MASTER

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CODE DEVELOPMENT AND ANALYSIS PROGRAM

RELAP5 PROGRESS SUMMARY

**SIMULATION OF SEMISCALE ISOTHERMAL BLOWDOWN
(TEST S-01-4A)**

JULY 1978

EG&G Idaho, Inc.

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RELAP5 PROGRESS SUMMARY
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(TEST S-01-4A)

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ABSTRACT

The RELAP5/MOD"0" LOCA analysis code has been applied to Simulation of the Semiscale Isothermal Blowdown Test (S-01-4A) from initiation to 60 seconds. Subcooled ECC injection was simulated from 23 seconds until accumulator emptying. The calculated results are in very good agreement with the experimental data. This is the first full system application of the RELAP5 code and only the pressurizer surge line resistance was modified to achieve the results reported.

An analysis of the code execution time using a time-step statistical edit is included.

INTRODUCTION AND SUMMARY

The RELAP5 code is an advanced, one-dimensional, fast running system analysis code which is being developed for US NRC-RSR. The objective of the project is to produce an economic, advanced, Best Estimate (BE) and Evaluation Model (EM) transient analysis code for use in the licensing process for Light Water Reactors (LWR). The code is based on the technology and experience embodied in the RELAP4 series of codes, but it is a completely new code having a top-down structure and based on a nonhomogeneous and nonequilibrium hydrodynamic model.

The RELAP5 code now includes models for most of the processes which occur during blowdown of a LWR and can be used to analyze interconnected components. Component models are included for pipes, branches, abrupt flow area change [2], pumps, check valves, trips, heat exchangers and break flow [3]. These models are integrated into a general purpose and user convenient system code framework. The code is operational and has been tested on several separate effects two-phase flow experiments and hypothetical test problems. Generally, good agreement with experimental data has been achieved and fast computer run times have been experienced [1] [3]. The subject of this report is the application of RELAP5 to the Semiscale isothermal blowdown experiment (test S-01-4A).

The isothermal blowdown was modeled up to 60 seconds, approximately the time of ECC accumulator emptying. This period includes ECC injection from 22 seconds to 60 seconds. Generally, the calculated results are in very good agreement with the data. Only the pressurizer surge line resistance required slight modification to obtain the results reported herein. No other code tuning was necessary or was undertaken in an

attempt to improve the data comparison. The break flow areas and other physical component dimensions used in the code are the actual test apparatus nominal dimensions. The break flows are calculated using the RELAP5 choking model without use of discharge coefficients. The Semiscale calculated results are presented both with and without heat transfer from the piping system and the vessel walls. In this way the magnitude of the heat transfer effect was established and, since this was the first application of the convective heat transfer package, a qualitative test of the convective heat transfer was provided.

The calculated results with heat transfer exhibit system pressures higher than the data at times beyond 20 seconds while the calculations without wall heat transfer produce pressures in good agreement with data. Further testing of the convective heat transfer package will be required to establish the correct heat transfer effect. This task will be accomplished in the course of the Semiscale heated blowdown simulation.

The early time calculated results show the existence of some thermal nonequilibrium effects while the long-term results demonstrate the existence of significant nonhomogeneous flow effects. ECC mixing, ECC bypassing and counter current flow in the downcomer are examples of such phenomena.

The calculational time for the RELAP5 simulation of the Semiscale isothermal blowdown to 60 seconds was 54 minutes of CDC 7600 CPU time. This time is greater than anticipated based on previous tests of the RELAP5 code (approximately 20 minutes was projected) and as a result a time step analysis was undertaken. A time step edit was added to the code which indicates which part of the system is limiting the time step and why it is being limited. An analysis of a run is included along with a projection of future computing time requirements.

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RELAP5 PROGRESS SUMMARY
SIMULATION OF SEMISCALE ISOTHERMAL BLOWDOWN
(TEST S-01-4A)

I. RELAP5 SYSTEM CODE OVERVIEW

The development of RELAP5 has proceeded to the point that significant LWR system modeling capability now exists. This capability has been used to model the MOD-1 Semiscale system isothermal blowdown (Test S-01-4A). A brief overview of the current RELAP5 capability is given in the following discussion.

1. CODE STRUCTURE

RELAP5 is structured in a top-down manner and the coding is modular so that various models and functions are isolated into separate subroutines. The structure and status of the code is illustrated by block diagrams in Figures 1 and 2. These block diagrams are somewhat simplified versions of the actual code structure, but they aid in understanding the inter-relationship of the code parts. Figure 1 is a diagram of the top two levels of code structure. The percent complete is shown by a vertical bar to the right of the particular block and those portions which will be included in the first released version of the code, RELAP5/MOD"0", are shown with solid borders. Figure 2 is a further breakdown of the TRAN routine. This branch performs the transient hydrodynamic calculation and comprises the majority of the two-phase modeling technology. Here again the percent complete is shown as a solid bar in the right hand side of the box and those parts to be included in RELAP5/MOD"0" are shown with solid borders.

A more detailed breakdown of the complete code structure is included in Appendix A with one sentence descriptions for the function of each subroutine.

2. INPUT DATA REQUIREMENTS

As the RELAP5 code has developed, an input description manual has been compiled using an interactive editor and text composing program, TEXTJAB, on the INEL CYBER 76-173. This system permits easy updating and modification as RELAP5 evolves. A copy of the current manual is included as Appendix B. This input manual is in use by the RELAP5 project team members and is the beginning of the users manual for RELAP5/MOD"0".

3. MAJOR CODE FEATURES

3.1 Hydrodynamic Components

The hydrodynamic calculation is primarily organized about control volumes and junctions and to a lesser extent about components. Components are organized collections of control volumes and junctions and are defined for either input convenience or to specify specialized processing. The physical space over which the hydrodynamic behavior is being simulated is subdivided into control volumes. The continuity and energy equations are approximated by finite difference approximations to the volume and surface integrals of these equations over each control volume. A junction is the connection of one control volume to another and is associated with the momentum equations. Finite difference approximations to the line integral of the streamtube form of the momentum equations are used.

In one-dimensional components, only the algebraic sign is needed to indicate the direction of vector quantities. Each control volume and

junction has a coordinate direction to which the vector quantities are related. The volume input specifies both the coordinate direction and the control volume orientation; i.e., vertical, horizontal, or slanted. The ends of the one-dimensional control volumes are designated as inlet and outlet consistent with the coordinate direction. The junction specifications include both the control volumes being connected and which ends are being joined. Care in program design and coding has insured that if coordinate directions are reversed, but the physical problem remains unchanged, the only differences in results are reversals in signs of the vector quantities associated with the changed coordinates.

The following hydrodynamic components are now available in RELAP5.

3.1.1 PIPE. This component is a series of control volumes and $n-1$ interior junctions, the outlet of each control volume is connected to the inlet of the next. PIPE components can be used for those portions of the system without branches. PIPE components offer input conveniences since most of the characteristics of the volumes and junctions in a pipe are similar and the input data requirements can be reduced accordingly. Because of the sequential connection of the volumes, junctions are generated automatically rather than being individually specified. Although the input is designed assuming considerable similarity, any of the control volume features such as flow area, orientation, or pipe roughness can be varied at each volume or junction.

3.1.2 BRANCH. This component is one control volume with up to nine associated junctions. Multiple junctions can be associated with either or both the inlet and outlet ends of the control volume. As the name implies, this component is used where there is flow merging or branching. A BRANCH component is the only one-dimensional volume permitted to have multiple junctions at a control volume inlet or outlet.

3.1.3 TEE. A TEE is a specialized application of a BRANCH. The "straight" portion of the tee is represented by two junctions attached to the inlet and outlet ends of the control volume. The "branched" flow from the tee is represented by two additional junctions. The additional junctions attach to the inlet and outlet of the BRANCH control volume and to the same end of the control volume connected to the branch leg of the tee. This technique for modeling a tee was used in the Semiscale simulation.

3.1.4 VALVE. A VALVE is a single junction with special processing to allow the junction flow area to be a function of time. Valve capability includes check valves, trip valves, and inertial valves. The inertial valves are not yet fully operational.

3.1.5 PUMP. A PUMP component is one control volume with two associated junctions attached to the volume's inlet and outlet. The pump dissipation energy is associated with the volume and the pump head is divided between the two junctions. The pump head rise and torque model is a modification of the model in RELAP4/MOD6 to be compatible with the two fluid momentum treatment.

3.1.6 SNGLVOL. This component is simply one volume.

3.1.7 SNGLJUN. This component is simply one volume.

3.1.8 TMDPVOL. This component is not an active volume but is a volume used for boundary conditions. The volume conditions are specified functions of time. When flow is into the volume, only pressure is used; when flow is out of the volume, density and internal energy are also used. At present, the kinetic energy of the fluid in TMDPVOL is determined by the outflow. An option to allow setting the kinetic energy to zero to allow for stagnation conditions is being considered.

3.1.9 TMDPJUN. This component is used to specify velocity boundary conditions as a function of time. A volume with a closed end does not need a TMDPJUN with zero velocity since those conditions are automatic for any volume end without a junction.

3.2 Process Models

3.2.1 Area Change Model. An area change model is applied at all junctions except time-dependent junctions. A junction is specified as having a smooth or an abrupt area change. A smooth area change is handled entirely by the streamtube form of the momentum equations. The abrupt area change model^[2] includes a two-fluid extension of the Bourda-Carnot model for the losses due to expansions, contractions, and orifices for two-phase flow.

3.2.2 Choking Model. A choking model^[3], which is based on the characteristics of the two-fluid hydrodynamic equations, is applied to all junctions except time-dependent junctions. This capability will allow choking at both break junctions and interior junctions.

3.3 Heat Structures

Heat structures can be represented by one-dimensional heat conduction in rectangular, cylindrical, or spherical geometry. Temperature dependent thermal properties can be obtained from built-in properties or can be supplied by the user. Internal heat generation, materials, and mesh point spacing can vary at each mesh interval. Boundary conditions on both sides can be insulated, specified heat flux, specified surface temperature, or heat transfer to a sink temperature using heat transfer coefficients. Surface or sink temperatures can be tabular or from hydrodynamic volumes. When hydrodynamic volumes are referenced, the heat transfer is coupled to the energy equation for the volume. Heat transfer coefficients can be tabular

or from heat transfer surfaces. The present surface is based on RELAP4/MOD6 heat transfer correlations. Internal heat sources are specified from tabular input.

3.4 Trips

Variable and logic trips are allowed. A variable trip evaluates a FORTRAN statement involving the operations: equal, not equal, greater than or equal, greater than, less than or equal and less than, between any two variables. The trip has occurred if the statement is true. The variables can be any of the functions advanced in time. The statement permits tests such as: Is a differential pressure greater than some value? Is a pressure less than some value? The time at which a trip becomes true is stored and can be specified as a variable in a subsequent trip statement.

Logical trips evaluate a FORTRAN statement relating two trips by the operations AND, OR, or XOR (exclusive OR). Both variable and logical trips can be latched or unlatched trips. Since logical trips can reference other variable and logical trips, complex logical statements can be constructed. Thus a trip valve can be open or closed depending on several different tests on pressure, differential pressures, flows, temperatures, etc. which are related through combinations of AND, OR, and XOR logic.

3.5 Time Step Control

An automatic time step control selects time steps for advancing the hydrodynamic solution. The principal control is adjusting the time step such that the maximum mass truncation error is maintained between set limits. Other considerations are the material transport limit and, the amount of extrapolation for the metastable states associated with flashing or condensation.

3.6 Output

3.6.1 Printed Output. Detailed input editing is provided and minor and major edits list the transient results. Minor edits list user selected quantities on a minimum amount of paper. Major edits list all transient results. The user can select the frequencies of these edits.

3.6.2 Plotted Output. The data comparison and variable plots for the Semiscale results were made directly by the RELAP5 code and illustrate the current capability. The plotting is still in an interim stage and more user convenient input for plotting directions is being coded for RELAP5/MOD"0".

3.6.3 Restart Capability. A Restart-Plot file can be generated and later used to restart the problem from previous time points. Currently, time step control, minor edit, and trip specifications can be changed at restart.

3.7 Miscellaneous Features

Free form input, convenient for card or terminal input, is used. A complete listing of the input, exactly as supplied by the user, is provided at input processing as well as an edited input listing. Card numbers on the input facilitate relating input data to program function. The card numbering and input processing philosophy was established to permit convenient methods to be used for maintaining base problems and for easy modification. Extensive error checking is performed. Processing design and the use of default values in place of errors permit input processing to continue in spite of serious errors. This permits several errors to be noted and corrected on each submittal rather than only one error detected per submittal.

RELAP5 is coded in FORTRAN for the Cyber-76 computer and operates under the standard SCOPE-2 operating system. RELAP5 uses several subroutines

from the INEL subroutine library, a few of which are coded in symbolic. The program can be converted to other large-scale computing systems.

The INEL Cyber-76 allows 160000_8 words of SCM and convenient FORTRAN access to LCM is limited to 400000_8 words. RELAP5 uses dynamic storage for all permanent data that is problem dependent and the input processing is extensively segmented. The Semiscale problem (consisting of 88 volumes, 93 junctions, and 62 heat structures totaling 327 mesh points) required 116744_8 SCM and 31000_8 LCM during the transient execution.

RELAP5 Top Level Structure

Figure 1. RELAP5 top level structure

— RELAP5/MOD"O"

RELAP5 Substructure

Figure 2. RELAP5 substructure - TRAN

II. RELAP5 SEMISCALE MOD-1 SYSTEM MODEL

1. GENERAL

The MOD-1 Semiscale system Test S-01-4A was conducted with a 200% cold leg break and with ECC injection into the cold leg of the intact loop. The initial isothermal temperature was 555⁰K (540⁰F) and the initial system pressure was 15.6 MPA (2250 psig). The Test S-01-4A was selected because it is the LOFT L1-4 counterpart test in Semiscale and the test produced typical results with high quality data. This test may also serve as a good base case for modeling LOFT tests at a later time.

The MOD-1 Semiscale system has been modeled using the RELAP5/MOD"0" system code in the current state of development which is described in the preceding section. Although the RELAP5/MOD"0" code is fully operational, some aspects of the code have not yet been thoroughly tested. The convection heat transfer calculations are a particular function which is used in the Semiscale model but will require more testing. Consequently, the results of the Semiscale simulation to be presented herein are made both with and without convective heat transfer in order to establish the reasonableness of the calculations.

The application of RELAP5 to simulation of the Semiscale MOD-1 system is the first full system application of RELAP5. While results in good agreement with data were obtained without code tuning, these results do not represent a comprehensive modeling study. The code results are presented in order to demonstrate the current RELAP5 capability.

2. SYSTEM MODEL AND NODALIZATION

RELAP5 input is component oriented and each component can be subdivided into a system of subcontrol volumes. The RELAP5 model of the Semiscale facility included 88 fluid control volumes and 93 flow junctions. The system nodalization is illustrated schematically on Figure 3 and the component information is summarized in Table I. A brief description of the Semiscale test facility^[4] as used for the isothermal blowdown is given in Appendix C. In the model, a total of 62 heat slabs (shown as shaded areas on Figure 3) were used to represent heat transfer in the intact loop steam generator, the vessel, core barrel and piping system. None of these components are modeled as active heat sources. Only the stored energy due to the initial system temperature is considered. However, as depressurization and flashing occur, significant wall to fluid temperature differences are developed and wall heat transfer is an important phenomena.

3. SPECIAL MODELING CONSIDERATIONS

The application of RELAP5 to simulation of the Semiscale isothermal blowdown followed closely the approach used in application of RELAP4 to the same problem^[5]. The following discussion covers those components for which a significant departure from the RELAP4 approach was taken or other special considerations were necessary.

3.1 Pressurizer

The pressurizer component was divided into 12 volumes with a finer nodalization near the bottom so as to define accurately the vapor and fluid interface as the liquid empties. The initial temperature of the vapor and fluid was near the saturation temperature at the system pressure

since the fluid heater was immersed in liquid. No thermal stratification was assumed. An orifice (75% of surge line area) at the pressurizer outlet was used to adjust the hydraulic resistance of the surge line to be in agreement with test data.

3.2 Pump

In Semiscale MOD-1 Test S-01-4A, power to the primary coolant circulating pump was cut off at blowdown to allow the pump to coast down to a speed of 1300 rpm. This speed was then maintained throughout the remainder of the test by manual control. Thus, instead of calculating the pump speed using the torque-inertia relation, the measured pump speed data were specified using the time-dependent pump speed option included in RELAP5/MOD"0".

3.3 Accumulator and Low Pressure Injection System

The ECC injection system was modeled by connecting the injection pipe to a time-dependent junction (J530) and a time-dependent volume (V-540). The volumetric flow rate and temperature (302.4°K) of the coolant fluid was specified as a function of time using data from Test S-01-4A.

3.4 Downcomer and Core

A relatively fine nodalization was used in the downcomer and core (12 and 14 nodes, respectively) in order to be able to use the same nodalization throughout blowdown, refill and reflood. Only blowdown results are presented in this report, however, future applications of RELAP5 will include calculation of the refill and reflood phases of the LOCA. The interphase friction in the downcomer was assumed to be negligible for all flow regimes as a result of the annular flow geometry.

3.5 Blowdown Loop Steam Generator Simulator and Pump Simulator

In the MOD-1 Semiscale system, the blowdown loop steam generator was simulated by two legs connected to form an inverted U tube. In each leg,

there are 7 three-hole orifice plates which were installed with the hole pattern rotated 60° from plate to plate. In the RELAP5 simulation the steam generator is modeled in the same manner as in RELAP4^[5]; i.e., by two legs connected in series to form an inverted U tube with 2 small orifices in each leg. The same orifice areas as used in the RELAP4 model^[5] were used. The MOD-1 pump simulator is a pipe with a constriction in each end and 14 three-hole orifice plates in series. This pump simulator is modeled in RELAP5, as in RELAP4, by a single volume with a small orifice at each end. Here again the orifice areas are the same as used in RELAP4^[5]. No special attempt was made to estimate the form loss coefficient for the simulators. All the losses are calculated routinely by the abrupt area change and choking models in RELAP5.

Figure 3. RELAP5 nodalization for Semiscale isothermal blowdown.

TABLE I

COMPONENT IDENTIFICATION FOR 200% BREAK (TEST S-01-4A) SEMISCALE

<u>Component No.</u>	<u>No. of Volume</u>	<u>Description</u>
C1, C440, C410	2, 1, 1	Intact loop hot leg pipe
C3	2	Steam generator inlet plenum
C5	4	Steam generator primary
C7	2	Steam generator outlet plenum
C9	6	Intact loop cold leg piping between steam generator outlet to pump inlet
C11	1	Pump
C13, C500, C511	1, 1, 1	Intact loop cold leg piping
C40	1	Inlet annulus
C41	12	Downcomer
C50	1	Lower plenum upper volume
C51	1	Lower plenum lower volume
C60	14	Core
C70	1	Upper plenum
C20	3	Broken loop cold leg piping
C30	2	Broken loop hot leg piping
C32	5	Broken loop simulated steam generator
C34	7	Broken loop piping and pump simulator
C100, C200	1, 1	Suppression tank
C410	2	Pressurizer surge line
C430	12	Pressurizer
C520	1	ECC injecting pipe
C540	1	Accumulator
C600	1	Steam generator secondary side

III. CALCULATED RESULTS

1. GENERAL

All calculated results are for a simulation of Semiscale Test S-01-4A (a 200% simulated double-ended break having the initial conditions 15.6 MPA pressure and 555°K uniform initial temperature). The location of the plotted parameters are referred to the component and volume numbers shown on the nodalization diagram, Figure 3, and further explained in Table I of Section II. The calculations were made both with and without wall heat transfer because the convective heat transfer routines are in an early state of checkout. The primary results are with calculated heat transfer, however, selected results for no calculated heat transfer are shown for comparison. Selected results for data comparison appear in the text while the remainder of the plotted results appear as Appendix D.

In all data comparisons, the data are for Semiscale MOD-1 Test S-01-4A and were obtained from Semiscale data tape, label MJJCLA14, volume serial number T9X859. This tape contains smoothed data and every tenth point was used in preparing the data comparisons. These data points were read into the RELAP5 plot routine for direct comparison to the calculated results.

2. SHORT-TERM RESULTS

The pressure response in the first 0.5 seconds is shown at both break locations. Figure 4 is the pressure at the vessel side of the break and Figure 5 is the pressure at the pump side of the break. The short-term response at the vessel side of the break, Figure 4, is in qualitative agreement with the data. Only the high frequency character of the data are not reproduced. The response at the pump side of the break is not as faithfully reproduced although some similarities are present as is evident from the comparison on Figure 5. The explanation for the differences at

the pump side of the break is that the model of the simulated pump and steam generator are highly simplified compared to the actual hardware. For example, the pump simulator consists of fourteen staggered orifice plates in series while only two orifice plates in series are used in the model. The effect of elbows and other minor plumbing irregularities are also neglected in the model. The slightly higher calculated pressure after the first tenth of a second, Figure 5, is most likely due to a higher assumed initial temperature (555°K) than actually existed in the experiment.

3. LONG-TERM RESULTS

The long-term calculations were carried out to 60 seconds (approximately the time of accumulator emptying and when nitrogen is injected into the system). ECC injection of 302.4°K water begins at 22 seconds and continues throughout the remainder of the simulated transient (60 seconds). The calculated results with heat transfer are compared to data on Figures 6 through 19, while the results without heat transfer are compared to data on Figures 20 through 22. Finally several examples of calculated results which clearly demonstrate nonhomogeneous and nonequilibrium behavior are presented on Figures 23 through 32.

Additional plots of long-term results are included as Appendix D. These results include pressures, void fractions, static qualities, phase temperatures and phase velocities for which data do not exist for comparison.

3.1 Pressurizer

The pressurizer pressure and temperature are shown on Figures 6 and 7, respectively. The pressure is in good agreement up to 20 seconds and the point of liquid emptying, the break in the curve at approximately 10 seconds, is in good agreement with the data. The calculated pressures beyond 20 seconds are higher than the data and may be due to over-

prediction of the heat transfer since results without heat transfer are in better agreement with the data. The difference between the calculated temperature, Figure 7, and the thermocouple data which occurs beyond 25 seconds is due to thermocouple dry out and influence of the pipe wall temperature.

3.2 System Pressures

The system calculated pressures are compared to data on Figures 8 through 11. Except at the pump side of the break, the pressures are in good agreement with data up to 20 seconds and are too high thereafter. Here again, too great a predicted heat transfer may be responsible. The pressure at the pump side of the break, Figure 11, is in good agreement with data at early and late times, but shows a sudden drop at about 18 seconds. The sudden drop is due to internal choking occurring at the second pump simulator orifice. Only two orifices in series are used to model the fourteen orifice plate turbine simulator, which explains the abrupt pressure drop rather than the smooth drop shown by the data.

3.3 System Densities

The calculated densities are compared to the data at several points in the system on Figures 12 through 17. Most of the calculated densities show an early drop compared to the data. This difference can probably be explained by the fact that the actual vapor formation is mostly at the walls which would lead to an inverted annular flow with low interphase drag, while the calculational model assumes a bubbly dispersed flow with high interphase drag. The calculated slip is thus less and greater liquid transport results.

After ECC injection begins, the calculated results bear a marked similarity to the data as slugs of liquid are transported through the system. Figure 12 is a plot of density at a point between the pump and the ECC injection point in the intact loop. A periodic process in which slugs of ECC water are drawn

into the pump discharge and then expelled is clearly evident. The density downstream of the ECC injection point is shown plotted on Figure 13. Very good agreement between the calculated results and data is obtained. The density at the vessel side of the break is shown on Figure 14. Here again there is marked similarity between the calculated results and the data. The carry over effect is clearly evident as slugs of liquid appear at the break. No special models were used to simulate this effect; i.e., a RELAP5 TEE model was used for the downcomer inlet annulus. The density at the pump side of the break is shown on Figure 15, which has the same characteristic as the pressure at this point; i.e., a sudden drop at 18 seconds corresponding to when choking occurred at the second pump simulator orifice. On Figure 15 the agreement with data is good at both early and late times.

The densities at the lower plenum are shown on Figures 16 and 17. The calculated density in the upper volume of the lower plenum (two volumes are used to model the plenum) is compared to the density measured at the downcomer exit. Quite good agreement is obtained, although the calculated densities appear high at times beyond 30 seconds. The bottom volume density in the lower plenum is shown on Figure 17 compared to the diagonal or average lower plenum density measurement. When the calculated densities of both volumes (Figures 16 and 17) are averaged, quite good agreement with the data from the diagonal densitometer on Figure 17 is obtained.

3.4 Break Mass Flows

The calculated break mass flows are compared to data on Figures 18 and 19. Here again quite good agreement with data is obtained. The early time flow at the vessel side of the break is high up to about 8 seconds. This fact is consistent with the early drop in density calculated to exist at most points in the system. Vapor formation at the walls and inverted

annular flow would result in a lower mass flow at the break. The peaks in mass flow rate which occur at approximately 50 seconds, Figure 18, are due to slugs of ECC water arriving at the break. The mass flow at the pump side of the break shown on Figure 19 is everywhere in good agreement with the data.

3.5 Adiabatic Results

The results calculated assuming no heat transfer from the system piping and vessel are shown on Figures 20 through 22. The upper plenum pressure is shown on Figure 20 and should be compared to Figure 8 for the result with heat transfer. The very good agreement with data shown on Figure 20 beyond 30 seconds tempts one to conclude that the heat transfer is overpredicted. However, when the densities in the lower plenum are examined, Figures 21 and 22 (see Figures 16 and 17 for the comparable result with heat transfer), one is forced to conclude that heat transfer is not entirely responsible since the calculated lower plenum densities are in better agreement with the data for the case with heat transfer.

3.6 Selected Results Without Data Comparisons

Calculated results for which there are no data for comparison, but which illustrate the ability of the code to model flooding, nonequilibrium and nonhomogeneous flow phenomena are presented on Figures 23 through 32. Figures 23 through 28 are plots of the void fraction at the top of the downcomer, the bottom of the core, the top of the core, and the upper plenum. The dumping or periodic flow of liquid down the downcomer is clearly illustrated by the results shown on Figures 23 and 24. Flooding of the lower core plate is evident from the results shown on Figures 25 and 26 wherein the void fraction at the bottom of the core (above the

lower core plate) is lower; i.e., more liquid, than in the lower plenum. This same phenomena occurs at the top of the core as shown on Figures 27 and 28. At most points in the transient the void fraction is lower in the upper plenum than beneath the upper core plate at the top of the core. Thus the flooding phenomenon is predicted by means of the RELAP5 mechanistic models which are employed at points of abrupt area change.

An example of calculated thermal nonequilibrium is given in the results shown on Figures 29 and 30. Figure 29 is vapor temperature just downstream of the ECC injection point. Figure 30 is the liquid temperature at the same point. Note that approximately 100°K temperature difference is predicted to exist at 45 seconds. At about 55 seconds the phases return to near equilibrium (a quiescent period) and then depart again due to convection of cold ECC (302.4°K) water into the volume.

An example of calculated nonhomogeneity (slip) is illustrated on Figures 31 and 32. The liquid and vapor velocities, respectively, are plotted for a point at the top of the downcomer. For both of these plots the positive direction is down the downcomer. Note that the liquid flow is generally positive, down, while the vapor flow is generally negative, up the downcomer; i.e., countercurrent flow.

Figure 4. Short term pressure response at vessel side of break

Figure 5. Short term response at pump side of break

Figure 6. Pressurizer pressure

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PRESSURIZER (V43001)

Figure 7. Pressurizer temperature

Figure 8. Upper plenum pressure

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

LOWER PLENUM (V5001)

Figure 9. Lower plenum pressure

Figure 10. Pressure at the vessel side of the break

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PUMP SIDE OF BREAK (V3407)

Figure 11. Pressure at the pump side of the break

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

COLD LEG CT-13 (VS1001)

Figure 12, Density at the pump discharge

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

VESSEL SIDE OF BREAK (V2003)

Figure 14. Density at the vessel side of the break

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PUMP SIDE OF BREAK (V3407)

Figure 15. Density at the pump side of the break

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

LOWER PLENUM (V5001)

Figure 16. Density at the downcomer discharge

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

LOWER PLENUM LOWER VOLUME (V5101)

Figure 17. Calculated density in the bottom volume of the lower plenum compared to diagonal densitometer density

Figure 18. Mass flow rate at the vessel side of the break

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PUMP SIDE OF BREAK (J90)

Figure 19. Mass flow rate at the pump side of the break

Figure 20. Upper plenum pressure for no heat transfer

Figure 21. Density at downcomer discharge without heat transfer

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

LOWER PLENUM LOWER VOLUME (V5101)

Figure 22. Calculated density for no heat transfer in bottom volume of lower plenum compared to diagonal densitometer density

Figure 23. Void fraction at downcomer inlet

Figure 24. Void fraction at downcomer discharge

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

LOWER PLENUM (V5001)

Figure 25. Void fraction in lower plenum

Figure 26. Void fraction above lower core plate

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6011)

Figure 27. Void fraction at top of core

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

UPPER PLENUM (V7001)

Figure 28. Void fraction in upper plenum

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

COLD-LEG (V1301)

Figure 29. Vapor temperature downstream of ECC injection point

Figure 30. Liquid temperature downstream of ECC injection point

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (J4102)

Figure 31. Liquid velocity at top of downcomer
(positive direction is down)

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
DOWNCOMER (J4102)

Figure 32. Vapor velocity at top of downcomer
(positive direction is down)

IV. CODE RUNNING TIME ANALYSIS

1. GENERAL

The RELAP5 code uses an automatic time step control algorithm which controls mass truncation error. The use of this technique is the primary reason that fast overall execution times have been achieved in code testing on sample problems. In addition, the automatic time step control feature aids in the elimination of water packing and phase transition problems encountered with similar codes.

The RELAP5 simulation of the MOD-1 Semiscale isothermal blowdown to 60 seconds has been run in 54 minutes of CDC 7600 CPU time. However, this time is at least a factor of three slower than anticipated based on previous experience with the code. In addition, test runs to 20 seconds with minor modifications to the code have been run in 4.5 minutes of CPU time. Thus, the purpose of this task was to investigate what is requiring the bulk of the run time and thereby determine how further run time economies could be effected. The results of this effort are reported herein.

2. TIME STEP CONTROL ALGORITHM

The RELAP5 time step control algorithm is based on the difference between density calculated from a conservative form of the mass continuity equation and density calculated from the transformed continuity equation (in terms of pressure, quality and energy), the equation of state, the static quality equation and the energy equation. This latter density is the one calculated in the course of the basic RELAP5 numerical semi-implicit integration. The difference between these two density values is a measure of the local mass truncation error.

The time step is selected such that the density error is maintained between preset limits. If at any time advancement the error exceeds the limits, that solution is discarded and the advancement is repeated using a smaller time step. On the other hand, if the error is smaller than a preset limit then the next advancement is made using a larger time step. The actual process includes other considerations besides error bounds and consists of the following four tests.

1. If the static quality is advanced to a value less than 0.0 or greater than 1.0, it is reset to the appropriate limit and the advancement is marked unsuccessful.
2. If the extrapolation to define water properties in the metastable states associated with flashing liquid or condensing vapor is greater than 10%, the advancement is marked unsuccessful.
3. If the density difference is greater than 10^{-4} , the advancement is marked unsuccessful.
4. If the pressure, static quality, or internal energy correspond to a thermodynamic state outside the range of the water property subroutines, the advancement is marked unsuccessful.

If the advancement is unsuccessful, the time step is halved and compared to the input minimum time step. If the halved time step is greater, than the minimum, the advancement is repeated with the halved time step. If the halved time step is smaller than the minimum, the unsuccessful advancement is accepted unless a water property failure occurred in which case the transient is terminated.

The first advancement is attempted with the user input maximum time step. If this or a subsequent advancement is unsuccessful, the time step

is halved. The halving of the time step continues until either a successful advancement is made, the advancement is accepted because of the minimum time step being reached, or the advancement is terminated.

When an advancement is successful and the density error (test 3) is less than 10^{-4} , the time step for the next advancement is doubled.

3. TIME STEP DIAGNOSTIC ADDITIONS

Transient results are plotted and printed at user selected multiples of the requested maximum time step. Major edits list all quantities advanced in time and is quite voluminous. Minor edits list only user selected quantities using a minimal amount of paper. When the Semiscale simulation task using RELAP5 was initiated, the only technique for obtaining debug output was through use of plot, minor, and major edits at each successful advancement and, after a failure, the last time step is repeated with most of the interim quantities printed.

As checkout of the Semiscale model proceeded, the need for more information concerning time step control became evident. Small model changes were having inordinate effects on time step sizes and hence run times. The following statistics are now accumulated and listed at each major edit: (1) the number of attempted advancements; (2) the number of repeated advancements; (3) the number of successful advancements; (4) for each volume, the number of times it had the highest density error, the lowest Courant limit, and the number of times it caused repeat advancements due to quality, extrapolation, density error, water property error, and Courant limit; and (5) for each junction, the number of times it was choked. These are accumulated both over the entire problem and over each major edit. The minimum, maximum, and average time step over a major edit are also listed.

4. TIME STEP ANALYSIS

The time step diagnostic routines were applied to the Semiscale isothermal blowdown run to 10 seconds of simulated transient time in order to accumulate statistics for analysis. During this run the time step was reduced a total of 1246 times for the following reasons:

(1) 996 times for excessive mass error, (2) 243 times for Courant limit exceeded, (3) 5 times for water property extrapolation limits and (4) 2 times for water property range exceeded. The most frequent cause for time step reduction was excessive mass errors. When mass error was responsible for time step reduction they occurred in fluid volumes having the following characteristics or processes:

1. Abrupt-Area changes
2. Choking (internal and at breaks)
3. Small volume, small diameter pipes

The components that caused most of the repeated time steps were the steam generator simulator and pump simulator in the broken loop. These components contain a few orifices having 15% - 85% abrupt area reductions that are used to model many orifice plates in series in the actual component. These two components caused 644 time steps to be repeated. These components were modeled using the abrupt area change model and internal choking was occurring intermittently.

Other components that contributed to repeated time steps were the breaks and pressurizer. The breaks were modeled with the abrupt area change model and choking occurred predominantly, resulting in 103 repeated advancements.

5. CANDIDATE RUN TIME IMPROVEMENTS

The preliminary results from the time step diagnostic analysis indicate several areas for potential run time improvement. In particular, the number of repeated time steps can be reduced and the average time step increased by more consistent nodalization and the avoidance of small volume and/or short length volumes which tend to be mass error and Courant number limited by smoothing transitions due to flow regime effects and choking and by simplified modeling of some flow losses.

Test runs with a reduced number of nodes have demonstrated that the first 20 seconds of the Semiscale simulation can be run in 4.5 minutes of CDC 7600 CPU time. This is a factor of 1/4 reduction of time required to produce the Semiscale results reported herein (up to 20 seconds simulated time).

Further run time improvements can be effected by smoothing transitions between regions of the flow regime maps and between choked and unchoked flow. These improvements will require refinement of the current models and consequently have not been tested.

The Semiscale simulation run time can be improved significantly by changing the technique for modeling the simulated steam generator and pump simulator. These components containing many orifice plates in series which were modeled using only 4 and 2 orifices respectively in series. The orifice calculations use the mechanistic abrupt area change models and this results in a situation where a very detailed hydrodynamic model is applied to a highly simplified representation of the actual physical situation. A more consistent and efficient approach is to approximate the distributed losses in these components by simple form loss factors. This approach would provide a smoother pressure drop and result in less frequent occurrence of choked flow.

In summary, it is feasible to accomplish significant run time reduction. A target time for the Semiscale problem included herein is 20 minutes of CDC 7600 CPU time (a decrease by a factor of 1/3) without renodalization and 15 minutes with a 25% reduction in number of nodes. Both of these calculations would result in accurate and acceptable simulations of the Semiscale isothermal blowdown.

V. CONCLUSIONS

The basic RELAP5 systems code is now fully operational and has been applied successfully to the Semiscale isothermal blowdown. This task was accomplished using a larger number of fluid control volumes than is available in the RELAP4 code.

The Semiscale isothermal blowdown to 60 seconds includes 38 seconds of subcooled ECC injection. The RELAP5 code correctly simulated this process without recourse to "water packing" fixes or any special treatment of this process. Significant nonhomogeneous and nonequilibrium conditions were predicted to accompany the ECC injection process.

The break mass discharge rates were predicted within the uncertainty band of the data without recourse to discharge coefficients or any adjustment to the nozzle throat areas. This was accomplished using the RELAP5 break flow model^[3] without recourse to fine or special nodalization at the break.

Flooding phenomena were predicted to exist at area constrictions in the core caused by core spacer plates. This result is a direct benefit of the mechanistic two-phase abrupt area change model^[2] developed for and employed in RELAP5. Further testing will be required to demonstrate the accuracy of flooding calculations, but this model will be very useful for modeling core quenching from above as a result of upper head injection.

Two facets of the simulation results indicate a need for further development:

First, the early time drop in density compared to data indicates that wall heat transfer effects may have to be

considered in flow regime selection, i.e., inverted annular or stratified flow may exist at low void fractions due to vapor formation at the walls.

Second, the convection heat transfer may be overpredicted due to error or misapplication of the correlations which results in too great a vapor formation rate throughout the system and, as a result, system pressures which are too high after ECC injection begins.

The computer time required for the RELAP5 Semiscale simulation was at least a factor of three faster than comparable results produced using RELAP4. However, time step analysis indicated that these times may be shortened by a factor of one-half to one-third by smoothing transitions associated with flow regime, abrupt area change and choking.

VI. REFERENCES

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APPENDIX A

RELAP5 SYSTEM CODE STRUCTURE AND DESCRIPTION

✓ Not scheduled for MOD"0"

* Further breakdown follows

FIGURE A-1. RELAP5 TOP LEVEL STRUCTURE

RELAP5

RELAP5 is the main program that routes control to the processing options based on information received from INPUT.

INPUT

INPUT controls all input data processing.

STSTAT

STSTAT controls solution of steady-state problem.

TRNSIS

TRNSIS controls modification necessary to switch from a steady-state problem to a transient problem.

TRNCTL

TRNCTL calls a subroutine to perform the final preparation for a transient advancement and calls the subroutine that controls the advancement.

PLOTMD

PLOTMD does the plotting of results either from transient data just computed or from data obtained from a restart-plot file.

REEDIT

REEDIT does the re-editing of data obtained from a restart-plot file.

STRIP

STRIP extracts user specified data from the restart-plot file and writes on another file in a form easily used by other programs (e.g., FRAP, data bank).

FIGURE A-2. RELAP5 INPUT LEVEL STRUCTURE

GNINIT

GNINIT performs once only initialization including setting fixed common block lengths and clearing them to zero.

RCARDS

RCARDS reads all the input data for a case and recognizes when all cases have been processed.

INP2

INP2 is an environmental library subroutine used to fetch data from the input pool. In the usage indicated on the RELAP5 INPUT Level Structure chart, it reads the problem type and routes control to the appropriate input processing subroutine.

RNEWP

RNEWP controls "R" and "I" level input processing for a new problem.

RDRST

RDRST controls "R" and "I" level input processing for a restart problem. (At present, time step and output frequencies, minor edit specifications and trips may be changed at restart.)

RPLOT

RPLOT processes input data for plotting from a restart-plot file.

RDREDT

RDREDT processes the input data for re-editing from a restart-plot file.

RSTRIP

RSTRIP processes input data for extracting data from a restart-plot file.

FIGURE A-3. RELAP5 RNEWP LEVEL STRUCTURE

RRSTD

RRSTD is a "R" level subroutine that processes the card indicating whether a restart-plot file is to be generated.

RTSC

RTSC is a "R" level subroutine that processes time step control information.

RMIEDT

RMIEDT is a "R" level subroutine that processes minor edit request data.

RCOMP

RCOMP is a "R" level subroutine that controls the processing of hydrodynamic component data.

RHTCMP

RHTCMP is a "R" level subroutine that processes heat structure data.

RGNTBL

RGNTBL is a "R" level subroutine that processes general table data such as power versus time, temperature versus time, etc.

RMADAT

RMADAT is a "R" level subroutine that processes thermal conductivity and heat capacity data.

RTRIP

RTRIP is a "R" level subroutine that processes trip data.

ITRIP

ITRIP is an "I" level subroutine that completes the processing of trip data.

ICOMP

ICOMP is an "I" level subroutine that, with lower level subroutines, completes the processing of hydrodynamic component data.

IHTCMP

IHTCMP is an "I" level subroutine that completes the processing of heat structure data, thermal properties, and source data, and initializes temperatures and heat transfer rates from a steady-state calculation.

IMI EDT

IMI EDT is an "I" level subroutine that completes the processing of minor edit data.

FIGURE A-4. RELAP5 RNEWP "R" LEVEL STRUCTURE

RSNGV

RSNGV is a "R" level subroutine that processes data for a single volume hydrodynamic component.

RSNGJ

RSNGJ is a "R" level subroutine that processes data for a single junction hydrodynamic component.

RTMDPV

RTMDPV is a "R" level subroutine that processes data for a time dependent (or boundary conditions) hydrodynamic volume.

RTMDPJ

RTMDPJ is a "R" level subroutine that processes data for a time dependent (or boundary condition) hydrodynamic junction.

RPIPE

RPIPE is a "R" level subroutine that processes data for a pipe hydrodynamic component.

RBRNCH

RBRNCH is a "R" level subroutine that processes data for a hydrodynamic branch (also tee although tee will eventually have its own subroutine).

RPUMP

RPUMP is a "R" level subroutine that processes input data for a pump.

RVALVE

RVALVE is a "R" level subroutine that processes input data for a valve.

RACUML

RACUML is a "R" level subroutine that processes input data for an accumulator.

FIGURE A-5. RELAP5 RNEWP "I" LEVEL STRUCTURE

STH2XI

STH2XI is an environmental subroutine that brings the water property file from disk.

ITRSCN

ITRSCN is an "I" level subroutine that checks for valid trip reference. (Also called by other "I" level subroutines).

ISTATE

ISTATE is an "I" level subroutine that uses various STH2X water property subroutines to initialize the hydrodynamic volumes to the conditions specified in the input.

IPIPE

IPIPE is an "I" level subroutine that completes the processing of hydrodynamic pipe data.

ISNGJ

ISNGJ is an "I" level subroutine that completes the processing of most junction data except junctions interior to a pipe.

IJPROP

IJPROP is an "I" level subroutine that computes the convected quantities in the hydrodynamic continuity and energy equations. (Similar to JPROP in transient phase.)

INVJT

INVJT is an "I" level subroutine that prepares an inverted junction table, i.e., a volume oriented table containing the number and locations of junctions attached to the inlet and outlet sides of volumes.

IEDIT

IEDIT writes a summary of hydrodynamic volume and junction conditions after completion of input processing.

INVOLV

INVOLV is an "I" level subroutine that computes the volume velocity.

FIGURE A-6. RELAP5 TRANSIENT CONTROL STRUCTURE

TRNSET

TRNSET brings required data from disk into SCM and LCM memory and performs all the final chores to enable efficient advancement of the transient calculations.

TRAN

TRAN controls the transient advancement.

DTSTEP

DTSTEP controls the time step sizes and determines when plotting, minor edits, major edits, and restart processing is to occur.

HYDRO

HYDRO controls the advancement of the hydrodynamics.

HTADV

HTADV controls the advancement of the heat structures.

IREKN

IREKN advances the space independent reactor kinetics.

TRIP

TRIP evaluates the trip conditions.

FIGURE A-7. RELAP5 DTSTEP LEVEL STRUCTURE

MOVER

MOVER moves hydrodynamic variables from new to old (old to new) time values if a time advancement is successful (unsuccessful).

PLTREC

PLTREC writes plotting information to the restart-plot file.

PLTWRT

PLTWRT writes user selected plot information to a scratch file for immediate plotting after completion of transient advancement.

MIREC

MIREC saves user selected data and prints a minor edit whenever fifty time frames have been saved.

RSTREC

RSTREC writes restart information to the restart-plot file.

OUTPUT

OUTPUT prints the major edit of transient results.

FIGURE A-8. RELAP5 HYDRO STRUCTURE

JPROP

JPROP computes the convected quantities in the hydrodynamic continuity and energy equations.

MDOT

MDOT computes terms for the liquid-vapor transfer model using derivatives computed in STATE.

DRAG

DRAG computes wall friction, added mass, and interphase friction terms.

HLOSS

HLOSS computes loss terms due to abrupt area change.

VEXPLT

VEXPLT does an explicit advancement of the momentum equations, and computes terms for incorporation of the implicit form of the momentum equation into the pressure equation.

PRESEQ

PRESEQ builds the matrix elements resulting from substituting the momentum sum and difference equations, the energy equation, and the continuity difference equation into a pressure equation which was obtained from the continuity sum equation and the equation of state.

SYSSOL

SYSSOL solves the simultaneous pressure equations formed by PRESEQ.

VFINL

VFINL computes the new time velocities using pressures from SYSSOL and terms saved from VEXPLT.

EQFINL

EQFINL computes new time internal energy and static quality for hydrodynamic volumes using pressures from SYSSOL.

STATE

STATE uses the equation of state to compute density, temperature, equilibrium quality, and various derivatives given pressure, internal energy, and static quality.

PUMP

PUMP computes pump rotational speed, head term for use in momentum equation, and dissipation term for energy equation.

VALVE

VALVE computes flow area and loss effects for use in momentum and energy equations.

FIGURE A-9. RELAP5 HTADV STRUCTURE

HTADV

HTADV controls the time advancement of heat structure temperatures and heat transfer rates and computes the heat input to hydrodynamic volumes from heat structures.

HTITDP

HTITDP advances in time the heat structure temperatures and heat transfer rates.

MADATA

MADATA evaluates the thermal conductivity and volumetric heat capacity for heat structures.

HTCOND

HTCOND evaluates the boundary conditions for heat structures.

HTRC1

HTRC1 evaluates heat transfer coefficients as a function of surface temperature and hydrodynamic conditions. This subroutine uses the RELAP4/MOD6 HTS2 heat transfer correlations.

CHFCAL

CHFCAL evaluates the critical heat flux as a function of surface temperature and hydrodynamic conditions. This subroutine uses correlations from RELAP4/MOD6 HTS2.

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RELAP5 SYSTEM CODE INPUT DATA REQUIREMENTS

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RELAP5 INPUT DATA REQUIREMENTS

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1.0 CARD_100, PROBLEM TYPE AND OPTION

This card is always required.

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

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

2.0 CARD_101, INPUT CHECK OR RUN OPTION

This card is optional.

W1(A) OPTION. Enter either INP-CHK or RUN; if card is omitted, RUN is assumed.

3.0 CARD_102, UNITS SELECTION

This card is optional. If card is omitted, SI units are assumed for both input and output. If card is used, enter either SI or BRITISH for each word.

W1(A) INPUT UNITS.

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

4.0 CARD_103, RESTART INPUT FILE CONTROL CARD

This card is required for all problem types (W1 of Card 100) except NEW.

W1(I) RESTART NUMBER.

RELAP5 Input Data Requirements

W2(A) ID. Id for attach of permanent file.

W3-W6(A) PERMANENT FILE NAME. Words 2 through 6 are used if the restart file is to be obtained from a permanent file. These words are not used if the file is already a local file or is being staged.

5.0 CARD_1042-RESTART-PILOT-FILE-CONTROL-CARD

This card can be entered for NEW, RESTART, and STRIP options. For the strip option, this card controls the strip file and the NONE option is not allowed. If this card is omitted, the default action on the Restart-Plot file is the same as the NOACTION option. To prevent the Restart-Plot file from being written, a card with NONE must be entered.

W1(A) ACTION OR ID FIELD. This word may not be blank. If NONE the file is rewound at the end of the problem but no further action is taken and the user should provide system control cards (REQUEST, STAGE, CATALOG, etc.) to dispose of file. If STAGE is entered, the file will be staged to tape when a RETURN(RSTPLT) control statement or end of job is reached. If STAGE-RTN is entered, the action is the same as for STAGE except that the file is immediately returned. If not blank and none of the above, this word is assumed to be an ID for cataloguing the Restart-Plot file as a permanent file. Only nine characters are allowed and the next word must be nonblank.

W2-W4(A) PERMANENT FILE NAME. These words are entered only if the Restart-Plot file is to be catalogued as a permanent file. The permanent file name can be up to forty characters. The Restart-Plot file is always returned at the beginning of a problem that writes a Restart-Plot file and this can limit the options in multiple case input.

6.0 CARDS_201-299-TIME-STEP-CONTROL-CARDS

At least one card of this series is required. Card numbers need not be consecutive.

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

W2(R) MINIMUM TIME STEP (sec).

RELAP5 Input Data Requirements

W3(R) MAXIMUM TIME STEP (sec).

W4(I) TIME STEP CONTROL OPTION. If d00 is entered, no time step control is used and the maximum time step (W3) is attempted for both hydrodynamic and heat structure advancement. The hydrodynamic time step will be reduced to material transport limit and for water property failures. If d01 is entered, heat transfer uses maximum time step and hydrodynamics uses error based on density check to control time step between minimum and maximum time step. The letter, d, which represents a number from 0 through 7 can be used to obtain extra output at every hydrodynamic time step. This number is treated as a three bit number consisting of a four bit, a two bit, and a one bit. If no bits are set, i.e., the number is 0, the standard output at the maximum time step is obtained. If the number is nonzero, output is obtained at each time step, and the bits indicate which output is obtained. If the one bit is on, major edits are obtained every time step, if the two bit is on, minor edits are obtained, and if the four bit is on, plot records are written every time step. These options should be used carefully since considerable output can be generated.

W5(I) MINOR EDIT AND PLOT FREQUENCY. Number of maximum time advances per minor edit and write of plot information.

W6(I) MAJOR EDIT FREQUENCY. Number of maximum time advances per major edit.

W7(I) RESTART FREQUENCY. Number of maximum time advances per write of restart information.

7.0 CARDS 301-399 MINOR EDIT REQUESTS

These cards are optional. If not present, no minor edits are printed. If 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.

W1(A) VARIABLE CODE.

W2(I) PARAMETER.

The quantities that can be edited and the required input are listed below. For convenience, quantities that can be used in plotting requests and trip specifications are also listed.

RELAP5 Input Data Requirements

7.1 GENERAL QUANTITIES

Code	Quantity
TIME	Time. The parameter is 0. This specification cannot be used for minor edit requests.
TIMEOF	Time of trip occurring. Parameter is trip number. This specification is allowed only on trip cards.
NULL	Specifies null field; allowed only on trip cards.

7.2 COMPONENT RELATED QUANTITIES

7.3 VOLUME RELATED QUANTITIES

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

Code	Quantity
RHO	Total density
RHOF	Liquid density
RHOG	Vapor density
U	Specific internal energy
UF	Specific liquid internal energy
UG	Specific vapor internal energy
VOIDF	Liquid void fraction
VOIDG	Vapor void fraction
VELF	Volume oriented liquid velocity
VELG	Volume oriented vapor velocity
P	Volume pressure
QUALS	Volume static quality
QUALE	Volume equilibrium quality
Q	Volume heat source
TEMPF	Volume liquid temperature
TEMPG	Volume vapor temperature
TEMP	Volume equilibrium temperature
SOUNDE	Volume sonic velocity

7.4 JUNCTION RELATED QUANTITIES

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

Code	Quantity
VELFJ	Junction liquid velocity
VELGJ	Junction vapor velocity
VELJ	Interface velocity
RHOFJ	Junction liquid density

RELAP5 Input Data Requirements

RHOGJ	Junction vapor density
UFJ	Junction liquid internal energy
UGJ	Junction vapor internal energy

7.5 HEAT STRUCTURE RELATED QUANTITIES

For the request code, HTPOW, the parameter is the heat structure-geometry number. For the remaining codes, the parameter is the structure-geometry number with a two digit code appended. For codes other than HTEMP, the code is 00 for the left boundary and 01 for the right boundary. For HTEMP, the code is the mesh point number.

Code	Quantity
HTPOW	Power input
HTRNR	Heat transfer rate
HTCHF	Critical heat flux
HTHTC	Heat transfer coefficient
HTEMP	Mesh point temperature

9.0 CARDS 500-599, IRIP INPUT DATA

These cards are optional.

9.1 CARD 500, 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 and all reentered trips are initialized to false.

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

9.2 CARDS 501-599, 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. The trip number is the same as its card number and trip numbers need not be consecutive. 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. Trips for new problems or trips introduced on restart are initialized to false.

RELAP5 Input Data Requirements

The variable codes and parameters are the same as described for minor edits, Section 7.0. NULL is allowed for the right side when only a comparison to the constant is desired. The parameter to be used with NULL is 0. The variable code TIMEOF with the parameter set to the trip number indicates the time at which the trip was last set.

- W1(A) VARIABLE CODE. On restart problems, this word can also contain DISCARD or RESET. DISCARD deletes the trip; RESET sets the trip to false. If DISCARD or RESET are entered, no further words are needed on the card.
- W2(I) PARAMETER.
- W3(A) RELATIONSHIP. May be either EQ, NE, GT, GE, LT, or LE, where the symbols have the standard Fortran meaning.
- W4(A) VARIABLE CODE.
- W5(I) PARAMETER.
- W6(R) ADDITIVE CONSTANT.
- W7(A) LATCH INDICATOR. If L, the trip once set true, remains true even if the condition later is not met. If N, the trip is tested each time advancement.

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 not 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.

9.3 CARDS 601-699, 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 Cards 501-599.

RELAP5 Input Data Requirements

- W1(I) TRIP NUMBER. The absolute value of this number must be one of the trip numbers defined by the 501-599 or 601-699 cards. A minus trip number indicates that the complement of the trip is to be used in the test.
- W2(A) OPERATOR. May be AND, OR, or XOR. 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 needed on the card and W1 is ignored.
- W3(I) TRIP NUMBER. Similar to W1.
- W4(A) LATCH INDICATOR. If L, the trip when set remains set. If N, the trip is tested each time advancement.

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

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

9.4 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.

- W1(I) TRIP NUMBER.
- W2(I) TRIP NUMBER. A second trip number need not be entered.

10.0 CARDS CCCXNN, HYDRODYNAMIC COMPONENTS

At least one volume must be described on these cards. The hydrodynamic card numbers are divided into fields where CCC is the component number and 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.

10.1 CARD CCC0000 COMPONENT NAME AND TYPE

This card is required for each component.

RELAP5 Input Data Requirements

W1(A) COMPONENT NAME. Use name descriptive of component's use in system.

W2(A) COMPONENT TYPE. Enter one of the following component types, SNGLVOL, TMDPVOL, SNGLJUN, TMDPJUN, PIPE, PUMP, BRANCH, or VALVE.

The remaining cards for each component are dependent on the type of component.

10.2 SINGLE VOLUME COMPONENT

A single volume component is indicated by SNGLVOL on card CCC0000. In junction references, the inlet code for this component is CCC000000 and the outlet code is CCC010000. Only one junction may be connected to the inlet and only one junction may be connected to the outlet. If a junction is not specified for an end, that end is considered a closed end.

10.2.1 Cards CCC0101-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 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. If none of the words are zero, they must satisfy the volume equals area times length within a relative error of 0.000001.

W4(R) ANGLE FOR HORIZONTAL ORIENTATION (deg). The absolute value of this angle must be less than 360 deg. This quantity is not used in the calculation but is specified for possible automated drawing of noding diagrams.

W5(R) ANGLE FOR VERTICAL ORIENTATION (deg). The absolute value of this angle must be less than 90 deg. The angle 0 deg is horizontal and positive angles have an upward direction.

RELAP5 Input Data Requirements

- W6(R) ELEVATION CHANGE (m, ft). A positive value is an increase in elevation. The absolute value of this quantity must be less than the volume length.
- W7(R) PIPE ROUGHNESS (m, ft).
- W8(R) HYDRAULIC DIAMETER (m, ft). If zero, the hydraulic diameter is computed from $2.0 * (\text{VOLUME AREA} / \text{PI})^{0.5}$.
- W9(I) VOLUME CONTROL FLAG. Enter fe where f is zero if wall friction effects are to be computed for the volume, f is 1 if wall friction is not to be computed, e is 0 for non-equilibrium (unequal temperature) and 1 for equilibrium (equal temperature) calculation.

10.2.2 Card_CCCQ2Q0_Single_Volume_Initial_Condition

This card is required for a single volume.

- W1(I) CONTROL WORD. If 0, the next three words are Pressure (Pa, lbf/in²), internal energy (J/kg, Btu/lb), and static quality; these quantities will be interpreted as non-equilibrium or equilibrium conditions depending on volume control flag. If 1, the next three words are temperature (K, degF), quality, and a zero. If 2, the next three words are Pressure (Pa, lbf/in²), quality, and a zero. If 3, the next three words are pressure (Pa, lbf/in²), temperature (K, degF), and a zero. The last three options always specify equilibrium conditions.
- W2-W4(R) QUANTITIES AS DESCRIBED UNDER W1.

10.3 TIME DEPENDENT VOLUME COMPONENT

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

10.3.1 Cards_CCCQ1Q1-CCCQ1Q9_Time-Dependent-Volume-Geometry

This card (or cards) is required for time dependent volumes and the card format is identical to the card(s) for a single volume (10.2.1).

RELAP5 Input Data Requirements

10.3.2 Card_CCC0200, Time-Dependent-Data-Control-Word

This card is required for time dependent volume components.

W1(I) CONTROL WORD FOR TIME DEPENDENT DATA ON CCC02NN CARDS. If 0, table has four word sets containing time (sec), pressure (Pa, lbf/in**2), internal energy (J/kg, Btu/lb), and static quality. If 1, table has three word sets containing time (sec), temperature (K, degF), and quality. If 2, table has three word sets containing time (sec), pressure (Pa, lbf/in**2), and quality. If 3, table has three word sets containing time(sec), pressure (Pa, lbf/in**2), and temperature (K, degF). The first type allows either non-equilibrium or equilibrium conditions depending on the volume control flag. The last three types allow only equilibrium conditions.

10.3.3 Cards_CCC0201-CCC0299, Time-Dependent-Volume-Data-Cards

These cards are required for time dependent volume components. The card numbers need not be consecutive, but time in a succeeding set must be equal or greater than time in the previous set. One or more sets of data up to 100 sets as described in 10.3.2 are allowed. Linear interpolation is used if the time argument lies between table entries. End point values are used if the time argument lies outside the table values. Thus only one set is needed if constant values are desired for all times. Step changes can be accommodated by entering the two adjacent sets with the same time or an extremely small time difference. Given two identical time values, the set selected will be the closest to the previous time value. Sets may be entered one or more per card or may be split across cards. The total number of words must be a multiple of either three or four depending on the control word (10.3.2).

10.4 SINGLE JUNCTION COMPONENT

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

10.4.1 Card_CCC0101, Single-Junction-Geometry-Card

This card is required for single junction components.

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- W1(I) FROM CONNECTION CODE TO A COMPONENT.
- W2(I) TO CONNECTION CODE TO A COMPONENT.
- W3(R) JUNCTION AREA (m**2, ft**2). If zero, area is set to minimum volume area of the adjoining volumes. For abrupt area changes, the junction area must be equal to or smaller than the minimum of the adjoining volume areas. For smooth area changes, there are no restrictions.
- W4(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.
- W5(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.
- W6(I) JUNCTION FLAGS. A four digit number, cahs, is entered where c=0 means that the choking model is to be applied, c=1 means that the choking model is not to be applied, a=0 means either a smooth area change or no area change, a=1 means an abrupt area change, h=0 means two velocity, h=1 means drift flux approximation, h=2 means one velocity, s=0 means full inertia treatment, s=1 means pseudo-steady state approximation.

10.4.2 Card CCC0201, Single Junction Initial Conditions

This card is required for single junction components.

- W1(I) CONTROL WORD. If 0, next two words are velocities, if 1, next two words are flows.
- W2(R) INITIAL LIQUID VELOCITY. This quantity is either velocity (m/sec, ft/sec) or flow (kg/sec, lb/sec) depending on the control word (W1).
- W3(R) INITIAL VAPOR VELOCITY. This quantity is either velocity (m/sec, ft/sec) or flow (kg/sec, lb/sec) depending on the control word (W1).
- W4(R) INTERFACE VELOCITY (m/sec, ft/sec).

10.5 TIME DEPENDENT JUNCTION COMPONENT

This component is indicated by TMDPJUN on Card CCC0000.

RELAP5 Input Data Requirements

10.5.1 CARD CCC0101 TIME DEPENDENT JUNCTION GEOMETRY

This card is required for time dependent junction components.

W1(I) FROM CONNECTION TO A COMPONENT.

W2(I) TO CONNECTION TO A COMPONENT.

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

10.5.2 Card CCC0200, Time Dependent Junction Control Word

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

W1(I) CONTROL WORD. If 0, second and third words of time dependent data are velocities. If 1, second and third words of time dependent data are flows. If card is missing, second and third words are assumed to be velocities.

10.5.3 Cards CCC0201-CCC0299, Time Dependent Junction Data

These cards are required for time dependent junction components. The card numbers need not be consecutive, but time on a succeeding set must be equal or greater than time on the previous set. One or more sets of data up to 100 sets may be entered. Each set consists of time (sec), liquid velocity (m/sec, ft/sec) or flow (kg/sec, lb/sec), vapor velocity (m/sec, ft/sec) or flow (kg/sec, lb/sec), and interface velocity (m/sec, ft/sec). The choice of velocity or flow depends on the control word (10.5.2). The interpolation and card formats for the time dependent data are identical to that in 10.3.3.

10.6 PIPE COMPONENT

A pipe component is indicated by PIPE on Card CCC0000. In junction connections, the code for component inlet is CCC000000 and the code for component outlet is CCC010000. Only one junction may be connected to the inlet and only one junction may

RELAP5 Input Data Requirements

be connected to the outlet. An end without a connecting junction is considered a closed end.

10.6.1 Card_CCC0001-Pipe-Information-Card

This card is required for pipe components.

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

10.6.2 Cards_CCC0101-CCC0199-Pipe-Volume-Flow-Area

The format is two words per set in sequential expansion format. 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.

10.6.3 Cards_CCC0201-CCC0299-Pipe-Junction-Flow-Areas

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

W1(R) INTERNAL JUNCTION FLOW AREA (M**2, FT**2). If cards are missing or a word is zero, 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.

10.6.4 Cards_CCC0301-CCC0399-Pipe-Volume-Lengths

This card is required for pipe components. The format is two words per set in sequential expansion format for NV sets. Card numbers need not be consecutive.

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W1(R) PIPE VOLUME LENGTH (m, ft).

W2(I) VOLUME NUMBER.

10.6.5 Cards_CCC0401-CCC0499_Pipe-Volume-Volumes

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

W1(R) VOLUME (M**3, FT**3). If cards are missing, volumes equal to zero are assumed. The program requires that the each volume's volume equal the its area times length. For any volume, at least two of the three quantities, area, length, or volume, must be nonzero. If one of the quantities is zero, it will be computed. If none of the quantities are zero, the volume must equal the area times the length within a relative error of 0.000001.

W2(I) VOLUME NUMBER.

10.6.6 Cards_CCC0501-CCC0599_Pipe-Volume-Horizontal-Angle

These cards are optional and if not entered, horizontal angles are set to 0. The horizontal angles are not used in the calculation but are entered for possible automated nodding graphics. The format is two words per set in sequential expansion format for NV sets and card numbers need not be consecutive.

W1(R) HORIZONTAL ANGLE (deg). The absolute value of the angle must be less than 360 deg.

W2(I) VOLUME NUMBER.

10.6.7 Cards_CCC0601-CCC0699_Pipe-Volume-Vertical-Orientation

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

W1(R) VERTICAL ANGLE (deg). The absolute value of the angle must be less than 90 deg. The angle 0 deg is horizontal, and positive angles have upward components.

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W2(I) VOLUME NUMBER.

10.6.8 Card_CCC0701-CCC0799_Pipe-Volume-Elevation-Change

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

W1(R) ELEVATION CHANGE (m, ft). Positive value is increase in elevation. Value must be equal to or less than volume length.

W2(I) VOLUME NUMBER.

10.6.9 Cards_CCC0801-CCC0899_Pipe-Volume-Eriction-Data

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

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

W2(R) HYDRAULIC DIAMETER (m, ft). If 0, hydraulic diameter is computed from $2.0 * (\text{VOLUME AREA} / \text{PI})^{0.5}$.

W3(I) VOLUME NUMBER.

10.6.10 Cards_CCC0901-CCC0999_Pipe-Junction-Loss-Coefficients

These cards are optional and if missing, energy loss coefficients are set to 0. The card format is three words per set in sequential expansion format for NV-1 sets and card numbers need not be consecutive.

W1(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.

W2(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W3(I) JUNCTION NUMBER.

RELAP5 Input Data Requirements

10.6.11 Cards CCC1001-CCC1099, Pipe Volume Control Flag

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

W1(I) CONTROL FLAG. Enter f_e where $f=0$ means that wall friction is computed for the volume, $f=1$ means that wall friction is not computed, $e=0$ means that a non-equilibrium (unequal temperature) equation of state is used, $e=1$ means that an equilibrium (equal temperature) equation of state is used.

W2(I) VOLUME NUMBER.

10.6.12 Cards CCC1101-CCC1199, Pipe Junction Control Flags

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

W1(I) CONTROL FLAGS. A four digit number c_ahs is entered where $c=0$ means that the choking model is to be applied, $c=1$ means that the choking model is not to be applied, $a=0$ means a smooth area change or no area change, $a=1$ means abrupt area change, $h=0$ means two velocities; $h=1$ means drift flux approximation, $h=2$ means one velocity; $s=0$ means full inertia treatment; $s=1$ means pseudo-steady state approximation.

W2(I) JUNCTION NUMBER.

10.6.13 Cards CCC1201-CCC1299, Pipe Volume Initial Conditions

This card is required for pipe components. The card format is five words per set in sequential expansion format for NV sets and card numbers need not be consecutive.

W1(I) CONTROL WORD. If 0, next three words are pressure (Pa, lbf/in²), internal energy (J/kg, Btu/lb), and static quality and these quantities will be interpreted as non-equilibrium or equilibrium conditions depending on volume control flag. If 1, next three words are temperature (K, degF), quality, and a zero. If 2, next three words are pressure (Pa, lbf/in²), quality, and a zero. If 3, next three words are pressure (Pa, lbf/in²), temperature (K, degF), and a zero. The last three options always specify equilibrium conditions.

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- W2(R) QUANTITY AS INDICATED BY THE CONTROL WORD.
- W3(R) QUANTITY AS INDICATED BY THE CONTROL WORD.
- W4(R) QUANTITY AS INDICATED BY THE CONTROL WORD.
- W5(I) VOLUME NUMBER.

10.6.14 Card_CCC1300, Pipe_Junction_Conditions_Control_Word

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

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

10.6.15 Cards_CCC1301-CCC1399, Pipe_Junction_Initial_Conditions

- W1(R) INITIAL LIQUID VELOCITY (velocity in m/sec, ft/sec or flow in kg/sec, lb/sec).
- W2(R) INITIAL VAPOR VELOCITY (velocity in m/sec, ft/sec or flow in kg/sec, lb/sec).
- W3(R) INTERFACE VELOCITY (m/sec, ft/sec).
- W4(I) JUNCTION NUMBER.

10.7 BRANCH COMPONENT

This component is indicated by BRANCH on Card CCC0000. In junction references, the code for component inlets is CCC000000 and the code for component outlets is CCC010000. More than one junction may be connected to the inlets and outlets. If an end has no junctions, that end is considered a closed end.

10.7.1 Card_CCC0001_Branch_Information_Card

This card is required for branch components.

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W1(I) NUMBER OF JUNCTIONS, NJ. NJ is the number of junctions described in the input data for this component and must be equal to or greater than zero and less than ten. Not all the junctions connecting to the branch need be described with this component input and NJ is not necessarily the total number of junctions connecting to the branch. Junctions described in single junctions, time dependent junctions, and other branches can be connected to this branch.

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

10.7.2 Cards CCC0101-CCC0109, Branch Volume Geometry Cards

These cards are identical to Cards CCC0101-CCC0109 for Single Volumes, Section 10.2.1.

10.7.3 Branch Volume Initial Conditions

This card is identical to Card CCC0200 for Single Volumes, Section 10.2.2.

10.7.4 Cards CCCN101, Branch Junction Geometry Card

These cards are required if NJ is greater than zero. Cards with N equal to 1 through 9 are entered, one for each junction. N need not be consecutive, but NJ cards must be entered. The card format other than N instead of 0 for the fourth digit is identical to Card CCC0101 of Single Junction Geometry Card, Section 10.4.1.

10.7.5 Cards CCCN201, Branch Junction Initial Conditions

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

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

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

W3(R) INTERFACE VELOCITY (m/sec, ft/sec).

10.8 VALVE JUNCTION COMPONENT

A valve junction component is indicated by VALVE on Card CCC0000

10.8.1 Card_CCC0101, Valve Junction Geometry Card

This card is required for valve junction components.

W1(I) FROM CONNECTION CODE TO A COMPONENT.

W2(I) TO CONNECTION CODE TO A COMPONENT.

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

W4(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.

W5(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.

W6(I) JUNCTION FLAGS. A four digit number, cahs, is entered where c=0 means that the choking model is to be applied, c=1 means that the choking model is not to be applied, a=0 means smooth or no area change, a=1 means abrupt area change, h=0 means two velocity, h=1 means drift flux approximation, h=2 means one velocity, s=0 means full inertial treatment, s=1 means pseudo-steady state approximation.

10.8.2 Card_CCC0201, Valve Junction Initial Conditions

This card is required for valve junction components.

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

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- W2(R) INITIAL LIQUID VELOCITY. This quantity is either velocity (m/sec, ft/sec), or flow (kg/sec, lb/sec) depending on the control word (W1).
- W3(R) INITIAL VAPOR VELOCITY. This quantity is either velocity (m/sec, ft/sec), or flow (kg/sec, lb/sec) depending on the control word (W1).
- W4(R) INTERFACE VELOCITY (m/sec, ft/sec).

10.8.3 Card CCC0301, Valve Data And Initial Conditions

This card is required for valve junction components. Three different types of valves are allowed.

10.8.3.1 CHECK VALVES

- W1(A) VALVE TYPE. Alphanumeric value must be CHKVLV for a checkvalve.
- W2(I) CHECK VALVE TYPE. Is -1 for flow operated check valve with hysteresis, is 0 for flow operated check valve without hysteresis, is 1 for pressure differential check valve.
- W3(I) CHECK VALVE POSTION. Valve is initially open if 0, closed if 1.
- W4(R) CLOSING BACK PRESSURE (Pa, lbf/in**2).
- W5(R) LEAK RATIO. Fraction of junction area for leakage when valve is nominally closed.

10.8.3.2 TRIP VALVE

- W1(A) VALVE TYPE. Alphanumeric value must be TRPVLV for a trip valve.
- W2(I) TRIP NUMBER. Must be a valid trip number. If trip is off, valve is closed; if trip is on, valve is open.

10.8.3.3 INERTIAL VALVE

The following words may be placed on Cards CCC0301-CCC0310.

- W1(I) VALVE TYPE. Alphanumeric name must be INRVLV for an inertial valve.
- W2(I) LATCH OPTION. Valve can open and close repeatedly if latch option is 0; valve either opens or closes only once if latch option is 1.

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- W3(I) VALVE INITIAL CONDITION. Valve is initially open if 0, initially closed if 1.
- W4(R) CLOSING BACK PRESSURE (Pa, lbf/in**2).
- W5(R) LEAKAGE FRACTION. Fraction of junction area for leakage when valve is nominally closed.
- W6(R) INITIAL FLAPPER ANGLE (deg). Flapper angle must be within the minimum and maximum angles specified in W7 and W8.
- W7(R) MINIMUM ANGLE (deg).
- W8(R) MAXIMUM ANGLE (deg).
- W9(R) MOMENT OF INERTIA OF VALVE FLAPPER (Kg-m**2, lb-ft**2).
- W10(R) INITIAL ANGULAR VELOCITY (rad/sec).
- W11(R) MOMENT LENGTH OF FLAPPER (m, ft).
- W12(R) RADIUS OF FLAPPER (m, ft).

10.9 PUMP COMPONENT

A pump component is indicated by PUMP on Card CCC0000. A pump consists of one volume and two junctions, one attached to each end of the volume.

10.9.1 Cards CCC0101-CCC0107, Pump Volume Geometry Cards

This card (or cards) are 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 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. If none of the words are zero, they must satisfy the volume equals area times length within a relative error of 0.000001.

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- W4(R) ANGLE FOR HORIZONTAL ORIENTATION (deg). The absolute value of this angle must be less than 360 deg. This quantity is not used in the calculation but is specified for possible automated drawing of nodding diagrams.
- W5(R) ANGLE FOR VERTICAL ORIENTATION (deg). The absolute value of this angle must be less than 90 deg. The angle 0 deg is horizontal and positive angles have an upward direction.
- 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.
- W7(I) VOLUME CONTROL FLAG. Enter 0 for non-equilibrium (unequal temperature) and 1 for equilibrium (equal temperature) thermodynamic calculation. No wall friction flag is allowed and no wall friction is computed for a pump. The printed output volume flags will show the no friction flag set to 1.

10.9.2 Card_CCC0108_Pump_Inlet_(Suction)_Junction_Card

- W1(I) VOLUME CODE OF CONNECTING VOLUME ON INLET SIDE.
- W2(R) JUNCTION AREA (m**2, ft**2). If zero, area is set to minimum of volume areas of adjacent volumes. If an abrupt area change, area must be equal to or smaller than minimum of adjacent volume areas. If a smooth area change, no restrictions exist.
- W3(R) FORWARD FLOW ENERGY LOSS COEFFICIENT.
- W4(R) REVERSE FLOW ENERGY LOSS COEFFICIENT.
- W5(I) JUNCTION FLAGS. A four digit number, cahs, is entered where c=0 means that the choking model is to be applied, c=1 means that the choking model is not to be applied, a=0 means a smooth or no area change, a=1 means an abrupt area change, h=0 means two velocity, h=1 means drift flux approximation, h=2 means one velocity, s=0 means full inertial treatment, s=1 means pseudo-state approximation.

10.9.3 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

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10.9.4 Card_CCC0200, Pump Volume Initial Conditions Card

This card is required for a pump component.

W1(I) CONTROL WORD. If 0, the next three words are pressure (Pa, lbf/in**2), internal energy (J/kg, Btu/lb), and static quality; these quantities will be interpreted as non-equilibrium or equilibrium conditions depending on the volume control flag. If 1, the next three words are temperature (K, degF), quality, and a zero. If 2, the next three words are pressure (Pa, lbf/in**2), quality, and a zero. If 3, the next three words are pressure (Pa, lbf/in**2), temperature (K, degF), and a zero. The last three input data options always specify equilibrium conditions.

W2-W4(R) QUANTITIES AS DESCRIBED UNDER W1.

10.9.5 Card_CCC0201, Pump Inlet Junction Initial Condition Card

This card is required for a pump component.

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

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

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

W4(R) INITIAL INTERFACE VELOCITY (ft/sec, ft/sec)

10.9.6 Card_CCC0202, Pump Outlet Junction Initial Condition Card

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

10.9.7 Card_CCC0301, Pump Index And Option Card

This card is required for a pump component.

W1(I) PUMP TABLE DATA INDICATOR. If 0, single phase tables are entered with this component. A positive nonzero number indicates that the single phase tables are to be obtained from the pump component

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with this number. If -1, use built in data for the Bingham pump. If -2, use built in data for the Westinghouse pump.

- W2(I) TWO PHASE INDEX. Enter -1 if two phase option is not to be used. Use 0 if two phase option is desired and two phase multiplier tables are entered with this component. Use nonzero if two phase option is desired and two phase multiplier table data are to be obtained from the pump component with the number entered.
- W3(I) TWO PHASE DIFFERENCE TABLE INDEX. Enter -1 if two phase difference table is not needed (i. e., if W2 is -1). Use 0 if table is entered with this component. Enter nonzero if table is to be obtained from pump component with this number.
- W4(I) PUMP MOTOR TORQUE TABLE INDEX. If -1, no table is used. If 0, table is entered for this component. If nonzero, use the table from component with this number.
- W5(I) TIME DEPENDENT PUMP SPEED INDEX. If -1, no table is used and pump speed is determined by torque-inertia equation. If 0, table is entered with this component. If nonzero, table from pump component with this number is used.
- W6(I) PUMP TRIP NUMBER. When trip is on, pump speed is no longer equal to initial speed or that from pump speed table but is computed from torque-inertia equation.
- W7(I) REVERSE INDICATOR. If 0, no reverse is allowed; if 1, reverse is allowed.

10.9.8 Card_CCC0302_Pump_Description_Card

This card is required for a pump component.

- W1(I) RATED PUMP VELOCITY (rad/sec, rev/min).
- W2(R) RATIO OF INITIAL PUMP SPEED TO RATED PUMP SPEED.
- W3(R) RATED FLOW (m^3/sec , gal/min).
- W4(R) RATED HEAD (m, ft).
- W5(R) RATED TORQUE (N-m, lbf-ft).
- W6(R) MOMENT OF INERTIA ($kg-m^2$, lb-ft²).

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- W7(R) RATED DENSITY (kg/m^3 , lb/ft^3). If zero, initial density is used.
- W8(R) RATED PUMP MOTOR TORQUE (M-m, lb-ft).
- W9(R) TF3, FRICTION TORQUE COEFFICIENT.
- W10(R) TF1, FRICTION TORQUE COEFFICIENT.
- W11(R) TF2, FRICTION TORQUE COEFFICIENT.
- W12(R) TF4, FRICTION TORQUE COEFFICIENT.

10.9.9 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 OF PUMP STOP (sec).
- W2(R) MAXIMUM FORWARD SPEED FOR PUMP STOP (rad/sec, rev/min).
- W3(R) MAXIMUM REVERSE SPEED FOR PUMP STOP (rad/sec, rev/min).

10.9.10 Cards-CCCXX00-CCCXX99, Single-Phase-Homologous-Curves

These cards are needed only if W1 of Card CCC0301 is 0. There are sixteen possible sets of homologous curve data to completely describe the single phase pump operation, that is, a curve for each head and torque for each of the eight possible curve types or regimes of operation. Entering all sixteen curves is not necessary, but a error will occur from an attempt to reference one that has not been entered.

Card numbering is CCC1100-CCC1199 for the first curve, CCC1200-CCC1299 for the second curve through CCC2600-CCC2699 for the sixteenth curve. Data for each individual curve are input on up to 99 cards which need not be numbered consecutively.

- W1(I) CURVE TYPE. Enter 1 for a head curve; enter 2 for a torque curve.
- W2(I) CURVE REGIME. See RELAP4/MOD5 manual for further information.

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W3(R) INDEPENDENT VARIABLE.

W4(R) DEPENDENT VARIABLE.

Additional pairs as needed are entered on this or following cards up to a limit of 100 pairs.

10.9.11 Cards CCCXX00-CCCXX99, Two-Phase Multiplier Tables

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

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

W2(R) VOID FRACTION.

W3(R) HEAD OR TORQUE MULTIPLIER DEPENDING ON TABLE TYPE.

Additional pairs of data as needed are entered on this or additional cards as needed up to a limit of 100 pairs. Void fractions must be in increasing sequence.

10.9.12 Cards CCCXX00-CCCXX99, Two-Phase Difference Tables

These cards are required only if W3 of Card CCC0301 is 0. The two phasedifference tables are homologous curves entered in a similar manner to the single phase homologous data. Card numbering is CCC4100-CCC4199 for the first curve, CCC4200-CCC4299 for the second curve through CCC5600-CCC6699 for the sixteenth curve. Data is the same as the data for the single phase data except the dependent variable is single phase minus two phase data.

10.9.13 Cards CCC6001-CCC6099, Pump Motor Torque Table Data

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

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

W2(R) PUMP VELOCITY (rad/sec, rev/min).

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W3(R) MOTOR TORQUE (N-m, ft-lbf).

Additional pairs as needed are added on this or additional cards up to a maximum of 100 pairs.

10.9.14 Cards CCC6101-CCC6199, Time-Dependent Pump Velocity Cards

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

W1(I) TRIP NUMBER. When trip is on, pump velocity table is used; when trip is off, tables are not used. This trip has priority over pump trip used to indicate torque-inertial table is to be used.

W2(R) TIME (sec).

W3(R) PUMP VELOCITY (rad/sec, 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.

11.0 CARDS 1CCCGXNN, HEAT STRUCTURE INPUT

These cards are required only if heat structures are described. The heat structure card numbers are divided into fields where:

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

G is a geometry number. The combination CCCG is a heat structure-geometry combination that is referenced in heat structure input data.

X is the card type.

NN is the card number within a card type.

11.1 Card 1CCCG000, General Heat Structure Data

This card is required for heat structures.

W1(I) NUMBER OF HEAT STRUCTURES WITH THIS GEOMETRY, NH.

RELAP5 Input Data Requirements

- W2(I) NUMBER OF MESH POINTS FOR THIS GEOMETRY, NP.
- W3(I) GEOMETRY TYPE. Enter 1 for rectangular, 2 for cylindrical, and 3 for spherical.
- W4(I) STEADY STATE INITIALIZATION FLAG. Use 0 for no steady state initialization, i.e., use the initial conditions entered on the input cards; use 1 for steady state calculation for initial conditions.
- W5(R) LEFT BOUNDARY COORDINATE (m, ft).

11.2 Card 1CCCG100, Heat Structure Mesh Flags

This card is required for heat structure input.

- W1(I) MESH LOCATION FLAG. If zero, mesh interval data are entered with this heat structure input. If nonzero, this heat structure-geometry is to use geometry from the heat structure-geometry (CCCG) number in this word.
- W2(I) MESH FORMAT FLAG. This word is needed only if W1 is zero although no error occurs if it is present when W1 is nonzero. The mesh interval data is given as a sequence of pairs of numbers in one of two formats. If this word is 1, the pairs of numbers contain the number of mesh intervals in this space and the right boundary coordinate. For the first pair, the left coordinate of the space is the left boundary coordinate entered in W5 of Card 1CCCG000; for succeeding pairs, the left coordinate is the right coordinate of the previous pair. If this word is 2, the format is sequential expansion of mesh intervals.

11.3 Cards 1CCCG101-1CCCG99, Heat Structure Mesh Interval Data

These cards are required if W1 of Card 1CCCG100 is zero. In format 1, the sum of the numbers of intervals must be NP-1. In format 2, the sequential expansion must be for NP-1 intervals. The card numbers need not be sequential.

Format 1.

- W1(I) NUMBER OF INTERVALS.
- W2(R) RIGHT COORDINATE (m, ft).

Format 2.

RELAP5 Input Data Requirements

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

W2(I) MESH NUMBER

11.4 Card-1CCCG200, Heat-Structure-Composition-Flag

This card is optional and if missing, W1 is assumed zero.

W1(I) COMPOSITION FLAG. If this word is zero, composition data is entered with the input data for this heat structure. If nonzero, this heat structure-geometry uses the compositions from the heat structure-geometry number given in this word.

11.5 Cards-1CCCG201-1CCCG299, Heat-Structure-Composition-Data

These cards are required if W1 of Card 1CCCG200 is zero. 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.

W2(I) INTERVAL NUMBER.

11.6 Card-1CCCG300, Heat-Structure-Distribution-Flag

This card is optional and if missing, W1 is assumed zero.

W1(I) SOURCE DISTRIBUTION FLAG. If zero, source distribution data is entered with the input data for this heat structure-geometry data. If nonzero, the source distribution for this heat structure-geometry is taken from the heat structure-geometry number in this word.

11.7 Cards-1CCCG301-1CCCG399, Heat-Structure-Distribution-Data

These cards are required if W1 of Card 1CCCG300 is zero. 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.

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W1(R) SOURCE VALUE.

W2(I) MESH INTERVAL NUMBER.

11.8 Card 1CCCG400, Initial Temperature Flag

This card is optional and if missing, W1 is assumed zero.

W1(I) INITIAL TEMPERATURE FLAG. If this word is zero, initial temperatures are entered with the input data for this heat structure-geometry data. If nonzero, the initial temperatures for this heat structure-geometry are taken from the heat structure-geometry number in this word.

11.9 Cards 1CCCG401-1CCCG499, Initial Temperature Data

These cards are required if W1 of card 1CCCG400 is zero. The card format is two numbers per set in sequential expansion format for NP mesh points.

W1(R) TEMPERATURE (K, degF).

W2(I) MESH POINT NUMBER.

11.10 Cards 1CCCG501-1CCCG599, Left Boundary Condition Data

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 NH sets.

W1(I) BOUNDARY VOLUME. This word specifies the hydrodynamic volume associated with the left surface of this heat structure. If zero, no volume is associated with the left surface of this heat structure. A zero temperature is associated with boundary volume zero when used as a surface temperature or a sink temperature in boundary conditions.

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

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be zero or nonzero, plus or minus.

- W3(I) BOUNDARY CONDITION TYPE. If,
- 0 a symmetry or insulated boundary condition is used. The boundary volume must be 0.
 - 1 a convective boundary condition where the heat transfer coefficient is obtained from heat transfer package 1 is used. The sink temperature is the temperature of the boundary volume.
 - 1000 the temperature of the boundary volume is used as the left surface temperature. If the boundary volume is zero, the surface temperature is set to zero.
 - 1xxx the temperature in general table xxx is used as the left surface temperature.
 - 2xxx the heat transfer rate from table xxx is used as the left boundary condition.
 - 3xxx a convective boundary condition is used where the heat transfer coefficient as a function of time is obtained from general table xxx. The sink temperature is the temperature of the boundary volume.
 - 4xxx a convective boundary condition is used where the heat transfer coefficient as a function of surface temperature is obtained from general table xxx. The sink temperature is the temperature of the boundary volume.

- W4(I) SURFACE AREA CODE. If 0, W5 is the left surface area. If 1, W5 is the surface area in rectangular geometry, is the cylinder height or equivalent in cylindrical geometry, or the fraction of a sphere (0.5 is a hemisphere) in spherical geometry.

- W5(R) SURFACE AREA OR FACTOR. As indicated in W4, this word contains the surface area (m², ft²) or a geometry dependent multiplier (m², ft² for rectangular, m, ft for cylindrical, or dimensionless for spherical geometries).

- W6(I) HEAT STRUCTURE NUMBER.

11.11 Cards_1CCC601-1CCC699:_Right_Boundary_Condition_Cards

These cards are the same as Cards 1CCC501-1CCC599 but for the right boundary. Note that the left and right surface areas must be compatible with the geometry.

11.12 Cards_1CCC701-1CCC799:_Source_Data_Cards

These cards are required for heat structure data. The card

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format is sequential format, five words per set, describing NH heat structures.

- W1(I) SOURCE TYPE. If 0, no source is used. If a positive number less than 1000, power from the general table with this number is used as the source. If 1000, the source is taken from the reactor kinetics calculation.
- W2(R) INTERNAL SOURCE MULTIPLIER.
- W3(R) DIRECT HEATING FOR LEFT BOUNDARY VOLUME.
- W4(R) DIRECT HEATING FOR RIGHT BOUNDARY VOLUME.
- W5(I) HEAT STRUCTURE NUMBER.

11.13 Cards 1CCC801-1CCC899, Additional Left Boundary Cards

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

- W1(I) CHF AND HEAT TRANSFER CORRELATION FLAGS. Enter zero.
- W2(R) HYDRAULIC DIAMETER (m, ft). If zero, hydraulic diameter from boundary volume is used.
- W3(R) HEATED EQUIVALENT DIAMETER (m, ft). If zero, hydraulic diameter is used.
- W4(R) CHANNEL LENGTH (m, ft).
- W5(I) HEAT STRUCTURE NUMBER.

11.14 Cards 1CCC901-1CCC999, Additional Right Boundary Cards

These cards are the same as Cards 1CCC801-1CCC899 but for the right boundary.

12.0 CARDS 201MMNN, HEAT STRUCTURE THERMAL PROPERTY DATA

These cards are required if Cards 1CCCGXNN, Heat Structure Input Cards are entered. These data if present are processed and

RELAP5 Input Data Requirements

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 number entered on Cards 1CCCG201-1CCCG299 correspond to this subfield. A set of Cards 201MMMNN must be entered for composition number used, but MMM need not be consecutive.

12.1 CARD 201MMM00, COMPOSITION TYPE AND DATA FORMAT

This card is required.

W1(A) MATERIAL TYPE. Thermal properties for five materials are stored within the program: Aluminum (AL), carbon steel (C-STEEL), stainless steel (S-STEEL), Uranium dioxide (UO2), and Zirconium (ZR). These properties are selected by entering the name in parentheses in this word. If a user supplied table or function is to be used, enter TBL/FCTN in this word.

The next two words are required only if TBL/FCTN was entered in W1.

W2(I) THERMAL CONDUCTIVITY FORMAT FLAG. Enter 1 if a table containing temperature and thermal conductivity is to be entered; enter 2 if functions are to be entered.

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 are to be entered and the temperature values are identical to the thermal conductivity table; enter 2 if functions are to be entered.

12.2 CARDS 201MMM01-201MMM49, THERMAL CONDUCTIVITY DATA

These cards are required if W1 of Card 201MMM00 contained TBL/FCTN. The card numbers need not be consecutive.

12.2.1 Table Format

If only one word is entered, that word contains the thermal conductivity which is assumed constant. Otherwise pairs of numbers are entered. The number of pairs is limited to 100. The

RELAP5 Input Data Requirements

temperatures must be in increasing order. The end point thermal conductivities are used for temperatures outside the range of temperatures.

W1(R) TEMPERATURE (K, degF).

W2(R) THERMAL CONDUCTIVITY (Watt/m-K, Btu/sec-ft/degF).

12.2.2 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 $k = A_0 + A_1TX + A_2TX^2 + A_3TX^3 + A_4TX^4 + A_5TX^{(-1)}$ 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 a following function must equal the upper bound of the previous function.

W1(R) LOWER LIMIT TEMPERATURE (K, degF).

W2(R) UPPER LIMIT TEMPERATURE (K, degF).

W3(R) A0 (watt/m-K, Btu/sec-ft-degF).

W4(R) A1 (watt/m-K², Btu/sec-ft-degF²).

W5(R) A2 (watt/m-K³, Btu/sec-ft-degF³).

W6(R) A3 (watt/m-K⁴, Btu/sec-ft-degF⁴).

W7(R) A4 (watt/m-K⁵, Btu/sec-ft-degF⁵).

W8(R) A5 (watt/m, Btu/sec-ft).

W9(R) C (K, degF).

12.3 CARDS 210MMM51-201MMM99, VOLUMETRIC HEAT CAPACITY DATA

These cards are required if W1 of Card 210MMM00 contains TBL/FCTN. The card numbers need not be consecutive.

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12.3.1 Table_Format

If only one word is entered, that word contains the volumetric heat capacity which is assumed constant. Pairs of temperatures and volumetric heat capacities are entered if the temperatures are different from the thermal conductivity table or functions were 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 heat capacities are used for temperatures outside the range of temperatures.

W1(R) TEMPERATURE (K, degF). If only volumetric heat capacities are being entered, this word is not entered.

W2(R) VOLUMETRIC HEAT CAPACITY (Watt/m³-K, Btu/ft³-degF).

12.3.2 Functional_Format

In the functional format, sets of nine quantities are entered, each set containing one function and its range of application. The function is $c = A0 + A1*TX + A2*TX**2 + A3*TX**3 + A4*TX**4 + A5*TX**(-1)$ where $TX = T-C$ and T is the temperature argument. Each function has a lower and upper limit of application. The first function entered must be for the lowest temperature range. The lower limit of a following function must equal the upper bound of the previous function.

W1(R) LOWER LIMIT TEMPERATURE (K, degF).

W2(R) UPPER LIMIT TEMPERATURE (K, degF).

W3(R) A0 (watt/m³-K, Btu/ft³-degF).

W4(R) A1 (watt/m³-K², Btu/ft³-degF²).

W5(R) A2 (watt/m³-K³, Btu/ft³-degF³).

W6(R) A3 (watt/m³-K⁴, Btu/ft³-degF⁴).

W7(R) A4 (watt/m³-K⁵, Btu/ft³-degF⁵).

W8(R) A5 (watt/m³, Btu/ft³).

RELAP5 Input Data Requirements

W9(R) C (K, degF).

13.0 CARDS 202IIINN, GENERAL TABLE DATA

These cards are required if any input references general tables. TTT is the table number and table references such as for power, heat transfer coefficients, or temperatures refer to this number. Data must be entered for each table that is referenced, but TTT need not be consecutive.

13.1 CARD 202TTT00, TABLE TYPE AND MULTIPLIER DATA

W1(A) TABLE TYPE. Enter POWER for power vs. time; enter HTRNRATE for heat transfer rate vs. time; enter HTC-T for heat coefficient vs. time; enter HTC-TEMP for heat transfer coefficient vs. temperature.

The following two or three words are optional and allow factors or unit changes to be applied to the table entries. If these words are omitted, the data is used as entered. One multiplier is used for time, power, heat transfer rate, and heat transfer coefficient; a multiplier and additive constant are used for temperature as $T = M \cdot TX + C$, where M is the multiplier, C is the additive constant, and TX is the temperature entered. The first one or two words apply to the argument variable, time or temperature; one word is applied if the argument is time, two words are used if the argument is temperature. The remaining one or two words are used for the function, two words being used if temperature is the function.

W2-W4(R) FACTORS. As described above, enter factors such that when applied to the table values entered, the resultant values have the appropriate units.

13.2 CARDS 202TTT01-201TTT99, 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 200.

W1(R) ARGUMENT VALUE (sec if time; K, degF if temperature).

RELAP5 Input Data Requirements

W2(R) FUNCTION VALUE (watt, Mw if power; K, degF if temperature, watt/m², Btu/sec-ft² if heat transfer rate; watt/m²-K, Btu/sec-ft²-degF if heat transfer coefficient).

APPENDIX C

SEMISCALE TEST FACILITY

The Semiscale Test Facility is shown in Figure A for the 1-1/2 Loop Mod-1 configuration modeled for this RELAP5/MOD"0" problem run. The Semiscale facility is an operating scale model that is used to simulate nuclear reactor plants, generally in Loss-of-Coolant Accident (LOCA) experiments. The Semiscale facility generates heat in the modeled reactor vessel through the use of electrically heated rods rather than fuel elements. It also has heat transfer by means of cooling water circulation through the steam generator secondary rather than by vapor generation.

The operating loop (shown with pressurizer, steam generator, and primary coolant pump) is generally modeled to represent the intact loop or loops of a reactor coolant system. The broken loop is modeled with components that hydraulically simulate a steam generator and loop pump. The breaks are simulated by rupture assemblies having controlled characteristic quick opening values. The blowdown is discharged into a header that conducts the vapor and water mixture to a collection vessel. This vessel has a controllable internal spray for vapor condensation. The combination of the header, vessel, and spray simulate the postulated backpressure of LOCA discharge into the containment of the plant modeled.

Figure C-1. Semiscale MOD-1 facility

APPENDIX D

ADDITIONAL SYSTEM PARAMETER PLOTS FOR RELAP5 SIMULATION OF SEMISCALE TEST S-01-4A

Additional plots of parameters for which there are no data comparisons, but which give additional insight to the phenomena occurring during the Semiscale blowdown are compiled herein. The plots include junction variables (liquid and vapor velocities) and the volume variables (pressure, liquid and vapor temperatures, void fraction, static and equilibrium qualities). They are selected throughout the system; i.e., at the vessel side of break, the pump side of break, upstream of pump inlet, upstream and downstream of the ECC injection, inlet annulus, downcomer, core, upper and lower plenum, pressurizer and surge line. The locations are identified by the junction or volume number in the figures. There are two qualities plotted. The static quality is related to void fraction in the calculation. The equilibrium quality is a reference which determines the vapor generation or condensation in the system. The major features of the results are summarized in following paragraphs.

The velocities of liquid and vapor at the vessel side of the break (J80), Figures D-1 and D-2, and the pump side of the break (J90), Figures D-8 and D-9, increase rapidly up to about 19 seconds. This increase corresponds to the increasing sonic velocity associated with increased void fraction. At this time the void fractions at the middle of the core and throughout the broken loop are over 0.8 (Figures D-5, D-12 and D-74). At a later time, beyond 20 seconds, the velocities at the vessel side of the break decline to low values at about 50 seconds, which corresponds

to the time at which ECC water fills the cold leg of the broken loop. At the same time the void fraction at the vessel side of the break is near zero (Figure D-5).

At 22 seconds, ECC injection begins. The water fills the pipe downstream of the ECC injection point (V1301, spool 15) at about 30 seconds and the void fraction in the pipe becomes zero (Figure D-36). The fluid temperature in the pipe (Figure D-34) drops significantly below saturation after 30 seconds. The ECC water also fills the pipe at the pump outlet (V51001, spool 13) at about 39 seconds as shown in the void fraction plot (Figure D-28). At 48 seconds some indication of ECC water also exists upstream of the pump inlet (V906). The relatively large peak in velocities at the pump inlet which occurs at about 50 seconds (Figures D-15 and D-16) and also throughout the intact loop cold leg (Figures D-23, D-24, D-31, D-32) may be the results of ECC water producing low void fraction in the pump which results in sharply modified pump performance.

ECC water appears in the inlet annulus at about 40 seconds (Figure D-42). Some liquid flows down the downcomer at 44 seconds as shown by the fluid velocity in Figure D-45 and the void fraction in Figure D-50. Some condensation probably occurs in the lower part of the downcomer during the time period from 44 to 53 seconds as evidenced by the void fraction (Figure D-58) and the fact that the liquid velocity is downward (positive direction) in this time period. In the downcomer region, there exists countercurrent flow over much of the transient (Figures D-45, D-46, D-53 and D-54). The pressure tends to push the vapor upward and the gravitational force causes the liquid to move downward. In general, the pressure in the upper part of the downcomer (V4103, Figure D-47) is lower than the pressure in the lower part of the downcomer (V4109, Figure D-55) during this period.

The void fraction at the center of the core (V6007, Figure D-74) and at the upper part of the core (V6011, Figure D-82) reaches more than 0.85 at 19 seconds. After this time the velocities in the core region oscillate randomly about zero (Figures D-61, D-62, D-69, D-70, D-77 and D-78). Since the plots are based on only one calculated point per second, the frequency of the oscillation can not be accurately estimated.

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
VESSEL SIDE OF BREAK (J80)

Fig. D-1 Liquid velocity at vessel side of break (J80).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

VESSEL SIDE OF BREAK (J80)

Fig. D-2 Vapor velocity at vessel side of break (J80)

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

VESSEL SIDE OF BREAK (V2003)

Fig. D-3 Liquid temperature at vessel side of break (V2003).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
VESSEL SIDE OF BREAK (V2003)

Fig. D-4 Vapor temperature at vessel side of break (V2003).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

VESSEL SIDE OF BREAK (V2003)

Fig. D-5 Void fraction at vessel side of break (V2003).

Fig. D-6 Static quality at vessel side of break (V2003).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

VESSEL SIDE OF BREAK (V2003)

Fig. D-7 Equilibrium quality at vessel side of break (V2003).

Fig. D-8 Liquid velocity in pump side of break (J90).

Fig. D-9 Vapor velocity in pump side of break (J90).

Fig. D-10 Liquid temperature in pump side of break (V3407).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PUMP SIDE OF BREAK (V3407)

Fig. D-11. Vapor temperature in pump side of break (V3407).

Fig. D-12 Void fraction in pump side of break (V3407).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PUMP SIDE OF BREAK (V3407)

Fig. D-13 Static quality in pump side of break (V3407).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PUMP SIDE OF BREAK (V3407)

Fig. D-14 Equilibrium quality in pump side of break (V3407).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

HOT-LEG CT10 (J905)

Fig. D-15 Liquid velocity at spool 10 near pump inlet (J905).

Fig. D-16 Vapor velocity at spool 10 near pump inlet (J905).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

HOT-LEG CT10 (V906)

Fig. D-17 Pressure at spool 10 near pump inlet (V906).

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RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

HOT-LEG CT10 (V906)

Fig. D-18 Liquid temperature at spool 10 near pump inlet (V906).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

HOT-LEG CT10 (V906)

Fig. D-19 Vapor temperature at spool 10 near pump inlet (V906).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

HOT-LEG CT10 (V906)

Fig. D-20 Void fraction at spool 10 near pump inlet (V906).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

HOT-LEG CT10 (V906)

Fig. D-21 Static quantity at spool 10 near pump inlet (V906).

Fig. D-22. Equilibrium quality at spool 10 near pump inlet (V906).

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RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)COLD-LEG CT13 (J50001)

Fig. D-23 Liquid velocity in spool 13 near pump outlet (J50001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

COLD-LEG CT13 (J50001)

Fig. D-24 Vapor velocity in spool 13 near pump outlet (J50001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

COLD-LEG CT13 (V51001)

Fig. D-25 Pressure in spool 13 near pump outlet (V51001).

Fig. D-26 Liquid temperature in spool 13 near pump outlet (V51001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

COLD-LEG CT13 (V51001)

Fig. D-27 Vapor temperature in spool 13 near pump outlet (V51001).

Fig. D-28 Void fraction in spool 13 near pump outlet (V51001).

Fig. D-29 State quality in spool 13 near pump outlet (V51001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
COLD-LEG CT13 (V51001)

Fig. D-30 Equilibrium quality in spool 13 near pump outlet (V51001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

COLD-LEG (J50002)

Fig. D-31 Liquid velocity in spool 15 after ECC injection (J50002).

Fig. D-32 Gas velocity in spool 15 after ECC injection (J50002).

Fig. D-33 Pressure in spool 15 after ECC injection (V1301).

Fig. D-34. Liquid temperature in spool 15 after ECC injection (V1301).

Fig. D-35 Vapor temperature in spool 15 after ECC injection (V1301).

Fig. D-36 Void fraction in spool 15 after ECC injection (V1301).

Fig. D-37 Static quality in spool 15 after ECC injection (V1301).

Fig. D-38 Equilibrium quality in spool 15 after ECC injection (V1301).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
INLET ANNULUS (V4001)

Fig. D-39 Pressure in inlet annulus (V4001).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

INLET ANNULUS (V4001)

Fig. D-40 Liquid temperature in inlet annulus (V4001).

Fig. D-41 Vapor temperature in inlet annulus (V4001).

Fig. D-42 Void fraction in inlet annulus (V4001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

INLET ANNULUS (V4001)

Fig. D-43 Static quality in inlet annulus (V4001).

Fig. D-44 Equilibrium in inlet annulus (V4001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (J4102)

Fig. D-45 Liquid velocity in upper part of downcomer (J4102).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (J4102)

Fig. D-46 Vapor velocity in upper part of downcomer (J4102).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (V4103)

Fig. D-47 Pressure in upper part of downcomer (V4103).

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RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (V4103)

Fig. D-48 Liquid temperature in upper part of downcomer (V4103).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (V4103)

Fig. D-49 Vapor temperature in upper part of downcomer (V4103).

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RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (V4103)

Fig. D-50 Void fraction in upper part of downcomer (V4103).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (V4103)

Fig. D-51 Static quality in upper part of downcomer (V4103).

Fig. D-52 Equilibrium quality in upper part of downcomer (V103).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (J4108)

Fig. D-53 Liquid velocity in lower part of downcomer (J4108).

Fig. D-54 Vapor velocity in lower part of downcomer (J4108).

Fig. D-55 Pressure in lower part of downcomer (V4109).

Fig. D-56 Liquid temperature in lower part of downcomer (V4109).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)
DOWNCOMER (V4109)

Fig. D-57 Vapor temperature in lower part of downcomer (V4109).

Fig. D-58 Void fraction in lower part of downcomer (V4109).

Fig. D-59 Static quality in lower part of downcomer (V4109).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

DOWNCOMER (V4109)

Fig. D-60 Equilibrium quality in lower part of downcomer (V4109).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (J6002)

Fig. D-61 Liquid velocity in lower part of core (J6002).

Fig. D-62 Vapor velocity in lower part of core (J6002).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6003)

Fig. D-63 Pressure in lower part of core (V6003).

Fig. D-64 Liquid temperature in lower part of core (V6003).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6003)

Fig. D-65 Vapor temperature in lower part of core (V6003).

Fig. D-66. Void fraction in lower part of core (V6003).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6003)

Fig. D-67 Static quality in lower part of core (V6003).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
CORE (6003)

Fig. D-68 Equilibrium quality in lower part of core (V6003).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (J6007)

Fig. D-69 Liquid velocity in middle of core (J6007).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
CORE (J6007)

Fig. D-70 Vapor velocity in middle of core (J6007).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6007)

Fig. D-71 Pressure in middle of the core (V6007).

Fig. D-72 Liquid temperature in middle of core (V6007).

Fig. D-73 Vapor temperature in middle of core (V6007).

Fig. D-74 Void fraction in middle of core (V6007).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6007)

Fig. D-75 Static quality in middle of core (V6007).

Fig. D-76 Equilibrium quality in middle of core (V6007).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (J6010)

Fig. D-77 Liquid velocity in upper part of core (J6010).

Fig. D-78 Vapor velocity in upper part of core (J6010).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6011)

Fig. D-79 Pressure in upper part of core (V6011).

Fig. D-80 Liquid temperature in upper part of core (V6011).

Fig. D-81 Vapor temperature in upper part of core (V6011).

Fig. D-82 Void fraction in upper part of core (V6011).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6011)

Fig. D-83 Static quality in upper part of core (V6011).

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RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

CORE (V6011)

Fig. D-84 Equilibrium in upper part of core (V6011).

Fig. D-85 Liquid temperature in upper plenum (V7001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
UPPER PLENUM (V7001)

Fig. D-86 Vapor temperature in upper plenum (V7001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

UPPER PLENUM (V7001)

Fig. D-87 Void fraction in upper plenum (V7001).

Fig. D-88 Static quality in upper plenum (V7001).

Fig. D-89 Equilibrium quality in upper plenum (V7001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
LOWER PLENUM (V5001)

Fig. D-90 Liquid temperature in lower plenum (V5001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

LOWER PLENUM (V5001)

Fig. D-91 Vapor temperature in lower plenum (V5001).

Fig. D-92 Void fraction in lower plenum (V5001).

Fig. D-93 Static quality in lower plenum (V5001).

Fig. D-94 Equilibrium quality in lower plenum (V5001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
PRESSURIZER (V43001)

Fig. D-95 Vapor temperature in top of pressurizer (V43001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)
PRESSURIZER (V43001)

Fig. D-96 Void fraction in top of pressurizer (V43001).

RELAP5 SIMULATION OF SEMI-SCALE TEST (S-01-4A)

PRESSURIZER (V43001)

Fig. D-97 Static quality in top of pressurizer (V43001).

Fig. D-98 Equilibrium quality in top of pressurizer (V43001).

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RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)P-PIPE (J41001)

Fig. D-99 Liquid velocity in inlet of the surge line (J41001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

P-PIPE (J41001)

Fig. D-100 Vapor velocity in inlet of the surge line (J41001).

Fig. D-101 Pressure near the inlet of the surge line (V41001).

P-PIPE (V41001)

Fig. D-102 Liquid temperature near the inlet of the surge line (V41001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

P-PIPE (V41001)

Fig. D-103. Gas temperature near the inlet of the surge line (V41001).

Fig. D-104 Void fraction near the inlet of the surge line (V41001).

RELAPS SIMULATION OF SEMI-SCALE TEST (S-01-4A)

P-PIPE (V41001)

Fig. D-105 Static quality near the inlet of the surge line (V41001).

Fig. D-106 Equilibrium quality near the inlet of the surge line (V41001).