
50008000	new

Table A17-1. New input cards for MOD3.3 and MOD3.2 input cards modified for MOD3.3

New or modified input cards	Status
50009000	new
5m010000	modified
Section A23.5.3	new

A17.1 Reactor Core Nodalization and Selection of Modeling Options

The first set of cards describe general core geometry, and are also used to input core-wide parameters. They are unique since they begin with the four digits '4000'.

A17.1.1 Card 40000100, Nodalization and Type of Reactor

This card is used to define general control parameters and to control the types of facility dependent phenomena to be modeled.

This card is required for NEW problems, and cannot be changed for RESTART problems.

W1(I) Number of axial nodes. The range[a] is $2 \leq x \leq 10$.

W2(I) Heat conduction flag. Always input the integer 1.

W3(I) Reactor environment.

This flag identifies phenomena for modeling fuel component meltdown and fission product release.

1 = PWR.

2 = BWR.

4 = ATR.

5 = Electrically heated core.

W4(I) Power history type.

This flag is used to specify the decay power reduction caused by the release of volatile fission products after fuel disruption. Six different built-in correction relations are provided, as follows:

1 = Generic PWR (33,800 MWD/tU).

2 = TMI (3,250 MWD/tU).

a. The upper limit for the number of axial nodes in a SCDAP component is set in the code at compile time by the parameter ndax.

3 = PBF Severe Fuel Damage Test Series.

4 = PBF (other test series).

5 = Full decay power.

6 = No decay power.

A17.1.2 Cards 40000201 through 40000299, Axial Node Heights

This card is required for a NEW problem and cannot currently be changed for RESTART problems. The card format is two words per set in sequential expansion format.

W1(R) Axial node height (m, ft). The range is $0.0 \text{ m} < x \leq 2.0 \text{ m}$.

W2(I) Axial node. Node number used for sequential expansion.

A17.1.3 Card 40000300 Parameters for Models of Fuel Rod Meltdown and Oxidation

This card and cards 40000310, 40000320, and 40000330 are optional for NEW or RESTART problems. These cards should be omitted for best-estimate calculations. They can be used when information is wanted on the sensitivity of calculated results to parameters in the modeling of oxidation and meltdown with a large degree of uncertainty.

W1(R) Threshold temperature for re-slumping of stationary drops of relocated fuel rod cladding and dissolved fuel (K). Default value: 2800 K. Coefficient name: tmpfal.

W2(R) Multiplier on ultimate strength of fuel rod cladding oxide layer (unitless). Default value: 2.5. Coefficient name: frcoxf

W3(R) Necessary fraction of coolant space filled with slumped cladding for further filling to not affect re-slumping of the slumped cladding and further filling to not affect oxidation of slumped cladding. Default = 0.55 (unitless). Coefficient name: epsox2.

W4(I) Option to suppress oxidation of fuel rod cladding directly below a molten pool, and thereby reduce possibility of small time steps; 0 = suppress oxidation, 1 = do not suppress oxidation, default= 1.

W5(R) Necessary fraction of coolant space filled with slumped cladding for affect on re-slumping of slumped cladding. Default value: 0.3. Coefficient name: fcirmv.

W6(R) Threshold fraction for oxidation of slumped cladding that prevents re-slumping of this material when its metallic part melts again (unitless). Default value: 4.5×10^{-2}. Coefficient name: tmplos.

W7(R) Minimum weight gain in oxygen of drops of slumped cladding before another spalling of the oxide layer on the drops occurs during reflood conditions (kg O/m^2). Default value: 1.7×10^{-2}. Coefficient name: cofhbs.

W8(R) Reduction factor on necessary fraction of oxidation of slumped cladding to prevent re-slumping upon melting (unitless). Default value: 0.4. Coefficient name: exphbs. W8 is applied in full to W6 when fraction of coolant space filled with slumped material is greater than W3. W8 is applied in part

when fraction coolant space filled with slumped cladding is greater than W5.

W9(R) Multiplier applied to thickness of cladding oxide layer dissolved by dissolution into adjacent metallic layer. This thickness of dissolution is applied in equation for stress in oxide layer. Default value: 3.5 (unitless). Coefficient name: fdsinc.

A17.1.4 Card 40000310 Continuation of Parameters for Models of Fuel Rod Meltdown and Oxidation

W1(R) Minimum effective fraction of surface area of intact cladding exposed to steam at location with slumped material (unitless). Default value: 0.333. Coefficient name: tdrslp.

W2(R) Minimum thickness of oxide layer on cladding for cracking of oxide layer during reflood and quenching (m). Default value: 0.5×10^{-4}. Coefficient name: tstrez.

W3(R) Effective diffusion coefficient for oxide layer of fuel rod cladding that cracks during reflood (m^2/s). Default value: $2.x10^{-6}$. Coefficent name: vdrop.

W4(R) Necessary value for sum of fraction of oxidation and fraction of coolant space filled with slumped material that results in durable oxide layer on fuel rod cladding at that location (unitless). Default value: 0.45. Coefficient name: blksup.

W5(R) Multipler on fraction of coolant space filled with slumped material in inequality measuring durability of oxide layer on fuel rod cladding and used with W4(R) of this card (unitless). Default value: 0.55. Coefficent name: drpsup.

W6(I) Input the integer "2". This input parameter is not used.

W7(R) Maximum rate of heatup by oxidation of intact cladding of fuel rods (W/m). Default value = 15500. Coefficent name: fdpdis.

W8(R) Fraction of change in phase of fuel at location that results in location changing into configuration of molten pool, 0 = no melting of fuel, 1 = complete melting of fuel (unitless). Default value = 0.5. Variable name = rgptol.

W9(R) Threshold hoop strain for double-sided oxidation of fuel rod cladding (unitless). Default value: 0.12. Coefficient name: foxmtc.

A17.1.5 Card 40000320, Parameters for Modeling of Molten Pool Spreading and Slumping

This card is optional for a NEW or RESTART problems. This card has been added to allow the user the ability to perform parametric studies on significant parameters, and is not required for a best-estimate calculation.

W1(R) Multiplication factor on fuel pellet diameter that defines minimum thickness that crust at bottom of molten pool must have in order to support and seal the molten pool (unitless). Default value: 1.0.

W2 (R) Minimum fractional flow area for outer-most flow channel in reactor core after fuel rods

in this channel have become molten. This parameter is intended to provide a means of comparing analyses of severe accident results which may exhibit non-symmetrical molten pools. Refer to Figure A17-1. Default value: 0.5.

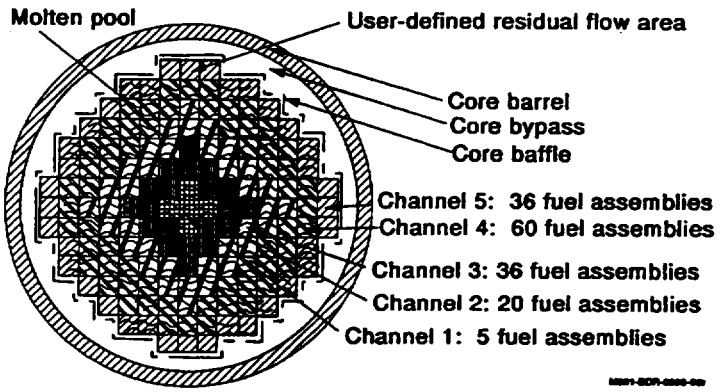

Figure A17-1. Definition of user-defined residual flow area after fuel melting for outermost flow channel in reactor core.

A17.1.6 Card 40000330 Parameters for Modeling of Fragmentation of Fuel Rods and Porous Debris Flow Losses

This card is optional for NEW or RESTART problems. This card is omitted except for sensitivity studies on the formation and thermal hydraulic behavior of porous debris.

W1(I) Index for selecting flow loss model for porous debris; 3 = detailed flow loss and heat transfer model for porous debris with transition smoothing models for porous debris not applied, 4 = detailed flow loss and heat transfer model for porous debris with transition smoothing models for porous debris applied, 2 = simplified flow loss and heat transfer model for porous debris (porous debris represented as intact rods with reduced hydraulic diameter). Default value: 3. Parameter name: nsmgeo.

W2(R) Increment of temperature above saturation temperature at which embrittled fuel rods fragment during quench (K). Default value: 100 K. Parameter name: tfrag.

W3(R) Maximum volume fraction of vapor for application of heat transfer regime for the single phase of liquid. Default value = 0.02. Parameter name: vlqthr.

W4(R) Maximum value of interphase drag for Tung and Dhir flow loss model[A-1] for porous debris for mist flow regime (N/m^3). Default value: $1.x10^9$. Parameter name: fifmsm.

W5(R) Maximum form loss coefficient for mist flow for Tung and Dhir flow loss model[A-1] for porous debris (unitless). Default value: 250. Parameter name: fmfmax.

W6(R) Maximum value of interphase drag for Tung and Dhir flow loss model for porous debris for flow regimes other than mist flow and inverted slip flow(N/m^3). Default value: $1.x10^9$. Parameter name:

fmfmax.

W7(R) Maximum value of interphase drag for Tung and Dhir flow loss model for porous debris for inverted slip flow regime (N/m^3). Default value: $1.x10^9$. Parameter name: fifsgm.

A17.1.7 Card 40000400, Gamma Heating

This card is optional for a NEW problem, and cannot currently be changed for RESTART problems.

W1(R) Gamma heat fraction. The fraction of power used to directly heat the coolant by gamma heating. The default is 0.026, and the range[a] is $0.0 \leq x \leq 0.057$.

A17.1.8 Card 40000500, Cladding Deformation and Oxidation

This card is optional for either NEW or RESTART problems and is used to define cladding ballooning parameters and two different models for oxidation. This card is omitted except for analyses to produce information for sensitivity studies or for fuel rods connected to unusually large upper plenums.

W1(R) Rupture hoop strain. The strain at which the cladding will rupture. The default is 0.18 and the range is $0.0 < x \leq W3$.

W2(R) Always input W1 + 0.02.

W3(R) Limit hoop strain. Strain limit for rod-to-rod contact. The default is 0.33 and the range[b]

is $0.0 < W3 \leq \frac{p-2r}{p}$ where p is pitch of the fuel rods and r is the fuel rod radius.

W4(I) Pressure drop flag. Flag for modeling pressure drop due to ballooning. The default is 0.

0 = Pressure drop caused by ballooning is modeled.

1 = Pressure drop caused by ballooning is not modeled. This input is defined when a fuel rod has such a large upper plenum that a significant pressure drop does not occur as the cladding balloons. Some test rods in FzK severe fuel damage tests had such a characteristic.

W5(I) Index for selecting model for mass transfer of H_2O from bulk fluid to cladding surface; 1 = RELAP5 model[A-2] (presence of noncondensible gases such as Argon taken into account), 2= Olander model[A-3] for binary diffusivity in mixtures of H_2O and H_2. Default value: 1. Parameter name: noxmod.

W6(I) Index for selecting correlation for diffusivity of ZrO_2; 0= Olander correlation[A-3], 1=Berdyshev correlation[A-4]. Default value: 0. Parameter name: mdzrdf.

---

a. Upper limit base on fission of ^{235}U.
b. Based on rod-to-rod contact.

A17.1.9 Card 40000600, Source of Component Power Data

This card is required for NEW problems, and may be changed for RESTART problems. The purpose of this card is to specify how the time-dependent core power is specified to SCDAP/RELAP5. A subsequent component-specific card (40CC1100) specifies the fraction of core power to be deposited in each component. Power in either molten pool or porous debris will be modified according to core power.

W1(A) Source of data ('table', 'cntrlvar' or 'kinetics').

W2(I) Table or control variable number (if necessary).

If the 'kinetics' option is specified, then the component power is calculated by the RELAP5 kinetics model. If the time-dependent core power is specified with either reactor kinetics or general table the units will be handled internally. If specified by a control variable, the power should be calculated in watts.

A17.1.10 Card 40001000, Grid Spacer Elevation

This card is optional and is used to define the elevation of each grid spacer. If this card is not used, then no grid spacers will be modeled. It may not be changed on RESTART.

W1(R) Elevation (m, ft). Elevation of the first grid spacer. The bottom of the core is at elevation zero.

WN(R) Elevation (m, ft). Elevation of the grid spacer n. The bottom of the core is at elevation zero. The range is $0.0\ m < x \leq 10.0\ m$.

A17.1.11 Cards 40001001 through 40001099, Grid Spacer Description

This card is required for a NEW problem only if a grid spacer elevation has been specified. This card cannot be changed for RESTART problems. Sequential expansion format is used.

W1 (I) Grid spacer material. Input one word per spacer.

0 = Zircaloy.

1 = Inconel.

W2(R) Mass of grid spacer (kg, lb_m). Mass per rod. Total mass of spacer divided by number of rods in array. The range is $0.0\ kg < x \leq 0.004\ kg$.

W3(R) Height of grid spacer (m, ft). The range is $0.0\ m < x < 0.125\ m$.

W4(R) Plate thickness of grid spacer (m, ft). The range is $0.0\ m < x \leq 0.01\ m$.

W5(R) Radius of contact (m, ft). The radius of a circle which will have the same area as the (R) contact area between the grid spacer and the fuel rod cladding. The range is $0.0\ m < x \leq 0.002\ m$.

W6(R) Loss coefficient for MOD3.3.

W7(I) Grid spacer number. Sequential expansion applies.

A17.1.12 Cards 40001101 through 40001199, Core Bypass Volume Identification

These cards are used to specify the core bypass hydrodynamic volume, which are used by model for radial spreading of core melt. These cards are required for a NEW problem and may not be changed during RESTART problems.

W1(I) Number of the RELAP5 hydrodynamic volume at bottom of core bypass region (9-digit number).

WN(I) Number of RELAP5 N-th hydrodynamic volume in core bypass region, where N = 2 = second volume from bottom, N = 3 = third volume from bottom, and so forth.

A17.1.13 Cards 40001201 through 40001299, Core Bypass Volume Elevations

These cards are used to specify the elevations of the core bypass volumes identified on Cards 40001101 through 40001199. The elevations are referenced from the bottom of the core to the top of each RELAP5 control volume.

W1(R) Elevation of bypass volume 1 (m, ft). Distance from bottom of core to top of bypass Volume 1, where Volume 1 is bottom most volume in core bypass region.

WN(R) Elevation of bypass Volume N (m, ft). Distance from bottom of core to top of bypass Volume N.

A17.1.14 Card 40001500 User Definition of Porous Debris Region

This card is not input for analyses of nuclear power plants or analyses of tests on fuel rods. It is only input when an analysis is to be performed of a porous debris region that exists at the start of the analysis instead of evolving from fuel rods due to damage progression. This card is optional for NEW or RESTART problems.

W1(I) Index for selecting the flow loss model for porous debris; 1 = Catton and Chung model,[A-6] 2 = Tung and Dhir model.[A-1] Default value: 1. Parameter name: ndbth1.

W2(I) Number of rings in inner part of debris region. If the debris porosity and particle size are uniform from centerline to outside surface of the debris region, then a distinction between inner and outer parts of the debris region is not made. Maximum number of rings is 16. Each ring may have a distinctive temperature and stack of RELAP5 control volumes. Default value = 1. Parameter name = ndbjin.

W3(I) Index identifying material in inner ring of debris; 1 = stainless steel, 2 = UO_2, 3 = ZrO_2, 4 = Zr. Default value: 1. Parameter name: ndbmt1.

W4(R) Porosity of debris in inner ring. Default value = 0.5. Parameter name = pordb1.

W5(R) Diameter of particles in inner ring of debris (m). Default value: $1.x10^{-3}$m. Parameter name: diadb1

W6(R) Power density in inner ring of debris (W/m^3). Default value: 0.0. Parameter name: pwrdb1.

W7(I) Number of rings in outer part of debris region. If the debris porosity and particle size are uniform from centerline to outside surface of the debris region, then omit this word and the rest of the words on this card. Maximum number of rings in inner and outer debris regions must sum to 16 or less. Default value = 0. Parameter name = ndbjot.

W8(I) Index identifying material in outer ring of debris; 1 = stainless steel, 2 = UO_2, 3 = ZrO_2, 4 = Zr. Default value: 1. Parameter name: ndbmt2.

W9(R) Porosity of debris in outer ring. Default value = 0.5. Parameter name = pordb2.

W10(R) Diameter of particles in outer ring of debris (m). Default value: $1.x10^{-3}$m. Parameter name: diadb2

W11(R) Power density in outer ring of debris (W/m^3). Default value: 0.0. Parameter name: pwrdb2.

A17.1.15 Card 40002000, Core Slumping Control Card

For a NEW SCDAP/RELAP5 problem, this card is required with at least the first two words present. A default value is provided for the remaining input.

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) Number of the RELAP5 control volume to receive any core region material that slumps to lower head.

W2(I) RELAP5 volume at top center of core. The bottom of this volume should be contiguous with the top of the core. This word may not be changed on RESTART.

W3(R) Minimum flow area per fuel rod in cohesive debris in core region (m^2). The default is 1.4E-6 m^2.

This parameter is used as follows: Let $A_o = (\text{Pitch}^2 - \frac{\pi d_r^2}{4})$; d_r = diameter of rods, then if $W3/A_o > 0.1$, cohesive debris formation does not result in complete flow blockage; otherwise it does. If one stack of RELAP5 control volumes overlays every first rod being analyzed, $W3(R) \geq 0.5\ A_o$.

A17.2 User Defined Options

A limited number of options have been implemented within the SCDAP/RELAP5 code to activate or deactivate specific models for code assessment. These options are activated (or deactivated) by entering a card with a sequence number equal to or greater than 40004001 and less than or equal to 40004999. The first word should be a recognized keyword from Table A17-2 and the second word should be a value as described by the second column.

These cards are optional on either NEW or RESTART problems.

Table A17-2. User defined options.

Keyword	Value	Default	Meaning
h2xport	on/off	on	When 'off', all oxidation calculations are performed but hydrogen is not released to the coolant stream
deform	on/off	on	When 'off', cladding deformation calculations are disabled.
truncate	on/off	off	When 'on', heat flux to coolant limited.
convect	on/off	on	When 'off', convection heat transfer is disabled.
rad	on/off	on	When 'off', radiation heat transfer is disabled.

A17.3 User-Specified Materials

The user may specify material properties for material indices 9-12 and 50-95 which are defined on Card 4CCC0300 for a "shroud" type of component. A series of Cards 40009NN1, 40009NN2, and 40009NN3 must be entered for each material to be specified, where nn is the material number whose properties are being specified.

Material Indices are listed in Table A17-3. Materials 50 through 59 are entered as pairs, even index being the material and odd index being the oxide.

Table A17-3. User-specified materials.

Index	Material
1	Zircaloy
2	Zr-U-O mixture (liquid)
3	Zr-U-O mixture (frozen)
4	Tungsten
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 properties
10	User-specified properties
11	User-specified properties
12	User-specified properties
13	Metallic uranium

Table A17-3. User-specified materials. (Continued)

Index	Material
14	Disabled
15	Aluminum
16	Al_2O_3
17	Lithium
18	Stainless steel 304
19	Stainless steel oxide
20	Control rod absorber material (Ag/In/Cd or B_4C)
21	Molybdenum (heater rod wire)
22	Copper (heater rod wire)
50-59	User-specified material properties

Material properties as a function of temperature are defined by a table of values, with the material temperature as the independent variable and the material property as the dependent variable.

A17.3.1 Card 40009NN0, Temperature

This card is optional for NEW and RESTART problems. This card is used to specify the temperatures at which the user-definable material properties are specified.

W1(R) Temperature #1 (K, °F).

WN(R) Temperature #2 (K, °F). A maximum of 10 data points may be entered.

If this card is not input the default values are as follows: 300, 550, 700, 873, 1,083, 1,173, 1,248, 1,700, 2,100, 2,500 (temperatures in degrees Kelvin).

A17.3.2 Card 40009NN1, Specific Heat

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN in the card number is the material index.

W1.. (R) Material specific heat at the ten values of temperatures shown above (J/kg•K), Btu/lb · °F.

A17.3.3 Card 40009NN2, Density

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material densities at the ten values of temperatures shown above (kg/m^3), lb/ft^3.

A17.3.4 Card 40009NN3, Thermal Conductivity

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material thermal conductivity at the ten values of temperatures shown above (W/m•K), Btu/ft · °F.

A17.3.5 Card 40009NN4, Surface emissivity

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material surface emissivity at the ten values of temperatures shown above (1/1).

A17.3.6 Card 40009NN5, Thermal expansion

This card is optional for NEW problems and cannot be input for RESTART problems. Note that the user may specify properties only for Materials 9, 10, 11, and 12. NN is the material index.

W1.. (R) Material thermal expansion at the ten values of temperatures shown above (1/1).

A18. CORE COMPONENTS

The reactor core is described by a group of components. Each component may represent one or more fuel rods, control rods or other core elements.

A18.1 Fuel Rod Component

This component describes a group of UO_2 fuel rods. The identification number of this component is "cc".All of the fuel rods that are described by this component are assumed to behave identically. Multiple groups of fuel rods may be described. It is recommended that for inner most group of fuel rods, cc = 01, and outer most group of fuel rods have the largest cc value for fuel rods.

A18.1.1 Card 40CC0000, Fuel Rod Component

This card is required for fuel rod components and may not be input for RESTART calculations.

W1(A) Component name. An eight-character name that should be descriptive of this component.

W2(A) Component keyword. Enter the four-character word "*fuel.*"

A18.1.2 Card 40CC0100, Number of Rods

This card is required for fuel rod components, and may not be input for RESTART calculations.

W1(I) Number of rods. Number of rods simulated by this component. All rods simulated by a single component are assumed to behave identically.

W2(R) Fuel rod pitch (m, ft.). The distance from fuel rod center to fuel rod center of adjacent fuel rods. The range[a] is $0.0126\ M \leq x \leq 0.0187$ m.

W3(R) Average burnup of fuel (MW-s/kg). This word is optional. The default is 0.0 and the range is _$0.0 \leq x \leq 4752000.0$ (MW-s/kg).

A18.1.3 Card 40CC0200, Fuel Rod Plenum Geometry

This card is required for fuel rod components and may not be input for RESTART calculations. The volume input is used in the calculation of internal gas pressure.

W1(R) Plenum length (m, ft.). The range is between 3% and 11% of the rod length.

W2(R) Plenum void volume (m^3, ft^3). Enter the plenum volume less the volume occupied by the spring. The range is $0.0 < x \leq 0.000049\ m^3$.

W3(R) Lower plenum void volume (m^3, ft^3). Enter the gas volume of the lower fuel rod plenum.

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a. All fuel performance and rod geometry range values are based on NUREG/CR-3950, PNL-5210, Vol. 6.

A18.1.4 Cards 40CC0301 through 40CC0399, Fuel Rod Dimensions

This card is required for fuel rod components, and may not be input for RESTART calculations. Radial dimensions of the fuel rod materials are specified for each axial node.

W1(R) As-fabricated fuel pellet radius (m, ft.). The range is $0.00385\ m \leq x \leq 0.00685\ m$. If this component represents a water rod, then define a fuel pellet radius of 1×10^{-4} m.

W2(R) As-fabricated inner cladding radius (m, ft.). The range is $W1 < x < W3$ and $0.003935\ m \leq x \leq 0.00634\ m$.

W3(R) As-fabricated outer cladding radius (m, ft.). The range is $\underline{W2} < x < \frac{W2\ \text{Card4ccc0100}}{2}$ and $0.00457\ m \leq x \leq 0.00715\ m$.

W4(I) Axial node.

A18.1.5 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for fuel rod components and may not be input for RESTART calculations. Specified on this card are the RELAP5 control volumes which will act as heat sinks for bottom crust of a molten pool or for top crust of a molten pool.

W1(I) RELAP5 control volume located just above fuel rod.

W2(I) RELAP5 control volume located just below fuel rod.

A18.1.6 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card is required for fuel rod components and may not be input for RESTART calculations. It specifies the RELAP5 hydraulic volumes that provide the boundary conditions for the core component. A hydraulic volume must be specified for each axial node of the component, but the same hydraulic volume may be specified for a number of axial nodes. The style of this card, specifying a volume number and an increment, has been designed to match the style RELAP5 uses to specify left and right boundary conditions for the heat structures. The user is referred to Cards 1CCCG501, in the RELAP5 heat structure specification, for further information.

W1(I) RELAP5 control volume number. This word specifies the hydrodynamic control volume number (of the form CCCNN0000) associated with the surface of this component. One volume number must be specified for each axial node of the component, starting with the bottom node (Node 1).

W2(I) Increment. This word (of the form NN0000) and W1 of this card are treated differently from the standard sequential expansion. W1 applies to the first axial node within a set. The increment is applied to W1 to obtain the volume connected to the next axial node. The increment is repeated up to the axial node identified by W3. W1 of the next set applies to the next axial node, and increments are applied as for the first set. The increment may be zero or nonzero, positive or negative.

W3(I) Axial node.

A18.1.7 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for fuel rod components and may not be input for RESTART calculations. This card specifies the radial nodalization. To correctly interpret the nodalization, all numbers for a specific axial node must be specified with a single card number. Use continuation cards if necessary. The radial nodalization may be specified by either of two formats, but not both.

Format 1

Specify the number of intervals to be used across each material. The code will divide the radial distance across each material into the number of equally spaced mesh intervals specified. The number of radial nodes will be n+1, which is the total number of intervals plus one. The maximum number of radial nodes is twenty.

W1(I) Number of equally spaced intervals across fuel.

W2(I) Number of intervals across gap. One interval is recommended.

W3(I) Number of equally spaced intervals across cladding.

W4(I) Axial node number.

Format 2

Specify the radial position of each radial node for each axial node. In this format, the user must be careful to input the same number of radial nodes for each axial node, although the position of the radial nodes may be changed for each axial node. The maximum number of radial nodes is twenty.

W1(R) Radius to radial node 1 (m, ft). Enter pellet center radius of 0.0.

WN(R) Radius to radial node N (m, ft.). Enter radial node N. Radial nodes must be placed at least at the material interfaces (i.e., fuel pellet radius, and cladding inner radius). Radial nodes must be entered in ascending order and end with the last node placed on the cladding outer surface.

WN+1(I) Axial node.

A18.1.8 Cards 40CC0601 through 40CC0699, Initial Temperatures

This card is required for fuel rod components, and may not be changed on RESTART calculations.

W1 (R) Temperature (K, °F). Initial temperature at Radial Node 1. The range is 300 K $\leq$ x $\leq$ 3,123 K.

WN (R) Temperature N (K, °F). Enter an initial temperature for each radial node to radial node N, which is the last radial node. The range is 300 K $\leq$ x $\leq$ 3,123 K.

WN+1(I) Axial node. Input temperature at each radial node.

A18.1.9 Card 40CC0801 through 40CC0899, Material Specification

This card is optional for NEW, and may not be changed on RESTART calculations. The user may specify material indices for the components. At least three material indices should be input.

W1(I) Material index for material layer closest to center of rod.

W2(I) Material index for next material layer.

WN(I) Material index for nth material layer.

The defaults for a fuel rod component are UO_2(index=6), fuel-cladding gap (index=9), and Zircaloy (index=1). Refer to Table A17-3 for a list of material indices.

A18.1.10 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems, and specifies the fraction of total core power which is generated in this component.

The approach to specify power is as follows. First, a total core time-dependent power is specified (Section A17.1.9). Then a component power multiplier (this card) is used to determine the fraction of core power deposited in this component. The power in a single fuel rod can then be determined by dividing the component power by the number of fuel rods represented by this component. The linear heat generation rate at an individual axial node is determined by multiplying the rod power by an axial power profile factor (Section A18.1.11 & Section A18.1.12) and dividing by the axial node length. The power density at a specific radial node can then be determined by multiplying the local linear heat generation rate by the radial power factor (Section A18.1.13) and dividing by the cross-sectional area associated with that radial node.

W1(R) Fraction. This is the fraction of the core power in this component.

The range for this power multiplier is $0.0 \leq x \leq 1.0$, and the default is 0.0.

A18.1.11 Card 40CC13P0, Axial Power Profile Time

In the card number, "P" is axial power profile number (start with Number 1).

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) End time for which this axial power profile applies (s).

A18.1.12 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

Card numbering is specified similarly to the previous card, with "P" in the card number indicating the axial power profile number. This information is required for each profile and must be specified for each axial node of the component. This input specifies the fraction of rod power which is deposited at the axial node. The axial power fraction will be normalized over the length of the component.

W1... (R) Axial power factor at axial nodes.

The range is $0.1 \leq x \leq 1.4$, and the default is 1.0.

A18.1.13 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is required for NEW problems and cannot be input for RESTART problems. The radial power factor is used to determine the power density at each radial node, based upon the local heat generation rate.

W1(R) Radial power factor.

W2(I) Radial node at which W1(R) applies.

The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$, and the default power factor is 1.0.

A18.1.14 Card 40CC1500, Shutdown Time and Fuel Density

This card is required for NEW problems and cannot be input for RESTART problems.

W1(R) Time of reactor shutdown (s). This word is required. If fuel rod power is being calculated by the RELAP5 reactor kinetics model (W2 = kinetics on Card 40000600), then W1 = 1×10^8 s.

W2(R) Fraction of fuel theoretical density. This word is required.

The range of the fraction of fuel theoretical density is $0.94 \leq x \leq 0.96$.

A18.1.15 Cards 40CC1601 through 40CC1699, Previous Power History

This card is optional for NEW problems and may not be changed on RESTART problems. A prior power history is required to initialize the fission product inventory (PARAGRASS). It is assumed that either a prior power history or the initial fission product inventory (see next card) will be specified prior to enabling the PARAGRASS calculation.

The 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. Time in this table is referenced to the start of the operation of the reactor and not to the start of the time in the transient analysis.

W1(R) Power history (W/m^3). The range is $40.57 \times 10^6 \frac{W}{m^3} \leq x \leq 279.3 \times 10^6 \frac{W}{m^3}$.

W2(R) Time (s).

A18.1.16 Card 40CC2000, Fission Products Tracked by PARAGRASS Model

This card is optional for fuel rod components and may not be input for RESTART calculations. This card is entered when initial inventory of fission products is not to be calculated by the code based on prior power history.

W1... (A) Species name. Enter the species (xe, kr, cs, i) to be tracked.

A18.1.17 Cards 40CC2001 through 40CC2099, PARAGRASS Species Mass

This card is required only if Card 40CC2000 above is entered.

W1(R) Mass of species (kg, lb/m). Enter the initial mass of the first species specified on Card 40CC2000.

WN(R) Mass of species N (kg, lb/m). Enter the initial mass of the next species specified on Card 40CC2000 and repeat until all species masses specified on Card 40CC2000 have been entered.

A18.1.18 Card 40CC2100, Fission Products to be Tracked by CORSOR Model

This card is optional and may not be changed on RESTART calculations.

W1... (A) Species name. Enter the species (te, zr, sr, fe, ru, zr*, ba) to be tracked.

A18.1.19 Cards 40CC2101 through 40CC2199, Initial Fuel Fission Product Mass

This card is required only if Card 40CC2100 above is present.

W1(R) Mass of species (kg, lb/m). Enter the initial mass of the first species specified on Card 40CC2100.

WN(R) Mass of species N (kg, lb/m). Enter the initial mass of the next species specified on Card 40CC2100 and repeat until all species masses specified have been entered.

A18.1.20 Card 40CC2200, Gap Fission Products

This card is optional and may not be changed on RESTART calculations. This card is normally omitted so that inventory of fission products in fuel-cladding gap is defined by the codes' fission gas release model.

W1... (A) Species name. Enter the species (xe, kr, cs, i, te) to be tracked.

A18.1.21 Cards 40CC2201 through 40CC2299, Initial Gap Fission Product Mass

This card is required only if Card 40CC2200 is present.

W1(R) Mass of species (kg, lb/m). Enter the initial mass of the first species specified on Card 40CC2200.

WN(R) Mass of species N (kg, lb/m). Enter the initial mass of the next species specified on Card 40CC2200 and repeat until all species masses specified have been entered.

A18.1.22 Card 40CC3000, Gas Internal Pressure

This card is required for NEW problems and cannot be input for RESTART problems.

W1(R) Helium gas as-fabricated inventory in an individual fuel rod in this component group (kg).

W2(R) Internal gas pressure in rod (Pa). (This value is used only to define a first guess of initial internal pressure for iteration procedure, so accurate values not required.)

A18.1.23 Cards 40CC3201 through 40CC3299, Time-Temperature-Pressure Profile

This card is optional for NEW problems. If omitted, no variation occurs in boundary conditions for calculating temperature distribution in fuel rod during burnup period before transient. This card cannot currently be input for RESTART problems. This card is normally omitted.

W1(R) Time (s). The time to which the axial surface temperature profile and fuel average hydrostatic pressure are used

W2(R) Cladding surface temperature (K).

W3(R) Fuel hydrostatic pressure (Pa).

A18.1.24 Card 40CC4000, Option Definition

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1(A) Keyword to identify optional model to be applied.

W2(A) Flag specifying whether to apply model. ('on' or 'off').

The default for each model is 'off'. See Table A18-1.

Table A18-1. Component optional models.

Keyword	Value	Meaning if 'ON'
limit	on / off	oxidation is limited due to rate of steam diffusion through hydrogen.

A18.1.25 Cards 40CC5101 through 40CC5199, Gap Conductance

This card is optional and may not be changed on RESTART. The intended use is to allow the SCDAP calculated steady-state temperature profile to better match an independent steady-state temperature profile by specifying the steady-state gap conductance. In other words, Cards 40CC5101 and 40CC5201 can be used to set the internal energy in fuel rods at the start of a transient to the internal energy calculated by a detailed steady-state analysis fuel rod code such as FRAPCON-3.[A-5] If this card is not entered, the gap conductance will be calculated by the code. Sequential expansion applies.

W1(R) Gap conductance at steady-state conditions just before start of transient ($W/m^2 \cdot K$, $Btu/s \cdot ft^2\ ^oF$)

W2(I) Axial node.

A18.1.26 Cards 40CC5201 through 40CC5299, Fuel Thermal Conductivity

This card is optional and may not be changed on RESTART. Sequential expansion applies.

W1(R) Fuel thermal conductivity multiplier. The default is 1.0.

W2(I) Axial node.

A18.2 Simulator Component

This input describes a group of electrically heated fuel rod simulators.

A18.2.1 Card 40CC0000, Simulator Component

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(A) Component name.

W2(A) Component type -- *cora*.

A18.2.2 Card 40CC0100, Number of Rods

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Number of rods.

W2(R) Rod pitch (m). The range is $0.0126\ m \leq x \leq 0.0187\ m$.

A18.2.3 Card 40CC0200, Simulator Rod Geometry

This card is required for NEW problems and cannot currently be input for RESTART problems. Two input variables are required. If appropriate, a third value may be specified.

W1(R) Plenum length (m, ft), the range is between 3% and 11% of the rod length.

W2(R) Plenum volume (m^3). The range is $0.0 < x \leq 0.000049\ m^3$.

W3(R) Lower plenum volume, if applicable (m^3, ft^3).

A18.2.4 Card 40CC0250, Upper Plenum Boundary Conditions

This card describes the source of sink temperature data to be used to model axial heat conduction calculations from the top of the simulator rod.

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1(A) Keyword. The default is no axial heat conduction is modeled.

control = sink temperature defined by control variable.

table = sink temperature define by general table.

W2(I) Upper boundary control variable or RELAP5 table number.

A18.2.5 Card 40CC0251, Lower Plenum Boundary Conditions

This card describes the source of sink temperature data to be used to model axial heat conduction calculations from the bottom of the simulator rod. This card is optional for NEW problems, and cannot currently be input for RESTART problems.

W1(A) Keyword. The default is no axial heat conduction is modeled.

control = sink temperature defined by control variable.

table = sink temperature define by general table.

W2(I) Lower boundary control variable or RELAP5 table number.

A18.2.6 Card 40CC0300, Heating Element

This card is required for all simulator components, and may not be specified on RESTART.

W1(R) Radius of tungsten (m, ft). The remaining words are required for special option 'cora' not equal to zero.

W2(R) Resistance in flexible cabling (OHMS). The remaining words are required for special option 'cora' > 0.

W3(R) Radius of Molybdenum (ft, m).

W4(I) Number of electrode zones.

A18.2.7 Cards 40CC0301 through 40CC0399, Simulator Dimensions

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Fuel pellet radius (m). The range is $0.00385\ m \leq x \leq 0.00685\ m$.

W2(R) Inner cladding radius (m). The range is $W1 < x < W3$ and $0.003935\ m \leq x \leq 0.00634\ m$.

W3(R) Outer cladding radius (m). The range is $\underline{W2} < x < \frac{W2\ \text{Card}\ 4CCC0100}{2}$ and $0.00457\ m \leq x \leq 0.00715\ m$.

W4(I) Axial node number.

A18.2.8 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 volume located above simulator rod.

W2(I) RELAP5 volume located below simulator rod.

A18.2.9 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 volume number. One volume number for each axial node, starting with Node 1.

A18.2.10 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for NEW problems and cannot currently be input for RESTART problems. The information may be entered in either Format 1 or 2, but not both.

Format 1

Specify the number of intervals to be used across each material. The code will divide the radial distance across each material into the number of equally spaced mesh intervals specified. The number of radial nodes will be n+1, which is the total number of intervals plus one.

W1(I) Number of equally spaced intervals across the fuel.

W2(I) Number of intervals across gap. One interval is recommended.

W3(I) Number of equally spaced nodes across the cladding.

W4(I) Axial node number.

Format 2

Specify the radial position of each radial node for each axial node. In this format, the user must be careful to input the same number of radial nodes for each axial node, although the position of the radial nodes may be changed for each axial node.

W1(R) Radius to radial node 1 (m, ft). Enter pellet center radius of 0.0.

WN(R) Radius to radial node N (m, ft.). Enter radial node N. Radial nodes must be placed at least at the material interfaces (i.e., fuel pellet radius, and cladding inner radius). Radial nodes must be entered in ascending order and end with the last node placed on the cladding outer surface.

WN+1(I) Axial node.

A18.2.11 Cards 40CC0601 through 40CC0699, Initial Temperatures

These cards use both axial and radial self-expansion. They are required for NEW problems and cannot currently be input for RESTART problems.

W1... (R) Initial temperature at radial node 1 (K). The range is 300 K $\leq$ x $\leq$ 3,123 K.

A18.2.12 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems, and specifies the fraction of total core power which is generated in this component.

The approach to specify power is as follows. First, a total core time-dependent power is specified (Section A17.1.9). Then a component power multiplier (this card) is used to determine the fraction of core power deposited in this fraction. The power in a single simulator can then be determined by dividing the component power by the number of simulators represented by this component. The linear heat generation rate at an individual axial node is determined by multiplying the rod power by an axial power profile factor (Section A18.2.13 & Section A18.2.14) and dividing by the axial node length. The power density at a specific radial node can then be determined by multiplying the local linear heat generation rate by the radial power factor (Section A18.2.15) and dividing by the cross-sectional area associated with that radial node.

W1(R) Fraction. This is the fraction of the core power in this component.

The range for this power multiplier is $0.0 \leq x \leq 1.0$, and the default is 0.0.

A18.2.13 Card 40CC13P0, Axial Power Profile Time

In the card number, "P" is axial power profile number (start with Number 1).

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) End time for which this axial power profile applies (s).

A18.2.14 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

Card numbering is specified similarly to the previous card, with "P" in the card number indicating the axial power profile number. This information is required for each profile and must be specified for each axial node of the component. This input specifies the fraction of rod power which is deposited at the axial node. The axial power fraction will be normalized over the length of the component.

W1... (R) Axial power factor at axial nodes.

The range is $0.1 \leq x \leq 1.4$, and the default is 1.0.

A18.2.15 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is required for NEW problems and cannot currently be input for RESTART problems. The radial power factor is used to determine the power density at each radial node, based upon the local heat generation rate.

W1(R) Radial power factor.

W2(I) Radial node at which W1(R) applies.

The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$, and the default power factor is 1.0.

A18.2.16 Card 40CC1500, Shutdown Time and Fuel Density

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Time of reactor shutdown (s). This word is required. In general, W1 = 1. x 10^8; this large value for W1 assures correct value for decay heat from RELAP5 reactor kinetics model.

W2(R) Fraction of fuel theoretical density. This word is required.

The range of the faction of fuel theoretical density is $0.94 \leq x \leq 0.96$.

A18.2.17 Card 40CC9000, Volume of External Volumes

This card is optional for NEW problems and cannot currently be input for RESTART problems. This card specifies the volume of external volumes which may be attached to the void volume of electrical heater rods.

W1... (R) Volume of external volumes (m^3, ft^3).

Up to 10 external volumes may be specified.

A18.2.18 Cards 40CC9001 through 40CC9099, Temperature History of External Volumes

This card is optional for NEW problems and cannot currently be input for RESTART problems. This card is used to specify the temperature history of external volumes which were specified in Section A18.2.17. The format of the card is to specify one point in the time-dependent temperature history of each volume.

W1(R) Time (s).

W2... (R) Temperature of external volume.

Word 2 is repeated for each external volume specified by card 40CC9000. A maximum of 10 time points may be specified.

A18.3 PWR Control Rod Component

A18.3.1 Card 40CC0000, PWR Component Identification

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(A) Component name.

W2(A) Component type -- control.

A18.3.2 Card 40CC0100, Number of Rods

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Number of rods. The range is $1 \leq x$.

W2(R) Control rod pitch (m). If a fuel rod component is entered, the control rod pitch should be equal to the pitch of the fuel rod, if it is in the same bundle.

A18.3.3 Card 40CC0300, Materials

This card is optional for NEW problems and cannot currently be input for RESTART problems. This card is intended to specify materials for non-standard control rod configurations. The default materials are control rod absorber material (Ag-In-Cd for pwr's, B_4C for bwr's), stainless steel, and zircaloy. If this card is present, three materials are specified by using the material indices specified in Table A17-3.

W1(I) Absorber material index. Material index for control rod absorber.

W2(I) Sheath material index. Material index for control rod sheath.

A gap is assumed between the second and third materials.

W3(I) Guide tube material index. Material index for guide tube.

A18.3.4 Card 40CC0301 through 40CC0399, Geometry

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Outer radius of control rod absorber (m, ft). The range is $0.0 < x < W2$.

W2(R) Outer radius of stainless steel sheath (m). The range is $W1 < x \leq W3$.

W3(R) Inner radius of zircaloy guide tube (m). The range is $W2 \leq x < W4$.

W4(R) Outer radius of zircaloy guide tube (m).

W5(I) Axial node for sequential expansion.

A18.3.5 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 control volume located above control rod.

W2(I) RELAP5 control volume located below control rod.

A18.3.6 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card specifies the RELAP5 hydrodynamic control volume which provides the boundary conditions for the control rod. A hydrodynamic volume must be specified for each axial node of the component. The style of this card, i.e., specifying a hydrodynamic volume number and an increment, has been chosen to match the style used by RELAP5 to specify heat structure left and right boundary conditions. This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 volume number.

W2(I) Increment.

W3(I) Axial node. Sequential expansion applies.

A18.3.7 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for NEW problems and cannot currently be input for RESTART problems.

This card may be entered in either Format 1 or 2, but you may not mix formats. A minimum of five radial nodes are required. Up to 20 radial nodes may be used. Nodes must be entered in consecutive order beginning with the first node at r = 0. Other required radial nodes must be placed at the outer radius of absorber material, the outer radius of stainless steel sheath, and the inner and outer radius of the zircaloy guide tube.

Format 1:

W1(I) Number of equally spaced intervals across the absorber material.

W2(I) Number of equally spaced intervals across the stainless steel sheath.

W3(I) Number of equally spaced nodes across the zircaloy guide tube.

W4(I) Axial node number for sequential expansion.

Format 2:

W1(R) Radial mesh spacing (m). Radial dimension of Node 1.

WN(R) Radial mesh spacing (m). Radial dimension of Node N.

WN+1(I) Axial node number.

Sequential expansion applies to this input.

A18.3.8 Cards 40CC0601 through 40CC0699, Initial Temperatures

This card is required for control rod components and may not be changed on RESTART calculations.

W1(R) Temperature (K, ^{o}F). Initial temperature at Radial Node 1. The range is 300 K $\leq$ x $\leq$ 3,123 K.

WN(R) Temperature N (K, ^{o}F). Enter an initial temperature for each radial node to radial node n, which is the last radial node. The range is 300 K $\leq$ x $\leq$ 3,123 K.

WN+1(I) Axial node.

A18.3.9 Card 40CC0700, Internal Gas Pressure

This card is optional for either NEW or RESTART calculations. It specifies the internal gas pressure of the control rod.

W1(R) Internal Gas Pressure (Pa, psi)

Default is 0.0 Pa.

A18.3.10 Cards 40CC1100, Power Input

These cards are optional for either NEW or RESTART calculations. Refer to Section A18.1.10, Section A18.1.11, Section A18.1.12, and Section A18.1.13 for directions on entering control rod power. If no power input cards are used, then a power multipler of 0.0 is applied to a uniform radial and axial power profile.

A18.4 BWR Control Rods

A18.4.1 Card 40CC0000, Component Identification

W1(A) Component name. Descriptive of role in system.

W2(A) Component type -- bwr.

A18.4.2 Card 40CC0100, Number of Rods

W1(I) Number of rods in component.

A18.4.3 Cards 40CC0301 through 40CC0399, Geometry

W1(R) Outer radii for B_4C absorber. The range is 0.0 m < x < W2.

W2(R) Stainless steel cladding outer radii. The range is W1 < x < 0.00935 m.

W3(I) Axial number for sequential expansion.

A18.4.4 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and may not be changed for RESTART problems.

W1(I) RELAP5 volume located above BWR rod.

W2(I) RELAP5 volume located below BWR rod.

A18.4.5 Cards 40CC0401 through 40CC0499, Hydraulic Volumes

This card is required for NEW problems and may not be changed for RESTART problems.

W1(I) RELAP5 volume number. One word for each axial node.

A18.4.6 Cards 40CC0601 through 40CC0699, Initial Temperatures

This card is required for NEW problems and may not be changed for RESTART problems.

W1(R) B_4C absorber initial temperature. The range is 300 K $\leq$ x $\leq$ 1,723 K.

W2(R) Stainless steel cladding initial temperature. The range is 300 K $\leq$ x $\leq$ 1,723 K.

A18.5 BWR Control Blade/Channel Box Component

These cards contain physical dimensions, hydraulic information, initial conditions, and radial spreading information for each BWR blade/channel box component.

A18.5.1 Card 4CCC0000, Component Name and Type

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(A) Component name. This is a descriptive name selected by the user. On most computers, there is an eight-character limit.

W2(A) Component type. Specify the keyword "bladebox."

A18.5.2 Card 4CCC0100, Number of Individual Structures

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(I) Number of individual BWR blade/box structures in this component. An individual blade/box structure consists of half of a control blade divided along the centerline of the row of absorber tubes (other half is symmetric) with length equal to Word 1 on Card 4CCC0300 and a channel box with length equal to the sum of Words 1 and 2 on Card 4CCC0300. The total mass represented by this component is equal to the mass of an individual blade/box structure multiplied by the value on this card. The range is $\underline{1} \leq x$.

A18.5.3 Card 4CCC0200, Radial Dimensions

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(I) Number of absorber tubes in a control blade wing. This variable is used only to specify the relative proportions of a control blade wing. The length (wetted perimeter) of a control blade is specified in Word 1 on Card 4CCC0300. The range is $\underline{1} \leq x$.

W2(R) Inside diameter of stainless steel absorber tube (m, ft). The range is $\underline{0.0} \leq x \leq 0.0070$ m.

W3(R) Thickness of stainless steel absorber tube wall (m, ft). The range is $\underline{0.0} \leq x \leq 0.0013$ m.

W4(R) Thickness of gap between absorber tube and control blade sheath (m, ft). Specify a thickness of 0.0 to eliminate the additional thermal resistance associated with this gap. The range is $\underline{0.0} \leq x \leq 0.0003$ m.

W5(R) Thickness of stainless steel control blade sheath (m, ft). The range is $\underline{0.0} \leq x \leq 0.0030$ m.

W6(R) Distance between control blade and channel box (m, ft). The range is $\underline{0.0} \leq x \leq 0.0100$ m.

W7(R) Thickness of zircaloy channel box wall (m, ft). The range is $\underline{0.0} \leq x \leq 0.0050$ m.

W8(R) Distance between channel box and first row of fuel rods (m, ft). The range is $\underline{0.0} \leq x \leq 0.0080$ m.

A18.5.4 Card 4CCC0300, Blade/Box Lengths and View Factors

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(R) Length (wetted perimeter) of control blade and channel box segment number 1 (m, ft). The range is $\underline{0.0}$ m $\leq$ x.

W2(R) Length (wetted perimeter) of channel box segment 2 (m, ft). This is the portion of the channel box not adjacent to a control blade. The range is $\underline{0.0}$ m $\leq$ x.

W3(R) Geometric view factor from channel box segment 1 to control blade. This factor is based on the area of channel box segment 1. The range is $\underline{0.0} \leq x \leq \underline{1.0}$.

W4(R) Geometric view factor from channel box segment 2 to control blade. This factor is based on the area of channel box segment 2. The range is $\underline{0.0} \leq x \leq \underline{1.0}$.

A18.5.5 Card 4CCC0400, Upper and Lower Volume Numbers

This card is required for NEW problems and cannot currently be changed for RESTART problems

W1(I) Volume number of hydraulic volume just above the fuel bundle volumes specified in Word 1 on Cards 4CCC0401 through 4CCC0499.

W2(I) Volume number of hydraulic volume just below the fuel bundle volumes specified in Word 1 on Cards 4CCC0401 through 4CCC0499.

A18.5.6 Cards 4CCC0401 through 4CCC0499, Volume Connections

These cards are required for NEW problems and cannot currently be changed for RESTART problems. A modified sequential expansion format is used where Words 1 and 2 are incremented by Word 3.

W1(I) Volume number of hydraulic volume connected to fuel bundle side of channel box axial node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W2(I) Volume number of hydraulic volume connected to control blade axial node and interstitial side of channel box axial node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W3(I) Volume number increment. This increment may be positive, negative, or zero.

W4(I) Axial node number used for the sequential expansion. The node numbers specified on these cards must be in ascending, but not necessarily consecutive, order. The range is $\underline{1} \leq x \leq \underline{N}$, where N is the number of axial nodes specified on Card 40000100.

A18.5.7 Card 4CCC0500, Initial Oxide Thicknesses

This card is optional for NEW problems and cannot currently be changed for RESTART problems.

W1(R) Initial thickness of ZrO_2 layer on fuel bundle side of channel box (m, ft). The thicknesses for the two channel box segments and all axial nodes are identical. The default is 0.0 m and the range is 0.0 m $\leq$ x $\leq$ 0.5*W7 on Card 4CCC0200.

W2(R) Initial thickness of ZrO_2 layer on interstitial side of channel box (m, ft). The thicknesses for the two channel box segments and all axial nodes are identical. The default is 0.0 m and the range is 0.0 m $\leq$ x $\leq$ 0.5*W7 on Card 4CCC0200.

W3(R) Initial thickness of stainless steel oxide layer on control blade surfaces (m, ft). The thicknesses for all axial nodes are identical. The default is 0.0 m and the range is 0.0 m $\leq$ x $\leq$ MIN (W3 on Card 4CCC0200, 0.5*W5 on Card 4CCC0200).

A18.5.8 Cards 4CCC0601 through 4CCC0699, Initial Temperatures

This card is required for NEW problems and cannot currently be changed for RESTART problems. A sequential expansion format is used.

W1(R) Initial temperature of control blade (K, °F). The temperatures of the three control blade radial nodes are identical at each axial node. The range is 300 $\leq$ x $\leq$ 1,505 K.

W2(R) Initial temperature of channel box (K, °F). The temperatures of the two channel box segments are identical at each axial node. The range is 300 $\leq$ x $\leq$ 1,523 K.

W3(I) Axial node number used for the sequential expansion. The node numbers specified on these cards must be in ascending, but not necessarily consecutive, order. The range is 1 $\leq$ x $\leq$ N, where N is the number of axial nodes specified on Card 40000100.

A18.5.9 Cards 4CCC0701 through 4CCC0799, Segment 1 Radial Spreading

These cards are optional for NEW problems and cannot currently be changed for RESTART problems. Specify one card for each component that can receive molten material from channel box segment 1. Omit this card if there are no components that can receive molten material from channel box segment 1.

W1(I) Component number of fuel rod or electrically-heated simulator rod component that can receive molten material from channel box segment 1.

W2(R) Mass fraction of molten material from channel box segment 1 received by component specified in Word 1. The range for individual mass fractions is 1.0e-6 $\leq$ x $\leq$ 1.0. The sum of all mass fractions on Cards 4CCC0701 through 4CCC0799 must be unity.

A18.5.10 Cards 4CCC0801 through 4CCC0899, Segment 2 Radial Spreading

These cards are optional for NEW problems and cannot currently be changed for RESTART problems. Specify one card for each component that can receive molten material from channel box segment 2. Omit this card if there are no components that can receive molten material from channel box segment 2.

W1(I) Component number of fuel rod or electrically-heated simulator rod component that can receive molten material from channel box segment 2.

W2(R) Mass fraction of molten material from channel box segment 2 received by component specified in Word 1. The range for individual mass fractions is $\underline{1.0e\text{-}6} \leq \underline{x} \leq \underline{1.0}$. The sum of all mass fractions on Cards 4CCC0801 through 4CCC0899 must be unity.

A18.6 Shroud Component

The shroud component represents structures such as an insulated shroud around a fuel assembly in a test reactor and the reflector around a reactor core.

A18.6.1 Card 40CC0000, Component Name

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(A) Component name.

W2(A) Keyword - *shroud.*

A18.6.2 Card 40CC0100, Number of Shroud Configurations

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Number of shrouds.

A18.6.3 Card 40CC0200, Shroud Geometry

This card is required for NEW problems and cannot currently be input for RESTART problems. Word 1 is required.

W1(R) Perimeter of inner shroud surface (m, ft). Required input.

A18.6.4 Card 40CC0300, Indices of Materials

This card is required for NEW problems and cannot currently be input for RESTART problems. A shroud component must have at least three materials (even if all three have the same index), and a maximum number defined by the parameter 'ndmatr' in common block 'scddat'. As transmitted by the INEL the maximum number of materials is ten.

W1... (I) Material index. Material layers beginning with outer layer (radial node 1 is at outer edge of outer layer). Indices from Table A17-3. The default materials are Zr, ZrO_2, and Zr.

A18.6.5 Cards 40CC0301 through 40CC0399, Material Layer Radial Coordinates

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1... (R) Coordinate of outer surface of each material layer (m). Assuming the outer surface of shroud has coordinate of "0.0", enter the remaining coordinates in consecutive order. Each material interface must fall on a mesh point.

A18.6.6 Card 40CC0400, Upper and Lower Hydrodynamic Volumes

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 control volume just above the shroud.

W2(I) RELAP5 control volume just below the shroud.

A18.6.7 Cards 40CC0401 through 40CC0499, Volume Number of Hydrodynamic Volumes

This card defines the RELAP5 control volume which provides the boundary conditions for the component. There are usually two control volumes defined for each axial node. However, for the shroud component only, there is the capability to specify a heat flux boundary condition on the outside of the shroud. This is done by specifying zero (0) for the outer hydrodynamic volume and then including Card 40CC8000. Refer to Cards 40CC8N01 through 40CC8N99, Heat Flux Boundary Condition Specifications for further information. This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) RELAP5 control volume number that is in contact with the inner surface of the shroud. This inner surface overlays the maximum radial node number for the shroud.

W2(I) RELAP5 control volume number that is in contact with the outer surface of the shroud. This outer surface overlays radial node number 1. Enter "zero" if adiabatic boundary at the outer surface of shroud (outer surface is at radial node 1).

W3(I) Increment.

W4(I) Axial node number.

A18.6.8 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card specifies the location of radial mesh points across the component. A heat conduction solution is performed at each radial mesh point. The radial mesh points are defined on a line perpendicular to outer surface of shroud and with the radial coordinates increasing in value in the direction pointing from outer surface to inner surface The radial coordinate of 0.0 is on outer surface of shroud and radial coordinate on inner surface of shroud is equal to wall thickness of shroud.

Error trapping includes checks to ensure that the first radial mesh point is located at 0.0, that the mesh points are in consecutive order, and that there is a mesh point at each material interface. For the first axial node only, all radial nodes must be on one card number, even if it is necessary to use continuation cards. The maximum number of radial nodes is twenty.

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1... (R) Input "0.0".

WN(R) Distance from outer surface of shroud to radial node N (m).

WN+1(I) Axial node number.

A18.6.9 Cards 40CC0601 through 40CC0699, Initial Temperature

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) Initial temperature at radial node 1(K).

WN(R) Initial temperature at radial node N (K).

WN+1(I) Axial node number. The range is 300 K $\leq$ x $\leq$ 2,033 K[a]

A18.6.10 Card 40CC0800, Embedded Flow Channel Geometry

This card allows the user to model embedded hydrodynamic flow channels within the SHROUD component. This card is optional for NEW problems, and cannot currently be input for RESTART problems.

W1(I) Number of the interval between radial nodes that contains embedded hydrodynamic flow channels, where internal number 1 is between radial nodes 1 and 2.

A18.6.11 Card 40CC0801 through 40CC0899, Embedded Flow Channel Hydrodynamics

If Card 40CC0800 is entered then this card is required. If not, then this card is not used.

W1(I) Hydrodynamic volume, linked to embedded flow channel at the lowest axial node.

W2(I) Increment. Number to be added to W1 to form hydrodynamic volumes for each volume above W1.

A18.6.12 Card 40CC0900, Molten Pool

This card is optional on either NEW or RESTART problems; and if entered, controls the interaction between the shroud component and a molten pool.

W1(I) Molten pool interaction flag; optional flag to determine whether or not shroud interfaces with molten pool. If "0" is entered then no interaction is modeled, if "1" is entered, then interaction is modeled. Default is to model shroud interaction with molten pool.

W2(R) Threshold thickness (m, ft). Threshold thickness of liquefied structural material for breakup of crust of solidified molten pool material at periphery of core. If maximum possible rate of melting of structure at periphery of core due to interaction with molten pool is to be modeled, this word should be 0.0, if minimum, this word should be 1.0.

A18.6.13 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems, and specifies the fraction of total core power which is generated in this component.

The approach to specify power is as follows. First, a total core time-dependent power is specified

a. Upper limit based on the melting point of zircaloy.

(Section A17.1.9). Then a component power multiplier (this card) is used to determine the fraction of core power deposited in this fraction. The power in a single shroud can then be determined by dividing the component power by the number of shrouds represented by this component. The linear heat generation rate at an individual axial node is determined by multiplying the shroud power by an axial power profile factor (Section A18.6.14 & Section A18.6.15) and dividing by the axial node length. The power density at a specific radial node can then be determined by multiplying the local linear heat generation rate by the radial power factor (Section A18.6.16) and dividing by the cross-sectional area associated with that radial node.

W1(R) Fraction. This is the fraction of the core power in this component.

The range for this power multiplier is $0.0 \leq x \leq 1.0$, and the default is 0.0.

A18.6.14 Card 40CC13P0, Axial Power Profile Time

In the card number, "P" is axial power profile number (start with Number 1).

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(R) End time for which this axial power profile applies (s).

A18.6.15 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

Card numbering is specified similarly to the previous card, with "P" in the card number indicating the axial power profile number. This information is required for each profile and must be specified for each axial node of the component. This input specifies the fraction of rod power which is deposited at the axial node. The axial power fraction will be normalized over the length of the component.

W1... (R) Axial power factor at axial nodes.

The range is $0.1 \leq x \leq 1.4$, and the default is 1.0.

A18.6.16 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is optional for NEW problems and cannot currently be input for RESTART problems. The radial power factor is used to determine the power density at each radial node, based upon the local heat generation rate.

W1(R) Radial power factor.

W2(I) Radial node at which W1(R) applies.

The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$, and the default power factor is 1.0.

A18.6.17 Card 40CC5000, Shroud Insulation and Failure

This card is required for NEW problems and cannot currently be input for RESTART problems.

W1(I) Index of material that has its insulation quality degraded after shroud fails. This index

must be one of the indexes on Card 40CC0300.

W2(R) Time at which shroud fails. After the time of shroud failure, both sides of the metallic Zr liner on the inside surface of the shroud are calculated to oxidize. In addition, a multiplier is applied to thermal conductivity of the shroud insulation.

W3(R) Multiplier on thermal conductivity for failed shroud.

A18.6.18 Cards 40CC8N01 through 40CC8N99, Heat Flux Boundary Condition

These cards are used to specify a table of heat flux as a function of time, to be applied on the outer surface of the shroud, and are read if, and only if, the hydrodynamic volume used for the outer surface boundary condition is specified as zero (0). The '100s' digit, shown as 'N' in the card number is used to determine the heat flux profile number for n-th time point, in that the first profile should be entered on Cards 40CC8101 through 40CC8199, and the second on 40CC8201 through 40CC8299, and so forth.

There are two possible formats for this card. In the first, a time is entered as Word 1, and a heat flux is entered as Word 2, with no additional input. In this format the specified heat flux will be applied to all axial nodes of the component. In the second format, a time is entered as Word 1, and a series of heat fluxes are entered as Words 2 through N, where N is the number of axial nodes plus 1. In this format, Word 2 specifies the heat flux to be applied at Node 1, Word 3 specifies that at Node 2, and so forth.

This card is required for NEW problems, and cannot currently be input for RESTART problems.

W1(R) Time (s).

W2(R) Heat flux (W/m^2, $Btu/s\text{-}ft^2$).

A18.7 ATR Fuel Element

A18.7.1 Card 40CC0000, Fuel Element Component

This card is required for NEW problems and may not currently be changed on restart.

W1(A) Component name.

W2(A) Keyword - *atr*.

A18.7.2 Card 40CC0100, Number and Perimeter of Fuel Element

This card is required for NEW problems and may not currently be changed on RESTART.

W1(A) Number of fuel elements.

W2(R) Average fuel element perimeter (m).

A18.7.3 Card 40CC0400, Upper and Lower Hydraulic Volumes

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) RELAP5 volume above the fuel element.

W2(I) RELAP5 volume below the fuel element.

A18.7.4 Cards 40CC0401 through 40CC0450, Inner Hydraulic Volumes

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) RELAP5 volume numbers connected to the inner surface.

A18.7.5 Cards 40CC0451 through 40CC0499, Outer Hydraulic Volumes

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) RELAP5 volume numbers connected to the outer surface.

A18.7.6 Cards 40CC0501 through 40CC0599, Radial Mesh Spacing

This card is required for NEW problems and may not currently be changed on RESTART.

W1(R) Radial node spacing (m). Starting from the outer surface. Uses axial self-expansion.

A18.7.7 Cards 40CC0601 through 40CC0699, Initial Temperature Distribution

This card is required for NEW problems and may not currently be changed on RESTART.

W1(R) Initial temperature (K). For each radial node at present axial node. Uses axial and radial self-expansion. The range is $300\ K \leq x \leq 913\ K$.[a]

A18.7.8 Cards 40CC0801 through 40CC0899, Material Types

This card is required for NEW problems and may not currently be changed on RESTART.

W1(I) Material index. The first and last index numbers must be 15 or 16. Also, the number of material indexes specified must equal the number of material layers specified on the next card. Must be constant with axial nodes, the numbers are used for consistency.

A18.7.9 Cards 40CC0901 through 40CC0999, Material Layer Spacing

W1(R) Material layer spacing (m). Starting from outer layer. Must be constant with axial nodes, the numbers are used for consistency.

A18.7.10 Card 40CC1100, Power Multiplier

This card is optional for NEW and RESTART problems. If not specified the component power is set to zero. One and only one word may be entered when power is specified with either a general table or control variable, and three words are required when the power is specified by reactor kinetics. See Section

a. Based on the melting point of aluminum.

A17.1.9

W1(R) Fraction. If power is specified with 'table' or 'cntlvar', this is the fraction of the core power in this component. If power is specified with 'kinetics' this is the fraction of the fission power in component 'CC'.

W2(R) If 'kinetics', fraction of fission product decay power in component 'CC'.

W3(R) If 'kinetics', fraction of actinide decay power in component 'CC'.

The range for all fractions are $0.0 \leq x \leq 1.0$

A18.7.11 Card 40CC13P0, Axial Power Profile Time

P axial power profile number. Start with Number 1. This card is required for NEW problems and may not currently be input for RESTART problems.

W1(R) End time (s).

A18.7.12 Cards 40CC13P1 through 40CC13P9, Axial Power Profile Data

This card is required for NEW problems and may not currently be changed on RESTART. This information is required for each profile.

W1... (R) Axial power factor at axial nodes. P axial power profile number. The range is $0.1 \leq x \leq 1.4$.

A18.7.13 Cards 40CC1401 through 40CC1499, Radial Power Profile

This card is required for NEW problem and may not currently be input for RESTART problems.

W1(R) Radial power factor.

W2(I) Radial node at pellet surface. The last radial node that is input must align with the outer radius of the fuel pellet. The range is $x \leq 20$.

A18.7.14 Card 40CC1500, Shutdown Time and Fuel Density

This card is optional for NEW problems and may not currently be input for RESTART problems.

W1(R) Time of shutdown (s). This card is required. Default is 1.0e8.

W2(R) Fraction of fuel theoretical density. This card is required. The range is $0.94 \leq x \leq 0.96$. Default is 0.95.

W3(R) U^{239} production per fission. This word is required only if the power for this component is computed using the decay option.

W4(R) U^{235} enrichment. This word is required only if the power for this component is computed using the decay option.

If the power data option on Card 1000 is 'decay,' then you must input either the 15XX Cards, or the 1600, 17XX, and 18XX Card series.

A18.7.15 Cards 40CC1601 through 40CC1699, Previous Power History

This card is optional for NEW problems and may not currently be input for RESTART problems. A prior power history can be defined for the decay heat calculation and is required to initialize the fission product inventory (PARAGRASS). The 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. Time in this table is referenced to the start of the operation of the reactor and not to the start of the transient analysis.

W1(R) Power history (W/m^3). The range is $40.57\times10^6\frac{W}{m^3} \le x \le 279.3\times10^6\frac{W}{m^3}$.

W2(R) Time (s).

A18.7.16 Cards 40CC2101 through 40CC2199, Fission Product Masses

This card is required.

W1(R) Initial mass of fission product NN (kg).

W2(I) Axial node for sequential expansion.

A19. UPPER PLENUM STRUCTURE AND CORE PLATE MODEL

This section describes the input cards that are required when using the upper plenum structure (UPS) model and which also may be used in place of a RELAP5 heat structure to model the core plate below a reactor core. Each UPS input card begins with a card number of the general form 48SSTTNN, where SS represents the user-specified upper plenum structure number, TT represents the card type, and NN represents the card count. Word numbers (W1, W2, etc.) are utilized in the following discussion to promote better understanding of the input requirements, but they are not part of the input data.

UPS input values are specified on six cards (or card sets) that contain information about nodalization, physical dimensions, initial conditions, and hydraulic boundary conditions for each different upper plenum structure. As many as ten upper plenum structures can be used in an input deck; although this limit can be increased by changing the value of parameter NMUPD and recompiling SCDAP/RELAP5.

The UPS input data can be specified in SI or British units. The "Input Units" parameter (Word 1) on RELAP5 Card 102 designates the system of units for the input cards.

To assist the user, the input variables are compared with a range of typical values. If a range violation is encountered, either a warning message or an error message will be printed in the output file. A warning message allows the calculation to proceed, but an error message causes the calculation to terminate after the completion of input processing. The range for a particular input variable is identified in this section in the following format:

Normal type - Print warning message beginning with "$$$$$$$$"

$\underline{0.0} \leq x \leq 1.0$

Underline - Print error message beginning with "********"

A19.1 Card 48SS0000, Axial Levels

This card is required for NEW problems and cannot currently be changed for RESTART problems.

W1(I) Total number of axial levels. The range is $\underline{1} \leq x \leq \underline{15}$. The upper limit of 15 axial levels can be increased by changing the value of parameter NMUPAX and recompiling SCDAP/RELAP5.

A19.2 Cards 48SS0101 through 48SS0199, Mesh Data

These cards are required for NEW problems and cannot currently be changed for RESTART problems. For each axial level NN, there must be one Card 48SS01NN.

W1.. (R) Initial lengths of nodes along conduction path (m, ft). For each axial level, specify one word for each conduction node. The number of words on a card defines the total number of conduction nodes at that axial level. The first word is the initial length of the left (or bottom) node, and the last word is the initial length of the right (or top) node. The range for the total number of conduction nodes at an axial level is $\underline{1} \leq x \leq \underline{6}$. The range of the initial lengths of nodes is $\underline{1.0e\text{-}6\ m} \leq x$. The upper limit of 6 conduction nodes at an axial

level can be increased by changing the value of parameter NMUPCN and recompiling SCDAP/RELAP5.

A19.3 Cards 48SS0201 through 48SS0299, Surface and Relocation Data

These cards are required for NEW problems and cannot currently be changed for RESTART problems. A sequential expansion format is used.

W1(R) Heat transfer surface area (m^2, ft^2). The surface areas of the left (or bottom) and right (or top) nodes at an axial level are identical. The range is $\underline{0.0\ m^2} < x$.

W2(I) Flag indicating surface orientation. Specify 0 for a vertical orientation or 1 or 2 for a horizontal orientation. If a horizontal structure is located at an axial level directly below a vertical structure, then a flag of 1 indicates that the horizontal surface blocks downward relocation from only the right surface, and a flag of 2 indicates that the horizontal surface blocks downward relocation from both the left and right surfaces. The range is x = 0, 1, or 2.

W3(R) Height along vertical relocation path (m, ft). The heights of the left and right nodes at an axial level are identical. For a horizontal surface, this height must be specified, but is not used. The range is $\underline{1.0e\text{-}6\ m} \leq x$.

W4(I) Axial level used for sequential expansion. The axial levels specified on these cards must be in ascending, but not necessarily consecutive order. The range is $\underline{1} \leq x \leq \underline{N}$, where N is the total number of axial levels specified on Card 48SS0000.

A19.4 Card 48SS0300, Initial Oxide Thicknesses

This card is optional for NEW problems and cannot currently be changed for RESTART problems.

W1(R) Initial thickness of left (or bottom) oxide layer (m, ft). The thicknesses for all axial levels are identical. The default is 0.0 m and the range is $0.0\ m \leq x \leq N$ where N is the initial length (or half of the initial length when there is only one node at an axial level) of the smallest right (or top) node specified on Cards 48SS0101 through 48SS0199.

W2(R) Initial thickness of right (or top) oxide layer (m, ft). The thicknesses for all axial levels are identical. The default is 0.0 m and the range is $0.0\ m \leq x \leq N$ where N is the initial length (or half of the initial length when there is only one node at an axial level) of the smallest left (or bottom) node specified on Cards 48SS0101 through 48SS0199.

A19.5 Cards 48SS0401 through 48SS0499, Initial Temperatures

These cards are required for NEW problems and cannot currently be changed for RESTART problems. For each axial level nn, there must be one Card 48SS04NN.

W1.. (R) Initial temperatures of nodes (K, °F). For each axial level, specify one word for each conduction node defined on Cards 48SS0101 through 48SS0199. The first word on a card is the initial temperature of the left (or bottom) node, and the last word is the initial

temperature of the right (or top) node. The range is $\underline{300\ K} \leq x \leq \underline{N}$ where N is the melting temperature of the metal.

A19.6 Cards 48SS0501 through 48SS0599, Hydraulic Boundary Conditions

These cards are required for NEW problems, and cannot currently be changed for RESTART problems. A modified sequential expansion format is used where Words 1 and 2 are incremented by Word 3.

W1(I) Volume number of hydraulic volume adjacent to left (or bottom) node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W2(I) Volume number of hydraulic volume adjacent to right (or top) node. This is the first volume number used in the sequential expansion. Each subsequent volume number is generated by adding the increment specified in Word 3.

W3(I) Volume number increment. This increment may be positive, negative, or zero.

W4(I) Axial level used for sequential expansion. The axial levels specified on these cards must be in ascending, but not necessarily consecutive order. The range is $\underline{1} \leq x \leq \underline{N}$, where N is the total number of axial levels specified on Card 48SS0000.

A20. RADIATION HEAT TRANSFER

SCDAP/RELAP5 has the capability of modeling radiation heat transfer between a group of core components, as described in Volume 1. Each group, called an enclosure, typically consists of a separate hydrodynamic flow channel, and an array of various rods which exchange heat through radiation. If the SCDAP components are modeling a reactor core, then a radiation enclosure is normally defined for a rod bundle in each stack of RELAP5 control volumes that represent the fluid flowing through the reactor core.

A20.1 Radiation Enclosure Number

The radiation heat transfer input is detected by the presence of the two digits '49' at the beginning of the card. The next two digits, specified as 'NN' in the following input description, denote the radiation enclosure number.

A20.1.1 Card 49NN0000, Enclosure Components

This card is required for NEW problems and cannot currently be input for RESTART problems. The presence of this card triggers radiation heat transfer input processing for the next enclosure.

W1(A) Keyword '***bundle***'.

A20.2 User Specified View Factor and Path Length

Either the 1000 or 2000 series cards are needed, but not both. The 1000 series allows the user to specify radiation view factors and path lengths on input, while the 2000 series causes the view factors and path lengths to be automatically generated. The 1000 series cards must be used if the enclosure includes a BWR blade/box component.

A20.2.1 Card 49NN1000, Number of Components in Enclosure

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1.. (I) List of component numbers in the enclosure.

The last component number on this card, if it is a shroud component, is assumed to enclose the radiation heat transfer; this implies that all previous components listed, that are shrouds, will have their outer surfaces exposed to this enclosure, and the last component listed will have it's inner surface exposed to this enclosure.

A20.2.2 Cards 49NN1001 through 49NN1099, View Factors

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1.. (R) View factors.

This input should be considered a square matrix of view factors, where, for example, the third word of the second row is the view factor from the third component specified on Card 49NN1000 to the second component specified on Card 49NN1000.

A20.2.3 Cards 49NN1101 through 49NN1199, Path Length

This card is optional for NEW problems and cannot currently be input for RESTART problems.

W1.. (R) Radiation path lengths.

Just as in Card 49NN1001, this input should be considered a square matrix of radiation path lengths, where, for example, the third word of the second row is the path length from the third component specified on Card 49NN1000 to the second component specified on Card 49NN1000.

A20.3 Code Calculated View Factor and Path Length

A20.3.1 Card 49NN2000, Pitch of Rods

W1(R) Pitch (m). Pitch of rods in enclosure.

W2(I) Component number of shroud enclosing this enclosure. This word is optional, and if omitted then the array of fuel rods are regarded as not being enclosed by a shroud.

A20.3.2 Cards 49NN2001 through 49NN2099, Enclosure Description

W1.. (I) Matrix of integers identifying the component in each slot of the enclosure. If any of these components has a diameter greater than W1 on CCard 49NN2000, then option for code calculation of view factors cannot be selected. Instead the view factors must be defined by the user in the A20.2 block of input.

The maximum size of the array is ndcomp x ndcomp, where ndcomp is a parameter defined at compilation which defines the maximum number of components handled by SCDAP/RELAP5. This parameter is defined to be 20.

A21. COUPLE Control Cards

These cards are input whenever a COUPLE calculation is begun. These cards can be entered on either NEW or RESTART problems. Every COUPLE calculation must begin with a 50000000 card. Card 5M010000 may be entered for each COUPLE mesh 'M'.

A21.1 Card 50000000 COUPLE Identification

This card is required, whenever a COUPLE mesh is to be input.

W1(A) Keyword. 'couple'

W2(A) Input format. Enter the keyword 'old' for old-style (formatted) input, or 'new' for unformatted, RELAP5 card number style input.

A21.2 Card 50004000 Heat Transfer on External Surface of Lower Head

This card is optional, and may be entered on either NEW or RESTART problems. If entered this card is used to control ex-vessel heat transfer correlations for the external surface of a lower head submerged in a pool of water.

W1(I) Containment volume. This volume is the number of a hydrodynamic volume representing the containment. Any COUPLE node which has this volume specified as the hydrodynamic volume for convective heat transfer will use the ex-vessel heat transfer correlations.

W2(R) Heat transfer coefficient. The heat transfer coefficient to use for vapor phase heat transfer, when the node is modeled as being uncovered.

W3(I) Correlation flag. Integer flag describing which set of boiling correlations to use. Two sets of correlations are currently available. Set 1 (W3 = 1) is a set of correlations for heat transfer to subcooled fluid. Set 2 (W3 = 2) is a set of correlations for heat transfer to saturated fluid. Note that whichever set of correlations are used, the sink temperature will be either the saturation temperature for the pressure in the volume identified in Word 1, or 10 K below that.

W4(I) Containment level variable. (General table if negative, control variable if positive.) The parameter which specifies the containment liquid level.

A21.3 Card 50005000 Fuel-Coolant Interaction

This card is optional, and may be entered only for NEW problems. For the general analyses of severe accidents, this card and cards 50006000 through 50009000 are omitted. The card defines parameters used in the calculation of the breakup of jets of molten core material penetrating into a pool of water. The mass flow rate, composition, temperature and timing of the jets of slumping material are defined on Cards 5M200000 through 5M20S301, which are described in Section A22. The FCI model is activated by defining W3 on Card 5M010000 (defined in Section A21.13) to be "1" and W4 on this card to be "2".

W1(R) Parameter to select either Fuel-Coolant Interaction (FCI) involving melted material slumping through holes in core plate or user-definition of size of particles resulting from FCI; -1 = user-definition of origin of FCI, > 0 = number of holes in core plate through which melted material slumps as a jet.

W2(R) If W1 = -1, then W2 = diameter of particles resulting from FCI (m). If W1 > 0, then W2 = diameter of jets of slumping material at point of origin (m).

W3(R) Interval of time associated with each discrete slumping (s). In the numerical solution, the slumping process is discretized so the number of different particles resulting from breakup is finite rather than unlimited. For example, if the slumping in actuality occurs continuously through a 1 s interval of time, and W3(R) has a value of 0.01, then the slumping is discretized into 100 (1/0.01) individual slumpings distributed through the 1 s of time is which the slumping occurred. For most analyses, 0.01 < W3 < 0.05.

A21.4 Card 50006000 Further Fuel-Coolant Interaction Parameters

W1(R) Maximum liquid volume fraction for all heat transfer from fuel-coolant interaction being received by vapor phase around the dispersed particles. Recommended input value is 0.0.

W2(R) Elevation of bottom of region in which FCI occurs with respect to elevation of inner surface of lower head at its centerline (m). Normally, W2 = 0.0.

W3(R) If W1 on Card 50005000 is < 0, then W3 = area of cross section of slumping material. In this case, W3 is factor in calculating the initial velocity of particles resulting from FCI along with the mass rate of slumping defined on Card 5M200000 and its associated cards. If W1 on Card 50005000 is > 0, then define W3 to be equal to 0.0.

W4(R) Input the integer 1.

A21.5 Card 50007000 Further Fuel-Coolant Interaction Parameters

W1(R) Elevation of bottom of stack of RELAP5 control volumes referenced in Card 50008000 with respect to bottom center of inside surface of lower head (m). For most analyses, W1 = 0.0.

A21.6 Card 50008000 RELAP5 Control Volumes in which FCI May Occur

W1(I) Volume number of bottom most RELAP5 control volume in stack of volumes in which FCI may occur (nine digit number).

W2(I) Volume number of RELAP5 control volume just above W1 in stack of volumes in which

FCI may occur (nine digit number).

W3(I) - Wn(I) Continue input in pattern shown by W1 and W2, where n = total number of RELAP5 control volumes in which FCI may occur. Continuation cards are allowed. The first continuation card has the number 500080001. Normally, ten or more RELAP5 control volumes overlay the region in which FCI may occur.

A21.7 Card 50009000 Elevations of RELAP5 Control Volumes in Which FCI May Occur

W1(R) Elevation of top of bottom most RELAP5 control volume in which FCI may occur with respect to elevation of bottom center of inner surface of lower head (m).

W2(R) Elevation of top of second from bottom RELAP5 control volume in which FCI may occur with respect to elevation of bottom center of inner surface of lower head (m).

W3(I) - Wn(I) Continue input in pattern shown by W1 and W2, where n = total number of RELAP5 control volumes in which FCI may occur. Continuation cards are allowed. The first continuation card has the number 500090001.

A21.8 Card 5M010000, Modeling Options for Lower Head Debris

This section describes COUPLE control cards which are specific to each COUPLE mesh. Each card number begins with two digits, '5' and 'M'. As described in the previous section, the '5' denotes that COUPLE input is being presented, and the 'M' represents the COUPLE mesh number. One of these cards can be read for each COUPLE mesh "M", where "M" is between 1 and the allowed maximum number of meshes. The maximum allowed number of meshes is defined by parameter 'maxcpm' in common block 'cpmdat'. The maximum number of allowed meshes is 5.

W1(I) COUPLE flag and input indicator.

0 = Used on a restart run to turn off the COUPLE model for mesh "M".

-1 = Used on a restart run to replace some of the values on this card for mesh "M".

1 = Read COUPLE input for mesh "M".

This option can be used on RESTART to add or change a COUPLE mesh, unless debris is received from core components and core slumping into the mesh has already started.

W2(I) The identification number of the RELAP5 Control Volume modeling the fluid contacted by molten material slumping from the core region to the lower head. If W4 = 1 on this card, then slumping of material to lower head results in water in this control volume being converted to steam due to heat transfer from slumping material. On a restart run, this word may not be changed, but a 0 may be entered as input.

W3(I) Debris source indicator for COUPLE mesh "M":

-1 = No slumping. Debris material is already present at the start of the application.

0 = Debris received from core components (default).

1 = User-defined slumping.

2 = Depends on components above mesh (non LWRs).

Only 1 mesh may be designated as receiving debris from SCDAP/RELAP5 core components.

W4(I) Flag for breakup of COUPLE debris. For general severe accident analyses, W4(I) = 0 or 1;

0 = Debris may be broken up (default).

1 = Debris is never broken up.

2 = Extent of breakup is calculated by Fuel-Coolant Interaction Model. In this case, W3 = 1, and Cards 5M200000 through 5M20S301 are input, and Cards 50005000 through 50009000 are also input.

W5(I) Input the integer '1'

W6(R) Input 1.0.

W7(I) Index for selecting heat transfer and flow loss model for porous debris in lower head of reactor vessel; 0 = simplified model, 1 = detailed heat transfer model and detailed Tung and Dhir[A-1] flow loss model, 2= detailed heat transfer model and detailed Catton and Chung[A-6] flow loss model. Default value: 2.

W8(I) Index to invoke write to an output file of the calculated transient temperature distribution in the lower head of a reactor vessel. This option is invoked when calculated temperature history for lower head is to be input into a computer code for a detailed structural analysis of the lower head. Temperature distribution written to file every ncount/W8 time steps, where ncount = current number of time steps. Output file name: coupfl. Default value: 0.

W9(R) Time at which molten pool in lower head stratifies into a metallic upper part and an oxidic lower part (s). Default value: $1.x10^{15}$.

W10(I) Index for selecting model for angular distribution in heat flux on inner surface of lower head supporting a molten pool; 1 = mini-ACOPO correlation[A-7], 2 = UCLA correlation[A-8]. Default value: 1. Warning: W10 must not be right of column 80 of this card.

A22. User-Defined Core Slumping

These cards enable the code user to specify a series of one or more slumpings of core material into a COUPLE mesh. At least one COUPLE mesh, and one SCDAP/RELAP5 core component must be specified. The user should note that the card number provides a significant amount of information to the code. The first digit is always '5' to identify it as COUPLE input. The second digit is 'M', the mesh number into which the slump enters. The third and fourth digits are '20' to identify this input as pertaining to user-defined slumping.

A22.0.1 Card 5M200000, Definition

The first card specifies a SCDAP/RELAP5 general table which is used as a multiplier on the debris power. The specification of the table number may not be changed on restart, although the table itself may be changed. The same table is applied to all slumps.

W1(I) Table number. Table to define the power decay of the slumps.

A22.0.2 Card 5M20S100, Duration

This card specifies the duration and power of each period of slumping. The card number uses the integer 'M' to specify the mesh into which material is slumped, and the integer 'S' to specify the slump number in chronological order, maximum of 25 slumps may be defined.

W1(R) Time at which core slumping begins (s). W1 (S-th slumping) > W2 (S - 1th slump). W1 must be greater than the time at which the analysis starts.

W2(R) Time at which core slumping ends (s).

W3(R) Power multiplier.

The total power in the slump (W) is defined by this factor multiplied by the value from the general table specified on Card 5M200000. The power added to the mesh for each time step is then (W3)*(table number from previous card) * (time step)/(W2 - W1), where W1, W2, and W3 are Words 1, 2, and 3, respectively, from this card.

A22.0.3 Card 5M20S200, Characteristics

W1(R) Temperature of slumped material (K).

W2(R) Radius of particles of slumped material (m).

W3(R) Porosity of slumped materials.

A22.0.4 Cards 5M20S301 through 5M20S399, Mass

W1(R) Mass of zircaloy that slumped during period (kg).

W2(R) Mass of metallic uranium (kg).

W3(R)	Mass of stainless steel (kg).
W4(R)	Mass of silver (kg).
W5(R)	Mass of boron carbide (kg).
W6(R)	Mass of uranium dioxide (kg).
W7(R)	Mass of oxidized zircaloy (kg).
W8(R)	Mass of aluminum (kg).
W9(R)	Mass of lithium (kg).
W10((R)	Mass of cadmium (kg).

A23. Input for Modeling of Reactor Vessel Lower Head and Supported Debris

The input data for the reactor vessel lower head and debris supported by the lower head consists 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 free-form 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.

Note that a RELAP deck terminator card (period card) should be input prior to the input described in Section A23.

A23.1 Title Block

A23.1.1 Header for Title Block

1-5(A) Block header. Since only the first four 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.

A23.1.2 Title Card

1-80(A) First title card.

A23.1.3 Title Card

1-80(A) Second title card. This is a good place to list the unit set employed.

A23.1.4 Block Terminator

Block terminator (blank card).

A23.2 Mesh Generation Block

A23.2.1 Header for Mesh Generation Block

1-8(A) Header for mesh generation block. Always input the following word: automesh.

A23.2.2 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 the material block assignment Card(s).

16-20(I) Geometric code.

0 = r-, z-axisymmetric.

1 = x-, y-plane body.

21-30(R) Multiplier. This multiplier operates on dimensions that are input on the line segment card(s) 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. (This word) x (value of input number) = (dimension in m).

A23.2.3 Line Segment Cards

Any reasonable combination of internal and external line segments that 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 set of (i, j) pairs can be input only once.

The elements that 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.

4-14(R) R-coordinate of 1st point.

15-22(R) Z-coordinate of 1st point.

If the line segment type (columns 67 to 71) is 0, then omit the input in columns 23 through 66.

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.

If the line segment type (columns 67 to 71) is 1, then omit the input in columns 45 through 66.

45-47(I) I-coordinate of 3rd point.

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 of 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 midpoint 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(vI)=ABS(vJ)] in that i, j plane. Note on a stepped diagonal segment that i is incremented first and then j.

Repeat the line segment Card 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 line segment Card for each segment of the surface of the mesh.

For modeling gap resistances, input two consecutive values of i or j that have identical coordinates.

A23.2.4 Mesh Generation Block Terminator

Block terminator (blank card).

A23.3 Material Block

A23.3.1 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 up to 15 different

materials. The materials and their identification numbers are listed in Table A23-1.

Table A23-1. COUPLE material indices.

Material	ID No.
Relocated debris	1
Stainless steel	2
Inconel	3
Carbon steel	4
Coolant	5
Null material	6
MHTGR graphite	7
MHTGR fuel compact	8
MHTGR target	9
MHTGR smeared (homogenized)	10
User-specified materials	11-15

For user-specified materials, the user supplies constant property values by entering the values on the Material Properties and Material Data Cards. For user-specified materials, the code will not model phase change.

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. The exception to this is the "no slumping" case (Word 3 = -1 on COUPLE Card 5M010000), in which Material 1 is already present at the start of the problem. If on the fission products card(s) the gap heat transfer is not specified for nodes that are part of null element, then no heat transfer will occur across the null element. Null elements are used to differentiate between two regions with different heat generation rates and to model heat transfer between two materials with a possible gap between them.

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. If material type is 1 and element is at start of analysis, input 1.

46-50(I) Always input the integer 0.

51-55(I) Always input the integer 0.

56-65(R) Particle diameter (mm).

A23.3.2 Material Block Terminator

Block terminator (blank card).

A23.4 Material Block

A23.4.1 Material Block Header

1-8(A) Block header. Always input the following word: material.

A23.4.2 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. In the current version of COUPLE input, if Material 5 is to be used, Materials 1, 2, 3, and 4 need also to be defined.

A23.4.3 Emissivity

1-10(R) Emissivity. Emissivity for internal radiation in material with ID No. 1. The standard value is 0.8.

A23.4.4 Material Properties

1-5(I) Material identification number. If material identification number greater than 11 is input, then properties are defined as input on this card (density) and on the Material Data Card, but the materials properties do not change with temperature.

11-20(R) Density of material (kg/m^3). If null material (an element used to model gap resistance), then leave these columns blank.

21-52(A) Material title information. For example, if stainless steel material, input "stainless steel."

A23.4.5 Material Data

These data are used as default values in case built-in procedures (derivative method in COUPLE) fail to meet specified criteria. If data are not available, low-temperature default data given in the following table should be input. These default values are required. If the input columns are left blank, the code does not automatically set the input variable to the default value. See Table A23-1.

1-10(R) Horizontal thermal conductivity, KR (J/m-s-K). Input 0.0 for null material.

11-20(R) Axial thermal conductivity, KZ (J/m-s-K). Input 0.0 for null material.

21-30(R) Specific heat capacity, CP (J/kg-K). Input 0.0 for null material.

31-80 Blank. Unless material = 7, then input next word.

31-40(R) Fast neutron fluence(n/cm**2).

Repeat the two previous cards until each type of material in the mesh has been defined.

If material = 10, then MHTGR is a smeared core, and insert the next card.

A23.4.6 MHTGR Material Data

1-10(R) Cross-sectional area of graphite (m**2).

11-20(R) Cross-sectional area of fuel compact (m**2).

21-30(R) Cross-sectional area of target (m**2).

31-40(R) Cross-sectional area of helium coolant channels (m**2).

41-50(R) Fast neutron fluence (n/cm**2).

The cross-sectional areas are in the plane perpendicular to longitudinal axis of the reactor core.

A23.4.7 Material Block Terminator

Block terminator (blank card).

A23.5 Time Step Data

A23.5.1 Time Step Data Block Header

1-4(A) Time step data block header. Always input the following word: step.

A23.5.2 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. If gap elements (elements with null material) are being modeled, then the computer run time can be very sensitive to this input value. To avoid excessive run time, it may be necessary to define the convergence parameter to be greater than 1.0, perhaps as large as 5.0.

61-70(R) Inner radius of lower head of vessel. Use the same units as the coordinates on the Line Segment Card. If a spherical lower head is not being modeled, input 0.0.

A23.5.3.1 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 the Line Segment Card. 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 or elevation of top surface of structural material supporting debris. Use the same units as the coordinates on the Line Segment Card. 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. Use the same units as for the Line Segment Card. Omit for the case of spherical lower head. Omit this input for the SCDAP/RELAP5/MOD2 version of the code. For the case of plane geometry, input 1.0.

41-50(R) Depth (thickness) of plane. Use the same units as for the Line Segment Card. Omit this input for axisymmetric geometry.

51-55(I) Transient configuration of debris slumping flag.

0 = Debris slumping is self-leveling throughout the COUPLE mesh.

1 = Configuration of slumped debris is defined by the user.

If this flag is set, the order in which elements receive slumped debris is defined by the user. The user can divide the elements into layers, which will fill sequentially as the debris slumps. Within each layer the debris is assumed to self-level across all elements in that layer. The user defines the layers of elements by adding cards immediately after this one; one card for each layer. The code limits the inputs to 25 elements per layer for up to 25 layers. The last card in the list should contain a single 0 to indicate the end of the list. Each card that defines a layer must conform to the format as defined below.

56-60 (I) Number of stacks of finite volumes through which liquefied core plate material may flow. Omit this input if flow of liquefied core plate material through porous debris is not to be modeled. Default value = 0. Coefficient name = nstkss.

A23.5.3.2 Source of melted material slumping onto debris bed (omit card if nstkss = 0 on previous card)

1-10 (R) Rate of slumping of core plate material onto debris bed ((kg/s)/m^2). If rate of slumping of zero is input, then rate of slumping is calculated.

11-20 (R) Start time of core plate slumping (s). If rate of slumping is to be calculated, input 1.0. Coefficient name = tscpss.

21-30 (R) End time of core plate slumping (s). If rate of slumping is to be calculated, then input 0.0. Coefficient name = tecpss.

31-40 (R) Melting temperature of core plate (K). Suggested value = 1730. Coefficient name = tpcpss.

A23.5.3.3 Material properties and accuracy of solution (omit card if nstkss = 0)

1-10 (R) Viscosity of liquefied stainless steel (kg/m.s). Suggested value = 0.0032. Coefficient name = viscss.

11-20 (R) Wetting angle of liquefied stainless steel in contact with debris (degrees). Suggested value = 90. Coefficient name = thtwet.

21-30 (R) Surface tension between liquefied stainless steel and debris (N/m). Suggested value = 0.45. Coefficient name = gamssu.

31-40 (R) Accuracy of solution for bed saturation (unitless). Suggested value = 0.001. Coefficient name = accbst.

A23.5.3.4 Identification of finite elements at top of debris bed (omit card if nstkss = 0).

1-5 (I) Number of a finite element at top of debris bed.

6-10 (I) Number of another finite element at top of debris bed.

11-15 (I) Continue defining in every five columns an identification number of a finite element until every finite element in top row of finite elements has been identified.

A23.5.3.5 User-Defined Layer of the COUPLE Mesh

1-4(I) Number of elements in this layer.

5-10(I) The element number in this layer. Five spaces for each element, continued on the next card if necessary.

The last card in the list must contain a single 0.

A23.5.3 Block Terminator

Block terminator (blank card).

A23.6 Internal Heat Generation Block

A23.6.1 Internal Heat Generation Block Header

1-10(A) Block header. Always input the following word: generation. The generation block is required input.

A23.6.2 Number of Materials Without 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 the Material Data Information Card. Otherwise, input the same number.

6-10(I) NAF. The number of pairs of lines of mass fractions input.

11-15(I) NFP. The number of lines of fission products input.

A23.6.3 Power Densities

These cards are optional for the "no slumping" COUPLE case (Word 3 = -1 on the Couple Card 5M0010000), and are not allowed otherwise. Each card defines a power density for a specified group of consecutive nodes. This input can be used for selected nodes to override the power density option set for all COUPLE Material 1 by SCDAP.

1-5(I) I1I of first node in the group.

6-10(I) J1J of first node in the group.

11-15(I) I2I of last node in the group.

16-20(I) J2Jof last node in the group.

21-30(R) X204 Multiplier of power density from Table N402. If N402 = 0, then X204 = constant power density (W/m^3).

31-35(I) N402 Number of RELAP5 general tables of power density (W/m^3).

A23.6.4 Block Terminator

Blank card.

A23.7 Material Without Internal Generation

A23.7.1 Material Numbers Without Internal Generation

1-5(I) First material number.

6-10(I) Second material number.

Continue in Columns 11-15, 16-20, etc., until all materials defined in the Material Properties Card have been identified. Null material must be defined as material with no internal heat generation.

A23.7.2 Mass Fractions

These cards are optional for the "no slumping" COUPLE case (Word 3 = -1 on the COUPLE Card 5M001000) and are not allowed otherwise. Each pair of cards defines the mass fractions for the constituents in a consecutive group of COUPLE elements with Material 1. These fractions are converted to atomic fractions and stored as such.

Card 1:

1-5(I) NEL1. Number of first element in the group.

6-10(I) NEL2. Number of last element in the group.

11-20(R) Mass fraction of zircaloy.

21-30(R) Mass fraction of metallic uranium.

31-40(R) Mass fraction of stainless steel.

41-50(R) Mass fraction of silver.

51-60(R) Mass fraction of boron carbide.

61-70(R) Mass fraction of uranium dioxide.

71-80(R) Mass fraction of oxidized zircaloy.

Card 2:

1-10(R) Mass fraction of aluminum.

11-20(R) Mass fraction of lithium.

21-30(R) Mass fraction of cadmium.

31-40(R) Mass fraction of soil.

This input overrides the SCDAP values for the elements specified.

A23.7.3 Block Terminator

Block terminator (blank card).

A23.8 Convection Data Block

A23.8.1 Convection Data Block Header

1-11(A) Block header. Always input the following word: convectsets.

A23.8.2 Number of Nodes with Convection

1-5(I) Number of nodes in finite element mesh at which convective heat transfer can occur. Nodes that are part of finite elements that receive relocated material should be defined as nodes at which convective heat transfer occurs. Otherwise, convective heat transfer will not be modeled from the surface of particles in porous debris or from the top surface of nonporous debris. Nodes at both surfaces of a gap modeled as null material must be defined. Maximum of 2000 nodes may be defined to have convective heat transfer or be part of gap heat transfer.

6-10(I) Input the integer 1.

A23.8.3 Boundary Conditions for Elements That Fill With Slumping Debris

1-10(R) Always input 1000.0.

11-20(R) Always input 500.0.

A23.8.4 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 the fission product Card 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) If these convective nodes are not modeling heat transfer across the gap, leave these columns blank. Otherwise, input gap heat transfer coefficient for case of materials in both

sides of the gap being solid state.

55-60(I) If these convective nodes are not modeling heat transfer across the gap, leave these columns blank. Otherwise, input -1.

A23.8.5 Number of Interfacing SCDAP/RELAP5 Volumes

Omit this card if -1 is input in columns 55-60 of the previous card.

1-10(I) Number of SCDAP/RELAP5 volumes that interfaces these nodes. Input the full nine-digit number.

The fission product and block terminator cards are repeated as many times as necessary to define all the convection boundary data.

A23.8.6 Block Terminator

Block terminator (blank card).

A23.9 Initial Temperature

A23.9.1 Initial Temperature Block Header

1-8(A) Block header. Always input the following word: tempsets.

A23.9.2 Number of Temperature Nodes

5-10(I) Number of nodes in mesh at locations that may be filled with slumping debris. Always input the integer 0.

16-20(I) Always input the integer 0.

21-30(R) Always input 0.0.

A23.9.3 Block Terminator

Block terminator (blank card).

A23.10 Plot Control

A23.10.1 Plot Control Header

1-5(A) Block header. Always input the following word: plots.

A23.10.2 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.

A23.10.3 Plot Control Block Terminator

Block terminator (blank card).

A23.11 Solution Control

A23.11.1 Solution Control Header

1-6(A) Block header. Always input the following word: couple.

A23.11.2 Solution Control Block Terminator

Block terminator (blank card).

A23.11.3 Problem Termination Card

1-11(A) Problem termination card. Always input the following words: end of data.

Input data for next COUPLE mesh being modeled.

A24. CARDS 1001 THROUGH 1999, STRIP REQUEST DATA

These cards are required only in STRIP-type problems. One or more cards are entered, each containing one variable request. Card numbers need not be consecutive. Variables are ordered on the STRIPF file in the order of increasing card numbers. If an incorrect variable request code is entered, the value will be 0.0. It is not flagged as an input error, since at some later time in the transient, a renodalization may result in the variable request code becoming correct.

W1(A) Alphanumeric part of the variable request code.

W2(I) Integer part of the variable request code.

A25. CARDS 1001 THROUGH 1999, COMPARE DUMP FILES CONTROL DATA

These cards are required only in CMPCOMS problems. One or more cards are entered, each containing one request to compare dump blocks on the files specified with the -A and -B options on the command line. Card numbers need not be consecutive.

W1(I) Dump file number from file specified on -A command line option, as defined in Appendix B.

W2(I) Dump file number from file specified on -B command line option, as defined in Appendix B.

The values in Words 1 and 2 on a succeeding card must be greater than the values on the preceding card. The values in Words 1 and 2 are the advancement number when the dump block was written. This information is written as a line in the printed output of the run writing the dump file. The form of the line is, "---Dmpcom no. nnn written, block no. mmm on unit u---," where nnn is the advancement count number, mmm is the count of the number of blocks written, and u is A or B indicating the file specified by the -A or -B option.

A26. References

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APPENDIX B

SCDAP/RELAP5

OPERATING PROCEDURES

B1. SCDAP/RELAP5 OPERATING PROCEDURES

When operating on Unix systems, the SCDAP/RELAP5 program can interpret a Unix-style command line. The command is written with all of the desired options. Each option is prefixed by a minus sign and, with the exception of the X option, must always be followed with a file name. See Table B1-1. The options may be specified in any order, but may not be repeated. If an option is not entered, the default is used. For operating systems other than Unix, the default file names must be used.

Table B1-1. Explanation of UNIX command line options.

Option	Default	Application
i	indta	The input data stream. This file must be available
o	outdta	The printed output. This file must not exist or else a diagnostic message will be issued followed by immediate termination.
r	rstplt	The restart / plot file. Must not exist for NEW problems and must exist for RESTART problems.
s	stripf	The strip output.
j	jbinfo	This is an optional file, created by the user, to place additional information on the output file. The contents of this file are echoed to the output file at the beginning of the job.
A	dumpfil1	The are files used to dump common and dynamic blocks for debugging purposes. These files must not exist for the run that creates them and must exist for the CMPCOMS run.
B	dumpfil2	
w	tpfh2o	Light water property table
d	tpfd2o	Heavy water property table
a	coupfl	
f	ftb1	Specifies a scratch word addressable file used only on CRAY versions. This file is a word addressable file, and the I/O is done by CRAY library subroutines, that have successfully resisted external open and close statements. This file is small and can fit in most directories. The file should be removed after execution, but no error occurs in subsequent calculations if it is not.
C	0	
X	N/A	

The command line capability eliminates the need to have all files needed for execution in the same directory or to copy/rename files to match the default names. For example, the command:

relap5.x -i myprob.i -o /usr/rjw/myprob.o -r /usr/rjw/myprob.r -w /u2/rjw/tpfh2o

takes the executable file and input file from the current directory, uses a temporary disk for the output and restart-plot files, and uses a water property file from a different directory.

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See Instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
NUREG/CR-6150, Rev. 2
Volume 3
INEL-96/0442

2. TITLE AND SUBTITLE
SCDAP/RELAP5/MOD3.3 Code Manual, Volume 3, Rev. 2

3. DATE REPORT PUBLISHED

MONTH	YEAR
January	2001

4. FIN OR GRANT NUMBER
W6095

5. AUTHOR(S)
L. J. Siefken, E. W. Coryell, E. A. Harvego, J. K. Hohorst

6. TYPE OF REPORT
Technical

7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3129

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above"; If contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Systems Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES
S. A. Arndt, NRC Project Manager

11. ABSTRACT (200 words or less)

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 and reactor core during severe accidents 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. The coolant system behavior is calculated using a two-phase model allowing for unequal temperatures and velocities of the two phases of the fluid, and the flow of fluid through porous debris and around blockages caused by reactor core damage. The reactor core behavior is calculated using models for the ballooning and oxidation of fuel rods, the meltdown of fuel rods and control rods, fission product release, and debris formation. The code also calculates the heatup and structural damage of the lower head of the reactor vessel resulting from the slumping of reactor core material. 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.

Volume 3 provides guidelines to code users based upon lessons learned during the developmental assessment process. A description of problem control and the installation process is included. Appendix A contains the description of the input requirements.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
SCDAP; RELAP5; thermal hydraulic; core behavior; light water reactor; severe accident; coolant system; two-phase model

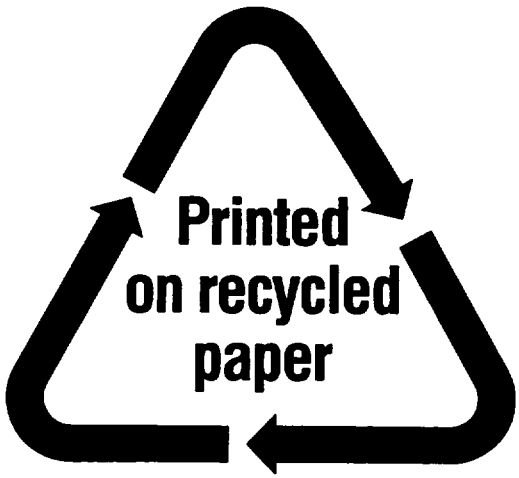
13. AVAILABILITY STATEMENT
Unlimited

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

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)



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