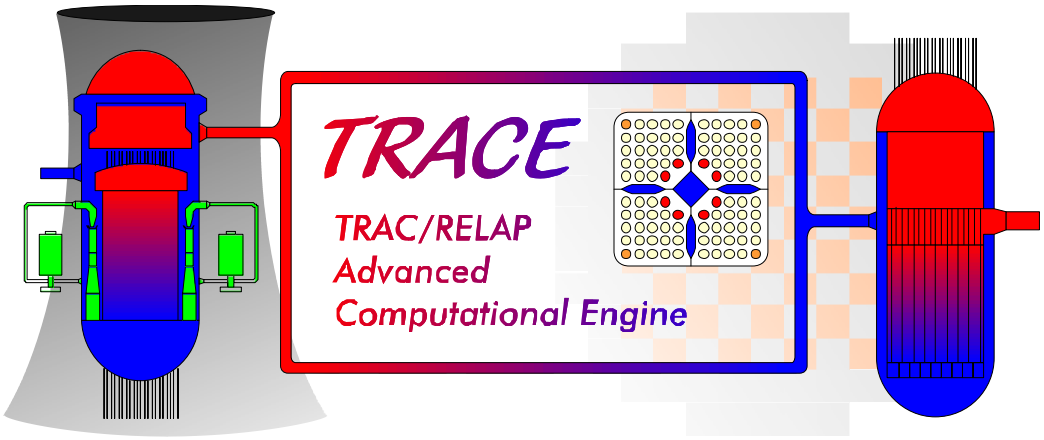


# TRACE V5.0
# USER'S MANUAL

## Volume 2: Modeling Guidelines



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Washington, DC 20555-0001

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# *Preface*

Advanced computing plays a critical role in the design, licensing and operation of nuclear power plants. The modern nuclear reactor system operates at a level of sophistication whereby human reasoning and simple theoretical models are simply not capable of bringing to light full understanding of a system's response to some proposed perturbation, and yet, there is an inherent need to acquire such understanding. Over the last 30 years or so, there has been a concerted effort on the part of the power utilities, the U. S. Nuclear Regulatory Commission (USNRC), and foreign organizations to develop advanced computational tools for simulating reactor system behavior during real and hypothetical transient scenarios. The lessons learned from simulations carried out with these tools help form the basis for decisions made concerning plant design, operation, and safety.

The TRAC/RELAP Advanced Computational Engine (TRACE - formerly called TRAC-M) is the latest in a series of advanced, best-estimate reactor systems codes developed by the U.S. Nuclear Regulatory Commission for analyzing transient and steady-state neutronic-thermal-hydraulic behavior in light water reactors. It is the product of a long term effort to combine the capabilities of the NRC's four main systems codes (TRAC-P, TRAC-B, RELAP5 and RAMONA) into one modernized computational tool..

This manual is one of three manuals that comprise the basic TRACE documentation set. The other two are the Theory Manual and Developmental Assessment Manual.



# *Overview of TRACE*

TRACE has been designed to perform best-estimate analyses of loss-of-coolant accidents (LOCAs), operational transients, and other accident scenarios in pressurized light-water reactors (PWRs) and boiling light-water reactors (BWRs). It can also model phenomena occuring in experimental facilities designed to simulate transients in reactor systems. Models used include multidimensional two-phase flow, nonequilibrium thermo-dynamics, generalized heat transfer, reflood, level tracking, and reactor kinetics. Automatic steady-state and dump/restart capabilities are also provided.

The partial differential equations that describe two-phase flow and heat transfer are solved using finite volume numerical methods. The heat-transfer equations are evaluated using a semi-implicit

time-differencing technique. The fluid-dynamics equations in the spatial one-dimensional (1D), and three-dimensional (3D) components use, by default, a multi-step time-differencing procedure that allows the material Courant-limit condition to be exceeded. A more straightforward semi-implicit time-differencing method is also available, should the user demand it. The finite-difference equations for hydrodynamic phenomena form a system of coupled, nonlinear equations that are solved by the Newton-Raphson iteration method. The resulting linearized equations are solved by direct matrix inversion. For the 1D network matrix, this is done by a direct full-matrix solver; for the multiple-vessel matrix, this is done by the capacitance-matrix method using a direct banded-matrix solver.

TRACE takes a component-based approach to modeling a reactor system. Each physical piece of equipment in a flow loop can be represented as some type of component, and each component can be further nodalized into some number of physical volumes (also called cells) over which the fluid, conduction, and kinetics equations are averaged. The number of reactor components in the problem and the manner in which they are coupled is arbitrary. There is no built-in limit for the number of components or volumes that can be modeled; the size of a problem is theoretically only limited by the available computer memory. Reactor hydraulic components in TRACE include PIPEs, PLENUMs, PRIZERs (pressurizers), CHANs (BWR fuel channels), PUMPs, JETPs (jet pumps), SEPDs (separators), TEEs, TURBs (turbines), HEATRs (feedwater heaters), CONTANs (containment), VALVEs, and VESSELs (with associated internals). HTSTR (heat structure) and REPEAT-HTSTR components modeling fuel elements or heated walls in the reactor system are available to compute two-dimensional conduction and surface-convection heat transfer in Cartesian or cylindrical geometries. POWER components are available as a means for delivering energy to the fluid via the HTSTR or hydraulic component walls. FLPOWER (fluid power) components are capable of delivering energy directly to the fluid (such as might happen in waste transmutation facilities). RADENC (radiation enclosures) components may be used to simulate radiation heat transfer between multiple arbitrary surfaces. FILL and BREAK components are used to apply the desired coolant-flow and pressure boundary conditions, respectively, in the reactor system to perform steady-state and transient calculations. EXTERIOR components are available to facilitate the development of input models designed to exploit TRACE's parallel execution features.



The code's computer execution time is highly problem dependent and is a function of the total number of mesh cells, the maximum allowable timestep size, and the rate of change of the neutronic and thermal-hydraulic phenomena being evaluated. The stability-enhancing two-step (SETS) numerics in hydraulic components allows the material Courant limit to be exceeded. This allows very large time steps to be used in slow transients. This, in turn, can lead to significant speedups in simulations (one or two orders of magnitude) of slow-developing accidents and operational transients.

While we do not wish to overstate the performance of the numerical techniques incorporated in TRACE, we believe that the current schemes demonstrate exceptional stability and robustness that will serve adequately in codes like TRACE for years to come. However, the models and correlations in the code can have a significant impact on the speed of a calculation; they can (and frequently do) affect adversely the time-step size and the number of iterations used. Because of the impact on the speed of the calculation and because the models and correlations greatly affect

the accuracy of the results, the area of model/correlation development may result in significant improvements in overall code performance.

# *TRACE Characteristics*

Some distinguishing characteristics of the code are summarized below.

## *Multi-Dimensional Fluid Dynamics*

A 3D (x, y, z) Cartesian- and/or (r, θ, z) cylindrical-geometry flow calculation can be simulated within the reactor vessel or other other reactor components where 3D phenomena take place. All 3D components, such as Reactor Water Storage Tank, where 3D phenomena are modeled, are named VESSEL although they may not have any relationship with the reactor vessel. Flows within a coolant loop are usually modeled in one dimension using PIPE and TEE components. The combination of 1D and 3D components allows an accurate modeling of complex flow networks as well as local multidimensional flows. This is important in determining emergency core coolant (ECC) downcomer penetration during blowdown, refill, and reflood periods of a LOCA. The mathematical framework exists to directly treat multidimensional plenum- and core-flow effects, and upper-plenum pool formation and core penetration during reflood.

## *Non-homogeneous, Non-equilibrium Modeling*

A full two-fluid (six-equation) hydrodynamic model evaluates gas-liquid flow, thereby allowing important phenomena such as countercurrent flow to be simulated explicitly. A stratified-flow regime has been added to the 1D hydrodynamics; a seventh field equation (mass balance) describes a noncondensable gas field; and an eigh1th field equation tracks dissolved solute in the liquid field that can plated out on surfaces when solubility in the liquid is exceeded.

## *Flow-Regime-Dependent Constitutive Equation Package*

The thermal-hydraulic equations describe the transfer of mass, energy, and momentum between the steam-liquid phases and the interaction of these phases with heat flow from the modeled structures. Because these interactions are dependent on the flow topology, a flow-regime-dependent constitutive-equation package has been incorporated into the code. Assessment calculations performed to date indicate that many flow conditions can be calculated accurately with this package.

## *Comprehensive Heat Transfer Capability*

TRACE can perform detailed heat-transfer analyses of the vessel and the loop components. Included is a 2D (r,z) treatment of conduction heat transfer within metal structures. Heat conduction with dynamic fine-mesh rezoning during reflood simulates the heat transfer characteristics of quench fronts. Heat transfer from the fuel rods and other structures is calculated using flow-regime-dependent heat transfer coefficients (HTC) obtained from a generalized boiling curve based on a combination of local conditions and history effects. Inner- and/or outer-surface convection heat-transfer and a tabular or point-reactor kinetics with reactivity feedback volumetric power source can be modeled. One-dimensional or three-dimensional reactor kinetics capabilities are possible through coupling with the Purdue Advanced Reactor Core Simulator (PARCS) program.

## *Component and Functional Modularity*

The TRACE code is completely modular by component. The components in a calculation are specified through input data; available components allow the user to model virtually any PWR or BWR design or experimental configuration. Thus, TRACE has great versatility in its range of applications. This feature also allows component modules to be improved, modified, or added without disturbing the remainder of the code. TRACE component modules currently include BREAKs, FILLs, CHANs, CONTANs, EXTERIORs, FLPOWERs, HEATRs, HTSTRs, JETPs, POWERs, PIPEs, PLENUMs, PRIZERs, PUMPs, RADENCs, REPEAT-HTSTRs, SEPDs, TEEs, TURBs, VALVEs, and VESSELs with associated internals (downcomer, lower plenum, reactor core, and upper plenum).

The TRACE program is also modular by function; that is, the major aspects of the calculations are performed in separate modules. For example, the basic 1D hydrodynamics solution algorithm, the wall-temperature field solution algorithm, heat transfer coefficient (HTC) selection, and other functions are performed in separate sets of routines that can be accessed by all component modules. This modularity allows the code to be upgraded readily with minimal effort and minimal potential for error as improved correlations and test information become available.



# *Physical Phenomena Considered*

As part of the detailed modeling in TRACE, the code can simulate physical phenomena that are important in large-break and small-break LOCA analyses, such as:

1) ECC downcomer penetration and bypass, including the effects of countercurrent flow and hot walls;
2) lower-plenum refill with entrainment and phase-separation effects;
3) bottom-reflood and falling-film quench fronts;

4) multidimensional flow patterns in the reactor-core and plenum regions;
5) pool formation and countercurrent flow at the upper-core support-plate (UCSP) region;
6) pool formation in the upper plenum;
7) steam binding;
8) water level tracking,
9) average-rod and hot-rod cladding-temperature histories;
10) alternate ECC injection systems, including hot-leg and upper-head injection;
11) direct injection of subcooled ECC water, without artificial mixing zones;
12) critical flow (choking);
13) liquid carryover during reflood;
14) metal-water reaction;
15) water-hammer pack and stretch effects;
16) wall friction losses;
17) horizontally stratified flow, including reflux cooling,
18) gas or liquid separator modeling;
19) noncondensable-gas effects on evaporation and condensation;
20) dissolved-solute tracking in liquid flow;
21) reactivity-feedback effects on reactor-core power kinetics;
22) two-phase bottom, side, and top offtake flow of a tee side channel; and reversible and irreversible form-loss flow effects on the pressure distribution



# *Limitations on Use*

As a general rule, computational codes like TRACE are really only applicable within their assessment range. TRACE has been qualified to analyze the ESBWR design as well as conventional PWR and BWR large and small break LOCAs (excluding B&W designs). At this point, assessment has not been officially performed for BWR stability analysis, or other operational transients.

The TRACE code is not appropriate for modeling situations in which transfer of momentum plays an important role at a localized level. For example, TRACE makes no attempt to capture, in detail, the fluid dynamics in a pipe branch or plenum, or flows in which the radial velocity profile across the pipe is not flat.

The TRACE code is not appropriate for transients in which there are large changing asymmetries in the reactor-core power such as would occur in a control-rod-ejection transient unless it is used in conjunction with the PARCS spatial kinetics module. In TRACE, neutronics are evaluated on a core-wide basis by a point-reactor kinetics model with reactivity feedback, and the spatially local neutronic response associated with the ejection of a single control rod cannot be modeled.

The typical system model cannot be applied directly to those transients in which one expects to observe thermal stratification of the liquid phase in the 1D components. The VESSEL component can resolve the thermal stratification of liquid only within the modeling of its multidimensional noding when horizontal stratification is not perfect.

The TRACE field equations have been derived assuming that viscous shear stresses are negligible (to a first-order approximation) and explicit turbulence modeling is not coupled to the conservation equations (although turbulence effects can be accounted for with specialized engineering models for specific situations). Thus, TRACE should not be employed to model those scenarios where the viscous stresses are comparable to, or larger than, the wall (and/or interfacial, if applicable) shear stresses. For example, TRACE is incapable of modeling circulation patterns within a large open region, regardless of the choice of mesh size.

TRACE does not evaluate the stress/strain effect of temperature gradients in structures. The effect of fuel-rod gas-gap closure due to thermal expansion or material swelling is not modeled explicitly. TRACE can be useful as a support to other, more detailed, analysis tools in resolving questions such as pressurized thermal shock.

The TRACE field equations are derived such that viscous heating terms within the fluid is generally ignored. A special model is, however, available within the PUMP component to account for direct heating of fluid by the pump rotor.

Approximations in the wall and interface heat flux terms prevent accurate calculations of such phenomena as collapse of a steam bubble blocking natural circulation through a B&W candy-cane, or of the details of steam condensation at the water surface in an AP1000 core makeup tank.



# *Intended Audience*

This manual has been written to reflect the needs of the those who desire to develop TRACE input models and run simulations with those models. It is written for both novice and advanced TRACE users, alike. While we have attempted to present the information in this manual as plainly as possible, we cannot guarantee that we have succeeded. If you find some section or blurb of text to be particularly difficult to understand, please make sure this information is commnunicated back to the development team so the issue can be rectified. Suggestions and actual rewritten text will be shamelessly accepted.

# Organization of This Manual

This manual is Volume 2 in a two-volume set. It is designed to 1) serve as a learning tool for understanding general modeling techniques, 2) present the conceptual model behind each component type and key subsystem, and 3) present specific user guidelines for each component type, model or major code feature. Volume 1 is designed to present the actual input format and information needed to be able to actually run the code and interpret its output.

Topics of discussion addressed in this manual include general modeling techniques, detailed component descriptions, and user guidelines.

# Reporting Code Errors

It is vitally important that the USNRC receive feedback from the TRACE user community. To that end, we have established a support website at *http://www.nrccodes.com*. It contains the TRACEZilla bug tracking system, latest documentation, a list of the updates currently waiting to be integrated into the main development trunk (called the HoldingBin), and the recent build history showing what changes have been made, when, and by whom. Access to the TRACE-specific areas of the site are password-protected. Details for obtaining access are provided on the public portion of the site.



# Conventions Used in This Manual

In general. items appearing in this manual use the Times New Roman font. Sometimes, text is given a special appearance to set it apart from the regular text. Here's how they look (colored text will, of course, not appear colored when printed in black and white)

ALL CAPS

Used for TRACE component names and input variable names

**BOLD RED, ALL CAPS**

Used for TRACE variable identifiers in the component card tables (column 2)

***Bold Italic***

Used for chapter and section headings

**Bold Blue**

Used for TRACE card titles, note headings, table headings, cross references

Plain Red

Used for XTV graphics variable names

**Bold**

Used for filenames, pathnames, table titles, headings for some tables, and AcGrace dialog box names

*Italic*

Used for references to a website URL and AcGrace menu items

`Fixed Width Courier`

Used to indicate user input, command lines, file listings, or otherwise, any text that you would see or type on the screen

Note – This icon represents a Note. It is used to emphasize various informational messages that might be of interest to the reader.

Warning – This icon represents a Warning. It is used to emphazize important information that you need to be aware of while you are working with TRACE.

Tip – This icon represents a Tip. It is used to dispense bits of wisdom that might be of particular interest to the reader.



For brevity, when we refer to filenames that TRACE either takes as input or outputs, we will generally refer to it using its default internal hardwired name (as opposed to the prefix naming convention to which you will be introduced in the following chapters). So for example, references to the TRACE input file name would use **tracin**; references to the output file would use **trcout**, etc.

# 1

# *Preparing an Input Model*

## *Overview*

The purpose of this section, is to first provide you with some perspective on the total effort required to prepare a plant model and use TRACE to simulate some desired transient. Figure 1-1 illustrates the process that one generally follows when creating an input model for a code like TRACE.



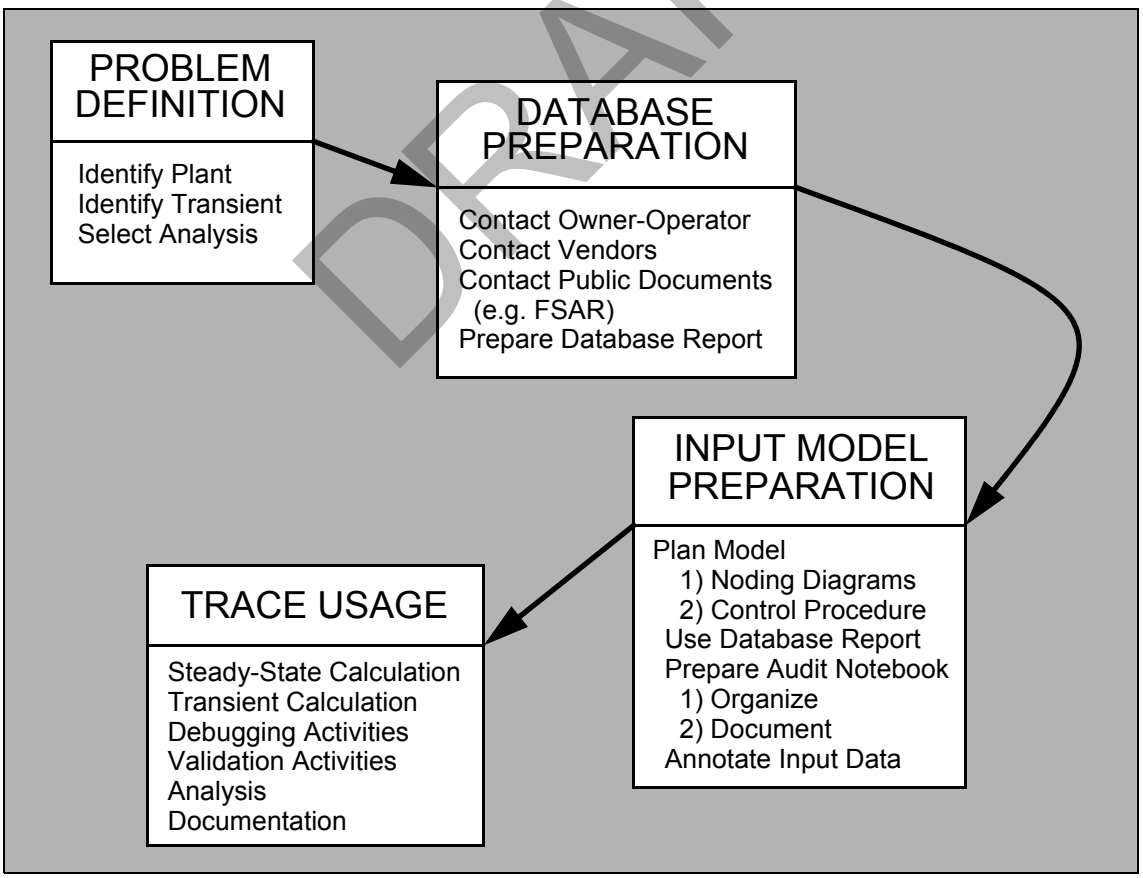


Figure. 1-1. Problem solving with the TRACE code

We believe that each of these steps is important to the successful application of TRACE. We have assumed that an assignment to perform an analysis of a transient in a specific nuclear power plant has been received and that a decision has been made to use TRACE to simulate the transient performance of the plant. We have further assumed that this plant has not been modeled previously; therefore, it will be necessary to collect the information needed to model the specific plant and prepare a TRACE input model from scratch.

# *Database Preparation*

An accurate assessment of the plant transient performance can be expected only if the model accurately depicts the plant features most important to the transient being examined. Therefore, you will need to collect information that provides a complete description of the plant and organize that information into some sort of database. Here, we use the term "database" in its more general sense, meaning simply an organized collection of the information. We do not mean that you have to (or even ought to) transfer the data into some sort of relational database program like Oracle, Sybase, Access, Paradox, or the like. We recommend that each item in your database be assigned a unique identifier; the numbers can be assigned in a serial fashion.



## *Data Requirements*

In general, the database that is required can be assigned to the following seven categories:

1) Thermal-hydraulic geometry data,
2) One-dimensional heat-transfer structural data,
3) Control procedures,
4) Initial and boundary conditions,
5) Model-selection parameters,
6) Reactor description (VESSEL), and
7) HTSTR component.

### *Data Requirements for Thermal-Hydraulic Geometric Data*

In TRACE, all hydraulic flow paths are modeled in 1D Cartesian geometry with the exception of the VESSEL component, which provides either 3-, 2-, or 1D modeling in Cartesian or cylindrical geometry. Let us consider first the mesh cells that are used to model the 1D hydraulic components (e.g., PIPEs, TEEs, VALVEs, etc). The thermal-hydraulic geometric data required for each 1D hydraulic mesh cell and the interfaces between mesh cells are

1) cell length,
2) cell fluid volume,

3) interface fluid flow area,
4) elevation at the cell center or the change in elevation from cell center to cell center,
5) interface hydraulic diameter, and
6) interface additive loss coefficients (so called K-factors).

A natural question at this point might be "how does one decide on how many cells should be used to model a 1D hydraulic component and where do I locate the cell interfaces"? General guidance about noding decisions will be provided in **Chapter 4**. The important point to remember is that for each cell, the six items of thermal-hydraulic data listed above must be provided. Therefore, the data-collection process must provide data of sufficient geometric detail to support the noding decisions you will make later as you prepare your model.

As you might expect, the database needs for modeling a reactor vessel in three dimensions are both more extensive than those for modeling 1D hydraulic components and are more challenging to process because of the complex geometry. In addition, the reactor's internal structure also must be defined. For these reasons, we have chosen to treat most of the unique 3D hydraulic VESSEL component features in a separate subsection provided later in this chapter.

## *Data Requirements for 1D Heat-Transfer Structural Data*

Conduction heat transfer in the cylindrical wall and convection heat transfer from the cylindrical-wall surfaces of a 1D component may be modeled as part of the hydraulic component itself or by explicitly declaring use of a separate heat structure (HTSTR) component. If wall heat transfer is of primary importance, you should consider explicitly declaring your own separate HTSTR component because it offers a wider range of modeling features and can perform a 2D conduction heat-transfer calculation with correlation-defined convection heat-transfer coefficients on both the inner and outer surfaces of the wall. The calculation of wall heat transfer as a part of the 1D hydraulic component models is much simpler. In this case, the only required geometry data are the inner radius, wall thickness, and the wall-material type. In some cases, wall heat-transfer coupling to the hydraulic fluid has little effect on the thermal-hydraulic behavior of a rapid transient and can be eliminated from the simulation model entirely.

## *Data Requirements for Control Procedures*

There are four basic building blocks in the TRACE control procedure: signal variables, control blocks, trips, and component-action tables. These entities are described in much more detail later in **Chapter 3**. Much shorter descriptions are provided here to provide some context for the discussion.

Signal variables are system parameters that are selected by the user for later use in the control procedure to define an input signal to a control block, a trip signal, or the independent variable of a component-action table. Examples of system parameters that may be used as signal variables include (but are not limited to) problem time, cell pressure, phasic temperature, interface phasic

velocity or mass flow, pump-impeller rotational speed, and dissolved-solute (boron) concentrations.

Control blocks are mathematical functions that operate on signal variable and/or other control block input signals to determine some output signal. Examples of control-block functions include arithmetic functions (like add, multiply divide), trigonometric functions (sine, cosine, tangent), derivative, integrators, logical boolean operators (AND, OR, NOT), Laplace transforms, tabular data, and PI/PID controllers. Large networks of control blocks are generally coupled together, either serially or in parallel, to perform the calculations necessary to simulate the response of a real plant's normal operating control functions or reactor protection system.

Trips are ON/OFF switches used to initiate (or terminate) some action by a component specified by the modeler (like a PUMP or VALVE). TRACE can simulate a spectrum of trip-controlled actions from the very simple to the more complex. The closing of a VALVE at a prespecified problem time is an example of a simple trip behavior. The information needed to define such a trip is just the particular VALVE component you wish to close and the problem time that the closure action should begin (usually problem time is measured from the time the steady-state or transient calculation started initially). Generally, transient calculations have simple trip-controlled component actions. However, as plant models more closely simulate the actual plant behavior and its automatic control features, trip-control modeling will become more complex.

The objective of defining signal variables, control blocks, and trips is to produce an adjustment in a component hardware action. This is accomplished within the context of the component's input specification, by defining what we call a component-action table. A component-action table is really nothing more than a way of defining the action a particular component takes as a tabular function of an independent variable.



Ultimately, your knowledge of the hardware actions that can possibly (or should) occur during normal operation or during the transient you wish to simulate, what circumstances will lead to those actions being taken, and how those actions should occur, will define what control procedures you need to define in your model. The major point to be emphasized here is that the control-system modeling decisions you make define your data requirements. If you are interested only in large break LOCAs, then your control-system modeling will probably be minimal. On the other hand, operational transients often require extensive control-system models. We hope that this brief section has helped you understand that you can successfully model a control system only to the extent that you know what it does, its response characteristics, and the information it processes in deciding its action.

## *Data Requirements for Initial and Boundary Conditions*

In general, initial-condition data are the easiest to provide. This is because transient calculations are usually initiated from a steady-state solution that is evaluated by TRACE. The initial condition for a steady-state calculation only requires that an ***estimate*** of the thermal-hydraulic steady-state solution be specified as part of the component data. That estimate can be good or bad. A bad estimate, which is easiest to input, generally requires more iterations by the steady-

state calculation to converge to the steady-state solution. A bad estimate, for example, would be to use constant pressures, constant void fractions, constant phasic temperatures and zero-flow phasic velocities for the entire flow loop. Even worse, would be to define initial states that are not thermodynamically possible (i.e. superheated steam at subcooled pressures) or are highly metastable. In a good estimate, spatial distributions of these parameters (that approximately conserve mass and energy in each cell) need to be input. A hydraulic-path steady-state initialization procedure is provided in TRACE to evaluate such spatial distribution estimates during the initialization phase. It is based on specifying the known or estimated thermal-hydraulic flow condition at a location in each 1D flow-channel hydraulic path.

A steady-state calculation evaluates the steady-state solution pressure, gas-volume-fraction, phasic-temperature, and phasic-velocity distributions throughout the system model. If the thermal-hydraulic modeling is correct and if constrained steady-state controllers are provided to adjust uncertain hardware actions to give known or desired steady-state thermal-hydraulic conditions, an accurate steady-state solution (and hence initial condition for the transient calculation) can be obtained. Again, a good estimate is not required for the input thermal-hydraulic condition if a steady-state solution is to be evaluated by TRACE. The hydraulic-path steady-state initialization procedure can be used to initialize a good estimate and save calculative effort. One exception is the input specification of the gas volume fraction distribution. Because the gas volume fraction distribution establishes the initial liquid inventoy (for example, on the steam-generator secondary side), care should be taken when specifying this parameter.

Boundary conditions may be specified using the BREAK and FILL components in any of three ways. First, boundary conditions that have pre-determined values during the course of a transient are specified explicitly in TRACE. The following types of boundary conditions can be imposed: constant or variable pressure, mixture velocity, or mixture mass flow with a constant or variable fluid state (gas volume fraction, phasic temperatures, noncondensable-gas pressure, and dissolved-solute concentration) for inflow. Again, the modeler must know what boundary condition is desired as a function of time or other appropriate independent variable. Second, boundary conditions that depend on the thermal-hydraulic solution may be specified implicitly through control procedures that apply all the time or may be trip activated during the course of a transient if user-defined conditions are satisfied. Third, a combination of the first and second approaches may be used.



## *Data Requirements for Reactor Vessel Description*

After deciding how to nodalize the VESSEL component [i.e. how many axial segments or levels (z-direction cells), radial segments or rings (x-direction cells), and azimuthal segments or sectors (y-direction cells)], you will need to identify the location of the lower plenum, reactor core, upper plenum, upper head, and downcomer within the reactor vessel. You will also need to identify the hot- and cold-leg entry points to the vessel and the location of vent valves and guide tubes, if they exist. The amount of data required is related to the noding decisions that you make. For each cell that you define within the 3D VESSEL component, you will need to provide the following geometrical data:

1) the cell fluid volume fraction; that is, the fraction of the geometric volume of the cell occupied by fluid (the remaining volume is occupied by structure);
2) the fraction of each cell face [azimuthal (θ or y), axial (z), and radial (r or x)] through which fluid may flow;
3) the hydraulic diameter at each cell face; and
4) the additive-friction-loss coefficients at each cell face for liquid and gas.

### *Data Requirements for HTSTR Components*

The geometry and material must be determined for all fuel rods, control rods, and structure (piping and support hardware) in the modeled plant. The user should determine whether reflood is expected to occur in the core region of the reactor vessel so that an informed decision can be made to model this phenomenon. Data also must be provided to define the neutronic characteristics of the reactor core. These include data about the axial, radial, and azimuthal power profiles; type of reactor-kinetics model needed; power history; and decay-heat characteristics.

## *Data Sources*

There are several sources of facility data that can provide the resource material from which a database can be developed. The best source is the facility owner. For nuclear power plants, this is the power utility that owns and/or operates the plant. The owner-operator is usually the single organization that collects all plant-related data. Experimental facilities can be owned by either governmental agencies, vendors, utility-sponsored research organizations, or owner's groups. In each case, the organization that owns and operates the facility is the best source of the information needed to construct a database. Companies that have manufactured major parts of the plant or experimental facility also are good sources of data. For nuclear power plants, a prime source of information is the reactor vendor.

The FSAR is an excellent, and readily available, source of data for nuclear power plants. The FSAR is a public document that contains both overall plant descriptions and specific plant-design data. However, the data are not sufficiently complete, particularly with regard to secondary systems, to permit complete plant modeling using only this data source. Information about the secondary systems of nuclear power plants must usually be obtained from the owner-operator.

To illustrate the types and sources of materials that you typically will need to compile before preparing a TRACE input model for a nuclear power plant, we have provided, in **Appendix A**, Table A-1 through Table A-9, a descriptive tabulation of such information from the calculation notebook of an input model developed for a Westinghouse three-loop nuclear power plant. This database listing is adequate for detailed modeling of both the primary and secondary coolant-system features of the plant. We have also provided in Table A-10 of **Appendix A**, a tabulation of the FSAR information used in preparing the Zion-1 plant model, thereby providing a more detailed listing of the FSAR information that is useful for input model development.

In some cases there may be data that are not readily available. In such instances, you will typically need to make some approximations based on engineering judgment to be able to completely specify the input model. When that happens, you really need to perform a sensitivity analysis to determine the effect of varying the estimated parameters through a range of possible values.

## *Documentation*

Once you have compiled your database, it is important to organize and document the information. We have found it helpful to assign each item in the database (for example: each drawing, table, or figure) a unique identifier number. As you can see from Table A-1, we have not used a complex system; we have just numbered the items serially as we obtained them. We have tried to maintain the first copy of each item in "as received" condition by making working copies that the modeler can use as desired. The originals are stored in physical volumes where they can be conveniently located.

The system just described has two objectives. The first is to provide a way to identify items in the database that are used in developing the plant model. The second is to provide a traceable path linking the entries in the TRACE input model back to the original database. Traceability is ensured by creating a document called the audit (or calculation) notebook. The audit notebook documents the development of the model; usually it is handwritten, but it must be well organized and legible. Information obtained from the database is cited by the reference number assigned in the database.



# *Input Model Preparation*

## *Notebook for Input Model Preparation*

Once the database is prepared, you are sufficiently prepared (at least from an organizational standpoint) to develop an input model. An important feature of model preparation is the organization of an audit notebook. The importance of this document cannot be overemphasized. The term "document" is used to convey the fact that the audit notebook is to be considered an end product of the input model preparation activity. The notebook must be well organized and legible (it is usually hand-written). There are several significant objectives in keeping an audit notebook. First, the notebook documents the modeling decisions that you make. Second, those input parameters developed from a separate calculation process are recorded. Third, the bases for the input values are identified. Often, the basis is information found in the database. By making clear reference to the information found in the database, you provide traceability between the numbers in the input model and the source data. If there are no specific data for a given input value (in other words, if you made an assumption), that fact must be recorded in the audit document. Because there are so many individual numbers that make up a full-plant input model, it is difficult to prepare an error-free model. However, when potential errors are discovered, the worth of the audit notebook becomes evident because the bases for the current input values are displayed. In

addition, the very process of structuring the model development effort to provide an audit notebook seems to reduce the number of errors that may be introduced during model development.

Documentation of the input model need not be restricted to notebooks. We have found it useful also to provide annotation within the input file itself (in the form of comments). Usually there are two types of annotations. The first is placed at the start of the input file as: (1) title comments that identify the facility being modeled, (2) information that will uniquely identify this specific input file, and (3) a reference to the audit notebook and database documents. The second type of annotation is distributed throughout the input-data file and is provided to help locate and identify data within the input file. This annotation would identify the data values for a given component; for example, cell lengths, cell fluid volumes, fluid flow areas, flow-channel hydraulic diameters, etc.

## *Plant Schematic*

Now that you have compiled a database and are ready to prepare your TRACE input model, you must begin to make decisions about how to model the plant or facility to be studied. In this section, we provide general guidelines to help you get started in the modeling process. The guidelines are illustrated by a TRACE model of a Westinghouse three-loop plant. More detailed modeling guidelines will be provided in **Chapter 4**

To be successful in preparing an input model, you must be (1) knowledgeable about the plant or facility and (2) knowledgeable about how to organize that information into a TRACE input model; this suggests that you will have reviewed the entire TRACE User's Manual before beginning to develop a plant model.



Step 1. Your first step should be to draw a schematic of the plant systems that you intend to model. In the first instance, this can be a simple line diagram. For example, the primary-system drawing would show the relative arrangement of the reactor vessel, the hot and cold legs, the reactor-coolant pumps, steam generators, pressurizer, accumulators, high-pressure injection system, and low-pressure injection system. If you are not sure whether or not you will incorporate a given element in the model, include it in the line diagram. An example schematic of a three-loop plant primary system is shown in Figure 1-2. You should also prepare a similar diagram for the secondary system if it is to be included in the plant model. .

Step 2. Your second step should to be to refine the simple line diagrams by preparing a second set of diagrams that subdivide the systems into components. To do so, you need to have a basic knowledge about the specific component models available in TRACE (see **Chapter 2**) and how they are to be applied. Sample component-level diagrams for the three-loop plant primary and secondary systems are presented in Figure 1-3 and Figure 1-4.

> *Guideline 1.* Divide the plant model into as few TRACE components as possible. The reason for doing this is for computational efficiency; having fewer components reduces the size of the TRACE network matrix that must be solved and reduces the number of

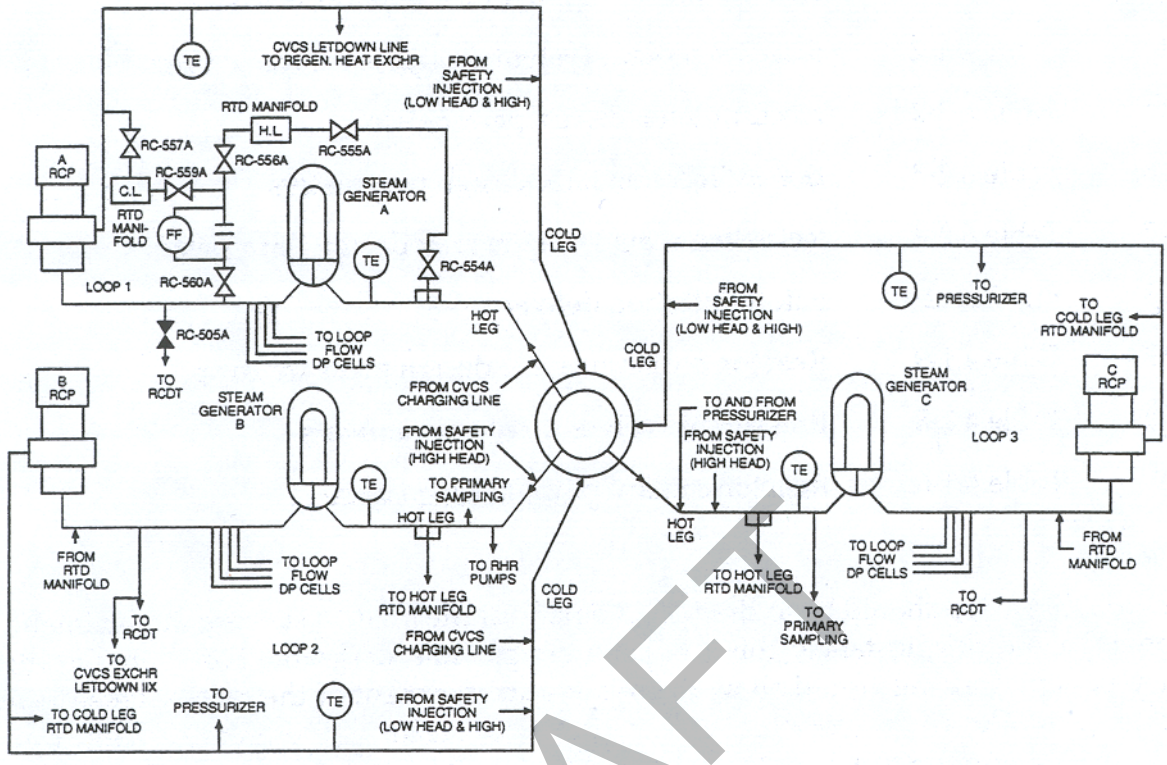


Figure. 1-2. Primary-side reactor-coolant system diagram for a three-loop plant.

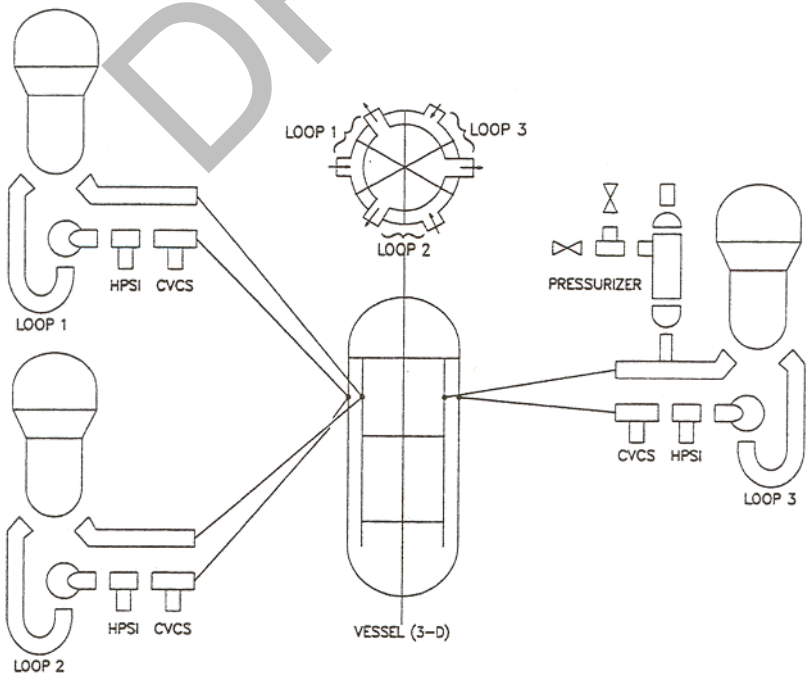


Figure. 1-3. Primary-system mod2eling overview for a three-loop plant.

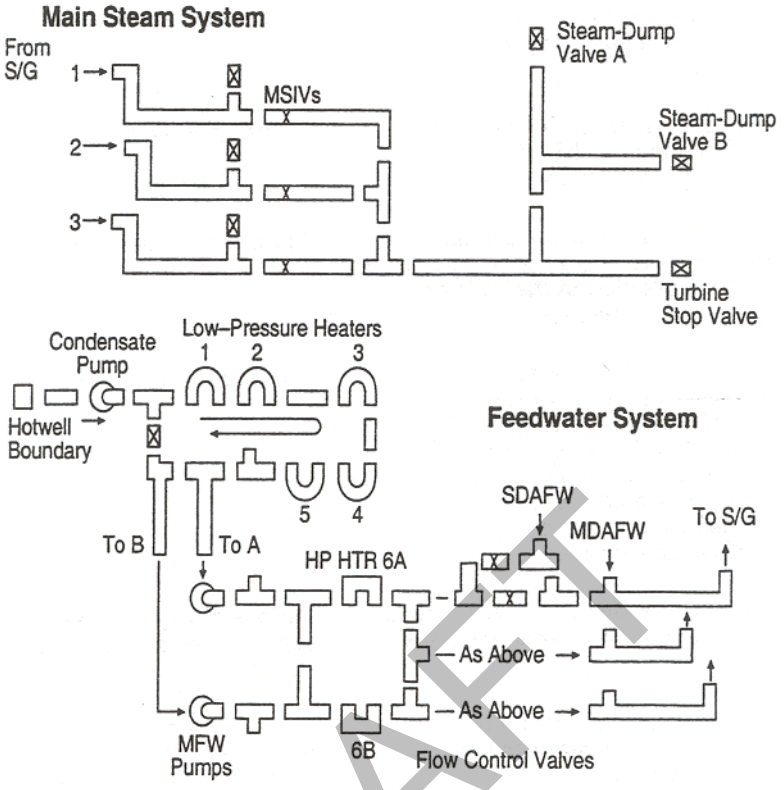


Figure. 1-4. Secondary-system modeling overview for a three-loop plant.



subroutine calls. There are several examples of this approach in Figure 1-3. The PUMP component includes some of the cold-leg piping. A TEE component is used when a separate side-leg connection needs to be modeled [for example, the high-pressure safety injection (HPSI), chemical and CVCS, and pressurizer side-leg pipes from the cold- and hot-leg pipe].

*Guideline 2.* Develop a rational component and junction numbering scheme. There are many possible schemes. The approach taken in the three-loop plant model was to use related numbers for similar components in different loops (for example, the hot-leg PIPE components are numbered 10 and 20 in loops 1 and 2, and the corresponding hot-leg TEE component is numbered 30 in loop 3; the tens digit is the loop number and the units digit reflects the component-order in going from the vessel's hot-leg connection to its cold-leg connection).

*Guideline 3.* As conveniently as possible, try to include all the modeling elements required (control procedures and components) in the steady-state calculation input model.

Step 3. The third step is to prepare noding diagrams for each of the systems to be modeled. We continue with the three-loop plant model that we are using as an example. Figure 1-5 is the reactor-vessel noding diagram; Figure 1-6 shows the reactor-vessel HTSTR (heat structure)

components; Figure 1-7 is the steam-generator noding diagram; Figures 1-8, 1-9 and 1-10 are the the noding diagrams for the three primary loops; Figure 1-11 is the emergency-core-cooling system noding diagram; Figure 1-12 presents the main-steam system and steam-dump system noding diagrams; and Figure 1-13 shows the high-pressure feedwater system noding diagram. Clearly, this is quite a jump from the component diagrams to the detailed noding diagrams. However, the step is not too great if taken one component at a time. Maintain an awareness of the transients you intend to analyze while preparing your steady-state calculation input file. Figure 1-14 shows the modeling for a steam-generator tube-rupture transient initiator that was included in the three-loop plant steady-state input-data model. A second approach is to prepare the steady-state input-data model so that it can be easily updated to include additional modeling elements in the transient-restart input file. Figure 1-15 illustrates the modeling changes for a SBLOCA in a restart input file. The position of the break-flow model can be identified by reference to Figure 1-9.



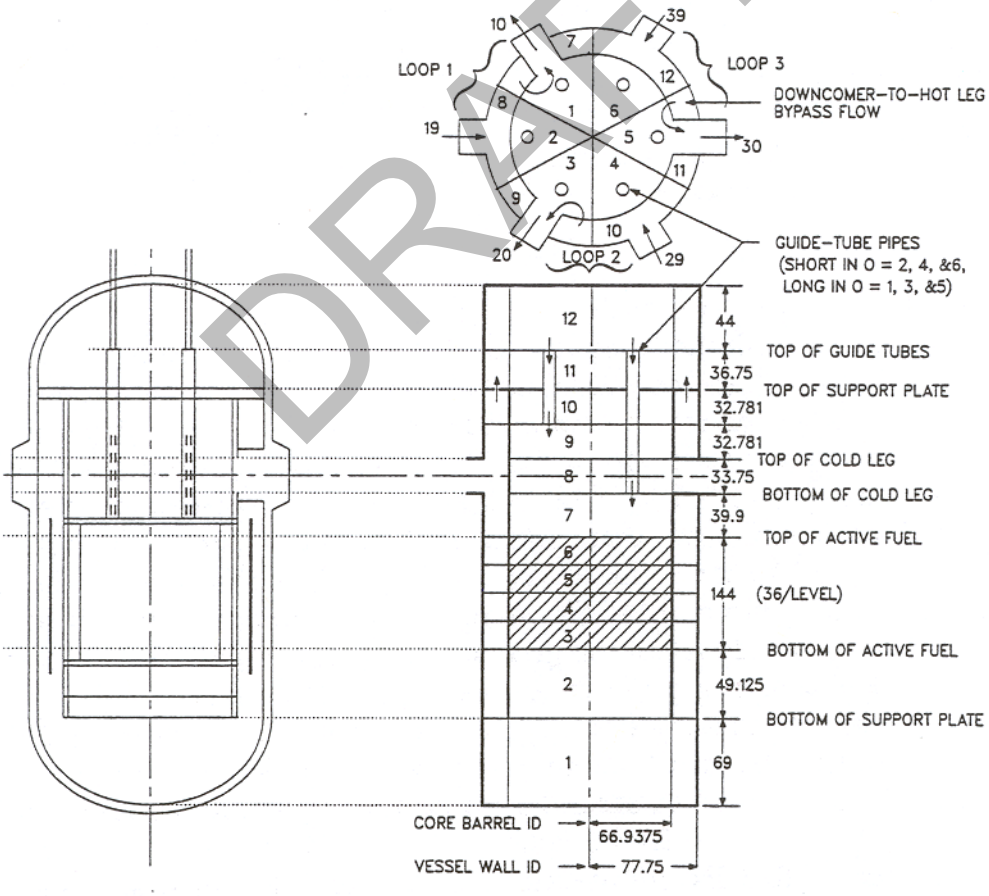


Figure. 1-5. Reactor-vessel noding diagram for a three-loop plant.

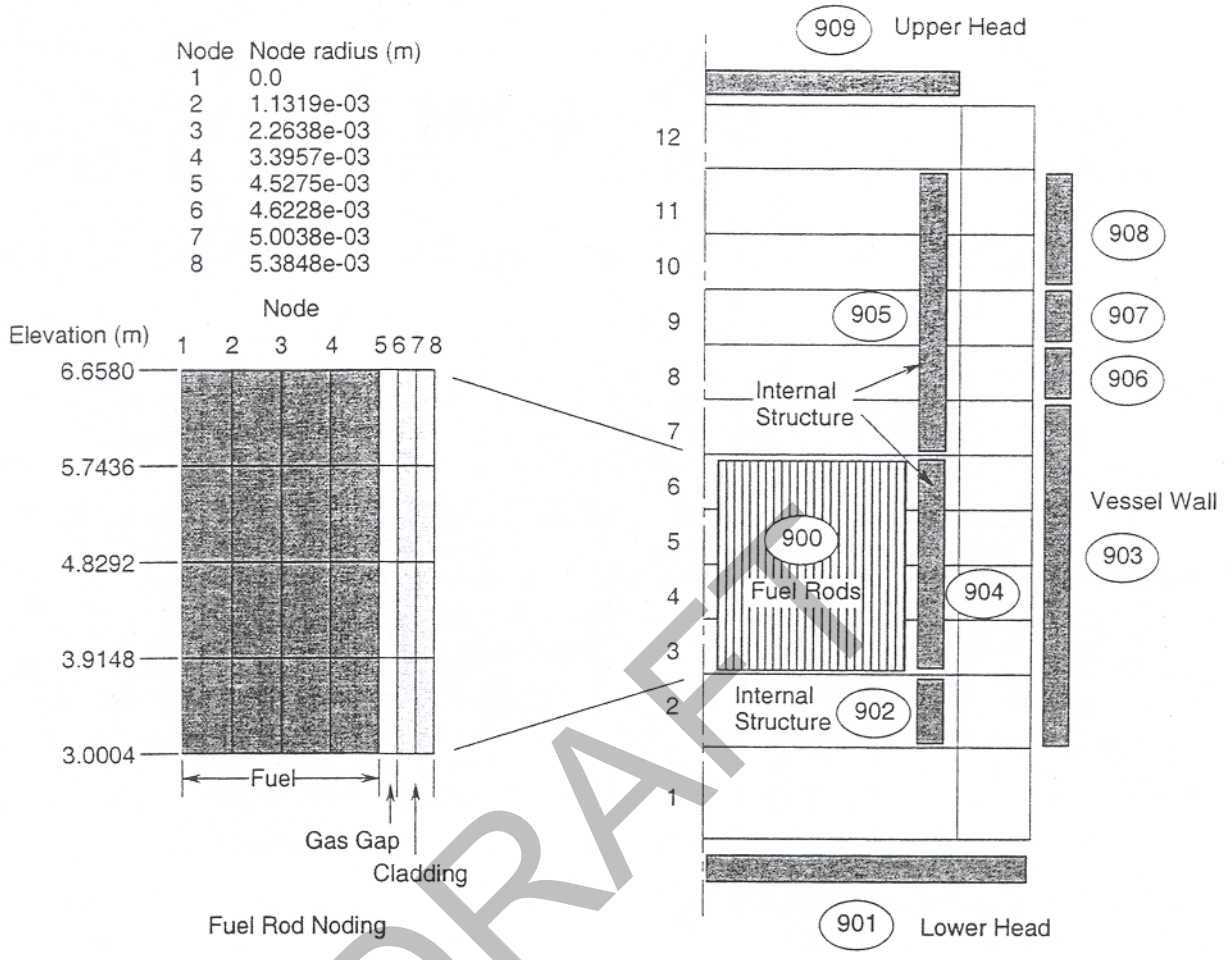


Figure. 1-6. Reactor-vessel HTSTR (heat structure) for a three-loop plant.

To node each component effectively, you will need to refer to the detailed guidelines presented in **Chapter 4**. However, this chapter is the appropriate place to give general guidance about good noding practice. We emphasize noding practices as a general guideline because these decisions can strongly affect the computational cost of each calculation, the physical phenomena that can be resolved, and the degree of ease or difficulty with which TRACE calculates its thermal-hydraulic solution.

> *Guideline 1.* Make each 1D thermal-hydraulic cell as large as you can justify. We recommend that you specify lengths of 1D cells that are between 0.1 m and 3.0 m. We generally use lengths toward the upper end of the range when spatial variation in the thermal-hydraulic solution is expected to be small. Since solutions represent an average across the flow channel, it normally does not make sense to select a cell length less than the hydraulic diameter. An exception exists to this rule when it is necessary to tightly limit numerical diffusion. By default, TRACE uses the stability enhancing two-step SETS numerical method. SETS numerics eliminates the material-Courant time step limitation[1] on the hydraulic solution normally imposed by semi-implicit numerical

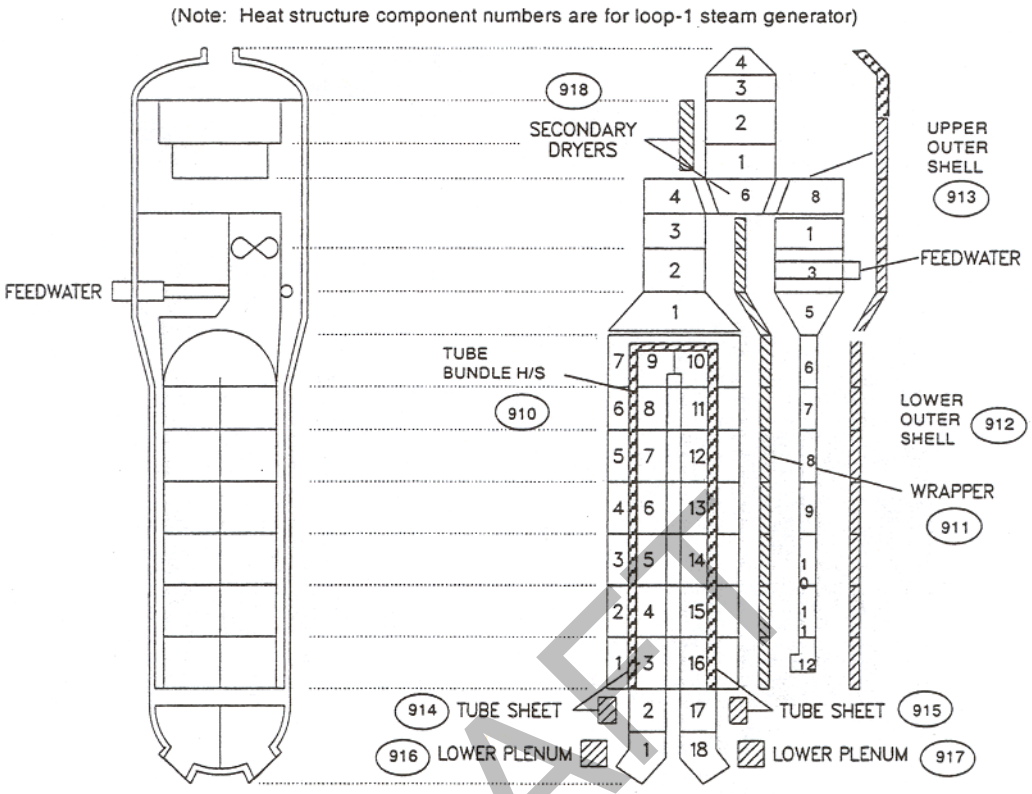


Figure. 1-7. SG noding diagram for a three-loop plant.



schemes. However, there are other time step limiters related to the size of the cell. These include time step checks on the gas volume fraction and pressure variation in time within a cell. Smaller cells are more susceptible to requiring smaller time steps and should be avoided when possible.

*Guideline 2.* Small cell sizes also should be avoided in the 3D VESSEL component. A doubling of the number of cells in the VESSEL can lead to more than a doubling of the computational time for that component. Also, the gas volume fraction and pressure variation in time in each cell limit the time step. Smaller cells are susceptible to more localized rapid transient behavior, which limits the time step size and should be avoided when possible.

*Guideline 3.* Cell sizes smaller than the guidelines are sometimes required in a localized region to accurately calculate phenomena that are of particular interest. For example, we have found it necessary to use fine noding to track the formation of liquid plugs in a portion of the cold leg following initiation of emergency core-coolant injection. Past

1. In other words, the time step must be less than the minimum of all results of cell length divided by fluid velocity

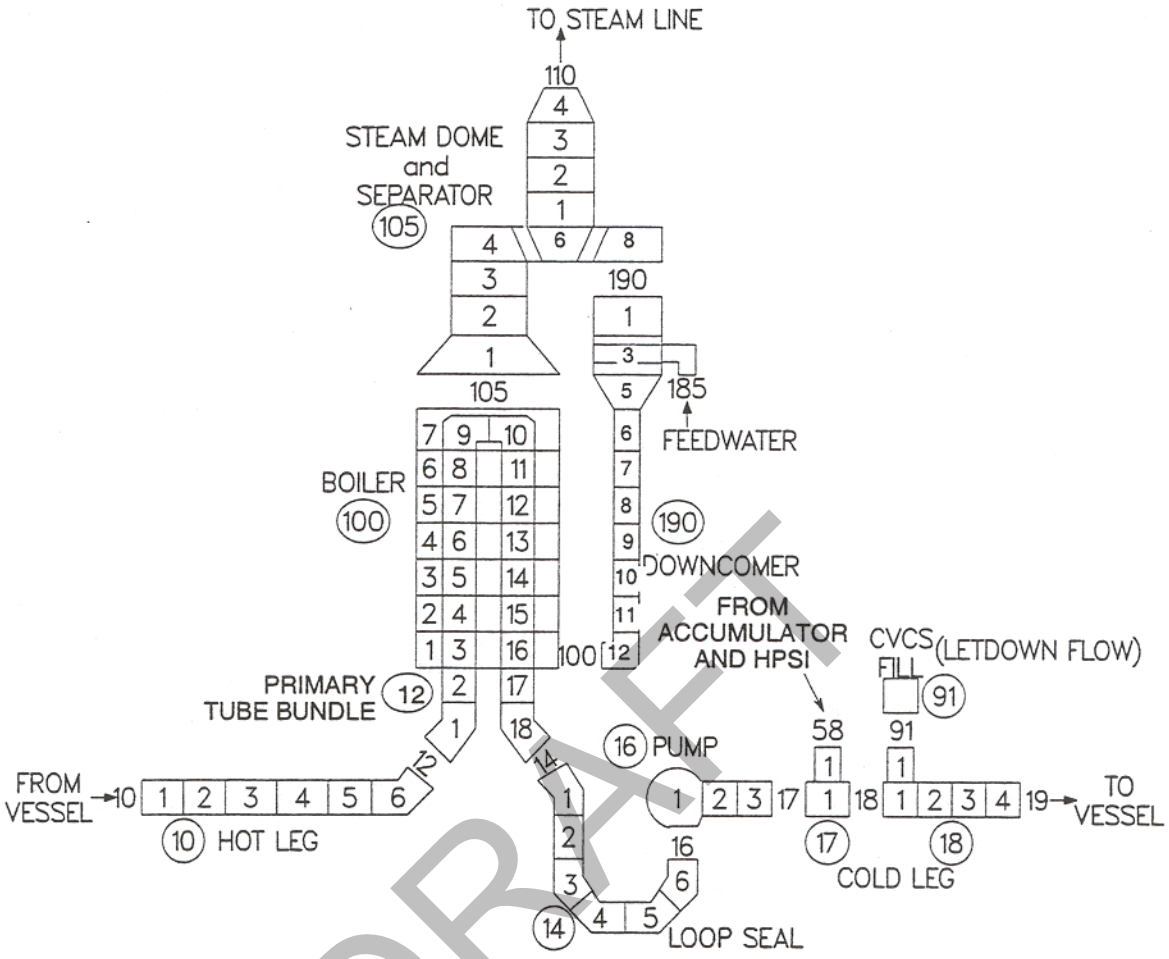


Figure. 1-8. Noding diagram for primary-system loop 1 for a three-loop plant.



code assessments have shown that accurate results for full-scale cold-leg injection tests can be obtained with nodings in the range of $0.7 < \Delta x/D < 2.5$ (see the UPTF-8b separate-effects test in Reference 1-1). We also have used finer noding to closely follow liquid levels on the steam-generator secondary side.

*Guideline 4.* After determining cell lengths, volumes, and flow areas, it is necessary that all irreversible form losses be estimated either from available plant data or from appropriate fluid-flow handbooks. The TRACE momentum-convection terms with flow-area ratios account for only reversible losses. Please note that for abrupt flow-area changes, a NFF < 0 will cause TRACE to estimate from the input geometry with an internal evaluation an abrupt flow-area change irreversible form loss. However, for smooth flow-area changes, the user must estimate an appropriate irreversible form loss to be input-specified by a FRIC (or K-factor).

*Guideline 5.* With knowledge of flow areas and the spcific accident scenario of interest, it is time to think about the physical phenomena associated with area changes. Optional input is available to allow TRACE to use special models for counter-current flow

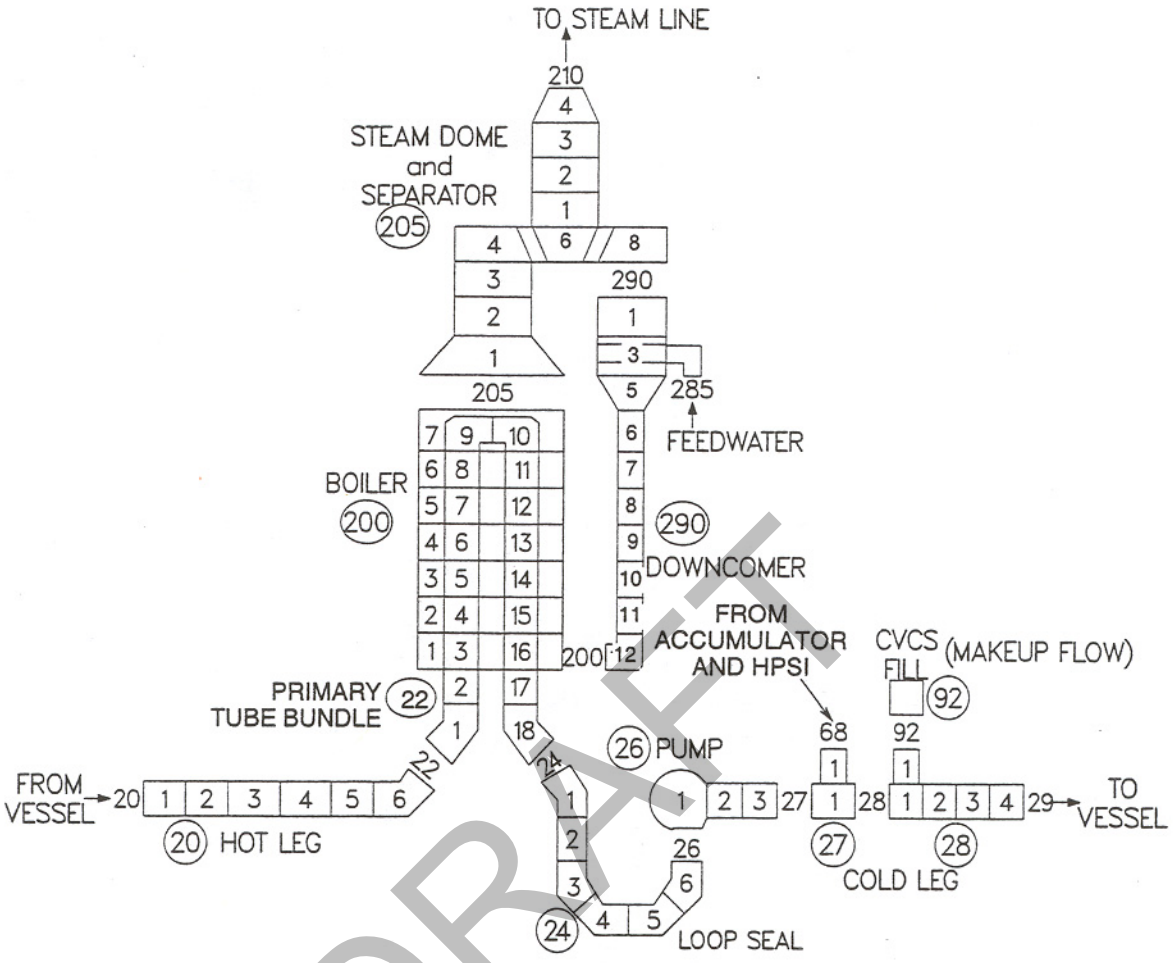


Figure. 1-9. Noding diagram for primary-system loop 2 for a three-loop plant.



limitation (CCFL) and choked flow at any cell edge. However, it is important to realize that these models were designed to operate at isolated locations. Activating these models at all cell edges will cause numerical feedback that will degrade or destroy the validity of a calculation. Only activate the CCFL model at area restrictions in a vertical flow path such as the upper core support plate. Only activate the choked flow model at edges representing an orifice or the beginning of a significant area expansion.

Step 4. Your fourth step is to prepare the input for the control procedure and components. Specific guidelines for preparing this input will be provided in **Chapter 4**; however, here are some general guidelines that will help you.

*Guideline 1.* There is a natural order to follow in preparing your input data. You should first prepare the component input data and then prepare the control-procedure input data for the component actions. This order is different from that in which the data are entered into the TRACE input file. Because signal-variable, control-block, and ID numbers must be entered as part of the component data (when the component has one or more component actions), you will need to make several passes through these component-

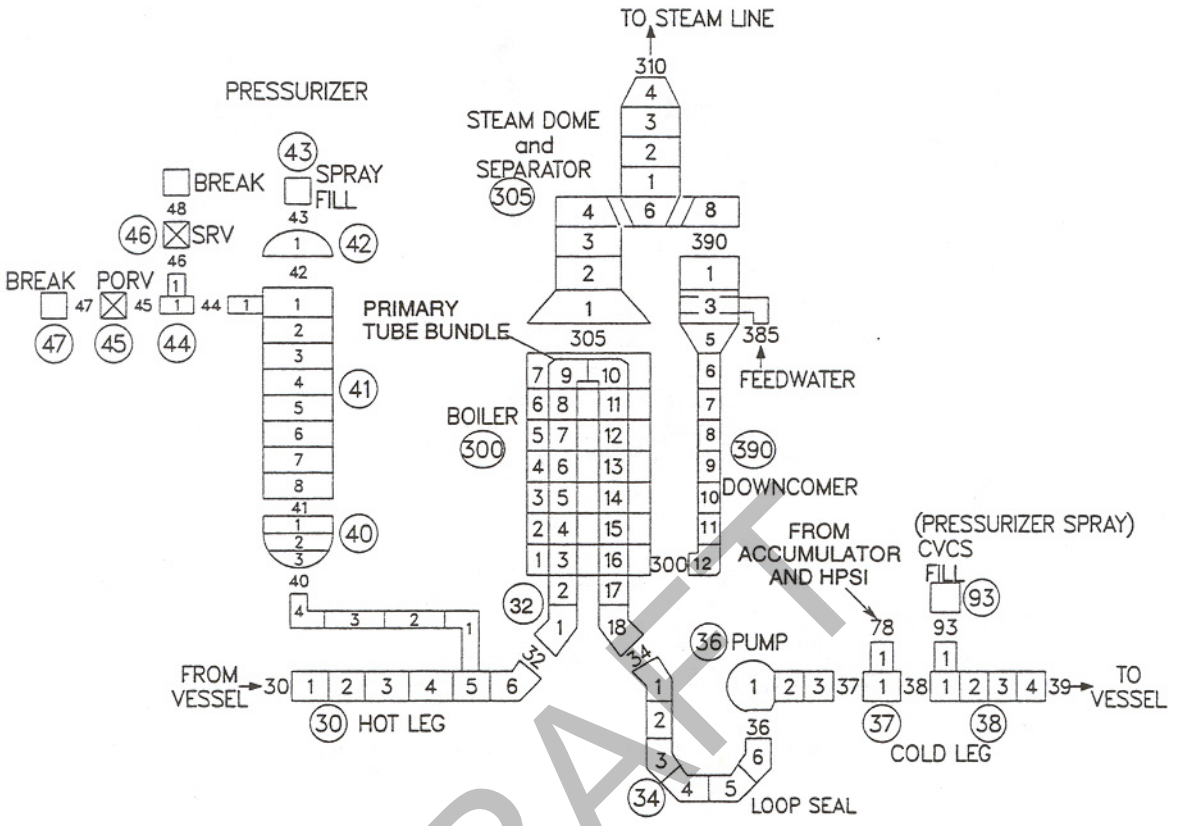


Figure. 1-10. Noding diagram for primary-system loop 3 for a three-loop plant.



data models before they are complete. It is helpful to keep a side list to identify these components that require control-procedure ID numbers for their component actions.

*Guideline 2.* Take the time to annotate the parameters of your input file as you specify their values. The time investment will be small, but the dividends for you and subsequent users of your input model are large. Experienced TRACE users prepare input templates for repetitive components such as PIPEs, TEEs, VALVEs, etc. before developing an input model. The template file could then be copied and data values entered for each component in the plant or facility system model.

*Guideline 3.* TRACE uses ID numbers as identifiers for signal variables, control blocks, and trips of the control procedure. Although not required, we have found it helpful to predefine numbering schemes for the signal variables, control blocks, and trips. These numbering schemes make it easier to locate specific ID numbers in the input-data file, interpret the output, and complete diagnostic activities. For example, some users identify positive ID-number signal variables and negative ID-number control blocks by ± four-digit integers with a zero in the thousandth column. Thus, the problem-time signal variable ID could be 0001 (or 1), the reactor-core power signal variable ID in VESSEL component 300 could be 0300 (or 300), and the pressure drop

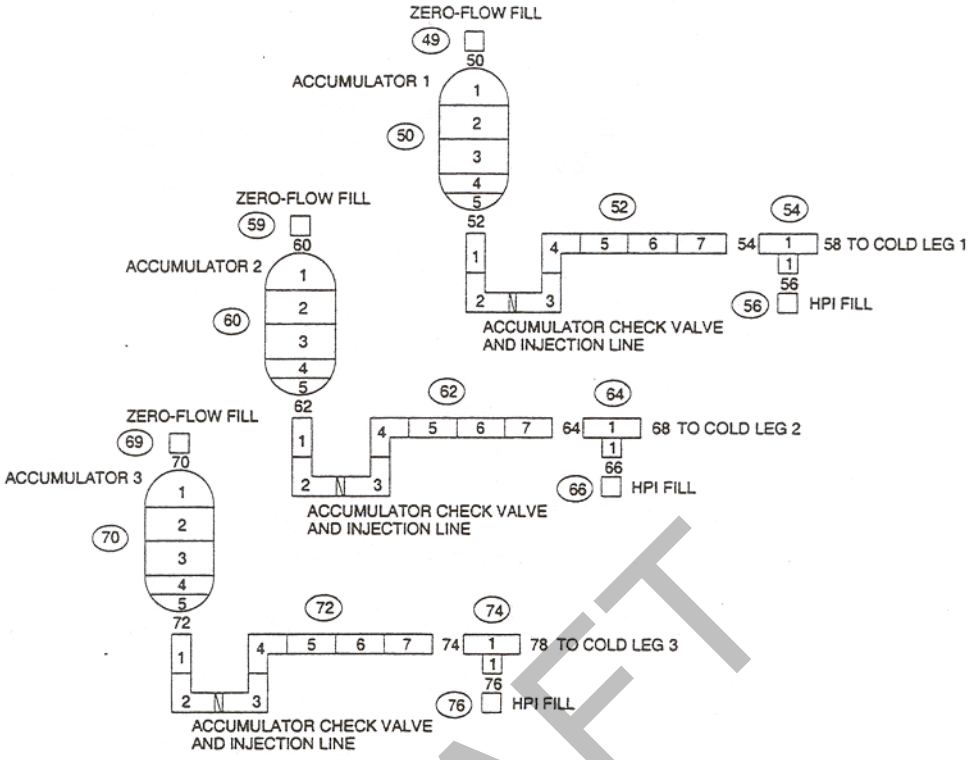


Figure. 1-11. Emergency-core-cooling system for a three-loop plant.

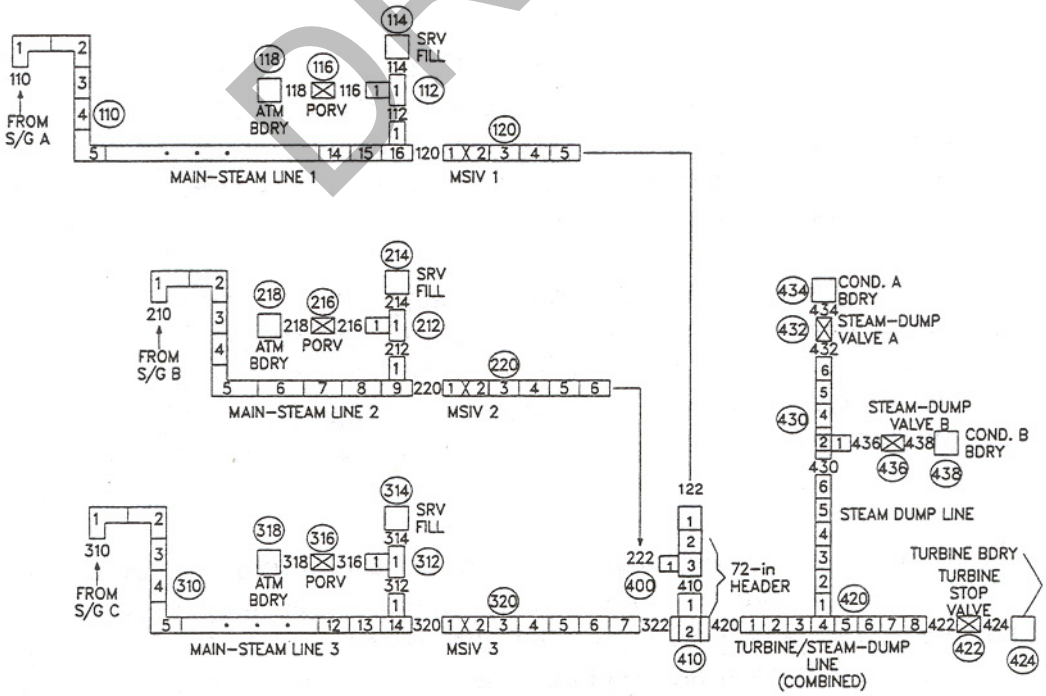


Figure. 1-12. Main-steam line and steam-dump systems for a three-loop plant.

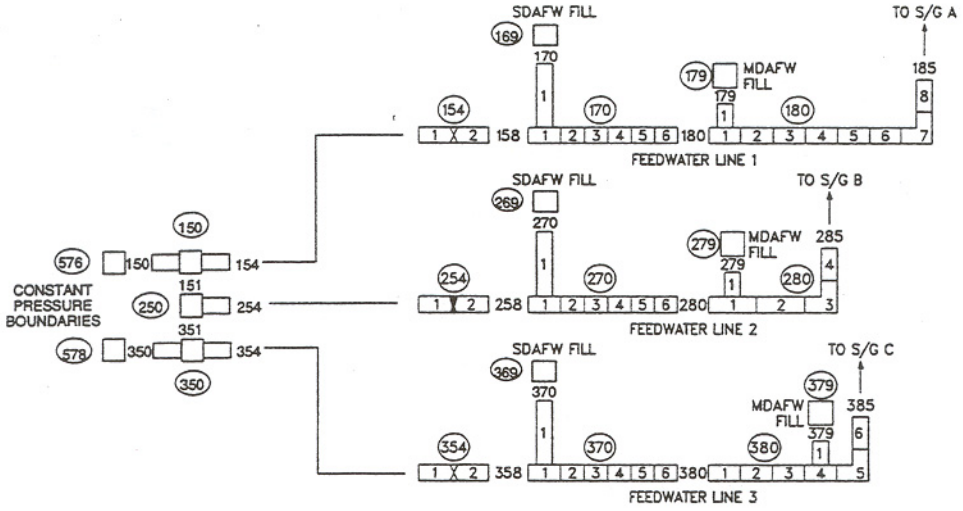


Figure. 1-13. High-pressure feedwater system for a three-loop plant.

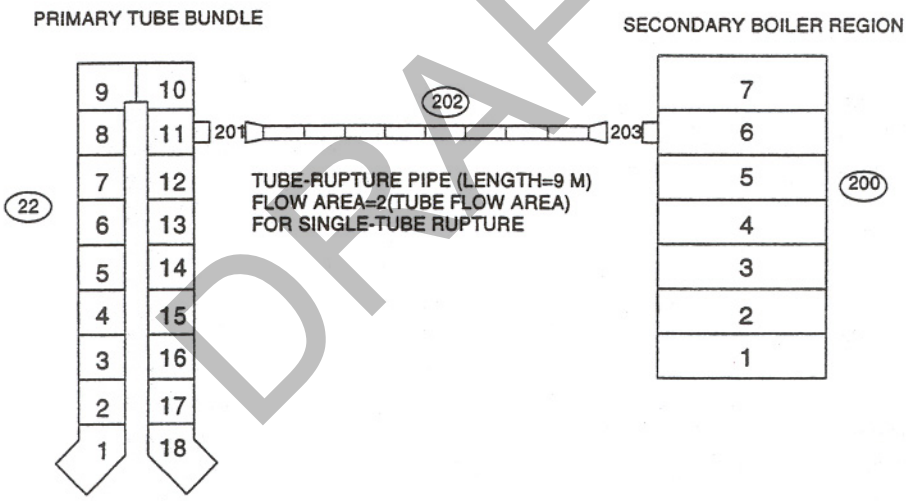


Figure. 1-14. SG tube-rupture model for a three-loop plant.

across the main steam-flow control valve of VALVE component 236 on the secondary side of loop 3 could be 0236 (or 236). A control block with ID -0300 (or -300) could integrate the reactor-core power, and a control-block network to control VALVE component 236 could begin with control block ID -231. Having done this, all trip ID numbers would be defined with ± four-digit integers with a nonzero in the thousandth column. That thousandth-column digit could be different for different groupings of trips that do different control functions.

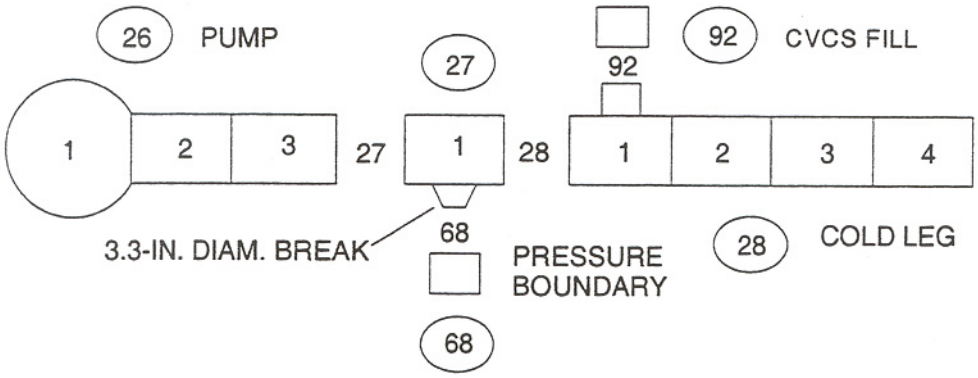


Figure. 1-15. Model changes for SBLOCA for a three-loop plant.

Step 5. The fifth, and final, step is to assemble the control procedure and individual components that you have defined into a complete TRACE input file and execute TRACE with that data as input.

*Guideline 1.* Check your output file and output echo of the input data to ensure that the values that TRACE reads in and uses for each input variable are the values you intended. There is a straightforward way to accomplish this. You can provide TRACE with a TEND end time of 0.0 s defined by one timestep data set at the end of the input file. TRACE reads and processes your input data, outputs an input-data echo, initializes the remaining component variables with appropriate output information, and then ends the calculation at the start of the first timestep.

*Guideline 2.* Carefully review the TRACE message and output files. Many times, TRACE's diagnostic warning messages will help you to eliminate a difficulty you are encountering. If TRACE finds any input values that are invalid, by its extensive internal input checking procedure, warning messages for each invalid value detected are output. If possible, TRACE aborts the calculation after all input data have been read in and processed. From experience with new input models, it is almost certain that TRACE will generate multiple pages of such warning messages when first executed upon a new input file. TRACE's input checking procedure is a great help in eliminating out-of-range values and data inconsistencies in your plant model.

*Guideline 3.* Evaluate your input-data model using the static-check, steady-state calculation option as described in Volume 1 and specified on Main-Data Card 4. You will be able to determine if the elevation changes around your primary-coolant loop provide closure of the loop by adding to zero. If they do not, you will have a spurious natural-circulation coolant flow around the loop when there should be none.

*Guideline 4.* The overall pressure-change flow loss around a loop can be checked by verifying that the TRACE steady-state solution has the rated loop mass flow at the design or measured loop pump-impeller rotational speed. If a faster (slower) pump-impeller rotational speed is required to obtain the design or measured loop mass flow, then the total flow resistance in the loop is too high (low).

*Guideline 5.* Typically plant data are available on total fluid volumes within selected components or groups of components. This information should be used to check the total volume of fluid that is output as part of each corresponding component's input-data echo.

# *References*

1-1 Boyack, B.E., et. al., "TRAC-M/F77, Version 5.5 Developmental Assessment Manual", Los Alamos National Laboratory report NUREG/CR-6730, (July 2001)

# 2

# *Component Models*



This section describes the TRACE component models. All available components are summarized in Table 2-1. Each subsection contained in this chapter presents a physical description of each component along with a typical noding diagram showing the conventions that are used to model the component. User options, restrictions on the use of the component, and input/output information also are presented here. Detailed input-data format specifications for each component are given in Volume 1 of this manual. Mathematical models including finite-difference approximations are provided in the TRACE Theory Manual.



**Table 2-1. TRACE Components**

| Name | Description |
|---|---|
| BREAK | Models pressure boundary conditions at the terminal junction of any 1D hydraulic component. Also specifies fluid properties for inflow from a boundary, for example, the containment building. |
| CHAN | Models a BWR fuel bundle or collection of fuel bundles |
| CONTAN | Models a reactor containment |
| EXTERIOR | Models a component that is non-existent in the current input file but does exist in another input file being run on a different processor. This component is only applicable to ECI-enabled simulations |
| FILL | Models mass flow/velocity boundary conditions at the terminal junction of any 1D hydraulic component. Also specifies fluid properties for inflow from a boundary, for example, for feedwater flow. |
| FLPOWER | Models power generated directly by the fluid. This has accelerator transmutation of waste applications. |
| HEATR | Models a feedwater heater or condenser |
| HTSTR | Models a solid cylinder, slab, or hemisphere for which the temperature distribution is to be computed. Most frequently used to model fuel rods and structural hardware inside a vessel and steam generator. |
| REPEAT-HTSTR | A user-convenience component designed to simplify the input requirements for the HTSTR component. |
| JETP | Models a BWR jet pump or collection of jet pumps |
| PIPE | Models flow in a 1D pipe or duct with direct energy deposition in the fluid or from the walls of the pipe. Serves as a general connector between components to model a system or parts of other structures such as a steam-generator and reactor-vessel down-comer. May be used to model pressurizers or accumulators. |
| PLENUM | Models a large volume connected to an arbitrary number of 1D hydraulic components. A single-cell component that acts like a momentum sink or a convector of momentum in one direction only. |
| POWER | Models the power deposited/generated in solid structures (i.e., HTSTR components) |

**Table 2-1. TRACE Components**

| | |
|---|---|
| PRIZER | Models a PWR pressurizer in one dimension. Recommended for modeling the heater/ sprayer section of a pressurizer. |
| PUMP | Models the one-dimensional interaction of a fluid with a centrifugal pump that includes two-phase effects. |
| RADENC | Models radiation between two surfaces |
| SEPD | Models TEE-like geometry with a coolant-phase separator model. Applications include the BWR separators and the secondary-side of PWR steam generators. |
| TEE | Models flow in two one-dimensional pipes or ducts and their common junction. Models either direct energy deposition in the fluid or through the walls of the pipe. Serves as a general connector between components where a 3-way branch capability is needed. |
| TURB | Models a single stage of a turbine device which extracts energy from the working fluid and produces power. A multistage turbine is modeled by coupling multiple TURB components. |
| VALVE | Models the flow through a one-dimensional pipe with the feature of an adjustable flow area. May be used to model various types of valves in both PWRs and BWRs, e.g., check, trip-controlled, and controller-activated valves. |
| VESSEL | Models a PWR vessel and its internals in Cartesian or cylindrical geometry and in one, two, or three dimensions. May be used to model any vessel-like structure in three dimensions but most applicable to the vessel of a nuclear reactor or a test facility modeling a nuclear reactor. |

# *BREAK Component*



The BREAK component imposes a pressure boundary condition one cell away from its adjacent component, as shown in Figure 2-16. It can be used anywhere fluid is able to enter or leave the system being simulated, and the pressure distribution as a function of time (or some other quantity which is, itself, a function of time) is known. It is commonly used to model the containment system in LOCA calculations or the coolant pressure at an outflow[1] boundary of a 1-D component. It may also be used to model an inflow boundary condition whereby the flow entering a 1-D component is defined by the pressure difference from the BREAK component to the connected volume.

While treated like any other component with respect to ID, input and output, the BREAK component differs from the other hydraulic components in that it may not necessarily represent, geometrically speaking, an actual physical entity in the system being modeled. Rather, it represents the known hydrodynamic conditions of an actual physical location in the system being modeled. The boundary conditions, which includes the pressure as well as other fluid state properties associated with the BREAK cell (which only become important for modeling inflow donor-cell convection), may be specified as constants, defined individually by signal variables or control blocks, or defined as tabular functions of a signal variable or control block. They can also be constant until a controlling trip is set ON and then evaluated based on a set of interpolation

1. For purposes of the discussion in this chapter, outflow is defined as flow from the connected 1-D component to the BREAK; inflow is defined as flow from the BREAK into the connected 1-D component. By convention, outflow is defined as having positive velocity at the BREAK component's junction and inflow is defined as having a negative velocity at the BREAK component's junction.

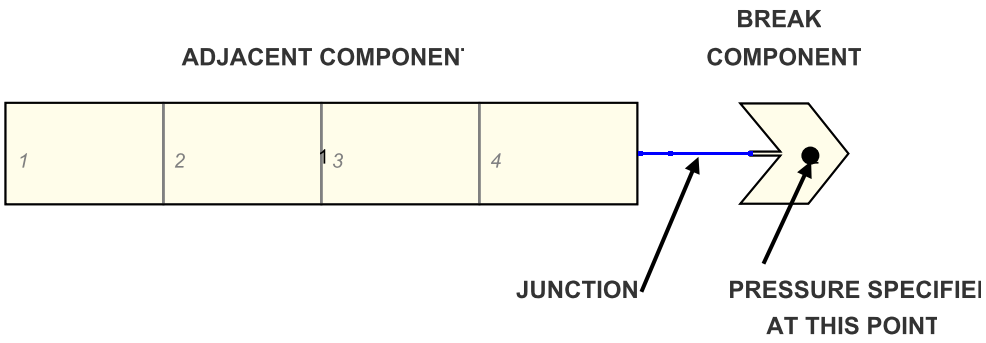


Figure. 2-16. BREAK-component noding diagram.

tables while the controlling trip remains ON. The input parameters needed to define a BREAK component are described in Volume 1.

Generally speaking, there are four modelling scenarios that arise which might call for the use of the BREAK component:

1) modeling outflow from a piping system into a large volume, such as might occur during a small break or large break LOCA.
2) modeling inflow from a large volume into a piping system, such as might occur from a containment if the pressure in the primary system drops below the drywell pressure.
3) you have a test section with a pressure tap downstream of the area of interest and you want to model that pressure tap location as the BREAK location (since you know the time-varying pressure distribution). The flow through the break is outflow. This might be the case for a critical flow separate effects test.
4) Same as 2, except that the pressure tap is upstream of the flow conditions being modeled, so the BREAK would be modeling inflow. The geometry of the test section at the pressure tap is the same or similar to the downstream flow geometry. This situation might arise if you are modeling some separate effects test case, or you are developing some simple verification test case and want to use the BREAK as a means to force some flow into the system, rather than use a FILL.



Warning – A BREAK component may not be connected directly to a VESSEL component, FILL, or a PLENUM component.

# *Break Modeling Options*

The BREAK component offers some flexibility in how the pressure boundary condition is specified. As previously stated, the boundary conditions, which includes the pressure as well as other fluid state properties, may be specified as constants, defined individually by signal variables or control blocks, or defined as tabular functions of an independent variable (defined by a signal variable or control block). The conditions can also be held constant until a trip is set ON and then evaluated based on the tabular-function BREAK tables while the controlling trip remains ON. The IBTY input option governs, at its most fundamental level, how the BREAK component behaves.

## *Constant Boundary Conditions (IBTY = 0)*

The simplest type of BREAK component you can specify (and probably most common) is one in which all the fluid boundary conditions are held constant for the entire simulation. This BREAK type would be appropriate if you were modeling atmospheric conditions in a very large volume (and you would not expect the pressure in that volume to change in any significant way as mass is added to it). Specifying such a BREAK type is simply a matter of setting IBTY = 0, and setting the initial fluid state variables (PIN, TIN, ALPIN, etc) equal to the desired constant values.

## *Table-Driven Boundary Conditions (IBTY = 1 – 5)*

Depending upon the specific IBTY value specified, it is possible to define a series of interpolation tables that govern how the pressure (and possibly other fluid state properties) behaves with time. These tables are known as 'component-action tables' in TRACE-specific jargon. Table 2-2 indicates exactly which fluid properties are table-driven for each IBTY value. If a particular fluid state property (say the void fraction, for example) is not table-driven, then its value is held constant according to its supplied initial value (ALPIN, in this case).



**Table 2-2. List of fluid state parameters obtained via table-lookup for each IBTY value**

| IBTY | Table-driven fluid parameters |
|---|---|
| 1 | pressure |
| 2 | pressure, temperature |
| 3 | pressure, temperature, void fraction |
| 4 | pressure, temperature, void fraction, non-condensible gas pressure |
| 5 | pressure, temperature, void fraction, non-condensible gas pressure, boron concentration |

At the start of each timestep, TRACE performs a table-lookup operation for each of the table-driven parameters. The results of those lookups feed into the new timestep's solution procedure, serving as the starting point for advancing the simulation to its new end-of-timestep condition. In all cases, the independent variable used to perform the necessary interpolations is obtained from a signal variable or control block. This means that the independent variable need not always be time (although in practice, it usually is). Please refer to **Chapter 3,** *Component-Action Tables* for a complete description of how BREAK tables function, in practice, including explanations of some of the more exotic features available to the user (like rate factor tables, constrained rates of change, scale factors, ON/OFF trip behavior, etc).

One thing to keep in mind is that depending upon the value of the ISAT input variable, the temperature tables may actually be overriden in favor of setting either the liquid or vapor temperature to the saturation temperature. This modeling option is discussed in more detail below in the section ***Saturation Temperature Use Option (ISAT)***.

One disadvantage of the table-driven BREAK types is that you are constrained to supplying the various fluid parameter tables in pre-determined combinations. It is not possible, for example, to specify just the total pressure and non-condensible partial pressure tables as the time-varying quantities of interest, without also being required to supply a temperature and void fraction table, as well. If that becomes an important modeling consideration, then you should consider using a BREAK driven by the control system directly (IBTY = 6), as discussed in the next section.



## *Control System-Driven Boundary Conditions (IBTY = 6)*

With the power of the entire control system behind it, this option provides the most flexibility in terms of being able to prescribe a series of time-dependent boundary conditions. Known as a "Generalized BREAK", this table type, defined by IBTY = 6, makes it possible to specify a series of signal variables or control blocks whose outputs directly define the values for the various fluid parameters (pressure, temperature, etc) imposed by the BREAK. It is possible to hold one or more parameters constant simply by defining its signal variable/control block ID as zero; without a signal variable/control block to draw from, TRACE will simply revert to using the defined initial value (PAIN, ALPIN, etc), instead.

It is worth noting that this BREAK type is not affected by two features that do impact the table-driven BREAK types — the allowed maximum rate of change (RBMX) and trip control (IOFF and IBTR). If trip control is truly necessary, such functionality can be enabled through judicious use of the trip-aware control blocks (ICBN = 62 and 63).

## *Containment-Coupled BREAK (IBTY = 7)*

It is possible to define a BREAK such that it is able to obtain its boundary conditions from an attached CONTAN compartment. This is accomplished by setting IBTY = 7 and specifying the COMPID variable equal to the CONTAN compartment from which the BREAK will obtain its boundary conditions. The details regarding how this modeling option works is explained in more

detail below in the section ***Coupling a CONTAN with BREAK and FILL Components*** (part of the CONTAN component description).

## *Saturation Temperature Use Option (ISAT)*

This option provides additional control over how the fluid temperature boundary conditions are determined. The main purpose of this option is to allow TRACE to override the normal operation of the temperature boundary condition (i.e. held constant, table-driven, or control system-driven) and force one or both of the phasic temperatures ($T_l$ or $T_g$) to track the saturation temperature (either exactly, or within some "Δ") that corresponds to the (possibly changing) break pressure. Table 2-3 provides a matrix of how the internal phasic temperatures are set based on the different values of ISAT and IBTY.

**Table 2-3. Matrix indicating where TRACE obtains its liquid and gas temperatures for the various combinations of IBTY and ISAT**

| ISAT | | IBTY Values | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **1** | **2** | **3** | **4** | **5** | **6[a]** | **7[b]** |
| **0** | $T_l$ = | **TIN** | **TIN** | **TLTB** | **TLTB** | **TLTB** | **TLTB** | **IBTLSV or TIN** | $T_{con,l}$ |
| | $T_g$ = | **TIN** | **TIN** | **TLTB** | **TLTB** | **TLTB** | **TLTB** | **IBTLSV or TIN** | $T_{con,g}$ |
| **1** | $T_l$ = | **TIN** | **TIN** | **TLTB** | **TLTB** | **TLTB** | **TLTB** | **IBTLSV or TIN** | $T_{con,l}$ |
| | $T_g$ = | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{con,g}$ |
| **2[c]** | $T_l$ = | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{con,l}$ |
| | $T_g$ = | **TIN** | **TIN** | **TLTB** | **TLTB** | **TLTB** | **TLTB** | **IBTVSV or TIN** | $T_{con,g}$ |
| **3** | $T_l$ = | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{con,l}$ |
| | $T_g$ = | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{sat}$ | $T_{con,g}$ |
| **4** | $T_l$ = | **TIN** | **TIN** | **TLTB** | **TLTB** | **TLTB** | **TLTB** | **IBTLSV or TIN** | $T_{con,l}$ |
| | $T_g$ = | **TIN** | **TIN** | **TVTB** | **TVTB** | **TVTB** | **TVTB** | **IBTVSV or TIN** | $T_{con,g}$ |
| **5[d]** | $T_l$ = | $T_{off,l}$ | $T_{off,l}$ | $T_{off,l}$ | $T_{off,l}$ | $T_{off,l}$ | $T_{off,l}$ | $T_{off,l}$ | $T_{con,l}$ |
| | $T_g$ = | $T_{off,g}$ | $T_{off,g}$ | $T_{off,g}$ | $T_{off,g}$ | $T_{off,g}$ | $T_{off,g}$ | $T_{off,g}$ | $T_{con,g}$ |

a. If IBTLSV or IBTVSV are specified as 0 (indicating that no signal variable or control block is available to control the liquid or vapor temperature, respectively), then the temperature value is held constant at the value specified by TIN.

b. $T_{con,l}$ and $T_{con,g}$ are the phasic temperatures calculated by the connected CONTAN compartment

c. For IBTY = 2–5, TRACE actually obtains the vapor temperature from the values supplied for the liquid temperature table, TBTL (also the case for ISAT = 0).

d. $T_{off,l} = T_{sat}$ + DELTL ; $T_{off,g} = T_{sat}$ + DELTV

As you can see, the effects of this option will override other specifications (for example, if you select IBTY=2 and supply a temperature table for TLTB, but set ISAT=5, the temperature value that TRACE will use is $T_{sat}$, and not the temperature interpolated from TLTB. The only exception to this rule is for IBTY = 7. In that case, the different values of ISAT will have no effect on the phasic temperatures; TRACE will always obtain them from the connected CONTAN compartment.



### *Use of the Active Break Option (ADJPRESS = 1)*

One other use of the BREAK component not yet discussed is its use as, what we call, an "active break". A very experienced user might note that in a normal FILL-PIPE-BREAK scenario, the boundary conditions are actually over-specified. This is because, while the BREAK is used to define the system pressure, the FILL also forces the user to define a pressure which helps to define the thermodynamic state of the fluid being convected into or out of the system. In the process of calculating the pressure distribution back through the system (starting at the BREAK), an inconsistency can develop between the FILL pressure and the pressure one cell removed, in the adjacent component. This inconsistency can manifest itself as a large pressure spike which affects the thermodynamic properties at the FILL, eventually affecting the energy equation solution. For normal light water reactor safety simulations this seeming inconsistency tends to be of little consequence (because the density of water is weakly dependent on pressure). However, for other working fluids, like an ideal gas, the problem may manifest itself more noticably.

The "active break" option is an attempt to allow the user to circumvent this overspecification of boundary conditions. Instead of using a FILL component to specify the mass flow, the mass flow should instead be defined using a combination of a BREAK with ADJPRESS=1 connected to a single junction PUMP (type 10 or 11). The active break uses the pressure from the adjacent cell, thereby eliminating a situation in which the user is able impose the pressure in two different places.



## *Specifying the BREAK Behavior*

The geometry of the BREAK component plays a large role in how it behaves. As a user, you have three input variables through which you are able to specify this geometry. The variables DXIN and VOLIN specify the BREAK's length and volume respectively. These are used to determine the volume-centered flow area from the following relationship:

$$A_{break\_\text{volume}} = \frac{VOLIN}{DXIN} \tag{2-1}$$

The BELV input is only used when IELV=1. It specifies the elevation of the BREAK's cell center and is used to compute the gravity vector at the junction between the BREAK and connecting volume.

For system outflow into the BREAK component, the flow in the connected junction is determined by the pressure difference between the BREAK component and the connected volume. If the connecting junction is choked, the junction thermodynamic properties are set equal to the conditions in the upstream connected volume. If the connecting junction is unchoked, the junction thermodynamic properties are defined as the length-weighted average between the connecting volume and the BREAK component. In this case, averaging of the BREAK component's thermodynamic properties with those of the adjacent volume for use in the junction momentum equation can be eliminated by defining a very small length, DXIN, for the BREAK component input. That is, a small value of DXIN relative to the DX of the adjacent connected volume will give a greater weighting to the connected volume for calculating the junction thermodynamic properties. Similarly, a large value of DXIN relative to the DX of the adjacent connected volume will provide greater weighting to the BREAK volume in calculating the thermodynamic properties of the connecting junction. The BREAK length, and therefore, the averaged properties, can have a pronounced effect on the interfacial drag and wall drag closure models.

The BREAK component can be used to model pressure-dependent inflow into a modeled system. In this case, the input values for fluid pressure, gas volume fraction, fluid temperatures, noncondensible-gas partial pressure, and solute concentration in liquid define the properties of the fluid convected into the adjacent volume. The connecting junction thermodynamic conditions are defined as the length-weighted average of the BREAK component and the connecting volume. As explained above, averaging the BREAK component's properties with those of its adjacent cell for their junction momentum cell can be eliminated by defining a very small BREAK-cell length (DXIN) (weighting factor). The user also should input a very large BREAK-cell volume or very small BREAK-cell length (for example, VOLIN = $10^{10}$ or DXIN = $10^{-10}$) to model a very large inflow area (defined by Eq. (2-1)).

Detailed guidance regarding how to set the VOLIN and DXIN inputs is provided in **Chapter 4,** *Break-flow modeling* Suffice it to say that the pressure condition that you specify for the BREAK always represents a static pressure. TRACE will internally calculate a dynamic pressure for the BREAK volume using the BREAK flow area defined by Eq. (2-1) and the length-weighted junction thermodynamic conditions determined during the problem solution. Consequently, the BREAK volume dynamic pressure is defined as:

$$P_{dynamic} = P_{static} + \frac{\dot{m}^2_{junction}}{2\rho_{junction} A^2_{break\_volume}} \tag{2-2}$$

where

$P_{dynamic}$ is the BREAK volume dynamic pressure.

$P_{static}$ is the BREAK volume static pressure (input).

$\dot{m}_{junction}$ is the mass flow rate for the junction connected to the BREAK volume.

$\rho_{junction}$ is the density of the fluid at the junction connected to the BREAK volume. It is a length-weighted average of the cell-centered densities in the two adjoining cells.

$A_{break\_volume}$ is the BREAK volume flow area defined by VOLIN / DXIN.



# *CHAN Component*

The CHAN component is used to simulate a BWR fuel assembly within the core region of a BWR pressure vessel (see Figure 2-17). As you can infer from that figure, the VESSEL component is typically used to simulate the lower plenum, downcomer, core bypass, mixing plenum, and steam dome. The separator dryer is simulated with one or more SEPD components. The core bypass is the region outside of the BWR fuel assemblies and within the core shroud. Control rods can be inserted in the core bypass region in the gaps between the fuel assemblies and PIPE components can be used to simulate the Control Rod Drive (CRD) Guide Tubes. The actual BWR fuel assemblies are simulated with the CHAN component, which uses 1D TRACE hydraulic components to simulate the flow through the fuel assemblies as well as the leakage path flow from the BWR fuel assembly into the core bypass. The CHAN component can be used to represent one or more actual BWR fuel assemblies. The number of CHAN components used to represent BWR fuel assemblies will depend upon the 3D VESSEL noding in the core region, the radial power distribution across the core, the types of the BWR fuel assemblies loaded in the core, and the inlet orifice configuration through the lower core support plate used to maintain a relatively uniform inlet flow through the BWR fuel assemblies.



The CHAN component is really just a wrapper around a number of other TRACE 1D hydraulic components, heat structures, and radiation heat transfer components. The CHAN component brings together in one place all of the input required to generate a TRACE BWR fuel assembly model; TRACE internally generates (i.e. spawns) the TRACE sub-components needed to simulate the flow and heat transfer associated with a BWR fuel assembly. The sub-components that may be generated from a single CHAN component are

1) PIPE - in-channel flow through BWR fuel assembly.
2) Powered HTSTR - for each fuel rod group(s) simulated.
3) Non-powered HTSTR - for the canister wall.
4) RADENC - Radiation heat transfer enclosure component to simulate radiation heat transfer from within the BWR fuel assembly.
5) Side Junction - Leakage path between CHAN and core bypass.
6) PIPE - for each water rod group simulated.
7) Two Side Junctions - for each water rod PIPE in the model.

8) Non-powered HTSTR - for each water rod PIPE in the model. To simulate the water rod pipe walls which have water rod fluid inside and in-channel fluid outside.

The PIPE sub-components are used to simulate the flow through BWR fuel assembly, the leakage path from the BWR fuel assembly inlet nozzle to the core bypass, and flow through any water rods within the BWR fuel assembly. Drilled holes in the BWR fuel assembly inlet nozzle are designed to supply this leakage flow that is important to minimize mechanical vibrations in the core bypass region. Leakage flow through the finger springs at the bottom channel box provides additional flow from the BWR fuel assembly into the core bypass. In addition there are direct flow paths from the lower plenum into the core bypass region. During accident analysis these leakage paths provide a flow path to fill the lower plenum and fuel assembly from any Emergency Core Cooling System (ECCS) water accumulating in the core bypass. In addition, during an Anticipated Transient Without Scram (ATWS), these leak paths provide a flow path for the borated solution from the core bypass into the inlet of the fuel assembly and into the lower plenum.

The HTSTR components are used to represent the conduction and gas-gap heat transfer within the fuel rods, the heat transfer between the fluid inside the water rods and the fluid inside the BWR fuel assembly, and heat transfer between the BWR fuel assembly fluid and the fluid in the core bypass (see Figure 2-18). Depending upon the BWR design, ECCS water may be added directly to the core bypass or may be sprayed into the mixing plenum. In either case, the accumulation of ECCS water in the core bypass region or liquid films falling from the mixing plenum can cool the BWR fuel assembly channel box and provide significant cooling to a BWR fuel assembly that has dried out. When the BWR fuel assembly is dried out, then radiation heat transfer to the relatively cooler channel box wall can be a significant source of heat transfer. In order to be able to simulate this radiation heat transfer mechanism, a RADENC sub-component can also be generated based on the CHAN input.

The number of fuel assemblies represented by the CHAN component is determined by the user input for NCHANS. The CHAN component simulates one or more fuel rod groups associated with the BWR fuel assembly, water rods, canister or channel box walls as well as leakage flow path between the channel box inlet and the core bypass region. For the CHAN components given in Figure 2-17, the normal flow direction is up — from the lower plenum through the CHAN to the mixing plenum. The leakage path from the CHAN inlet to the core bypass is also indicated in Figure 2-17. The canister wall heat structure is a two-sided heat structure with in-channel fluid on the inside of the heat structure and the core bypass fluid on the outside. Within the CHAN component, heat transfer occurs from the grouped fuel rods to the in-channel fluid, as well as from inside a water rod(s) to the in-channel fluid. Fuel rods may be a combination of full length and partial length fuel rods. Water rods provide another flow path through the BWR fuel assembly.

There will be a separate HTSTR component for each fuel rod group, for the canister wall, and for the water rod wall if the water rod exists in the fuel assembly design. There will be a 1D hydro component for the in-channel flow through the CHAN component, for the leakage path, and for the water rod(s) if the design contains a water rod.

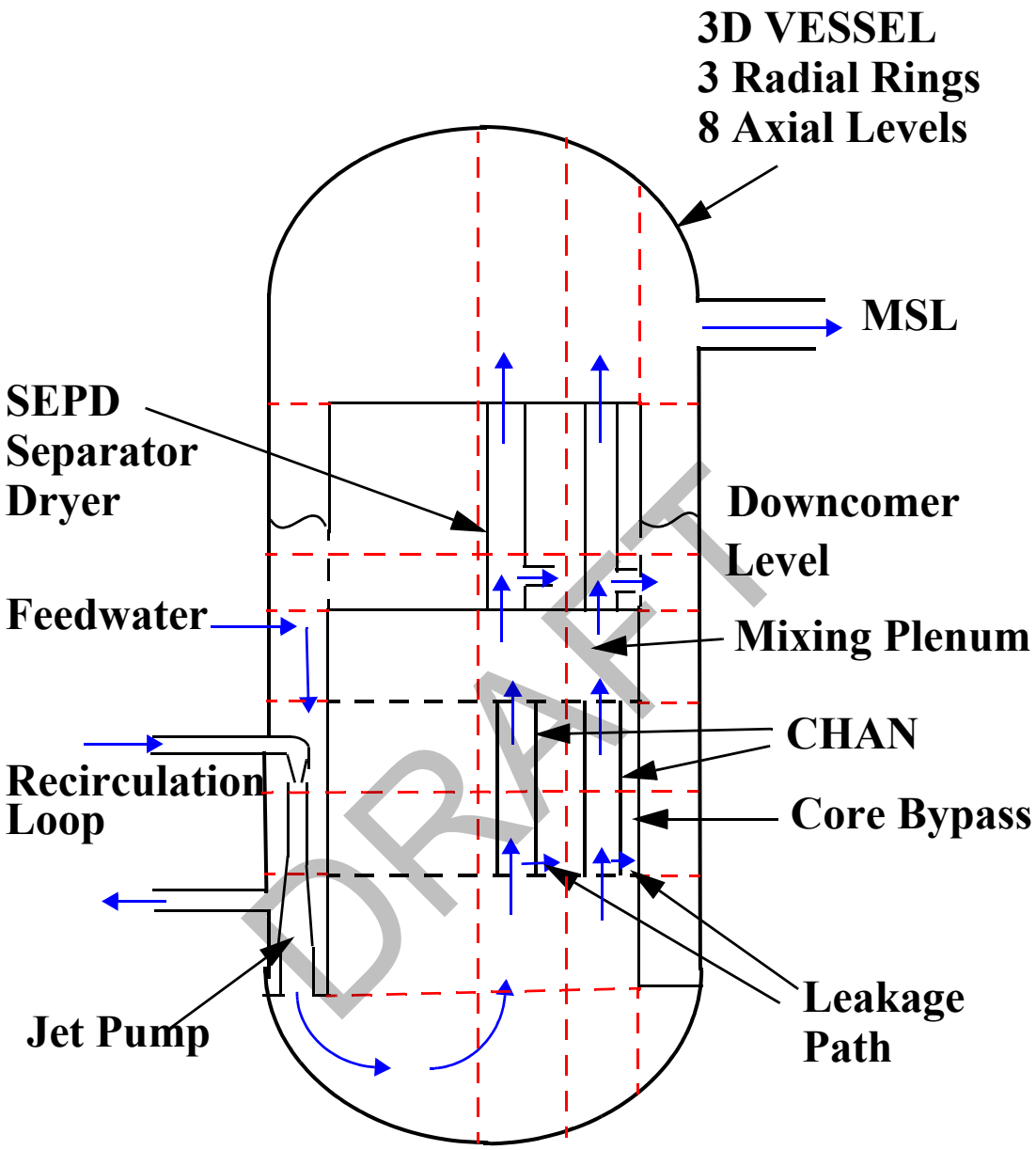




Figure. 2-17. TRACE BWR Model.

## *Modeling Fluid Leak Paths*

It can seen that at the inlet to the CHAN components in Figure 2-17, there is a leakage path between the CHAN component inlet and the core bypass region. Drilled holes in the BWR fuel assembly inlet nozzle are designed to supply this leakage flow that is important to minimize mechanical vibrations in the core bypass region. Leakage flow through the finger springs at the

bottom channel box provides additional flow from the BWR fuel assembly into the core bypass. In addition there are direct flow paths from the lower plenum into the core bypass region. During accident analysis these leakage paths provide a flow path to fill the lower plenum and fuel assembly from any ECCS water accumulating in the core bypass. For the CHAN input, the NSIDES variable represents the number of leak paths plus two times the number of water rods simulated in the CHAN component (i.e., NUMWATERRODS). Please note that NSIDES can only be input for the CHAN component if USESJC (i.e., namelist input) is 2 or 3. If there is one leak path and one water rod to be simulated, then NSIDES would be input as 1 + 2 * NUMWATERRODS = 1 + 2 * 1 = 3. The CHAN component input then expects NSIDES set of input cards that defines these side junctions. For the two side junctions for each water rod simulated, the side junction input would be:

NCLK = axial cell number in the CHAN component where the water rod inlet/outlet is located
JUNLK = unique junction number to be associated with this side junction.

The geometry of the water rod inlet and outlet will be specified via the water rod geometry input. Note that in general, one simulated water rod may represent more than one actual water rod in the BWR fuel assembly. For example, the 10x10 fuel assembly in Figure 2-18 includes two relatively large water rods, both of which have the same geometry. So NUMWATERRODS could equal one and RDX for the water rod group would equal two. Note also that the side junctions for the water rod must appear before the side junction input for the leakage path.



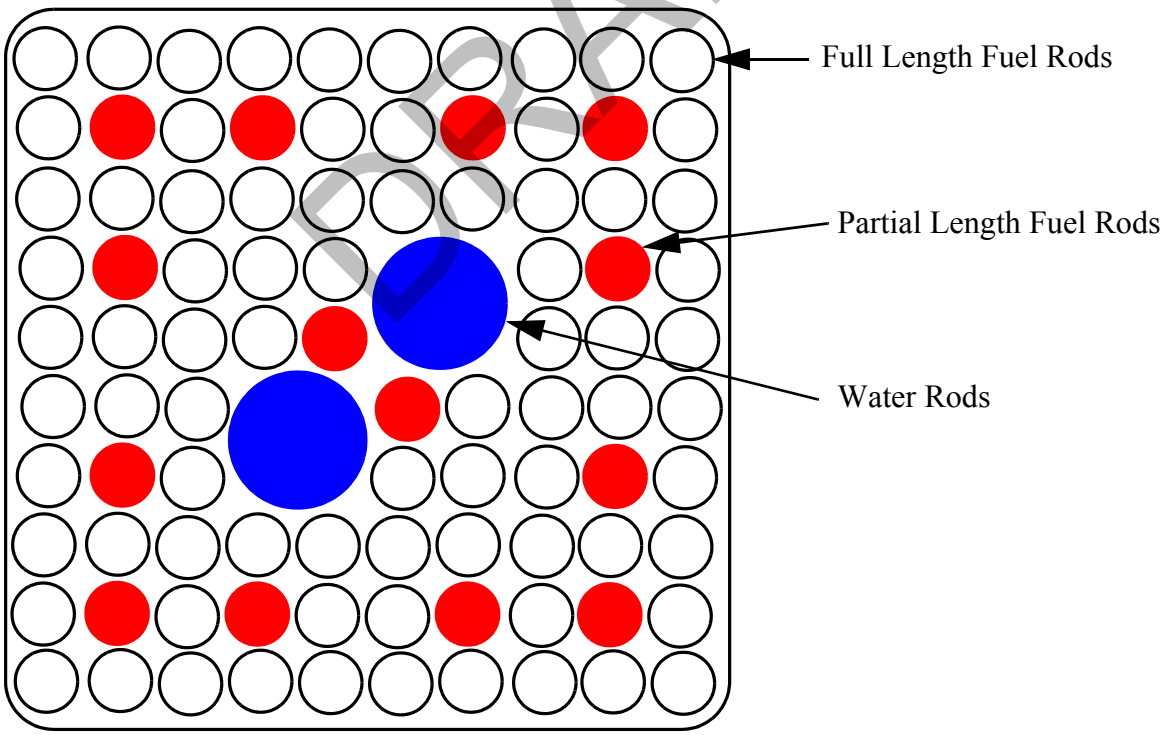


Figure. 2-18. 10x10 Fuel Assembly with Partial Length Fuel Rods and Two Large Water Rods.

For the leakage path JUNLK would be input as zero. When JUNLK is input as zero, then NCMPTO, NCLKTO, and NLEVTO input is used to define which hydro component/cell number the side junction is connected "to". The "from" for the side junction is from the CHAN's spawned PIPE component and the cell number is defined by the NCLK input. Also, when JUNLK is input as zero, then the FALK, CLOS, VLLK, VVLK, and DELZLK defines the leak path flow area, flow loss coefficient, initial liquid/vapor velocities and the elevation difference between the cell centers of the leak path "from" and "to" hydro cells. The elevation difference to input for DELZLK is illustrated in Figure 2-19.

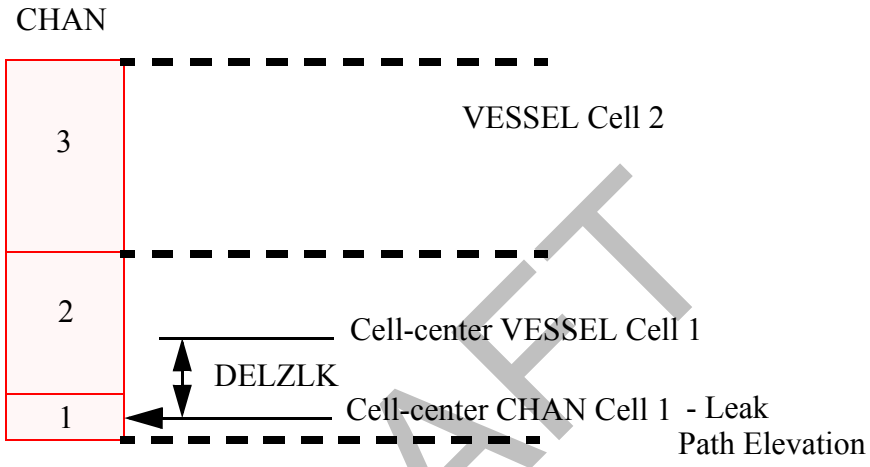


Figure. 2-19. Sketch for DELZLK.



## *Using the Offtake Model*

If USESJC (i.e., namelist input) is input as 3, then for each side junction (i.e., NSIDES) with JUNLK equal to zero, the user must provide input for THETA and IENTRN. THETA is the angle between the low-numbered cell portion of the component and a vector that points out through the side junction. For the leak path for the holes drilled in the BWR fuel assembly inlet nozzle, THETA would be 90 degrees (i.e., leak path flow is a right angle to the normal flow direction through the CHAN). The offtake entrainment option is intended to simulate small breaks in large horizontal pipes where the stratified flow in the horizontal pipe affects what is convected out the break. Therefore, for leakage path input, IENTRN should be input as zero (i.e., turn off the offtake model for leakage path). For the side junctions for the inlet/outlet for the water rods, JUNLK is input as non-zero, which implies that THETA and IENTRN input is not required for these side junctions when USESJC is input as 3. When USESJC is input as 2, then THETA defaults to 90 degrees and IENTRN defaults to zero.

# *Modeling Side junctions*

See the ***Modeling Fluid Leak Paths***, ***Using the Offtake Model***, and ***Modeling water rods*** sub-sections.

# *CHF modeling*

There are four CHF options for the ICHF input flag, available for all heat structure components in a given TRACE model:

0 = convection heat transfer only, no boiling heat transfer (i.e., no wall nucleation is allowed although phase change can still occur)
1 = CHF from AECL-IPPE CHF Table, no critical quality calculated.
2 = CHF from AECL-IPPE CHF Table, critical quality from Biasi correlation.
3 = CHF from AECL-IPPE CHF Table, critical quality from CISE-GE correlation.

When ICHF is input as zero, then only convective heat transfer is calculated with no nucleate boiling or boiling transition allowed. If ICHF is greater than 0, then the full boiling curve is used to calculate heat transfer coefficients and a critical heat flux is calculated based on the AECL-IPPE CHF Table. For low mass fluxes, the AECL-IPPE CHF table follows Zuber CHF pool boiling correlation so at low and counter-current flows in a CHAN component if ICHF greater than 0, then effectively Zuber CHF for pool boiling will be used. If ICHF is greater than 1, then in addition to a critical heat flux a critical dryout quality will be calculated (i.e., based on Biasi for ICHF = 2 and based on CISE-GE for ICHF = 3). The Biasi correlation is based on a larger data base including mass fluxes from 100 kg/m$^2$-s to 6000 kg/m$^2$-s and in general tends to be less conservative than CISE-GE. CISE-GE is based on rod bundle data for 7x7 and 8x8 fuel assemblies and includes local power peaking effects. Mass flux data range for CISE-GE is 300 kg/m$^2$-s to 1400 kg/m$^2$-s. For the CISE-GE correlation (i.e., ICHF = 3), when the mass flux is between -700 kg/m$^2$-s and 300 kg/m$^2$-s or if the flow is counter-current, then the critical dryout quality defaults to one and boiling transition will be based solely on the AECL-IPPE CHF Table. If ICHF = 3, and the mass flux is greater than 300 kg/m$^2$-s or less than -700kg/m$^2$-s, then boiling transition can occur if the local heat flux is above the critical heat flux obtained from the AECL-IPPE CHF Table or if the steam quality is above the critical dryout quality predicted by the CISE-GE boiling length correlation. If ICHF = 2 and the mass flux is greater than 300 kg/m$^2$-s and co-current, then boiling transition can occur if the local heat flux is above the critical heat flux obtained form the AECL-IPPE CHF Table or if the steam quality is above the critical dryout quality predicted by the Biasi boiling length correlation.

Boiling length correlations tend to be more accurate than a "local conditions" critical heat flux correlation for high quality, high mass flux conditions which tend to introduce memory effects when the heat flux is nonuniform for BWR applications (Refs. 2-12, 2-14). The boiling length correlations essentially take into account the history or total amount of energy added to the two-phase mixture upstream from the dryout point. Because of the upstream history effect included

into the boiling length correlation it is not appropriate to use a boiling length correlation for counter-current flow.

## *Solute tracking*

The ICONC input for the CHAN component is currently over-written with the following logic: if ISOLUT is zero, then ICONC is set to zero, if ISOLUT is non-zero, then ICONC is set to one. If ICONC is zero, then the CONC array is not input. If ICONC is one, then the CONC array (i.e., solute concentration at each axial level for the CHAN component) must be input. If ICONC is two, then the CONC and S (i.e., density of the plated-out solute at each axial level for the CHAN component) arrays must be input. However, the current coding for the CHAN component does not allow for ICONC = 2. This is a code bug will be fixed in a future version of TRACE.



## *Axial conduction*

If IAXCND is zero, then for all of the heat structures associated with this CHAN, only heat conduction in the radial direction will be calculated (i.e., no axial conduction). If IAXCND is input as one, then all of the heat structures associated with this CHAN component will calculate both axial and radial heat conduction. Currently, the CHAN input ignores the IAXCND input and all heat structures associated with a CHAN component include only radial heat conduction. This code bug will be fixed in a future version of TRACE.

Axial heat conduction is important when there are significant axial temperature gradients. This occurs during quenching of fuel rods and canister walls and water rod pipe walls.



## *Liquid level tracking option - LIQLEV*

This option is not currently used in TRACE 5.0.

## *Modeling CHAN alone vs. within other components*

Modeling a CHAN alone versus a CHAN contained within another component mainly effects the heat transfer on the outside of the canister walls and the inlet, outlet, and leak path hydrodynamic boundary conditions. If a CHAN is modeled within a VESSEL component (see Figure 2-17), then outside surface of the canister walls is in contact with the fluid in the core bypass region. For the CHAN input, component number that the CHAN component is contained within is input as IPVHT. If IPVHT is non-zero, then the IDROD and NHCELO must be input and the CHAN input for HOUTL, HOUTV, TOUTL, and TOUTV is ignored. There is only one element in the IDROD array and the input for this array locates where the CHAN component is located in the horizontal plane of the VESSEL component (i.e., ij = j + (i - 1) * NTSX, where i, j is the cell index in the horizontal plane for the VESSEL component and ij is the input IDROD(1) and NTSX

for the VESSEL component is the total number theta sectors for the VESSEL component). The NHCELO(1:NCELLS) array locates which axial level for VESSEL component IPVHT, is in contact with the outside surface of the canister wall heat structure for each CHAN axial level.

For the example in Figure 2-17, let NTSX = 1, NRSX = 3, NCELLS = 6, IPVHT = 1, then one possible set of inputs for CHAN in the first ring of VESSEL component number = 1 would be: IDROD(1) = 1, NHCELO(1:3) = 4, NHCELO(4:6) = 5. This input puts the first three axial levels of the CHAN outside surface of the canister wall in contact with the VESSEL component fluid cell at level 4 first ring. The last three axial levels of the CHAN outside surface of the canister wall is in contact with the VESSEL component fluid cell at level 5 first ring. The input for the CHAN in the second ring of the VESSEL component number = 1 would be: IDROD(1) = 2, NHCELO(1:3) = 4, NHCELO(4:6) = 5. For this CHAN, the first three axial levels of the canister wall outside surface is in contact with the VESSEL level 4 second ring. The last three axial levels of the CHAN canister wall outside surface is in contact with the VESSEL level 5 second ring.

For the sample input in **Appendix B,** *3 CHANs & POWER Comp. Test Problem*, CHANs 25, 26, 27 all have IPVHT = 3, which implies that these three CHANs are in VESSEL component number = 3. The IDRODO(1) input is 1 for three CHANs, which implies that the CHANS are located in the first radial ring. The NHCELO(1:4) input is 2, 3, 4, and 5, which implies that the VESSEL axial level number for the first CHAN canister outside wall is 2, the VESSEL axial level number for the second CHAN canister outside wall is 3, etc.

Again for the example in Figure 2-17, the inlet/outlet junction numbers for the CHAN component (i.e., JUN1 and JUN2) will also appear in the VESSEL input for source locations. The "to" input for the leakage path will point to the appropriate cell in the core bypass of the VESSEL component and will not appear in the VESSEL input for source locations.

If the IPVHT is input as zero, then the user input for HOUTL, HOUTV, TOUTL, and TOUTV will be used to determine the outside surface canister wall heat structure conduction boundary condition. For example, if IPVHT = HOUTL = HOUTV = zero is input, then the outside surface canister wall heat structure conduction boundary condition is adiabatic. The inlet/outlet junction numbers for the CHAN would point to other hydro components (i.e., FILL, BREAK, PIPE, etc.). This standalone CHAN modeling is typically used to simulate a test facility that does not include a core bypass or as a development test to test some aspect of the CHAN component in a relatively simple geometry. Typically the leakage path side junction is not used for a CHAN standalone model, but it can be used if the hydro volume to be the "to" for the leakage path is available in the TRACE model. For this case if the junction number and geometry has already been defined as part of some other 1D hydro component input, then leakage path JUNLK would be non-zero and point to that 1D hydro component junction. However, if the leakage path junction is not defined by the input for another 1D hydro component, then JUNLK would be input as zero and the "to" cell information and geometry of the leakage path will defined as part of the CHAN component input.

# *Modeling Canister Walls*

The canister walls axial node height is the same as the fluid cell lengths (i.e., DX(1:NCELLS) CHAN component array input). The canister wall thickness is given by the user input for TH and is assumed to be a square consistent with the user input for WIDTH giving the inside perimeter of the square (see Figure 2-20). The number of radial nodes, is defined by the user input for NODES. The number of axial nodes is given by NCELLS. However, if fine mesh or reflood is turned on for this CHAN component, then the coarse mesh axial levels for the canister wall may be split into smaller axial levels until there are the coarse mesh axial levels at the same elevation and with the same size for the fuel rod, water rod, and canister wall heat structures.

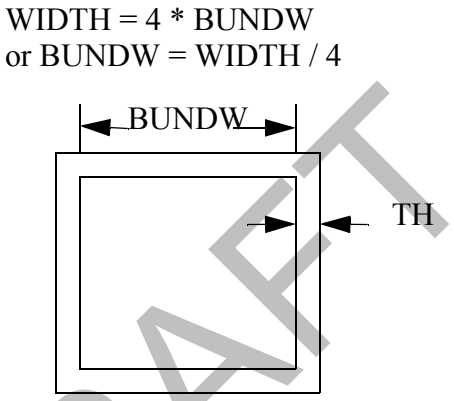




Figure. 2-20. Sketch of Canister Wall Geometry.

Figure 2-21 is a sketch of the axial noding for a CHAN component with NCELLS = 7, NCRZ = 6, and ICRNK = 1, with a full length fuel rod, a partial length fuel rod, and a water rod contained within the CHAN component with fine mesh turned off. For this case the canister wall heat structure (HS) has seven axial coarse mesh levels.

Figure 2-22 is a sketch of the axial noding for the same CHAN component with fine mesh turned on. The fine mesh logic splits the first and last coarse mesh heat structure axial level into two coarse mesh axial levels. In order to keep the axial levels consistent for the radiation heat transfer enclosure model, axial level elevations and coarse mesh node sizes must be consistent for all of the CHAN HS that may appear in a radiation heat transfer enclosure (i.e., full length fuel rod, partial length fuel rod, water rod wall, and canister wall). The first axial level for the canister wall HS is split into two coarse mesh axial levels according to the fine mesh/reflood logic. Since there are no other HS at this axial level, then does not impact the axial noding for any other CHAN HSs. However, when the first axial level of the full length and partial length fuel rods are split into two axial levels, then canister wall must also be split into two axial coarse mesh levels of the same size.

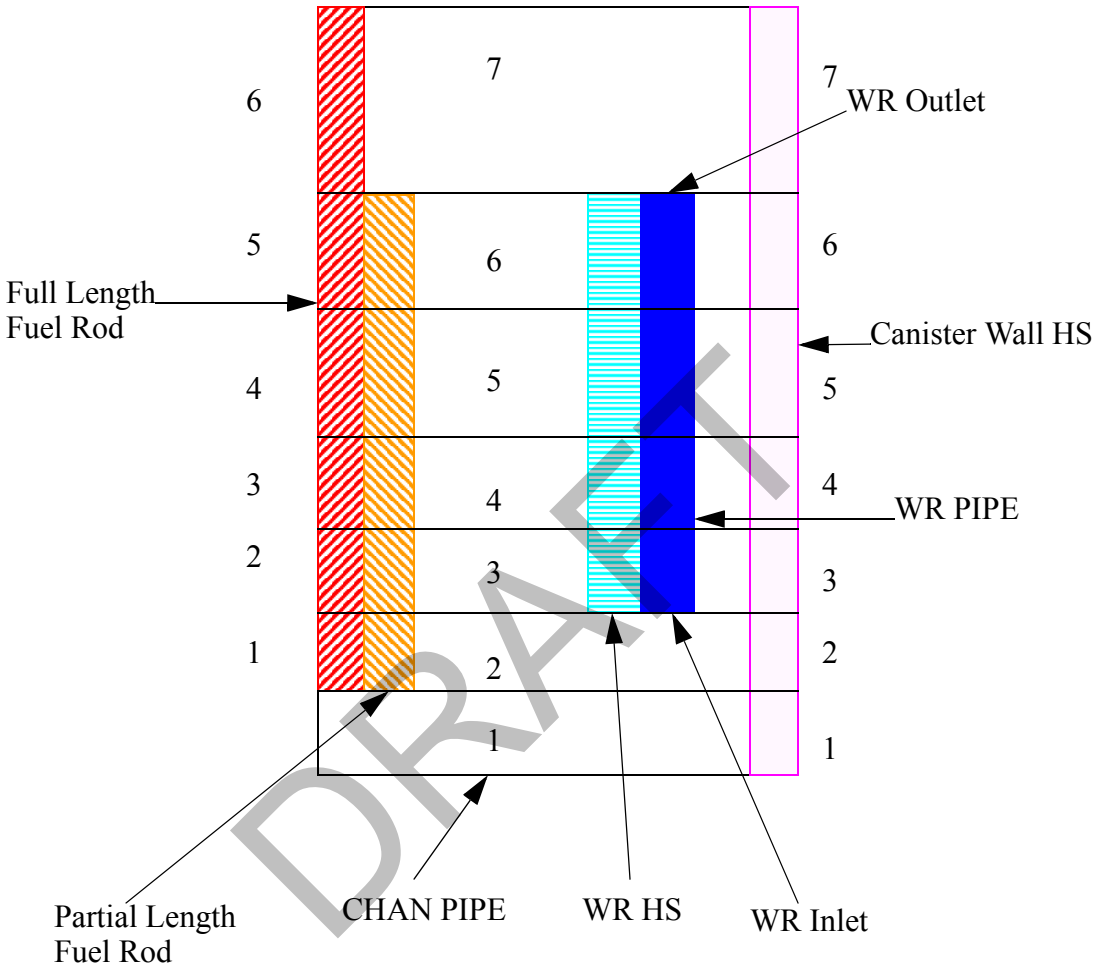


Figure. 2-21. Sketch of CHAN Axial Noding.

Splitting of the first axial coarse mesh level for the water rod wall HS, requires that the full length fuel rod, partial length fuel rod, and canister wall HSs be split into the same coarse mesh axial levels. For this example, the final number of axial coarse mesh levels for the canister wall HS is 12.

## *Modeling partial length fuel rods*

For partial length fuel rods in a given fuel assembly, the advanced BWR fuel design flag must be turned on (i.e., ADVBWRF = 1). For the fuel design sketched in Figure 2-18 QUADSYM would be 0, and the NUMWATERRODS could equal one or two. If NUMWATERRODS is 1, then one

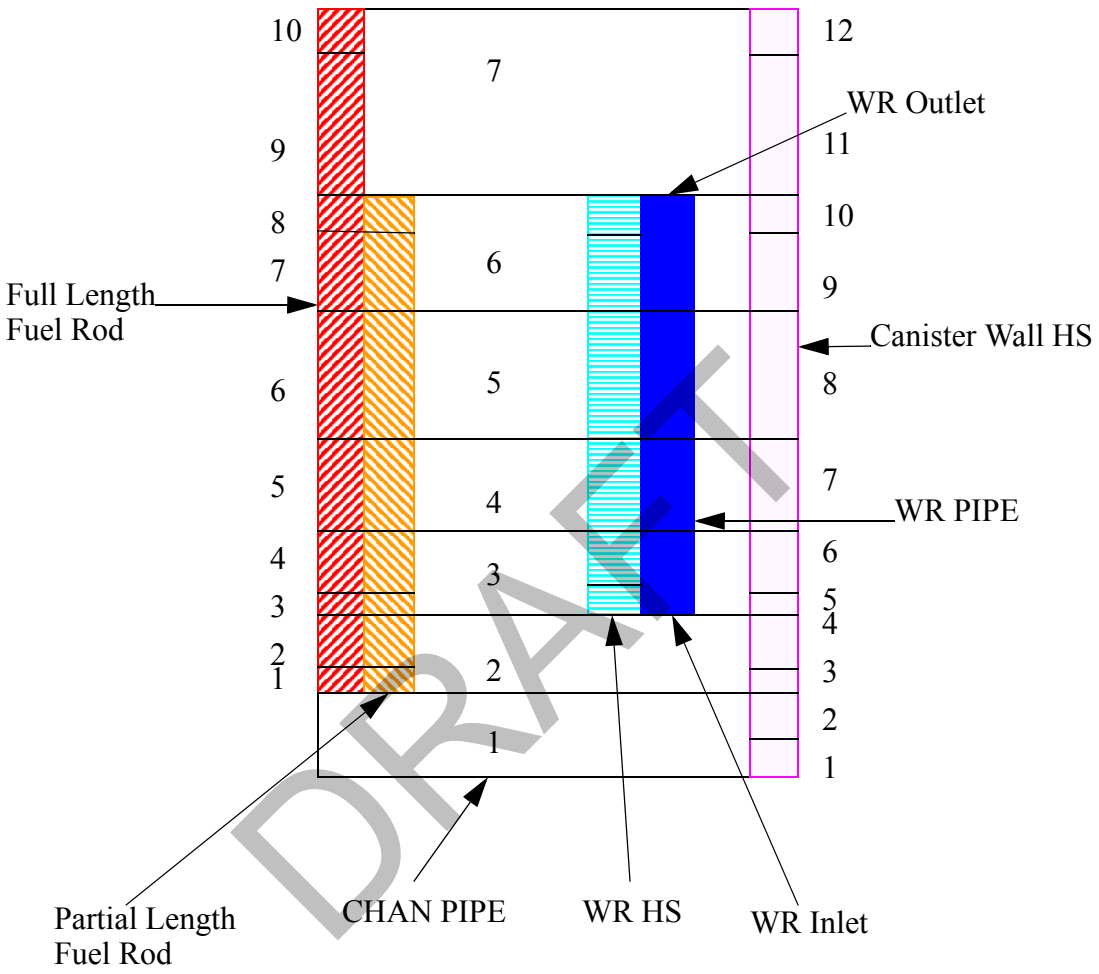




Figure. 2-22. Sketch of CHAN Axial Noding with Fine Mesh Turned On.

PIPE/HTSTR combination will be spawned by the CHAN component to represent both water rods in this fuel design.

For the fuel assembly design sketched in Figure 2-18, there are 14 partial length fuel rods, 78 full length fuel rods, and 2 water rods. For a 10x10 fuel assembly there are 100 potential fuel locations. For the fuel assembly in Figure 2-18, 8 of those potential fuel rod locations are taken up by the 2 water rods. The TRACE internal indexing scheme for a 10x10 fuel assembly is given in Figure 2-23. For a 10x10 fuel assembly (i.e., NROW = 10), there are 100 fuel rod locations. Those 100 fuel rod locations may be occupied by a full length fuel rod, a partial length fuel rod, or a water rod.

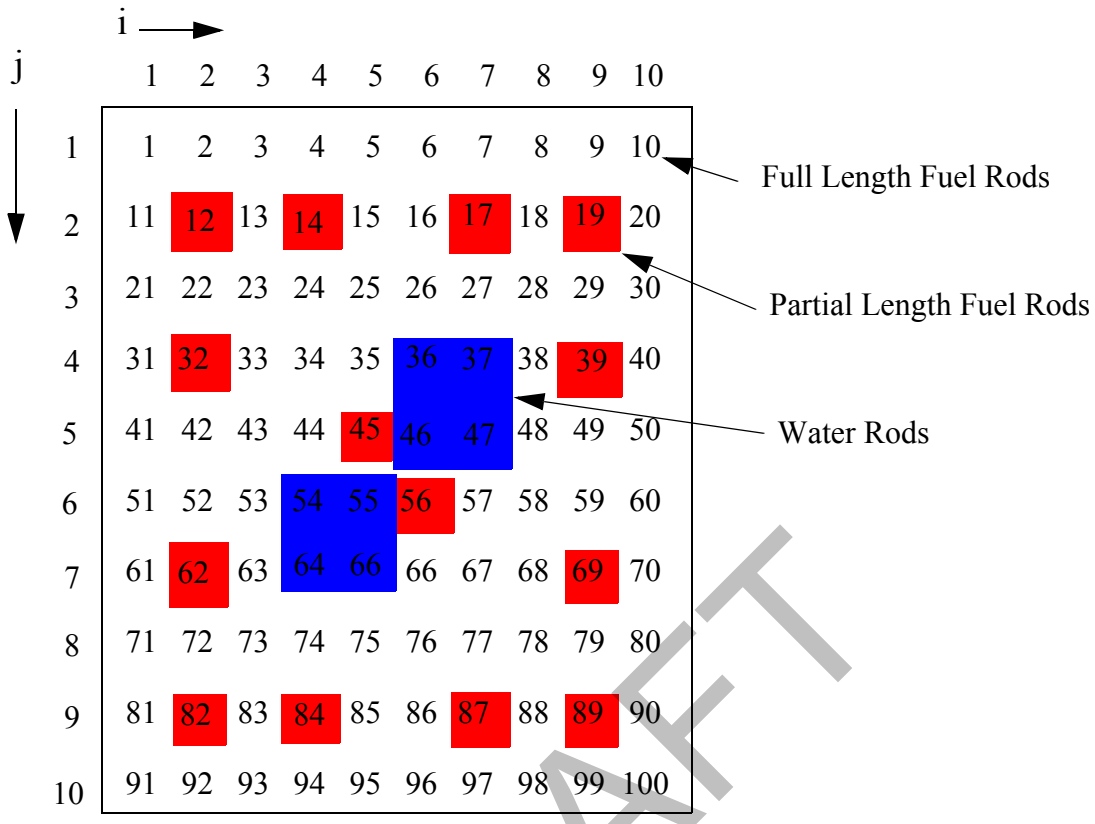


Figure. 2-23. Sketch of TRACE Index for 10x10 Fuel Assembly.



These fuel rod locations may be referenced by the 1D vector index that goes from 1 to 100 for this example, or by the i,j indices given in Figure 2-23. For example, the 1D vector index of 14 refers to the i,j index of 4, 2. The partial length rods in Figure 2-18 are located at indices 12, 14, 17, 19, 32, 39, 45, 56, 62, 69, 82, 84, 87, and 89 (see Figure 2-23). The minimum number of fuel rod groups required to represent the partial length rods, full length rods, and water rods given by the 10x10 fuel assembly in Figure 2-18 is 3 (i.e., one fuel rod group for the full length fuel rods, one fuel rod group for the partial length fuel rods, and one rod group for the water rods). For this fuel assembly if NGRP was input as 3, then the RDX array input would be: RDX(1:3) = 78.0, 14.0, 2.0. Note if NUMWATERRODS was input as 2, then the minimum input for NGRP would be 4 (i.e., one for full length fuel rod, one for partial length fuel rod, and two for two water rod groups). For this example, it shall be assumed that NUMWATERRODS is input as 1.

First rod group must always be a full length fuel rod group (i.e., 78 full length fuel rods). Second rod group would be the partial length fuel rods (i.e., 14 partial length fuel rods), and third rod group would be the water rod group (i.e., 2 water rods).

The MRODS array, defines which rod group is associated with each of the fuel rod locations defined by a NROW x NROW fuel assembly. The MRODS array is dimension by NROW x NROW + 1 (i.e., for each fuel rod location and one extra for the channel box). Therefore, for the 3 rod groups and the 10x10 bundle given in Figure 2-23, the MRODS array input would be:

```
* MRODS for 10x10 with full, partial, and water rods - Card Set 60
        1    1    1    1    1 s   *  First row is all full length rods.
        1    1    1    1    1 s.
        1    2    1    2    1 s   *  Second row is mixed partial and full.
        1    2    1    2    1 s
        1    1    1    1    1 s   *  Third row is all full length rods.
        1    1    1    1    1 s.
        1    2    1    1    1 s   * Fourth row is mixed full, partial, and water rod.
        3    3    1    2    1 s
        1    1    1    1    2 s   * Fifth row is mixed full, partial, and water rod.
        3    3    1    1    1 s
        1    1    1    3    3 s   * Sixth row is mixed full, partial, and water rod.
        2    1    1    1    1 s
        1    2    1    3    3 s   * Seventh row is mixed full, partial, and water rod.
        1    1    1    2    1s
        1    1    1    1    1 s   *  Eighth row is all full length rods.
        1    1    1    1    1 s.
        1    2    1    2    1 s   *  Ninth row is mixed partial and full.
        1    2    1    2    1 s
        1    1    1    1    1 s   *  Tenth row is all full length rods.
        1    1    1    1    1 s.
        4e                        *  Last rod group is the channel box/canister wall.
```

Note for this example, the fourth rod group is the canister wall.

Which fuel rods are full length and which fuel rods are partial length is determined by the LEVROD input (i.e., CHAN component input). All of the fuel rod locations identified in the MRODS array input are defaulted to the full length (i.e., start at axial level ICRNK + 1 and end at NCELLS). The ending location of the fuel rods is redefined via the LEVROD input. Assuming the axial noding given in Figure 2-22 for the fuel assembly given in Figure 2-18, then the LEVROD input would be:

```
*   I    J    LEVROD - Card Set 63
    2    2        6   *  m = 2 + (2-1) * 10 = 12
    4    2        6   *  m = 4 + (2-1) * 10 = 14
    7    2        6   *  m = 7 + (2-1) * 10 = 17
    9    2        6   *  m = 9 + (2-1) * 10 = 19
    2    4        6   *  m = 2 + (4-1) * 10 = 32
    9    4        6   *  m = 9 + (4-1) * 10 = 39
    5    5        6   *  m = 5 + (5-1) * 10 = 45
    6    6        6   *  m = 6 + (6-1) * 10 = 56
    2    7        6   *  m = 2 + (7-1) * 10 = 62
    9    7        6   *  m = 9 + (7-1) * 10 = 69
    2    9        6   *  m = 2 + (9-1) * 10 = 82
    4    9        6   *  m = 4 + (9-1) * 10 = 84
```

```
 7        9        6   *   m = 7 + (9-1) * 10 = 87
 9        9        6   *   m = 9 + (9-1) * 10 = 89
-1
```

Note there is one input for each of the 14 partial length fuel rods. All of the fuel rods are defaulted to end in level NCELLS which is 7 for this example. The partial length fuel rods end in level 6. Since ICRNK is input as 1, then all of the fuel rods start in level 2. The i, j input for the LEVROD array is defined as i = column number and j = row number for the fuel rod location matrix defined by the 10x10 fuel rod location index. For example, the index in the MRODS array (i.e., m) is related to the i,j index by m = i + (j-1) * NROW.

Note if IBEAM is input as 1, then MRODS is not input, but the grouped view factors and path lengths must be input. When IBEAM is input as 1 and ADVBWRF is input as 0, the grouped view factors input are assumed to be the same at all axial levels. Therefore, grouped view factors and path lengths are only input for one axial level and assumed to be constant for all other axial levels. However, when IBEAM is input as 1 and ADVBWRF is input as 1, then grouped view factors and path lengths must be input for each powered axial level for the CHAN component (i.e., NCRZ axial levels). In addition, LEVRODG and WRODFLG must be input. The LEVRODG identifies which fuel rod group are full length and which fuel rod group are partial length fuel rod groups. For the example in Figure 2-21, LEVRODG(1) would be 7 (i.e., the first fuel rod group is a full length and ends in level 7) and LEVRODG(2) would be 6 (i.e., the second fuel rod group is a partial length fuel rod group and ends in CHAN PIPE cell 6). The WRODFLG identifies the water rod geometry for the water rod group. For the example in Figure 2-21, WRODRLG(1:3) = 0, 0, 1, since the first two rod groups are fuel rods and the third rod group is a water rod with a water rod geometry index of 1. Note if IBEAM is input as 0 and ADVBWRF is input as 1, then LEVRODG and WRODFLG arrays are not input.



## *Modeling water rods*

Modeling of water rods with the CHAN component requires that advanced BWR fuel design flag (i.e., ADVBWRF) be input as 1. For the fuel bundle design in Figure 2-18 the NUMWATERRODS could be input as 1 or 2, since the number of actual water rods in the fuel assembly is 2. If NUMWATERRODS is input as 1, then the two actual water rods will be simulated with one water rod group. If there is a need to simulate the two water rods with two separate water rod groups, then NUMWATERRODS would be input as 2. However, there is no significant modeling advantage to modeling the two water rods as two separate water rod groups, unless there is some geometry difference associated with the water rods (i.e., different inlet or outlet geometry or water rod length or etc.).

The side junction input locates where the water rod inlet and outlet junctions connect to the CHAN PIPE component. If junction numbers 111 and 333 are unique junction numbers in the TRACE input model (i.e., junction numbers not used by any other fluid component), then side junction input for the axial noding given Figure 2-21 would be:

```
*  NCLK      JUNLK - Card Set 4
```

```
3          111    * Water rod inlet junction number
6          333    * Water rod outlet junction number
```

Water rod inlet flow is from CHAN PIPE cell number 3 and outlet flow is into CHAN PIPE cell number 6. The geometry of the water rod will be defined by the water rod geometry input and should not be input as part of the side junction input. Fuel rod locations in the NROWxNROW set of fuel rod potential locations that are occupied by the water rod group(s) is given in the MRODS array input. Note if IBEAM is input as zero, then the MRODS array is input. If IBEAM is input as one, then the MRODS array is not input and the grouped view factors and path lengths are input. If IBEAM is input as one and ADVBWRF is input as 1, then the in addition to the grouped view factors and paths, the LEVRODG and WRODFLG must be input. LEVRODG input identifies which fuel rod groups are partial length fuel rods and which fuel rod groups are full length fuel rods. For the axial noding in Figure 2-21 and assuming one full length fuel rod group and one partial length fuel rod group the LEVRODG(1:2) would equal 7, 6. The full length fuel rod group ends in CHAN PIPE cell 7 and the partial length fuel rod group ends in CHAN PIPE cell 6. The WRODFLG array identifies the water rod geometry index. For the example 10x10 fuel rod design given in Figure 2-18 and Figure 2-21 with only one water geometry the WRODFLG(1:3) input would be 0, 0, 1. The first two rod groups are fuel rod groups. The third rod group is a water rod with geometry index of 1 (i.e., there is only one water rod geometry).

Where the center of each water rod is located in the fuel assembly and the water rod geometry flag is given by Card Set Number 64. Note Card Set Number 64 is not input if IBEAM is input as 1. An example, for Card Set Number 64 input for the two water rods given in Figure 2-18 is:

```
*   i    j   WaterRodFlgs  xLoc      yLoc - Card Set 64
    4    6         1       0.06404  -0.09596
    4    7         1       0.0       0.0
    5    6         1       0.0       0.0
    5    7         1       0.0       0.0
    6    4         1       0.09596  -0.06404
    6    5         1       0.0       0.0
    7    4         1       0.0       0.0
    7    5         1       0.0       0.0
   -1
```

The i, j index input above identifies the fuel rod location indices occupied by the water rod. The first water rod occupies fuel rod location indices 4,6; 4,7; 5,6; and 5,7. The water rod geometry flag = 1 points to the first set of water rod geometry defined by Card Sets 67, 68, 69, 70, and 71. The xLoc, yLoc dimensions defines the location of the center of the water in the fuel assembly geometry. The upper left hand corner of the fuel assembly geometry is defined to the origin (i.e., 0.0, 0.0). So the center of the first water rod is located 0.06404 m to right of the origin and 0.09596 m down from the origin (see Figure 2-24). The second water rod occupies fuel rod location indices 6,4; 6,5; 7,4 and 7,5. The water rod geometry is the first set of water rod geometry defined by Card Sets 67, 68, 69, 70, and 71. If geometry of the second water was different than the first water rod, then the water rod geometry flag would have pointed to the appropriate set of water rod geometry input. The center of the second water rod is located

0.09556 m to the right of the origin and 0.06404 m down from the origin. Note the water rod geometry index input is for all fuel rod locations occupied by a water rod and is terminated by inputting a -1 for the i index input. The xLoc and yLoc input is not repeated and is only input for the first i,j fuel rod location index for a given water rod.

An example input for water rod geometry Card Sets 67 through 73 is given below:

```
*     geoType   rNodes - Card Set 67
        1                2
*
* WR dia = 0.024 m
*    wRInlet  wROutlet    dia      sideA     sideB - Card Set 68
             3           6     0.024
*
* 0.1" = 0.00254 m
*       th           rCorner    flowArea   flowAreaI   flowAreaO - Card Set 69
       0.00254
*
*      hyDia    hyDiaI     hyDiaO    thermDiaI   thermDiaO - Card Set 70
          0.0      0.01       0.01
*
*      FLossI    FLossO    RLossI    RLossO - Card Set 71
            2.0        1.0        1.5          0.5
*
*    matWR - Card Set 72
      f 6 e
*
*      TW - Card Set 73
    f 500.0 e
```

Card set 67 identifies the geometry (IGEOM = 1 - cylindrical, = 2- rectangular, = 3 - square, or = 4 general) and the number radial nodes in the water rod heat structure (i.e., WRNODES). For the example given above the water rod geometry is cylindrical. The water rod inlet and outlet CHAN PIPE cell indices are 3 and 6 for this example and must be consistent with the side junction input for the water rod inlet and outlet. The outer diameter for this cylindrical water rod geometry is 0.024 m. The SIDEA and SIDEB dimensions are ignored for this water rod geometry, since IGEOM is not equal to 2 or 3 (i.e., rectangular or square). If IGEOM is input as 2, then both SIDEA and SIDEB must be input. If IGEOM is input as 3, then SIDEA is used as the dimension of the square. The definitions for SIDEA and SIDEB are given in Figure 2-25.

The TH input is the thickness of the water rod wall (see Figure 2-25 and Figure 2-26). The RCORNER input (see Figure 2-25) is only used if IGEOM is 2 or 3. If the FLOWAREA (i.e., flow area of the water rod), FLOWAREAI (i.e., water rod inlet flow area), and FLOWAREAO (i.e., water rod outlet flow area) are input as negative or zero, then TRACE will calculate these flow areas other geometry input (i.e., for IGEOM = 1 DIAI = inside diameter for the water = DIA - 2 * TH and FLOWAREA = pi * DIAI**2 / 4). For IGEOM = 2, the default flow area is (SIDEA

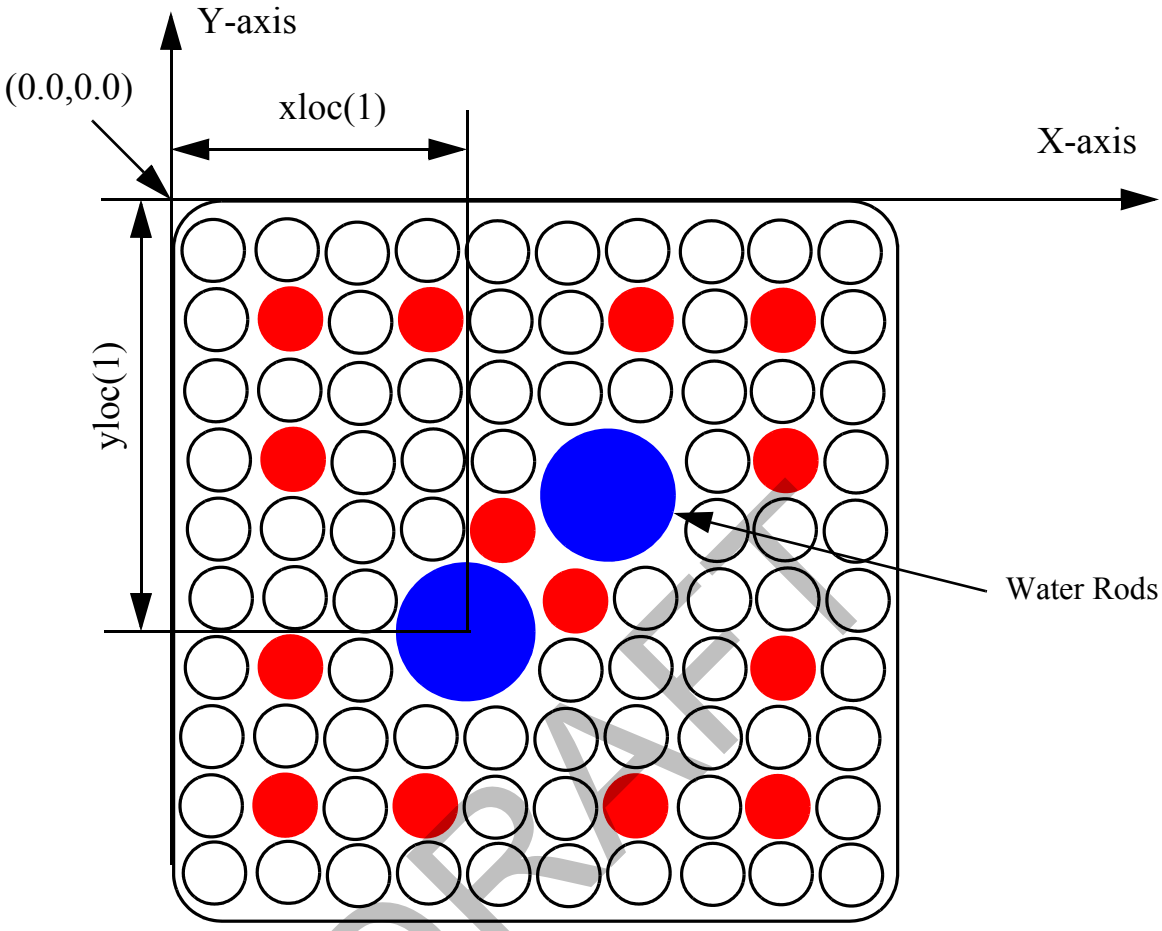




Figure. 2-24. Sketch of Location of Center of Water Rod.

- 2*TH) * (SIDEB - 2*TH). For IGEOM =3, the default flow area is (SIDEA - 2*TH)**2. If IGEOM = 4, then these three flow areas (i.e., FLOWAREA, FLOWAREAI, and FLOWAREAO) must be input as positive numbers. For IGEOM = 1, 2, or 3, the default for FLOWAREAI and FLOWAREAO is FLOWAREA.

If HYDIA (i.e., hydraulic diameter for the water rod) is negative or zero, then HYDIA is defaulted to DIAI = DIA - 2 * TH for IGEOM = 1. For this example, HYDIA = 0.024 - 2 * 0.00254 = 0.01892m. The default for HYDIAI and HYDIAO is HYDIA. For this example, HYDIAI and HYDIAO have been input as 0.01 m. For IGEOM = 4, all three hydraulic diameters must be input as positive numbers.

The thermal diameter to be used for heat transfer correlations on the inside and outside surfaces of the water are input as THERMDIAI and THERMDIAO. For IGEOM = 1, 2, or 3, the default for

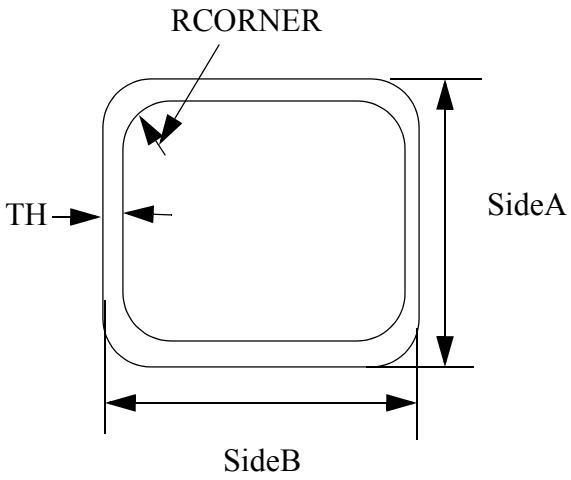


Figure. 2-25. Sketch of Rectangular Water Rod Geometry.

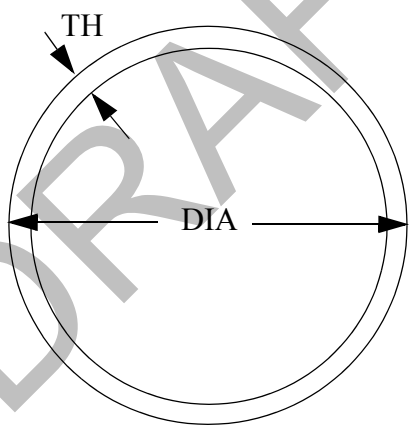




Figure. 2-26. Sketch of Cylindrical Water Rod Geometry.

THERMDIAI and THERMDIAO is the hydraulic diameters HYDIAI and HYDIAO, respectively. For IGEOM =4, these thermal diameters must be positive numbers.

Card Set 71 is the water rod inlet and outlet forward and reverse flow losses. This input must be zero or positive numbers (i.e., negative input is not allowed). Card set 72 is the material type numbers for the radial heat structure nodes for the water rod heat structure. Card set 73 is the initial heat structure radial temperature distributions for all axial levels in the water rod. The water rod temperature distribution is read in as one array. For the this example, the first two temperatures input will be radial temperature for the first axial level of the water rod. The next

two temperatures input will be the radial temperature for the second axial level of the water rod. This example has 4 axial levels and a total of 8 temperatures will be input for the TW array.

## *Radiation & View Factor Modeling*



The radiation model associated with the CHAN component can be turned off by input NORAD = 1. Turning the radiation heat transfer model on for the CHAN component results in an additional sub-component (i.e., RADENC) which will be internal generated by TRACE from the CHAN input. The RADENC component will have NCRZ axial levels, if FMON and REFLOODON are both zero. A radiation heat transfer enclosure for each coarse mesh axial level is included in the RADENC component. If FMON or REFLOODON is non-zero, then the fine mesh logic in TRACE will increase the number of coarse mesh axial levels and the RADENC sub-component will have an increased number of coarse mesh axial levels to match the CHAN component HS coarse mesh axial levels. The fine mesh logic adds an extra coarse mesh axial level at the top and bottom of each HS component within a CHAN component if FMON or REFLOODON is non-zero (see Figure 2-21 and Figure 2-22). In order to maintain radiation heat transfer enclosures with consistent HS axial levels and axial level heights, extra coarse mesh axial levels must be added for all of the HS contained within the CHAN radiation heat transfer enclosure.

For the CHAN component axial noding given in Figure 2-21 and if FMON = REFLOODON = 0, then the RADENC component spawned by the CHAN component will have six axial levels (i.e., a radiation heat transfer enclosure at each axial level of the RADENC component). The number of coarse mesh axial levels for the full length fuel rod group determines the number of axial levels for the RADENC component. The first radiation heat transfer enclosure (i.e., first axial level for the RADENC) will include the full length fuel rod group, the partial fuel rod group, and the inside surface of the canister wall (see Figure 2-27). There is no water rod at the first axial level of the RADENC component for this example. The second axial level of the RADENC component will include the full length fuel rod group, the partial fuel rod group, the water rod group, and the inside surface of the canister wall (see Figure 2-18). The last axial level of the RADENC component will include the full length fuel rod and the inside surface of the canister wall (see Figure 2-28).

If FMON or REFLOODON is non-zero, then the added extra coarse mesh axial levels results in the axial HS noding given in Figure 2-22. With the extra coarse mesh axial levels the full length fuel rod now has 10 coarse mesh axial levels, which implies that the RADENC component will also have 10 axial radiation heat transfer enclosures. The RADENC component only calculates radiation heat transfer between the HS surfaces within each axial level, which implies that no axial radiation heat transfer between axial levels is calculated. When fine mesh is turned on, an average surface temperature is calculated for each coarse mesh axial level and this average coarse mesh axial level surface temperature is used to calculate the radiation heat transfer fluxes. When fine mesh is off, then there is only one surface temperature for each coarse mesh axial level and not averaging is required. The purpose of the extra coarse mesh axial level is to improve the accuracy for the prediction of the start of a quench front coming up from the bottom or down from the top when a HS is quenching. Fine mesh should only be turned on for a CHAN component if

the anticipated transient is going to result in significant dryout and heat up for the fuel rods and then quenching.

For each coarse mesh axial level radiation heat transfer enclosure will only calculate radiation heat transfer if the following criteria are all satisfied:

1) At least one of the HS convective surfaces contained within the radiation heat transfer enclosure must be in post-CHF heat transfer mode.
2) The maximum super heat (Twall - TSat) for all of the HS surfaces contained within the radiation heat transfer enclosure must be greater than 100K.
3) The difference between the maximum surface temperature and the minimum surface temperature within the radiation heat transfer enclosure must be greater than 10K.

The purpose of these criteria is to ensure the radiation heat transfer calculations are not included into the CHAN component computations unless there will be significant radiation heat transfer. If the transient of interest will never result in post-CHF heat transfer or significant fuel rod heat up, then it would be appropriate to input NORAD as one.

If NORAD is input as zero, then grouped view factors and path lengths must either be provided by the user (i.e., IBEAM is equal to 1) or TRACE will calculate them (i.e., IBEAM equal to 0). If the path lengths provided are non-zero, then the steam/water droplet mixture within the radiation heat transfer enclosure will absorb and re-emitted thermal radiation. The models for emissivity and absorption of a steam/water droplet mixture used in TRACE are given in Reference 2-18. If the path lengths are zero, then two-phase mixture within the radiation heat transfer enclosure is assumed to be transparent and does not participate in the radiation heat transfer enclosure calculations.

The axial noding in Figure 2-21 indicates that there are three different geometries or three different sets of view factors and path lengths required to simulate radiation heat transfer for this CHAN component. For axial level one for the RADENC component where the full length fuel rod, partial length fuel rod, and canister wall are present there will be one set of view factors and path lengths. The missing water rods will represent "holes" in the horizontal plane at this axial level (see Figure 2-27). The horizontal plane geometry for RADENC axial levels 2 through 5 is given by Figure 2-18, while the horizontal plane geometry for RADENC axial level 6 is given by Figure 2-28.

The presence of partial length fuel rods and/or water rods in a BWR fuel assembly implies that the advanced BWR fuel design flag input for the CHAN (i.e., ADVBWRF) must be input as 1. If ADVBWRF is input as 1 and IBEAM is input as 1, then grouped view factors and path lengths must be input for each axial level. If ADVBWRF is input as 0 and IBEAM is input as 1, then grouped view factors and path lengths must be input for one axial level and TRACE will assume that the these view factors and path lengths are the same for all axial levels for the spawned RADENC component.

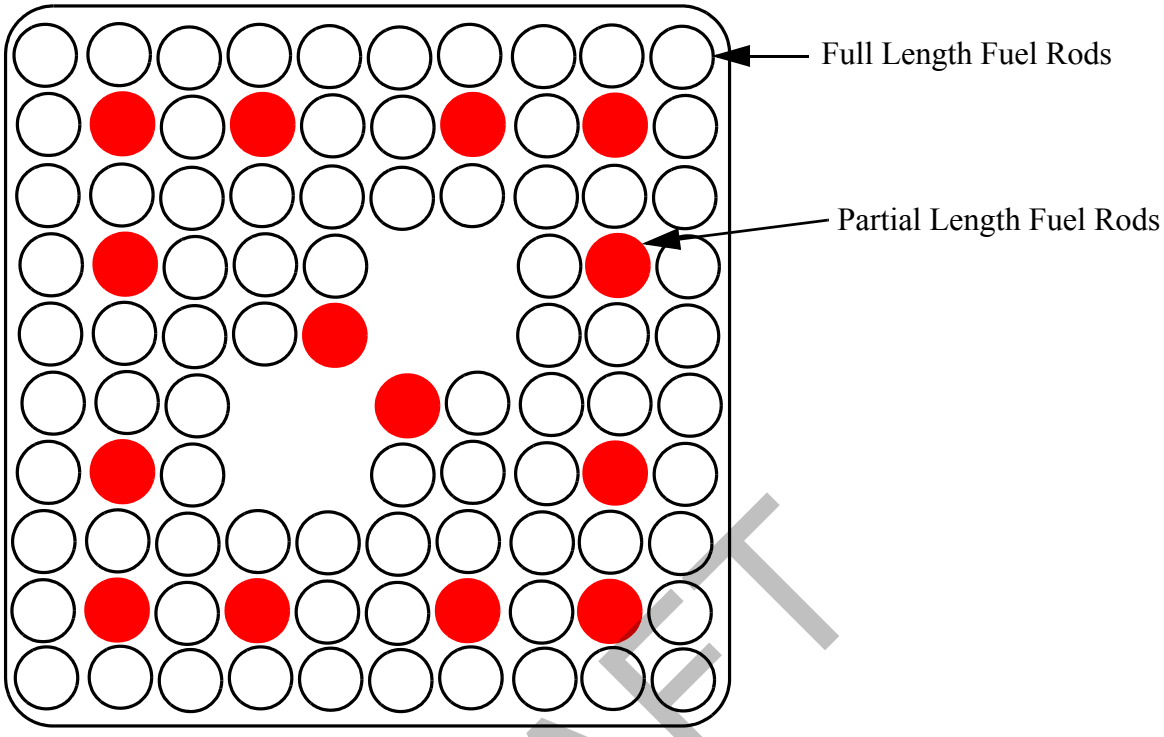


Figure. 2-27. 10x10 Fuel Assembly with Partial Length Fuel Rods and Without Water Rods.



If IBEAM is input as 1, then the user input view factors and path lengths are input as 1D arrays. The conversion from 1D vector input for these arrays to the 2D view factor and path length matrix goes as:

viewFact(i, j) = viewFact1D(j + (i-1) * (nGrps+1))
where,
viewFact(i,j) is the view factor from rod group i to rod group j.
viewFact1D is the user input 1D array of grouped view factors.
nGrps is the number of fuel rod and water rod groups in this model. The + 1 is for the channel box rod group.

This implies that view factor vector input is ordered as the view factors from the first rod group rod group to all other rod groups, then the view factors from the second rod group to all other rod groups, etc. The path length user input follows this same ordering of input.

If IBEAM is input as 0, then TRACE will calculate the grouped view factors and path lengths based on the fuel assembly geometry defined by the CHAN input. TRACE uses the CHAN input for WIDTH, PDRAT, RADRD(NODESR), and NROW to determine the location of fuel rods within a fuel assembly. The inside dimension of the canister wall is given by

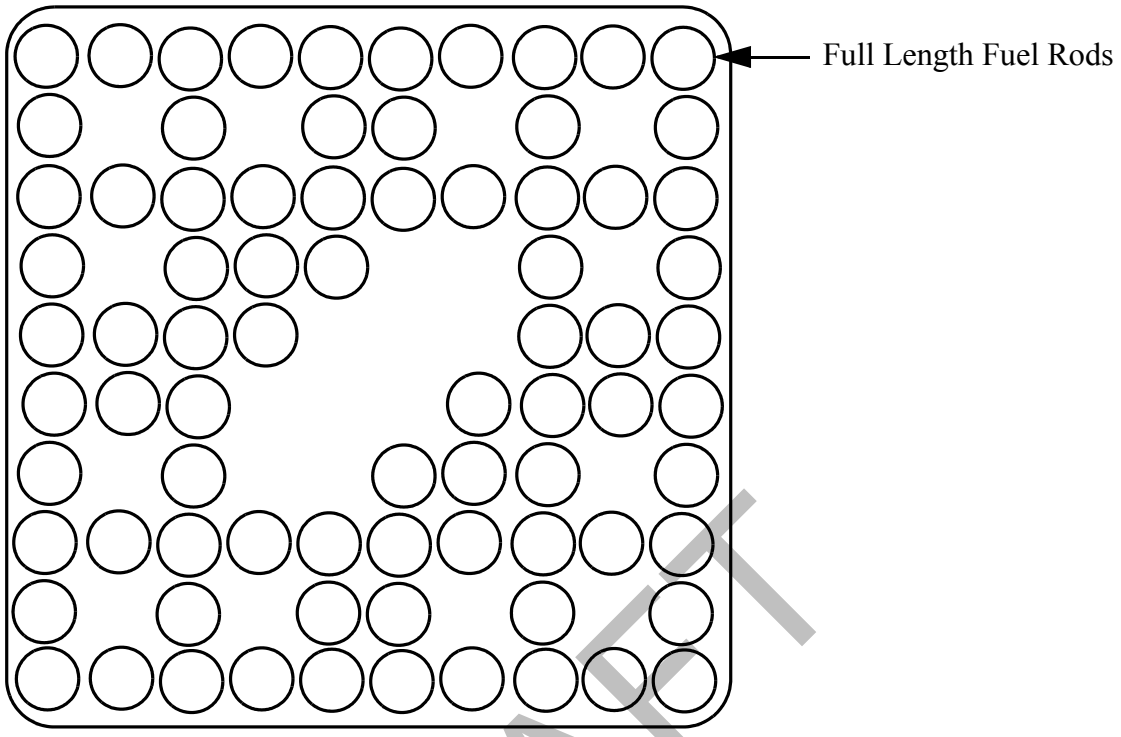


Figure. 2-28. 10x10 Fuel Assembly without Partial Length Fuel Rods and Water Rods.

$BUNDW = (WIDTH)/4$ (see Figure 2-20). The radius of the fuel rod is $R_f = RADRD(NODESR)$. The diameter of the fuel rod is

$$D_f = 2 \cdot R_f \,. \tag{2-3}$$

The pitch between the fuel rod centers is

$$P = PDRAT \cdot D_f. \tag{2-4}$$

The distance between the inside surface of the canister wall the edge of the first fuel rod is

$$d_e = (BUNDW - ((NROW - 1) \cdot P) - D_f)/2 \,. \tag{2-5}$$

The center of the first fuel rod in the x,y plane with the origin at the upper left hand corner of the fuel assembly will be $x = d_e + D_f/2$ and $y = -(d_e + D_f/2)$. The center of the second fuel rod in

the first row in the x,y plane will be $x = d_e + D_f/2 + P$ and $y = -(d_e + D_f/2)$. The center of the first water rod would be at $x = d_e + R_f + 3.5 \cdot P$ and $y = -(d_e + R_f + 4.5 \cdot P)$.

After the fuel rods and water rods have been located within the x,y plane then TRACE uses one of two methods to calculate the view factors for the individual fuel rods, water rods, and canister wall for each horizontal plane configuration contained within the CHAN component input. For the example given by Figure 2-18 and Figure 2-21, there will be three separate geometric configurations in the horizontal plane (see Figure 2-18, Figure 2-27, and Figure 2-28). The two methods used to calculate the view factors are the cross-string method (Refs. 2-15, 2-16) and the Monte Carlo method (Refs. 2-16, 2-17). The cross-string method view factor is given by:



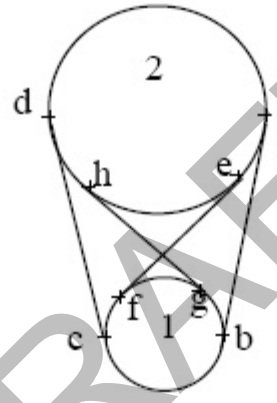


Figure. 2-29. Cross-string Method.

$$F_{ij} = \frac{lengthOfCrossString - lengthOfUnCrossString}{2 \cdot perimeterOfSurface1}. \quad (2\text{-}6)$$

For Figure 2-29, the cross-string formula yields:

$$A_1 \cdot F_{12} = \frac{L_{ac} + L_{db} - L_{ab} - L_{dc}}{2}. \quad (2\text{-}7)$$

As the view between two objects (i.e., fuel rods, water rod, canister wall) is blocked by other objects then the geometric considerations required to determine the crossed-string and un-crossed string lengths becomes complex (see Figure 2-30). For these complicated geometries TRACE will automatically use the Monte Carlo method for calculating the view factors. The user may also force TRACE to use the Monte Carlo method for calculating the view factors by input NVFRAYS > 0. NVFRAYS is the number of rays emitted from each object within the BWR fuel assembly to determine the view factor from that object to all other objects within the BWR fuel

assembly. The Monte Carlo method may require a significant amount of cpu time to calculate the view factors for a given BWR fuel design. Some testing of the method indicates that a minimum level of accuracy is obtained for NVFRAYS of at least 100,000. For each ray from a given object two random numbers are generated (i.e., one to locate where the ray is emitted from on the perimeter of the surface and one to determine the direction of the ray from that point on the surface of the object). The object that is first intersected by the ray is counted in the sum of first intersections by object j for rays emitted from i (i.e., Nij). The view factor from i to j is then Nij / NVFRAYS. According to Reference 2-17, for a view factor on the order of 0.001, 95% confidence level with 5% accuracy requires 1,535,103 rays. The CPU time required to generate view factors using the Monte Carlo method with NVFRAYS = 100,000 for a typical 8x8 BWR fuel assembly is ~10 seconds and for NVFRAYS = 1,000,000 is ~350 seconds on a 3.4 GHz PC. Each time TRACE calculates the view factors and path lengths for a given BWR fuel design, the grouped view factors and path lengths are written to local files that include the file extension .gvf. The input contained in these local files can be used with IBEAM = 1, to bypass the TRACE view factor calculation. This way, CPU expensive view factor calculations need only be performed once for a given rod bundle configuration.

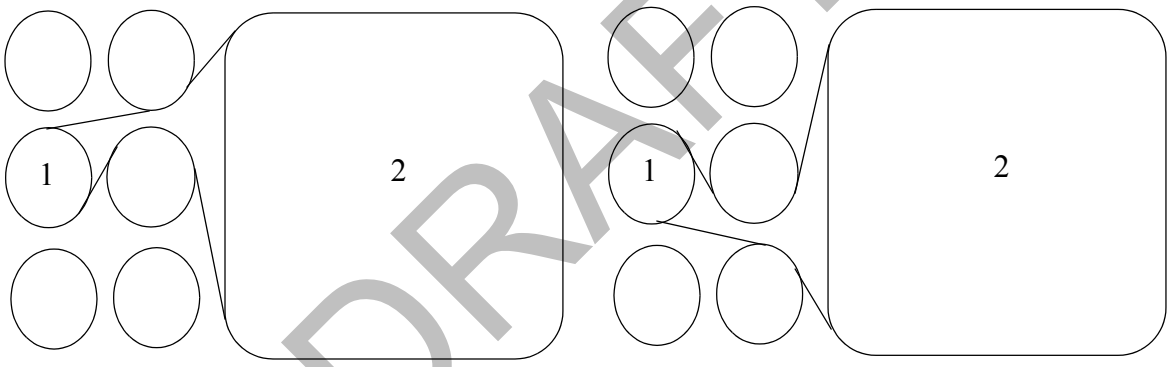




Figure. 2-30. Un-crossed Strings Between Partial Blocked Fuel Rod and Rectangular Water Rod - Includes both Views from 1 to 2.

The view factors calculated must conform to the conservation of radiate thermal energy

$$\sum_{j=1}^{N} F_{ij} = 1 \tag{2-8}$$

and reciprocity

$$A_i \cdot F_{ij} = A_j \cdot F_{ji}. \tag{2-9}$$

Note that N is in general equal to at least NROWxNROW + 1 (i.e., the + 1 is for the canister wall). For example, for a 10x10 fuel assembly, there would at most be view factors for 101 surfaces. For the example given in Figure 2-18 with the two relatively large water rods, there will be 95 individual surfaces for which view factors and path lengths are calculate before calculating the grouped view factors and path lengths. For the example given in Figure 2-18 the view factor matrix $VF_{ij}$ would be dimensioned 95 by 95. In addition, the view factors and path lengths matrices are calculated at each axial level when ADVBWRF = 1, since the geometry may change from one axial level to the next. When ADVBWRF = 1, TRACE only re-calculates the view factors and path lengths for a given axial level if the geometry changes relative to the last axial level for which it calculated view factors and path lengths. Therefore, for the coarse mesh axial noding given in Figure 2-21, view factors and path lengths will be calculated for RADENC component axial levels 1, 2, and 6. View factors and path lengths calculated for RADENC component axial level 2 will also be used for axial levels 3, 4, and 5.

When TRACE calculates the view factors for a given BWR fuel assembly, the conservation of radiant thermal energy is used to estimate any accumulation of round-off error by requiring that the view factor from surface i to itself is given by

$$VF_{ii} = 1 - \sum_{j=1,\, j\neq i}^{N} VF_{ij}. \tag{2-10}$$

If $VF_{ii}$ is calculated to be large (i.e., > 0.03) for a fuel rod or water rod which should have a zero view factor to itself, then an error message will be written and the calculation stopped. If the Monte Carlo method is used and a large relatively error in the view factor calculation is detected, then the user should re-run with a larger value for NVFRAYS. If the cross-string method is used and a relatively large error is detected, then there may be an input error with the CHAN geometry (i.e., a water rod and a fuel rod is located such that they overlap within the BWR fuel assembly - occupy the same space). In addition, the cross-string method is based on the assumption that the PDRAT > 1 and < $\sqrt{2}$. A pitch to diameter ratio outside this range will result in an error message.

This is a conservative approach to allow the round-off error for the view factors to accumulate in the view factor for surface i to itself. When radiation heat transfer is important for a BWR, the radiation heat transfer that tends to cool the fuel rods is from the fuel rods to the relatively cool canister wall or to the steam/water droplets between the fuel rods. When the view factor to itself for a given fuel rod is increased, then less thermal radiation is allowed to be transferred away from the fuel rod.

A negative view factor is not allowed. If $F_{ii}$ is calculated to be negative, then the view factor from the fuel rod/water rod to the canister wall is increased until $F_{ii}$ is zero. In general, TRACE will adjust calculated view factors to ensure conservation of radiate thermal energy and

reciprocity. If the adjustments are large then an error message will be written and the calculation stopped.

The view factors will be adjusted to include anisotropic corrections if NOANI is input as zero. The anisotropic correction is based on Reference 2-19 and is given by:

$$\overline{F}_{ij} = F_{ij} \cdot (1 - \mu_{ij}) \, , \, i \neq j \tag{2-11}$$

and

$$\overline{F}_{ii} = F_{ii} + \sum_{j=1 \, , \, j \neq i}^{N} \overline{F}_{ij}, \tag{2-12}$$

where $\overline{F}_{ij}$ is the modified view fraction. The values used for the anisotropic correction factor are those suggested by Tien (Ref. 2-19) (i.e., $\mu_{ij}$ is 0.5 for rod to rod views and $\mu_{ij}$ is 0.15 for channel box wall to rod views). The effect of the anisotropic correction is to decrease the overall view from the rods to the channel box and increase the view of the rods to back to itself.

The path length between two circular objects (i.e., two fuel rods or fuel rod and cylindrical water rod) is given by the following formula

$$L_{ij} = d_{ij} - \frac{\pi}{4} \cdot (R_i + R_j), \tag{2-13}$$

where $d_{ij}$ is the distance between the centers for the two circles and $R_i$ is the radius of circle i. The path length between a fuel rod or water rod (i.e., circle) and a wall is given by the following formula

$$L_{ij} = d_{ij} + \left(\frac{\pi}{4} - 1\right) \cdot R_i \, . \tag{2-14}$$

The individual view factors for each fuel rod, water rod, and wall for the BWR fuel assembly design must be grouped according to the rod groups given in the MROD array. Of course the grouping at each axial level will also depend upon whether or not the partial length fuel rod group or water rod group is present at that axial level. If ms is the set of fuel rods, water rods, or canister wall associated with the $m^{th}$ rod group and ns is the set of fuel rods, water rods, or canister wall associated with the $n^{th}$ rod group, then the grouped view factors and path lengths are given by

$$FG_{mn} = \frac{\sum_{i=ms} A_i \sum_{j=ns} F_{ij}}{A_m} \tag{2-15}$$

and

$$LG_{mn} = \frac{\sum_{i=ms} A_i \sum_{j=ms} F_{ij} \cdot L_{ij}}{A_m \cdot FG_{mn}}, \tag{2-16}$$

where $A_m = \sum_{i=ms} A_i$. Note that the conservation of the thermal radiate energy

$$\sum_{n=1}^{N} FG_{mn} = 1 \tag{2-17}$$

and reciprocity

$$A_m \cdot FG_{mn} = A_n \cdot FG_{nm}, \tag{2-18}$$

also applies to the grouped view factors. In addition grouped view factors and path lengths are not allowed to be negative. If the user supplies the grouped view factors and path lengths, then these Eq. (2-17) and Eq. (2-18) must be satisfied by the user input.

If a fuel rod group or water rod group does not exist at a given axial level, then view factors from the non-existing rod group to all other groups is zero and the view factor to itself is one. This allows the RADENC component to have the same number of HS at each axial level for this component, and ensures that the non-existing HS does not contribute to the radiation heat transfer exchange at that axial level. The path lengths for a fuel rod or water rod group that does not exist at a given axial level is also set to zero. Note in general for a rod group that includes more than one fuel rod, the view factor to itself and the path length to itself can be non-zero. This reflects that the radiation heat transfer emitted from a fuel rod group to itself will in general travel some distance between being absorbed or reflected from another fuel rod within the rod group. The steam/water droplet mixture between the fuel rods within the rod group can absorb, re-emit, or scatter this emitted thermal radiation.

The emissivity for the inside surface of the canister wall is given by EMCIF1, EMCIF2, and EMCIF3. These three constants represent a quadratic fit to surface emissivity as a function of the surface temperature of the inside surface of the canister wall

$$\epsilon = EMCIF1 + EMCIF2 \cdot T_s + EMCIF3 \cdot T^2{}_s. \quad (2\text{-}19)$$

The emissivity for the outside surface of the fuel rods and water rods is based on the input for EMCOF1, EMCOF2, and EMCOF3 . The emissivity for the fuel and water rods depends upon the following fit

$$\epsilon = EMCOF1 + EMCOF2 \cdot T_s + EMCOF3 \cdot T^2{}_s \ . \quad (2\text{-}20)$$

The exception to this is if the surface is wetted (i.e., not in film or transition boiling), then a surface emissivity of 0.96 is used. The emissivity of 0.96 is representative of water wetting the HS surface.

## *Modeling multiple rod groups*

Full length fuel rods, partial length fuel rods, and water rods must be grouped into separate groups as a minimum. Additional grouping with the water rods may be required if the water rod geometry varied within a given BWR fuel design. In addition, the fuel rods may be divided into smaller groups by grouping fuel rods of similar fuel pin peaking factors or to obtain more accurate radiation heat transfer modeling. For example, the 8x8 BWR fuel assembly given in Figure 2-31 will be simulated with 6 fuel rod groups and would provide a relative accurate simulation of the radiation heat transfer for this assembly design. The four corner rods are in rod group 1. Each of the corner rods will have the same view factors and path lengths to the rods and canister wall and therefore will behave in a similar manner in terms of the radiation heat transfer. In addition, the corner rods typically have very similar fuel rod peaking factors. There may be some variation in corner rod peaking since the core bypass gap tends to be wider on the side of the fuel assembly where control rods enter the core bypass. However, the variation is typically relatively small. The second rod group is all of the fuel rods next to the canister wall that are not corner rods. Again, these rods will have similar view factors and path lengths and similar fuel rod peaking. The third rod group is all fuel rods that are one row in from the canister wall, while the fourth rod group is two rows in from the canister wall. Again these groups are determined by similar view factors and path lengths and fuel rod peaking. The sixth rod group is the two water rods in this fuel assembly and the fifth rod group is the fuel rods closest to the water rods and therefore will typically have a larger fuel rod peaking factor than the other surrounding rods.

The MROD input for this BWR fuel assembly is given below:

```
* MROD input - Card Set 60
    1   r06 2      1 s            * first row
    2   r06 3      2 s            * second row
    2       3  r04 4    3     2 s * third row
    2       3      4    5     6 s  * fourth row
```

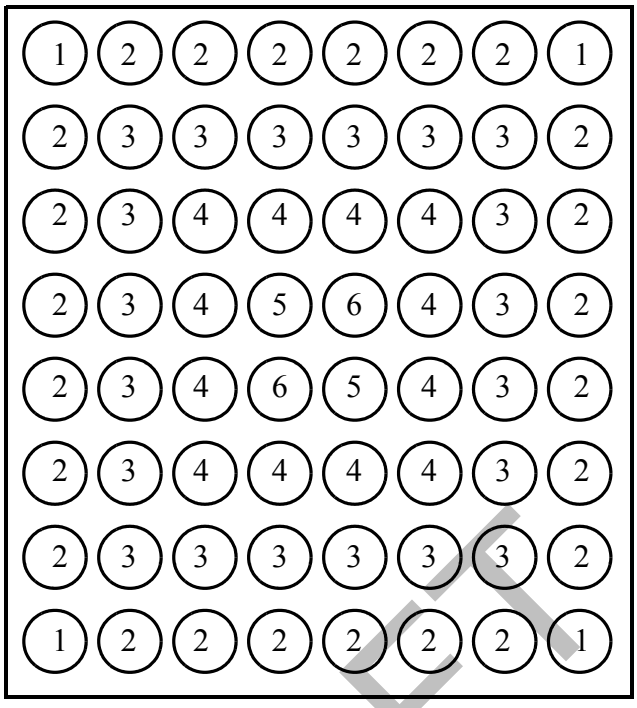


Figure. 2-31. 8x8 Fuel Assembly Simulated with 6 Rod Groups.

```
4       3       2 s
2       3       4     6     5 s  * fifth row
4       3       2 s
2       3   r04 4     3     2 s * sixth row
2   r06 3       2 s             * seventh row
1   r06 2       1 s             * eighth row
7 e                             * channel box
```

For this example, NGRP would be 6 (i.e., there are 6 rod groups) and the seventh group is for the channel box/canister wall. Note the water rod group(s) should always be the last rod group(s).

The most detailed noding would be for each fuel rod and water rod to be a separate rod group. However, this is typically not necessary since fuel rods at similar geometric locations with similar power levels will result in very similar HS temperatures since the CHAN PIPE is a 1D hydro model. The radial variations in HS behavior for a CHAN component are due to differences in the view factors, path lengths, and power level. Given the fuel rod pin to pin power peaking, additional groups for a typically 8x8 fuel assembly may be appropriate, but for most applications the example rod grouping given above will be more than adequate. A similar approach can be applied to 10x10 or any other BWR fuel assembly design to capture the variation in pin to pin powers and the grouping according to similar geometric locations within the fuel assembly.

The fuel rod to fuel rod peaking factor for the rod groups within a CHAN component is input via the CPOWR array. The CPOWR value for a given group of fuel rods can be obtained by averaging the fuel rod peaking for all of the fuel rods within the rod group. CPOWR for a water rod group defaults to a value of zero. Direct moderator heating of the water within the BWR assembly and within the core bypass is simulated by the POWER component.

## *Modeling an unpowered region*

The powered region with a CHAN component starts as CHAN PIPE cell index ICRNK + 1 and extends to cell index ICRNK + NRCZ. The axial power shape for the CHAN fuel rod HS is specified in the POWER component. If there is an axial level within the CHAN component between ICRNK+1 and ICRNK+NCRZ that is at zero, power then the ZPWTB array input with the POWER component must reflect this axial power distribution (see **Volume 1, Chapter 7** of the Theory Manual).

Within the CHAN component, the RDPWR - fuel rod radial power, CPOWR - rod to rod power peaking with the BWR fuel assembly, and RADPW - CHAN to CHAN power peaking are input. The RDPWR array extends radial across the fuel rod at NODESR radial locations. Since these radial locations typically include the fuel rod gap and cladding some portion of the RDPWR is typically zero (i.e., only the fuel pin itself is powered).

## *Metal water reaction*

When NMWRX is input as one, the metal-water reaction model is turned on for the fuel rod HS components associated with the CHAN component. The metal-water reaction model simulates the oxidation of the zirconium cladding that occurs at relatively high temperatures (i.e., > 1273.15 K). If NMWRX is input as one and if the surface temperature of a given CHAN fuel rod HS surface temperature is above 1273.15 K, then the following zirconium-steam exothermic reaction is simulated:

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2 + heat \tag{2-21}$$

The reaction-rate equation is based on References 2-20 and 2-22 and assumes a sufficient supply of steam and is given below:

$$\tau \cdot \frac{d\tau}{dt} = \eta_1 \cdot e^{\left(-\frac{\eta_2}{T}\right)} \tag{2-22}$$

where $\tau$ is the total oxygen consumed (kg/m$^2$), $\eta_1$ = 16.8 kg$^2$/m$^4$s, and $\eta_2$ = 2.007x10$^4$ K. The kinetic parameter is converted to an effective zirconium-oxide layer thickness according to:

$$1.5 \cdot (R_0 - r) = \frac{\tau}{0.26 \cdot \rho_{ZrO_2}} \tag{2-23}$$

where $r$ is the reacting surface radius (m), $R_0$ is the cladding outer radius (m), and $\rho_{ZrO_2}$ is the density of zirconium oxide (kg/m$^2$), which is approximated to be $0.9 \cdot \rho_{Zr}$. The method outlined in Reference 2-20 is used to solve for the zirconium-oxide penetration depth and the associated heat source. The heat source is added to the cladding of the fuel rods at the appropriate coarse mesh axial location and the total hydrogen generated is calculated.



## *Fuel clad interaction option*

If NFCI is input as one, then the dynamic gap model is turned on for the fuel rod CHAN HSs. The dynamic gap model calculates the gap heat transfer coefficient as a function of gap-gas conductance, fuel-cladding contact conductance, and fuel-cladding thermal radiation. The model is based on References. 2-22, 2-23, and 2-24. Currently the fuel-cladding contact conductance is assume to be zero. The gas-gas conductance and fuel-cladding thermal radiation are based on gas gap dimensions based on the relative thermal expansion of the fuel and cladding. Since the gap heat transfer coefficient for this model is a function of the radial temperature distribution across the fuel rod and the radial temperature distribution is a function of the gap heat transfer coefficient, the user via NFCIL can specify the number of times through the dynamic gap model and the conduction solution per time step. The recommended value for NFCIL when NFCI is input as 1, is 1. Testing of this capability indicates that for the typical radial temperature distribution per time step one pass through the dynamic gas gap model and the conduction is sufficient to obtain a converged solution for the fuel rod radial temperature profile.



## *Fine mesh modeling*

Fine mesh modeling for the CHAN HS components is turned on when FMON or REFLOODON is input as non-zero. The fine mesh model should be turned on if the anticipated transient TRACE calculation may result in significant dryout and heat up of the fuel rods with the CHAN component. The TRACE fine mesh logic increases the CHAN HS component coarse mesh axial noding and adds permanent fine mesh axial HS nodes, and may add and delete non-permanent fine mesh axial nodes. These additional HS axial levels, adds computer storage requirements and results in increase cpu costs for the conduction solution for the CHAN component HS and increases the size of the TRACE output files. The intent of this increased axial noding is to improve the accuracy of the TRACE conduction solution when there are steep axial gradients in the HS temperature profiles. For example, the axial gradient at a quench front moving through a BWR fuel assembly either from quenching from the bottom (i.e., refill of the fuel assembly) or the top of the HS (i.e., ECCS water falling from the top of the fuel assembly). Therefore fine mesh should not be turned on if for the anticipated transient the BWR fuel assembly represented by the CHAN component will not dryout. In addition, if the fine mesh model is turned on for the CHAN

component, then IAXCND should also be set to 1, to include the axial conduction that would be significant due to the steep axial temperature gradients at a quench front.

The fine mesh logic adds an extra coarse mesh axial level at the top and bottom of each HS component within a CHAN component if FMON or REFLOODON is non-zero (see Figure 2-21 and Figure 2-22). In order to maintain radiation heat transfer enclosures with consistent HS axial levels and axial level heights, extra coarse mesh axial levels must be added for all of the HS contained within the CHAN radiation heat transfer enclosure (see ***Radiation & View Factor Modeling***). The total number of fine mesh axial levels for a fine mesh fuel rod HS is given by the user input NZMAX. The total number of fine mesh axial levels for the fine mesh canister wall HS is given by the user input NZMAXW.

Permanent fine mesh axial levels are added in each coarse mesh axial level according to the NFAX array input. Permanent fine mesh axial levels cannot be removed or moved to a different axial level. Therefore, there is a minimum value for NZMAX that goes as:

$$NZMAX \geq 2 + \sum_{i=1}^{NCRZ} NFAX(i) \tag{2-24}$$

Since the fine mesh logic increases the number of coarse mesh HS axial levels and also requires NFAX to be consistent at each coarse mesh axial level for each HS included in the RADENC component, it is difficult for the user to determine the minimum NZMAX and NZMAXW. TRACE includes logic to increase NZMAX to ensure that it is large enough to include all of the permanent fine mesh if necessary. However, the intent of the model is to be able to add and delete non-permanent fine mesh axial levels to be able to follow steep axial profile gradients and a typical input value for NZMAX is 200. Steep axial temperature gradients are not expected for the canister wall and a typical input value for NZMAXW is 100. Note as NZMAX and NZMAXW are increased, cpu storage requirements and cpu costs increase.

Non-permanent fine mesh axial levels will be added when the axial temperature gradient is larger than the following formula given below, which depends upon the convective heat transfer mode at the HS surface.

If the convective heat transfer is film boiling, then the temperature difference limit is:

$$\Delta T_l = MAX(25\ ,\ 5 + 0.067 \cdot \Delta T_s + 0.000028 \cdot (\Delta T_s)^2) \tag{2-25}$$

where, $\Delta T_l$ is the temperature difference limit above which a fine mesh axial level is added, $\Delta T_s$ is the heat structure surface temperature miss the saturation temperature.

If the convective heat transfer is transition boiling, then the temperature difference limit is:

$$\Delta T_l = MIN(25\ ,\ 5 + 0.067 \cdot \Delta T_s) \tag{2-26}$$

If the convective heat transfer is nucleate boiling, then the temperature difference limit is:

$$\Delta T_l = MIN(5\ ,\ 25/\Delta T_s) \tag{2-27}$$



For all other heat transfer regimes, the temperature difference limit is $\Delta T_l$ = 25 K. Non-permanent fine mesh axial levels will be removed if the axial temperature gradient is 1/2 the temperature difference limit for adding new fine mesh axial levels.

New non-permanent fine mesh fuel rod axial levels will not be added if the current total number of fine mesh axial levels is equal to NZMAX or if the resulting axial mesh height is less than DZNHT. New non-permanent fine mesh canister wall axial levels will not be added if the current total number of fine mesh axial levels is equal to NZMAZW or if the resulting axial mesh height is less than DZNHTW. Note the user input for DTXHT1 and DTXHT2 are not used and have been replaced with the temperature difference limit formulas given above based on the convective heat transfer regime.

The user input for UNHEATR is used when FMON or REFLOODON is non-zero. UNHEATR is the fraction of the HS perimeter that is not heated. This number is used in the reflood interfacial heat transfer, shear, and wall drag models to allow liquid films at axial elevations where the fuel rods are in post-CHF heat transfer. For a BWR fuel assembly this input would be the perimeter of the inside surface of the channel box plus the perimeter of the water rods divided by the perimeter of all HS surfaces.



## *Grid spacer modeling*

Currently, TRACE input is provided to locate grid spacers within a CHAN component, however there is currently no model within TRACE that uses this information. This modeling feature is under development and slated for inclusion in a future TRACE version.

# *CONTAN Component*

The CONTAN component was developed to simulate a BWR containment. It was incorporated into TRACE from TRAC-BF1/MOD1 (Ref. 2-3). A typical BWR containment configuration is shown in Figure 2-32. It consists of a drywell, drywell vents, and a suppression pool or wetwell. Vacuum breakers connect the air space of the drywell with the suppression pool; they are normally closed. Residual removal systems (RHR) are installed to cool the suppression pool liquid and to provide the drywell spray in case of an accident resulting in the coolant leaking from the primary cooling loop (PCL) to the containment. The drywell cooling during normal operation is provided by the containment cooling systems.

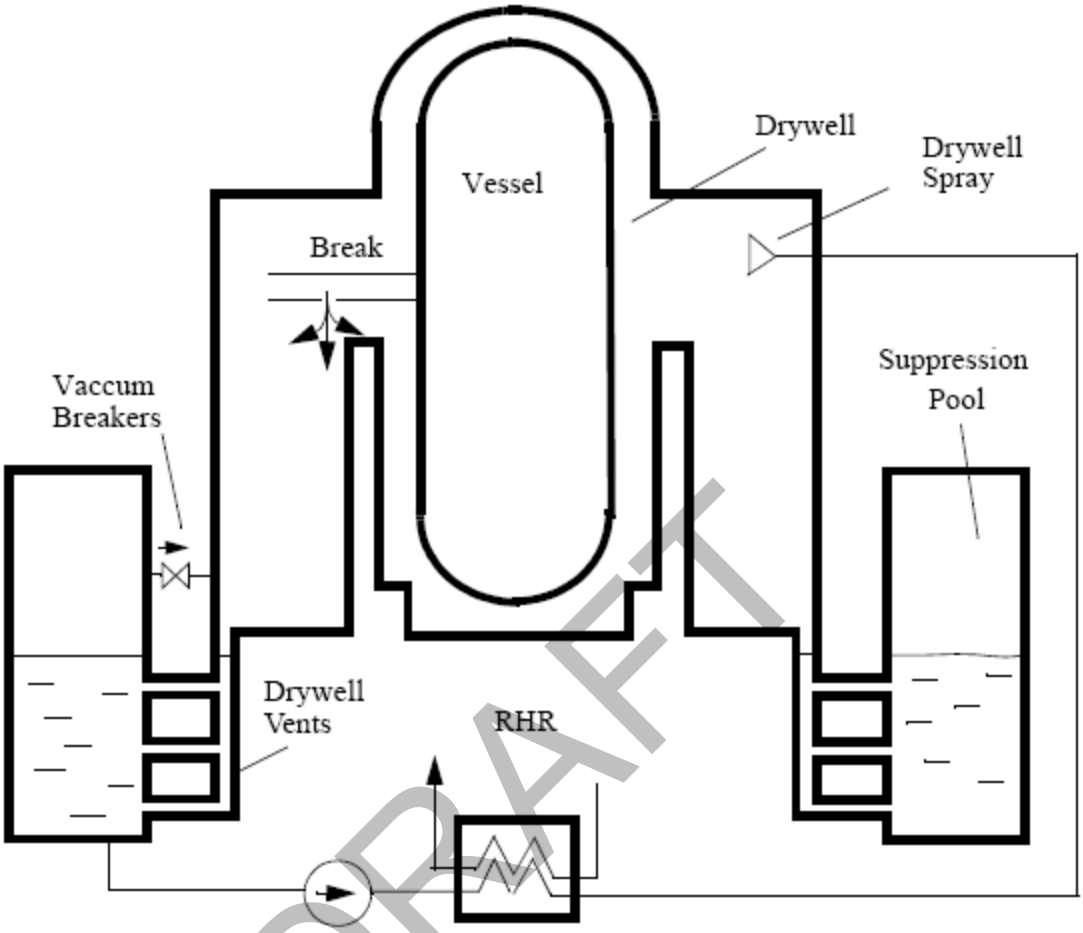




Figure. 2-32. A typical BWR containment.

The CONTAN component is based on the lumped parameter containment analysis in CONTEMPT-LT (Ref. 2-27), where the containment is modeled as a collection of compartments, each of which contains a well-mixed vapor and liquid region. Mass inventories of liquid water, steam, and noncondensible gas (air), and total energy inventories of vapor and liquid are computed as functions of time.

During normal operation of a reactor, the containment is isolated from the fluid in the PCL, while during a postulated loss of accident (LOCA), the high energy fluid from the PCL is discharged into the drywell. The discharge of high temperature PCL fluid into the drywell raises the temperature and pressure of the drywell and results in the flow of non-condensable gas and steam mixture through the drywell vents into the suppression pool. Note in order for the drywell vents to clear, the pressure difference between the drywell and wetwell must overcome the static head of water in the drywell vents. As the steam and non-condensable gas flows into the suppression pool from the drywell, part of the steam condenses and the non-condensable gas accumulates in the upper space of the suppression pool. During the post blow-down phase, operators may activate the RHR system and the drywell spray, which reduces the drywell pressure. The

resulting negative pressure differences across the vacuum breakers open the valves to equalize the pressure between the drywell and the wetwell.

After the pressure of the PCL recedes below the point that sustains critical flow at the break, the containment pressure will influence the depressurization of the PCL. During ECCS injection and post blow-down periods, there is a possibility that PCL pressure may be lower than the containment pressure. This may result in the flow of non-condensable gases from the containment back into the PCL.

In order to simulate the system interactions between the containment and the PCL during a LOCA, it is necessary to model the mass and energy transport within the containment as well as the PCL. The following physical processes are modeled by the CONTAN component:

a) The pressurization of a large volume due to high-pressure and high-temperature fluid discharge;
b) Pressure induced flow among the large containment volumes;
c) Convective heat transfer between containment volumes and the solid surfaces (i.e., RPV wall, drywell shell surface, and RHR heat exchanger.
d) Interfacial heat and mass transfer between pool and vapor regions by free convection;
e) Interactions between the PCL and containment.

The CONTAN component employs the following six basic components to model the containment calculation:

1) compartment;
2) heat structure;
3) cooler;
4) passive flow junction;
5) forced flow junction;
6) source/sink flow junction.



For the model given in Figure 2-32, the CONTAN component would predict the time-dependent pressure and temperature and air/steam mixture in the drywell, which would appear in the TRACE model in the BREAK component used to simulate the ambient conditions for the break in the piping external to the BWR VESSEL component. In addition, the ambient temperature of the drywell would provide the sink temperature for the outside surface of the heat structures used to represent the RPV walls. Note that currently, the sink temperature of the TRACE RPV heat structures are not affected by the CONTAN calculation. This capability may be addressed in future versions of TRACE, if necessary. However, the heat loss by the TRACE RPV heat structures can be included in the CONTAN energy balance. Note that there is currently an index error in this logic in that TRACE uses the inside surface heat transfer coefficient, even when it is the outside surface of the TRACE HS that is in contact with the drywell space. Also, note that this logic only works for TRACE HTSTR components with a slab geometry. Therefore, until this coding is fixed, this capability should only be used with slab TRACE HS, with the inside surface seeing the drywell and the outside surface seeing the primary fluid.

The calculation is performed by explicit integration of a coupled system of ordinary differential equations of the form:

$$\frac{d\vec{Y}}{dt} = \vec{F}(\vec{Y}, t) \tag{2-28}$$

where,

$\vec{Y}$ = vector of mass and energy inventories in containment compartments.

t = time

$\vec{F}(\vec{Y}, t)$ = forcing functions associated with mass and energy balances for the containment compartments.

The explicit integration of Eq. (2-28) yields,

$$\vec{Y}(t + \Delta t) = \vec{Y}(t) + \vec{F}(\vec{Y}, t) \cdot \Delta t \tag{2-29}$$

The components of the forcing function in Eq. (2-29) can be written as:

$$\vec{F}(\vec{Y}, t) = \sum_{i=2}^{6} \sum_{j=1}^{N_i} \vec{F}_{ij}[(\vec{Y}(t), t)] \tag{2-30}$$

where,

$N_i$ = number of containment compartments of type i used in the containment model.

$i$ = component type index which corresponds to =1 for COMPARTMENT, = 2 for HEAT STRUCTURE, = 3 for COOLER, = 4 for PASSIVE JUNCTION, = 5 for FORCED JUNCTION, and =6 for SOURCE/SINK JUNCTION.

$\vec{F}_{ij}(\vec{Y}, t)$ = contribution to $\vec{Y}$ due to the jth component of type i.



The CONTAN component solution is advanced at the same time step size as the normal hydrodynamic time step size. Because of the difference in time scales between the containment and the RPV fluid dynamics, we anticipate that the explicit integration of the CONTAN models will always be stable. However, if the time step size becomes large enough, the explicit CONTAN model integration may become unstable. If this occurs, then the calculation must be repeated with a reduced time step control.

An example input for the CONTAN component that includes two compartments, one heat structure, one cooler, one passive flow junction, one forced flow junction and one source/sink flow junction is given in Table 2-4.

**Table 2-4. Example Input for CONTAN Component.**

```
*******   type            num             id        ctitle
contan                    903            903 $903$ containment
*       ncomt        nhs          ncool          njct      njctf
```

```
        2           1           1             1         1
*       njcts       ncomtb       ncomtv        nnlev
        1           0           0             0
*
*  compartment data
*
* itrkl *  1  0e
* itrks *  0  0e
* ictbl * 51 52e
* vol   * 1782.   152.e
* vmax  * 1782.   152.e
* p     * 1.013e5  3.03e5e
* tl    * 300.  300.e
* tv    * 300.  500.e
* frsb  * 0.  0.e
* frab  * 1.  1.e
* cuch  * 1. -1.e
* dpdt  * 5000.  0.e
* apool * 1.e-8  0.1e
* pa    * 1.000e5  1.013e5e
* rml   * 6.0e5  0.1e
* nword * 2 3e
* depth * 0.0 0.0 1782.0 10.0e
* depth * 1.0 0.1 2.0 0.2 3.0s
* depth * 0.3e
*
*   heat structure data
*
* itrkh * f 0  e
* icti  * f 51 e
* icto  * f 52 e
* nodax * f  1 e
* nodra * f  3 e
* ihstb * f 81 e
* iregi * f 0  e
* irego * 0e
* radi  * 5.e
* rado  * 5.0015e
* row   * 7712.e
* cpw   * 482.7e
* cw    * 204.2e
* hlic  * f 0.0 e
* huic  * f 0.0 e
* hloc  * f 0.0 e
* huoc  * f 0.0 e
* hdavg * f 2.0 e
* areai * 15.e
* areao * 15.e
* tempht* 350. 400. 450.e
*
*  cooler
*
* icltb * 103e
* ictc  * 52e
* iregc * 0e
* itypc * 1e
* htc   * 1.0e+4e
* ntq   * 2e
* tcorqc* 0.0 300. 3000.0 300. e
*
*
*  passive junction
*
* ict1  * 52e
* ict2  * 51e
* ijctb * 71e
* itypp * 3e
* hd    * 2.42e
* area  * 0.1e
* rlen  * 13.02e
* fr    * f 10.0e
* dpcr  * -0.5e
```

```
*
*
* forced junction
*
* ictf1 * 51e
* ictf2 * 52e
* iftyp * 2e
* ijctf * 30e
* nqfj  * 2e
* nspray* 2e
* qfjunc* 0.0 0.01 100.0 0.01e
* spraye* 0.0 0.9 50.0 0.9e
*
*
* source junction
*
* istyp * 1e
* icts  * 52e
* ijcts * 31e
* nqso  * 3e
* ntso  * 2e
* qso   * 0.0  0.01  2.0  0.01 300.0s
* qso   * 0.01e
* tso   * 0.0 300.0 100.0 300.0e
*
```

# *Modeling Compartments*



The COMPARTMENT model is composed of a vapor and liquid region. Both regions are assumed to be perfectly mixed and each region is assumed to be a single-phase fluid. A single pressure is calculated for each COMPARTMENT and is used to calculate both the vapor and liquid properties. The temperature of the two regions is allowed to be different to simulate non-equilibrium within a given COMPARTMENT for the liquid and vapor phases. The vapor region is an isothermal mixture of non-condensable gas (air) and steam. The pressure of the air-steam mixture is assumed to be the sum of the partial pressures of the steam and non-condensable gas. Liquid droplets in the vapor region are not modeled explicitly. However, spray modeling is accommodated via a forced flow junction (see ***Modeling Forced Flow Junctions*** below).

Based on this methodology, the mass of the liquid, steam, and non-condensable gas (air) and total internal energy of the vapor and liquid are computed as a function of time with the solution of Eq. (2-29). After the mass and energy are determined, the pressure and temperature in the vapor region is calculated. If the mixture is superheated, the pressure and temperature are calculated based on a two-dimensional iterative scheme. If the mixture is saturated, a similar one-dimensional scheme is used to determine the pressure and temperature of the mixture. Once the state of the vapor region is determined, all saturated liquid will be transferred from the vapor space to the pool region, and the liquid temperature is calculated by a one-dimensional iterative procedure using the pressure from the vapor region.

For the example input in Table 2-4, there are two compartments simulated (i.e., numbers 51 and 52). Compartment 51 has a volume (i.e., VOL) of 1782 $m^3$ and compartment 52 has a volume of 152 $m^3$. Compartment 51 has the level tracking flag turned on while compartment 52 does not. Spill volumes (i.e., VMAX) for both compartments is equal to the total volume of each compartment. Initial pressure for compartment 51 is 1.013 bars with an air partial pressure of 1.0

bars, while the initial pressure for compartment 52 is 3.03 bars with an air partial pressure of 1.013 bars. The initial liquid and vapor temperatures for compartment 51 are both 300 K. For compartment 52, the initial liquid temperature is 300 K and the initial vapor temperature is 500 K. With FRSB input as zero, all steam vented to the pool will be assumed to be condensed. With FRAB input as one, all non-condensable gas vented to the pool will be assumed to be in equilibrium with the liquid in the pool. The CUCH input implies that the Ucihda correlation for condensation is fully included for compartment 51 and ignored for compartment 52.

The initial pressure rate (i.e., DPDT) for compartment 52 is zero, while the initial pressure rate for compartment 51 is 5000 Pa/s. The interfacial area (i.e., APOOL) between the liquid pool and vapor space for compartment 51 is $1.0 \times 10^{-8}$ $m^2$, which is the smallest number allowed for this input. APOOL input this small effectively turns off heat transfer between the liquid pool and vapor space. The interfacial area between the liquid pool and vapor space for compartment 52 is 0.1 $m^2$. The initial liquid mass (i.e., RML) for compartment 51 is 600,000 kg and 0.1 kg for compartment 52. Note compartment 52 must have a non-zero liquid water mass, however the water mass of 0.1 kg implies that compartment 52 is essentially full of vapor. The volume vs. depth table for compartment 51 is given in Table 2-5 and the volume vs. depth table for compartment 52 is given in Table 2-6 . The volume vs. depth table for compartment 51 implies that the depth is a linear function of the volume from 0 to 10 m (i.e., compartment is 10 m tall and has uniform cross sectional area = 178.2 $m^2$). The volume vs. depth table for compartment 52 implies that the cross sectional area is constant at 10 $m^2$ = 1/0.1 = 2/0.2 = 3/0.3.



**Table 2-5. Volume versus Depth Table for Compartment 51 in Table 2-4.**

| Volume($m^3$) | Depth(m) |
|---|---|
| 0.0 | 0.0 |
| 1782.0 | 10.0 |

**Table 2-6. Volume versus Depth Table for Compartment 52 in Table 2-4.**

| Volume($m^3$) | Depth(m) |
|---|---|
| 1.0 | 0.1 |
| 2.0 | 0.2 |
| 3.0 | 0.3 |

Note that one method for simulating the flow of liquid between compartments is via the compartment spilling model. The compartment spilling model requires that ITRKS be input as non-zero and points to the receiver compartment ID for which the spilled liquid will appear. If ITRKS is non-zero and points to the appropriate compartment ID and the liquid volume in the donor cell compartment reaches VMAX, then any additional liquid added to the donor cell compartment will be spilled into the receiver compartment (i.e., ID = ITRKS). This could be used to simulate the geometry given in Figure 2-33.

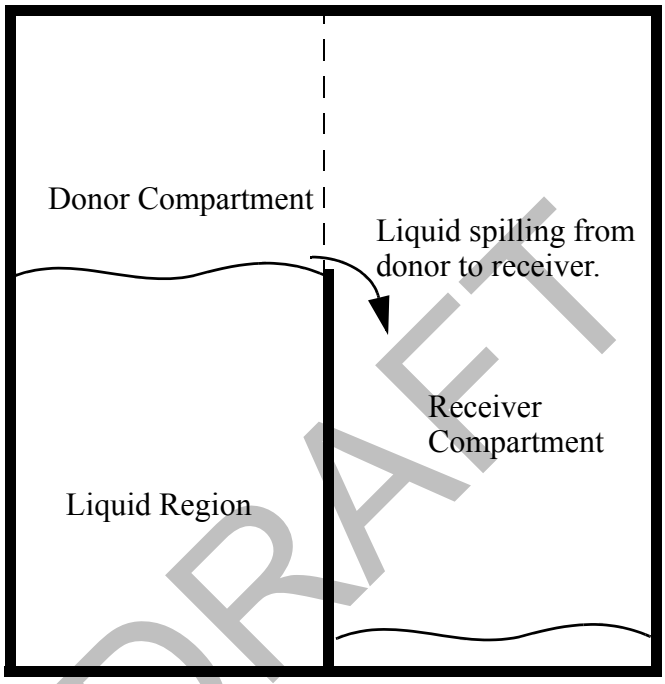




Figure. 2-33. Compartment Spilling Model.

## *Modeling Heat Structures*

The heat transfer between a thermal mass and a compartment fluid region will be modeled by the CONTAN heat structure component. CONTAN heat structures are modeled as cylindrical shells with conduction in the radial direction only. The axis of the cylinder is assumed to be vertical and the inner and outer surfaces of the structure may lie in two separate compartments (i.e., a wall separating two compartments), depending upon how the user specifies the input for ICTI and ICTO (i.e., ICTI is compartment ID for heat structure inner surface and ICTO is compartment ID for heat structure outer surface). If the heat structure is contained within a single compartment, then ICTI and ICTO can both be set to the same compartment ID.

The conduction solution for CONTAN heat structure component assumes cylindrical geometry. However, other geometries can be simulated by ensuring that the user input for AREAI and AREAO is equivalent to the actual heat structure surface area and that the thickness of the heat

structure (i.e., RADO - RADI) is equivalent to the actual heat structure thickness. In general, as the radius of a cylindrical shell increases, the shell approaches slab geometry. For example, a slab with an inner and outer heat transfer area of 10 $m^2$ and a thickness of 0.1 m, can be accurately approximated with a cylindrical shell with AREAI = AREAO = 10 $m^2$ and RADI = 10 m and RADO = 10.1 m. The cylindrical geometry volume can be compared to the actual volume of the slab to estimate the error in the cylindrical conduction solution in terms of the implied volume in the change in stored energy term in the conduction equation (see Eq. (2-31)).

$$e = \frac{RADO - RADI}{2 \cdot RADI} \tag{2-31}$$

For this example, Eq. (2-31) implies a 0.5% error in the implied volume in the cylindrical conduction equation solution.

The heat structure component uses a sub-set of the TRAC-BF1/MOD1 (Ref. 2-3) heat transfer correlation package to calculate the heat transfer coefficients to the vapor and liquid regions in a compartment and then solves the transient conduction equation for cylindrical geometry to determine the temperature profile across the heat structure. The heat transfer coefficient is either to single-phase liquid or single-phase vapor, depending upon whether the heat structure surface is in contact with the vapor space or liquid pool. The vapor/liquid single phase HTC is based on the maximum of the laminar, natural convection, or turbulent TRAC-BF1/MOD1 HTC correlations. The CONTAN heat transfer coefficient is based on the Nusselt number:

$$Nu = \frac{hD_H}{k} \tag{2-32}$$

where,
*Nu* = Nusselt number.

*h* = heat transfer coefficient, $h = \frac{Nu \cdot k}{D_H}$.

$D_H$ = hydraulic diameter.
*k* = thermal conductivity for the vapor phase or liquid phase depending up whether the heat structure surface sees the vapor space or the liquid pool.

The laminar heat transfer, the CONTAN Nusselt number is 4. For natural convection the following correlation by McAdams (Ref. 2-28) is used:

$$Nu = 0.13 \cdot (Gr \cdot Pr)^{0.3333} \tag{2-33}$$

where,

*Gr* = Grashof number = $\frac{g\beta \left| T_w - T_f \right| \rho^2 D_H^{\ 3}}{\mu^2}$.

$Pr$ = Prandtl number = $\frac{\mu c_p}{k}$.

$g$ = acceleration of gravity.
$\beta$ = expansion coefficient for the fluid seen by the CONTAN heat structure surface. For heat transfer to the vapor space $\beta$ is approximated as $1/T_v$ and for heat transfer to the liquid pool $\beta$ is given by $-\frac{1}{\rho_l} \cdot \frac{\partial \rho_l}{\partial T_l}$.
$T_f$ = fluid region temperature.
$T_w$ = heat structure surface temperature.
$\rho$ = density for the fluid seen by the CONTAN heat structure surface.
$\mu$ = viscosity for the fluid seen by the CONTAN heat structure surface.
$c_p$ = specific for the fluid seen by the CONTAN heat structure surface.
$k$ = thermal conductivity for the fluid seen by the CONTAN heat structure surface.

For turbulent heat transfer, the correlation is Dittus-Boelter (Ref. 2-29):

$$Nu = 0.023 \cdot Re^{0.8} Pr^{0.333} \tag{2-34}$$

where,

$Re$ = Reynolds number = $\frac{\rho V D_H}{\mu}$.

$V$ = fluid velocity.

The properties used in these heat transfer correlations are either based on the vapor phase or on the liquid phase, depending upon whether the heat transfer surface sees the vapor space or the liquid pool. The CONTAN heat structure surface sees the vapor space or the liquid pool depending upon the user input for ITRKH, IREGI, IREGO, HLIC, HUIC, HLOC, and HUOC. If ITRKH is input as zero, then the input for IREGI and IREGO determine whether or not the inside and outside surface of the heat structure sees the vapor space or the liquid pool.

The energy flow rate from the containment fluid region to the heat structure is given by:

$$\dot{Q} = hA(T_f - T_w) \tag{2-35}$$

where,

$\dot{Q}$ = heat transfer rate from the containment fluid region to the heat structure.
$h$ = heat transfer coefficient for the containment fluid region.
$A$ = surface area.

For the example input in Table 2-4, the heat structure will always be considered in the region identified by IREGI and IREGO (i.e., ITRKH = 0). The inside surface of the heat structure is in contact with compartment 51 and the outside surface of the heat structure is in contact with

compartment 52 (i.e., ICTI = 51 and ICTO = 52). The number of axial levels for this heat structure is one (i.e., NODAX = 1) and three radial nodes (i.e., NODRA = 3). User ID for this heat structure is 81 (i.e., IHSTB = 81). The inside and outside surface of this heat structure is in contact with the vapor regions of compartments 51 and 52 (i.e., IREGI = 0 and IREGO = 0). The inside radius of this heat structure is 5.0 m and the outside radius is 5.0015 m (i.e., RADI = 5 and RADO = 5.0015). Density of this heat structure is ROW = 7712 kg/m3 and the specific heat of this heat structure is CPW = 482.7 J/kg-K. The thermal conductivity of the heat structure is CW = 204.2 W/m-K. The inside and outside surface area (i.e., AREAI and AREAO) of this heat structure is 15 $m^2$. The initial radial temperature profile (i.e., tempht) is 350, 400, and 450 K.



# *Modeling Coolers*

The cooler component of the CONTAN component simulates the effect of a convective heat source/sink in a containment compartment component. The cooler heat exchange characteristics are specified by the user in either of two forms:

a) The user specifies a constant overall heat transfer coefficient (*hA*) and a coolant fluid temperature ($T_c$) that may vary with time. In this case the energy flow rate from the containment compartment is calculated from

$$\dot{Q} = hA(T_f - T_c) \tag{2-36}$$

b) The user specifies a cooling rate $\dot{Q}_c$, as a function of time. The energy flow rate from the containment compartment where the cooler is located is:

$$\dot{Q} = \dot{Q}_c \tag{2-37}$$



For the example input in Table 2-4, the cooler ID = 103 is located in compartment 52. The cooler is in contact with the vapor region of compartment 52 (i.e., IREGC = 0). The cooler type is ITYPC = 1, which implies that the cooler HTC times surface area and the cooler temperature must be input. For this example, the HTC times surface area is 10,000 W/K (i.e., HTC = 10000) and the cooler temperature table (i.e., TCORQC) is given by Table 2-7.

**Table 2-7. Cooler Temperature Table for Input Example Given in Table 2-4.**

| Time(s) | Temp(K) |
|---|---|
| 0.0 | 300.0 |
| 3000.0 | 300.0 |

# *Modeling Passive Junctions*

The passive junction simulates pressure-induced flow between two compartments. Three types of passive flow junctions are available:

1. **Single phase gas flow between vapor regions of two compartments**.

   Flow may occur in either direction depending upon the pressure gradient. This type of junction is intended to simulate an opening or passage connecting two rooms in an containment. The flow rate is assumed to be the lesser of the two values obtained by assuming: a) steady pipe flow or b) steady orifice flow through the junction. For steady pipe flow the mass flow rate is:

$$\dot{M} = \rho A V \tag{2-38}$$

   where,
   $\rho$ = vapor density in the donor cell compartment vapor region.
   $A$ = user-supplied junction flow area.
   $V$ = junction velocity.

   Junction velocity is computed from the pipe flow equation:

$$P_D - P_R = \frac{fL}{2D_H}\rho V^2 \tag{2-39}$$

   where,
   $P_D$ = fluid pressure in the donor cell compartment.
   $P_R$ = fluid pressure in the receiver compartment.
   $f$ = friction factor.
   $L$ = junction length.
   $D_H$ = junction hydraulic diameter.

   The friction factor for turbulent pipe flow is:

$$f = 0.316\,Re^{-0.25} \tag{2-40}$$

   and for laminar pipe flow is:

$$f = \frac{64}{Re} \tag{2-41}$$

   The transition Reynolds is assumed to be 1189.

   The mass flow rate for orifice flow is:

$$\dot{M} = \rho A V C_d \tag{2-42}$$

where,
$C_d$ = orifice discharge coefficient = 0.6.

The velocity is calculated from the Bernoulli equation assuming reservoir type flow to the orifice:

$$P_D - P_R = \frac{\rho V^2}{2} \tag{2-43}$$



2. **Single-phase gas flow in one direction only between the vapor regions of two compartments**.

   This type of junction simulates the pressure relief valve which allows flow in one direction when the pressure difference between the two compartments reaches a prescribed value. The mass flow rate is computed in the same manner as for the type 1 passive flow junction, except that the pressure difference used in the velocity determination includes the minimum pressure difference for flow to occur.

$$P_D - (P_R + \Delta P_{crit}) = \frac{fL}{2D_H}\rho V^2 \tag{2-44}$$

$$P_D - (P_R + \Delta P_{crit}) = \frac{\rho V^2}{2} \tag{2-45}$$

   where,
   $\Delta P_{crit}$ = minimum pressure difference for flow to occur.

3. **Single-phase gas flow in one direction only between the vapor region of the donor cell compartment and the liquid region of the receiver compartment**.

   This type of passive flow junction can be use to simulate the vent flow between the wetwell and drywell of a BWR containment. The mass flow rate is calculated based on the type 2 passive flow junction model. The minimum pressure difference for flow to occur is the gravity head difference required to clear the drywell vents (see Figure 2-32).

The fluid mass flow rates predicted by the passive flow junction model are used to compute the respective rate of changes of mass and energy inventories in the donor and receiver compartments.

For the example input in Table 2-4, the passive flow junction (i.e., IJCTB = 71) is from compartment 52 to compartment 51 and is of type 3. The minimum pressure drop for flow (i.e., DPCR) is -0.5 Pa. The hydraulic diameter (i.e., HD) is 2.42 m. The flow area (i.e., AREA) is 0.1

$m^2$. The flow length (i.e., RLEN) between compartments 52 and 51 is 13.02 m. The friction factor for pipe flow (i.e., FR = 10) is non-zero which implies that the CONTAN component will not calculate the friction factor based on the Reynolds number, but will use this input as a constant in the pipe flow calculation.

Note that passive flow junctions only involve the flow of the vapor phase between compartments. The flow of liquid phase between compartments can only be simulated via the compartment spilling model (see compartment model input) or via the forced flow junction model.

## *Modeling Forced Flow Junctions*

The forced flow junction component simulates an active containment system that transports liquid or vapor from one compartment to another. The user specifies the volumetric flow rate as a function of time and the spray efficiency if the flow represents a spray cooler (see drywell spray in Figure 2-32). Rates of change of mass and energy inventories in the donor and receiver compartments are computed from the junction mass flow rates as in the case of the passive flow junction. It should be noted that for all containment flow junctions the flow work is attributed to the vapor region energy inventories in the donor and receiver compartments (i.e., the liquid phase is assumed to be incompressible).

There are three types of forced flow junctions:

1) **Single phase gas flow between the vapor regions of two compartments**.

   This forced flow junction transfers gas flow from one compartment's vapor region to another compartment's vapor region at the volumetric flow rate specified in the volumetric flow rate table.

2) **Single phase liquid flow between the liquid regions of two compartments**.

   This forced flow junction transfers liquid flow from one compartment's liquid region to another compartment's liquid region at the volumetric flow rate specified in the volumetric flow rate table.

3) **Single phase liquid flow from the liquid region of one compartment to the vapor region of another compartment**.

   This forced flow junction transfers liquid flow from one compartment's liquid region to another compartment's vapor region at the volumetric flow rate specified in the volumetric flow rate table. This forced flow junction type can be used to simulate a spray cooler.

For the example input in Table 2-4, the forced flow junction (i.e., IJCTF = 30) is from compartment 51 (i.e., ICTF1) to compartment 52 (i.e., ICTF2) and transfer liquid from the liquid region of compartment 51 to the liquid region of compartment 52 (i.e, IFTYP = 2). The volumetric flow is 0.01 $m^3/s$ and the spray efficiency is 90%. The spray efficiency indicates how much of the subcooling in the spray is available to condense steam.

## *Modeling Source/Sink Junctions*

The source/sink flow junction component simulates an external source of liquid water pumped into the containment. The user specifies the volume flow rate of liquid into or out of the containment compartment and if the junction is a source of the liquid inlet temperature. The mass and energy flow rates into the compartment that is connected to the source/sink junction are computed accordingly.

For the example input in Table 2-4, junction 31 (i.e., IJCTS = 31) is a source (i.e., ISTYP = 1). The volumetric flow rate into compartment 51 (i.e., ICTS = 51) is 0.01 $m^3/s$. The temperature of the water flowing into compartment 51 via this source junction is 300 K.

## *Coupling a CONTAN with BREAK and FILL Components*

The fluid conditions calculated in a CONTAN compartment can be used in a TRACE BREAK and/or FILL component. As the fluid conditions in the CONTAN compartment changes, the fluid conditions in the BREAK and/or FILL component will change. For the example given in Figure 2-32, the BREAK component used to represent the pressure boundary condition for the broken primary coolant loop pipe would obtain its pressure, temperature, void fraction, and non-condensable mass fraction from the CONTAN compartment used to represent the drywell. The pressure, temperature, and non-condensable mass fraction in the drywell will be changing during the transient as steam flows into the drywell from the broken PCL pipe and as steam and non-condensable gas flows from the drywell into the wetwell. If the BWR design for the Low Pressure Core Injection (LPCI) system pumps water from the suppression pool to the PCL, then a FILL component can be set up to obtain fluid conditions for the liquid pool in the wetwell CONTAN compartment to simulate this behavior. The suppression liquid pool temperature could be changing during the transient as steam from the drywell is condensed in the suppression pool.



The pressure, temperature, void fraction, and non-condensable mass fraction calculated in a CONTAN compartment can be used as the boundary conditions in a TRACE BREAK component. The BREAK component given in Table 2-8 obtains it's pressure, temperature, void fraction, and non-condensable mass fraction from CONTAN compartment 52, since it uses IBTY = 7. The COMPID input is positive, which implies that the BREAK component will use the vapor space properties. If COMPID had been negative, then the BREAK component properties would have come from the liquid pool. The BDSPRAY = 0.9 implies that in the CONTAN compartment if any liquid flows back into the break, 90% of that liquid will reach thermal equilibrium with the CONTAN compartment vapor. If COMPID had been negative, then the BDCOND = 0.9 would have implied that 90% of the vapor injected into the BREAK component would be in thermal equilibrium with the liquid pool. If the BREAK component input in Table 2-8 was included in a TRACE model with the CONTAN component input in Table 2-4, then the initial TRACE BREAK pressure would be 3.03 bars with a non-condensable gas partial pressure of 1.013 bars and a vapor phase temperature of 500 K. The void fraction in the BREAK component would be one. As the pressure, temperature, and non-condensable mass fraction

changes as the CONTAN compartment solution advances, then the TRACE BREAK component fluid conditions change as well.

**Table 2-8. Example Input for BREAK Component Type 7.**

```
*******   type            num             id        ctitle
break                     702              702 bkn-loop containment break
*         jun1           ibty           isat           ioff
            802              7              0              0
*         dxin           volin          alpin           tin            pin
    3.0000e-01     9.0000e-02     0.0000e+00     3.0000e+02     1.030e+05
*         pain          concin           rbmx          poff           belv
    0.0000e+00     0.0000e+00     0.0000e+00     0.0000e+00     0.0000e+00
*        compid
         52
*        bdspray         bdcond
         0.9             0.9
```

The pressure, temperature, void fraction, and non-condensable gas fraction calculated in a CONTAN compartment can be used as the fluid conditions in a TRACE FILL component. The example input in Table 2-9 uses a CONTAN compartment for fluid conditions in the FILL since IFTY < 0. For this example, the CONTAN compartment ID is 51 (i.e., COMPID = -51). Since COMPID < 0, the FILL component will obtain its fluid conditions from the liquid pool in compartment 51. The input for BDCOND = 0.9 implies that if the flow is into the FILL and includes vapor phase, then 90% of the vapor phase will be in thermal equilibrium with the liquid pool in the CONTAN compartment. If the example input in Table 2-9 was used with the sample input in Table 2-4, then the initial pressure for the FILL component would be 1.013 bars and the liquid phase temperature would be 300 K. The void fraction for the FILL component would be zero, since it is connected to the liquid pool in CONTAN compartment 51.

**Table 2-9. Example Input for FILL Component Type 7.**

```
*******   type            num             id        ctitle
fill                      701              701 $701$ int-loop hpis & lpis
*         jun2           ifty           ioff
            803             -4              0
*         iftr           ifsv           nftb           nfsv           nfrf
              0              1              4              0              0
*       twtold          rfmx         concin          felv
    0.0000e+00     1.0000e+05     0.0000e+00     0.0000e+00
*        compID
           -51
*      bdspray         bdcond
            0.9            0.6
*         dxin          volin          alpin          vlin           tlin
    3.0000e-01     9.0000e-02     0.0000e+00     0.0000e+00     4.000e+02
*          pin           pain         flowin          vvin           tvin
      1.05e+05     0.5000e+05     0.0000e+00     0.0000e+00     4.000e+02
*         vmscl          vvscl
    1.0000e+00     0.0000e+00
* vmtb  *     0.0000e+00   0.0000e+00    1.0000e+01   5.0000e-01    5.1000e+01
* vmtb  *     5.0000e-01   1000.0        5.0000e-01e
```

# *EXTERIOR Component*



The EXTERIOR component is a key element of the Exterior Communications Interface (ECI) and running TRACE in a multi-tasking (parallel) mode. It provides the linkage between different pieces of a simulation model that have been separated for running in different processes across one or more physical processors. It may help you to conceptualize the EXTERIOR component as basically just abbreviated information for a "component" that is modeled on an exterior process with which one or more components in this process must communicate.. This is not necessarily the whole story in terms of how an EXTERIOR component may be applied, but it should help you to understand how it functions, at least initially.

We put quotes around the word component, because when we talk about needing to communicate with a "component" on an exterior process, we don't *necessarily* mean a TRACE component (as in a PIPE, TEE, VALVE, etc). While the most straightforward use of the EXTERIOR component is to break an existing TRACE simulation into separate pieces by running multiple instances of TRACE across multiple processes, it is, by no means, the only application. The EXTERIOR component affords you the ability to connect TRACE to more detailed models or programs designed to focus on one particular aspect of your simulation. Examples would include containment models, a CFD code, a core make-up tank model (like REMIX), or any other computer program which may require data from TRACE. The only prerequisite is that the external program has been modified to allow it to communicate with TRACE.

The use of the EXTERIOR component requires the creation of a file called **taskList**; this is where you define the network topology to be used for the simulation. Details regarding creation and use of the **taskList** file are provided in **Volume 1, Chapter 1**. One point worth noting here, however, is that EXTERIOR components are not a necessary prerequisite for initiating a multi-process run. It is, in fact, possible to have TRACE communicating with other programs or processes without needing to define EXTERIOR components in your input model. Examples of this type of simulation are provided in the HTML-based ECI training material on the TRACE release CD.



## *Specifying the EXTERIOR Input*

After you have defined the interprocess boundaries for your multi-process simulation, as discussed in **Volume 1, Chapter 1**, the next step is to split the model into separate pieces and insert one or more EXTERIOR components at the breakpoints of those models. Of course, if the satellite process is not a TRACE process, but some other more detailed modeling program, use of an EXTERIOR component in that program's input file would not be appropriate (but you would still need to define it in your TRACE input model).

In general, one EXTERIOR component is required for ***each component in a satellite process*** which must communicate with the current input model. The NJUNS parameter allows you to set the actual number of flow junctions that the component in the satellite model has with the current process. In most situations, NJUNS will simply be 1. Situations that might lead to NJUNS > 1

include connections to a VESSEL component, or connections to a TEE or PIPE with side junctions (in which two or more of the side connections cross the interprocess boundary).

When defining an EXTERIOR component, you also need to define the nature of the interprocess connection. The COMPTYPE input variable allows you to do this. While this parameter seems to offer you a choice in defining the exact type of connection the EXTERIOR component should represent (i.e. fluid component, heat structure, power, etc), for all practical purposes, the only choice that holds any meaning is COMPTYPE = 1 (fluid component). A value of COMPTYPE = 2 is meaningless because it is no longer necessary to actually define an EXTERIOR component to represent the interprocess connections between a heat structure and fluid component; TRACE can automatically generate an ECI search for missing heat structure connections to fluid components. Values of COMPTYPE = 3 or 4 are simply not implemented.

For each exterior junction included in the NJUNS count, you must supply a JUNNUM value (via separate instances of Card Number 4) to identify its user-assigned ID number on the satellite process (that value must match on both processes).

The NDIM, NX, NY, NZ, JUNIX, JUNIY, JUNIZ, and JUNFACE parameters have not been thoroughly tested so they really do not serve a useful purpose at this point. They represent an attempt to account for coupling scenarios where it is not natural, in the satellite process, to think in terms of junction numbers, as we do in TRACE. This might become an issue, for example, if we were to try to couple TRACE to a CFD code. In cases where the EXTERIOR component represents another TRACE component on a satellite process, we recommend simply setting all the above values 1, when the parameter is even necessary. This even holds true for NDIM when the EXTERIOR component represents a TRACE 3D VESSEL.

Use of EXTERIOR components has one other level of complexity. One task in the multi-task calculation must be designated as the "central" process. It will have the responsibility for sorting out the task-to-task fluid flow path topology. As a result, if your simulation includes two or more satellite processes that communicate with each other directly, the input for the central task must include one extra EXTERIOR component with NJUNS = 0.



## *Example Showing Use of the EXTERIOR Component*

This example illustrates how one might go about splitting a model for simulation across multiple processes. The mesh topology is contrived specifically to illustrate the various circumstances under which an EXTERIOR component may be needed, and what one should input for the NJUNS and JUNNUM input variables. The nodalization for this problem is shown in Figure 2-19. In the original model appearing at the top, you should take note of the fact that junctions 3 and 4 represent connections between the same two components, but junctions 5 and 6 represent connections between three separate compoents. This detail does become important in terms of the number of EXTERIOR components required and how the NJUNS and JUNNUM parameters are set. .

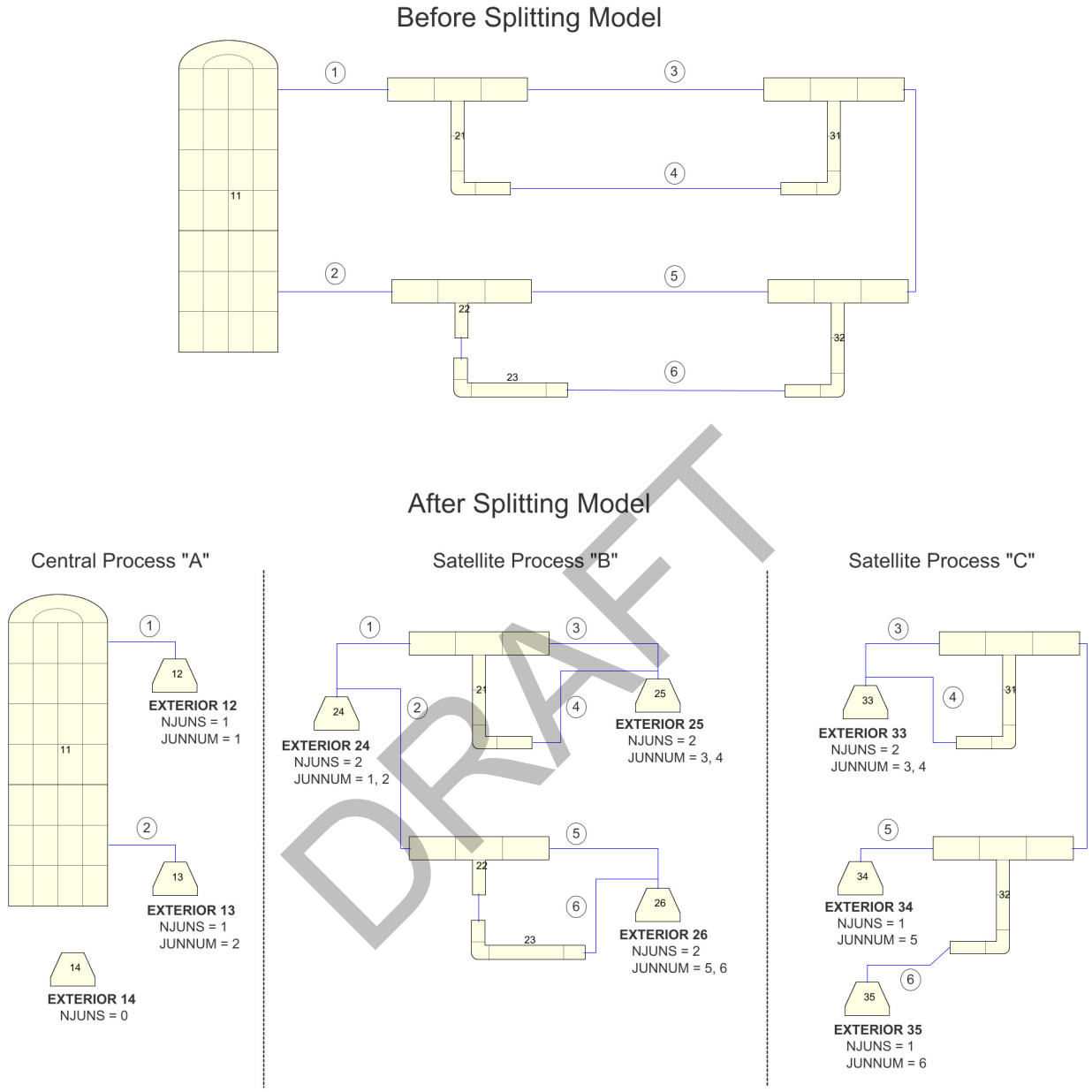


Figure. 2-34. EXTERIOR-component Example Problem.

The bottom half of the figure shows how the model has been split for multi-task operation. We have chosen to split the model into three different pieces — we shall run the VESSEL component on the central process, and allocate the remaining components across two additional satellite processes. Junctions 1 & 2 define the boundary between the central process "A" and satellite process "B" and junctions 3 through 6 define the boundary between satellite processes "B" and "C".

Remember that an EXTERIOR component represents all the junctions on the other side of the process boundary that belong to a single component. This means that the input model for process "B" only requires three EXTERIOR components (24, 25, 26) — one each to represent the junction pairs (1&2), (3&4), and (5&6), belonging to components 11, 31, and 32 respectively. In each of these cases, you would specify NJUNS = 2 and list the appropriate junction numbers on the JUNNUM cards. The same holds true for satellite process "C" with regards to the EXTERIOR component (33). It represents junctions 3 & 4, since they both belong to the same TEE component (21) on process "B".

The situation is a little different for junctions 5 & 6 on satellite process "C". In this case, since those junctions belong to two different components on process "B", process "C" requires two additional EXTERIOR components (34 and 35) — one for each junction. In this case, NJUNS = 1. The same reasoning holds true for junctions 1 & 2 on the central process.

At this point, you are probably wondering "What about EXTERIOR component 14 on the central process?". It is needed because the central process has the responsibility for sorting out the task-to-task fluid flow path topology, even for satellite-to-satellite process communications. You can think of it as representing all the flow paths between process "B" and "C" the the central process must establish communication paths for. Since it doesn't represent any one specific flow junction, we set NJUNS=0. Had we decided to make satellite process "B" the central process instead, that additional EXTERIOR component would not have been needed, since all communications would then be routed through the central process itself (and it would therefore know how to establish all the communication links needed by the simulation).



# *FILL Component*

The FILL component is used to impose boundary conditions at any 1D hydraulic component junction. Consequently, this component differs from the other hydraulic components in that it does not model any physical-system component, per se, and it does not perform any hydrodynamic or heat-transfer calculations; however, it is treated like any other component with respect to ID, input, and output.

A FILL component imposes a coolant velocity or mass-flow boundary condition at the junction with its adjacent component, as shown in Figure 2-35. For example, the ECC injection or secondary-side feedwater may be modeled with a FILL component.

The velocity or mass-flow boundary condition as well as its fluid properties are specified in one of three ways according to the FILL-type IFTY option selected. For the first type, the homogeneous fluid velocity and fluid properties are specified; for the second type, the homogeneous fluid mass flow and fluid properties are specified; and for the third type, nonhomogeneous fluid velocities and fluid properties are specified. For each type, the relevant parameters may be constant, interpolated from input FILL-component action tables, constant until a controlling trip is set ON to require their evaluation from their action tables, or defined by signal-variable or control-block signals. The independent variable of the FILL table's tabular data

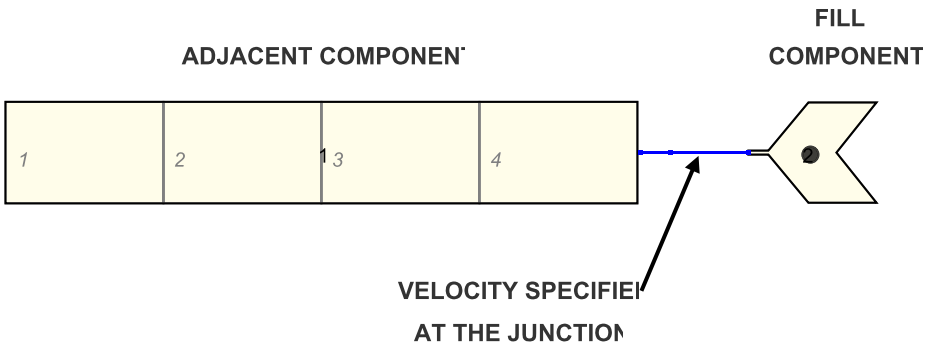


Figure. 2-35. FILL-component noding diagram.

is a signal-variable modeled-system parameter or a control-block output signal. When the FILL's coolant velocity or mass flow varies rapidly, using this value may lead to a hydrodynamic instability in the numerical solution. This can be avoided by using a TWTOLD-weighted average of the parameter's previous value and the current specified value or limiting the parameter's time rate of change by RFMX.

The input parameters needed to define the FILL component is described in Volume 1. The FILL component specified fluid pressure, gas volume fraction, fluid temperatures, non-condensable-gas partial pressure, and solute concentration in liquid define the properties of the fluid convected into the adjacent component if an inflow condition occurs. By convention, inflow to the adjacent component corresponds to a positive velocity at the FILL component's JUN1 junction. A FILL component may not be connected directly to a BREAK or PLENUM. It may be connected directly to a VESSEL component or a side junction in a 1D component.



# *FLPOWER Component*

This component, while available for use, is not currently supported by the NRC.

# *HEATR Component*

HEATR components can be used in TRACE to model the feedwater heaters and/or the main steam condensers, allowing specific modeling of balance-of-plant components that may play relevant roles in the analysis of a complete nuclear power plant. The HEATR component implemented in TRACE is inherited from the correspondent TRAC-B component and is essentially based on a TEE template, with additional special logic coded to treat opportunely the specific geometry and physical phenomena occurring in the shell side of the heat exchanger. A

HEATR is usually employed in combination with a PIPE and HTSTR for modeling of the two separate fluid paths of closed feedwater heaters. A typical modeling configuration is shown in Figure 2-36.

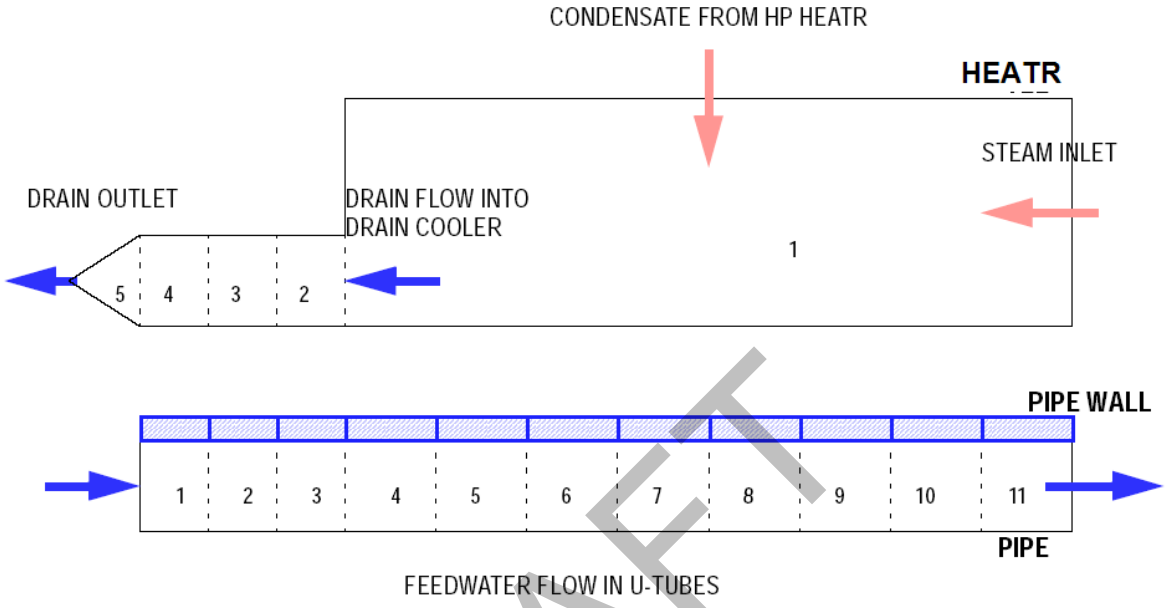


Figure. 2-36. TRACE modeling of a feedwater heater using a HEATR for the shell side and a PIPE for the tubes bank.



## *Applicability*

The TRACE HEATR component is inherited from the corresponding TRAC-B component and maintains its applicability field. Specifically, a HEATR can be used to model the shell (condensing) side of a closed-type feedwater heater, and is meant to be coupled to a PIPE and HTSTR to include modeling of the feedwater flow and heat transfer within the heaters.

A HEATR (or a series thereof) component can also be employed to model the main steam condensers, again in combination with a PIPE and HTSTR, which in this case would model the circulating cooling water.

More generally, a HEATR-PIPE-HTSTR combination can be employed in modeling closed-type heat exchangers (i.e., with no mass exchange between the hot and the cold paths), when the TRACE user desires to maintain detailed control over important operational features of the heat exchanger and specifically: the water level; the drain flow rate and geometrical details of the shell side. If such modeling detail is not sought, or if the need arises to model an open heat exchanger, then the use in combinations of regular TEE, PIPE and HTSTR components could be sufficient.

# *HEATR Configuration.*

The HEATR component is based on a TEE template and general modeling features are common between the two components. This section provides HEATR-specific information and practical guidelines for setting up the nodalization of the component and coupling it to a PIPE-HTSTR combination.



## *Orientation.*

As for regular components, the orientation of the HEATR is determined by the input GRAV cards. The user is advised that the input card IVERT (Word 1 input Card 5) is not used in the code, although it needs to be input.

## *Component Junctions.*

Being based on a TEE template, the HEATR allows and requires modeling of three junctions, for the shell side of a heat exchanger. When modeling a feedwater heater, the three junctions are meant to model: (1) the inlet steam (extraction steam from the main steam line); (2) the inlet condensate draining from a higher pressure (hotter) heater; and (3) the condensate draining out of the component. When modeling a steam condenser, the three junctions can be used to model (1) the inlet exhaust steam from the turbine; (2) the non-condensable gas extracted by the jet ejectors (for this purpose, a negative-velocity FILL could be employed)[1]; and (3) the feedwater outlet. If the user wants to use only two junctions (i.e., simply for the inlet and outlet of the hot fluid), then the third junction can be specified as a dead end.



## *Modeling the shell volume.*

The first cell of the HEATR component is specifically designed to model the shell volume of a closed heat exchanger, where a hot liquid-gas mixture condenses as heat is transferred to the liquid flowing inside the tubes on the cold water side. Thus, the user should specify the first HEATR cell as the joining cell (J-cell) of the component and input its geometry (DX, VOL and FA) according to the dimensions of the entire shell volume.

In order to further detail the configuration of the shell volume, the user can additionally include input tables SHLTB and LEVTB.

Table LEVTB allows detailed geometrical modeling of the shell volume. It is used to input data pairs of void fraction and collapsed liquid level data for the shell region. In practice this table defines the fraction of the shell volume occupied by the fluid as a function of a vertical coordinate. The shell liquid level is measured from the bottom of the shell volume. Therefore, the

1. This second junction could also be used to model another extraction steam from a turbine at a different stage, or inlet condensate draining from the hot side of the feedwater heaters.

data pair correspondent to [void fraction=1, level=0 (m or ft)] should always appear in the table. Likewise, the data pair [void fraction=0, level=total shell height] should always be in the table. If a linear variation occurs between those two extremes (as it would be the case for a vertical shell with constant cross-section area along the elevation), then no additional pairs are required for the input table, as the linear interpolation is calculated by the code automatically. If the variation of collapsed liquid level with the shell void fraction is non-linear (as it would occur for horizontal cylindrical shells, see Figure 2-37), then the user should consider specifying additional data pairs as needed.

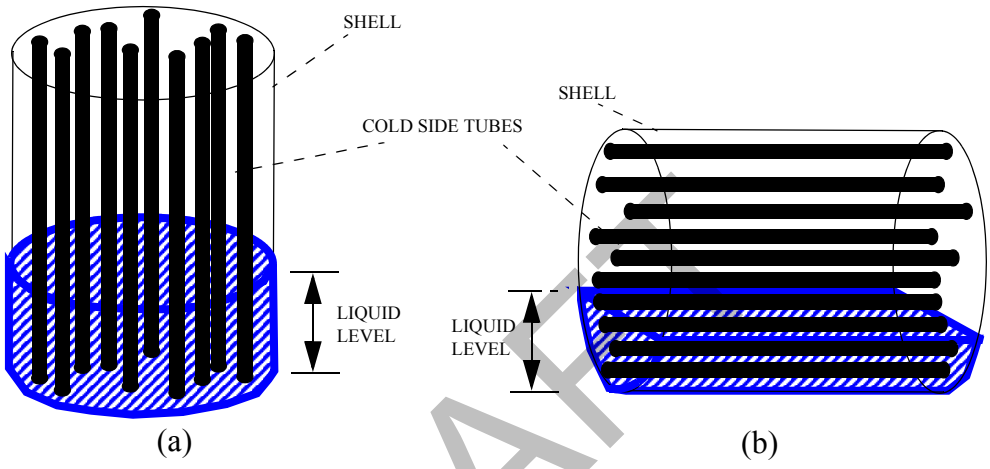


Figure. 2-37. Schematic of vertical (a) and horizontal (b) cylindrical shells with once-through straight tubes (for simplicity of representation). In (a), volume and area fractions vary linearly along a vertical coordinate (collapsed liquid level); the variation is non-linear in (b).



Table SHLTB allows for detailed specification of the geometrical distribution of the cold pipes inside the shell volume. It is used to input data pairs of shell void fraction and fraction of heat transfer area between the cold tubes and the liquid in the shell region. In other words, this table defines the area fraction of cold tubes that are wetted for a given shell void fraction, assuming stratification. When the shell volume is entirely occupied by steam, then the fraction of heat transfer area for the liquid is clearly zero. On the other hand, when the shell volume is entirely occupied by liquid, then the fraction of heat transfer area for the liquid is one. Thus, the data pairs [void fraction=0, liquid heat transfer area fraction=1] and [void fraction=1, liquid heat transfer area fraction=0] must appear in the table. If the variation of heat transfer area with the void fraction is linear, then no additional data pairs are needed. If the variation of heat transfer area with the void fraction is non-linear (e.g., for horizontal cylindrical configuration, see Figure 2-37), then the user should consider specifying additional data pairs as needed.

## *Modeling the drain cooler.*

The user is requested to specify in input (card IVPS) the junction location for the drain control valve. The junction that models the drain valve should fall within the drain cooler region and therefore, at least two cells should be employed to model the cooler region, so that the internal junction can be used to model the drain valve[1]. The user is requested to further input the fully-open valve area and hydraulic diameter and the initial fractional area (cards AVLVE, HVLVE and FAVLVE), while the task of adjusting the valve area during the calculation is usually achieved by using appropriately the code control system (card IVSV). Guidelines on controlling the drain valve area are given in a following section.

The location of the inlet to the drain cooler is specified with card HDCIN, in terms of elevation above the bottom of the shell volume. At every time step, the code compares this input elevation to the stratified liquid level in the shell and, if the liquid level is above the cooler inlet, then liquid only is admitted into the drain cooler region. This is the normal operating condition of the component. If, for any reason, during the calculation the liquid level falls below the drain cooler inlet, that steam only would be admitted into the drain cooler region. This is an anomalous situation.

Table NDCTB allows for detailed specification of the geometrical distribution of the cold pipes inside the drain cooler region, similarly to table SHLTB described before for the shell volume. Table NDCTB is used to input data pairs of drain cooler void fraction and fraction of heat transfer area between the cold tubes and the liquid in the cooler region. In other words, this table defines the area fraction of cold tubes that are wetted for a given drain cooler void fraction, assuming stratification. The same guidelines indicated before for table SHLTB and the shell region are also valid for table NDCTB.



## *Notes on the HEATR side arm.*

Since the first cell of the main branch should always be used as J-Cell for the component, the side arm of the HEATR is always connected to the first cell of the main branch. Depending on the user's intention, the side arm could either model an inlet drain from an upstream heater, or a second extraction steam inlet from a turbine stage, or the gas ejectors of a condenser. The geometry of the side arm should be input accordingly.

## *Modeling the cold water side.*

The cold side of a heat exchanger is to be modeled with a dedicated line of components, usually a PIPE and a HTSTR. The PIPE models the liquid path within the cold fluid side and the HTSTR models the pipe walls and the heat transfer from the hot to the cold side. Thus, the heat structure

1. This brings the minimum number of cells in the main branch of a HEATR to three: the first, large cell models the shell volume, while the second and third model the drain cooler region.

must be connected to fluid cells on both sides: the shell volume or drain cooler region on the hot side and the water pipes on the cold side.

The user is advised that input cards DTUBE and DBAFF, which would be relevant to the geometry of the cold tube banks and influence the heat transfer on the shell side, are not currently used in the code. They must, however, be input (as any real number).

## *HEATR Control*

The steady-state operation of a feedwater heater (or steam condenser) encompasses obtaining the right equilibrium, in the shell side, between the liquid level and the condensate drain flow rate. The TRACE user can control the HEATR operation, and achieve such equilibrium for the shell side, by controlling the drain valve flow area, with an opportune use of control blocks and signal variables. For this purpose, signal variable LIQLEV, available for the HEATR component, carries the current value of the shell liquid level. A typical control configuration would apply corrections to the drain control valve (card IVSV) as a function of the deviation of the liquid level and/or the drain flow rate from their set-point values.

# *HTSTR & REPEAT-HTSTR Component*



The HTSTR component evaluates the dynamics of conduction, convection, and gap-gas radiation heat transfer in a fuel-rod or structure hardware element. The pipe walls modeled by all other components are also evaluated by the HTSTR component. All fluid components (i.e., PIPE, TEE, JETP, etc.) that include input for a pipe wall, internally spawn one or more HTSTR components, which provide for the simulation of the conduction and convection from the pipe wall to the fluid. For user convenience, this pipe wall modeling capability has remained a part of the modeling capability provided by these fluid components, even though using the HTSTR component input provides the user with more flexibility and capabilities. A HTSTR component must be used to model both powered and unpowered elements in a VESSEL component. In all future modeling, the TRACE user is encouraged to use HTSTR components input for coupling heat structures (HS) to fluid components because of the flexibility and extended features that a HTSTR component provides. The HTSTR component is also referred to as the Heat Structure (HS) component.

The heat-transfer modeling in a HTSTR-component hardware element is in either cylindrical (r,z) or cartesian (x,z) or spherical (r,$\phi$) 2D geometry. The TRACE user selects the hardware-element geometry by specifying HSCYL = 0, 1, or 2 in the HTSTR component input (see Table 2-10, component number 900). HSCYL = 0 implies a slab or cartesian geometry, HSCYL = 1 implies a cylindrical geometry and HSCYL = 3 implies a spherical geometry.

The HTSTR-component hardware element has an inner surface and an outer surface. The inner surface for a HTSTR component is at the radius of the first radial node and the outer surface for a HTSTR component is at the radius of the last radial node for cylindrical geometry. The inner and outer surface HS boundary conditions (BC) must be identified for each axial level for a given HS

component. Figure 2-38 shows the 2D heat structure noding and the convective coupling to hydraulic cells at its inner and outer surfaces (perpendicular to the r or x direction). Table 2-10 shows the HTSTR component input for this double-sided heat structure. The number of r- or x-direction and z-direction nodes is defined by user input for NODES and NZHTSTR, respectively. If NODES = 1, a one-node lumped-parameter heat-transfer solution is evaluated in the x or r direction without axial heat transfer. Node rows defined through input are located on hydraulic-cell centers in the z direction. This implies that HS convective boundary heat transfer coefficients (HTCs) are evaluated based on cell center fluid properties. However, any number of HS axial levels can be associated with a single fluid cell.



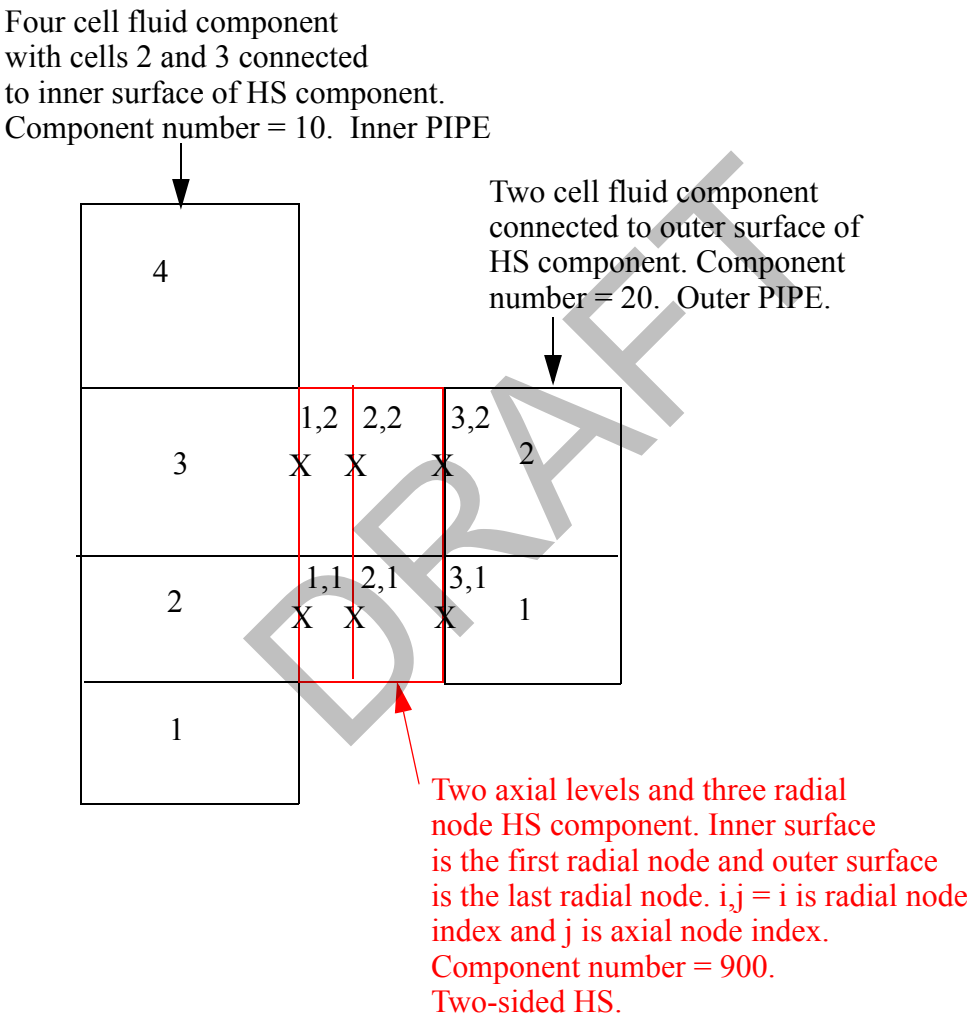




Figure. 2-38. HTSTR-component example with hydraulic-cell coupling on both the inner and outer surfaces (see Table 2-10 for HS input for this example)

The inner and outer surfaces are defined individually by one of thirteen different heat-transfer boundary conditions that are input specified by IDBCIN and IDBCON for each axial level (i.e., NZHTSTR) for a given HTSTR component. The IDBCIN and IDBCON are input for each axial level and for each axial level IDBCIN(k)/IDBCON(k) can be input as one of the following values:

- 0 - defines a constant heat flux heat-transfer surface. For each axial level with IDBCIN(k)/IDBCON(k) = 0, the surface heat flux is given in the QFLXBCI/QFLXBCO input. Note an adiabatic HS surface boundary condition is defined when QFLXBCI/ QFLXBCO = 0.0.
- 1 - defines a heat-transfer surface with input-specified constant-value HTCs and sink temperatures for the gas- and liquid-coolant phases that are heat-transfer coupled to the inner or outer surface. For each axial level with IDBCIN(k)/IDBCON(k) = 1, the HTC are input as HTCLIQI/HTCLIQO and the sink temperature is input as TFLUIDI/ TFLUIDO.
- 2 - defines a heat-transfer surface coupled to hydraulic-component cells that are input-specified; heat-transfer coefficients and temperatures are evaluated by the TRACE hydrodynamic solution for the gas- and liquid-coolant phases that are heat-transfer coupled to the inner or outer surface. For each axial with IDBCIN(k)/IDBCON(k) = 2, the fluid cell connected to the heat structure surface is input via HCOMIN/HCOMON, HCELII/HCELIO, HCELJI/HCELJO, and HCELKI/HCELKO.
- 3 - heat-transfer surface boundary conditions is heat flux specified via a general table. General table number is specified via the NUMBCI1/NUMCBCO1 input for each axial level where IDBCIN(k)/IDBCON(k) is equal to 3.
- 4 - heat-transfer surface boundary conditions is heat transfer coefficient and a sink temperature specified via two separate tables. General table numbers at each axial level for which are specified in the NUMBCI1/NUMBCI2 and NUMBCO1/NUMBCO2 input.
- 5 - heat-transfer surface boundary conditions is a fixed surface temperature. The surface temperature boundary condition for each axial level where IDBCIN(k)/IDBCON(k) is equal to 5 is input via the TSURFIN/TSURFON input.
- 6 - heat-transfer surface boundary conditions is a HTC and the sink temperature is from the TRACE solution for the coupled fluid cell for this heat structure surface. HTC tables are specified in the HTCLIQI/HTCLIQO input. For each axial with IDBCIN(k)/ IDBCON(k) = 6, the fluid cell connected to the heat structure surface is input via HCOMIN/HCOMON, HCELII/HCELIO, HCELJI/HCELJO, and HCELKI/HCELKO.
- 7 - heat-transfer surface boundary condition is the surface temperature. The surface temperature is specified via a signal variable or control block output. The ID for the SV/ CB is specified at each axial level where IDBCIN(k)/IDBCON(k) =7 via NUMBCI1/ NUMBCO1 input.)
- 8 - heat-transfer surface boundary condition is HTC specified via a signal variable (SV) or control block (CB). The fluid temperatures are calculated by the TRACE hydrodynamic solution. The SV/CB ID for each axial level where IDBCI(k)/IDBCO(k) = 8 is input via the NUMBCI1/NUMBCO1 input. For each axial with IDBCIN(k)/

IDBCON(k) = 8, the fluid cell connected to the heat structure surface is input via HCOMIN/HCOMON, HCELII/HCELIO, HCELJI/HCELJO, and HCELKI/HCELKO.

- 9 - heat-transfer surface boundary condition is sink temperature specified via a signal variable (SV) or control block (CB). The heat transfer coefficient is calculated by the TRACE HTC models. The SV/CB ID for each axial level where IDBCIN(k)/ IDBCON(k) = 9 is input via the NUMBCI1/NUMBCO1 input. For each axial with IDBCIN(k)/IDBCON(k) = 9, the fluid cell connected to the heat structure surface is input via HCOMIN/HCOMON, HCELII/HCELIO, HCELJI/HCELJO, and HCELKI/ HCELKO.
- 10 - heat-transfer surface boundary condition is a heat flux specified via a signal variable (SV) or control block (CB). The SV/CB ID for each axial level where IDBCIN(k)/ IDBCON(k) = 10 is input via the NUMBCI1/NUMBCO1 input.
- 11 - heat-transfer surface boundary condition is a surface temperature specified via a general table. The general table number for each axial level where IDBCIN(k)/ IDBCON(k) = 11 is input via the NUMBCI1/NUMBCO1 input.
- 12 - heat-transfer surface boundary condition is a heat flux specified via a general table. The general table number for each axial level where IDBCIN(k)/IDBCON(k) = 12 is input via the NUMBCIN/NUMBCON input.

Note that only for HS BC options 2, 6, 8, and 9 will the HS surface heat flux be transferred to a fluid cell defined by HCOMIN/HCOMON, HCELII/HCELIO, HCELJI/HCELJO, and HCELKI/ HCELKO. All other HS BC options do not involve heat transfer to a fluid cell. In general, a definition of the surface temperature or a surface heat flux or a surface heat transfer coefficient and sink temperature eliminates any heat transfer to a fluid cell.

The IDBCIN = 2 and IDBCON = 2 boundary condition provides the TRACE user with the capability to couple any two hydraulic cells within the modeled system with a conduction and surface-convection heat-transfer path. Any number of heat structure surfaces can be coupled to a given hydraulic cell. When IDBCIN = 2 is input for a given axial level, then for that axial level HCOMIN, HCELII, HCELJI, and HCELKI must be input (see Table 2-10). When IDBCON = 2 is input for a given axial level, then for that axial level HCOMON, HCELIO, HCELJO, and HCELKO must be input. HCOMIN/HCOMON identified the fluid component number associated with the convective boundary condition. If the fluid component is a 1D component, then HCELII/HCELIO is the 1D fluid component cell index. HCELJI/HCELJO and HCELKI/ HCELKO must be input, but are ignored for 1D fluid components. If HCOMIN/HCOMON points to a 3D fluid component, then i,j,k index for the 3D fluid component must be input via the HCELII/HCELIO, HCELJI/HCELJO, and HCELKI/HCELKO.

The ITTC, LIQLEV, and DTXHT(1:2) inputs are currently not used. The ICHF input selects the critical heat flux model to be used with this HS component. The available options are

0 = convection heat transfer only, no boiling heat transfer (i.e., no wall nucleation is allowed although phase change can still occur);
1 = CHF from AECL-IPPE CHF Table, no critical quality calculated.
2 = CHF from AECL-IPPE CHF Table, critical quality from Biasi correlation.

3 = CHF from AECL-IPPE CHF Table, critical quality from CISE-GE correlation.

When ICHF is input as zero, then only convective heat transfer is calculated with no nucleate boiling or boiling transition allowed. ICHF input as zero, would be appropriate for a pipe wall that is not heated, but represents a heat transfer path to the environment and during the transient the fluid conditions on the inside of the PIPE is either all steam or all liquid (i.e., no significant boiling or condensation heat transfer).

If ICHF is greater than 0, then the full boiling curve is used to calculate heat transfer coefficients and a critical heat flux is calculated based on the AECL-IPPE CHF Table. If ICHF is greater than 1, the in addition to the AECL-IPPE CHF Table, a dryout critical quality is calculated based on a boiling length correlation (i.e., based on Biasi for ICHF = 2 and based on CISE-GE for ICHF = 3). Boiling length correlations tend to be more accurate than a local conditions critical heat flux correlation for high quality, high mass flux conditions which tend to introduce memory effects when the heat flux is nonuniform for BWR applications (Ref. 2-12). The boiling length correlations essentially take into account the history or total amount of energy added to the two-phase mixture upstream from the dryout point.

The Biasi correlation (Ref. 2-13) is based on a larger data base including mass fluxes from 100 $kg/m^2$-s to 6000 $kg/m^2$-s and in general tends to be less conservative than CISE-GE. The original Biasi CHF correlation is converted to a boiling length correlation in Reference 2-14. CISE-GE is based on rod bundle data for 7x7 and 8x8 fuel assemblies and includes local power peaking effects. Mass flux data range for CISE-GE is 300 $kg/m^2$-s to 1400 $kg/m^2$-s. For the CISE-GE correlation (i.e., ICHF = 3), when the mass flux is between -700 $kg/m^2$-s and 300 $kg/m^2$-s or if the flow is counter-current, then the critical dryout quality defaults to one and boiling transition will be based solely on the AECL-IPPE CHF Table. If ICHF = 3, and the mass flux is greater than 300 $kg/m^2$-s or less than -700$kg/m^2$-s, then boiling transition can occur if the local heat flux is above the critical heat flux obtained from the AECL-IPPE CHF Table or if the steam quality is above the critical dryout quality predicted by the CISE-GE boiling length correlation. If ICHF = 2 and the mass flux is greater than 300 $kg/m^2$-s and co-current, then boiling transition can occur if the local heat flux is above the critical heat flux obtained form the AECL-IPPE CHF Table or if the steam quality is above the critical dryout quality predicted by the Biasi boiling length correlation.

An input of NOFUELROD = 1, implies that this HS is a non-fuel rod HS. When a HS component input is not a fuel rod, then the required input is reduced. The plane input determine which flow direction is parallel to the HS axial direction when the HS surface (i.e., inner/outer) is connected to a 3D fluid component. For the example in Table 2-10, the plane input is ignored, since this HS references two 1D fluid components (i.e., PIPE components 10 and 20; the IDBCIN/IDBCON HCOMIN/HCOMON input variables).

Heat transfer is evaluated implicitly in the r or x direction and explicitly (NAMELIST-input NRSLV = 0 option default) or implicitly (NRSLV = 1 input) in the z or $\phi$ direction when the HTSTR-component axial-conduction input parameter IAXCND = 1. If IAXCND = 0 is input, then TRACE does not evaluate axial-conduction heat transfer.

Input of NMWRX equal to one, turns on the metal water reaction model for this HS component. The metal-water reaction model simulates the oxidation of the zirconium cladding that occurs at relatively high temperatures (i.e., > 1273.15 K). If NMWRX is input as one and if the surface temperature of a given HS surface temperature is above 1273.15 K, then the following zirconium-steam exothermic reaction is simulated:

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2 + heat \tag{2-46}$$

The reaction-rate equation is based on References 2-20 and 2-22 and assumes a sufficient supply of steam and is given below:

$$\tau \cdot \frac{d\tau}{dt} = \eta_1 \cdot e^{\left(-\frac{\eta_2}{T}\right)} \tag{2-47}$$

where $\tau$ is the total oxygen consumed (kg/m$^2$), $\eta_1$ = 16.8 kg$^2$/m$^4$s, and $\eta_2$ = 2.007x10$^4$ K. The kinetic parameter is converted to an effective zirconium-oxide layer thickness according to:

$$1.5 \cdot (R_0 - r) = \frac{\tau}{0.26 \cdot \rho_{ZrO_2}} \tag{2-48}$$

where $r$ is the reacting surface radius (m), $R_0$ is the cladding outer radius (m), and $\rho_{ZrO_2}$ is the density of zirconium oxide (kg/m$^2$), which is approximated to be $0.9 \cdot \rho_{Zr}$. The method outlined in Reference 2-20 is used to solve for the zirconium-oxide penetration depth and the associated heat source. The heat source is added to the cladding of the fuel rods at the appropriate coarse mesh axial location and the total hydrogen generated is calculated.

Input of zero for NFCI and NFCIL turn off the pellet-cladding gap conductance model. If namelist input ITHD is zero, then HDRI and HDRO (i.e., inside/outside HS surface thermal diameter) are ignored and the fluid component hydraulic diameter is used as the thermal diameter in the TRACE HTC correlations. If namelist input ITHD is one, then HDRI and HDRO must be greater than zero, if the inside/outside surface HS boundary condition (BC) option is convective. HDRI/HDRO is the thermal diameter that will be used in the heat transfer correlations for the fluid heat transfer coefficients (HTC) for heat transfer from the wall to the fluid for a convective BC option.

Input of zero for NHOT implies that there will no hot rod HS components associated with this HS component. A hot rod HS component has the same geometry as the HS that it is associated with and sees the same HS BCs and fluid conditions, but is at a different power level. In addition, the heat flux from a hot rod component is not transferred from the hot rod to the fluid component.

Input of zero for FMON and REFLOODON, turns off the fine mesh option and reflood heat transfer models. The input for NFAX, NZMAX, DZNHT, and HGAPO are ignored for the example in Table 2-10, since it is a non-fuel rod HS with fine mesh turned off.

**Table 2-10. Two-Sided Heat Structure Example**

```
*************************************************************************
*         type           num            id        ctitle
         htstr           900           900 $900$ 2-sided HS
*      nzhtstr          ittc         hscyl          ichf
              2             0             1             1
*    nofuelrod         plane        liqlev        iaxcnd
              1             2             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
              1             0             0         0.000         0.000
*         nhot         nodes          fmon         nzmax     refloodon
              0             3             0             2             0
*     dtxht(1)       dtxht(2)         dznht         hgapo
            3.0           10.0          0.01           0.0
* idbcin*  2   2  e
* idbcon*  2   2  e
*        hcomi         hcelii        hcelji        hcelki
              10             2             0             0 e
              10             3             0             0 e
*        hcomo         hcelio        hceljo        hcelko
              20             1             0             0 e
              20             2             0             0 e
* dzhtstr * f   1.0e+00e
* rdx     *  f   5000.0 e
* radrd   *  i1 .008  .009 e
* matrd   *  f 12 e
* nfax    *  f 1 e
* rftn    *  f 549.3 e
```



The DZHTSTR array is input as the axial height for each axial level for the HS component. For the example in Table 2-10 the axial level heights are 1 m each for two axial levels. The RDX input is essentially a scale factor that allows the total HS surface area and HS volume to be calculated based on the geometry for a single HS element. For this example, there are 5000 (i.e., rdx = 5000) actual HS elements represented by HS component number 900. Each individual HS element is cylindrical geometry with an inside radius of 0.008 m and an outside radius of 0.009 m (see the RADRD input variable) and a total axial height of 2.0 m (see dzhtstr input). The total inside surface area for HS component 900 for the example in is $2*\pi*0.008*2*5000 = 502.33$ m$^2$. The total outside surface area for HS component 900 for this example is $2*\pi*0.009*2*5000 = 565.49$ m$^2$. The total volume for HS component 900 is $\pi*(0.009^2–0.008^2)*2*5000 = 0.534$ m$^3$. According to Table 2-11, the material type for this HS is inconel. Note that in general the material type identification number (i.e., MATRD) is input for each material type region between the radial nodes where HS temperature is calculated. Therefore, if NODES = 3, then there will be two regions (i.e. NODES-1 = 2) for which material type identification numbers must be input.

**Table 2-11. Material Type Index**

| Material Type Index | HS Material |
|---|---|
| 1 | mixed oxide |

**Table 2-11. Material Type Index**

| Material Type Index | HS Material |
|---|---|
| 2 | zircaloy |
| 3 | fluid-clad gap gases |
| 4 | boron-nitride insulation |
| 5 | constantan/ Nichrome heater wire |
| 6 | stainless steel, type 304 |
| 7 | stainless steel, type 316 |
| 8 | stainless steel, type 347 |
| 9 | carbon steel, type A508 |
| 10 | inconel, type 718 |
| 11 | zircaloy dioxide |
| 12 | inconel, type 600 |



If the fine mesh is off, for this HS, then NFAX (i.e., number of permanent fine mesh axial levels per coarse mesh axial level) is ignored. If fine mesh is on, then NZMAX must be greater than the sum of NFAX over the number of axial levels plus two.

$$NZMAX \geq 2 + \sum_{i=1}^{NZHTSTR} NFAX(i) \tag{2-49}$$

If NZMAX is input too small to included all of the permanent fine mesh axial levels, then TRACE will issue a warning message and increase the size of NZMAX and re-allocate the fine mesh arrays to be consistent with the modified NZMAX variable. The RFTN input is the initial temperature distribution for this HS component. Since this is a non-fuel rod HS, then no additional input is required.

An example HS input for a fuel rod is given in Table 2-12. Note NOFUELROD is input as zero, which implies this input is for a fuel rod HS and additional fuel rod related input will be required as compared to the non-fuel rod input in Table 2-10. The example in Table 2-12 is a cylindrical fuel (i.e., HSCYL = 1), with five axial coarse mesh axial levels (i.e., NZHTSTR = 5), and eight radial nodes (i.e, NODES = 8). The inner radius for this HS input (i.e., RADRD(1)) is zero, therefore this is a solid cylindrical fuel rod. The inner surface is the center line of the solid cylindrical fuel rod and therefore will have an adiabatic HS BC (i.e., IDBCIN = 0, with QFLXBCI = 0.0). In this case the HS outer surface BC is convective at all axial levels (i.e., IDBCON = 2) and the fluid component number associated with this outer surface is one (i.e., HCOMON = 1) and the 1D fluid cells are 1 through 5 for HS levels 1 through 5.

The total height for this HS is 3.6576 m (i.e., sum of the DZHTSTR array input). The number of actual fuel rods represented by this fuel are is 39,372 (i.e., rdx = 39372). There are four radial material regions in the fuel pellet (i.e., MATRD(1:4) = 1) and fuel rod gap is the fifth radial region (i.e., MATRD(5) = 3) and the last two radial regions are cladding (i.e., MATRD(6:7) = 2). Note that MATRD array is input for the material type between the radial nodes. Therefore, if there are 8 radial temperature nodes (i.e., NODES = 8), then there are 7 (i.e., NODES - 1 = 7) material type regions between the temperature nodes. In general the HS temperatures are calculated at the material type boundaries between the radial material type regions and at the inner and outer surface for a HS component.

Since NFCI is input as one for this example HS input, the gas gap conductance will be calculated based on the TRACE pellet-cladding gap conductance model, once per time step (i.e., NFCIL = 1). The user input for HGAPO will be ignored. If NFCI was input as zero, then the HGAPO input would be used for the pellet-cladding gap heat transfer coefficient, which would be applied as a constant for all axial levels.

This initial temperature distribution (i.e., RFTN) is input for each of the 8 radial nodes for each of the 5 axial levels starting with radial node number 1 for the first axial level. The first 8 values input for the RFTN array is the radial temperature distribution for the first axial level. There will be a total of 40 temperatures (i.e., 8x5 = 40) input for this example for the rftn array. Note that if fine mesh was turned on for this HS, then fuel rod temperatures at the very bottom and top of the HS would also have to be input. If fine mesh was turned on then this HS would require 56 temperatures to be input (i.e., 8 x (5+2) = 56). The extra axial levels at the top and bottom of the HS are required when fine mesh is turned on to ensure accurate calculation of the timing of the formation of a quench front at the top or bottom of the HS. Depending upon the axial power profile and fluid conditions just prior to the appearance of a quench front, the very top and bottom edges of the HS can be at significantly different temperature than the first coarse mesh axial level.

The additional fuel rod input (i.e., FPUO2, FTD, etc.) is defined in Volume I for the HTSTR component.

**Table 2-12. Fuel Rod HTSTR Example.**

```
*******   type           num            id        ctitle
htstr                      4             4 powered rod
*      nzhtstr          ittc         hscyl          ichf
```

```
              5              0              1              1
*     nofuelrod          plane         liqlev         iaxcnd
              0              3              0              0
*         nmwrx           nfci          nfcil          hdri           hdro
              0              1              1            0.0            0.0
*          nhot          nodes           fmon          nzmax      refloodon
              0              8
*      dtxht(1)       dtxht(2)          dznht          hgapo
            3.0           10.0            0.0         6000.0
* idbciN * f 0 e
* idbcoN * f 2 e
* qflxbci *
     0.0  e
     0.0  e
     0.0  e
     0.0  e
     0.0  e
*   idbcoN  hcomoN   nhcelio   nhceljo   nhcelko
              1        1         0          0e
              1        2         0          0e
              1        3         0          0e
              1        4         0          0e
              1        5         0          0e
* dhtstrz *  5.5180e-01  6.4000e-01  7.3000e-01    9.1000e-01    8.2580e-01e
* nrdx  *     3.9372e+04e
* radrd *     0.0000e+00    2.3225e-03    3.2845e-03    4.0227e-03    4.6450e-03
* radrd *     4.7400e-03    5.0500e-03    5.3600e-03e
* matrd * r04           1              3r02           2e
* nfax  * f   0 e
* rftn  *    6.5100e+02    6.4200e+02    6.3300e+02    6.2400e+02    6.1500e+02
* rftn  *    5.9790e+02    5.8080e+02    5.7800e+02    7.6800e+02    7.4300e+02
* rftn  *    7.1800e+02    6.9300e+02    6.6850e+02    6.2860e+02    5.8870e+02
* rftn  *    5.8180e+02    8.3310e+02    7.9810e+02    7.6310e+02    7.2810e+02
* rftn  *    6.9560e+02    6.4510e+02    5.9550e+02    5.8540e+02    8.3020e+02
* rftn  *    7.9620e+02    7.6220e+02    7.2820e+02    6.9570e+02    6.4610e+02
* rftn  *    5.9660e+02    5.8770e+02    7.6460e+02    7.4300e+02    7.1800e+02
* rftn  *    6.9300e+02    6.7010e+02    6.2860e+02    5.9430e+02    5.8770e+02 e
* fpuo2 *     0.0000e+00e
* ftd   *     9.4000e-01e
* gmix  *     9.4700e-01    5.0000e-03    3.4000e-03    6.0000e-04    0.0000e+00
* gmix  *     4.4000e-02    0.0000e+00e
* gmles *     0.0000e+00e
* pgapt *     7.3430e+06e
* plvol *     0.0000e+00e
* pslen *     0.0000e+00e
* clenn *     0.0000e+00e
* burn  * f   1.0000e+03e
```



An example input that includes all of the available HS BC options is given in Table 2-13. The HS in Table 2-13 is a two-sided HS with seven axial levels. Each axial level inside and outside surface BC are different, except for the six and seven axial levels for the outside surface which both use IDBCO = 12 (see the IDBCIN and IDBCON array input in Table 2-13). When IDBCIN = 0, then the boundary condition heat flux must be input for that axial level (see input for first axial level inside surface).

**Table 2-13. HS BC Example**

```
*****************************************************************************
*         type           num            id        ctitle
         htstr           900           900 $900$ 2-sided HS Test idbc options
*      nzhtstr          ittc         hscyl          ichf
              7             0             0             1
*    nofuelrod          plane         liqlev         iaxcnd
              1             2             0             1
*         nmwrx           nfci          nfcil          hdri           hdro
              1             0             0         0.000          0.000
```

```
*        width
           1.0
*         nhot          nodes          fmon         nzmax     refloodon
             0              3             0            21             0
*     dtxht(1)       dtxht(2)         dznht         hgapo
            3.0           10.0          0.01           0.0
* idbcin*   0   1  2  3  4 s
            5   6  e
* idbcon*   7   8  9 10 11 s
           12  12  e
*
*  bc inner surface axial level 1 idbcin = 0
*  constant heat flux BC
*      qflxbci
      -9.0e+05e
*
*  bc inner surface axial level 2 idbcin = 1
*  HTC and sink temperature BC
*      htcliqi       tfluidi
       40000.0         550.0e
*
*  bc inner surface axial level 3 idbcin = 2
*  Convective BC
*       hcomin        hcelii        hcelji        hcelki
            10             3             0             0 e
*
*  bc inner surface axial level 4 idbcin = 3
*  heat flux general table BC
*       numBCI - general table number for heat flux table.
           100e
*
*  bc inner surface axial level 5 idbcin = 4
*  HTC and sink temperature general tables BC
*      numBCI1       numBCI2
            200           300e
*
*  fixed surface temperature BC.
*  bc inner surface axial level 6 idbcin = 5
*       tSurfI
         550.0e
*
*  bc inner surface axial level 7 idbcin = 6
*  HTC bc with sink temperatures determined from TRACE fluid cell.
*      htcliqi       htcvapi        hcomin      hcelii  hcelji hcelki
       20000.0           0.0          10.0         7.0  f 0.0 e
*
*  bc outer surface axial level 1 idbcon = 7
*  HS surface temperature determined from control block id = -1
*       numBCO
            -1e
*
*  bc outer surface axial level 2 idbcon = 8
*  HTC BC from control block id = -2 and fluid temperature from TRACE model.
*       numBCO        hcomon        hcelio       hceljo hcelko
            -2            20             2       f 0 e
*
*  bc outer surface axial level 3 idbco = 9
*  Sink temperature from control block id = -3 and HTC from TRACE models.
*       numBCO        hcomon        hcelio       hceljo hcelko
            -3            20             3       f 0 e
*
*  bc outer surface axial level 4 idbco = 10
*  Heat flux from control block id = -4.
*       numBCO
            -4e
*
*  bc outer surface axial level 5 idbco = 11
*  Surface temperature BC is from general table 400.
*       numBCO
           400e
*
*  bc outer surface axial level 6 and 7 idbco = 12
```

```
*  HTC from general tables 500 and 600 with sink/fluid temperatures
*  from TRACE solution.
*       numBCO        hcomon        hcelio       hceljo hcelko
           500            20             6       f 0 e
           600            20             7       f 0 e
*
* dzhtstr * f   0.1e
* rdx    *  f   5000.0 e
* radrd  *  i1 0.0  0.1 e
* matrd  *  f 12 e
* nfax   *  f 1 e
* rftn   *  f 549.3 e
```

A negative heat flux boundary condition is energy transfer into a HS and a positive heat flux boundary condition is energy transfer from the HS. When a heat flux has been specified for a given HS boundary condition (i.e., surface and axial level) there is no energy transfer to or from a fluid cell. The specified heat flux is assumed to be to the environment surrounding the TRACE model.

Axial level 4 has IDBCIN = 3 (i.e., a heat flux BC table) and IDBCON = 10 (i.e., a heat flux BC signal variable/control block), which would normally be an incomplete set of boundary conditions for axial level 4. In general there are an infinite number of HS radial temperature distributions which will satisfy a inner and outer surface heat flux BC. However, since axial condition has been turned on for this HS component (see IAXCND input), there should be only one radial temperature distribution that satisfies both the inner and outer surface heat flux BC and the axial temperature distribution consistent with steady-state axial condition. In general, heat flux BC specified on both the inner and outer surfaces for a given HS axial level should be avoided.

For this example (i.e., Table 2-13), HSCYL has been set to zero (i.e., slab or cartesian geometry). Therefore, the inside surface area is the same as the outside surface area. The total inside/outside surface area is dzhtstr(k)*width*rdx(1) = 0.1*1.0*5000 = 500 $m^2$. That implies that an inner surface boundary condition of -30,000 w/m2 and an outside surface boundary condition of 30,000 w/m2 would result in a linear temperature profile across that HS at steady-state such that -k(dT/dx) = 30,000, assuming constant conductivity across the HS and ignoring axial conduction.

The HTSTR input given in Table 2-14 is for a hemi-spherical shell HS component (i.e., HSCYL = 2) with an inner radius of 2m and a thickness of 0.1m. The inner HS BC condition is convective to 3D VESSEL component number 2 at ijk cells 2,1,1 and 2,1,2. The outer surface temperature is fixed HTC = 10 and a fixed sink temperature of 300K.

**Table 2-14. Spherical HS Example**

```
*******   type            num             id        ctitle
htstr                       1              1 powered-spherical HS
*      nzhtstr          ittc          hscyl           ichf
             2             0              2              1
*    nofuelrod         plane         liqlev         iaxcnd
             0             2              0              0
*        nmwrx          nfci          nfcil           hdri          hdro
             0             0              0        0.25231       0.35231
*       dTheta (multiples of pi)
          2.0
*        nhot          nodes          fmon           nzmax      refloodon
             0             3              0               0              0
```

```
*     dtxht(1)      dtxht(2)         dznht         hgapo
    5.0000e+00    1.0000e+01    5.0000e-02    0.0000e+00
* idbciN * 2 2e
* idbcoN * 1 1e
*      hcomiN        hcelii         hcelji        hcelki
             2             2              1             1e
             2             2              1             2e
*     htcLiqo       tfluido
         10.0         300.0e
         10.0         300.0e
* dzhtstr * f 1.0 e
* rdx   *     1.0e
* radrd * 2.000  2.05  2.10e
* matrd * f            51e
* nfax  * f            0e
* rftn  * f   5.5000e+02e
```

A specific example of the coupling of an HTSTR component that models reactor fuel rods to the core region of a 3D VESSEL component is given in **Appendix B,** *W4LOOP Test Problem* (see VESSEL component 1 and HTSTR components 140, 171, 172, and 173). The noding for the VESSEL component in this model is 7 axial levels with 2 radial rings and 4 theta sectors. The fuel rod HTSTR components are component numbers 140, 171, 172, and 173.

HTSTR component 140 is located in ring one first theta in axial levels 3, 4, 5 for the VESSEL component (see Table 2-15 input for HCOMON, NHCELIO, NHCELJO, and NHCELKO). Note the VESSEL component input defines the core region to be in the first radial ring (i.e., icrr = 1) at axial levels, 3, 4, and 5 (i.e., icrl = 2 and icru = 5). HTSTR component 171 is located in ring one and the second theta in axial levels 3, 4, and 5 for the VESSEL component. HTSTR component number 172 is in the third theta sector and HTSTR component 173 is in the fourth theta sector. The POWER for these four fuel rod HSs is provided via POWER component number 174.

Note that HTSTR components 171, 172, and 173 are repeated HS input. Geometry, noding, and initial conditions are the same for these three HS components as HTSTR component number 140. The only additional input required for repeated HS components is the HS BC information. Note that all four HTSTR components (i.e., 140, 171, 172, and 173) each include one hot fuel rod component (i.e., NHOT = 1 for HTSTR component number 140 and 171, 172, and 173 are repeats of 140). The additional rod-to-rod peaking for hot rods is in the POWER component input (i.e., POWER component number 174).

HTSTR component number 140 will internally create a hot rod HS which will have a component number of 140001. This internally created HS component is typically referred to as a spawned component, spawned by HTSTR component 140 (i.e., parent) and HS component 140001 is a sub-component or child of HS component 140. This hot rod HS component will be located in the same fluid cells as the HS 140 (i.e., ring one, theta one, axial levels 3, 4, and 5). The hot rod will have the same HS BC, geometry, and noding. Only the power level will be different by the rod-to-rod peaking factor input in POWER component number 174. HTSTR component numbers 171, 172, and 173 will have hot rod HS numbers 171001, 172001, and 173001 located in the same fluid cells as HS numbers 171, 172, and 173. A hot rod HS can be used to determine the peak clad temperature for a fuel rod that is at a higher power level than the average fuel rod simulated by the parent component HS.

**Table 2-15. HTSTR Component Numbers 140, 171, 172, and 173 in Appendix B,** *W4LOOP Test Problem*

```
*         type           num            id        ctitle
htstr                    140           140 $140$ reactor-core fuel rods
*      nzhtstr          ittc         hscyl          ichf
             3             0             1             1
*       nopowr        plane        liqlev        iaxcnd
             0             3             1             1
*        nmwrx         nfci         nfcil          hdri          hdro
             1             1             1    0.0000E+00    1.3000E-02
*         nhot        nodes        irftr         nzmax        irftr2
             1             8            12           100             0
*       dtxht1       dtxht2        dznht         hgapo         shelv
    4.0000E+00    5.0000E+01    5.0000E-03    6.0000E+03    2.9750E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             1            3e
            26             1             1            4e
            26             1             1            5e
*      dhtstrz
f   1.2141E+00e
*          rdx
    9.8430E+03e
*        radrd
    0.0000E+00    2.0000E-03    3.0000E-03    4.0000E-03    4.6427E-03s
    4.7422E-03    5.0500E-03    5.3594E-03e
*        matrd
r04          1             3             2            2e
*         nfax
f            5e
*         rftn
f   5.5000E+02e
f   5.5000E+02e
*        fpuo2
f    0.0000E+00e
*          ftd
f    9.4500E-01e
*         gmix
    1.0000E+00 f  0.0000E+00e
*         gmles
f    0.0000E+00e
*         pgapt
f    1.0000E+07e
*         plvol
f    0.0000E+00e
*         pslen
f    0.0000E+00e
*         clenn
f    0.0000E+00e
*         burn
f   1.5400E+04e
f   1.5400E+04e
*         type           num            id        ctitle
htstr                    171           171 $140$ reactor-core fuel rods
*     numOrgHS
            -140
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
```

```
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             2             3e
            26             1             2             3e
            26             1             2             4e
            26             1             2             5e
            26             1             2             5e
*         type           num            id         ctitle
htstr                    172           172 $140$ reactor-core fuel rods
*     numOrgHS
         -140
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             3             3e
            26             1             3             3e
            26             1             3             4e
            26             1             3             5e
            26             1             3             5e
*         type           num            id         ctitle
htstr                    173           173 $140$ reactor-core fuel rods
*     numOrgHS
         -140
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             4             3e
            26             1             4             3e
            26             1             4             4e
            26             1             4             5e
            26             1             4             5e
```



HTSTR components 140, 171, 172, and 173 all have fine mesh turned on (i.e., FMON = 1). The fine mesh capability is used to accurately simulate the steep axial temperature profiles at or near to a quench front at the fuel rod clad surface. Accurate calculation of the propagation of the quench requires accurate simulation of the axial condition around a quench front and the changes in heat transfer regimes and heat transfer coefficients ahead and behind the quench front.

When fine mesh capability is turned on, then the HTSTR component has the capability to dynamically add and remove additional axial fine-mesh node rows during the TRACE calculation. Input for FMON or REFLOODON determines whether or fine mesh is on. If either or both of these inputs are non-zero, then fine mesh is on. Fine mesh can only be turned on for a given HS component, when the HTSTR component is first provided to a TRACE input model. This implies that if fine mesh is to be turned on it will be turned on for a steady-state calculation

before any transient restarts are executed from the steady-state calculation. TRACE adds and removes axial fine-mesh node rows in either of two ways.

1) When fine mesh is on, TRACE adds NFAX(k) input-specified permanent axial fine-mesh node rows to each of the k = 1, NZHTSTR axial-cell intervals, with equal axial spacing within each interval. These permanent axial fine-mesh node rows remain in place for all steady-state and/or transient time calculated by TRACE. In addition, the fine mesh logic splits the first and last coarse mesh axial levels into two coarse mesh axial levels. Therefore, when fine mesh is on NZHTSTR is redefined to be NZHTSTR(user input) + 2. The new bottom and top coarse mesh axial levels get only one permanent fine mesh axial level. In addition, when fine mesh is on, NFAX cannot be less than three. Total number of permanent fine mesh when fine mesh is the sum of nfax for each axial level with the minimum for nfax set to 3 plus 2 for the added permanent fine mesh at the top and bottom of the HS axial mesh. For HTSTR in Table 2-15 the total number of permanent fine mesh will be NFAX(1) + NFAX(2) + NFAX(3) + 2 = 17.

2) TRACE may either add or remove a temporary axial fine-mesh node row. This occurs when:
   - the surface temperature change between axial node rows coupled to TRACE hydraulic cells (where IDBCI = 2 or/and IDBCO = 2) exceeds a value based on the heat transfer regime a fine mesh axial level is added or a fine mesh axial level is removed if the surface temperature gradient is less than a value based on the heat transfer regime,
   - adding the axial node row will not reduce the axial distance between node rows below the input-specified DZNHT minimum value, and
   - permanent fine mesh node rows are not removed independent of the axial temperature gradient.



The surface temperature gradient at which a temporary fine mesh axial level is added is given by the formula based on the heat transfer regime at the surface of the HS. If the heat transfer regime is post-CHF, then,

$$\Delta T_l = MAX(25\ ,\ 5 + 0.067 \cdot \Delta T_s + 0.000028 \cdot (\Delta T_s)^2) \tag{2-50}$$

If the heat transfer regime is transition-boiling, then,

$$\Delta T_l = MIN(25\ ,\ 5 + 0.067 \cdot \Delta T_s) \tag{2-51}$$

If the heat transfer regime is nucleate-boiling, then,

$$\Delta T_l = MIN(5\ ,\ 25/\Delta T_s) \tag{2-52}$$

For all other heat transfer regime (i.e., single phase to liquid HT, etc.), then,

$$\Delta T_l = 25 \tag{2-53}$$

Where,

$\Delta T_s$ = Twall - Tsat = Superheat of the HS surface temperature above the fluid saturation temperature.

The temperature limit to remove a temporary fine mesh axial level is one-half of the ΔT for adding a fine mesh node row. The temperature limit to remove temporary fine mesh axial levels at one-half of the temperature limit to add temporary fine mesh ensures that the fine mesh logic does not cycle and add and delete the same temporary fine mesh axial level each time step. The total number of axial node rows (input + permanent + temporary) cannot exceed the input-specified NZMAX. Note in general as NZMAX is increased by the user, then the cpu costs and memory costs associated with the TRACE run increases. For a typical fuel rod quenching NZMAX should not be input to be more than 400 and an NZMAX of 200 results in accurate quench front propagation calculations. In addition, the user input for DZNHT on the order of 1 mm), ensures that accurate axial temperature profiles will be calculated without significant waste of cpu resources.

Note that when fine mesh is turned on then the radial temperature distribution at the bottom and top must be input as well as the radial temperature distribution for the coarse mesh HS cell centers. For this example, HS 140 has 3 coarse mesh axial levels and 8 radial nodes. Therefore, the total number of values that must be input for the RFTN array when fine mesh is on, is 8 x (3+2) = 40. The first 8 values input for the RFTN array will be for the radial temperature distribution for the bottom edge of the fuel rod. The next 8 values input for the RFTN array are for the first coarse mesh axial level. The last 8 values input for the RFTN array are for the top edge of the fuel rod. The input of fuel rod radial temperature profiles at the bottom and the top of the fuel rod results in a model that can more accurately predict the start of a quench front at the top or bottom of fuel rod HS. Essentially it provides for a more accurate prediction of the stored energy above the quench temperature, that must be quenched in order for a quench front to start moving up or down the fuel rod.

Figure 2-39 illustrates the renoding that occurs at time zero when fine mesh is turned on. The fine mesh logic increases the number of coarse mesh axial node rows by two, by splitting the top and bottom axial levels into two axial levels. For the example in Table 2-15 and Figure 2-39 the user input axial heights for the top and bottom HS axial node rows is 1.2141m, with NFAX(1:NZHTSTR) equal to 5. For this input, the axial node height of new first axial level is equal to DHTSTRZ(1) / (NFAX(1) * 4) = 1.2141 / (5 * 4) = 0.060705 m (see Figure 2-39). The axial node height for the second coarse mesh axial level when fine mesh is on for this example will be 1.2141 - 0.060705 = 1.1534 m. The axial node height for the last axial level is equal to DHTSTRZ(NZHTSTR) / (NFAX(NZHTSTR) * 4) = 0.060705 m and the axial height for the next to last coarse mesh axial level = 1.1534 m. For the permanent fine mesh, the new first and last axial levels heights stay the same. Since, nfax was input for each of the three original axial levels as 5, then the new coarse mesh axial levels 2, 3, and 4 will get 5 permanent fine mesh axial levels. The axial node height for these permanent fine mesh axial levels will be equal to DHTSTRZ(k) /

NFAX(k) = 1.2141 / 5 = 0.24282 m. The exception to this formula is permanent fine mesh axial level 2 and 16. The heights of permanent fine mesh axial levels 2 and 16 are calculated such that dzhtstr-fine-mesh(1) + dzhtstr-fine-mesh(2) = 0.24282 m and dzhtstr-fine-mesh(16) + dzhtstr-fine-mesh(17) = 0.24282. Therefore, for this example the height of the permanent fine mesh axial levels 2 and 16 = 0.24282 - 0.060705 = 0.182115 m (see Figure 2-39). In summary, the permanent fine mesh axial levels heights for this example are: dzhtstr-fine-mesh(1) = dzhtstr-fine-mesh(17) = 0.060705 m, dzhtstr-fine-mesh(2) = dzhtstr-fine-mesh(16) = 0.182115 m, and dzhtstr-fine-mesh(3:15) = 0.24282 m (see Table 2-16).

**Table 2-16. HS Component 140 Axial Level Sizes With Fine Mesh Renodalization.**

| Cell Index | User Input Coarse Mesh DZ (m) | Coarse Mesh with Fine Mesh Renode DZ (m) | Permanent Fine Mesh DZ (m) |
|---|---|---|---|
| 1 | 1.2141 | 0.060705 | 0.060705 |
| 2 | 1.2141 | 1.153395 | 0.182115 |
| 3 | 1.2141 | 1.2141 | 0.24282 |
| 4 | | 1.153395 | 0.24282 |
| 5 | | 0.060705 | 0.24282 |
| 6 | | | 0.24282 |
| 7 | | | 0.24282 |
| 8 | | | 0.24282 |
| 9 | | | 0.24282 |
| 10 | | | 0.24282 |
| 11 | | | 0.24282 |
| 12 | | | 0.24282 |
| 13 | | | 0.24282 |
| 14 | | | 0.24282 |
| 15 | | | 0.24282 |
| 16 | | | 0.182115 |
| 17 | | | 0.060705 |
| total | 3.6423 | 3.6423 | 3.6423 |

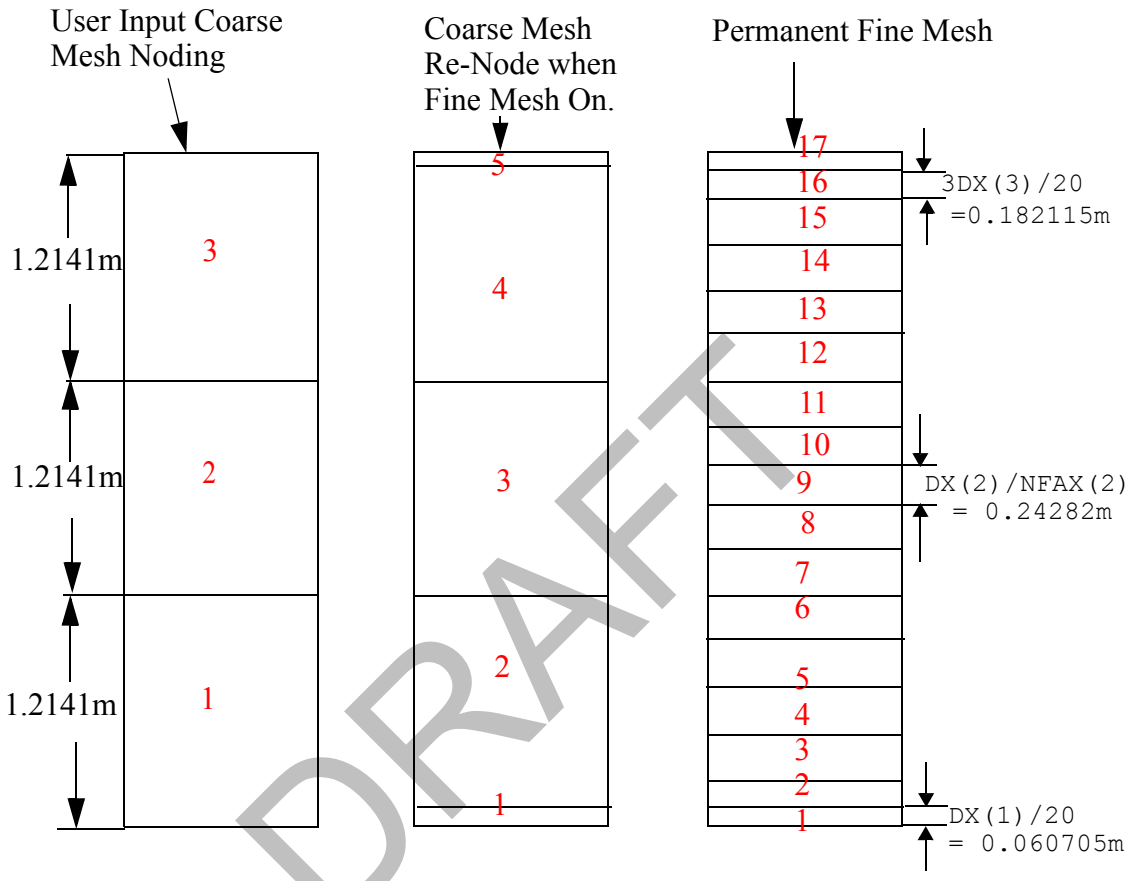




Figure. 2-39. HS Component 140 Axial Re-Noding When Fine Mesh is On.

When FMON or REFLOODON is non-zero, then the full reflood heat transfer package is used. Reflood parameters (i.e., quench front location) must be obtained from the reflood HS components and passed back to the VESSEL component hydrodynamic models. Since any number of HS components may be connected to the core region fluid cells in a VESSEL component, it is necessary to specify in the input which reflood HS components will be used to obtain these reflood parameters. The NHSCA array (which is input with the VESSEL component when the RLFDINPUT variable is non-zero) identifies those reflood HS components. In addition, the unheated fraction of the HS surface area for the core region is also input as part of the VESSEL component input when RLFDINPUT is non-zero. You can see examples of this in the VESSEL input listing in **Appendix B,** *W4LOOP Test Problem*.

If the FMON or REFLOODON is non-zero for a HS that is associated not with a VESSEL component, but rather with a PIPE component, then for the PIPE component, PIPETYPE must be input as type 7 (i.e., PIPE component input). Note that when PIPETYPE is 7 (i.e., implies a 1D

reflood fluid component), then two additional inputs (i.e., NGRIDSPACERS - number of grid spacers and UNHEATFR - unheated fraction of the HS surface must be input for the PIPE component. If NGRIDSPACERS is greater than zero, then the axial position of the grid spacers must also be input for the PIPE component.



# *JETP Component*

Jet pumps are used inside the reactor pressure vessels of some Boiling Water Reactors (BWRs) as part of the reactor recirculation system. BWR/3 to BWR/6 designs have been equipped with jet pumps (Ref. 2-12). A typical BWRs will have 20 jet pumps, divided into two groups of ten jet pumps, with each group associated with a recirculation loop outside of the pressure vessel. Jet pumps are located inside the RPV in the downcomer annulus between the core shroud and the RPV wall (see Figure 2-17).

The drive flow is from one of two recirculation lines which exit the RPV through a penetration in the lower downcomer and is pumped to a higher pressure using a variable speed recirculation pump (BWR/3s, BWR/4s, and some BWR/5s) or a two speed pump and flow control valve combination (some BWR5s and BWR6s), and then distributed through a manifold into a number of risers. Each riser penetrates the vessel low in the downcomer annulus and continues to rise until capped with a rams head flow divider which directs the flow from the riser into two jet pump nozzles.



The high velocity and relatively high momentum flow through the drive line nozzle entrains fluid from the downcomer into the suction of the jet pump. The two flows (i.e., drive and suction) merge together in the jet pump throat or mixing section. The diffuser section below the mixing section recovers some of the velocity head as static head and discharges the merged flow into the lower plenum. The suction flow can be as large as twice the magnitude of the drive flow.

The TRACE JETP component is a TEE component with internal models included to simulate the flow losses, mixing losses, and pressure recovery in a jet pump. A typical JETP component noding is given in Figure 2-40. The TRACE input consistent with this noding diagram is given in Table 2-17. The first two cells of the primary leg of the TEE component is the mixing region of the JETP component where the drive nozzle flow mixes with the suction flow. The third cell is the diffuser and the fourth cell is the tail pipe where the discharge flow exits into the lower plenum. The three cells in the side leg of the JETP component represent the drive line with the first cell of the side leg as the drive nozzle. Therefore, in order to correctly simulate the jet pump geometry, JCELL must be input as one and COST must be input as one. The drive nozzle injects directly into the top of the mixing region and the angle between the low numbered portion of the primary side of the JETP and the secondary leg is zero degrees (i.e., COST = cosine of zero = 1.0). The GRAVs for the primary side of the JETP will all be -1.0 (i.e., primary side is pointing down and difference in elevation between cell centers is equal to -delta-x of cell centers). For this example, the number of jet pumps simulated by this JETP component is (i.e., NJETP) one.

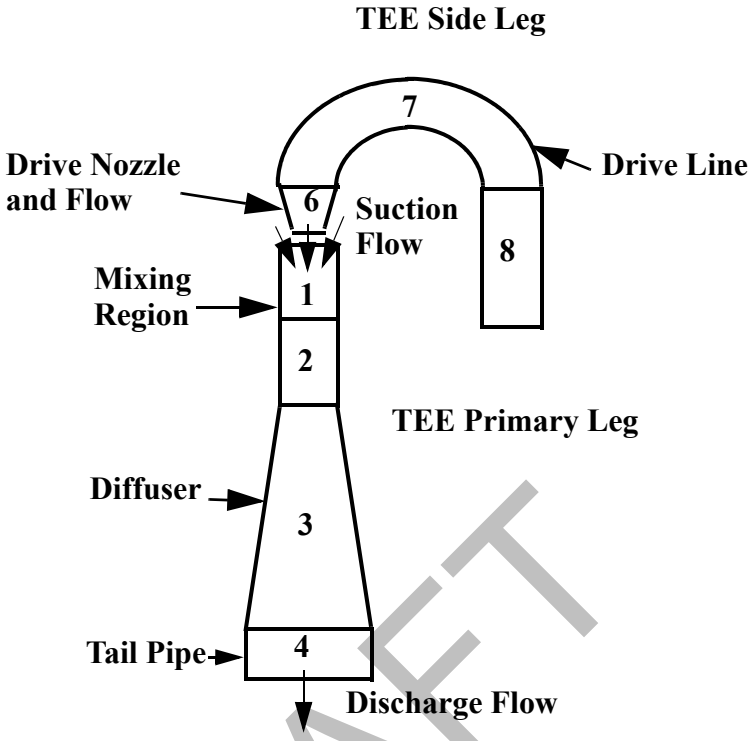


Figure. 2-40. Seven Cell JETP Component Noding Diagram.



The irreversible loss coefficient model for the diffuser and nozzle is based on Idel'Chik (Ref. 2-25) and for expansion through a diffuser/nozzle the irreversible loss factor is:

$$K_e = C_e(\tan\alpha)^{1.5}(1 - A^*)^2 \tag{2-54}$$

where,
$K_e$ = Expansion irreversible loss factor.
$C_e$ = Expansion constant.
$\alpha$ = Angle of the diffuser.
$A^*$ = Area ratio of outlet to inlet flow area.

For contraction through a diffuser/nozzle the irreversible loss factor is:

$$K_c = C_c\sin\alpha(1 - A^*) \tag{2-55}$$

where,
$K_c$ = Contraction irreversible loss factor.
$C_c$ = Contraction constant.

The angle of the diffuser/nozzle is determined based on the change in the hydraulic diameter across each cell in the diffuser/nozzle. Note the mixing region has no change in flow area or hydraulic diameter so no irreversible loss will be calculated for these cell edges. The expansion/ contraction diffuser/nozzle loss coefficient models are applied at all interior cell edges for the JETP component (i.e., all cell edges except the suction inlet, discharge outlet, and drive line last cell edge). The user input flow loss coefficient for all interior cell edges will be over-written with the value predicted by the expansion/contraction diffuser/nozzle models describe above.



**Table 2-17. INEL 1/6 Scale Jet Pump Model**

```
*
*******   type            num             id        ctitle
jetp                        1              1 1/6th scale inel jetp model
*         jcell          nodes           ichf          cost          epsw
               1              0              0    1.0000e+00    0.0000e+00
*        iconc1         ncell1          jun1          jun2         ipow1
               0              4              2             3             0
*        radin1            th1        houtl1        houtv1        toutl1
     0.0000e+00     0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*        toutv1
     0.0000e+00
*        iconc2         ncell2          jun3         ipow2
               0              3              1             0
*        radin2            th2        houtl2        houtv2        toutl2
     0.0000e+00     0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*        toutv2
     0.0000e+00
*         njetp
               1
*        epsdff         epsdfr         epsnzf         epsnzr
     5.5000e+00     3.8000e-01    5.5000e+00     3.8000e-01
*        finlet         fotlet
     4.0000e-02     4.5000e-01
*
* dx    * r02  1.8080e-01      4.3650e-01      5.8000e-02 e
* vol   * r02  1.1942e-04      9.2712e-04      2.3615e-04 e
* fa    *      4.9766e-04 r02  6.6052e-04 r02  4.0715e-03 e
* fric  * f    0.0 e
* fricr * f    0.0 e
* grav  * f   -1.0 e
* hd    *      1.4600e-02 r02  2.9000e-02 r02  7.2000e-02 e
* nff   * f    1 0 e
* alp   * f    0.0 e
* vl    * f    0.0 e
* vv    * f    0.0 e
* tl    * f  560.0 e
* tv    * f  560.0 e
* p     * f    7.5e+06 e
* pa    * f    0.0 e
*
* dx    *      6.8500e-02      6.9743e-02      2.0520e-01 e
* vol   *      3.2761e-05      4.8643e-05      1.6503e-04 e
* fa    *      1.6286e-04      7.2583e-04      6.9746e-04      8.0425e-04 e
* fric  * f    0.0e
* fricr * f    0.0e
* grav  * r02  1.0        r02 -1.0 e
* hd    *      1.4440e-02      3.0400e-02      2.9800e-02      3.2000e-02 e
* nff   * f    1  e
* alp   * f    0.0 e
* vl    * f    0.0 e
* vv    * f    0.0 e
* tl    * f  560.0 e
* tv    * f  560.0 e
* p     * f    7.5e+06 e
* pa    * f    0.0 e
```

For forward flow through the diffuser, $C_e$ = EPSDFF and the recommended value is 5.5. For reverse flow through the diffuser, $C_c$ = EPSDFR and the recommended value is 0.38. For the example in Table 2-17, these defaults are the values input, however if -1.0 had been input, then the defaults (i.e., EPSDFF = 5.5 and EPSDFR = 0.38) would have been used. Note that reverse flow through the side leg of the JETP (i.e., the drive line) is from the nozzle into the mixing region (i.e., positive flow is in the direction of higher cell number). Therefore, for the nozzle forward flow is an expansion and $C_e$ = EPSNZF and the recommended value is 5.5, which is also the default for this input. For reverse flow through the nozzle, $C_c$ = EPNZFR and the recommended value is 0.38, which is also the default for this input.

The area ratio to be used in the above formulas is based on the cell average flow areas which is determined based on vol(i)/dx(i) from the user input. For the example JETP component in Table 2-17, the cell average flow areas for cells 2 and 3 are:

$$\frac{vol(2)}{dx(2)} = \frac{0.00011942}{0.1808} = 0.0006605\,\mathrm{m}^2 \tag{2-56}$$

and

$$\frac{vol(3)}{dx(3)} = \frac{0.00092712}{0.4365} = 0.002124\,\mathrm{m}^2, \tag{2-57}$$

respectively. Therefore, the area ratio for the cell edge between cells 2 and 3 is

$$A^* = \frac{0.0006605}{0.002124} = 0.311\ . \tag{2-58}$$

The angle of the diffuser is based on the following formula:

$$\alpha = \mathrm{atan}\left[\frac{HD(j+1) - HD(j)}{2DX(j)}\right] \text{ (see Figure 2-41).} \tag{2-59}$$

For the geometry given in Table 2-17, for j = 3, the diffuser angle calculated to be ~2.82 degrees. Therefore, the expansion loss for forward flow at the cell edge between cells 2 and 3 would be

$$K_e = 5.5 \cdot \left[\frac{HD(4) - HD(3)}{2DX(3)}\right]^{1.5} \cdot (1 - A^*)^2 = 0.0285\ . \tag{2-60}$$

A similar expansion forward flow loss coefficient would be calculated for the cell edge between cells 3 and 4. The contraction reverse flow loss coefficient for the cell edge between cells 2 and 3 would be:

$$K_c = 0.38 \cdot \sin 2.82 \cdot (1 - 0.311) = 0.0129\,. \tag{2-61}$$

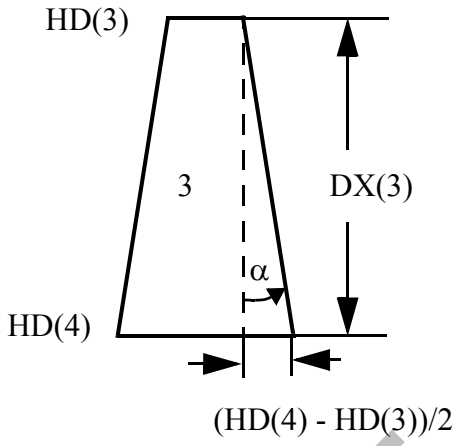


Figure. 2-41. Diffuser Angle.

A similar contraction reverse flow loss coefficient would be calculated for the cell edge between cells 3 and 4.

FINLET is the suction positive flow irreversible loss coefficient, which has a recommended value of 0.04, which is also it's default. The FINLET flow loss factor will be added to the user input for FRIC(1) and FINLET + FRIC(1) will be the total positive flow loss at the jet pump suction. For reverse flow at the jet pump suction, a contraction loss is calculated according to the following formula:

$$K_{cs} = 0.5 - 0.7A^* + 0.5(A^*)^2 \tag{2-62}$$

The area ratio in this formula is based on the flow areas at cell edges 1 and 2 (i.e., $A^*$ = FA(1) / FA(2)). For the jet pump in Table 2-17, the area ratio between cell edges 1 and 2 is 0.00049766/ 0.00066052 = 0.75344, which implies a contraction loss of 0.256 for reverse suction flow. The contraction loss based on the above formula is added to the user input reverse loss coefficient for reverse flow at the jet pump suction to give a total reverse flow loss of FRICR(1) + $K_{cs}$ (FRICR user input). Note if NFRC1 (i.e., namelist input) is input as 1, then user input forward additive loss is equal to the reverse flow additive loss (i.e., FRICR(1) = FRIC(1)).

FOTLET is the discharge positive flow irreversible loss coefficient, which has a recommended value of 0.45, which is also it's default. The discharge cell edge index is NCELL1 + 1 and FOTLET is added to the user input reverse flow loss so that the total reverse flow loss at the discharge cell edge would be FRICR(NCELL1+1) + FOTLET.

Note that the current version of TRACE does not convert FINLET and FOTLET to friction factor additive losses when IKFAC = 0 (i.e., namelist input). Therefore, if IKFAC is equal to 0, then

FINLET and FOTLET must be converted to friction factor additive losses manually by the user. If IKFAC is input as 1, then no manual conversion of FINLET and FOTLET is required. The formula for converting from K-factor form loss to a friction factor additive loss is:

$$K = \frac{2fL}{D} \tag{2-63}$$

where,

K = K-factor form loss factor (i.e., $\Delta P = K\frac{\rho V^2}{2}$).

f = TRACE friction factor additive loss (i.e., $\Delta P = \frac{fL\rho V^2}{D}$).

L = Cell-center to cell-center distance.
D = Hydraulic diameter at cell edge.

Which implies that:

$$f = \frac{KD}{2L} \tag{2-64}$$

Future version of TRACE will be modified so that FINLET and FOTLET do not have to be manually converted to additive friction factor losses when IKFAC = 0.

Mixing losses and nozzle losses that are a function of the M-ratio (i.e., suction mass flow rate divided by drive nozzle mass flow rate) have been obtained based on the data in Reference 2-26. These losses will be internally calculated by TRACE and applied to the appropriate cell edges during the transient calculations (see the Theory Manual).

The remaining JETP component input is the same as the TEE component input. Note that the user input flow loss factors for cell edges internal to the JETP component will be over-written with the internally calculated flow losses. The exception is at the suction cell edge (i.e., j = 1), at the discharge cell edge (i.e., j = NCELL1 + 1), and at the inlet to the drive line (i.e., last cell edge in the secondary side of the JETP component). The user input flow loss factors at these locations will not be over-written.

The number of fluid cells used to represent a jet pump with the JETP component can be increased or decreased as long as the nozzle, drive line, mixing zone, diffuser, and tail-pipe are simulated. In Table 2-18 is an example full scale jet pump model input. In this model the primary side of the JETP has 3 cells (i.e., one for mixing zone, one for diffuser, and one for tail-pipe) and the drive line and nozzle is simulated with two cells (see Figure 2-42). This would be the minimum number of cells that can be used to simulate a jet pump. More cells would be appropriate if during the accident analysis of interest there was expected to be significant variations of fluid properties (i.e., void fraction) in the primary or secondary side of the JETP model.

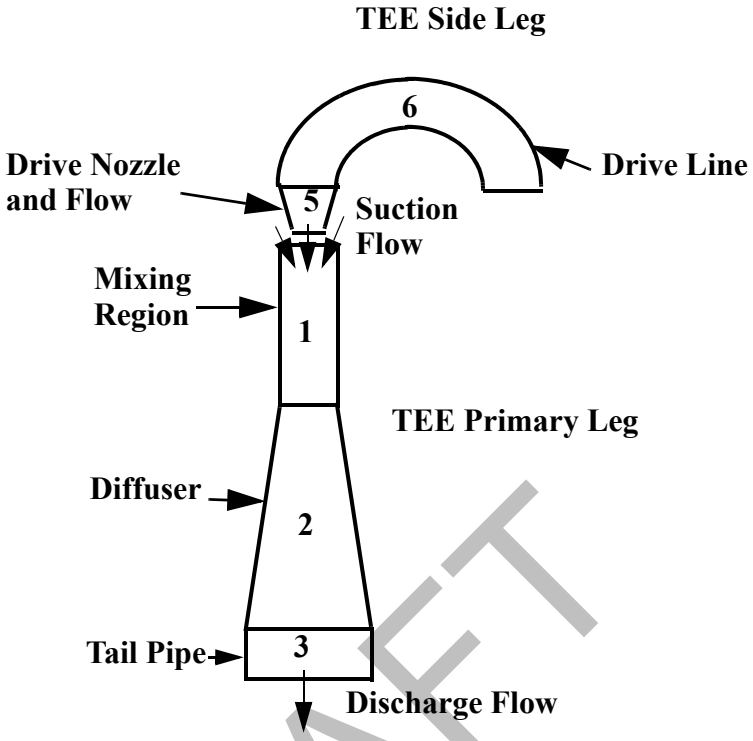


Figure. 2-42. Five Cell JETP Component Noding Diagram.



For the full scale jet pump, NJETP = 10, therefore this JETP component is simulating 10 actual jet pumps in the TRACE BWR model. NHCOM = 1, which implies that this JETP model is inside of VESSEL component (i.e., VESSEL component number = 1) and the outside surface of the JETP pipe walls will be in contact with VESSEL fluid cells. The VESSEL fluid cells are identified via the IDROD1/NHCEL1 input for the primary side of the JETP component and IDROD2/NHCEL2 input for the secondary side of the JETP component. IDROD1 = IDROD2 = 4 implies that this JETP component is located in the fourth radial ring of VESSEL component number 1. This assumes that the number of theta sectors in the VESSEL component is one (i.e., an r-z cylindrical VESSEL). IDROD1 and IDROD2 is the cell number in the radial-theta plane and is equal to j + (i -1) * NTSX, where i = radial ring index, j is the theta sector index, and NTSX (i.e., VESSEL component input) is the total number of theta sectors in the VESSEL component. The axial level number for the VESSEL fluid cell is given in the NHCEL1 and NHCEL2 input. So for this example, the mixing zone pipe wall outside surface of the JETP component is in cell i = 4, j = 1, and k = NHCEL1(1) = 4 (i.e., axial level 4) of VESSEL component number 1. The diffuser pipe wall outside surface of the JETP component is in cell i = 4, j = 1, k = NHCEL1(2) = 3 (i.e., axial level 3) of VESSEL component number 1. The tail-pipe wall outside surface of the JETP component is in cell i = 4, j = 1, k = NHCEL1(3) = 3 of VESSEL component number 1. The drive line (i.e., JETP secondary side) outside pipe wall surface is in VESSEL component number 1, radial ring 4 and axial level 5 (i.e., NHCEL2(1:2) = 5).

**Table 2-18. Full Scale Jet Pump Model**

```
*
*  type                  num            id          ctitle
jetp                      30             0          jet pump - first loop
*        jcell          nodes          ichf          cost          epsw
             1              1             0           1.0           0.0
*       iconc1         ncell1          jun1          jun2         ipow1
             1              3           993           994             0
*        iqptr          iqpsv         nqptb         nqpsv         nqprf
             0              0             0             0             0
*        radin             th         houtl         houtv         toutl
         0.104       8.585E-3           0.0           0.0           0.0
*        toutv          pwin         pwoff         rpwmx         pwscl
           0.0            0.0           0.0        1.0E20           1.0
*         qpin          qpoff        rqpmx         qpscl         nhcom
           0.0            0.0           0.0           1.0             1
*       iconc2         ncell2          jun3         ipow2
             0              2           990             0
*       iqptr2         iqpsv2        nqptb2        nqpsv2        nqprf2
             0              0             0             0             0
*       radin2            th2        houtl2        houtv2        toutl2
         0.127        9.27E-3           0.0           0.0           0.0
*       toutv2          pwin2        pwoff2        rpwmx2        pwscl2
           0.0            0.0           0.0        1.0E20           1.0
*        qpin2         qpoff2        rqpmx2        qpscl2
           0.0            0.0           0.0           1.0
*        njetp
            10
*       epsdff         epsdfr        epsnzf        epsnzr
           5.5           0.38           5.5          0.38
*       finlet         fotlet
          0.04           0.45
* dx1   *          2.526          2.192          0.191e
* vol1  *        0.08566          0.216        0.03495e
* fa1   *        0.02891        0.03391           0.183          0.183e
* fric1 * f          0.0e
* fricr1* f          0.0e
* grav1 * f         -1.0e
* hd1   *         0.1919         0.2078         0.4827         0.4827e
* icflg1*              1              0              0             0e
* nff1  * f           1e
* lccfl1* f           0e
* alp1  * f          0.0e
* vl1   *     19.389012      24.952075      4.6221039      4.6219686e
* vv1   *     20.387126       25.62026      4.9899411      5.0042484e
* tl1   *       548.231        548.333        548.342e
* tv1   *        557.44        560.505        560.772e
* p1    *    6.839238E6     7.15578E6    7.183882E6e
* pa1   * f          0.0e
* ilev1 * f           -1e
* qpp1  * f          0.0e
* matr  * f            6e
* tw1   *       548.235        548.333        548.333e
* idrod1*              4e
* nhcel1*              4              3              3e
* conc  * f          0.0e
* dx2   * f        0.832e
* vol2  *        0.01155        0.02113e
* fa2   *      4.996E-3         0.0254         0.0254e
* fric2 *           0.0            0.0         0.268e
* fricr2*           0.0            0.0         0.268e
* grav2 *           1.0          -0.63          -1.0e
* hd2   *        0.07976         0.1798         0.255e
* icflg2*              1              0              0e
* nff2  * f           1e
* lccfl2* f           0e
* alp2  * f          0.0e
* vl2   *    -57.060391     -11.221962     -11.221773e
* vv2   *    -58.013109     -12.035249     -11.979949e
* tl2   *       548.689         548.73e
* tv2   *       569.136        570.208e
```

```
* p2    *   8.108622E6  8.233525E6e
* pa2   * f        0.0e
* ilev2 * f         -1e
* qpp2  * f        0.0e
*  matr *   f 6e
* tw2    *     548.665     548.665e
* idrod2 *           4e
* nhcel2 *           5           5e
```



The JETP component provides the following jet pump performance parameter in the TRACE ASCII output file and as graphics variables:

$$M = \frac{W_s}{W_d} \tag{2-65}$$

where,
$M$ = M-ratio for jet pump.
$W_s$ = Suction mass flow rate.
$W_d$ = Drive mass flow rate.

The N-ratio is the ratio of the specific energy increase of the suction flow divided by the specific energy decrease of the drive nozzle flow. There are two methods used to calculate the N-ratio (i.e., applicable method and effective method). The effective method includes the change in elevation and dynamic heads and is given below:

$$N_e = \frac{P_{ds} - P_s + (Z_{ds} - Z_s)\rho g + \frac{\rho V_{ds}^2}{2} - \frac{\rho V_s^2}{2}}{P_d - P_{ds} + (Z_d - Z_{ds})\rho g + \frac{\rho V_d^2}{2} - \frac{\rho V_{ds}^2}{2}} \tag{2-66}$$

where,
$N_e$ = Effective N-ratio.
$P_{ds}$ = Discharge pressure.
$P_s$ = Suction pressure.
$P_d$ = Drive nozzle pressure.
$Z_{ds}$ = Discharge elevation.
$Z_s$ = Suction elevation.
$Z_d$ = Drive nozzle elevation.
$\rho$ = Mixture density.
$V_{ds}$ = Discharge velocity.
$V_s$ = Suction velocity.
$V_d$ = Drive nozzle velocity.

Experimental data for jet pump performance may be taken in horizontal geometry. The effective N-ratio is independent of orientation and can be used to compare the performance of horizontal jet

pumps with vertical jet pumps. The applicable N-ratio ignores the change in elevation and assumes that the kinetic heat in the suction and discharge is not significant and is given below:

$$N_a = \frac{P_{ds} - P_s}{P_d - P_{ds} + \frac{\rho V_d^2}{2}} \tag{2-67}$$

where,
$N_a$ = Application N-ratio.

In addition, jet pump efficiencies are calculated based on the application and effective N-ratios and are available as a graphics variable and in the TRACE ASCII output file.

$$\eta_e = M \cdot N_e \tag{2-68}$$

$$\eta_a = M \cdot N_a \tag{2-69}$$

# *PIPE Component*



The PIPE component models coolant flow in a 1D tube, channel, duct, or pipe. It can be used with BREAK- and/or FILL-component boundary conditions to model 1D flow in a pipe, or it can be used as a connecting pipe between other components to model a reactor system or experimental facility. It has the capability to model coolant flow-area changes, wall heat sources, and heat transfer between the wall inner and outer surfaces. A large number of material types are available within the code to model the wall material in the wall's conduction heat-transfer calculation. The user can specify other material properties as well.

Figure 2-43 shows a typical noding diagram for a PIPE component containing a venturi tube and an abrupt flow-area change. The numbers within the PIPE indicate cell numbers, and those above the PIPE indicate cell-interface numbers. The geometry is specified by providing a volume and length for each cell, and a flow area and hydraulic diameter at each cell face. The junction-interface variables, JUN1 and JUN2, provide reference numbers for connecting the PIPE to other component junctions. The numerical methods used to model coolant and wall thermal hydraulics in the PIPE are described in the TRACE Theory Manual.

Input options are available to model a 2D volumetric heat source in the wall, wall 1D radial conduction heat transfer, wall-surface convection heat transfer based on flow-regime dependent heat-transfer coefficients on the inner surface and input-specified constant heat-transfer coefficients on the outer surface, and wall-surface coolant-flow friction factors. The wall heat-transfer calculation is evaluated when the input number of heat-transfer nodes, NODES, is greater than zero. A critical heat flux (CHF) calculation can be evaluated by setting the input parameter ICHF to 1. Wall friction and irreversible form losses caused by abrupt or gradual coolant flow-

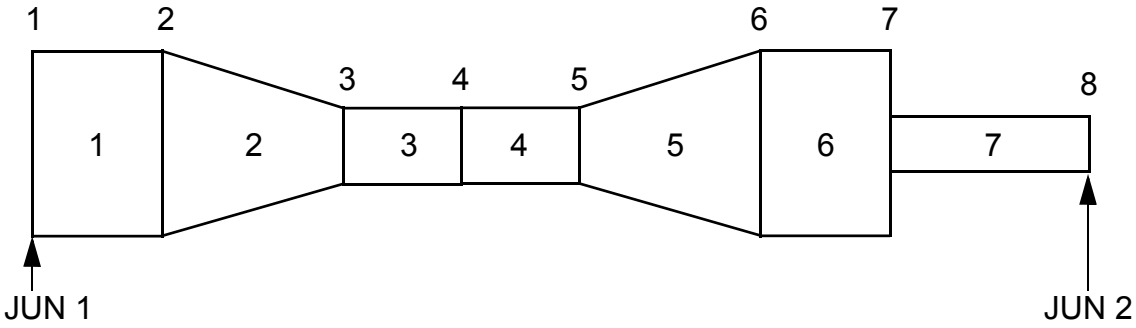


Figure. 2-43. PIPE-component noding diagram.

area change and coolant flow turning are evaluated by specifying appropriate option values for the input arrays, NFF and FRIC, at each cell face. These arrays are described in the PIPE's input specification section in Volume 1

Heat can be deposited directly in the coolant by setting the input parameter IPOW to 1. A power-to-the-fluid table defines the total power that is uniformly distributed in the coolant per unit length for all of the mesh cells of the PIPE component.

## *Single Junction Component*

A PIPE, VALVE, and PUMP component can be used as a single junction component. This is done by setting NCELLS to 0. A single junction component is just that, a junction without volume. To use any of these components as a single junction the user has to set the NAMELIST variable USESJC=1, 2, or 3 (see the NAMELIST input description in **Volume 2, Chapter 6** for additional information concerning USESJC).

A single junction component was developed to allow for conversion of RELAP5 input model into TRACE input models. A single junction component is similar to a RELAP5 junction. So typically, single junction components will be used when a RELAP5 input model is converted to TRACE. In addition, the CHAN component spawns a single junction component to simulate the leakage path flow from the CHAN inlet to the core bypass (see ***CHAN Component*** above).

In general a single junction component is appropriate when there is essentially no fluid volume associated with the flow path. For example, a small break in the side of a PIPE component can be modeled with a single junction component. Flow through the single junction component will use the upstream fluid conditions in the PIPE component to determine the velocities in the small break. If choked, critical velocities will be determined from the upstream fluid conditions in the PIPE component. If the small break is simulated with a PIPE or a TEE, then the small break PIPE leg will have at least one fluid volume cell, which will be typically small to represent the fluid volume associated with the thickness of the PIPE wall and flow area of the break. Typically,

these small fluid volume cells can be numerically difficult to solve and a more robust small break model is to use a single junction component for a small break in the side of a PIPE.

If a one dimensional fluid component is to be connected to a PIPE component at an interior fluid cell, then a single junction component can be used to provide the connection. However, if USESJC is equal to 2 or 3, then the PIPE component may include input for the side junction associated with the connections that is not a normal connection associated with JUN1 or JUN2. This eliminates the need for developing the input for an additional component for the input model (i.e., a single junction component).

Note also, that input of JUN1 and/or JUN2 equal to zero implies a dead-end PIPE component. Using JUN1 and/or JUN2 set to zero to dead-end a PIPE component again saves developing the input for another fluid component (i.e. zero velocity FILL) and therefore is more efficient from the standpoint of the number fluid component inputs that must be developed for a given TRACE input model.

## *Special Model Options for Pipes*

There are a total of 8 special model options for a PIPE component. A PIPE component can be used to model an accumulator by setting the input parameter PIPETYPE to 1, 2, or 3. This evaluates a gas/liquid interface sharpener; outputs the liquid level, volumetric flow, and liquid volume discharged from the component; and acts as a liquid separator model at JUN2, the gas phase is not allowed to flow across the JUN2 interface, when PIPETYPE 2 is selected. PIPETYPE 3 models a spherical accumulator. When a PIPE component is used to model an accumulator, one fluid cell should be used to represent the bulk of the tank. One additional relatively small cell may be added at the bottom of the tank to improve the timing of release of nitrogen from the accumulator. In the case of PIPETYPE 3 only one cell can be used.

PIPETYPE 5 models falling film condensation heat transfer in vertical tube bundles. PIPETYPE 7 models a pipe connected to a heat structure which have the fine mesh model turned on. When this option is used two additional inputs are required which are important for reflood calculations. The number of spacer grids associated with this pipe are input as well as the fraction of the heat structure surface that is not heated or can support a liquid film even thought the fuel rods are in post-CHF heat transfer regimes. PIPETYPE 8 models wall condensation phenomena for drywells.

PIPETYPE 4 and 6 are placeholders for two special options that are not currently active. PIPETYPE 4 will model a horizontal pressure tube fuel bundle like those found in a CANDU reactor. PIPETYPE 6 will model the condensation phenomena in a suppression pool.

## *Side Junctions*

The PIPE, VALVE, and PUMP components can all have side junctions when NAMELIST variable USESJC is set to 2 or 3. Using the PIPE component in conjunction with a single side

junction or multiple side junction the pipe can be used to model a tee or plenum. Each cell can have any number of side junctions attached to it. Figure 2-44 shows a PIPE component (PIPE 2) with two other PIPE components (PIPE 4 & PIPE 5) attached to cell 3 using side junctions. Table 2-19 shows an abbreviated input for PIPE 2. In this example PIPE 2 has two side junctions connected to cell 3 and have junction numbers 3 and 4 respectively. PIPE 4 connects to JUNLK 3 and PIPE 5 connects to JUNLK 4. When USESJC is set to 2 all side junction angles $\theta$ are set to 90 degree angles. When USESJC is set to 3, as in this example, two additional inputs are required. The angle $\theta$ which the side tube connects at and wether or not the side junction mass flow should be calculated with the offtake model. The angle $\theta$ is defined as the angle from the low-numbered cell end of PIPE 1 to PIPE 2 (see Figure 2-73). Mass, momentum, and energy convection occur across all side junction interfaces.



**Table 2-19. Example Side Junction Input Problem**

```
*****************
* namelist data *
*****************
*
 &inopts
  usesjc=3
 &end
*
.
.
.
*******   type            num         userid              component name
pipe                        2              1                      unnamed
*       ncells          nodes           jun1          jun2           epsw
             5              0              1             2            0.0
*       nsides
             2
*         nclk          junlk         ncmpto        nclkto        nlevto
             3              3              0             0             0
*        theta         ientrn
            90.0            0
*         nclk          junlk         ncmpto        nclkto        nlevto
             3              4              0             0             0
*        theta         ientrn
           135.0            0
```



In the current implementation it is recommended that side junctions be connected to straight section of pipe. The cells before and after the cell with the side junction connected to it should have approximately the same flow area. If the pipe is not straight the user may introduce some unintentional pressure losses.

# *PLENUM Component*

Warning – This component is deprecated. We do not recommend that you use this component any longer. Use a PIPE with multiple side junctions instead.

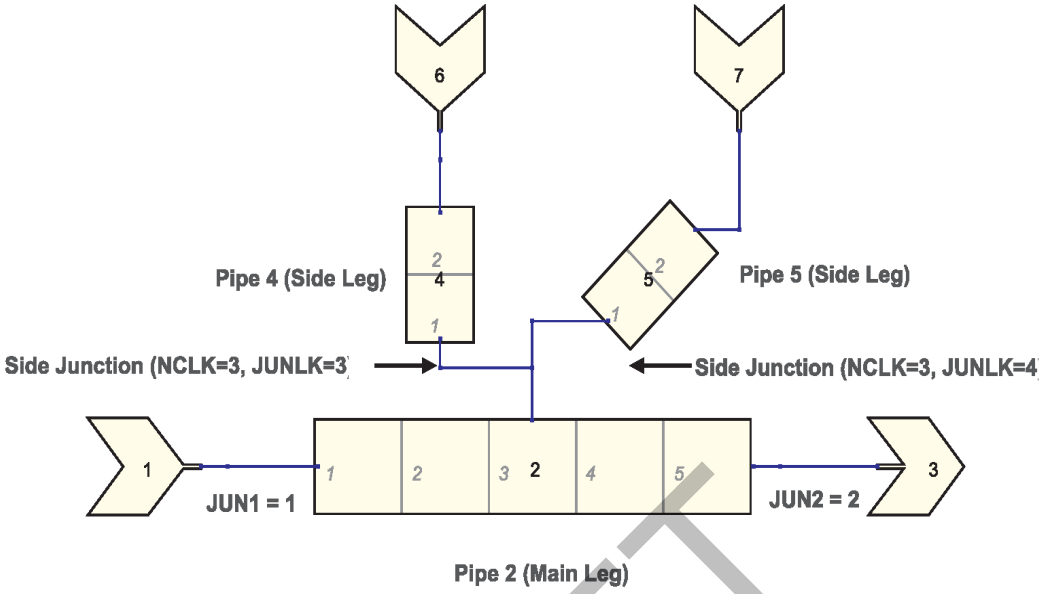


Figure. 2-44. PIPE-component noding diagram.

The PLENUM component models the thermal hydraulics of a volume connected to an arbitrary number of 1D hydraulic components. It is a single-cell component that the user can either set up as a momentum sink (where all inflow momentum is converted to a coolant pressure rise) and/or for convecting momentum across the cell from one side (having JUNS1 junctions) to the other side (having JUNS2 junctions). The effect of an elevation change between the PLENUM cell and its adjacent-component junction cells is evaluated. There are single values for the coolant pressure, non-condensable gas pressure, gas volume fraction, liquid temperature, vapor temperature, and solute concentration in the PLENUM cell. At each of its NPLJN junctions, TRACE evaluates the standard 1D, two-fluid motion equations with the PLENUM-cell momentum flux set to zero (when JUNS1 = 0 and JUNS2 = 0) or convected across the cell in one direction (when $0 < JUNS1$, $0 < JUNS2$, and $2 \leq JUNS1 + JUNS2 \leq NPLJN$). There is no requirement that the liquid and gas velocities be equal at a junction. The existence of stratified flow results from the constitutive correlations if the momentum-cell mean coolant velocity falls below a threshold velocity and the elevation change falls below a threshold slope at each PLENUM-cell junction.

No interface data are input for the PLENUM component except for the junction-number connections to its cell. The PLENUM component requires one or more junctions. All pertinent junction-parameter information is obtained by the 1D hydraulic components that are connected to the PLENUM cell. The user specifies as many PLENUM-side cell lengths as junctions such that each junction has its own associated PLENUM-cell length. The PLENUM component does not require identical cell lengths for its single cell. TRACE uses the PLENUM-cell length for each junction in its motion equation solution for the junction. In particular, the GRAV elevation

parameter at a given junction (input by the adjacent 1D hydraulic component) is defined in terms of the cell lengths from the adjacent-component cell and the PLENUM-cell junction.

Currently, TRACE does not allow HTSTR components to be coupled by convection heat transfer to a PLENUM cell. A PLENUM-component junction cannot be connected to a BREAK, FILL, PLENUM, or VESSEL component junction. Signal variables cannot define a PLENUM-cell parameter. If needed, the signal variable should be defined in the adjacent 1D hydraulic-component cell.



# *POWER Component*

The POWER component supplies power to one or more HTSTR components or to one or more CHAN components. The total power distributed among the HTSTR components associated with a given POWER component is determined either from a user specified table of powers (i.e., rpwtb), an initial power (i.e., rpowri), from a point kinetics calculation or from 3D transient neutronics calculation (i.e., PARCS). How the total power is distributed is determined by the user input for radial, HS-to-HS, and axial power distribution profiles, if TRACE is run independent of PARCS. Each user input power profile is normalized as well as the power density for each individual HS temperature node to ensure that the total power as specified by the user or point-kinetics models is conserved. If TRACE is run coupled with PARCS, then the 3D distribution of the power is determined by PARCS, however a POWER component is still needed in the TRACE model to set up the arrays that will provide the PARCS power densities to TRACE heat structures.



The POWER component in the TRACE model from **Appendix B,** *W4LOOP Test Problem* is repeated in Table 2-20. For this example, there are four HS components (i.e., User's Guide Volume I POWER Component input - NPWR = 4) for which POWER component number 174 will provide power (i.e., HTNUM (1:NPWR) = 140, 171, 172, and 173). The IPWRTY option determines whether or not the POWER will be calculated from a point kinetics calculation or a table lookup. For this example, IPWRTY = 6 implies that the reactor power will be from a table lookup and requires that the IRPWSV - the independent variable for the table look, NRPWTB - number of data points in the table, and RPWTB - reactor power table must be supplied.

The initial total power is given by the input for RPOWRI = 3250 MW. The transient total power is determined by the input to the RPWTB array. For this example, IPWRAD is zero, which implies that the power distribution is determined from the input for the RDPWR, CPOWR, RPKF, and ZPWTB. The RDPWR input is for the radial power distribution across a fuel pellet. When IPWRAD is zero, then the RDPWR array is input for the 8 HS radial nodes and this radial distribution is assumed to be the same at all axial levels. If the user wanted the radial power distribution to vary from one axial level to the next, then IPWRAD must be input as one. With IPWRAD input as one, then the input for NRPWR is used to determine if the RPWRT array must be input. The RPWRT array is the radial locations across the HS, where the radial power profile factors are to be input. Normally, the RPWRT array is assumed to be equal to the RADRD array for the HS component. However, if IPWRAD is equal one and NRPWR > 1, then RPWRT array must be input and TRACE will take the RDPWR array input for the RPWRT radial locations and

convert them to the radial power locations at the RADRD locations consistent with the HS radial noding.

For this example, all four of the HS components powered by POWER component 174 have the same geometry, noding, and material types. If one or more of these four HS components were different (i.e., NODES = 9 rather than NODES = 8, or etc.), then the RDPWR and ZPWTB arrays would have to be input for each of the four HS components, rather than assumed to be the same for all four HS components. With the HS components associated with a given POWER component have the same geometry, noding, and material types, then only one set of power profiles are required to define the power distribution. If there is any variation between the HTSTR components associated with a given POWER, then the radial and axial power profiles must be input for each HS component in the same order as the HS component appears in the HTNUM array.

The CPOWR array is for the HS to HS power distribution if the POWER component is associated with more than one HS component. The RPKF array is for the rod-to-rod power peaking for hot rods if any of the HS components associated with this POWER component has a spawned hot rod HS. The ZPWTB array is for the axial power distribution. The user input for the RDPWR, CPOWR, and ZPWTB arrays are normalized. The RDPWR array is normalized such that sum of RDPWR(i) * vol(i) = sum of vol(i) , where i goes from 1 to the number of radial nodes and vol(i) is the volume of each radial node. The CPOWR array is normalized such that sum of CPOWR(n) * rdx(n) = sum of rdx(n), where n goes from 1 to NPWR and rdx(n) is the number actual HS elements represented by the nth HS component. The axial power distribution is normalized such that sum of ZPWTB(k+1) * DHTSTRZ(k) = sum of DHTSTRZ(k), where k goes from 1 to NZHTSTR and DHTSTRZ(k) is the axial node heights for the HS components powered by this POWER component. If there is variation in geometry, noding, or material types for the HS associated with a given POWER component, then these normalizations will include all of the HS components associated with the POWER component.

Note that the axial power profile for this example is input as five different values (i.e., six values input to fill the ZPWTB array, but the first value is the independent signal variable associated with this axial power profile). Note that since NZPWTB is input as one, the axial power profile is constant and will not change with time. If NZPWTB was input as two, then a total of twelve values would be expected for the ZPWTB array (i.e., one for the time associated with the first axial power profile, then five values for the axial power profile at that time, then the time associated with the second axial power profile and then five values for the axial power profile at the second time). As time changed, then the axial power profile would be linearly interpolated between these axial power profiles. For this example, IZPWSV, the signal variable/control block output for the independent value in the ZPWTB table is input as 1, which is signal variable for problem time. Any signal variable or control block output in the TRACE input model could be used as the independent variable for the ZPWTB table, therefore this axial power profile table could be made to be depend upon the core average void fraction, or fraction of control rod insertion into the core, or etc. For this example, in Table 2-20, the axial power profile is constant with time (i.e., NZPWTB = 1).

Since NZPWZ is input as zero, then the ZPWTB axial power profile must be input for each of the coarse mesh nodes for the HS components powered by this POWER component. Note any NZPWZ input less than two, will result in NZPWZ getting redefined to NZHTSTR. Normally, that would imply only 3 values required since, NZHTSTR = 3 for HS component number 140. However, since FMON is non-zero for HS component number 140, then the fine mesh logic will add two extra coarse mesh axial levels to this HS component. Therefore, there must be five values input for the axial power profile. When NZPWZ is input as zero, then the ZPWZT array is not input by the user, but is inferred from the HS DHTSTRZ array. If NZPWZ > 1, then NPZWZ values must be input for the ZPWZT array. If NZPWZ > 1, then the ZPWTB table results at ZPWZT axial locations will be integrated to determine the axial power profile at the HS component coarse mesh axial locations.



Note that direct moderator heating of the fluid cells associated with the HS components powered by the POWER component can be simulated via the PROMHEAT and DECAHEAT inputs in the POWER component input. The direct moderator heating is only added to the liquid phase and the actual direct moderator heating is determined by scaling PROMHEAT and DECAHEAT by the liquid volume fraction in the fluid cells associated with the HS components powered by this POWER component.



**Table 2-20. POWER Component from Appendix B,** *W4LOOP Test Problem*

```
*         type            num             id          ctitle
power                     174            174  Power Comp for reactor power
*          npwr
             4
*        htnid
           140            171            172            173e
*       irpwty           ndgx           ndhx           nrts          nhist
             6              0              0             10              0
*       irpwtr          irpwsv         nrpwtb         nrpwsv         nrpwrf
             0              1             20              0              0
*       izpwtr          izpwsv         nzpwtb         nzpwsv         nzpwrf
             0              1              1              0              0
*       ipwrad          ipwdep       promheat       decaheat       wtbypass
             0              0
*        nzpwz           nzpwi         nfbpwt          nrpwr          nrpwi
             0              0              0              1              0
*        react           tneut         rpwoff         rrpwmx         rpwscl
    0.0000E+00     0.0000E+00     0.0000E+00     1.0000E+20     1.0000E+00
*       rpowri           zpwin         zpwoff         rzpwmx
    3.2500E+09     0.0000E+00     0.0000E+00     0.0000E+00
*       extsou           pldr          pdrat         fucrac
    0.0000E+00     0.0000E+00     1.3340E+00     1.0000E+00
*        rdpwr
    1.2109E+00     1.2371E+00     1.2703E+00     1.3201E+00     1.3823E+00s
    0.0000E+00     0.0000E+00     0.0000E+00e
*        cpowr
    1.0000E+00     1.0000E+00     1.0000E+00     1.0000E+00e
*         rpkf
            1.1            1.2            1.3            1.4e
*        zpwtb
     0.0000e+00     0.93748  0.93748      1.20535      0.83715s
     0.83715e
*        rpwtb
    0.0000E+00     3.2500E+09     1.0000E-01     2.2700E+08     1.0000E+00s
    1.9500E+08     2.0000E+00     1.8800E+08     5.0000E+00     1.7500E+08s
```

```
1.0000E+01    1.6200E+08    1.5000E+01    1.5200E+08    2.0000E+01s
1.4600E+08    5.0000E+01    1.2300E+08    7.5000E+01    1.1300E+08s
1.0000E+02    1.0700E+08    1.2500E+02    1.0400E+08    1.5000E+02s
1.0000E+08    2.0000E+02    9.4000E+07    2.5000E+02    8.8000E+07s
3.0000E+02    8.4000E+07    3.5000E+02    8.0000E+07    4.0000E+02s
7.7000E+07    5.0000E+02    7.2500E+07    9.0000E+02    5.5000E+07e
```

For the steady-state run, the power is held at the value of RPOWRI, and for the transient the values in table RPWTB are used to model reactor scram. During a steady-state the RPWTB table is not evaluated to determine the reactor power or reactivity. Table RPWTB consists of a set of independent/dependent-variable pairs; the independent variable is specified by input-variable IRPWSV to be signal variable 1 (problem time in the deck this example), and the total number of table pairs is specified by input variable NRPWTB. Note that the initial (at problem time 0.0) power value in table RPWTB is equal to RPOWRI ($3.25 \times 10^9$ W). If only a constant power were desired, IRPWTY would be entered as 5, RPOWRI would be used, and no table would be input. Details on the point kinetics model are provided in the TRACE Theory Manual.

A reactivity feedback model is provided that is based on the core-region power-weighted, volume-averaged fuel temperature, moderator temperature, gas volume fraction, and boron concentration. TRACE combines this feedback reactivity with programmed (control-rod insertion) reactivity that is input specified to provide the driving function for the point-reactor kinetics evaluation of fission power generated within the NPWR HS components associated with the POWER component. When the point kinetics model is not being used, reactivity feedback effects optionally may also be evaluated and sent to the output. The TRACE Theory Manual provide details on the TRACE reactivity feedback model. Complete input specifications for the reactivity feedback model are given in Volume 1 of the User's Guide in the POWER component's input description. The HTSTR component has a decay-heat model that combines the point-kinetics fission power with the power from decaying fission-product precursors to define the total thermal power generated in the HS elements. Details of this model are given in the TRACE Theory Manual. The default option for this model is the 69-group, ANS-79, decay-heat standard with the additional capability, if desired, of evaluating the heavy-element decay of $^{239}$U and $^{239}$Np. As an alternative, the user may select the 11-group ANS-72 decay-heat standard that was the default in earlier versions of TRAC-PF1. Users may define their own model by inputting the decay-heat parameters for an input-specified number (input variable NDHX) of groups. The same can be done for the delayed-neutron parameters and its number of groups (input variable NDGX) for the point-reactor kinetics model. The use of variables NDGX and NDHX is explained in Volume 1 in the section on POWER component input. The initial decay-heat precursor concentrations and the initial delayed-neutron concentrations can be input specified or evaluated by TRACE based on steady-state or power-history specified conditions.

If IRPWTY = 1, 2, 3, 4, 11, 12, 13, or 14, and NDGX is input as greater than zero, then the user must supply via POWER component input the delayed neutron fractions and time constants. If NDGX is input as zero, then the default 6 group delayed neutron model is used and the user does not need to supply the input for delayed neutron model.

If IRPWTY = 1, 2, 3, 4, 11, 12, 13, or 14, and NDHX is greater than zero and not equal to 69 or 71, the user must supply the decay heat fractions and time constants. There are a number of decay heat models available as default. The following decay heat default models are available:

- NDHX = 69, implies the 69 decay heat group ANS 79 decay heat standard.
- NDHX = 71, implies the 69 decay heat group ANS 79 decay heat standard plus heavy-element decay for $U^{239}$ and $Np^{239}$ for a total of 71 decay heat groups.
- NDHX = -11, implies the 11 decay heat group ANS 73 standard that was the default in TRAC-PF1/MOD1.
- NDHX = -23, implies the 23 decay heat group ANS 79 decay heat standard for $U^{235}$ only fissions.
- NDHX = -25, implies the 23 decay heat group ANS 79 decay heat standard for $U^{235}$ only fissions plus heavy-element decay for $U^{239}$ and $Np^{239}$ for a total of 25 decay heat groups.
- NDHX = -92, implies the 92 decay heat group ANS 94 decay heat standard.
- NDHX = -94, implies the 92 decay heat group ANS 94 decay heat standard plus heavy-element decay for $U^{239}$ and $Np^{239}$ for a total of 94 decay heat groups.

Table 2-21 is an example of the POWER component that is providing power to three CHAN components (see **Appendix B,** *3 CHANs & POWER Comp. Test Problem*.). For this example the three components referenced in the HTNUM array input (i.e., 25, 26, 27) are CHAN components rather than HTSTR components. The CHANPOW = 1 is the flag that indicates that the HTNUM array will include CHAN components rather than HTSTR components. Each CHAN component powered by the POWER component may have one or more HTSTR components for each fuel rod group defined in the CHAN component input. For this example, each CHAN of the three CHAN components have two fuel rod groups (i.e., one for the full length fuel rods and one for the partial length fuel rods).



**Table 2-21. POWER Component that powers 3 CHANs**

```
*         type           num            id        ctitle
power                     28            28 chan medium
*          npwr       chanPow
             3             1
*         htnum
            25            26           27e
*        irpwty          ndgx          ndhx          nrts         nhist
             7             0             0            10             0
*        irpwtr         irpwsv        nrpwtb        nrpwsv        nrpwrf
           101             1             3             1             0
*        izpwtr         izpwsv        nzpwtb        nzpwsv        nzpwrf
             0             1             1             0             0
*        ipwrad         ipwdep      promHeat      decaHeat      wtBypass
             0             0    0.0000E+00    0.0000E+00    0.0000E+00
*         nzpwz          nzpwi         nfbpwt         nrpwr         nrpwi
             4            -1             0             1             0
*         react          tneut         rpwoff        rrpwmx        rpwscl
    0.0000E+00    0.0000E+00    0.0000E+00    1.0000E+20    1.0000E+00
*        rpowri          zpwin         zpwoff        rzpwmx
   1.50000E+07   0.00000E+00   0.00000E+00   1.00000E+20
*        extsou          pldr          pdrat         fucrac
    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
```

```
*        zpwzt
   0.00000E+00   9.10600E-01   1.82120E+00   2.73180E+00e
*        zpwtb
   0.00000E+00   6.92308E-01   1.03846E+00   1.26923E+00   1.03846E+00e
*        rpwtb
   0.00000E+00   1.50000E+07   5.00000E+02   1.50000E+07   2.00000E+03s
   1.50000E+07e
```

When the POWER component powers CHAN components, then RDPWR and CPOWR input is not part of the POWER component input, but is part of the CHAN component input. In addition, an additional power distribution array is also required to identify the CHAN-to-CHAN power distribution. As a carryover from the BWR version of TRAC, the RADPW array is input for each axial level in a CHAN component, but it is normally input as the same value for each axial level, since the ZPWTB array input with the POWER component provides the axial power distribution for the reactor core. However, if there was a variation in axial power profile from one CHAN component to the next, then the RADPW array could be used to provide that variation. Also the CPOWR array that is input in the CHAN components is the rod group to rod group peaking relative to the power in the CHAN component, rather than the rod to rod peaking relative to the total reactor power, when CPOWR is input as part of the POWER component input.

For this POWER component example NZPWZ is input as four, which implies that the ZPWZT array must be input as part of the POWER component. The total height of the full length fuel rods for the CHAN component for this example is 2.7318 m, so the axial power is specified to be from ZPWZT(1) = 0.0 to ZPWZT(NZPWZ) = 2.7318 m.

The total reactor power for this example is 15 MW and the three CHAN components each have NCHANS = 2, which implies that there are six BWR fuel assemblies in this BWR core. That implies that the average BWR fuel assembly power is 15/6 = 2.5 MW in this model. The RADPW input for CHAN component 25 is 1.0, which implies that the average fuel assembly power for this CHAN component is 2.5 MW. The RADPW input for CHAN component 26 is 0.8, which implies that the average fuel assembly power for this CHAN component is 0.8 * 2.5 = 2 MW. The RADPW input for CHAN component 27 is 1.2, which implies that the average fuel assembly power for this CHAN component is 1.2*2.5 = 3 MW. Note that each CHAN component in this model includes a different number of fuel rods, some of which are full length and some of which are partial length, so actual fuel rod power depends not only upon the average fuel assembly power, but also on the number of full length and partial length fuel rods in the fuel assembly simulated by the CHAN component.

CHAN component 25 has 112 full length fuel rods and 16 partial length fuel rods. CHAN component 26 has 48 full length fuel rods and 16 partial length fuel rods. CHAN component 27 has 78 full length fuel rods and 14 partial length fuel rods. Therefore, the total number of fuel rods for this model is 2*(112 + 16 + 48 + 16 + 78 + 14) = 568 fuel rods, which implies an average rod power of 15 MW / 568 = 26.4085 KW per fuel rod.

Once the total thermal power, $P_{tot}$, is determined (either by explicit input specification or by the point-reactor kinetics and decay-heat models in TRACE), it is applied to a 3D power distribution that is also input specified. In the following discussion of the 3D power shape we indicate array elements by the indices i, j, and k and also refer to two arrays that are used internally by the code.

The TRACE user does not need to be an expert on the array indexing or the internal arrays, but using this nomenclature here makes the explanation of TRACE's overall power shape normalization easier to follow. Throughout the discussion here the index i indicates a radial (or Cartesian x) direction in an individual HS component, j indicates the HS index in the horizontal plane of the core, and k indicates an axial location. The array references that contain complex offsets are given here simply to show that we are describing both axial and radial data. The appropriate format in which to input such combined data is described in Volume 1.

The 3D power distribution can be specified by one of two basic methods:

(1) input variable IPWRAD = 0: Three separate 1D power distributions are superimposed by multiplication of a HS 1D power shape RDPWR(i), a horizontal-plane HS-to-HS power shape CPOWR(j), and an axial 1D power shape ZPW(k), [i.e., RDPWR(i)*CPOWR(j)*ZPW(k)]. Arrays RDPWR and CPOWR are directly input; array ZPW is derived from input array ZPWTB as described below. Also, as described below, array ZPW may be further manipulated internal to the code to allow the user to specify the power shape at locations other than the basic HTSTR axial node locations.

(2) input variable IPWRAD = 1: A radial-axial 2D power shape ZPW(k+{i-1}*NZPWZ) and a horizontal-plane HS-to-HS 1D power shape CPOWR(j), [i.e., ZPW(k+{i-1}*NZPWZ)*CPOWR(j)] are superimposed by multiplication. In this case, array CPOWR is directly input, and array ZPW is derived from input array ZPWTB. As described below, array ZPW may be further manipulated internal to the code to allow the user to specify the power shape at locations other than the basic HTSTR axial and radial node locations. Complete details on the IPWRAD=1 option are given in Volume 1.

The ZPW(k) or ZPW(k+{i-1}*NZPWZ) power shape is defined by linearly interpolating it from an input-specified axial power-shape table, ZPWTB, having one or more power shapes that are a function of an input-specified signal-variable or control-block parameter. ZPWTB can be input defined with un-normalized power-density values at each location in the power shape for one or more power shapes when IPWDEP= 0. For IPWDEP = 0 and 1, TRACE normalizes the 3D power profile so that the total power is conserved. For IPWDEP = -1 or 1, signal variable/control block identifiers must be input for radial/axial power profiles. For IPWDEP = -1, there is no normalization and it is assumed that the signal variable/control block input for each axial and radial node gives the actual power density for that node. Only the IPWDEP = 0 option is currently supported in TRACE. The other IPWDEP options will be made available in future versions of TRACE as determined by user needs.

The 1D axial or 2D radial or Cartesian and axial locations in ZPWTB may or may not be defined at the node locations of the heat-structure component. This defining form is provided as a convenience to the user whose power-shape data may be defined at different locations from that of the HTSTR nodes. Internal to TRACE, the ZPW(k) or ZPW(k+{i-1}*NZPWZ) power shape at input-specified locations is converted to a power shape at the HS axial node locations, which is stored in internal array ZPWFB(k) (indexed as ZPWFB(k+{i-1}*{NZHTSTR+1}) when the IPWRAD = 1, which implies 2D power shape option is used).

The horizontal-plane power distribution CPOWR(j) is applied to j = 1, NPWR HS average-power elements which is referenced by the POWER component input. Horizontal originally referred to the geometry plane in a VESSEL component that is perpendicular to the axial direction. The user needs to be aware that the axial direction of the HS element and the hydraulic cells that it may be coupled to on either of its surfaces may not necessarily be the vertical (gravity-vector) direction.

The input-specified ZPWTB axial-power-shape table (or combined axial/radial when IPWRAD=1) has four aspects of its definition that need further clarification:

1) the input form for each of the table's |NZPWTB| data pairs,
2) the capability to define the z-direction dependence of the axial power shape with NZPWZ axial-shape values that may differ from the NZHTSTR node-row values defined for the HS components powered by this POWER component (this capability generalizes to the r- or x- direction when the 2D power shape option (IPWRAD=1) is used),
3) the capability for TRACE to define a more detailed z-direction dependence from the axial-power-shape table as permanent and temporary fine-mesh node rows are added by TRACE to the HS axial node rows shown in Figure 2-39, and
4) the NZPWI input option defining how the z-direction dependence of the axial-power shape is defined (this capability generalizes to the r- or x- direction when the 2D power shape option (IPWRAD=1) is used).

These four items are discussed in the following three paragraphs, where for simplicity we consider only the axial direction (IPWRAD=0). Essentially, we are describing the user's attempt to simulate a time dependent axial power profile which may be dependent upon the core average void fraction.

The axial-power-shape table (i.e., ZPWTB) defines one or more axial-power shapes as a function of a user-specified control parameter. An example of varying axial power profile are shown in Figure 2-45, where three different axial-power shapes are defined for three different core-region volume-averaged values of the gas volume fraction. In these power profiles core voiding progresses axially downward and locally reduces the neutronic power because of reduced neutron moderation. When the core becomes fully voided (a gas volume fraction of unity), the axial-power shape is flatter because of enhanced neutron leakage out of the core region. This axial-power-shape table example would be input specified having NZPWTB = 3 data pairs, with each data pair in the table having (1+NZPWZ) values; that is, a gas volume-fraction value and NZPWZ axial-power-shape value associated with the gas volume-fraction value.

To determine the axial-power shape with NZHTSTR values needed by TRACE (internal array ZPWFB), the value of the core-region volume-averaged gas volume fraction (defined by a input-specified signal variable evaluated by TRACE) is used by TRACE to interpolate (between two of the axial-power shapes in the ZPWTB table) a ZPW(k) axial-power shape linearly with NZPWZ values. Then the ZPW(k) axial-power shape is numerically integrated over each of the NZHTSTR axial intervals of the heat-transfer node-row cells to determine the NZHTSTR node-row average power densities that define the desired ZPWFB(k) axial-power shape. The axial power level for

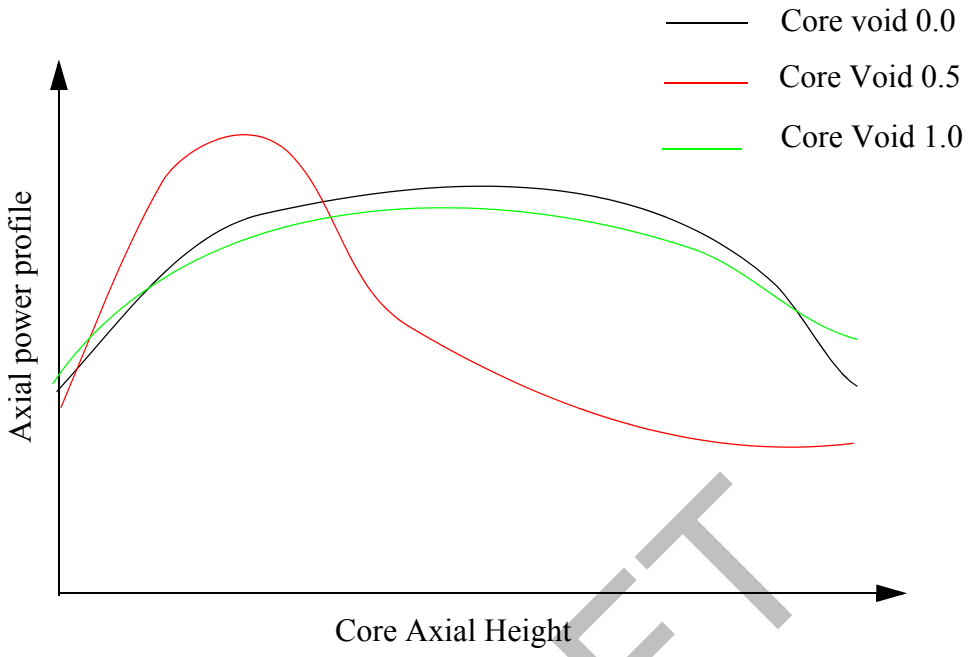


Figure. 2-45. Three Axial Power Profiles as a Function of Core Average Void Fraction.

each fine mesh node within a coarse mesh HS axial level is assumed to be the same. Therefore the axial power distribution is not affected by the adding or deleting of fine mesh axial levels for a given HS component.

Another aspect to be described in applying the axial-power-shape table ZPWTB is the NZPWI input option defining the z dependence of the NZPWZ power density values for each of its shapes. NZPWI has three option values: –1 defines a histogram power shape with step changes at axial locations ZPWZT(k); 0 defines a histogram power shape with step changes midway between axial locations ZPWZT(k); and 1 defines a power shape with linear variation between the power-density values at axial locations ZPWZT(k) for k=1,2,...,NZPWZ. In defining the ZPWZT(k) axial locations of the power densities in the axial-power shape, the user should define ZPWZT(1) = Z(1) and ZPWZT(NZPWZ) = Z(NZHTSTR+1), where Z(k) defines the axial cell edge locations of the NZHTSTR+1 coarse mesh axial levels as shown in Figure 2-38 and Figure 2-39.

Examples for axial power profiles are given in Figure 2-46 (i.e., NZPWI = -1), Figure 2-47 (i.e., NZPWI = 0), and Figure 2-48 (i.e., NZPWI = 1). These three examples are for a HTSTR component that is 3 m in height and the corresponding POWER component input would have NZPWZ = 4 for all three cases and the ZPWZT and ZPWTB input is the same for three cases. However, the resulting axial power profile is significantly different depending upon the value for NZPWI. The POWER component will normalize the user input ZPWTB. Assume that the HTSTR powered by this POWER component has NZHTSTR = 6 and DHTSTRZ = 0.5 for all six axial levels. For the NZPWI = -1, example in Figure 2-46, the integral under the axial power

profile would be 0.75*1 + 1.25*1 + 0.9*1 = 2.90m, which implies a normalization factor of 3.0 / 2.90. The resulting normalized axial power profile for this example would be ZPWTBABS(1:4) = 0.7759, 1.2931, 0.9310, 0.0517. Note for this example the power profile point at 3.0 m is not used.

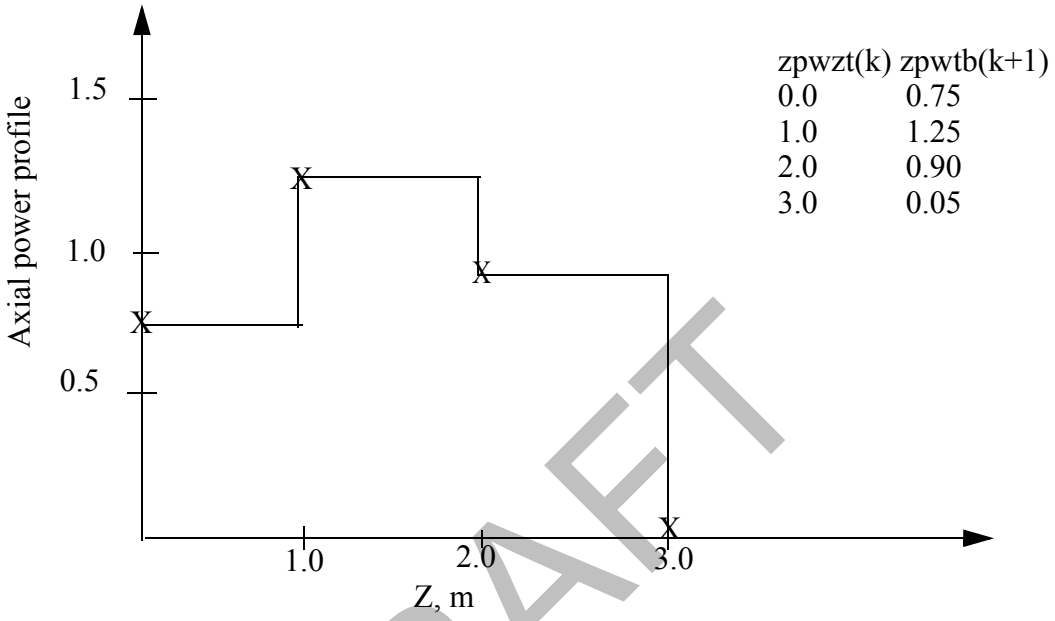


Figure. 2-46. Axial Power Profile for NZPWI = -1.

For the NZPWI = 0 example in Figure 2-47, the integral under the axial power profile would be 0.75*0.5 + 1.25*1 + 0.9*1 + 0.05* 0.5 = 2.55 m and the normalization factor for this axial power profile would be 3.0 / 2.55 = 1.1765. The normalized axial power profile would be ZPWTBABS(1:4) = 0.8824, 1.4706, 1.0588, 0.0588.

For the NZPWI = 1 example in Figure 2-48, the integral under the axial power profile would be 1*(1.25+0.75)/2 + 1*(0.9+1.25)/2 + 1*(0.05+0.9)/2 = 2.55m and the normalization factor for this axial power profile would be 3.0 / 2.55 = 1.1765. The normalized axial power profile would be ZPWTBABS(1:4) = 0.8824, 1.4706, 1.0588, 0.0588.

The power density in an HTSTR-component element node i, in horizontal-plane cell j and in axial node-row k is defined in TRACE by

$$P(i,j,k) = S \cdot P_{tot} \cdot RDPWR(i) \cdot CPOWR(j) \cdot POWZ(k) . \quad (2\text{-}70)$$

The scale factor, S, is defined to normalize the 3D power distribution to a core-region volume-averaged value of unity [for i = 1,NODES, j = 1,NPWR, and k = 1,NZHTSTR]; i.e.,

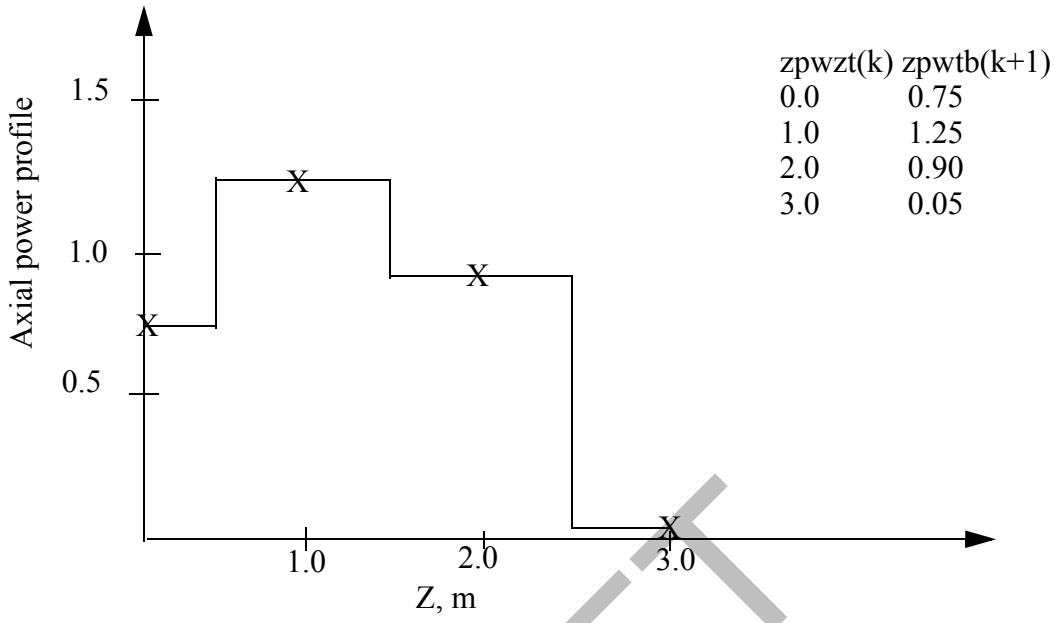


Figure. 2-47. Axial Power Profile for NZPWI = 0.



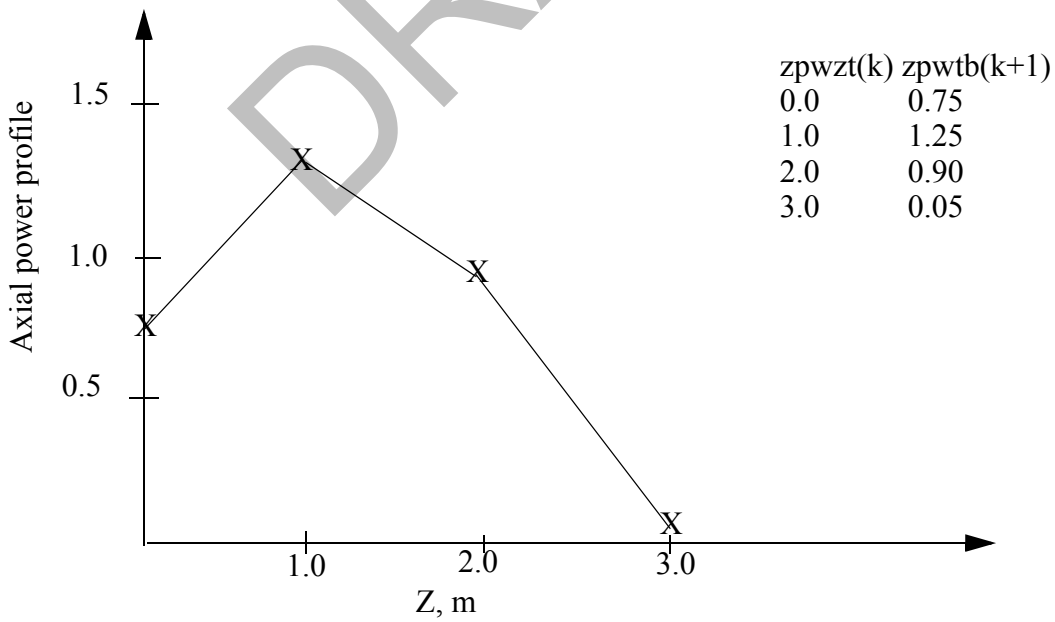


Figure. 2-48. Axial Power Profile for NZPWI = 1.

$$S = 1 / [\Sigma_{i,j,k}] \, AREA(i) \cdot RDPWR(i) \cdot RDX(j) \cdot CPOWR(j) \cdot DZ(k) \cdot POWZ(k)\}] \,, \quad (2\text{-}71)$$

where AREA(i) is the horizontal-plane power-region cross-sectional area of the HS element node i, RDX(j) is the number of average-power HS elements in powered HS j, and DZ(k) is the axial-direction length of the node-row heat-transfer cell k.

In addition to the NPWR different average-power HS elements in the horizontal plane, the TRACE user also can define hot rod HS elements that do not couple their thermal solution back to the hydraulic cells from which their surface boundary condition is defined. For these additional HS elements, the TRACE user input specifies a power-peaking factor, RPKF(j), that also is applied in the local power density (i.e., Eq. (2-70)).

If value input for IRPWTY > 10, then the reactivity coefficient arrays RCTF - fuel temperature reactivity coefficient array , RCTC - moderator temperature reactivity coefficient array, RCAL - void fraction/moderator density reactivity coefficient array, and RCBM - solute-concentration reactivity coefficient array must be input. These arrays represent four dimensional tables that provide the four reactivity feedback coefficients as function of the core average fuel temperature, the moderator temperature, the void-fraction/moderator density, and the solute-concentration. The format for these four dimensional tables are consistent with the four-dimensional interpolation routine used by TRACE. These four dimensional tables can be input as one, two, three, or four dimensional tables determined by the values input in the IRCJTB(1:4, 1:4) matrix. The array input IRCJTB(1:4, 1) is the dimensions of the fuel temperature reactivity feedback coefficient table (i.e., RCTF). The array input IRCJTB(1:4, 2) is the dimensions of the moderator temperature reactivity feedback coefficient table (i.e., RCTC). The array input IRCJTB(1:4, 3) is the dimensions of the void fraction/moderator density reactivity feedback coefficient table (i.e., RCAL). The array input IRCJTB(1:4, 4) is the dimensions of the fuel temperature reactivity feedback coefficient table (i.e., RCBM). Note IRCJTB(i,j) must be greater than zero.



The number of reactivity coefficients to be input for the RCTF array is determined by IRCJTB(1, 1) * IRCJTB(2, 1) * IRCJTB(3, 1) * IRCJTB(4, 1). In addition, for the RCTF array input there will be IRCJTB(1,1) fuel temperatures input, IRCJTB(2,1) moderator temperatures, IRCTB(3,1) void fractions, and IRCJTB(4,1) solute concentrations. Therefore, the total number of inputs for the RCTF array is IRCJTB(1,1) + IRCJTB(2,1) + IRCJTB(3, 1) + IRCJTB(4, 1) + IRCJTB(1, 1) * IRCJTB(2, 1) * IRCJTB(3, 1) * IRCJTB(4, 1). The total number of inputs for these four reactivity feedback coefficient tables is:

$$N_j = \sum_{i=1}^{4} IRCJTB(i, j) + \prod_{i=1}^{4} IRCJTB(i, j) \quad (2\text{-}72)$$

where, j = 1 is for the fuel temperature reactivity feedback coefficient, j = 2 is for the moderator temperature reactivity feedback coefficient, j = 3 is for the void-fraction/moderator density reactivity feedback coefficient, and j = 4 is for the solute-concentration reactivity feedback coefficient. The IRCJTB(1:4, 1:4) input must be greater than zero. An input of 1 for IRCJTB(i, j)

reduces the dimensionality for the $j^{th}$ reactivity feedback table. For example, an IRCJTB(1:4, 1) = 5, 1, 1, ,1, implies a one-dimensional fuel temperature reactivity table with five fuel temperature reactivity feedback coefficients at five fuel temperatures. An example RCTF input for this IRCJTB(1:4,1) would be RCTF(1:13) = 500.0, 600.0, 700.0, 800.0, 900.0, 0.0, 0.0, 0.0, -1.0e-07, -2.0e-07, -3.0e-07, -4.0e-07, -5.0e-7. Five fuel temperatures are input, then three zeros for the moderator temperature, void fraction, and solute-concentration, then the five fuel temperature reactivity feedback coefficients for a total of 13 inputs. Since there is only one entry for the moderator temperature, void fraction, and solute-concentration, it doesn't matter what values are input for this independent parameters. IRCJTB(i, j) = 1, implies that the jth reactivity feedback coefficient table is not a function of the $i^{th}$ independent variable parameter (i.e., i = 1 implies fuel temperature, i = 2 implies moderator temperature, i = 3 implies void fraction/moderator density, and i = 4 implies solute-concentration).

An example, for the POWER component input with reactivity feedback tables is given in .Table 2-22. For this example, the fuel temperature reactivity coefficient table dimensions is input as IRCJTB(1:4, 1) = 2, 2, 1, 1, which implies 10 inputs for the RCTF array (i.e., 2 fuel temperatures, 2 moderator temperatures, one void fraction, and one solute concentration, and 4 fuel temperature reactivity coefficients). This implies that the fuel temperature reactivity feedback coefficient table is a two-dimensional table and has the values given in Table 2-23

**Table 2-22. POWER Component with Reactivity Feedback Input**

```
*  type          num             id      ctitle
  power          901            901   reactor power
* npowr
   1
* htnid
   1e
*       irpwty          ndgx          ndhx          nrts          nhist
           11             0            71             5              1
*         q235          q239          q238          qavg         r239pf
    2.0000e+02    2.0000e+02    2.0000e+02    2.0000e+02    8.0000e-01
*       fisphi          rans          fp235         fp238
    3.0000e+00    1.0000e+00    9.7000e-01    3.0000e-02
*       izpwtr        izpwsv        nzpwtb        nzpwsv        nzpwrf
            0             1             1             0             0
*       ipwrad        ipwdep
            0             0
*        nzpwz         nzpwi        nfbpwt
            0             0             0
*        react         tneut         rpwoff        rrpwmx        rpwscl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    1.0000e+00
*       rpowri         zpwin         zpwoff        rzpwmx
   5.02655e+04    0.0000e+00    0.0000e+00    0.0000e+00
*       extsou          pldr          pdrat         fucrac
    0.0000e+00    0.0000e+00    1.3000e+00    7.0000e-01
*  ircjtb(1,j)   ircjtb(2,j)   ircjtb(3,j)   ircjtb(4,j)        ibu(j)
            2             2             1             1             0
            2             2             1             1             0
            1             1             2             1             0
            1             1             1             1             0
*    ifbtyp(1)     ifbtyp(2)     ifbtyp(3)
            0             0             0
*    ircjfm(1)     ircjfm(2)     ircjfm(3)     ircjfm(4)        isnotb
            0             0             0             0             0
*       powexp          bpp0          bpp1          bcr0          bcr1
    2.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
* rdpwr * f   1.0000e+00e
* cpowr *     1.0000e+00e
```

```
* zpwtb * f   1.0000e+00e
* rctf  *     5.0000e+02   1.0000e+03    300.0         400.0  r02 0.0000e+00s
             -1.0e-07      -2.0e-07     -3.0e-07      -4.0e-07e
* rctc  *     400.0        600.0         300.0         500.0  r02 0.0000e+00s
             -6.0e-07     -8.0e-07      -7.0e-07      -9.0e-07e
* rcal  * r03 0.0000e+00   0.4           0.0          -1.0e-04      -2.0e-04e
* rcbm  * f   0.0000e+00e
```

**Table 2-23. Fuel temperature Reactivity Feedback Coefficients (i.e., RCTF input).**

| $T_f$(K) | $T_m$(K) | $\frac{\partial k_{eff}}{\partial T_f}$ (1/K) |
|---|---|---|
| 500 | 300 | $-10^{-7}$ |
| 1000 | 300 | $-2\times10^{-7}$ |
| 500 | 400 | $-3\times10^{-7}$ |
| 1000 | 400 | $-4\times10^{-7}$ |

The moderator temperature table points are given in Table 2-24.

**Table 2-24. Moderator Temperature Reactivity Feedback Coefficients (i.e., RCTC input).**

| $T_f$(K) | $T_m$(K) | $\frac{\partial k_{eff}}{\partial T_m}$ (1/K) |
|---|---|---|
| 400 | 300 | $-6\times10^{-7}$ |
| 600 | 300 | $-8\times10^{-7}$ |
| 400 | 500 | $-7\times10^{-7}$ |
| 600 | 500 | $-9\times10^{-7}$ |

The void fraction reactivity feedback coefficient table for this example is given in Table 2-25.

**Table 2-25. Void Fraction Reactivity Feedback Coefficients (i.e. RCAL input).**

| $\alpha$ | $\frac{\partial k_{eff}}{\partial \alpha}$ |
|---|---|
| 0.0 | -1x10$^{-4}$ |
| 0.4 | -2x10$^{-4}$ |

The interpolation formula used for the fuel temperature reactivity coefficient table is linear surface interpolation. For the 2D table for the fuel temperature reactivity feedback coefficient given in Table 2-23, the formula would be:

$$\frac{\partial k_{eff}}{\partial T_f}[T_f, T_m] = f_{11}(1-w_f)(1-w_m) + f_{21}w_f(1-w_m) + f_{21}(1-w_f)w_m + f_{22}w_f w_m \quad (2\text{-}73)$$

where,

$f_{11}$ = -10$^{-7}$ is $\frac{\partial k_{eff}}{\partial T_f}$ at $T_f = T_{f1}$ = 500 K and $T_m = T_{m1}$ = 300 K.

$f_{21}$ = -2x10$^{-7}$ is $\frac{\partial k_{eff}}{\partial T_f}$ at $T_f = T_{f2}$ = 1000 K and $T_m = T_{m1}$ = 300 K.

$f_{12}$ = -3x10$^{-7}$ is $\frac{\partial k_{eff}}{\partial T_f}$ at $T_f = T_{f1}$ = 500 K and $T_m = T_{m2}$ = 400 K.

$f_{22}$ = -4x10$^{-7}$ is $\frac{\partial k_{eff}}{\partial T_f}$ at $T_f = T_{f2}$ = 1000 K and $T_m = T_{m2}$ = 400 K.

$w_f = \frac{T_f - T_{f1}}{T_{f2} - T_{f1}}$, linear weighting factor for the fuel temperature.

$w_m = \frac{T_m - T_{m1}}{T_{m2} - T_{m1}}$ , linear weighting factor for the moderator temperature.

The weighting factors are restricted to be greater than or equal to zero and less than or equal to one, so there is no extrapolation outside of the table. For this example, the fuel temperature reactivity feedback coefficient at core average fuel temperature of 600K and a moderator temperature of 350K would be:

$$\frac{\partial k_{eff}}{\partial T_f}[600, 350] = 0.4f_{11} + 0.1f_{21} + 0.4f_{12} + 0.1f_{22} = -2.2 \cdot 10^{-7} \quad (2\text{-}74)$$

For a four dimensional table, the interpolation formula is expanded to include linear weighting factors for each of the four dimensions.

$$f[T_f,\ T_m,\ \alpha,\ B] = \sum_{i=I}^{I+1}\left[\sum_{j=J}^{J+1}\left[\sum_{k=K}^{K+1}\left[\sum_{l=L}^{L+1} f_{ijkl}\cdot w_{fi}\cdot w_{mj}\cdot w_{\alpha k}\cdot w_{Bl}\right]\right]\right] \tag{2-75}$$

where,
$f_{ijkl}$ = reactivity feedback coefficient at point *i, j, k, l*.

$w_{fI}$ = fuel temperature linear weighting factor at $i$ = I $\quad w_{fI} = \dfrac{T_{fi+1} - T_f}{T_{fi+1} - T_{fi}}$ .

$w_{fI+1}$ = fuel temperature linear weighting factor at $i$ = I+1 $\quad w_{fI+1} = \dfrac{T_f - T_{fi-1}}{T_{fi} - T_{fi-1}}$ .

$w_{mJ}$ = moderator temperature linear weighting factor at $j$ = J $\quad w_{mJ} = \dfrac{T_{mj+1} - T_m}{T_{mj+1} - T_{mj}}$ .

$w_{mJ+1}$ = moderator temperature linear weighting factor at $j$ = J+1 $\quad w_{mJ+1} = \dfrac{T_m - T_{mj-1}}{T_{mj} - T_{mj-1}}$ .

$w_{\alpha K}$ = void fraction linear weighting factor at $k$ = K $\quad w_{\alpha K} = \dfrac{\alpha_{k+1} - \alpha}{\alpha_{k+1} - \alpha_k}$ .

$w_{\alpha K+1}$ = void fraction linear weighting factor at $k$ = K+1 $\quad w_{\alpha k+1} = \dfrac{\alpha - \alpha_{k-1}}{\alpha_k - \alpha_{k-1}}$ .

$w_{BL}$ = void fraction linear weighting factor at $l$ = L $\quad w_{BL} = \dfrac{B_{l+1} - B}{B_{l+1} - B_l}$ .

$w_{BL+1}$ = void fraction linear weighting factor at $l$ = L+1 $\quad w_{BL+1} = \dfrac{B - B_{l-1}}{B_l - B_{l-1}}$ .

This formula is applied to the two fuel temperature points that contain $T_f$ (i.e., $T_{fI} \le T_f \le T_{fI+1}$), the two moderator temperature points that contain $T_m$ (i.e., $T_{mJ} \le T_m \le T_{mJ+1}$), the two void fraction points that contain $\alpha$ (i.e., $\alpha_K \le \alpha \le \alpha_{K+1}$), and the two solute concentration points that contain $B$ (i.e., $B_L \le B \le B_{L+1}$). Again, the weighting factors are restricted to be greater than zero or equal to zero and less than or equal to one, which implies no extrapolation outside of the table bounds.

The IBU(j) array that is input in the POWER component determines the units of the solute-mass concentration in reactivity feedback tables j = 1, 2, 3, 4, where j = 1 implies fuel temperature reactivity feedback coefficient table, j = 2 implies moderator temperature reactivity feedback coefficient table, j = 3 implies void fraction/moderator density reactivity feedback coefficient, and j = 4 implies solute-mass concentration reactivity feedback coefficient table. IBU(j) = -2 or 0

implies that the solute-mass concentration is $B_r$ - parts solute mass per million parts liquid-coolant mass (ppm) and IBU(j) = -1 or 1 implies that solute-mass concentration is $B_m$ - the density of mass of solute in the coolant-channel volume (kg/m$^3$, lb$_m$/ft$^3$). IBU(4) = -2 or - 1 implies that the solute-mass concentration reactivity coefficient is in terms of the change in $B_r$ and IBU(4) = 0 or 1 implies the solute-mass concentration reactivity coefficient is in terms of the change in $B_m$.



The form of the reactivity coefficient is given by the IRCJFM(j) array. IRCJFM(j) = 0 implies that the j$^{th}$ reactivity coefficient table is of form $\frac{\partial k_{eff}}{\partial x}$. IRCJFM(j) = 1 implies that the j$^{th}$ reactivity coefficient table is of form $\frac{1}{k_{eff}} \cdot \frac{\partial k_{eff}}{\partial x}$. IRCJFM(j) = 2 implies that the j$^{th}$ reactivity coefficient table is of form $x \cdot \frac{\partial k_{eff}}{\partial x}$. IRCJFM(j) = 3 implies that the j$^{th}$ reactivity coefficient table is of form $\frac{x}{k_{eff}} \cdot \frac{\partial k_{eff}}{\partial x}$. For j = 1, the fuel temperature reactivity coefficient table, $x$ is equal core average fuel temperature, $T_f$. For j = 2, the moderator temperature reactivity coefficient table, $x$ is equal core average moderator temperature, $T_m$. For j = 3, the void fraction/moderator density reactivity coefficient table, $x$ is equal core average void fraction or moderator density, $T_m$ or $\rho_m$. For j = 4, the solute-concentration reactivity coefficient table, $x$ is equal solute mass concentration, $B_r$ or $B_m$.



Note IBU(4) input determines whether or not for j = 4, $B_r$ or $B_m$ is x in the form of the reactivity feedback coefficient. For j = 3, the IFBTYP(3) determines if x is the core average void fraction or moderator density. If IFBTYP(3) = 0, then the j = 3 reactivity feedback coefficient is in terms of changes in core average void fraction. If IFBTYP(3) = 1, then the j = 3 reactivity feedback coefficient is in terms of changes in moderator density. IFBTYP(1) is currently not used. IFBTYP(2) = 0 implies that the moderator temperature is based on void weighted liquid and vapor phase temperature. IFBTYP(2) = 1 implies the moderator temperature is based on the liquid phase temperature.

# *PRIZER Component*

A PWR pressurizer is a large fluid-volume reservoir that maintains the coolant pressure within the reactor primary-coolant system and compensates for changes in the coolant volume caused by system transients. During normal operation, this reservoir contains the highest-energy fluid in the primary-coolant system. It is usually maintained 50–60% full of saturated liquid that is pressurized by the saturated steam (vapor) above it. The pressurizer controls the primary-coolant system pressure by hydraulic coupling through a long surge line connected to one of the hot legs.

The PRIZER component simulates the pressurizer reservoir. This component normally models only the pressurizer reservoir with the connecting surge line modeled by a PIPE or TEE component. A typical noding diagram in Figure 2-49 shows that the PRIZER component may be connected at both its junctions to other 1D hydraulic components. The top or the bottom reservoir may be closed by setting JUN1 or JUN2 to zero. This creates a deadend with zero flow areas and zero velocities. This can also be accomplished by connecting the junction to a zero velocity or mass-flow boundary-condition FILL component. The bottom of the PRIZER component is connected to the surge line. For TRACE steady-state calculations, the PRIZER component is replaced automatically with the equivalent of a BREAK component at each of its junctions. The input-specified thermal-hydraulic conditions in the PRIZER component during steady-state calculations remain unchanged except for the component's wall temperature, which is calculated by conduction heat transfer to obtain a steady-state, wall-temperature profile.

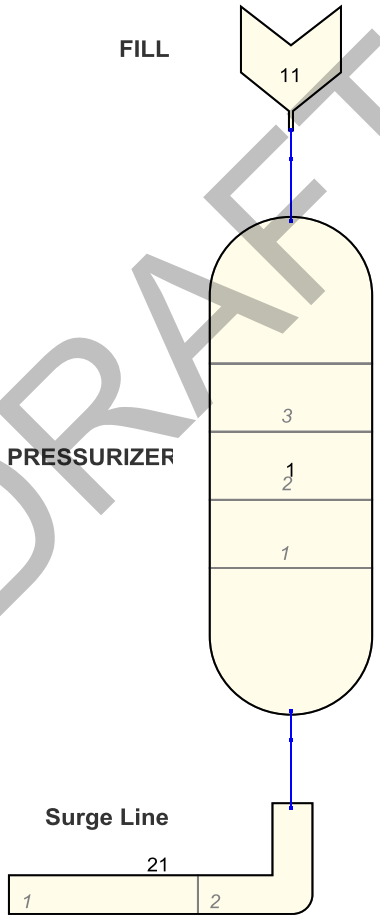


Figure. 2-49. PRIZER-component noding diagram.

The PRIZER component includes heater/sprayer logic to serve as a system pressure controller but not to simulate the actual heater/sprayer hardware. The user input specifies a desired-pressure set point, PSET, and a pressure deviation, DTMAX. Heater/sprayer logic adds or removes a

maximum power of QHEAT when the PRIZER pressure is lower or higher than PSET, respectively. The power that is input to the PRIZER-component fluid is proportional to the difference between PSET and P(1), the pressure in cell 1; that is,

$$Qin = \min[\ 1, \max[\ -1, \{\ PSET - P(1)\ \} / DPMAX\ ]] \cdot QHEAT, \tag{2-76}$$

with the magnitude of Qin less than or equal to QHEAT. This power is distributed over all PRIZER-component fluid cells having liquid. The fraction of power input to the liquid in each mesh cell is equal to the fraction of the PRIZER's total liquid mass that is in that cell. If pressure control is not desired, then set QHEAT to zero. The sprayers can be modeled directly using a pipe with side junctions. The control system can then be used to trip the spray on and off and control the flowrate.



Power is not added to the liquid if the collapsed liquid level $X_L$ is less than the input-specified minimum level, ZHTR. The collapsed liquid level is determined as follows. The total liquid volume is summed over all mesh cells of the PRIZER component and then sequentially the volume $Vol_j$ of each cell, starting at the bottom cell NCELLS, is subtracted from that total liquid volume until the remainder of the total liquid volume is less than or equal to the volume of the next cell I. The collapsed liquid level is the summed length of the collapsed liquid in those NCELLS – I + 1 cells

$$X_L = \sum_{j=NCELLS}^{I-1} \Delta X_j + \Delta X_I \cdot \frac{\left( Vol_L - \sum_{i=NCELLS}^{I-1} Vol_i \right)}{Vol_I} \tag{2-77}$$

where $Vol_L = \sum_{j=1}^{NCELLS} (1-\alpha_j) \cdot Vol_j$ and $\alpha_j$ is the gas volume fraction in volume $Vol_j$ of each cell *j*. Note that $X_L$ is the collapsed-liquid coolant-channel length and not the vertical height of the collapsed liquid.

Wall-friction coefficients are calculated by specifying an NFF friction-factor correlation option value at each cell interface of the component. The homogeneous-flow, friction-factor correlation option |NFF| = 1 is suggested for the PRIZER-component wall. Irreversible form losses resulting from abrupt flow-area changes can be evaluated when NFF < 0 is input. Irreversible form losses resulting from non-abrupt flow-area changes and flow around internal sprayer/heater hardware can be modeled by FRIC (and RFRIC when NFRC1 = 1) additive loss coefficients at each cell interface.

The text output edit for a PRIZER component is similar to that of a PIPE component with the addition of four variables specific to the pressurizer: (1) discharge liquid volumetric flow, (2) total liquid volume discharged, (3) collapsed liquid level, and (4) heater/sprayer power input to the pressurizer liquid at the time of the output edit.

# *PUMP Component*

The PUMP component describes the interaction of the system fluid with a centrifugal pump. It calculates the pressure differential across the pump impeller and the pump impeller's angular velocity as a function of the fluid flow rate and fluid properties. The model can simulate any centrifugal pump and allows for the inclusion of two-phase effects.

The pump is modeled by a 1D hydraulic component with N = NCELLS ≥ 2 mesh cells. Figure 2-50 shows a typical noding diagram for the PUMP component. The pump impeller's source of momentum to the fluid is modeled as a source to the motion equation of the interface between cells 1 and 2. The momentum source is positive for normal pump operation where a pressure rise occurs from cell 1 to cell 2. This results in increasing cell numbers and a positive coolant velocity in the normal flow direction.



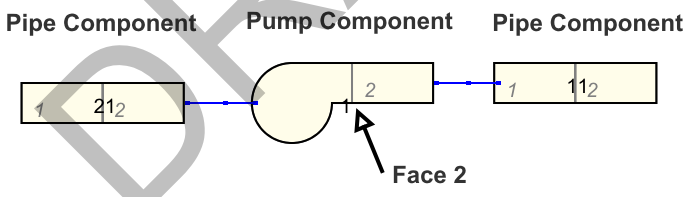


Figure. 2-50. PUMP-component noding diagram.

The following considerations were made in creating the PUMP component:

1) compatibility with adjacent components should be maximized,
2) choking at the pump-impeller interface should be predicted automatically by the pump-curve data, and
3) the calculated pressure rise across the pump-impeller interface should agree with that measured at steady-state conditions.

The first two criteria precluded the use of a lumped-parameter model. The PUMP component is really nothing more than a PIPE component with pump-curve correlations defining the pump-impeller interface momentum source, SMOM.

The PUMP-component model is identical to the 1D PIPE-component model except that the motion equations for the interface between cells 1 and 2 are approximated by

$$\frac{V_l^{n+1} - V_l^n}{\Delta t} = \frac{\left[ P_l^{n+1} - P_2^{n+1} + \left\{ \Delta P^n + (\delta \Delta P / \delta V)^n \cdot (V_l^{n+1} - V_l^n) \right\} \right]}{\bar{\rho}_{m,(3/2)}^n \cdot \Delta X_{3/2}} - g \cdot \cos\theta \qquad (2\text{-}78)$$

and

$$V_g^{n+1} = V_l^{n+1} , \qquad (2\text{-}79)$$

where $\Delta P^n + (\delta \Delta P / \delta V)^n \cdot (V_l^{n+1} - V_l^n)$ is the SMOM first-order approximated pressure rise momentum source across the pump-impeller interface at the end of timestep $n+1$ evaluated from the pump-curve correlations. The steady-state solution form of Eq. (2-78) is

$$\Delta P = P_2 - P_1 + \bar{\rho}_{m \cdot 3/2} \cdot g \cdot \Delta X_{3/2} \cdot \cos\theta , \qquad (2\text{-}80)$$

which is the desired model. Friction and form losses do not enter explicitly into the pump-impeller interface motion equation. Therefore, wall drag and additive friction losses are not modeled between the centers of cells 1 and 2 [NFF(2) = 0 and FRIC(2) = 0.0].

The pressure rise $\Delta P^n$ and its derivative with respect to the coolant velocity $((\delta P)/(\delta V))^n$ for the pump-impeller interface is evaluated only once at the beginning of each timestep. This momentum source is applied in the coolant motion equation at the pump-impeller interface.

The correlation pump curves describe the pump head and torque response as a function of fluid volumetric flow and pump-impeller speed. Homologous curves (one curve segment represents a family of curves) are used for this description because of their simplicity. These curves describe, in a compact manner, all operating states of the pump obtained by combining positive or negative pump-impeller angular velocities with positive or negative fluid volumetric flows.

The following definitions are used in the subsequent development:

H = the pump head, $(\Delta P)/\rho_m$ ({Pa m$^3$ kg$^{-1}$, m$^2$ s$^{-2}$, or N m kg-$^{1}$}, lbf ft lbm$^{-1}$),

Q = the impeller-interface volumetric flow rate, $A_{3/2} \cdot V_{3/2}$ (m$^3$ s$^{-1}$, ft$^3$ s$^{-1}$), and

Ω = the pump-impeller angular velocity (rad s$^{-1}$, rpm),

where $\Delta P$ is the pressure rise across the pump-impeller interface and $\rho_m$ is the impeller-interface upstream coolant-mixture density. To allow one set of curves to be used for a variety of pumps, the following normalized quantities are used:

$$h = H/H_R \quad ,$$

$$q = Q/Q_R \quad , \text{ and}$$

$$\omega = \Omega/\Omega_R \tag{2-81}$$

where $H_R$ is the rated head RHEAD, $Q_R$ is the rated volumetric flow RFLOW, and $\Omega_R$ is the rated pump-impeller rotational speed ROMEGA for the pump. The pump similarity relations (Ref. 2-4) shows that

$$h/\omega^2 = f(q/\omega) \ . \tag{2-82}$$

For small ω this correlation is not satisfactory, and the following combination of variables is used,

$$h/q^2 = f(\omega/q) \ . \tag{2-83}$$

Eq. (2-82) is used in the range $0 \le |q/\omega| \le 1$ and results in two separate curves, one for $\omega > 0$ and one for $\omega < 0$. Eq. (2-83) is used in the range $0 \le |\omega/q| \le 1$ and yields two separate curves, one for $q > 0$ and one for $q < 0$. The four resulting curve segments, as well as the curve selection logic used in TRACE, are shown in Table 2-26.

To account for two-phase coolant effects on pump performance, the pump curves are divided into two separate regimes. Data indicate that two-phase coolant pump performance in the gas volume-fraction range of 0.2 to 0.8 is degraded significantly in comparison with its performance at gas volume fractions outside this range. One set of curves describes the pump performance for single-phase coolant (at a 0.0 or 1.0 gas volume fraction), and another set describes the two-phase, fully degraded performance at gas volume fractions between 0.0 and 1.0. For single-phase conditions, the curve segments for correlation Eq. (2-82) are input as HSP1 for $\omega > 0$ and HSP4 for ωþ< 0, and Eq. (2-83) curve segments are input as HSP2 for $q > 0$ and HSP3 for $q < 0$. The two-phase, fully degraded version of Eq. (2-82) is input as curve HTP1 for $\omega > 0$ and HTP4 for $\omega < 0$ and Eq. (2-83) curve segments are input as HTP2 for $q > 0$ and HTP3 for $q < 0$.

The pump head at any gas volume fraction is calculated from the relationship,

$$H = H_1 - M(\alpha) \cdot [H_1 - H_2] \quad , \tag{2-84}$$

where

H = the total pump head,

$H_1$ = $h_1 H_R$ = the single-phase pump head ($h_1$ is the non-dimensional head from the single-phase homologous head curves),

$H_2$ = $h_2 H_R$ = the two-phase fully degraded pump head ($h_2$ is the non-dimensional head from the fully degraded homologous head curves),

$M(\alpha)$ = the head degradation multiplier HDM, and

$\alpha$ = the upstream gas volume fraction.

At this point, no knowledge of the coolant mixture density is required to calculate H from the homologous head curves. However, the upstream coolant mixture density is used to convert the total pump head H to the pressure rise across the pump impeller, by the definition of Eq. (2-78).

The development of homologous torque curves parallels the previous development for homologous head curves. The dimensionless hydraulic torque is defined by:

$$\beta = T_{hy} / T_R \quad , \tag{2-85}$$

where $T_{hy}$ is the hydraulic torque and $T_R$ is the rated torque RTORK. The convention used is that a positive $T_{hy}$ works to retard positive pump angular velocity. The dimensionless torque β correlated as either β / ω or β / q just as the dimensionless head h was correlated. For single-phase conditions, the correlations yield the corresponding four curve segments TSP1, TSP2, TSP3, and TSP4. The two-phase fully degraded correlations produce four corresponding curves: TTP1, TTP2, TTP3, and TTP4. The homologous torque-curve segments are correlated in the same manner as the head-curve segments shown in Table 2-26 (replace h with β). For the special case of ω = q = 0.0, TRACE sets $\beta_1 = \beta_2 = 0.0$.

**Table 2-26. Definitions of the four curve segments that describe the homologous pump-head curves[a]**

| Curve Segment | $\left\|\frac{q}{\omega}\right\|$ | $\omega$ | $q$ | Correlation |
|---|---|---|---|---|
| 1 | $\leq 1$ | $> 0$ | | $\frac{h}{\omega^2} = f\left(\frac{q}{\omega}\right)$ |
| 4 | $\leq 1$ | $< 0$ | | |

**Table 2-26. Definitions of the four curve segments that describe the homologous pump-head curves[a]**

| Curve Segment | $\left\|\frac{q}{\omega}\right\|$ | $\omega$ | $q$ | Correlation |
|---|---|---|---|---|
| 2 | > 1 | | > 0 | $\frac{h}{q^2} = f\left(\frac{\omega}{q}\right)$ |
| 3 | > 1 | | < 0 | |

a. For the special case of both ω = 0.0 and q = 0.0, the code sets h= 0.0

The single-phase torque $T_1$ is dependent upon the fluid density and is calculated from

$$T_1 = \beta_1 \cdot T_R \cdot (\rho_m / \rho_R) \quad , \tag{2-86}$$

where $\beta_1$ is the dimensionless hydraulic torque from the single-phase homologous torque curves, $\rho_m$ is the pump upstream mixture density, and $\rho_R$ is the rated density RRHO. The density ratio is needed to correct for the density difference between the pumped fluid and the rated condition. Similarly, two-phase fully degraded torque $T_2$ is obtained from

$$T_2 = \beta_2 \cdot T_R \cdot (\rho_m / \rho_R) \quad , \tag{2-87}$$

where $\beta_2$ is the dimensionless hydraulic torque from the two-phase fully degraded homologous torque curves. For two-phase conditions, the pump-impeller torque is calculated from

$$T = T_1 - N(\alpha) \cdot [T_1 - T_2] \quad , \tag{2-88}$$

where T is the total pump-impeller torque and N(α) is the torque degradation multiplier TDM.

In addition to the homologous head and torque curves, the head and torque degradation multipliers in Eq. (2-84) and Eq. (2-88) are input specified. These functions of gas volume fraction are nonzero only in the gas volume-fraction range where the pump head and torque are either partially or fully degraded.

The PUMP component treats the pump-impeller angular velocity $\Omega$ as a constant value that is input each timestep (and may vary) when the motor is energized. After the drive motor is tripped, the time rate of change of the pump-impeller angular velocity $\Omega$ is proportional to the sum of the moments acting on it and is calculated from

$$I\frac{\partial \Omega}{\partial t} = -\sum_i T_i = -(T + T_f) \, , \tag{2-89}$$

where I is the combined impeller, shaft, and motor-assembly moment of inertia EFFMI, T is the hydraulic torque on the pump-impeller, and $T_f$ is the torque caused by friction and by the bearing and windage.

$$T_f = C_0 + C_1\frac{\Omega}{\Omega_R} + C_2\frac{\Omega|\Omega|}{\Omega_R^2} + C_3\frac{\Omega^3}{\Omega_R^3}\,, \tag{2-90}$$

where $C_0$, $C_1$, $C_2$, and $C_3$ are input constants TFR0, TFR1, TFR2, and TFR3, respectively. If the pump-impeller angular velocity (pump speed) drops below the input specified value of TFRB, then a second set of constants are used to determine $T_f$.

$$T_f = C'_0 + C'_1\frac{\Omega}{\Omega_R} + C'_2\frac{\Omega|\Omega|}{\Omega_R^2} + C'_3\frac{\Omega^3}{\Omega_R^3}\,, \tag{2-91}$$

where $C'_0$, $C'_1$, $C'_2$, and $C'_3$ are input constants TRFL0, TRFL1, TRFL2, and TRFL3, respectively. The constants $C_0$, $C_1$, $C_2$, $C_3$, $C'_0$, $C'_1$, $C'_2$, and $C'_3$ should be determined from experimental data. As the pump speed approaches zero, the $C_0$ and $C'_0$ contributions are linearly decreased to zero to ensure that there are no friction losses at a pump speed of zero. The reduction of $C_0$ and $C'_0$ contributions to $T_f$ begins when the pump speed drops to 1/10 of the rated speed.

The hydraulic torque T is evaluated using the homologous torque curves and Eq. (2-88); it is a function of the volumetric flow, the upstream gas volume fraction, the upstream coolant-mixture density, and the pump-impeller angular velocity. For timestep n+1, Eq. (2-89) is evaluated explicitly as

$$\Omega^{n+1} = \Omega^n - \frac{\Delta t}{I}\left[T(Q\,,\alpha\,,r\,,\Omega) + C_0 + C_1\frac{\Omega^n}{\Omega_R} + C_2\frac{\Omega^n|\Omega^n|}{\Omega_R^2} + C_3\frac{(\Omega^n)^3}{\Omega_R^3}\right]. \tag{2-92}$$

The wall heat-transfer NODES, wall-friction NFF, and CHF-calculation ICHF options are the same for the PUMP component as for the PIPE component. In addition, the following options are specified: pump type IPMPTY, trip-controlled pump-motor action IPMPTR, reverse rotation IRP, degradation IPM, and pump-curve type OPTION. Input variables IPMPTR and NPMPTB specify, respectively, the controlling trip ID number for pump-trip action and the number of pairs of points in the pump-speed table PMPTB. If IPMPTR = 0, no pump-trip action occurs, and the pump runs for the entire calculation at the constant pump-impeller angular velocity (rotational speed) OMEGAN. If IPMPTR ≠ 0 and the IPMPTR trip is initially OFF, the pump-impeller angular velocity is defined by signal variable or control block ID number NPMPSD or by OMEGAN when NPMPSD = 0. If the IPMPTR trip is OFF after being ON, OMGOFF defines the pump-impeller angular velocity. In all situations, the rate of change of the pump-impeller angular velocity is constrained by its maximum rate ROMGMX.

The pump model accounts for energy deposited to the fluid though irreversible losses caused by friction in the pump impellers by adding source terms to the liquid and vapor energy equations. Users can turn this option on by setting the name list variable PumpFricQ = .TRUE. For normal pump operation the heat is added to cell 2, for reverse pump operation the heat is added to cell 1. The heat generated is determined by

$$q_{fric} = T\Omega - H\dot{m} \tag{2-93}$$

There are several restrictions and limitations in the current version of the PUMP component. Because there is no pump motor torque vs. pump-impeller speed model, the pump-impeller rotational speed is assumed to be input if the pump motor is energized. Pump noding is restricted so that the cell numbers increase in the normal flow direction where the total number of component cells NCELLS > 2, the pump momentum source is located at the interface between cells 1 and 2 of the PUMP component, and the wall friction and additive loss coefficient between cells 1 and 2 are zero [NFF(2) = 0 and FRIC (2) = 0.0]. A flow-area change should not be modeled between cells 1 and 2. Finally, the pump-head degradation multiplier and the torque degradation multiplier are assumed to apply to all operating states of the pump.

A PIPE, VALVE, and PUMP component can be used as a single junction component. This is done by setting NCELLS to 0. A single junction component is just that, a junction without volume. To use any of these components as a single junction the user has to set the NAMELIST variable USESJC=1. The PIPE, VALVE, and PUMP components can all have side junctions when NAMELIST variable USESJC is set to 2 or 3 (see ***PIPE Component*** above for more information on side junction).



## *Pump Types*

Six types of pumps are available. For pump type IPMPTY = 0, the pump-impeller interface coolant-mixture velocity is defined by signal variable or control block NPMPSD when trip IPMPTR is OFF and by the PMPTB coolant-mixture velocity table when trip IPMPTR is ON. For pump type IPMPTY = 1, the pump-impeller angular velocity is defined by OMEGAN when NPMPSD = 0 or by signal variable or control block NPMPSD when trip IPMPTR is OFF and by the PMPTB pump-speed table when trip IPMPTR is ON. The independent variable for the PMPTB table may be elapsed time since the trip was set ON or any signal variable or control block. For pump type IPMPTY = 1, the torque calculation is not used. Pump type IPMPTY = 2 is similar to IPMPTY = 1 except that a PMPTB pump-speed table is not input. Instead, the pump-impeller angular velocity is calculated from Eq. (2-92) when trip IPMPTR is ON. For pump type IPMPTY = 3, the pump motor torque is controlled by the control system. This option requires the pump-motor torque table abscissa-coordinate variable ID which defines the independent-variable parameter in the pump motor torque table. For pump type IPMPTY = 10, the control blocks set the value of the liquid and vapor velocity. These values are set with control blocks ICBVL and ICBVV respectively. Pump type IPMPTY = 11 is the same as IPMPTY = 10 except the control blocks set the value of the liquid and vapor mass flow rates. Both of these pump types are single

junction components (SJC). To use them ncells is set to zero and the cell volume and length is set to zero.

If the IRP = 1 reverse-rotation option is specified, the pump-impeller is allowed to rotate in both the forward and reverse directions. If reverse rotation is not allowed by specifying IRP = 0, the pump-impeller will rotate in the forward direction only. In this case, if negative rotation is calculated (for pump type IPMPTY = 2 with trip IPMPTR ON), the pump-impeller angular velocity is set to zero. If IRP = 0 and a negative pump-impeller angular velocity is defined by input parameters, fatal error messages will be printed by subroutines PUMPD, PUMPX, and PUMPSR, and the calculation will abort.



If the IPM = 1 degradation option is specified, two-phase degraded pump head and torque are calculated from Eq. (2-84) and Eq. (2-88). If the degradation option is turned off by IPM = 0, only the single-phase pump head and torque homologous curves are used [equivalent to setting $M(\alpha)$ and $N(\alpha)$ to zero in Eq. (2-84) and Eq. (2-88)].

## *User-Defined and Built-In Pump Curves*

The user may specify pump homologous curves through input by OPTION = 0 or may use the built-in pump curves of OPTION = 1 through 4. The OPTION = 1 built-in pump curves are based on the Semiscale/Mod1 system pump (Refs. 2-5 through 2-8). The Semiscale pump curves for single-phase homologous pump head HSP, two-phase fully degraded homologous pump head HTP, pump-head degradation multiplier HDM, single-phase homologous torque TSP, and torque degradation multiplier TDM are provided in Figure 2-51 through Figure 2-55, respectively. The OPTION = 2 built-in pump curves is based on the Loss-of-Fluid Test (LOFT) system pump (Ref. 2-9). The LOFT pump curves for single-phase homologous pump head HSP, two-phase fully degraded homologous pump head HTP, pump-head degradation multiplier HDM, single-phase homologous torque TSP, and torque degradation multiplier TDM are shown in Figure 2-56 through Figure 2-60, respectively. For lack of data, the two-phase fully degraded homologous torque curves TTP for both Semiscale and LOFT pumps are zero. The OPTION = 3 or 4 built-in pump curves model Bingham and Westinghouse manufactured pumps respectively. The Bingham and Westinghouse pump curves for single-phase homologous pump head HSP, two-phase fully degraded homologous pump head HTP, single-phase homologous torque TSP, and two-phase fully degraded homologous torque curves TTP are shown in Figure 2-61 through Figure 2-68. The user may specify degraded head and torque multipliers for both the Bingham and Westinghouse pumps by setting IPM = 2, otherwise the LOFT multipliers will be used. Where applicable, the curves are numbered corresponding to the conditions provided in Table 2-26.

Because these homologous curves are dimensionless, they can describe a variety of pumps by specifying the desired rated head RHEAD, rated torque RTORK, rated volumetric flow RFLOW, rated density RRHO, and rated pump-impeller rotational speed ROMEGA as input. We recommend that for full-scale light water reactor analyses, plant-specific pump curves be input;

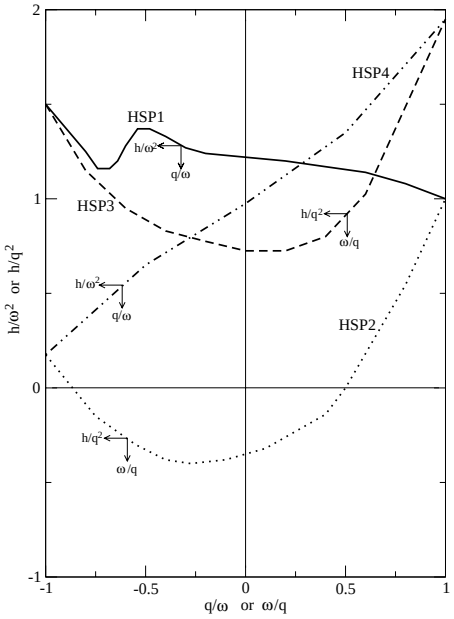


Figure. 2-51. Semiscale single-phase homologous pump-head curves.

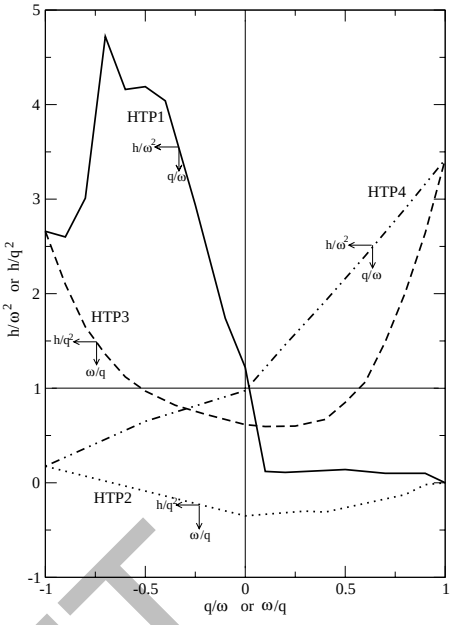


Figure. 2-52. Semiscale two-phase fully degraded homologous pump-head curves.

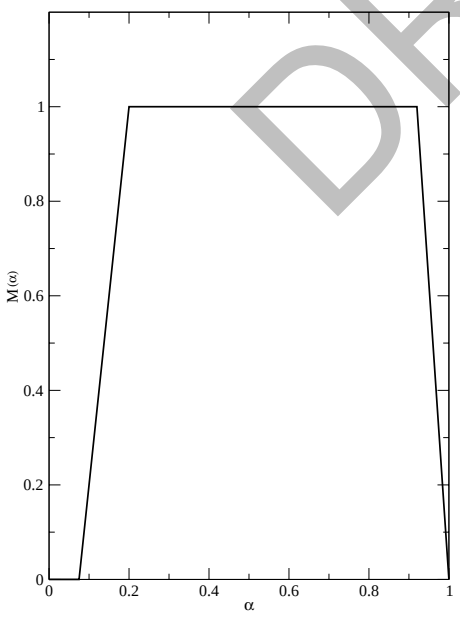


Figure. 2-53. Semiscale pump-head degradation multiplier curve.

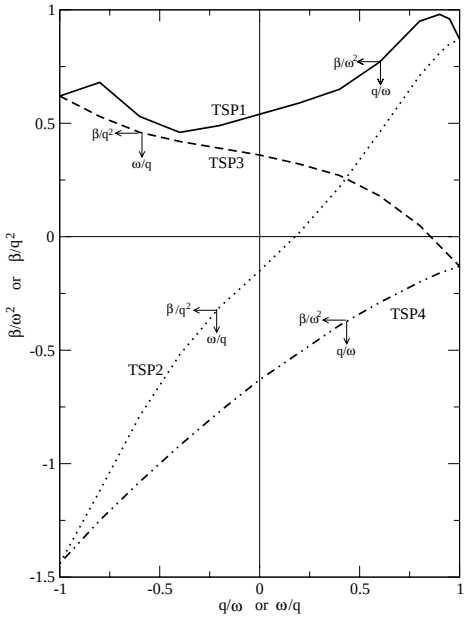


Figure. 2-54. Semiscale single-phase homologous toque curves.

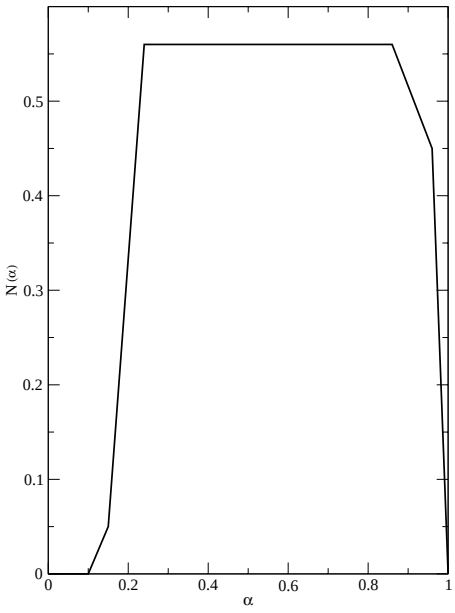


Figure. 2-55. Semiscale torque degradation multiplier curve.

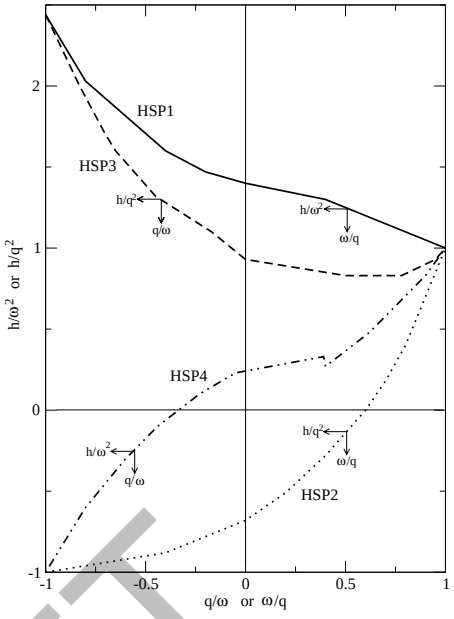


Figure. 2-56. LOFT single-phase homologous pump-head curves.



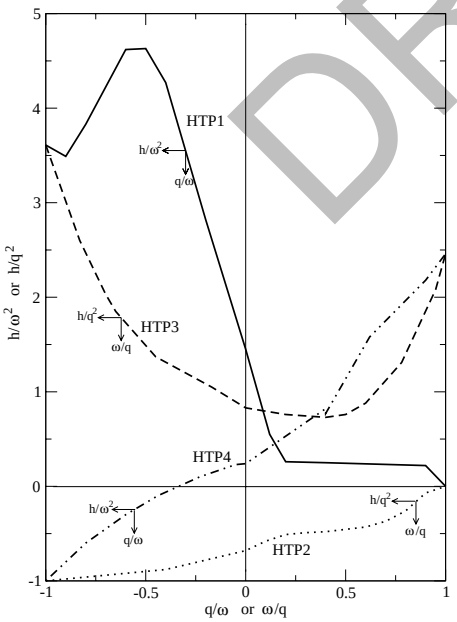


Figure. 2-57. LOFT two-phase fully degraded homologous pump-head curves.

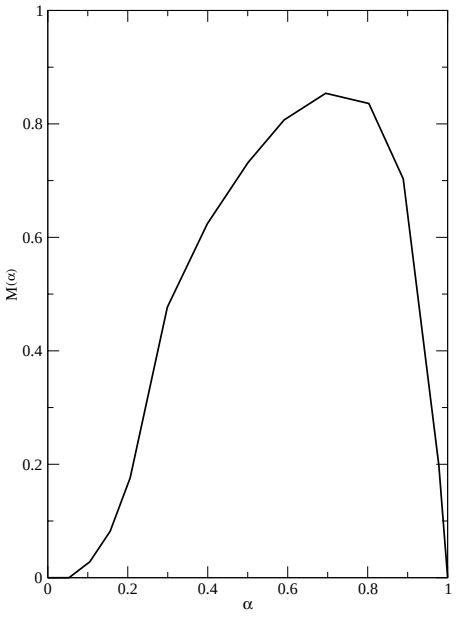


Figure. 2-58. LOFT pump-head degradation multiplier curve.

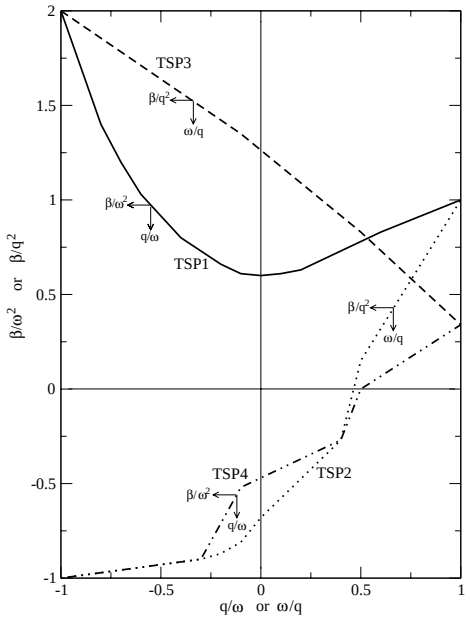


Figure. 2-59. LOFT single-phase homologous torque curves.

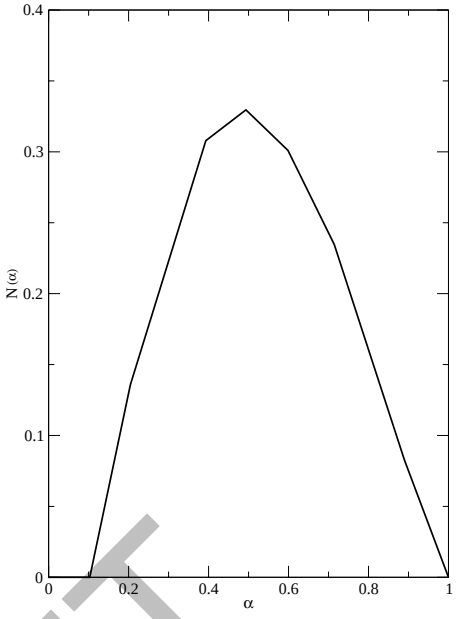


Figure. 2-60. LOFT torque degradation multiplier curve.

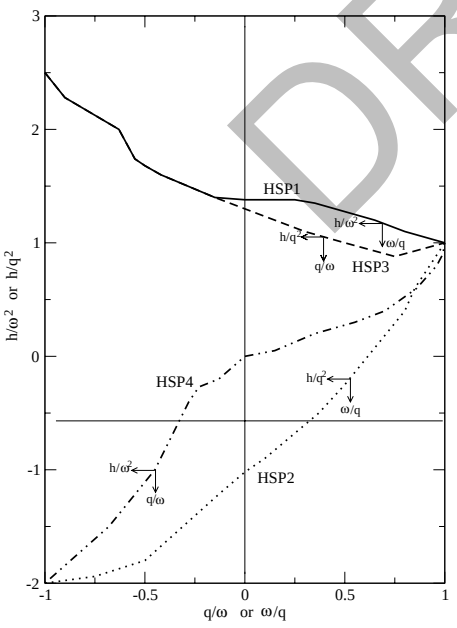


Figure. 2-61. Bingham single-phase homologous pump-head curves.

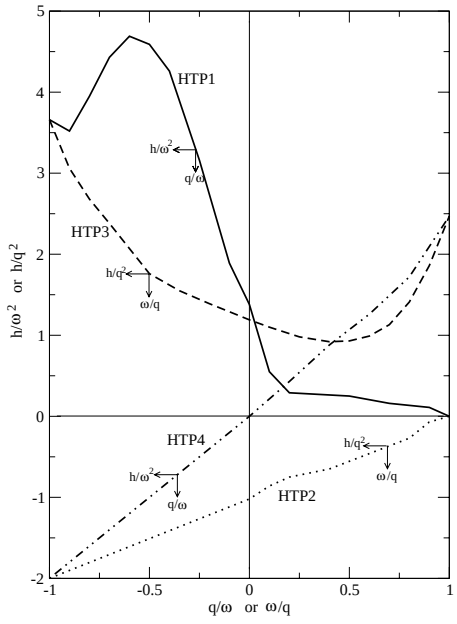


Figure. 2-62. Bingham two-phase fully degraded homologous pump-head curves.

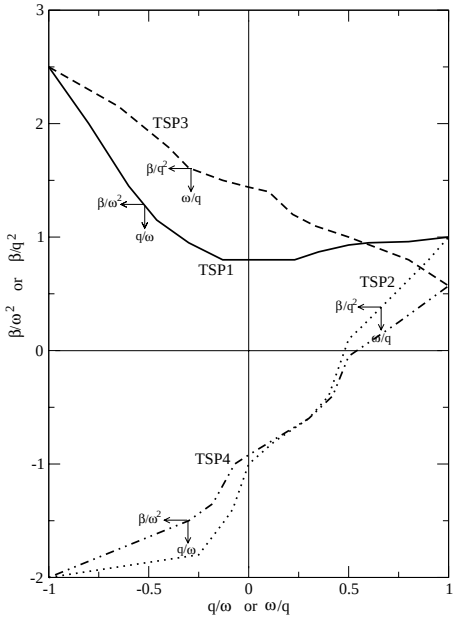


Figure. 2-63. Bingham single-phase homologous torque curves.

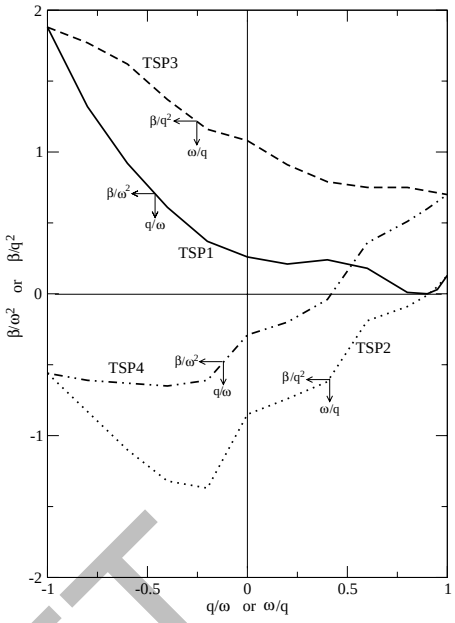


Figure. 2-64. Bingham two-phase fully degraded homologous torque curves.

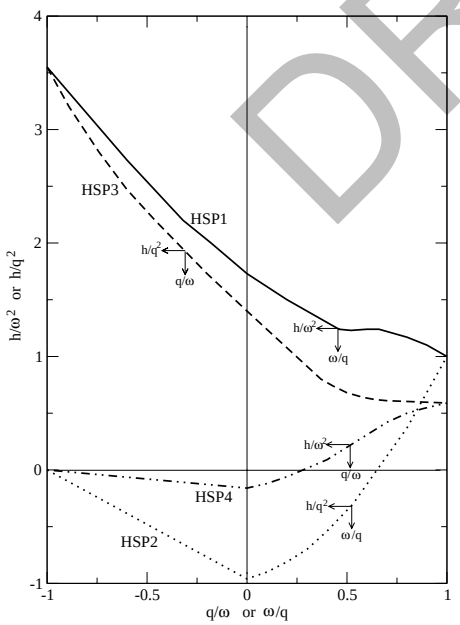


Figure. 2-65. Westinghouse single-phase homologous pump-head curves.

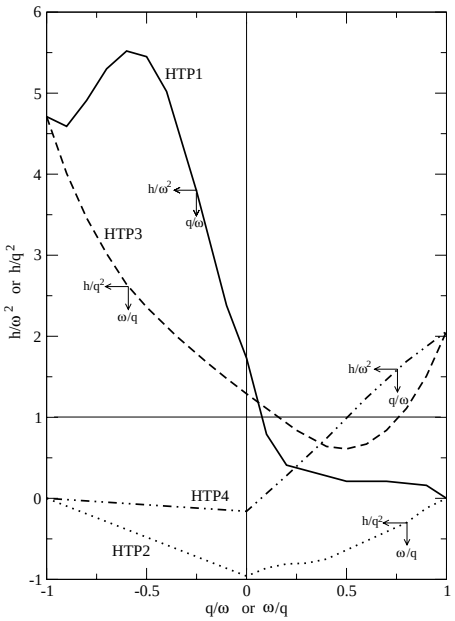


Figure. 2-66. Westinghouse two-phase fully degraded homologous pump-head curves.

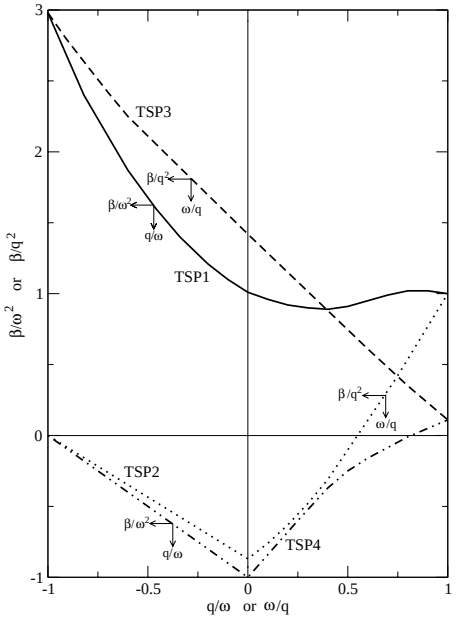


Figure. 2-67. Westinghouse single-phase homologous torque curves.

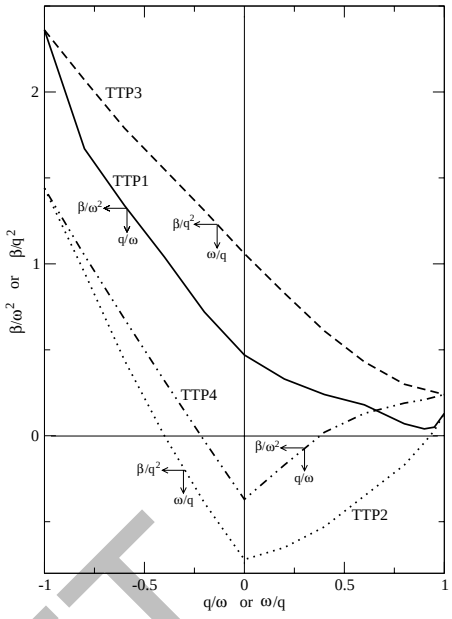


Figure. 2-68. Westinghouse two-phase fully degraded homologous torque curves.



however, if such data are unavailable, the OPTION = 2, 3, or 4 LOFT, Bingham, or Westinghouse pump curves generally should be used.

## *Pump Component Input*

The PUMP component input consists of the same geometric and initial-condition hydrodynamic data that are required for the PIPE component. In addition, parameters specific to the pump model are required, as described above and in the input specifications, Volume 1. The PMPTB table as well as the homologous pump-curve arrays must be input in the following order:

$$x(1), y(1), x(2), y(2), \ldots, x(n), y(n) \quad .$$

Here x is the independent variable and y is the dependent variable. Furthermore, the independent variable must increase monotonically in the order of its input: i.e.,

$$x(1) < x(2) < \ldots < x(n-1) < x(n) \quad . \tag{2-94}$$

Linear interpolation is used within the tabular arrays.

# *RADENC Component*



A capability to model thermal-radiation heat transfer was added to TRACE. See Reference 2-3, Reference 2-18 and the TRACE Theory Manual for a description of the theoretical basis of the radiation heat transfer model. The radiation heat transfer model in the BWR version of TRAC was incorporated into a new component model (i.e., RADENC). The model is based on the radiation-enclosure method that evaluates radiative exchanges between discrete surfaces of HTSTR components that may be convection heat-transfer coupled to particular hydraulic-component cells. An option is available to include participation of the intervening two-phase fluid coolant. If the fluid participates in the radiative exchange, the model assigns radiation-related properties to each of the fluid phases according to a radiation flow-regime map based on the gas volume fraction. The net radiative heat flux at each HTSTR surface and the energy absorbed by the fluid are coupled to the overall energy conservation equations that determine the structure and fluid temperatures. A CHAN component will spawn a RADENC component for the radiation heat transfer enclosure within the BWR fuel assembly. The RADENC component can be used directly in the TRACE input to define any number of HS surfaces to be a radiation heat transfer enclosure. Note in general there must be at least two HS surfaces to define a radiation heat transfer enclosure.

To apply the radiation heat-transfer model, the user specifies NAMELIST variable NENCLOSURE ≥ 1. This integer defines the number of radiation heat transfer enclosures to be included in the input model. A RADENC component is input for each radiation heat transfer enclosure. For each enclosure, the number of axial levels (i.e,. NZLEVEL > 0), the number of surfaces per axial level (i.e., NHSS > 1) to be involved in radiative heat transfer enclosure for each axial level must be defined (see Table 2-27 and **Appendix B,** *RadEncCylinder Test Problem* for the complete input listing).



For the example in Table 2-27, there is one axial level and 2 HTSTR surfaces that define the radiation heat transfer enclosure. The two HTSTR surfaces are defined to be HS component number 1 (i.e., NUMHSS = 1) for the outer surface (i.e., RNHSS = NODES = 26) and for HS axial level 1 (i.e., ZNHSS = 1) and HS component number 2 inside surface (i.e., RNHSS = 1) and for HS axial level 1 (i.e., ZNHSS = 1).

In general there is matrix of view factors (i.e., VF (i, j) for i = 1, NHSS and j = 1, NHSS) required to define the radiation heat transfer view factors for a given enclosure. However, the following two equations are required for this matrix of view factors:

$$A(i) * VF(i, j) = A(j) * VF(j, i) \tag{2-95}$$

$$\sum_{j=1}^{NHSS} VF(i, j) = 1 \tag{2-96}$$

Eq. (2-95) is reciprocity for the view factors and Eq. (2-96) conserves the radiate energy leaving a surface. Given Eqs. (2-95) and (2-96), the minimum number of view factors required to be input for the view factor matrix is the upper off diagonal terms.

$$\begin{bmatrix} VF(1,1) & VF(1,2) \\ VF(2,1) & VF(2,2) \end{bmatrix} \tag{2-97}$$

Which implies that for this test problem only one view factor is required in the input (i.e., VF(1,2)). The view factor from the outer surface of the inner HS to the inner surface of the outer HS is 1.0 (i.e., co-centric cylinders), which implies from Eq. (2-96) that VF(1,1) is zero. The HS surface 2 to 1, given from Eq. (2-95) as VF(1,2) * A(1) / A(2) = VF(2,1) = 0.5, since $R_i$ = 1m and $R_o$ = 2 m (see **Appendix B,** *RadEncCylinder Test Problem* for the geometry of HS components 1 and 2). Given that VF(2,1) = 0.5, then VF(2,2) = 1- VF(2,1) = 0.5.

**Table 2-27. Example Input For RADENC Component**

```
*******   type           num            id        ctitle
radenc                     3             3        Radiation HT enclosure
*       nzlevel          nhss
              1             2
*        numhss         rnHSS          znHSS
              1            26              1
              2             1              1
*        Upper diagonal view fraction matrix array.
           1.0 e
*        Diagonal and upper off-diagonals for path length.
           f 0.0 e
           f 0.0 e
```



In general the path length from surface 1 to surface 2 is the same as the path length from surface 2 to 1. Therefore, the minimum number of path lengths to input is the path lengths for the diagonal and upper diagonal elements of the path length matrix.

$$\begin{bmatrix} PL(1,1) & PL(1,2) \\ PL(2,1) & PL(2,2) \end{bmatrix}$$

For this test problem the path lengths are input as zero since there is no fluid cells between the two surfaces to absorb or emit radiate thermal energy.

The emissivity for each HS surface is determined from the HTSTR input. The HTSTR input makes the emissivity of a given HS surface a quadratic function of the surface temperature. Input a zero for the linear (i.e., EMCIF2/EMCOF2) and 2nd order (i.e., EMCIF3/EMCOF3) coefficients results in a constant emissivity. If all three coefficients are input as zero, then this HS surface becomes a surface of symmetry for the radiation heat transfer calculation (i.e., all thermal radiation energy emitted to this surface is reflected from this surface). If the surface emissivity is one, then that HS surface is a black surface (i.e., all thermal radiation energy emitted to this

surface is absorbed, there is no reflected thermal radiation heat transfer). In general the HS surface emissivity cannot be less than zero or greater than one.

Table 2-28 is RADENC example input for a radiation heat transfer enclosure that is defined by 8 HS surfaces. Only the upper off-diagonal view factors must be input. For the first HS surface there are seven upper off-diagonal view factors that are input (i.e., VF(1, j), j = 2 to 8). For the second HS surface there are six upper off-diagonal view factors that are input (i.e., VF(2, j), j = 3 to 8). This continues on until the last view factor to input is the view factor for VF(7, 8). In some cases the view factor is zero, which implies that there is no direct view from the $i^{th}$ HS surface to the $j^{th}$ HS surface. In some cases the view factor is one, which implies that the $i^{th}$ HS surface can only see the $j^{th}$ HS surface.

For the path lengths, the diagonal plus the upper off-diagonal must be input. Therefore, for the first HS surface there are 8 path lengths that must be input (i.e., PL(1, j), j = 1, 8). The last path length to be input is PF(8,8). A zero for the path length implies that the fluid between the two surfaces will not contribute to the radiation heat transfer via absorption or emission of thermal radiate energy. A non-zero for the path length implies that the fluid between the two surfaces absorbs and emits thermal radiation according to the models described in the TRACE Theory Manual. Note that a HS surface that can see itself (i.e., VF(8,8) not equal to zero), may also have an average path length associated with the thermal radiation transfer with itself.



**Table 2-28. RADENC Component Example With NHSS = HS.**

```
************************************************************************
*     type            num             id      ctitle
radenc                907             907     Radiation heat transfer enclosure
*  nzlevel          nHSS
         1             8
*   numHSS         rnHSS          znHSS
        902             2              1
        905             2              1
        903             2              1
        903             1              1
        904             5              1
        906             1              1
        901             2              1
        902             1              1
*   Upper off-diagonal view factor matrix.
*       VF(1,2)   VF(1,3)   VF(1,4)   VF(1,5)   VF(1,6)   VF(1,7)   VF(1,8)
*                 VF(2,3)   VF(2,4)   VF(2,5)   VF(2,6)   VF(2,7)   VF(2,8)
*                           VF(3,4)   VF(3,5)   VF(3,6)   VF(3,7)   VF(3,8)
*                                     VF(4,5)   VF(4,6)   VF(4,7)   VF(4,8)
*                                               VF(5,6)   VF(5,7)   VF(5,8)
*                                                         VF(6,7)   VF(6,8)
*                                                                   VF(7,8)
*
*       VF(1,2)   VF(1,3)   VF(1,4)   VF(1,5)   VF(1,6)
*       VF(1,7)   VF(1,8)
        0.08397   0.03669   0.00000   0.01279   0.61685s
        f 0.0 e
*
*       VF(2,3)   VF(2,4)   VF(2,5)   VF(2,6)   VF(2,7)
*       VF(2,8)
        0.0       0.00000   0.0       0.424500  0.000s
        0.000e
*
*       VF(3,4)   VF(3,5)   VF(3,6)   VF(3,7)   VF(3,8)
        f 0.0 e
```

```
*
*       VF(4,5)   VF(4,6)   VF(4,7)   VF(4,8)
        0.87037   f 0.00000 e
*
*       VF(5,6)   VF(5,7)   VF(5,8)
        f 0.0 e
*
*       VF(6,7)   VF(6,8)
        f 0.0 e
*
*       VF(7,8)
        1.000 e
*
*       Path lengths for the diagonal and upper off-diagonals of the
*       path length matrix.
*
*       PL(1,1)   PL(1,2)   PL(1,3)   PL(1,4)   PL(1,5)
*       PL(1,6)   PL(1,7)   PL(1,8)
        0.07341   0.08268   0.03437   0.0000    0.03852 s
        0.07501   f 0.0 e
*
*       PL(2,2)   PL(2,3)   PL(2,4)   PL(2,5)   PL(2,6)
*       PL(2,7)   PL(2,8)
        r05 0.0   0.23825  f 0.000e
*
*       PL(3,3)   PL(3,4)   PL(3,5)   PL(3,6)   PL(3,7)
*       PL(3,8)
        f 0.0 e
*
*       PL(4,4)   PL(4,5)   PL(4,6)   PL(4,7)   PL(4,8)
        0.01194   0.00178   f 0.00000 e
*
*       PL(5,5)   PL(5,6)   PL(5,7)   PL(5,8)
        f 0.0 e
*
*       PL(6,6)   PL(6,7)   PL(6,8)
        0.28118   f 0.0 e
*
*       PL(7,7)   PL(7,8)
        0.0       0.00394e
*
*       PL(8,8)
        0.05093 e
```



Note that the example inputs in Table 2-27 and Table 2-28 are both for radiation heat transfer enclosures that contain only one level. The example in Table 2-29 is for a four HS surface radiation heat transfer enclosure with two axial levels. The HS surfaces for the radiation heat transfer enclosure for the first axial level of the enclosure are input as the first four lines of input for NUMHSS, RNHSS, and ZNHSS. The second axial level enclosure is defined with the second set of four inputs for NUMHSS, RNHSS, and ZNHSS. The first set of upper off-diagonal view factors are input for the first axial level radiation heat transfer enclosure and the second set of upper off-diagonal view factors are input for the second axial level radiation heat transfer enclosures. Same for the path lengths (i.e., first set for first axial level and second set for the second axial level).

Note that if the user wanted to simulate radiation heat transfer in the axial direction for this example, then the input would be modified to have NZLEVEL = 1 and NHSS = 8. Axial view factors from one HS surface at one axial level to another HS at another axial level would have to be determined.

**Table 2-29. RADENC Component Example Input with Two Axial Levels.**

```
*
*********************************************************
*      type          num            id     ctitle
radenc               907           907  Radiation enclosure with two axial levels
*   nzlevel         nhss
          2            4
*    numHSS        rnHSS         znHSS
         901            1             1
         902            1             1
         903            1             1
         904            1             1
         901            1             2
         902            1             2
         903            1             2
         904            1             2
*   Upper off-diagonal view factor matrix.
*          2
*       ********
*       *      *
*     1 *      * 3
*       *      *
*       ********
*          4
*      VF(1,2)   VF(1,3)   VF(1,4)
*                VF(2,3)   VF(2,4)
*                          VF(3,4)
       0.29289  0.41422  0.29289 e
                0.29289  0.41422 e
                          0.29289 e
*
       0.29289  0.41422  0.29289 e
                0.29289  0.41422 e
                          0.29289 e
*
*   Diagonal and upper off-diagonal path length matrix.
*      PL(1,1)   PL(1,2)   PL(1,3)   PL(1,4)
*                PL(2,2)   PL(2,3)   PL(2,4)
*                          PL(3,3)   PL(3,4)
*                                    PL(4,4)
       0.00000   0.00000   0.00000   0.00000 e
                 0.00000   0.00000   0.00000 e
                           0.00000   0.00000 e
                                     0.00000 e
*
       0.00000   0.00000   0.00000   0.00000 e
                 0.00000   0.00000   0.00000 e
                           0.00000   0.00000 e
                                     0.00000 e
```



# *SEPD Component*

This section describes the phase separation model used in TRACE and addresses unique modeling features of the SEPD component. In addition, user's guidelines are provided for typical SEPD applications and input preparation.

The SEPD component is usually employed to model the steam separators and moisture dryers located inside the reactor vessel of boiling water reactors or in the secondary side of the steam generator units of pressurized water reactors. More generally - but within the range of applicability and the limitations described in this section - the SEPD component can be employed

in the TRACE modeling of thermal-hydraulic facilities with liquid-gas separators and/or moisture dryers.

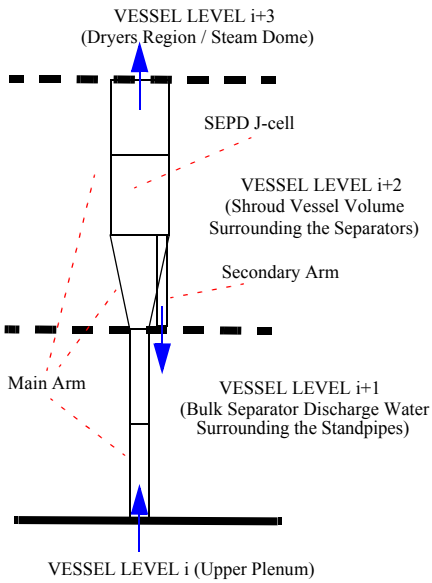


Figure. 2-69. Example of SEPD Nodalization Scheme (length and flow areas not to scale)

A typical noding diagram of the SEPD component (for example, used in connection with internal junctions of a vessel component) is shown in Figure 2-69 In TRACE, the SEPD component is in effect a modified TEE for which a special solution is obtained at the joining cell (J-cell). The formal derivation of the phase separation model and attainment of the special solution at the SEPD joining cell are described in details in **Volume 1, Chapter 8** of the Theory Manual. The complete description and instructions for the input specifications of the SEPD component are given in Volume 1 of this manual. This section describes the modeling features offered by the SEPD component by addressing the following topics:

- Applicability.
- Useful definitions.
- Broad overview of the TRACE phase separation model:

-The underlying concept.

-Assumptions.

  - Control of the separator function.
- Modeling options, methods and guidelines:
  - General features, guidelines and limitations.
  - Phase separation with constant performance parameters ("simple separator")
  - Perfect phase separation ("ideal separator").
  - Phase separation process with variable performance parameters.
  - General Electric's model for 2- or 3-stage steam separators ("mechanistic separator")
  - Steam dryers.



# *Applicability*

The SEPD component available in TRACE is an evolution of the correspondent components of the codes RELAP5 and TRAC-B and maintains the field of applicability of the predecessors. In particular, the SEPD component is applicable to modeling of the fluid flow and heat structures of the centrifugal steam separators (including standpipes, separator barrels and liquid discharge shroud) and the chevron moisture dryers located inside the reactor vessel of boiling water reactors or the corresponding hardware on the secondary side in the steam generators of pressurized water reactors.

Since a good deal of modeling flexibility is offered to the user with the component, it is pointed out here that the SEPD has also potential for applicability to modeling of different configurations of static (i.e., with no moving parts and no momentum sources) liquid-gas separators and/or moisture dryers, which might be employed in some thermal-hydraulic facilities and that the user is seeking to model with TRACE (T-junction separators, gravity separators, special design dryers, etc.) In these atypical situations, the user is cautioned that the utilization of the SEPD component would fall outside its primary applicability range and it is therefore recommended that the user consults directly with the code caretaker for the U.S. Nuclear Regulatory Commission for modeling advise.



# *Definitions*

In this manual section about the SEPD model, we refer to the terms *steam separators* and *dryers* with their most usual meaning in the thermal-hydraulics field of the nuclear technology, as just discussed in the Applicability paragraph.

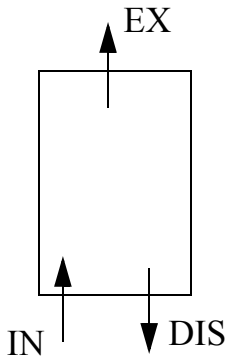


Figure. 2-70. The separator as a "black box"

Let us make reference to Figure 2-70 and represent the separator as a confined control volume ("black box") with three flow junctions: a single inlet and two outlets. Suppose that we observe and measure a two-phase, liquid-gas mixture entering the separator; let $\dot{m}_{l,IN}$ be the inlet mass flow rate of liquid and $\dot{m}_{g,IN}$ the inlet mass flow rate of gas. Suppose further that we observe and measure a bulk gas flow, containing a small amount of liquid, flowing out of the first outlet (the separator *exit*); let $\dot{m}_{l,EX}$ be the liquid and $\dot{m}_{g,EX}$ the gas mass flow rates at such exit. Suppose, finally, that we observe and measure a bulk flow of liquid, with a very small weight fraction of gas, exiting from the second outlet (the separator *discharge*); let $\dot{m}_{l,DIS}$ be the liquid and $\dot{m}_{g,DIS}$ the gas mass flow rates at such discharge. The presence of liquid traces in the exit bulk gas flow and the presence of gas traces in the discharge bulk liquid flow are indications of an imperfect phase separation process, whereas the *perfect* (or *ideal*) separation would result in pure gas flow at the exit and pure liquid flow at the discharge. Some parameters for characterizing the performance of a liquid/gas separation process are defined as follows.

The *separator inlet quality* is defined as the ratio:

$$x_{IN} = \frac{\dot{m}_{g,IN}}{\dot{m}_{g,IN} + \dot{m}_{l,IN}} \tag{2-98}$$

The *liquid carry-over quality* is defined as the ratio:

$$x_{CO} = \frac{\dot{m}_{l,EX}}{\dot{m}_{l,EX} + \dot{m}_{g,EX}} \tag{2-99}$$

The *vapor carry-under quality* is defined as the ratio:

$$x_{CU} = \frac{\dot{m}_{g,DIS}}{\dot{m}_{g,DIS} + \dot{m}_{l,DIS}} \tag{2-100}$$

An ideal (perfect) separator would perform with $x_{CO} = 0$ and $x_{CU} = 0$. In reality, imperfect separation always occurs and the performance characteristics of a separator component are often represented by expressing $x_{CO}$ and $x_{CU}$ as functions of $x_{IN}$.

Another important parameter that is used to measure the performance of a separator is the pressure drop across the component. A discussion on this topic is postponed to a later section. Some definitions and a discussion on the performance parameters of chevron-type dryers are postponed to the section on moisture dryers modeling.



# *The TRACE Separator Model*

The TRACE separator model can be ideally described as working on two levels.

At a first conceptual level, the separator model is a "black-box" consisting of a control cell with three flow junctions for the separator inlet (two-phase mixture), exit (wet steam) and discharge (bulk liquid with traces of gas) flows. Because of its functionality, the J-cell of the TEE component is a quite natural choice for the actualization of the separator control cell. Thus, the SEPD is essentially a specialized TEE component. At the J-cell, "black-box" level, the separator model triggers a special solution of the field equations, in order to result, when possible, with the prescribed separator performance, in terms of $x_{CO}$ and $x_{CU}$, at exit and discharge junctions. At this fundamental level, the user has no control over the separator model and can only observe the outcome of it.

The separator performance parameters $x_{CO}$ and $x_{CU}$ are determined at a different conceptual level of the model. At this second, specialized level, several options are available for describing the phase separation process occurring "inside the black-box". These options range from the simplest approach, that is the user-definition of constant $x_{CO}$ and $x_{CU}$ (including the particular case of

ideal separation, where $x_{CO} = 0$ and $x_{CU} = 0$), to a more elaborated option consisting in the user-definition of variable $x_{CO}$ and $x_{CU}$, to the mechanistic separator option, in which the separator performance is calculated by the code as a function of the local flow conditions, according to an analytical model developed in past years by General Electric Co. (Ref. 2-11). Available at this second level is also the dryers option, whose net result is a further modification of the SEPD $x_{CO}$, based on a calculated dryers efficiency. The user has extensive input access and control over the features at this specialized level of the model.



A broad description of the fundamental conceptual level of the separator model follows in the remainder of this subsection. A description of the various user options that are available at the specialized level of the model is then given in the next subsection entitled ***Modeling Options and Guidelines.***.

## *The Underlying Concept*

At the "black-box" separator level, given the inlet conditions (flow rate and quality) and the desired separator performance parameters ($x_{CO}$ and $x_{CU}$), the objective of the model is twofold: first, the desired values for the flow variables at the exit and discharge junctions of the SEPD J-cell must be determined; then, such solution must be prescribed to the TRACE numerical scheme in a consistent way.



It is well known that in general, the void fraction at a given flow station can be formulated in terms of (i) the mass flow quality, (ii) the ratio between the phasic velocities (or slip ratio) and (iii) the ratio between the phasic densities at that face (Ref. 2-10). For the SEPD J-cell, given the desired mass flow qualities $x_{CO}$ and $x_{CU}$ at the exit and discharge junctions, the void fractions convected across those faces can be quickly calculated when the phasic densities are known and if the slip ratio at those junctions is assumed to be unitary. That is, in the assumption of homogeneous flow at the exit and discharge junctions of the separator, the void fractions at those faces can be immediately calculated from the prescribed $x_{CO}$ and $x_{CU}$, since the phasic densities at the current (given) pressure and temperature are known within the solution of the field equations. If it is further assumed that the phasic mass flows entering and exiting the separator "black-box" are balanced, then the individual mass flow rates can be determined. That is, assuming further that no phase change occurs within the separator "black-box" and steady state operation (no mass build-up or removal), then the liquid and gas mass flow rates (and the phasic velocities that are assumed homogeneous) at the exit and discharge junctions can be calculated individually.

Once the values of the junction void fractions and homogeneous phasic velocities are determined from the prescribed $x_{CO}$ and $x_{CU}$, then the TRACE separator model transfers the information into a modified solution scheme for the SEPD J-cell. The modified solution scheme relies on the computational framework that is available in TRACE for tracking water levels in a similar way the off-take and the accumulator models use it.

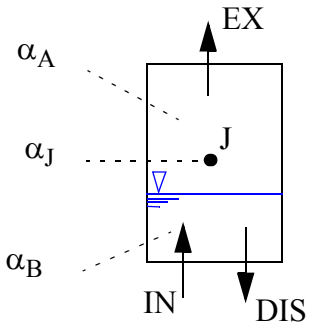


Figure. 2-71. Level Tracking Framework applied on top of the Separator "black box"

In a nutshell, the TRACE level tracking logic can be described by making reference to the schematic shown Figure 2-71.

For a computational cell where the presence of a water level is detected, additional variables are introduced, among which are the void fractions $\alpha_A$ and $\alpha_B$ of the regions above and below the liquid/gas interface (and convected through the two open edges of the cell). Then, within the level tracking framework, the field equations are modified in order to make opportune use of those variables for the evaluation of the convected macroscopic quantities and the flux terms. From this description, it should become clear how the separator model makes use of the Level Tracking framework. Figure 2-71 shows the level tracking structure that is applied on top of the separator black-box. If the SEPD J-cell is viewed as a computational cell with a water level, and if the interface is located above the discharge edge and below the exit edge, then the correspondence between the level tracking variables $\alpha_A$ and $\alpha_B$ and the separator model variables $x_{CO}$ and $x_{CU}$ can be intuitively identified.

Nevertheless, the application of the level tracking logic to the SEPD J-cell presents two complications in that (i) the J-cell has three flow junctions to the neighboring cells, whereas a regular 1D level tracking cell has only two junctions, and that (ii) no information is given about the average void fraction of the SEPD J-cell and its value would remain indeterminate for this black-box type of separator. The first difference is overcome when the discharge velocity at the J-cell side junction, which is assumed common to both phases, is imposed to the solution rather than addressed by the level tracking logic. The magnitude of the homogeneous discharge velocity is obtained from the considerations discussed earlier (assuming balanced inlet and outlet flow rates) and depends on the prescribed separator performance. In order to address the second complication regarding the determination of the J-cell average void fraction $\alpha_J$, the magnitude of the discharge velocity is adjusted within the separator model logic (with a simple proportional control scheme) in order to impose an additional restrictive condition that the difference between the void fraction in the J-cell and the void fraction in the adjacent cell from the inlet side (cell J-1) be minimized. That is, the discharge velocity is used to regulate the void fraction of the J-cell, in such way that the J-cell void fraction follows as close as possible a target value, which is chosen to be the void fraction of the cell preceding the J-cell (in the direction of the two-phase flow entering the SEPD J-cell in regular operation).

In sum, by assuming homogeneous flow at the exit and discharge junctions, the desired $x_{CO}$ and $x_{CU}$ qualities are used to calculate the void fractions at those junctions. By further assuming no phase change and steady-state equilibrium of the entering and exiting mass flows for the separator, a homogeneous discharge velocity can also be preliminarily calculated. As the discharge velocity is also used to control the void fraction in the J-cell, this "first guess" for the discharge velocity is then adjusted in such way that the difference between the void fractions of the J-cell and the neighboring cell on the inlet side is minimized. The resulting discharge velocity

is imposed to the TRACE numerical solution for the side junction of the J-cell, while the J-cell average void fraction and the junction (convected) void fractions are passed to the level tracking logic for utilization in the modified field equations for the main stream of the J-cell. The discharge velocity is prescribed to the TRACE numerical solution by adjusting the total friction factors at the discharge junctions for the semi-implicit scheme and by direct substitution at the stabilizer step of the SETS scheme. The level tracking logic then triggers the complete solution of the modified field equations for the main stream of the J-cell, including the homogeneous velocity at the exit junction and the pressure solution.

Two facts should be noted in conclusion of this overview. First, the assumption of balanced inlet and outlet mass flows is only used to calculate an initial value for the discharge velocity; that assumption is then dropped when the discharge velocity is adjusted to control the J-cell void fraction. Thus, the TRACE separator model effectively allows for disequilibrium inlet and outlet flows, with transient mass accumulation or removal from the SEPD J-cell. In fact, logic is implemented to by-pass the separator model (and the SEPD component becomes a regular TEE) during a calculation when the local flow conditions become inconsistent with the regular function of flow separation, such as for situations of single phase flow or reversed flows (when the J-cell void fraction becomes 1 or 0 or the velocities change sign). This feature of the model is explained in more details later in the section entitled ***Control of the Separator Function***. Finally, it should be noted that the level tracking framework is applied "on top of the black box", in order to reproduce and enforce in the code a phase separation process, given some performance parameters as input. Therefore, the application of the level tracking is not an attempt to model the underlying physics of the two-phase flow separation occurring "inside the black box".



## *Assumptions*

It is opportune to list at this point the assumptions on which the TRACE separator model is based, as these further define the field of applicability and the limitations of the separator model. A discussion on these assumption is given in the **Volume 1, Chapter 8** of the Theory Manual.

1) Homogeneous flow at the exit and discharge flow junctions.
2) No phase change inside the SEPD component.
3) During regular SEPD operation, the void fraction of the J-cell follows the void fraction of the cell J-1 (i.e., the void fraction history of the fluid in the separator barrel follows the void fraction history of the fluid in the standpipes).
4) Vertical configuration of the J-cell.

## *Control of the Separator Function*

As it was introduced earlier, logic is included in the TRACE separator model that switches the SEPD model on and off according to the flow conditions of the J-cell. For reasons that should be evident, the SEPD model is not used in the code when the flow in the J-cell is predicted to become single phase (and/or the water level is predicted to cross a cell boundary), as it might occur during

certain transient scenarios. The SEPD model is also by-passed should the J-cell edge velocities change sign (i.e., when, for any reasons, the flow is predicted to enter the separator from the exit face and/or the flow is predicted to exit the separator from the inlet face). When that occurs, the SEPD component behaves at all effects as a regular TEE component as the separator function is deactivated. A graphic variable, called isSepSep is used to flag the status of the SEPD component: when isSepSep = 1, the separator model is active and the SEPD component is carrying out its regular function; when isSepSep = 0, the separator model is skipped in the code and the SEPD component is behaving at all effects as a regular TEE component.

During the calculation, once the SEPD becomes flagged with isSepSep = 0, the separator function will be resumed only when the following conditions are satisfied: 1) a water level can be detected for the J-cell; 2) the edge velocities are consistent with a regular separator function; and 3) the J-cell average void fraction returns within a user-defined range, defined by input variables ALPSMN and ALPSMX. The reason for resuming the separator function only when the J-cell void fraction is above ALPSMN and below ALPSMX, as opposed to using 0 and 1 as extremes, is to avoid situations where the SEPD component is continuously switching between on and off, thus causing artificial oscillation in the system. Should the user notice such a situation (when the graphic variable "isSepSep" is jumping very quickly between 0 and 1), a possible remedy would be to narrow the range defined by ALPSMN and ALPSMX. During model development, it was found that values of ALPSMN = 0.05 and ALPSMX = 0.9 very often resulted in acceptable SEPD behavior (see also Table 2-30 for an example input).



# *Modeling Options and Guidelines.*

The TRACE user may choose either to define by input specifications the separator performance parameters $X_{CO}$ and $X_{CU}$ or may choose to let the code calculate the separator performance based on built-in models. The available user-defined separator options include the constant performance parameters specification (input variable ISTAGE = 0) and the generic performance parameters specification (ISTAGE = 1). The code-calculated option (ISTAGE = -3, -2, 2 or 3) will trigger the utilization in the code of a mechanistic separator model. Additionally, a moisture dryers model can be activated on top of each separator option (by input variable NDRYR). These modeling options are described in detail in the remainder of this section, following an overview of general modeling features and limitations of the SEPD component.

## *General Features, Guidelines and Limitations*

The SEPD component is essentially a specialized TEE component for which a special solution is enforced at the J-cell in order to achieve a phase separation process following some separator performance parameters. As such, the SEPD offers the same general modeling features described for the TEE component, with some exceptions due to its specialized nature, as described below. Although in BWR plant models the SEPD component is typically connected to inner junctions of a VESSEL component, it can be connected in general to any 1-D component, including FILL and BREAK components.[1]

**Component configuration.** A first limitation in the use of the SEPD is that the numerical model assumes the J-cell to be oriented upward. It is strongly recommended to specify the SEPD configuration in such a way that the fluid flow (for normal operation) in the entire main arm is directed upward and the flow in the secondary arm is directed downward. Thus, the user is recommended to define the SEPD input cards GRAV and COST accordingly[1]. It is customary and recommended to model a steam separator by using the first few cells of the SEPD main arm to model the separator standpipe; the SEPD J-cell then represents the swirling vane(s) inside the separator barrel, while the secondary arm models the liquid discharge passage (see Figure 2-69). "Exotic" configurations, such as a single-cell SEPD component or a SEPD component with no side arm, should not be adopted.[2]

**Modeling multiple separators.** The SEPD input flow areas and volumes should be defined based on the values for a single physical separator being modeled. Then, the total number of separators to be modeled with the SEPD is defined with the input variable NSEPS. This would be equivalent to defining the SEPD input FA and VOL as the total separators flow areas and volumes and then specifying NSEPS = 1, although the user should find the first option more useful, at least for sake of input clarity. In any case, NSEPS must be input greater or equal than one (i.e., cannot be specified as zero in order to model dryers only; dryers modeling is discussed later in this section).

**Additive loss coefficients and separator pressure drop.** Although additive loss coefficients are to be input at all SEPD junctions, as for a regular TEE component, the user is warned that a non-zero additive loss coefficient, input for the internal junction of the SEPD J-cell, would not cause the expected effect. This is because such coefficient is not used (but it still must be input) during the regular SEPD operation (isSepSep =1) for the calculation of the velocities, as the separator special solution is adopted at that junction. For all other junctions, non-zero additive loss coefficients would cause the expected momentum loss and should be input as usual, where required and according to given technical specifications or references. In the absence of technical specifications for the additive loss coefficients, and if a nominal pressure drop is known for the separators being modeled, it would be opportune to use and adjust the additive loss coefficients in order to achieve the target, specified pressure drop. In this regard, the mechanistic separator option offers some additional information. In fact, when the mechanistic separator is used, an additional graphical variable is available, called "dpss", which reports the pressure drop across the separator as predicted according to the General Electric's separator model (either for a GE 2-stage or 3-stage separator). Such pressure differential is not actually imposed to the TRACE solution but is output for user's reference. If and when appropriate, the user may choose to adjust the additive loss coefficients for the SEPD in order to achieve a pressure drop close to that predicted by the mechanistic model. It must be stressed though, that such mechanistic model was originally



1. As for a regular TEE, though, it is not recommended to connect the J-cell directly to a boundary condition component.
1. SNAP directly enforces the SEPD vertical configuration during GUI input preparation. It is currently possible to define a generic orientation for both arms of the SEPD component by ASCII input editing but this should be avoided.
2. The current limitation that constrains utilization in TRACE of a single-cell SEPD also denies the correct automatic SNAP conversion of the RELAP5 separator component into TRACE.

developed by GE (Ref. 2-11) for their line of 2-stage and 3-stage separators. The extension and adoption of the GE model to a different separator design is not generally appropriate.

**Initial conditions.** Particular care must be used in the determination of the input initial conditions for a SEPD component, because of the special numerical solution for the SEPD J-cell and the model logic that de-activates the separator function when the current local flow conditions are not consistent with a process of phase separation. The user is warned that carelessly input SEPD initial conditions (such as null velocities, or unitary void fraction in the J-cell) would very likely affect negatively the initial iterations of the calculation, often causing the calculation to deviate from an expected path or to halt prematurely. The input initials velocities should be consistent with the expected separator performance and the easiest way to determine the initial values should be for the user to determine a mass flow balance (inlet flow equal outlet flow) for the SEPD J-cell with the input initial velocities and void fractions. Also because of the special separator logic, the input initial void fraction in the J-cell should be close (or equal) in value to the void fraction in the cell J-1 (this is not a strict requirement, although input initial J-cell void fractions of 1 or 0 would cause the SEPD to behave from the very beginning of the calculation as a regular TEE without carrying out the separator function). The initial void fraction in the cell J-1 (standpipes) should be input with the expected separator inlet void fraction (perhaps calculated from the expected separator inlet flow quality and assuming a reasonable slip ratio). Such approximate, first guess, values for velocities and void fractions should be sufficient for the purposes of a correct and efficient initialization of the input model.

## *Constant Performance Parameters ("Simple Separator")*

The easiest way to specify the separator performance by input is to use constant values for $x_{CO}$ and $x_{CU}$ (ISTAGE = 0 option). These user-supplied parameter values are used throughout the calculation regardless of the changing conditions in the SEPD component. It is well known that the separators performance is a function of the inlet flow conditions and, therefore, this option is best suited for calculations where an accurate simulation of the steam separators is not required and the SEPD flow conditions are not expected to vary significantly during the calculation. On the other hand, if the SEPD component plays a relevant role in the calculation and the flow conditions are expected to vary significantly in time, then it is recommended that the user consider employing the generic separator (ISTAGE = 1), where the separator performance parameters (that can be available or estimated) can be defined as generic functions of the flow variables.

The following is an extract of SEPD input specifications for a simple separator, as it appears in the ASCII input. In this example, the carry-over and carry-under qualities are constant for the

calculation (ISTAGE=0) and set to $x_{CO}$ = 0.05 and $x_{CU}$ = 0.003 (these are also the default values set when the user inputs carry-over and carry-under qualities less than zero or higher than one).

**Table 2-30. Example input for a Simple Separator**

```
*******   type            num             id          ctitle
sepd                        2              2    simple separator
*         jcell         nodes           ichf           cost          epsw
                3             0              0    1.0000e+00    0.0000e+00
*         nseps         ndryr         istage            xco           xcu
                1             0              0    5.0000e-02    3.0000e-03
*     alpsmn          alpsmx
      5.0000e-02    9.0000e-01
*        iconc1         ncell1          jun1           jun2          ipow1
                0             5              1              2              0
```



## *Perfect Phase Separation ("Ideal Separator")*

The ideal separator is a particular case of the simple separator, where the carry-over and carry under qualities are $x_{CO}$ = 0 and $x_{CU}$ = 0. The user looking to simulate a perfect phase separation, though, is cautioned with the same arguments presented earlier for the simple separator.

## *Separator with Variable Performance Parameters*

If the separator performance parameters $x_{CO}$ and $x_{CU}$ are known or can be estimated, then the generic separator option (ISTAGE = 1) offers the greatest modeling flexibility. Typically, the carry-over and carry-under qualities for a given separator design are available in technical specifications as functions of the inlet quality (often represented in separator performance plots). Or they may be available through tabular data or in alternative formulations. With the generic separator option, the user can supply such performance data for the separator as generic functions of the flow conditions or of any variable that is available through control blocks or signal variables. In fact, to use this option, the user indicates in input two control-block numbers, ICBS1 and ICBS2, that have been designed to evaluate the values of $x_{CO}$ and $x_{CU}$. For example, control-block function numbers 101 or 102, which linearly interpolates tabular data as a function of one, two or three independent variables, should be useful in defining $x_{CO}$ and $x_{CU}$ from performance tables. Nevertheless, the user adopting this separator option is warned and recommended to use extra care so that the definition of the control blocks ICBS1 and ICBS2 is consistent with realistic and plausible values for a separator $x_{CO}$ and $x_{CU}$. If, for example, the carry-over and/or carry-under qualities at some point during the calculation assume un-physical values (for example $x_{CO}$ = 1 and $x_{CU}$ = 0, or $x_{CO}$ = 0 and $x_{CO}$ = 1), then the calculation will halt on error or return unacceptable results.[1]



1. There is an update in the code holding bin that would prevent a code crash in case the users' defined Xco and Xcu are not physically consistent

The following is an extract of SEPD input specifications with variable performance parameters based on the control system (ISTAGE = 1), as it appears in the ASCII input. In this example, the carry-over and carry-under qualities are linked throughout the calculation to the control system variables given by words ICBS1 and ICBS2, which in the specific example are the control blocks number -100 and -200. Therefore, the values of 0.01 and 0.001 that appear in the third line of this example for XCO and XCU are not used for the calculation (but still, they must be input), as the carry-over and carry-under qualities are given at each time step by the control system. Obviously, the user must provide, at the appropriate location, the input specifications for the control variables used under words ICBS1 and ICBS2, using opportunely any of the available options for control system input.

**Table 2-31. Example input for a Variable-Performance Separator**

```
*******   type            num             id        ctitle
sepd                        2              2   variable xco and xcu
*         jcell         nodes           ichf           cost          epsw
              3             0              0    1.0000e+00    0.0000e+00
*         nseps         ndryr         istage            xco           xcu
              1             0              1           0.01         0.001
*     alpsmn         alpsmx
     5.0000e-02    9.0000e-01
*         icbs1         icbs2
           -100          -200
*        iconc1        ncell1          jun1          jun2          ipow1
              0             5             1             2              0
```



## *GE 2- or 3-Stage Separator ("Mechanistic Separator")*

With this option, activated in input with ISTAGE = -3, -2, 2 or 3, the user supplies detailed geometric parameters describing the physical separator. Default values, as prescribed by GE, are available. The coding that supports this option was written by General Electric Company, and it assumes a design identical or very similar to that used for GE 2-stage or 3-stage BWR steam separators. If the user wishes to model a separator that differs substantially from a GE separator, then this option probably will produce unreliable results. Details of the specific model design and implementation of this modeling option can be found in the Theory Manual and in Reference 2-11.

Input of ISTAGE = 2 or 3 activates the mechanistic separator option, for two- or three-stage geometry respectively. With this option, the user is required to input additional information on the physical separators being modeled, as listed in Table 2-32, and as described in the Volume 1 of the User's Guide and in the Theory Manual. The numerical values reported in Table 2-32 are the default values, available for two and three stage separator models when ISTAGE is input to -2 or -3 respectively.

**Table 2-32. Additional Input Variables for Mechanistic Separator**

| Input Variable | Description | Default Values | |
|---|---|---|---|
| | | ISTAGE = -2 | ISTAGE = -3 |
| AI | Standpipe Flow Area | 0.0186 $m^2$ | |
| AN | Standpipe Nozzle Exit Flow Area | 0.0144 $m^2$ | |
| RH | Radius of Separator Hub at Inlet | 0.0809 m | |
| THETA[a] | Angle of Separator Swirling Vane | 48.0 degree | |
| RR1 | Radius of Separator Pick-off Ring | 0.0857 m | |
| RWS | Inner Radius of Separator Wall | 0.1079; 0.0698 m | 0.1079; 0.1079; 0.1079 m |
| RRS | Inner Radius of the Pick-off Ring | 0.0698; 0.0698 m | 0.0857; 0.0952; 0.0984 m |
| ADS | Flow Area of Discharge Passage | 0.0416; 0.0029 $m^2$ | 0.0096; 0.0096; 0.0096 $m^2$ |
| DDS | Hydraulic Diameter of Discharge Passage | 0.0456; 0.0122 m | 0.0254; 0.0254; 0.0254 m |
| HBS | Barrel Length | 0.8778; 0.1625 m | 1.0699; 0.3842; 0.3842 m |
| HSK | Axial Distance Between the Discharge and the Swirling Vane | 0.2127; 0.0 m | 0.4508; 0.0; 0.3842 m |
| CKS | Loss Coefficient at the Discharge Passage | 10.0; 0.5 | 2.5; 1.429; 2.563 |
| EFFLD | Effective L/D coefficient at the Pick-off Ring | 450.0; 95.85 | 53.44; 194.64; 424.96 |

a. Contrarily to what reported in the Input Manual, the THETA input variable needs to be expressed in degrees instead of radiants. This is due to an unnecessary instruction line in the code that was inherited from TRAC-B and was never commented out in TRACE as it should have. A trouble report and suggested fix for this bug is being prepared.

The following is an extract of SEPD input specifications with mechanistic separator option, as it appears in the ASCII input.

**Table 2-33. Example input for a Mechanistic Separator**

```
*******   type            num             id        ctitle
sepd                        2              2    mechanistic separator
*        jcell          nodes           ichf          cost           epsw
               3              0              0    1.0000e+00    0.0000e+00
*        nseps          ndryr         istage           xco           xcu
               1              0             -3          0.01         0.001
*    alpsmn         alpsmx
    5.0000e-02    9.0000e-01
*        icbs1          icbs2
              -300            0
*       iconc1         ncell1           jun1          jun2          ipow1
               0              5              1             2              0
```

The performance parameters of the mechanistic separator are calculated internally by the code based on the input geometry and local flow conditions. In order to determine the carry-over and carry-under qualities, the mechanistic separator model requires the specification of the hydrostatic pressure head of the bulk water surrounding the separators. The user is required to specify this information with card ICBS1, in form of a control variable carrying the value of the height of liquid column (in meters or feet) surrounding the separators, with the reference zero for this level being the separator discharge section. For example, ICBS1 can be opportunely specified as a control block carrying information about the collapsed water level of the hydraulic cells surrounding the SEPD (control block number -300 is used in the example above for this purpose).

When the mechanistic separator is used, an additional graphical variable is available, called "dpss", which reports the pressure drop across the separator as predicted according to the mechanistic separator model. Such pressure differential is not actually imposed to the TRACE solution but is output for user's reference. If and when appropriate, the user may choose to adjust the additive loss coefficients of the SEPD in order to achieve a pressure drop close to that predicted by the mechanistic model.



## *Moisture Dryers*

The dryers model is available for all types of separator options described above and can be activated by setting the input variable NDRYRS to any non-null integer number[1] (i.e., the dryers option is not activated when NDRYRS = 0; it is activated by setting NDRYRS = 1, for example).

The activation of the dryers option will result in a further separation of the moisture from the bulk vapor at the SEPD exit junction, in addition to the separation process performed in the J-cell according to the chosen ISTAGE option and input performance specifications. In other words, when the dryers option is activated, the SEPD carry-over quality is the result of two successive actions: first, an initial $x_{CO}$ is calculated according to any of the input separator performance

1. This is because, in legacy TRAC-B input files, NDRYRS used to represent the number of actual chevron dryers being modeled with the SEPD.

specifications described in previous paragraphs; then a further correction is applied according to the dryers performance specification. In fact, the dryers model simply applies a correction to the void fraction $\alpha_{EX}$ convected across the exit junction of the SEPD J-cell, as a function of a calculated *dryers efficiency* $\varepsilon_D$.

When $\varepsilon_D = 1$ (100% efficiency), the dryers model enforces the condition that $\alpha_{EX} = 1$ (and consequently, $x_{CO} = 0$, perfect separation at the exit junction); If $\varepsilon_D = 0$, then the convected void fraction is not modified and the resulting $x_{CO}$ is just the value calculated according to the separator model alone (i.e., the dryers option is activated but no dryers action is performed); for dryers efficiency $\varepsilon_D$ between 0 and 1, the convected void $\alpha_{EX}$ is linearly interpolated between the donor value (the void resulting from the separator model alone) and 1.

The dryers inlet moisture quality $x_{D,IN}$ is defined as the ratio between the inlet mass flow of moisture and the inlet mass flow of mixture (in the code, this quantity is directly obtained from the separator exit flow quality). The dryers efficiency $\varepsilon_D$ is then calculated as a function of the dryers inlet moisture $x_{D,IN}$, a critical quality $x_{CRIT}$ and a user-input parameter DELDIM, in the following way:

- $\varepsilon_D = 0$ when $x_{D,IN} > x_{CRIT}$ + DELDIM (the dryers cannot perform when the inlet moisture is above the total dryers capacity);
- $\varepsilon_D = 1$ when $x_{D,IN} < x_{CRIT}$ (the dryers perform perfectly when the inlet quality is below the critical quality);
- $\varepsilon_D$ is linearly interpolated between 0 and 1 when $x_{CRIT} < x_{D,IN} < (x_{CRIT}$ + DELDIM).

Thus, the dryers critical quality $x_{CRIT}$ represents the upper limit for the inlet quality which results in a perfect dryers performance, and is calculated in the code as a linearly decreasing function of the inlet vapor velocity based on two additional input variables: VDRYL and VDRYU. Intuitively, if the vapor velocity is low, then the interfacial force exerted by the gas phase on the liquid droplets is too low and the dryers can perform optimally by de-entraining all the liquid; on the other hand, when the vapor velocity is very high, it exerts a larger interfacial force on the droplets and more of the entrained liquid gets through the dryers vanes. Thus, VDRYL represents the lower limit vapor velocity, below which the dryers efficiency is always 100%; for velocities above VDRYL, the dryers efficiency starts to deteriorate and VDRYU is the upper limit vapor velocity, above which the dryers efficiency can never be 100%. When input as 0.0, input variables VDRYL and VDRYU assume their default values, which are set to very high velocities (1000.0 and 1001.0 m/s) in order to specify a dryers efficiency of 100% (perfect dryers) independently of the inlet moisture quality.

Figure 2-72 shows a plot that summarizes the above considerations and definitions about the dryers performance specifications, and should result useful for a user willing to specify a custom dryers performance. The dryers efficiency is 100% (perfect separation at the exit face[1]) for vapor velocities below the user-defined limit VDRYL. The dryers efficiency can never be 100% for vapor velocities above the user-defined limit VDRYU. The dryers efficiency is 0% (no moisture

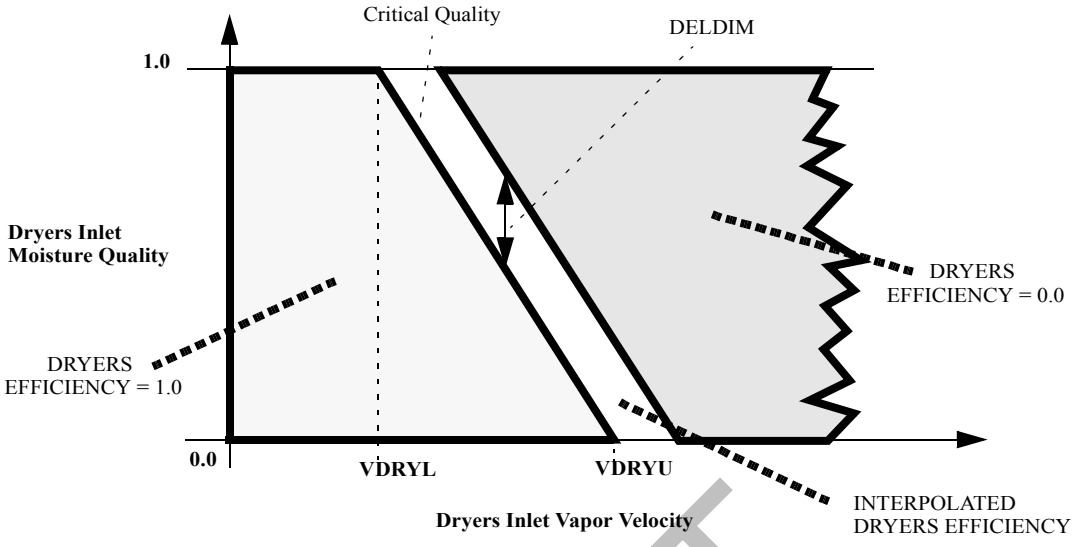


Figure. 2-72. Map of Dryers Efficiency for Varying Inlet Conditions

separation performed by the dryers) for moisture fractions above the dryers capacity, which is given by the sum of the critical quality and the user defined quantity DELDIM.

# *TEE Component*

The TEE component is actually two pipe components connected using a single junction. This component remains primarily for legacy purposes. All new decks should use pipe components with side junctions to represent a TEE. The TEE component models the thermal hydraulics of three piping branches, two of which lie along a common channel while the third enters at an angle $\theta$ from the other channel. In TRACE, the TEE component is conceptually treated as two PIPEs, as shown in Figure 2-73. Theta is defined as the angle from the low-numbered cell end of PIPE 1 to PIPE 2. The low-numbered cell end of PIPE 2 connects to PIPE 1. PIPE 1 extends from cell 1 to cell NCELL1 and connects to PIPE 2 at cell JCELL. PIPE 2 begins at cell 1 and ends at cell NCELL2. It should be noted that, internally, TRACE creates a dummy TEE cell as a means of accounting for the extra internal TEE junction cell and stems from an attempt to maintain the N-to-N+1 cells-to-faces ratio applicable to all pipe-like components. It is purely an artifact of the FORTRAN array data structures used to store TEE data and does not serve any useful programmatic purpose. In terms of input, when referencing TEE side tube cells in the control system input, the user should count cell numbers as if the phantom cell does not exist. So for example, the second cell in the side-tube would be referenced as NCELL1+2. However, when

1. The fact that perfect separation may be predicted by the dryers model for the J-cell exit cell does not imply that perfect separation also occurs at the discharge junction; at the discharge junction, the carry-under quality is determined by the separator model alone and the dryers option has no influence on XCU.

coupling TEE side-tube cells to HTSTR components or when interacting with the graphics file (via ACGrace), users must explicitly account for the ghost cell. So if a user creates a HTSTR that is supposed to couple to the side-tube of the TEE, then the first side-tube cell would be referenced as NCELL1+2. Similarly, the user would choose cell NCELL1+2 to plot, let's say, the pressure in the first side-tube cell. See Volume 1 for more details.

Mass, momentum, and energy convection occur across all three interfaces of JCELL. PIPE 2 sees this convection across its connection to JCELL as a boundary condition from cell JCELL of PIPE 1; PIPE 1 sees this convection across its connection to secondary-side cell 1 as a special JCELL boundary condition from cell 1 of PIPE 2. Liquid or gas can be prevented from entering the TEE secondary side by setting the input value of FRIC at the interface between JCELL and secondary-side cell 1 to a value greater than $10^{20}$ or less than $-10^{20}$, respectively. Actually, such a liquid or gas separator can be modeled at any mesh-cell interface. A generalized separator model is available in the SEPD component that otherwise is a TEE component.

Detailed input-data specifications for a TEE component are given in Volume 1 of the Users Guide. Input and output information is very similar to that of a PIPE component except that two separate PIPE-like parts are involved.



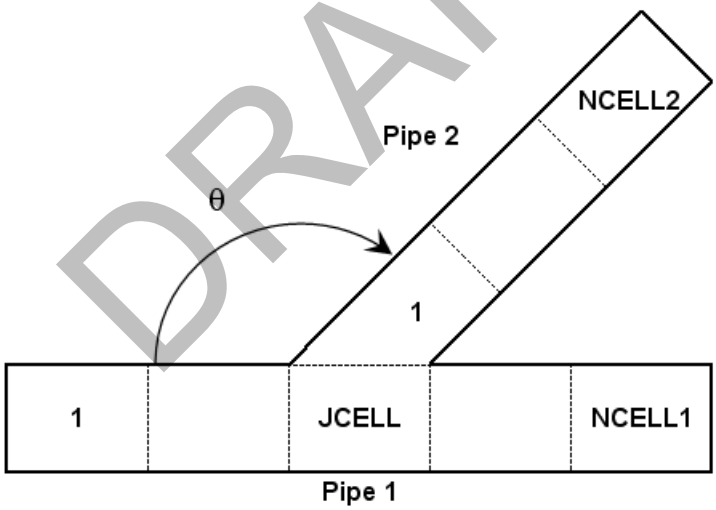


Figure. 2-73. TEE-component noding diagram.

# *TURB Component*

The TURB component is a special case TEE component, which includes additional models to simulated the operation of a steam turbine**.** Specifically, energy removal from the flow due to the conversion of fluid energy to mechanical energy, the efficiency of the turbine, and the pressure losses through the steam turbine are simulated with the TURB component. In addition, the TURB

component includes capability to simulate liquid drains or steam taps and the dynamics of multi-stages and turbine rotor assembly.

The input for the TURB component is the same as the TEE component, with additional input items required to simulate a steam turbine. The TURB component must be simulated with 2 cells in the primary arm of the TEE component (i.e., NCELL1 = 2) and with one cell in the side arm (i.e., NCELL2 = 1) and the side arm connects to cell 2 of the primary arm (i.e., JCELL = 2) (see Figure 2-74). The flow through the turbine is not treated in detail based on first principals, but is simulated by adjusting the momentum and energy flow at cell edge 2 consistent with a lumped momentum and energy balance for the turbine component. The additional input items required to simulate a steam turbine are given below.

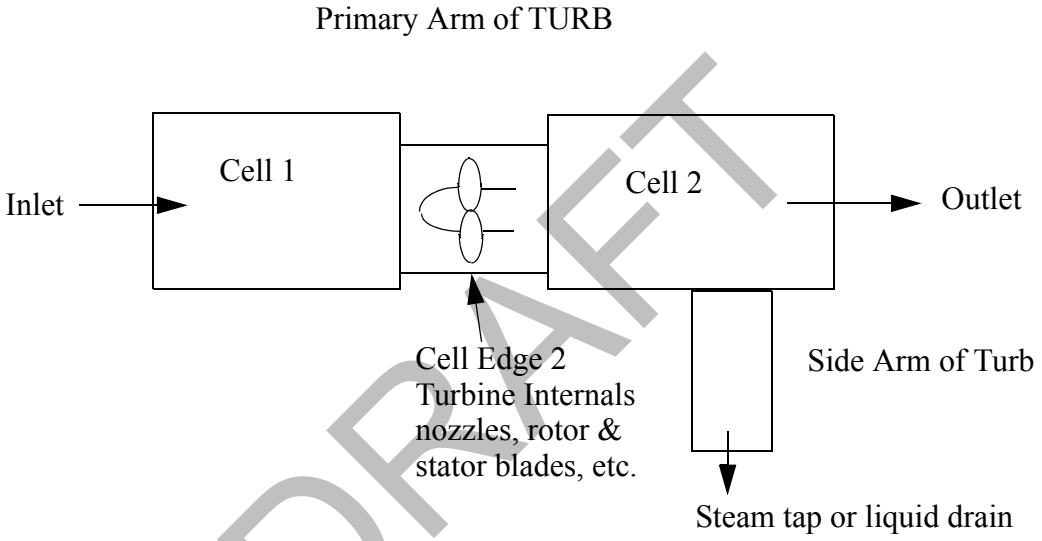




Figure. 2-74. TURB Component Noding.

The EFISHR input variable is the rated turbine efficiency, which is between zero and one. The energy extracted from the flow through the turbine is determined from Eq. (2-101).

$$Q = \dot{m}\eta\Delta h_{ideal} \tag{2-101}$$

where
Q is the mechanical energy extracted from the turbine flow (J/s = w).
$\dot{m}$ is the mass flow rate through the turbine (kg/s).
$\eta$ is the turbine efficiency.
$\Delta h_{ideal}$ is the ideal isotropic total enthalpy change across the turbine (J/Kg).

The turbine efficiency at non-rated turbine conditions is given by Eq. (2-102).

$$\eta = \eta_r(2\psi - \psi^2) \tag{2-102}$$

where,

$\eta_r$ is the rated turbine efficiency (i.e. EFISHR user input).

$\psi$ is the ratio of the rated mass flow times the rotor angular velocity over the mass flow rate times the rated rotor angular velocity $= \frac{\dot{m}_r \Omega}{\dot{m} \Omega_r}$. $\psi$ is limited to the range $0 \le \psi \le 2$.

$\dot{m}_r$ is the rated mass flow rate through the turbine (i.e. RMDOT user input) (kg/s).

$\Omega_r$ is the rated angular velocity (i.e. OMEGTR user input) (rad/s).

$\Omega$ is the angular velocity (rad/s).

RMDOT is the user input for the rated turbine mass flow rate (kg/s, $lb_m$/hr) and OMEGTR is the user input for the rated angular velocity (rad/s, rpm) in Eq. (2-102).

OMEGT is the initial angular velocity of the turbine rotor (rad/s, rpm). This is the initial condition that will be used to solve the angular momentum balance differential equation for the transient response of the turbine rotor (see Eq. (2-103)). The turbine angular velocity will be OMEGT until the turbine trip is true (see ITURTR input).

$$I\frac{d\Omega}{dt} = T - T_f - T_b \tag{2-103}$$

where,

$I$ is the turbine rotor moment of inertia (kg-$m^2$).

$\Omega$ is the angular velocity of the turbine rotor (rad/s).

$T$ is the rotor torque supplied by the steam flow through the turbine (Nt-m).

$T_f$ is the friction rotor torque (Nt-m).

$T_b$ is the bearing and windage torque (Nt-m).

If more than one TURB is on a given rotor shaft, then must be summed for all of the TURB components associated with that rotor shaft and there will be a single angular velocity for that rotor shaft. Eq. (2-104) is the sum of Eq. (2-103) over all TURB components associated with a given rotor shaft.

$$\sum_t I_t \frac{d\Omega}{dt} = \sum_t [\, T - T_f - T_b]_t \tag{2-104}$$

where, t is over all TURB components associated with a given rotor shaft. INERT is the turbine rotor moment of inertia (kg-$m^2$, $lb_m$-$ft^2$) in Eq. (2-103) and TORQTR is input for the rated turbine

torque (Nt-m, lbf-ft). The rotor torque supplied by the steam flow through the turbine is given by Eq. (2-105).

$$T = \frac{Q}{\Omega} = \frac{\eta_r \dot{m}_r \Delta h_{ideal}}{\Omega_r}\left[2 - \frac{\dot{m}_r \Omega}{\dot{m}\Omega_r}\right] \tag{2-105}$$

CTRQTB is the user input for the bearing and windage frictional coefficient (). The bearing and windage torque is given by Eq. (2-106). CTRQTB is $C_b$ in Eq. (2-106).

$$T_b = C_b \frac{\Omega|\Omega|}{(\Omega_r)^2} \tag{2-106}$$

SEPEFF is the turbine separator efficiency between zero and one. The input for SEPEFF is used to determine the separator efficiency of the turbine when the TRAC-B separation model is used (i.e. ITSEP = 1). It is recommended that the user turn off the TRAC-B separation model (i.e. ITSETP = 0 and set SEPEFF = 0.0 and IKFAC = 1 in the TRACE namelist input. Then TRACE user input for FRIC (i.e. 1.0e+21 and -1.0e+21) can be used to turn on the TRACE separator models for the steam and liquid drains. A FRIC of $10^{12}$ at a cell edge results in essentially no liquid flow across that cell edge, while a FRIC of $-10^{12}$ at a cell edge results in essentially no vapor flow across that cell edge. A FRIC of $10^{21}$ results in TRACE using a wall drag friction coefficient of $10^{21}$ for the liquid phase and a wall drag friction coefficient of 0.0 for the vapor phase and zero interfacial shear at that cell edge. A FRIC of $-10^{21}$ results in TRACE using a wall drag friction coefficient of 0.0 for the liquid phase and a wall drag coefficient of $10^{21}$ for the vapor phase.

ITSEP is the side arm separation model option flag. ITSEP = 1 implies that the TRAC-B separation model will be used in the turbine component, while ITSEP = 0 turns off the TRAC-B separation model. The recommendation is to use ITSEP = 0 (i.e. turn off the TRAC-B separation model) and use the TRACE separation model based on user input for FRIC.

NSTAGE is the number of stages lumped in series. For a multi-stage turbine, the pressure ratio in the governing equations for turbine component goes as $\left(\frac{P_2}{P_1}\right)^{1/(NSTAGE)}$. It is recommended that NSTAGE = 1, since modeling each stage separately has no significant impact on run time.

JROT is the turbine rotor number or shaft number. This allows several TURB components to be associated with the same rotor shaft. Maximum number of rotor shaft numbers allowed is ten and JROT should be numbered sequentially from one to NROT, where NROT is the maximum number of rotor shafts in the model. NROT is determined by TRACE during initialization, based on the user input for JROT. The current TRACE rotor shaft logic is in error and will be fixed in a future version of TRACE. The current TRACE rotor shaft logic allows TURB components on the same rotor shaft to spin at different speeds.

SATFLAG is the saturation exit flag. SATFLAG = 1 forces the exit conditions to be at saturation. SATFLAG = 0 does not force the exit conditions to be at saturation. If SATFLAG = 0 is used, then the user may have to adjust the TURB flow areas to ensure a critical flow at the turbine nozzle and at saturation condition at the exit.

ITURTR is the turbine trip number. If ITURTR is not equal to zero and the trip that it refers to is on, then the turbine angular velocity is calculated from Eq. (2-103). If ITURTR is zero or the trip that it refers to is off, then the turbine angular velocity does not change from OMEGT. The integration logic for Eq. (2-103) is currently in error and will be fixed in a future version of TRACE. The logic error in the TURB component integration of Eq. (2-103) results in the integration of the transient differential equation three times per time step. In addition, there is an error in the logic for summing Eq. (2-103) for all of the TURB components associated with a given rotor shaft and if there is more than one TURB on a given rotor shaft, the correct set of summed hydraulic torques and bearing and windage torques will not be solved. This will be fixed in a future version of TRACE.

Table 2-34 is a TURB component example input. For this example, the turbine efficiency is 0.8, with an rated angular velocity of 188.5 rad/s and a rated mass flow rate of 1936 kg/s. It is a single stage turbine on rotor shaft 1. The TRAC-B separation model is turned off (i.e. ITSEP = 0) and the liquid drain includes a FRIC = -1.0e+21 which allows liquid to drain through the side arm of the TURB component. The exit conditions for the TURB will be forced to be at saturation (i.e., SATFLAG = 1). The moment of inertia for this turbine is $1.2 \times 10^6$ kg-m$^2$. The bearing and windage loss coefficient is $10^5$ Nt-m and the rated torque is $10^6$ Nt-m. The turbine trip number is 100. The turbine angular velocity will be 188.5 rad/s until trip 100 is on, then angular velocity will depend upon the solution of Eq. (2-103).



**Table 2-34. TURB Example Input**

```
*
*******   type            num             id        ctitle
turb                        2              2  simulated hp turbine
*        jcell          nodes           ichf          cost           epsw
               2              0              0    0.0000e+00    0.0000e+00
*       iconc1         ncell1          jun1          jun2          ipow1
               0              2              6             2              0
*       radin1            th1        houtl1        houtv1        toutl1
    5.0000e-01    5.0000e-02    0.0000e+00    0.0000e+00    3.7300e+02
*       toutv1
    3.7300e+02
*       iconc2         ncell2          jun3         ipow2
               0              1             10             0
*       radin2            th2        houtl2        houtv2        toutl2
    5.0000e-01    5.0000e-02    0.0000e+00    0.0000e+00    3.7300e+02
*       toutv2
    3.7300e+02
*       EFISHR         sepeff         omegt         inert          rmdot
            0.8            0.0         188.5       1.2e+06         1936.0
*        itsep         nstage          jrot       satflag         iturtr
               0              1             1             1            100
*       omegtr         ctrotb        torqtr
         188.5       100000.0    1000000.0
* dx    * f    10.0 e
* vol   * f    10.0 e
* fa    *       1.0       0.5       1.0 e
* fric  * r02   1.7       1.7 e
```

```
* rfric * f     0.0 e
* grav  * f     0.0 e
* hd    * f     1.0 e
* nff   * f       0  e
* alp   * f     1.0 e
* vl    * f     0.0 e
* vv    * f     0.0 e
* tl    * f 533.7 e
* tv    * f 533.7 e
* p     * f   4.7e+06 e
* pa    * f   0.0 e
*
* dx    *    10.0 e
* vol   *     0.1 e
* fa    * f   0.01 e
* fric  *    -1.0e+21     0.0e
* rfric *    -1.0e+21 0.0e
* grav  * f   0.0 e
* hd    * f   0.01 e
* nff   * f   0 e
* alp   * f   1.0 e
* vl    * f   1.0 e
* vv    * f   0.0 e
* tl    * f 533.7 e
* tv    * f 533.7 e
* p     * f   4.7e+06 e
* pa    * f   0.0 e
```

# *VALVE Component*

The VALVE component is used to model various types of valves associated with light-water reactors. TRACE models 13 different valve types. The valve action is modeled by a component action that adjusts the flow area and hydraulic diameter at a cell interface of a 1D hydraulic component as shown in Figure 2-75. The VALVE component's adjustable flow area may not be located at a VALVE-component junction unless that junction is connected to a BREAK component.



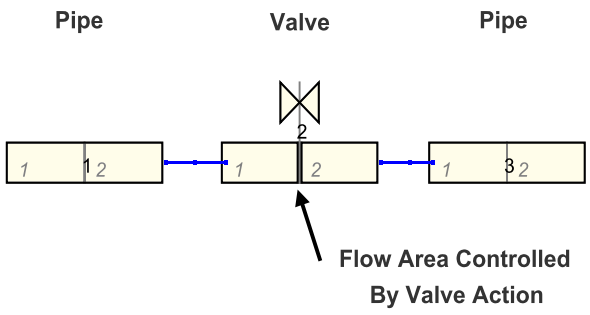


Figure. 2-75. VALVE-component noding diagram.

# *Valve Flow Area*

Two forms are provided for specifying the adjustable flow area of the valve. The adjustable flow area FA can be computed directly from an adjustable flow-area fraction FAVLVE according to

$$FA = FAVLVE \cdot AVLVE \tag{2-107}$$

where AVLVE is the input specified fully open adjustable flow area of the VALVE. In the second form, the flow area is calculated from the XPOS relative position of the valve stem where a guillotine-like blade is assumed to cut a circular cross-section flow channel. XPOS is the fraction of the circular cross-section diameter that the blade does not occupy.

FAVLVE = 1.0 or XPOS = 1.0 corresponds to a fully open valve with flow area AVLVE. The input-specified hydraulic diameter HVLVE for the VALVE's adjustable interface is its fully-open value. As the adjustable-interface flow area changes, its hydraulic diameter is evaluated based on the flow area.

FAVLVE or XPOS is input specified as a constant or a tabular function defined by a valve-adjustment table. An input-specified trip with ID number IVTR may control the evaluation of the table. The valve-adjustment table is evaluated only when the trip set status is ON. To increase the flexibility of modeling various types of valves, two valve tables may be input for a trip-controlled valve. The first table is evaluated when the trip set status is $ON_{forward}$, and the second table is evaluated when the trip set status is $ON_{reverse}$. Consistency is maintained in the interpolated state from both tables. The independent variable for the table/s is a modeled-system parameter defined by a signal variable or a control block.



# *Valve Types*

Many different types of valves can be modeled because of the flexibility to choose the independent variable of the VALVE component-action table/s and to perform table evaluation under trip control. Simple valves that either open or close when a trip is set ON may be modeled using a VALVE table that has relative time (since trip initiation) as the independent variable (a NVTB# < 0 VALVE table# = 1,2). Only two pairs of tabular data, ($t_1$, $y_1$) and ($t_2$, $y_2$) where $t_1 < t_2$ and y = FAVLVE or XPOS, are needed to define a constant rate of adjustment. The $(y_2 - y_1)/(t_2 - t_1)$ slope of the data is positive for a VALVE that opens and negative for a VALVE that closes. The initial or last evaluated FAVLVE or XPOS closure state of the VALVE is the interpolated value of y for t = 0. The minimum and maximum closure states of the VALVE are $y_1$ and $y_2$, respectively. Valve leakage can be simulated by restricting the $y_1$ value to be greater than zero. Simple valves can be used to model pipe breaks or the opening of rupture disks where $t_2 - t_1$ is small for a rapid opening of the VALVE adjustable flow area.

A steam-flow control valve (SFCV) or power-operated relief valve (PORV) can be modeled using an $ON_{reverse}$ - OFF - $ON_{forward}$ trip to control it. With the trip signal being the monitored pressure, the trip's $S_1$, $S_2$, $S_3$, and $S_4$ set points are the start closing pressure, end closing pressure, end

opening pressure, and start opening pressure, respectively. The rate of opening ($ON_{forward}$ state) defined by the first VALVE table can be different from the rate of closing ($ON_{reverse}$ state) defined by the second VALVE table. The rate of opening and closing will be the same if only the first VALVE table is defined. A relative value (summed change each timestep times the trip set-status value) independent variable needs to be defined for the VALVE table/s.

The example input in Table 2-35 is for a check valve (i.e., IVTY = 3) that has two separate tables for valve opening and closing. If IVSV = 1, points to a time signal variable, then VALVE 62 opens in 0.1 seconds when trip 620 (i.e., IVTR = 620) is $ON_{forward}$, and closes in 1.0 second when trip 620 is $ON_{reverse}$. The example input in Table 2-35, could be used as an accumulator check valve if the trip 620 is based on the differential pressure between cells 2 and 3 in VALVE component 62. If the trip 620 set points were: $S_1$=-300, $S_2$=-100, $S_3$=1000, and $S_4$=3000 and signal variable input to trip 620 was the pressure difference between cells 2 and 3 of VALVE 62, then when P(2) - P(3) > 3000, then the VALVE 62 would open in 0.1 seconds. When P(2) - P(3) < -300, then VALVE 62 would close in 1.0 second. This difference in the valve opening pressure differential and closing pressure differential tends to eliminate VALVE chatter (i.e., VALVE opening switching to VALVE closing each time step due to feedback between the valve opening/ closing and pressure difference across the valve.



**Table 2-35. Example Input for Valve with Separate Opening/Closing Tables.**

```
********   type            num        userid                 component name
valve                       62            62 $62$ acc-2 check valve
*       ncells          nodes          jun1          jun2           epsw
             7              0           656           456    1.0000e-05
*         ichf          iconc          ivty          ivps          nvtb2
             0              0             3             3             -2
*         ivtr           ivsv         nvtb1          nvsv          nvrf
           620              1            -2             0             0
*       ivtrov         ivtyov
             0              0
*         rvmx           rvov         fminov        fmaxov
    1.0000e+10    1.0000e+10    0.0000e+00    1.0000e+00
*        radin             th         houtl         houtv         toutl
    8.6500e-02    2.3000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv          avlve         hvlve         favlve          xpos
    3.0000e+02    5.0870e-02    2.5451e-01    0.0000e+00    0.0000e+00
*
* dx    *     1.04242e00    1.96901e00r02 3.1090e+00r03 3.3500e+00e
* vol   *     5.3030e-02    1.0016e-01r02 1.2033e-01r03 1.2964e-01e
* fa    * r03 5.0870e-02r05 3.8700e-02e
* kfac  * f   0.0000e+00e
* rkfac * r02 0.0000e+00    1.0000e+20r05 0.0000e+00e
* grav  * r02-1.0000e+00    0.0000e+00    1.0000e+00r04 0.0000e+00e
* hd    * r03 2.5451e-01r05 2.2225e-01e
* nff   * r07         -1             1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * r03 3.2200e+02    3.5000e+02    3.7900e+02    4.3600e+02    4.9300e+02
* tl    * e
* tv    * r03 3.2200e+02    3.5000e+02    3.7900e+02    4.3600e+02    4.9300e+02
* tv    * e
* p     * r02 4.4471e+06r05 1.5500e+07e
* pa    * f   0.0000e+00e
* vtb1  * r02 0.0000e+00    1.0000e-01    1.0000e+00e
* vtb2  * r02 0.0000e+00 f  1.0e
```

A quick opening/closing PORV can be modeled by using a VALVE table with the monitored pressure as the independent variable and a step-change function for FAVLVE or XPOS. It is important that the step function not be too steep or the valve flow area may oscillate each timestep between being open and closed. This is due to valve fluid flow and pressure coupling where valve over-adjustment results in the oscillation. A bank of PORVs can be modeled with a single VALVE component in the same manner by using a multistep function to simulate the multiple pressure set points corresponding to the multiple valves. The VALVE closure state is evaluated at the start of each timestep; the VALVE has a step change at the beginning of the timestep and is held constant during the timestep. Along with the flexibility to simulate many different valve types with generic models TRACE also has several specific valve models. These models are discussed in the following sections.

## *Multiple Banks of Safety Relief Valves with Automatic Depression System Trip*

Each bank of safety relief valves (SRV) open and close independently based on a pressure set point. The pressure is monitored in the cell directly before the mess-cell interface where the valve flow area is to be adjusted. The number of banks is specified using NVTB1. For each SRV bank the VTB1 tables are defined by tuples having the following from [independent-variable, dependent variable #1, dependent variable #2, ...]. One tuple is provided for each discrete SRV bank. The independent variable in the tuple is defined by IVSV variable and corresponds to the pressure used to determine the opening and closing of the SRV bank. The dependent variables in the tuples are valve bank fraction area relative to AVLVE, valve bank initial opening pressure, valve bank initial closing pressure, valve bank form loss coefficient, valve bank fractional hydraulic diameter relative to HVLVE, valve bank low/low opening pressure, and valve bank low/low closing pressure. The number of dependent values the user needs to input is dependent on the value of IVTRLO.



The form loss coefficient is used to compute an equivalent form loss for the open valve banks assuming that the banks open starting with the lowest numbered bank and close starting with the highest numbered bank. The sixth and seventh words become active only after the trip defined by IVTRLO is on.

The example input in Table 2-36, is for a VALVE component with IVTY = 7 and simulates 13 safety relief valves, which open in three banks. IVSV = 104 would be the upstream pressure that will be compared to the VALVE opening and closing pressures given in the VTB1 table. The valve area (i.e., AVLVE = 0.079855), would be determined to represent the open valve flow area for all 13 SRVs. If the signal variable given by IVSV = 104 is above 7.2 MPa but less than 7.79 MPa, then the first bank of 4 SRVs would be open (i.e., FAVLVE = 4/13 = 0.3077). If the upstream pressure is above 7.79 MPa, but less than 7.86 MPa, then the first and second bank of 8 SRVs would be open (i.e., FAVLVE = 8/13 = 0.6154). If the upstream pressure is greater than 7.86 MPa, then all 13 SRVs will be open. For this example, the closing pressure is slightly lower than the opening pressure and this helps to eliminate valve chatter (i.e., valve opening, then closing the next time step).

**Table 2-36. Example Input for Banks of SRVs**

```
********   type            num       userid                component name
valve                       59           59      $59$ safety relief valves
*       ncells         nodes          jun1          jun2           epsw
             2             0           988          1020            0.0
*         ichf         iconc          ivty          ivps          nvtb2
             1             0             7             2              0
*         ivtr          ivsv         nvtb1          nvsv          nvrf
             0           104             3             0              0
*       ivtrov        ivtyov
             0             0
*         rvmx          rvov        fminov        fmaxov
          10.0          10.0           0.0           1.0
*        radin            th         houtl         houtv         toutl
           0.0           0.0           0.0           0.0           0.0
*        toutv         avlve         hvlve        favlve          xpos
           0.0      0.079855      0.130175           0.0           0.0
* dx     *            0.5           0.5e
* vol    *        0.08651       0.08651e
* fa     *        0.17302           0.0      0.17302e
* kfac   *            0.2           1.5           0.9e
* kfacr  *            0.2           1.5           0.9e
* grav   *            1.0           1.0           0.0e
* hd     *       0.130175      0.130175      0.130175e
* nff    *              1             1             1e
* alp    *            1.0           1.0e
* vl     *  -1.67203E-3           0.0   2.88122E-6e
* vv     *   7.33599E-6           0.0   4.71773E-8e
* tl     *        559.564       373.145e
* tv     *        562.425       543.706e
* p      *    7.060779E6    1.015866E5e
* pa     *            0.0     188.3218e
*               favlve         popen         pclose       k-loss  hyd-D-fraction
* vtb1   *        0.3077       7.72E6        7.68E6          1.5          1.0s
* vtb1   *        0.6154       7.79E6        7.75E6          1.5          1.0s
* vtb1   *        1.0000       7.86E6        7.82E6          1.5          1.0e
```

## *Check Valves*

TRACE has three types of check valves. A static pressure controlled check valve without hysteresis, a static pressure controlled check valve with hysteresis, and a dynamic pressure controlled check valve. All three check valves will be opened based on the pressure difference across the mesh-cell interface number where the valve flow area is adjusted. The pressure difference is determined by using the following formulation:

$$\Delta P = P_{j-1} - P_j - \Delta P_g + P_{Dynam} - \Delta P_{Add} \tag{2-108}$$

where,

$\Delta P$ = Pressure differential across the mesh-cell interface where the valve flow area is adjusted

$P_{j-1}$ = Pressure in the cell just before the mesh-cell interface where the valve flow area is to be adjusted.

$P_j$ = Pressure in the cell just after the mesh-cell interface where the valve flow area is to be adjusted.

$P_g$ = The static pressure head due to gravity for cells j-1 and j.

$P_{Dynam}$ = The dynamic pressure as shown in Eq. (2-109).

$\Delta P_{Add}$ = Additional pressure difference needed to open valve due to spring loading.

For the static pressure controlled check valve without hysteresis $P_{Dynam} = 0$ in Eq. (2-108) and the valve will open if $\Delta P > 0$ and close if $\Delta P < 0$. If $\Delta P = 0$ the valve will remain unchanged.

An example input for a check valve (i.e., IVTY = 9) based on the static pressure without hysteresis is given in Table 2-37. For this example input $\Delta P_{Add}$ is 10000 Pa and the fully closed condition includes a leak flow area of 0.0005 m$^2$ (i.e., LEAKARAT = 5.0e-04). When the pressure in cell 1 is larger than the pressure in cell 2 by at least 10000 Pa, then the check valve flow area will be AVLVE = 0.2033 m$^2$. When the pressure difference between cells 1 and 2 is less than 10000 Pa, then the check valve flow area will be 0.0005 m$^2$.

**Table 2-37. Check Valve Example Input**

```
*
*******   type             num          userid                component name
valve                      515             515                check valve
*       ncells           nodes             jun1          jun2           epsw
             2               0              456           656            0.0
*         ichf           iconc             ivty          ivps          nvtb2
             1               0                9             2              0
*         ivtr            ivsv            nvtb1          nvsv           nvrf
             0               0                0             0              0
*       ivtrov          ivtyov
             0               0
*         rvmx            rvov           fminov        fmaxov
          1.0E20             0.0             0.0           0.0
*        radin              th           houtl         houtv          toutl
           0.0             0.0             0.0           0.0            0.0
*        toutv           avlve           hvlve         favlve           xpos
           0.0          0.2033           0.509           0.0            0.0
*      hysterr           adddp        leakarat
             0            1.0E4           5.0E-4
* dx    * f          0.3e
* vol   * f         0.09e
* fa    *            0.3          0.0          0.3e
* kfac  *            0.5        5.485          1.0e
* kfacr *            1.0        5.485          0.5e
* grav  * f          0.0e
* hd    * f   0.6180387e
* nff   * f           1e
* alp   * f          0.0e
* vl    * f          0.0e
* vv    * f          0.0e
* tl    * f       300.00e
* tv    * f       300.00e
```

```
* p     * f      1.0e6e
* pa    * f        0.0e
```

For the dynamic pressure controlled check valve the valve remains open until the pressure difference given by Eq. (2-108) is $\Delta P > 0$ and will remain open until $\Delta P < 0$. The dynamic pressure is given as:

$$P_{Dynam} = \frac{1}{2}[(1-\alpha)\rho_l v_l |v_l| + \alpha p_v v_v |v_v|] \tag{2-109}$$

If the valve is a static pressure with hysteresis or a dynamic pressure controlled check valve a hysteresis with respect to the forces opening and closing the valve is included in the model. This is done by using the length weighted mass flux shown in Eq. (2-110).

$$G = \frac{1}{2}[dx_{j-1}\{(1-\alpha_{j-1})\rho_{l(j-1)} v_{lj} + \alpha_{j-1} p_{v(j-1)} v_{vj}\} + dx_j\{(1-\alpha_j)\rho_{lj} v_{lj} + \alpha_j p_{vj} v_{vj}\}] \tag{2-110}$$

The check valves discussed above are RELAP5 style check valves. The user can also create simple check valves by using a VALVE table with the appropriate pressure gradient across the adjustable VALVE interface as its independent variable. The effect of hysteresis, where the pressure gradient is different for check-valve opening and check-valve closing, can be modeled with two VALVE tables. Alternatively, a check valve can be modeled as a trip-controlled VALVE with the pressure gradient defining the trip signal. When the trip is set $ON_{forward}$ or $ON_{reverse}$ for a pressure gradient that is large enough to open or small enough to close the check valve, the VALVE table evaluates the rate of FAVLVE or XPOS adjustment change.



## *Inertial Swing Check Valve*

The motion of the inertial swing check valve is modeled using Newton's Second Law of Motion. In this model it is assumed that the area change of the orifice with respect to time changes as a function of the inertial valve geometry. This valve also has three latching options: LATCHOPT = 0, the valve is allowed to open and close freely, LATCHOPT = 1, the valve is allowed to open or close only once, LATCHOPT = 2, the valve will only latch at the maximum position. The valve flow area, angular velocity, and angle are calculated using Newton's second law of motion Eq. (2-111).

$$\Sigma T = I\varpi \tag{2-111}$$

where,

$T$ = Torque due to pressure ( $T_P$), friction ( $T_F$), or weight ( $T_w$)

$I$ = Moment of Inertia

$\varpi$ = Angular Acceleration

There are three different forces used in this model to determine the opening and closing of the valve. The torque due to weight of the valve, the torque caused by the pressure differential in the cell before the valve and the cell directly after the valve, and the torque due to friction.

$$T_P = (P_{j-1} - P_j) A_p L \tag{2-112}$$

$$T_w = -gmL\sin\theta \tag{2-113}$$

$$T_F = \Delta P_{Add} A_R L \tag{2-114}$$

where,

$P_{j-1}$ = Pressure in the cell just before the mesh-cell interface where the valve flow area is to be adjusted.

$P_j$ = Pressure in the cell just after the mesh-cell interface where the valve flow area is to be adjusted.

$A_p$ = Projected area of the swing valve disk. The projected area of the swing valve decreases as the valve opens. It is calculated using $A_p = \pi r^2 \cos\theta$.

$L$ = The length of the swing valve measured from the hinge to the center of inertia.

$g$ = Gravitational acceleration constant

$m$ = Mass of the swing valve.

$\theta$ = The angular position of the disk, $\theta = 0$ is fully closed.

$\Delta P_{Add}$ = Additional pressure difference needed to open valve due to friction or other forces.

$A_R$ = Total area of the swing valve.

The new time angular velocity and angle can now be calculated using Eq. (2-115) and Eq. (2-116). Eq. (2-111) can be used to calculate the new time angular acceleration.

$$\omega^n = \omega^{n-1} + \varpi^n \Delta t \tag{2-115}$$

$$\theta^n = \theta^{n-1} + \frac{1}{2}(\omega^{n-1} + \omega^n)\Delta t \tag{2-116}$$

## *Motor-Controlled Valve (TRAC-B Style)*

The operation of this valve is controlled based on the pressure in a cell specified by the user. The user also defines the attempted valve operation. The valve can be in a stationary state, opening state, or closing state. The pressure in the cell that the user has defined is checked against four pressure set points to determine further valve operation. The user must input the pressure above which the valve begins to open, the pressure below which the valve stops opening, pressure below which the valve begins to close, and the pressure above which the valve stops closing. There has to be a cell present with a volume to set the control pressures, therefore this valve type can not be used as a single junction component.

There are three different ways this valve can relate the stem position to the valve flow area. The valve area will change linearly proportional to the valve stem position if IVPG =1. If IVPG = 2 The valve area is a S-shaped function of stem position. This function acts as if there is a guillotine cut of the circular cross section. If IVPG = 3 then a user defined function relating valve area to stem position is used. For this option the user must input the specified function in the VLTB tables.

## *Motor-Controlled Valve (RELAP5 Style)*

The operation of this valve is controlled by two trips; one opens the valve and the other closes the valve. The speed at which this valve opens and closes is controlled using either a constant rate parameter or a table of fractional stem position versus area. This valve can be latched on the open state or closing state. This means that if the valve is latched on open the valve can not be closing and if the valve is latched on closing it can not be opened. If one of these is latched and the other gets set the code will stop. In addition, valve flow coefficient ($C_v$) data can be input with this valve type. $C_v$ input requires that the user set NVTB2 > 0 and additional input cards. Reverse $C_v$ flow coefficients are input in valve table VLTB.

A PIPE, VALVE, and PUMP component can be used as a single junction component. This is done by setting NCELLS to 0. A single junction component is just that, a junction without volume. To use any of these components as a single junction the user has to set the NAMELIST variable USESJC=1. The PIPE, VALVE, and PUMP components can all have side junctions when NAMELIST variable USESJC is set to 2 or 3 (see ***PIPE Component*** above for more information on side junction).

# *VESSEL Component*



The VESSEL component generally models a light water reactor vessel and its associated internals. The component is 1-, 2-, or 3D in Cartesian or cylindrical geometry and uses a six-equation, two-fluid model to evaluate the flow through and around all internals. The internals of a light water reactor vessel include the downcomer, fuel-assembly reactor core, and upper and lower plena. Modeling options and features incorporated into the VESSEL component are designed mainly for LOCA analysis, but the VESSEL component can be applied to other transient analyses as well. A mechanistic reflood model that evaluates quenching or dryout for an arbitrary number of quench fronts is programmed (see ***HTSTR & REPEAT-HTSTR Component*** above for remarks on the additional top-down/bottom-up reflood model that is part of TRACE). This requires that the VESSEL component that models the reactor vessel be coupled to HTSTR components that model the fuel-assembly rods or other metal structures. A detailed description of the fluid-dynamics and solution methods for the 3D VESSEL component can be found in the TRACE Theory Manual. In this section, the VESSEL geometry and other important related considerations will be discussed.

A 3D, two-fluid, thermal-hydraulic model in (r, $\theta$ , z) cylindrical geometry will be described. The user, however, can select (x, y, z) Cartesian rectangular geometry as well. A regular mesh-cell grid, with variable mesh spacings in each of the three directions of a right-circular cylinder, defines the geometric region of solution of the VESSEL. This encompasses the downcomer, reactor core, and upper and lower plena, as shown in Figure 2-76 and Figure 2-78. The user defines the mesh by input specifying the radial r (or x), azimuthal $\theta$ (or y), and axial z coordinates of the mesh-cell boundaries:

$$r_i \quad i = 1 \, , \ldots , NRSX \quad ,$$

$$\theta_j \; j = 1 \, , \ldots , NTSX \quad , \text{and}$$

$$z_k \; k = 1 \, , \ldots , NASX \tag{2-117}$$

where NRSX is the number of radial rings, NTSX is the number of azimuthal sectors (angular segments), and NASX is the number of axial levels. By default, $r_0$, $\theta_0$, and $z_0$ are zero. The point ($r_i$, $\theta_j$, $z_k$) is a vertex in the cylindrical-coordinate mesh. The system-model elevation at ($r_0$, $\theta_0$, $z_0$) is input-specified by SHELV. Figure 2-77 illustrates the mesh construction. Mesh cells are formed as shown in Figure 2-79 and identified by an axial level number and a (horizontal-plane) cell number. For each axial level, the cell number is determined by first counting the cells azimuthally (y-direction) counter-clockwise (looking in the negative z direction) and then counting radially (x-direction) outward starting with the first azimuthal sector (y) and the innermost ring (x) cell, as shown in Figure 2-77. Figure 2-79 also shows the relative-face numbering convention that is used in connecting other 1D hydraulic components to a VESSEL-cell face (interface). Note that only three faces per mesh cell are identified because the other three faces are defined by neighboring VESSEL cells.

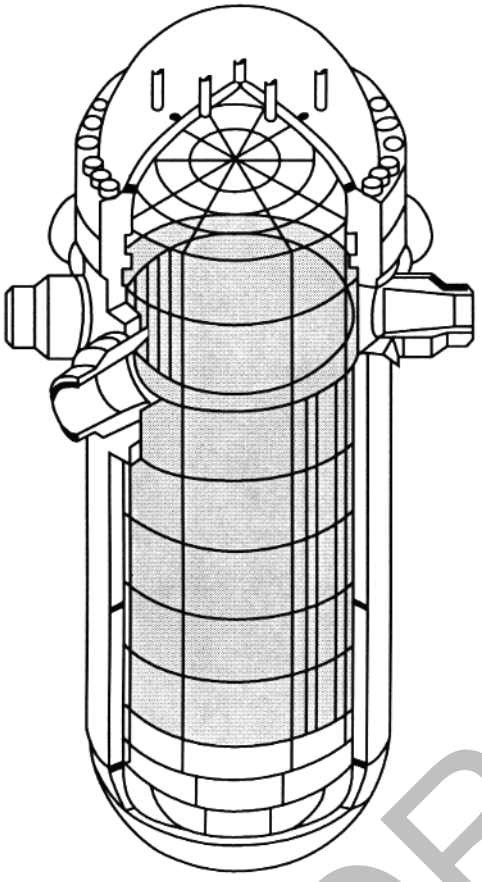

Figure. 2-76. Cell noding diagram for a typical PWR vessel.

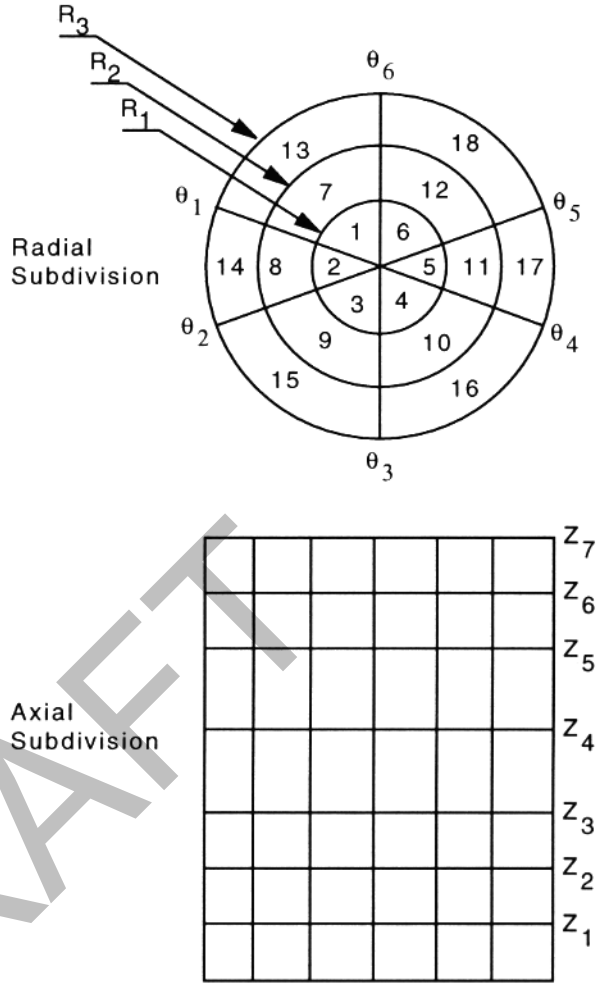


Figure. 2-77. VESSEL geometry: 3D mesh construction with three rings, six azimuthal sectors, and seven axial levels.



Normally, the orientation of the VESSEL component has its z-coordinate axis pointing upward (the gravitational unit vector points in the negative z-coordinate axis direction). The TRACE user can specify a general orientation of the VESSEL component by inputting NAMELIST input variable NVGRAV = 1. The gravitational unit vector components GXRC (r or x direction), GYTC (θ or y direction), and GZC (z direction) are input as part of the VESSEL-component data. The gravitational acceleration constant GC is input as well to replace TRACE's internal default value of 9.80665 m $s^{-2}$ for the entire hydraulic-system model.

All fluid flow areas (of cell faces) and all fluid volumes (of cells) are dimensioned so that internal structure within the vessel can be modeled by the VESSEL component. Cell flow areas and volumes are computed on the basis of geometric mesh spacings and the cell portion that is fluid

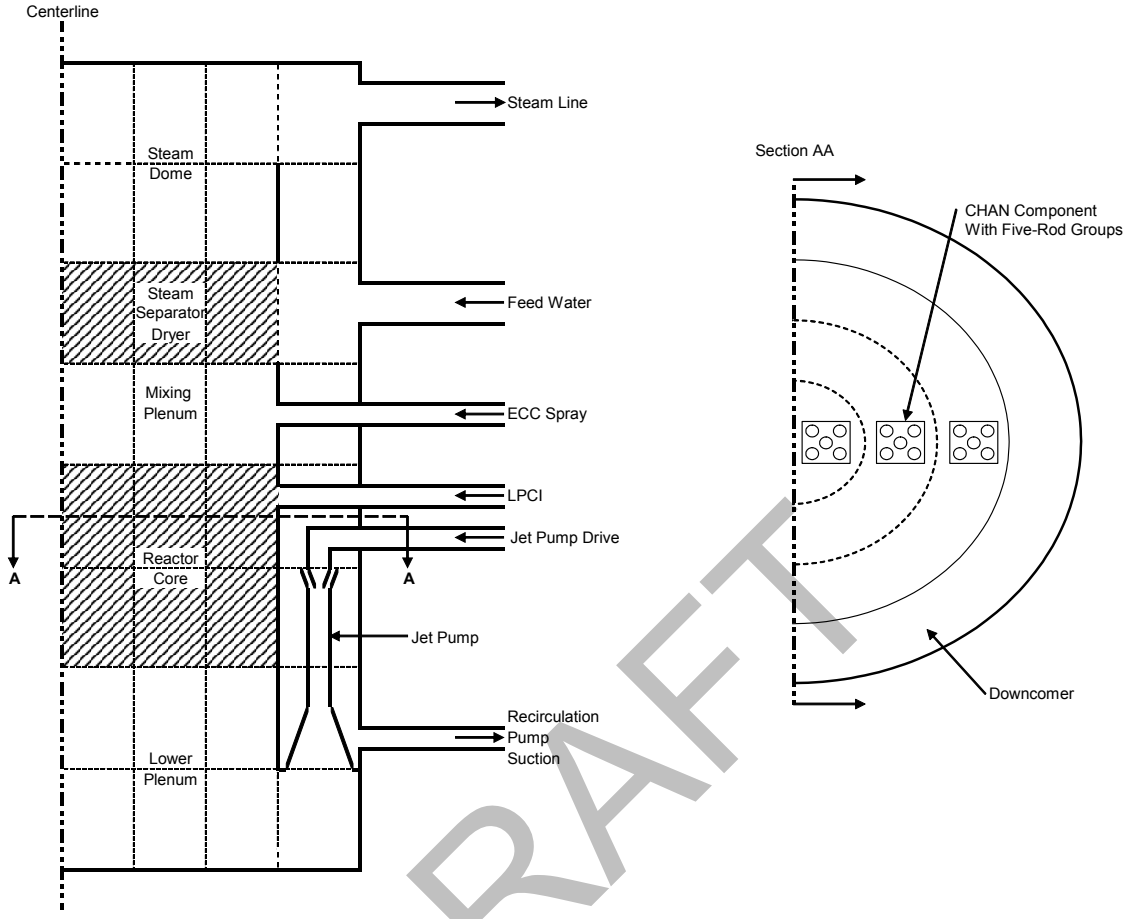


Figure. 2-78. Cell noding diagram for a typical BWR vessel.



according to cell flow-area and volume fractions that are input specified. The fluid flow areas and volumes are used in the fluid-dynamics and heat-transfer calculations**.**

Flow-area restrictions and the volume occupied by structure within each mesh cell are modeled through the difference between the geometric cell and its fluid portion. For example, the downcomer wall is modeled by setting the appropriate cell-face flow-area fractions to zero. A VESSEL feature is provided to do this automatically in TRACE if the upper-axial, lower-axial, and radial downcomer-position parameters IDCU, IDCL, and IDCR are specified by k, k, and i values [in Eq. (2-117)], respectively, different than zero. NAMELIST input variable IGEOM3 = 1 allows the user to input non-zero flow-area fractions in the downcomer wall that model leakage flow paths while IDCU, IDCL, and IDCR define the downcomer position so that downcomer and lower-plenum global parameters can be evaluated and written to the graphics file. Flow restrictions at the top and bottom core-support plates require flow-area fractions between zero and one. Figure 2-80 shows the cell faces that have flow-area restrictions to model the downcomer and core support plate. While input variables (NSGRID) do exist for specifying axial locations of spacer grids in the reactor core region, there is currently no spacer grid models in TRACE to take advantage of that information.

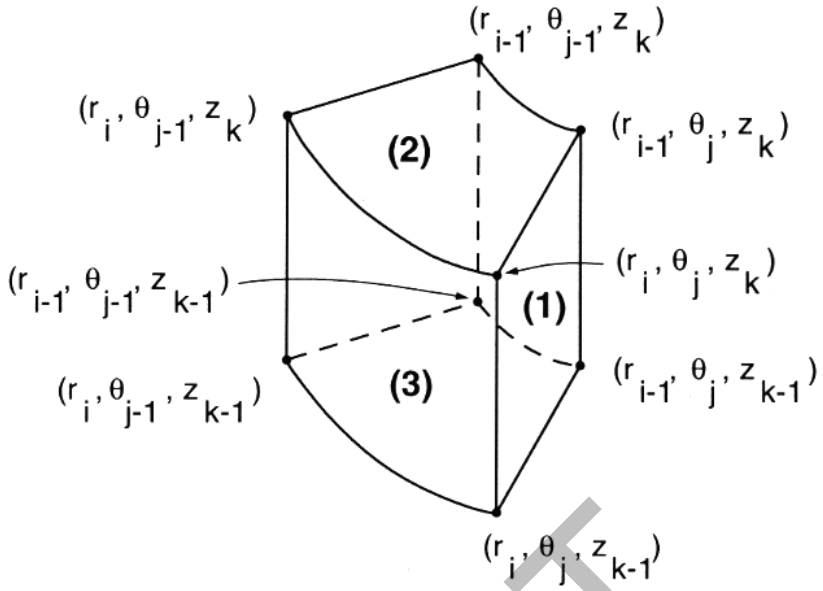


Figure. 2-79. Shown are the vertex corners of a 3D mesh cell and the face numbers on the near-side faces. Faces 1, 2, and 3 are in the θ , z, and r directions, respectively.

Piping connections from other 1D hydraulic components to the VESSEL are made to the faces of VESSEL mesh cells. These VESSEL connections are referred to as source connections. An arbitrary number of source connections per cell face is allowed, and each mesh cell in the VESSEL can have a 1D hydraulic component connected to it.

Input parameters LISRL, LISRC, LISRF, and LJUNS are used to define such a connection. LISRL defines the axial level number, LISRC defines the (horizontal-plane) cell number, and LISRF defines the cell-face number at which the connection is made. If LISRF is positive, the source connection is made to the cell face shown in Figure 2-79 with the direction of positive flow outward from the cell. If LISRF is negative, the source connection is made on the opposite face in Figure 2-79 with the direction of positive flow inward to the cell. For example, LISRF = 1 is the azimuthal face at $\theta_j$, LISRF = –1 is the azimuthal face at $\theta_{j-1}$, LISRF = 2 is the axial face at $z_k$, LISRF = –2 is the axial face at $z_{k-1}$, LISRF = 3 is the radial face at $r_i$, and LISRF = –3 is the radial face at $r_{i-1}$. The parameter LJUNS identifies the junction number of the 1D hydraulic component connected to this cell face. Figures 2-78 and 2-81 show several examples of VESSEL pipe connections. Note that internal as well as external cell-face connections are allowed.

The flow-area change reversible form loss at a source-connection junction is based on the connecting 1D hydraulic-component cell VOL/DX cell-averaged flow area changing to the VESSEL cell-face flow area times the fluid volume fraction in the cell. Generally, the flow area in the VESSEL that the source-connection fluid-flow experiences is much larger than that of the VESSEL cell's fluid. The flow-area change irreversible form loss at a source-connection junction must be input specified by FRICs (or K-factors). TRACE does not evaluate an abrupt flow-area change irreversible form loss by setting NFF = 0 at the source connection's 1D hydraulic-

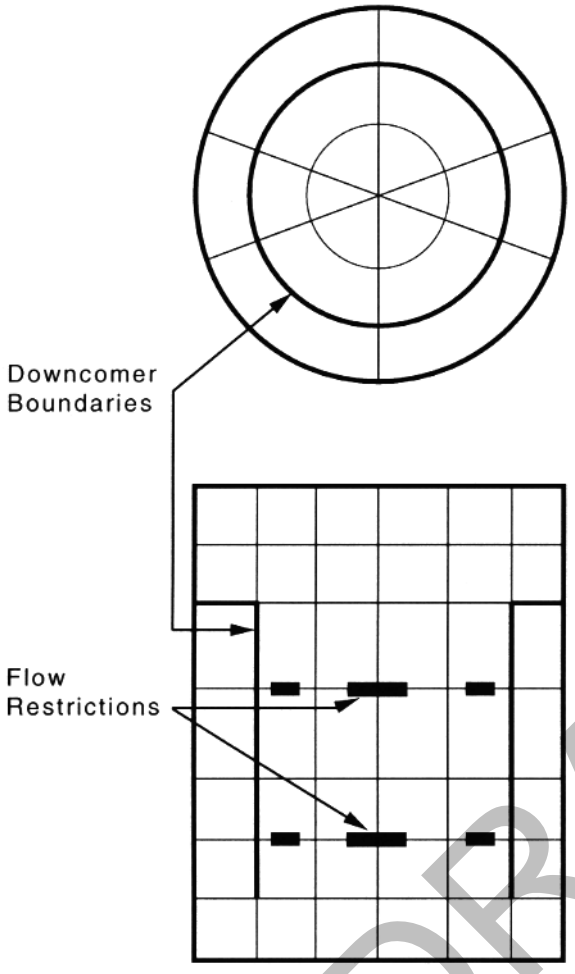


Figure. 2-80. Flow restrictions and downcomer modeling

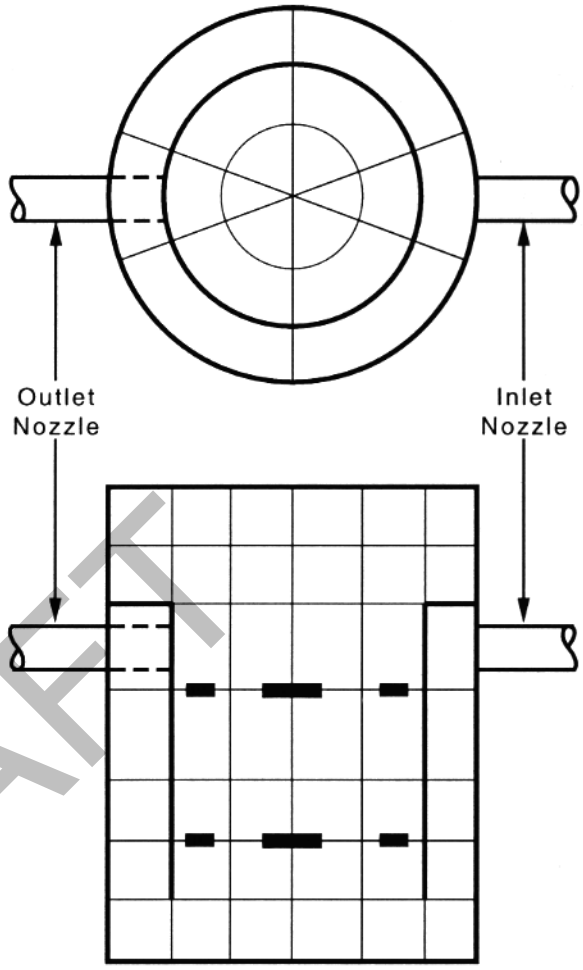


Figure. 2-81. PIPE component connections to the VESSEL component.



component junction. To evaluate both these losses, TRACE needs to know the VESSEL's flow area for each source connection's fluid flow. TRACE approximates that flow area with the VESSEL cell's fluid flow area for the reversible form loss but does not do the same for the irreversible form loss. This is because normally reversible form losses are evaluated internally by TRACE based on the momentum-convection term with flow-area ratios, and irreversible form losses are input specified by FRICs (or K factors).

A VESSEL option models the Babcock & Wilcox vent valves that are located in the wall between the upper plenum and downcomer. These vent valves permit flow directly from the upper plenum to the downcomer and out the cold leg for a cold-leg break. They are modeled by the same flow area AVENT in the outer radial face of NVENT cells for the NVENT vent valves. A variable FRIC irreversible form loss is defined to model opening and closing. The vent valves can be modeled by input-specified constant pressure-drop setpoints for each vent valve being open or

closed with constant FRIC values for each. A FRIC value is interpolated for pressure drops that are in between. The vent valves also can be modeled by an input-specified table of FRIC irreversible form loss vs pressure drop across the vent valve tabular data. Only one table is input for all vent valves when defined by tabular data.

The reactor-core region in the VESSEL is specified by the upper axial-level, lower axial-level, and outer radial edge positional parameters ICRU, ICRL, and ICRR, respectively, of the cylindrical region. Figure 2-82 shows a reactor-core region example where ICRU = 4, ICRL = 2, and ICRR = 2. Each axial column of mesh cells in the reactor-core region can contain an arbitrary number of fuel rods modeled by a HTSTR component. One average HTSTR element represents the average of the ensemble of fuel rods in each axial column of mesh cells. Its HTSTR-component heat-transfer calculation couples directly by convection heat transfer from the fuel-rod surface to the fluid dynamics of the VESSEL component. The thermal analysis of any HTSTR-component supplemental-power HTSTR element (at a power different than the average power) does not feed back or couple directly to the fluid-dynamics analysis of the VESSEL component. However, the average fluid condition in the coupled VESSEL mesh cell is used to evaluate the supplemental- as well as average-power HTSTR elements.

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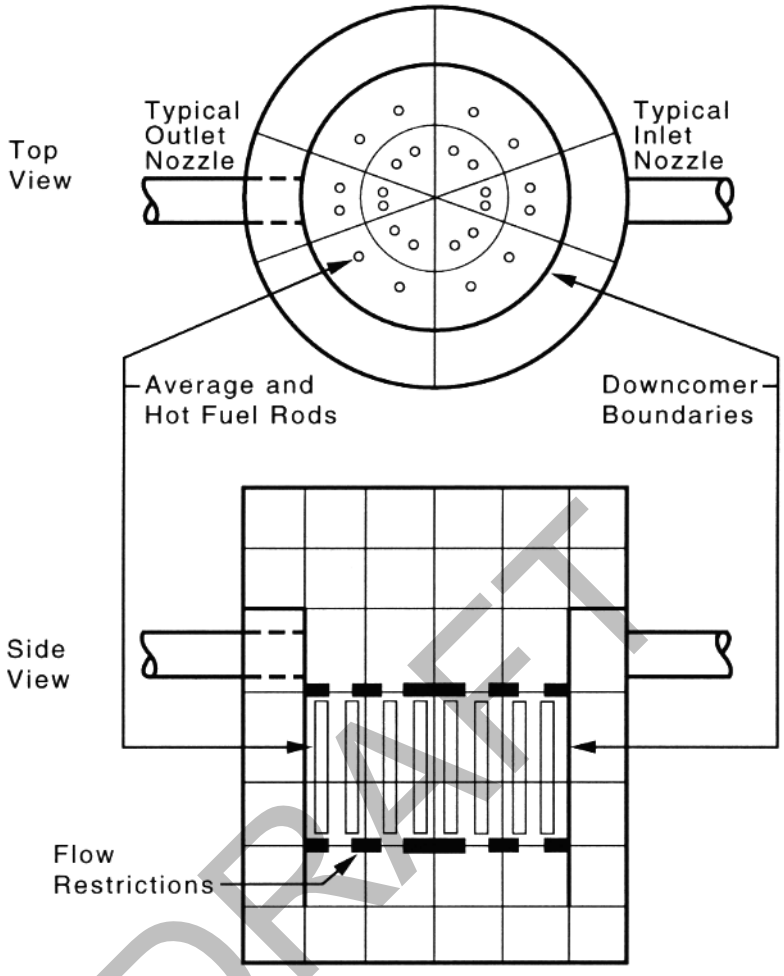


Figure. 2-82. Reactor-core region inside the VESSEL component.



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# 3

# *Control Procedure*



In reactors, electronic and mechanical systems are put into place which give the operating staff either manual or automatic control over system behavior. In manual mode the operator receives data from sensors located throughout the system and consciously decides which component actions need to take place in order to achieve a desired effect. Examples of component actions include opening and closing valves, turning pumps on/off, and inserting or withdrawing control rods. In automatic mode, electronic circuits exist which can take some of the intervention away from the operator to automatically control certain functions. Parameters like temperature, water level, pressure, flow rate, and power can be detected, and using predetermined set points, the electronic logic decides how to adjust the various components so that control is maintained.



The TRACE control procedure is the means by which the code user is given the same level of control over his or her computer model as a reactor operator has over his or her real reactor system. It also allows the user to model automatic control of regulating hardware as well as abnormal hardware behavior. Abnormal hardware behavior might consist of opening a valve in a line connected to an atmospheric-pressure boundary condition to simulate a pipe break.

The control system in TRACE is general and flexible. As a user,. you are able to define the specific control procedures that TRACE will evaluate. The generality and flexibility inherent to the defining form for the control procedure, however, will require you to think through the modeling details and control specifications to construct the desired control-procedure model. If you are a new code user, you may find the process difficult at first, but with examples and experience, it should become relatively straightforward to specify a control procedure that implements the desired control logic.

Figure 3-83 provides a conceptual model of the TRACE control system (shown within the dashed-line box) and how it interacts with the model of the physical system (shown within the solid-line box). The physical system model consists of the geometric description of the various components that comprise the system (pipes, valves, pumps, reactor vessel, etc.), the mesh connectivity between these components, the mass, momentum, and energy states of the coolant (density, velocity, pressure, temperature, etc.) and the metal structure properties (temperature, material properties, power, etc). As you can see, a TRACE control system is comprised of four basic building blocks: signal variables, trips, control blocks, and component-action tables. Signal variables are modeled-system parameters with real values that the user selects as signals for application in the TRACE control procedure. They are equivalent to the signals that an operator

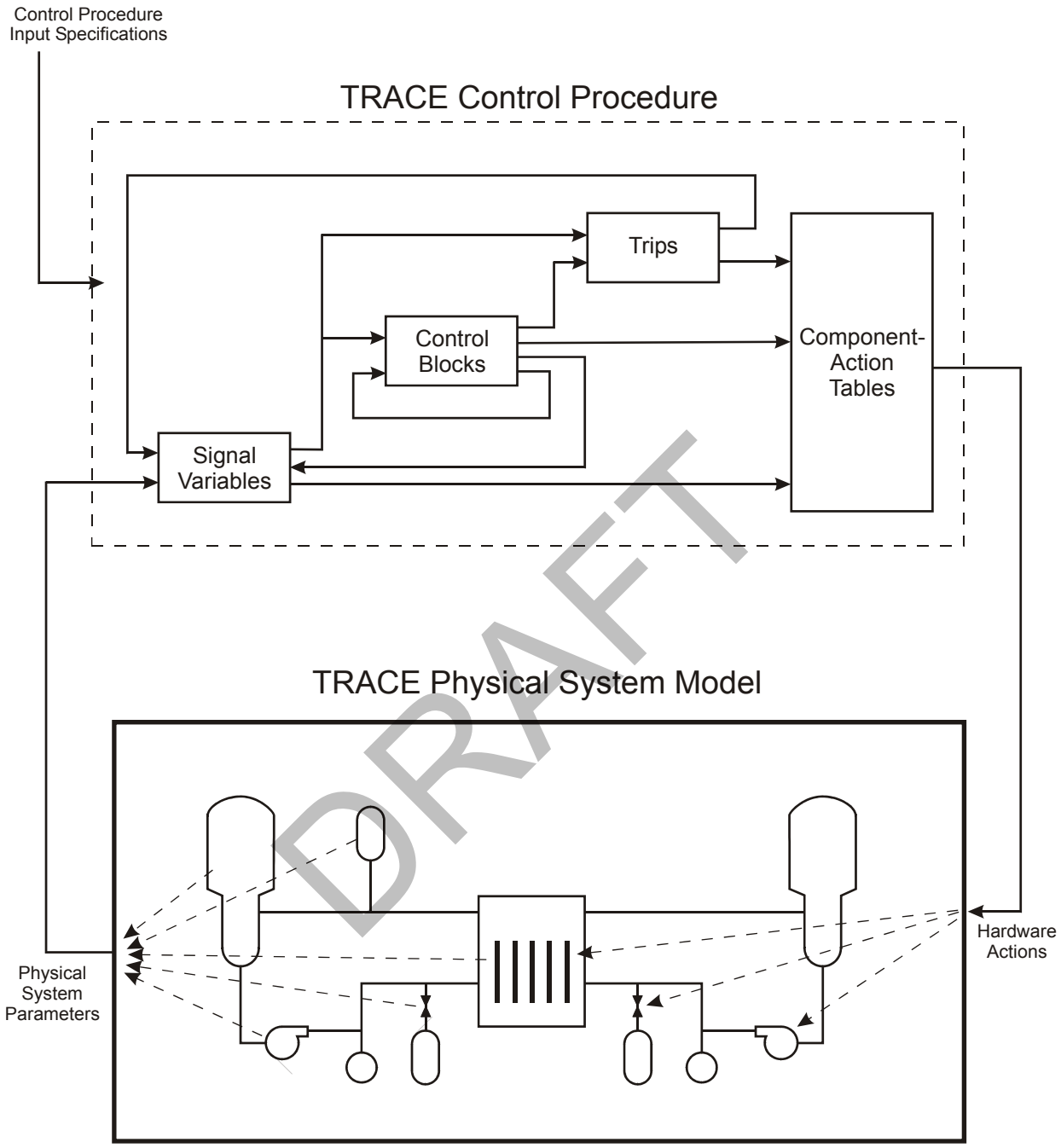





Figure. 3-83. Conceptual structure of the TRACE control system and how it interacts with a system model.

receives from the various detectors throughout a plant. Examples include core power, coolant temperature, fuel temperature, pump speed, valve position, etc. Control blocks are function operators which take as input either signal variables or the output from other control blocks and manipulate them in some way to produce a single output. Examples include operators like summers, logic gates, integrators or functions of independent an variable. A trip is an ON/OFF

logical switch whose status (i.e. ON or OFF) is determined by comparing some parameter in the system model (which you, as the user, must define) against one or more setpoints. Trips essentially provide the means by which you can control the timing of mechanical actions (i.e. opening and closing valves, adjusting pump speed, reactor scram, etc) based on predetermined set points of signal variable inputs. Component-action tables provide a means for modeling the adjustable hardware action of a component. They are essentially just lookup tables from which the response of some key component parameter may be determined as a function of an independent variable (obtained from the output of a trip, control block, or signal variable).

In the following five sections of this chapter, these four basic tools and the automatic sorting logic are described. The TRACE control procedure for evaluating steady-state calculations will be described in the final section. Later in this chapter, we will show with examples how these basic building-block tools can be used to construct control procedures of varying complexity, their purpose and how a control procedure interacts with a hardware component through a component-action table. Detailed input specifications for TRACE's control system are provided in Volume 1.



# *Signal Variables*

Conceptually, signal variables are the only means by which information is communicated to the control system from the rest of an input model. In its simplest form, a signal variable is nothing more than a specialized control block which takes its input from some parameter at any one of various locations in the computational mesh and sends that value to its own output. Signal inputs can originate from parameters that are global to an entire model (i.e. time), part of the hydrodynamic component database (i.e. pressure), part of the heat structure database (i.e. wall temperature), part of the kinetics database (i.e. power), or part of the control system itself (i.e. trip output signals).



For component parameters, some signal variables require defining their location at a specific mesh cell center, mesh cell-edge, or heat-transfer node. Some signal variable types are definable only for specific component types (for example, pump speed is only applicable to PUMP components). While signal variables are, by nature, single-valued parameters, their definition may span a range of locations to determine quantities like the maximum, minimum, or average over a range of mesh locations, or a difference between two values in space or time. Thus most signal variables (but not necessarily all) may take on up to six different functional forms which define what the output signal represents. When ISVN > 0, the form of the signal variable may be either the parameter value in a mesh cel, the maximum, the minimum, or volume-weighted average parameter value in a series of contiguous cells in a single component. When ISVN < 0, the form of the signal variable may be either the difference in the parameter's values in two given cells (in a single component) or the difference in the parameter's value since the last timestep. In either case (ISVN < 0 or ISVN > 0), the exact functional form that gets used is further defined by what we set for ICN1 and ICN2.

The following are a few examples of signal variable parameters: problem-time, pressure, temperature, density, internal energy, velocity, mass-flow, solute-concentration, reactor-core power, pump-impeller rotational speed, and valve flow area or stem position. Specific details and examples of how such definitions are specified can be found in Volume 1. In particular, Table 6-1 in that volume lists all the different signal-variable parameters available to the TRACE user.

In addition to serving as inputs to control systems, trips, or component-action tables, signal variables may also serve as means for creating user-defined output or graphics quantities. The user assigns to each signal variable a unique positive identification (ID) number as a means for distinguishing one from the other in the output and graphics files and for cross-referencing by components and control system entities later in the input file. They need not be specified in any particular order; TRACE contains a procedure for automatically sorting them so they are evaluated in the proper order.

The values of signal-variable parameters are calculated at the beginning of each timestep based upon the state of the modeled system at that time. This means that signal variables evaluated at time level n actually represent information calculated for time level n-1. This can have two ramifications. First, when plotting signal variable values from the graphics file, if you compare its value with the actual paramater the signal variable references, you will notice a slight single timestep offset. Second, this step-wise variation in signal variables can result in a fractional timestep delay for initiating and varying control-procedure actions by TRACE. The timing error can accumulate over time, leading to significant errors (especially if the timestep is large) in the timing of significant trip ON/OFF actions (such as initiating the opening of a closed valve). In these cases, the timing error can be minimized by defining trip-initiated timestep data cards for the corresponding trip. The TRACE timestep size is limited by such a trip to complete the timestep when the trip signal is expected (based on linear extrapolation) to cross its setpoint for changing the OFF/ON status of the trip.



# *Control Blocks*

Control blocks are function operators that operate on zero or more input signals to determine an output signal. The number of input signals depends on the function operator selected. The input signal to a control block can be a signal variable or the output from another control block (or itself). The input and output signals are always real-valued parameters, even those that are logical (0.0 or 1.0) in nature. Volume 1 of the User's Guide lists all the different control-block function operators available in TRACE. Control block ID numbers are negative to distinguish them from signal-variable ID numbers. They are evaluated by TRACE in an order that is automatically determined by the code. This process is described below in ***Automated Sorting Procedure***.

The desired logic of a control system can be defined and evaluated by coupling control blocks in series and/or in parallel with a control-logic network. System parameters defined by signal variables usually provide input signals for some, if not all, of the control blocks. Depending upon the specific control block type of interest, the initial value of a control block's output signal can either be user-specified (using the control block constant defined by the CBCON2 input variable)

or evaluated internally by TRACE based upon assumed initial steady-state conditions of the modeled system. The user specifies the initial value using the CBCON2 input parameter except for control-block function numbers 11, 26, 30, 51, and 59 where CBCON2 is actually used by the control block in defining its functional behavior. A control block that is implicitly coupled to itself through its input/output signals may be in a signal loop of control blocks all of which TRACE cannot initialize internally. TRACE provides a warning message when this is encountered and aborts the calculation after all input data have been processed. The user can remedy this by specifying a non-zero value for CBCON2 to initialize the output signal from one of the control blocks in the signal loop. The desired output signal from a control-logic network usually is from the final control block in the control-block evaluation procedure.

# *Trips*



A trip is an ON/OFF switch that can be used for the following:

1) to decide when to evaluate a component hardware action,
2) to define a ±1.0 or 0.0 (ON or OFF) status signal for application within a control block (such as a switch signal for logic-gate operator control blocks),
3) to define a blocking or coincidence trip (when combined with other trip status values).

A trip's status is evaluated at the beginning of a timestep, and held constant over that timestep, but it may vary from timestep to timestep. When the controlling trip for a component hardware action is ON (its status value is ±1.0), the component action is evaluated at the beginning of each timestep. When the controlling trip is OFF (its status value is 0), the component action is not evaluated at each timestep, and the action value remains constant at its previously evaluated (or initially defined by ISET) state.



Associated with the input specification of a trip are the trip-signal definition and setpoint values. A trip-signal can be any of the following:

- a signal variable or control block (signal-variable trip or simple-setpoint trip),
- an arithmetic-operator expression operating on signal-variable or control-block values (signal-expression trip),
- the sum or product of the status of two or more trips (trip-controlled trip).

Setpoints are values that define the exact state of the trip ($ON_{forward}$, $ON_{reverse}$, or OFF), based upon where the actual trip-signal lies, as compared to the setpoint point(s). For some trip types, the rate of change (increasing or decreasing) in the trip-signal becomes important in that it helps to define which setpoints get used to define the state of the trip. The OFF status for a trip has the value of 0.0. The ON status has up to two forms: $ON_{forward}$ and $ON_{reverse}$ with status values of +1.0 and -1.0, respectively. This distinction in ON states only has meaning for trips that control the evaluation of component-action tables (discussed below) and even then, only under limited circumstances. See the section below titled ***Specifying the Component-Action Table Itself*** for a

complete discussion of this behavior. The only important point you should take away from this section is that the nomenclature of “forward” or “reverse” with regard to the trip status has no direct correlation to whether a hardware action either increases or decreases. In other words, you cannot assume that a trip status of $ON_{forward}$ will always cause, let’s say, a valve to open and $ON_{reverse}$ to always cause it to close. We recommend that unless you have need to define componant-action tables which might rely on this distinction (such as those tables whose independent variable is "time since trip"), you simply ignore the "forward/reverse" designation and treat trips as simply being ON or OFF[1].

Two other trip parameters that need to be specified: are the setpoint delay times and the flags for applying optional setpoint factor tables. When a trip-signal crosses a setpoint value, TRACE will reset the trip status, but only after the specified setpoint delay time. This enables you to model the actual time delay of signal transmission and initiation of hardware-action movement, as experienced in a real plant or experimental facility. Setpoint factor tables enable you to vary the setpoint values by applying table-interpolated factors to them. The actual variation in control-procedure setpoints resulting from electronic drift of automatic-control hardware or operator timing when performing manual adjustments can be modeled with these tables.

TRACE also provides functionality, via a series of special trip types, that will allow you a) to generate special restart-data edits to the dump file, b) to terminate the TRACE calculation, and c) to implement a special set of timestep data for a particular time interval that you must specify. These actions are done by TRACE at the end of the timestep when a trip so defined was set ON at the beginning of the timestep. After using the special set of timestep data for DTEND seconds, TRACE returns to the regular timestep data it would have been using at that time. This special timestep data option also has the special feature of limiting the timestep size to complete the timestep when the trip signal is expected (based on linear extrapolation) to cross its setpoint value for changing to either an OFF or ON status.



The user assigns each trip an ID number to reference the trip in the control-procedure specification. A trip ID number can be either positive and negative valued. Only trips with negative-valued ID numbers are evaluated at the beginning of each timestep during a steady-state calculation; trips with positive-valued ID numbers are not evaluated during a steady-state calculation and remain at their input-specified ISET status throughout a steady-state calculation. During a transient calculation, all trips are evaluated each timestep.

# *Component-Action Tables*

Modeling the hardware action of a component is accomplished using a component-action table. The different types of hardware actions and the components to which they apply are shown in Table 3-38. Generally speaking, component-action tables define hardware actions as a tabular

1. This would have an effect on how you interpret the meaning of and overall choice in value for the ISRT input parameter.

function of some independent variable. The independent variable is specified through the use of a signal variable or control block. When a component-action table is input with no tabular data, the signal variable or control block simply defines the dependent variable (the hardware action) directly.

**Table 3-38. List of Available Hardware Actions in TRACE**

| Component Parameters That Can Be Controlled | Applicable Components |
|---|---|
| Pressure and fluid-state boundary condition | BREAK |
| Velocity or mass-flow and fluid-state boundary condition | FILL |
| Metal surface heat transfer boundary condition | HTSTR[a] |
| Reactor-core programmed reactivity or neutronic power | POWER |
| Reactor-core axial-power shape | POWER |
| Energy deposition directly in the coolant | PIPE, TEE, HEATR, JETP, SEPD, TURB |
| Energy generation in the wall | PIPE, PUMP, TEE, HEATR, JETP, SEPD, VALVE |
| Pump-impeller rotational speed | PUMP |
| Pump interface liquid & vapor velocity or mass flow rate | PUMP[a] |
| Separator carryover/carryunder | SEPD[a] |
| Valve flow-area fraction or relative stem position | VALVE |
| Drain valve flow area | HEATR[a] |
| In-beam power | FLPOWER[a] |
| Decay power in the fluid | FLPOWER[a] |

a. does not necessarily follow the typical input conventions for a component-action table (discussed below)

One important point to keep in mind is that while we present component-action tables in the context of the control system (as Figure 3-83 shows graphically), the input variables for a component-action table are actually specified as part of the component-input data, not in the control system section of an input file. To make it easier for users to more readily identify the component-action table input within an input file, the relevant input variables follow a standard naming convention, as shown in Table 3-39. In that table, and in the following discussion, we use the string 'XXX' in the variable names as placeholders for the one to three character strings unique to each specific component-action table type.

Each variable shown in the table allows you to configure, in some way, one of the basic building blocks of a component-action table:

- a trip used to control how and whether the component-action table should be evaluated,
- the independent variable (i.e. time, pressure, etc),
- the dependent-variable (i.e. the component-action itself),
- dependent-variable scale factor,
- a rate factor table,
- maximum rate of change constraint,
- the initial value of the component action,
- OFF value (value of the component action when the trip's status is OFF)

**Table 3-39. Component-Action Table Input Variable Naming Conventions**

| Variable[a] | Description |
|---|---|
| IXXXTR | The trip ID number that controls the evaluation of the component-action table. |
| IXXXSV | Signal variable or control block ID number whose value defines the independent variable of the component action table. |
| NXXXTB | The number of table entries ((x,y) pairs) in the component-action table. |
| XXXTB | The series of (x,y) values that define the component-action table itself. |
| XXXIN | Initial value of the component action |
| XXXOFF | Value of the component action to be used when the controlling trip is OFF after being ON. This parameter is not used of there is no controlling trip. |
| RXXXMX | Maximum rate of change of the component-action table. This value will constrain the interpolated value if the rate of change in value from one timestep to the next exceeds the threshhold established by this parameter. |
| XXXSCL | Scale factor for the component-action table. The dependent value in the table is multiplied by this value. |
| NXXXSV | Signal variable or control block ID number whose value defines the independent variable of the rate factor table. |
| NXXXRF | The number of table entries ((x,y) pairs) in the rate factor table |
| XXXRF | The series of (x,y) values that define the rate factor table. |

a. the string 'XXX' denotes a one to three letter string unique to each specific component-action table type. For example, the power-to-the-wall table generally uses "QP" or "QP3", while a valve area fraction table is denoted by a "V".

# *Specifying Trip Control of a Component Action Table*

In most cases, the evaluation of a component-action table may be controlled by a trip. The status of the trip tells TRACE whether it should evaluate the component-action table at the beginning of the timestep. As is probably intuitively obvious, a trip status of $ON_{forward}$ or $ON_{reverse}$ indicates the table should be evaluated and a status of OFF indicates the table should not be evaluated[1]. Without trip control, the component-action table is evaluated at the start of every timestep during a transient calculation. During a steady-state calculation, component-action tables are not evaluated at the start of a timestep unless they are trip-controlled and the controlling trip's status is ON

You are able to establish the use of trip control for a component-action table using the IXXXTR input variable. You simply reference the ID number of some existing trip in your input model; the actual definition of the trip with the ID number referenced here is specified in the trip input-data section located elsewhere in the input file. If no trip control is to be used, then IXXXTR should be defined with a zero.



# *Specifying the Component-Action Table Itself*

The heart of a component-action table is comprised of three input variables: IXXXSV, XXXTB, and NXXXTB. The IXXXSV input variable is a signal variable or control block ID number[2] that defines the physical-system parameter that is ultimately used as the independent variable to the component-action table. So for example, you might specify the ID number to a pressure signal variable (ISVN=21) for a pump-speed table that uses pressure as the independent variable. The XXXTB input variable is an array card in which you define a series of (x,y) pairs of numbers that define the component-action table itself. The NXXXTB variable establishes both a) the number of (x, y) pairs of data that you intend to provide for the XXXTB variable and b) through its sign convention (i.e. plus or minus), the precise form of the independent variable.

When NXXXTB is positive, the independent variable is the actual calculated value of the signal variable/control block defined by the IXXXSV parameter. When NXXXTB is negative, the independent variable is the sum of the change in the value of the signal variable/control block (SV/CB) over the previous timestep. For this latter form, the initial value of the component action corresponds to the component-action value in the table with an independent variable value of zero.



Note – Internal to TRACE, a bit of trickery is employed when it comes to evaluating a component-action table whose independent variable is the sum of the change in the SV/CB's value over each timestep. Rather than keep track of the running sum of the change in SV/CB each timestep, the code

1. Normally, this means that the hardware action remains constant with respect to the previous timestep, but this may not always be the case (the PUMP speed tables being one example).
2. Positive ID numbers define signal variables; negative ID numbers define control block output variables.

employs a scheme whereby the entire set of abscissa coordinate (x) values in the table are shifted each timestep by the current value of the independent variable, effectively re-establishing a new x-axis zero point for the table. From a user's perspective, you do not normally need to be concerned with the details of this internal table translation scheme. It is, however, worth noting that it happens because you will be able to see its effect when the component-action table is output on a restart (i.e. you will note shifted x-coordinate values in the output file).

When NXXXTB is negative and the table to be evaluated is under trip control (IXXXTR > 0), the sum of the change in the SV/CB over each time step is further multiplied by the value of the controlling trip's status (i.e. ON/OFF). OFF has the value 0, and the two forms of ON, $ON_{forward}$ and $ON_{reverse}$, have values +1 and -1, respectively. The net effect of this feature is that the trip status value affects the direction of interpolated movement in the table.

You may be saying to yourself right about now, "OK, but what does the term 'interpolated movement' mean?" Well, it means that if we were to plot out the component-action table on a piece of graph paper, a trip status of $ON_{forward}$ or $ON_{reverse}$ governs whether changes in the independent variable each timestep move us to the right or left (along the x-axis) on that graph. But it is not correct to simply assume that $ON_{forward}$ will always move us to the right and $ON_{reverse}$ will always move us to the left, as intuition might suggest. It really depends upon whether the value of the SV/CB is positive or negative. When the value of the SV/CB is positive, a trip status of $ON_{forward}$ will tend to cause the independent variable to increase in value, moving us to the right in the component-action table. When the value of the SV/CB block is negative, a trip status of $ON_{forward}$ will tend to cause the independent variable to decrease in value, moving us to the left in the table. The situation is exactly the opposite when the trip status is $ON_{reverse}$ - a positive SV/CB value will tend to move us to the left, and a negative SV/CB value will tend to move us to the right. The only time this convention does not strictly hold true is when the value of the SV/CB crosses the x-axis. In those situations, the direction of interpolated movement in the component-action table is governed by whether the positive or negative SV/CB value dominates the overall determination of the independent variable.



The effect the values for IXXXTR, IXXXSV, and NXXXTB have on defining the independent variable are summarized in Table 3-40. Evaluation of the component-action table is controlled by a trip when IXXXTR ≠ 0. No component-action table is defined (i.e. the component action is held constant) when IXXXSV = 0 is input. When NXXXTB = 0 is input with IXXXSV ≠ 0, a table is defined, but it has no tabular data. This is a special case where the component action is defined directly by the value of a signal variable or control-block - no table lookup actually gets performed.

**Table 3-40. Defined Forms of the Component-Action Table's Independent Variable**

| Component-Action Table's Defining Variables | | | |
|---|---|---|---|
| **IXXXTR** | **IXXXSV** | **NXXXTB** | **Independent Variable Form[a]** |
| All values | > 0 | ≥ 0 | SV |

**Table 3-40. Defined Forms of the Component-Action Table's Independent Variable**

| Component-Action Table's Defining Variables | | | |
|---|---|---|---|
| 0 | > 0 | < 0 | ΔSV |
| ≠ 0 | > 0 | < 0 | ΔSV*ISET |
| All values | < 0 | ≥ 0 | CB |
| 0 | < 0 | < 0 | ΔCB |
| ≠ 0 | < 0 | < 0 | ΔCB*ISET |

a. SV denotes a signal variable's value; CB denotes a control-block's output value.



A component-action table (with |NXXXTB|*2 values) is entered in the array data section of the component input. All component-action tables, with two exceptions, have one component-action value for each independent variable value. Thus, there are two values for each of the |NXXXTB| pairs in their tabular data. The two exceptions are the axial-power-shape and the energy-generation-in-the-wall component-action tables. In these cases, for each independent variable, the dependent-variable is really an entire tuple of values. For the axial-power table, entire axial-power shape with a relative-power value at each axial interface in the POWER component must be provided. For the heat generation in the wall table, when QPIN (or QP3IN) is less than zero, the dependent variable becomes a power shape distribution that specifies the power to the wall at each mesh cell from cell 1 to cell NCELLS in the mesh segment. When QPIN (or QP3IN) is greater than zero, the power table specifies the total power to the wall (distributed evenly to each mesh cell)



## *Specifying Rate Factor Tables*

Rate factor tables give you the power to specify a multiplicative factor to a component-action table's independent variable. Being in the form of a table, this factor may actually vary with respect to time or some other variable. In this way, you are essentially able to adjust the rate of interpolated movement in the component-action table. This gives you the flexibility, for example, to define a table such that the further a trip signal departs from its desired value, (i.e. the set-point value that turns the trip OFF), the larger the rate factor and the faster the component action can be adjusted in order to return the trip signal back to its desired value.

Warning – Rate factor tables are not recommended for general use. They are an anachronism from a time early in the development of TRAC-P before the existence of control blocks. The functionality this feature provides can be replicated entirely using a combination of control blocks, signal variables, and/or trips. We document them here for completeness and to serve as a source of reference when working with or reviewing old legacy TRAC-P input models. We recommend that existing rate-factor tables be converted to control systems whenever possible.

Specifying a rate-factor table first requires that a component-action table actually be defined (IXXXSV ≠ 0). Input variables NXXXSV and NXXXRF define a rate-factor table in the same way that IXXXSV and NXXXTB, respectively, define a component-action table. In addition to the six independent variable forms in Table 3-40, entering IXXXTR ≠ 0, NXXXSV = 0, and NXXXRF ≠ 0 defines the independent variable form for the rate-factor table to be the difference between the trip-signal value and the trip set-point value that turns the trip OFF.

When a rate-factor table is defined, the procedure for evaluating the component-action value is as follows. First, TRACE evaluates the rate-factor table's independent variable value (defined by IXXXTR, NXXXSV, and NXXXRF). The value is then used to linearly interpolate in the rate-factor table (when NXXXRF ≠ 0) or define directly (when NXXXRF = 0) the rate-factor value. Next, the component-action table's independent variable value (defined by IXXXTR, IXXXSV, and NXXXTB) is evaluated and multiplied by the rate factor. This product value is used to interpolate linearly in the component-action table (when NXXXTB ≠ 0) or define directly (when NXXXTB = 0) the component-action value. The component action in the input model is then defined with this value. This procedure is evaluated at the beginning of each time step with the current state of the system parameters to evaluate the independent variable forms for both tables. Not defining a rate-factor table (NXXXSV = 0 and NXXXRF = 0) reduces the above procedure to evaluating the component-action table's independent variable value and then using that value to interpolate linearly in the component-action table or define directly the component-action value.

## *Defining other component-action table input*

There are also a series of miscellaneous input variables that define the behavior of some (but not all) component-action table types. They each have the following general form: XXXIN, XXXOFF, RXXXMX, and XXXSCL. Variable XXXIN defines the initial value for the component action. This value is used when the component action is to be held constant or when the user is evaluating the component action under trip control and the trip is initially OFF. For component actions that are trip controlled, variable XXXOFF defines the component-action value that is used when the trip is OFF after having been ON. Entering XXXOFF = $-1 \times 10^{19}$ defaults TRACE to using the last component-action table value evaluated when the trip was ON. Variable RXXXMX defines the maximum rate of change of the component-action value allowed by the user during the simulation. When the component action evaluated from the table varies faster than this maximum rate, the component action is redefined to vary at the maximum rate. Later when the rate of change of the table-evaluated component action falls below the maximum rate, the applied component-action value will be able to catch up to the value determined from the table. Variable XXXSCL is a scale factor that gets applied to the all the dependent-variable values of the component-action table immediately after the table has been read in from input..

# *Automated Sorting Procedure*

The control procedure is evaluated at the very beginning of each timestep. In general, control system entities are evaluated in the following order: first signal variables, then control blocks, and

finally trips. Component-action tables are evaluated at the beginning of the hydrodynamic solution. While this is true, in general, it is possible for certain signal variable outputs to be based on the outputs of control blocks, or control blocks to be connected in such a way that implicit loops are created such that their outputs serve as their own inputs. If left unresolved, this has the potential to lead to situations in which a control system's outputs are not entirely consistent with its own inputs.

To prevent such situations from happening, TRACE employs an automatic sorting algorithm to determine the optimal execution sequence for all signal variables, control blocks, and trips within a control system. The user-assigned ID numbers for each entity are retained for graphing and editing purposes, but are not used as part of the internal control system calculation. The automatic sorting algorithm sorts the control blocks in the following manner:

1) Place signal variables at the top of the evaluation stack except those whose inputs require outputs from trips;
2) Place trips, which provide input to signal variables or control blocks below any signal variables loaded at the top of the evaluation stack.
3) Place control blocks that do not receive inputs from other control blocks;
4) Place control blocks whose inputs have all been loaded in the evaluation stack.
5) If there are still control blocks left unloaded, then implicit loops exist. The starting point of each implicit loop is located and each loop is placed in the execution stack . The groups of control blocks comprising each implicit loop are located and inserted in the execution stack as a single entity such that the blocks supplying inputs to the loop lie above the loop, and blocks requiring input from the loop lie below the loop.
6) Load remaining signal variables whose inputs rely on trips below all control blocks
7) Load remaining trips (whose outputs do not feed into any control blocks or signal variables)





# *Time Step Sub-Cycle Scheme*

The maximum control system time step size should be 1/10 of the shortest delay time occurring in any logic delay (LDLY) control blocks. With the time step sub-cycle scheme, if the TRACE control system time step logic determines that the maximum allowable control system time step size is greater than or equal to the thermal-hydraulic time step size, the thermal-hydraulic time step size will be used for the control system time step size. If it is less than the thermal-hydraulic time step size, the thermalhydraulic time step size will be sliced into the smallest number of equal intervals such that the interval size is less than or equal to the maximum control system time step size. This interval is then used as the control system time step size. In this manner, the control system calculation may be divided into several sub-steps while it catches up with the thermal-hydraulic calculation. At the end of this series of sub-steps, the control system calculation is at the same time level as the thermal-hydraulic calculation.

# *Control Procedure for Steady-State Calculations*

TRACE performs a transient calculation by successively evaluating the end-of-timestep solution for discrete timesteps and stepping forward in time. This same procedure is followed when evaluating a steady-state calculation but with added internal-control features applied. Steady-state calculations generally are performed to provide the initial conditions for a transient calculation restarted.

There are three types of steady-state calculations: generalized, constrained, and static check. A generalized steady-state (GSS) calculation asymptotically evaluates the time-independent steady-state solution of a modeled system where adjustable-hardware actions (like valve opening/ closing, reactor scram, pump speed changes, etc) are held constant at their input-specified values. A constrained steady-state (CSS) calculation is evaluated in the manner of a GSS calculation but with the addition of user-selected controllers that adjust specific component parameters (hardware actions) to achieve desired steady-state values for specific thermal-hydraulic parameters. These proportional-plus-integral (PI) controllers adjust somewhat uncertain hardware actions to achieve known or desired thermal-hydraulic conditions. A static-check steady-state (SCSS) calculation checks for the presence of unknown or erroneous momentum or energy sources in the modeled system by setting the rotational speed of all pumps and energy sources to zero. All coolant flow in the system should decelerate to zero because of wall-drag surface friction as the SCSS calculation is evaluated.

The initial solution estimate for a steady-state calculation is specified as part of the component data. It is easiest for the user to define this initial solution estimate at isobaric, isothermal, no-flow, and no-power conditions. Doing so results in the steady-state calculation requiring more calculative effort to convergence to the desired steady-state solution than if a better initial solution estimate were specified. TRACE has the option of internally initializing better-estimate steady-state phasic temperature and velocity distributions with the hydraulic-path steady-state (HPSS) initialization procedure. This option is based on specifying steady-state temperature, coolant flow, and power source/sink conditions that the user estimates for each hydraulic-path 1D flow channel. It is significantly easier to specify this thermal-hydraulic information for a dozen 1D flow channels than for a thousand mesh cells and interfaces in the system model. The calculative effort of the GSS or CSS calculation when applying this option generally is reduced by an approximate factor of two.



# *Examples*

In this section, we show you how control procedures can be developed. We start with very simple examples to illustrate how the signal variable, control block, trip, and component-action table building blocks of the control procedure are interconnected. Subsequent examples will become more complex to illustrate more of the capabilities and subtleties of a TRACE control procedure.

# *Example 1: Trip-Controlled Valve Closure*

Consider a simple trip procedure where we require that a valve close when the pressure in a specific hydraulic-component cell falls to or below a specified value. We also require that the valve close and remain completely closed throughout the rest of the calculation regardless of what the monitored pressure does thereafter. The valve could be, for example, a turbine stop valve (TSV) and the pressure could be the pressure in the pressurizer. If this pressure falls below a given value, the reactor-core power is tripped off and the TSV is required to start closing with an assumed 1 second delay. The valve is required to close rapidly (0.5 s from full open to full closed) and remain closed (unless operator action is taken, which will not be modeled here). We will focus only on the elements of this particular control specification and indicate where the input data for its control procedure would appear in the TRACE input file. For this control procedure, we must know the pressurizer pressure at all times, how to communicate this information to the trip, and how to communicate the trip status to the VALVE component it controls.



We make the pressurizer pressure available to our control procedure by defining a signal variable. We also define the problem time by a signal variable because it will be used to define the independent variable in the VALVE component-action table for adjusting the flow area of the VALVE. This signal-variable input data would be placed in the signal-variable section of the input file. Assuming that the pressurizer is modeled by component 22 and its pressure is monitored in cell 1, the signal variable input data would be



```
:
        *      idsv       isvn       ilcn       icn1       icn2
                  1          0          0          0          0  * time
                  2         21         22          1          0  * pressure
```

Each signal variable ID number value (IDSV) is chosen by the user. We have identified signal variable ID = 1 to be problem time (ISVN = 0). Because problem time is not associated with any component, the other input variables (ILCN, ICN1, and ICN2) are 0. We have identified signal variable ID = 2 to be pressure (ISVN = 21). The value of ILCN is 22, which is the component number for the pressurizer it models. The variable ICN1 = 1 identifies cell 1 as the location in component ILCN where the pressure is to be monitored. No second-cell entry is required for ICN2, so zero is entered. You should get in the habit of using frequent comments (initiated by a "*" character) so that other users can identify the nature of the input data more readily. The tendency is not to comment because at the time of preparing the input data, the nature of the data may seem obvious. Generally, such is not the case a few weeks or months later, even for the analyst who originally develops the model.

The trip input data for our control procedure with comments and variable name labels would be

```
:
  * trip 1 turbine stop valve closes on low primary-side pressure
  *              idtp            isrt            iset            itst            idsg
                  113               1               0               1               2
```

```
*           setp(1)          setp(2)
         1.3100e+07       1.0000e+08
*           dtsp(1)          dtsp(2)
         1.0000e+00       1.0000e+04
*           ifsp(1)          ifsp(2)
                0                0
```

The trip ID identifier number of 113 for IDTP is chosen by the user. The value of ITST = 1 identifies the trip signal as being defined by a signal variable or control block (later we will show a control-block output signal being defined as the trip signal). The value of IDSG = 2 identifies the trip signal as being defined by signal variable ID = 2 (the pressurizer pressure in component 22, cell 1). IDSG > 0 defines a signal-variable ID number and IDSG < 0 defines a control-block ID number. To determine the values for ISRT and ISET, we need to review additional concepts about the trip's defining form (i.e. how its setpoints and incoming trip signal relate to one another).

Initially and during normal plant operation, the pressurizer pressure will be well above the pressure setpoint at which the reactor-core power is to trip off and the TSV is to close. During this time period of operation, we want the TSV to be open, and we do not want any change in its valve-closure component-action state. When no evaluation of a component-action is desired at the start of the simulation, the initial status of its controlling trips should be OFF (corresponds to an ISET value of 0). Thus, we input ISET = 0 for the initial status of trip ID 113.

For our desired control procedure, we will need a trip with only two possible states - OFF and $ON_{forward}$. Initially ISET = 0 defines the trip status to be OFF so the TSV's valve-closure component-action table is not evaluated. When the pressurizer pressure falls below a specified setpoint value, we want the trip's status to be set by TRACE to $ON_{forward}$. With a status of $ON_{forward}$ for trip ID 113, the TSV's component-action table is evaluated at the start of each timestep. We want that evaluation to close the TSV. Figure 3-84 shows the trip-signal value range along a horizontal line with our desired $ON_{forward}$ and OFF subranges delineated by desired setpoint values of $S_1 = 1.31\times10^7$ Pa and $S_2 = 1.0\times10^8$ Pa. Trips have two setpoints between subranges to model hysteresis and to avoid an oscillating change in status between timesteps. The trip signal is compared with the setpoint closest to the subrange that it is testing for a change of status to. When ISET = 0, the trip signal is compared against setpoint $S_1$ to test for a change of status to $ON_{forward}$ and when ISET = 1, the trip signal is compared against setpoint $S_2$ to test for a change of status to OFF. The trip signal range specified in Figure 3-84 correponds to ISRT = 1. $S_1 = 1.31\times10^7$ Pa is our desired pressurizer pressure setpoint for tripping the reactor-core power off and closing the TSV. Initially, the pressurizer pressure is greater than $S_1$, so when it falls to or below setpoint $S_1$, the status of the trip is changed to $ON_{forward}$ and the TSV component-action table is evaluated to perform value closure. If a pressure spike were to occur during this problem time causing the pressurizer pressure to exceed $S_2$ before the TSV is completely closed, the TSV component-action evaluation would stop and the TSV would remain partially open until the pressurizer pressure once again decreased to or below $S_1$. This would prevent the trip logic

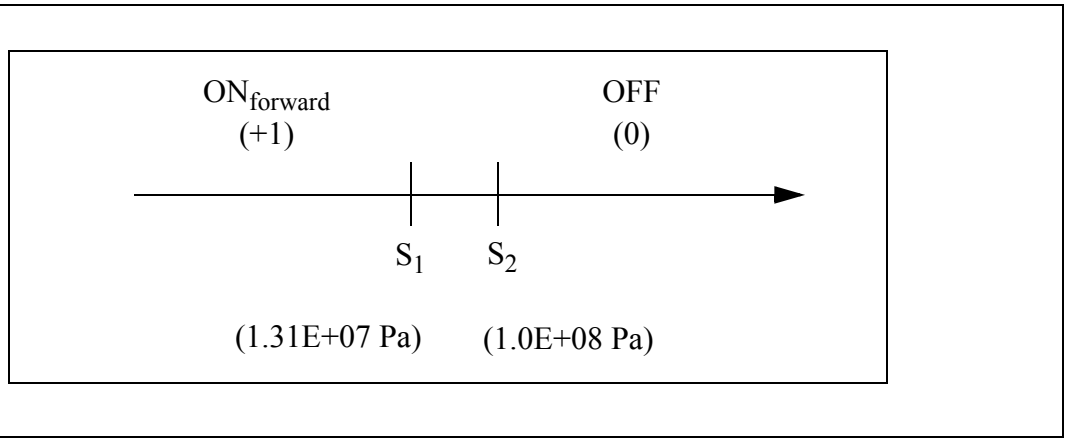



Figure. 3-84. Trip-signal setpoint diagram for turbine stop valve control.



controlling TSV closure from operating as intended. To avoid this possibility, we specify the value of setpoint $S_2$ high enough so that it is very unlikely the pressurizer pressure will reach this value during the calculation [i.e., $S_2$ = SETP(2) = $1.0\times10^8$ Pa].

In the trip input data above, the setpoint delay time DTSP(1) has been set to 1.0, indicating that the trip will institute a 1.0 s delay (after the trip signal falls to or below $S_1$) before the status of the trip is changed to $ON_{forward}$. This simulates the time required by the controllers in a PWR plant to initiate TSV closure after the pressurizer pressure trip signal is issued. Trip control of the reactor-core power would require a similar (but different) trip with DTSP(1) defining the delay time for control-rod insertion into the reactor core before the reactor-core power is affected as defined by its component-action table. Trip ID 113 could be used if that delay time also is 1.0 s. The second setpoint delay time DTSP(2) has been set to $1.0\times10^4$ s, indicating that the trip will institute a 10,000 s time delay (after the trip signal rises to or above $S_2$) before the status of the trip changes to OFF. For calculation problem times less than 10,000 s, this definitely prevents the trip from being turned OFF and stopping TSV closure. Actually, a DTSP(2) delay time ≥ 1.5 s [DTSP(1) plus the 0.5 s time require for TSV closure] would accomplish this as well. Because the $S_1$ and $S_2$ setpoint values are to remain fixed (constant) during the calculation, we do not require setpoint-factor tables to vary them, and so we set IFSP(1) and IFSP(2) equal to zero.

To see how the status of trip ID 113 is communicated to the TSV (VALVE component 44), let's look at the input data shown in Figure 3-85. Volume 1 contains a detailed description of the VALVE component's input format. The numbered annotations on Figure 3-85 are discussed in the items that follow with the same number.

1) The parameter IVTR = 113 is the identifying (ID) number of the trip that controls the VALVE's component-action table evaluation. This provides the necessary linkage to the control system so that TRACE knows exactly which trip is to be used to control the evaluation of the VALVE's component-action table.

2) The parameter IVSV = 1 is the ID identifying number of the independent variable for the VALVE component-action table. The fact that it is positive indicates that it refers to a signal variable - in this case the problem time signal variable with IDSV = 1.

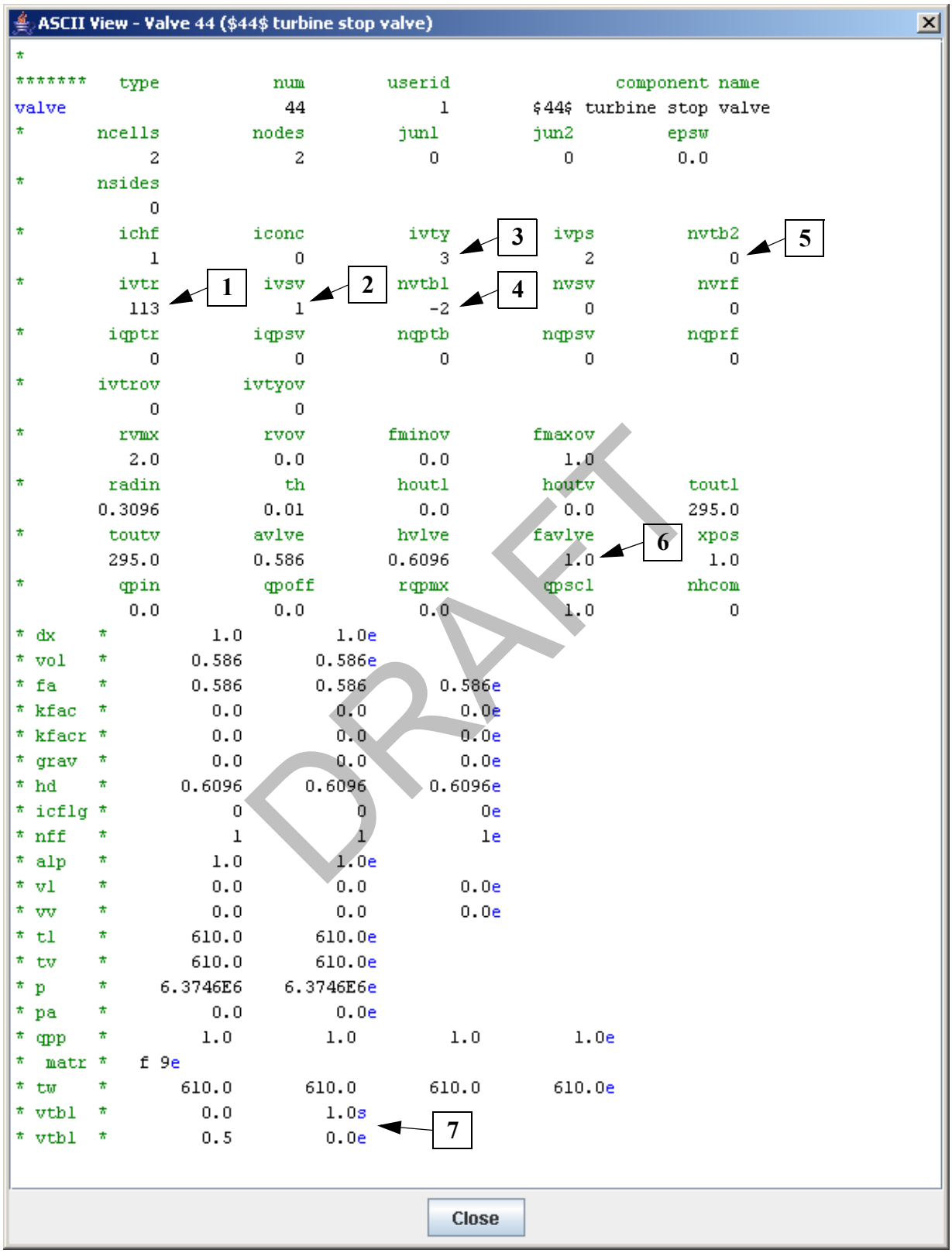



Figure. 3-85. Input Component Data for the Turbine Stop Valve

3) The parameter IVTY = 3 specifies the VALVE-type option. In our example, we require a constant flow area while the controlling trip ID 113 is OFF and the evaluation of a flow-area fraction vs independent variable table when the status of the controlling trip is $ON_{forward}$. Referring to the VALVE-component input-data specification in Volume 1, we see that IVTY should be 3 for this type of VALVE control and adjustment.

4) The absolute value of parameter NVTB1 is the number of table (x,y) pairs in the (first) VALVE component-action table - in this case two. Because we do not know when the pressurizer pressure will fall to or below setpoint $S_1$, we cannot specify a VALVE component-action table based on problem time from the start of the transient calculation as the table's independent variable; i.e., we do not know when to start closing the VALVE by its table definition. We deal with this by making the value of NVTB1 negative. The effect of this is to make the table's independent variable its "relative" value rather than "absolute" value (when NVTB1 > 0). Its "relative" value is the change in the signal variable/control block value (in this case, problem time) from when the trip was activated (set to $ON_{forward}$). When the trip ID 113 status changes to $ON_{forward}$, the independent variable sums the timestep size (change in problem time) multiplied by the trip's status value for each timestep. OFF has the status value 0, and the two forms of ON, $ON_{forward}$ and $ON_{reverse}$, have status values of +1 and -1, respectively. Actually, it does this every timestep, but the addend is 0.0 when the trip is OFF (status value = 0). Figure 3-86 shows the VALVE component-action table (see note #7 on Figure 3-85) with the x-axis being the "relative" value of the SV/CB signal. With a trip status of $ON_{forward}$, the table's independent variable is evaluated to be the time interval since the trip was activated to an $ON_{forward}$ state. For our example, if the pressurizer pressure falls to or below setpoint $S_1$ at 2.1 s after the start of the transient calculation, the trip ID 113 status would be set to $ON_{forward}$ at 3.1 s because the trip setpoint $S_1$ has a 1.0 s time delay assigned to it. At problem time 3.35 s, the value of the independent variable for the VALVE component-action table would be

$$(3.3\ \text{s} - 0.0\ \text{s}) \cdot 0.0 + (3.35\ \text{s} - 3.1\ \text{s}) \cdot 1.0 = 0.25\ \text{s}$$

5) The parameter NVTB2 = 0 is the number of table (x,y) pairs in the (second) VALVE component-action table - in this case, there are none. Hypothetically speaking, if NVTB2 were set to be nonzero with the same numerical sign as NVTB1, it would be evaluated when the status of the controlling trip is $ON_{reverse}$. Such a VALVE table could be used, for example, to open the VALVE with a different time dependence from the first VALVE table, which is used to close the VALVE. NVTB2 = 0 is input here because we only wish to close the VALVE; a different time dependence isn't needed even if we wished both to close and open the VALVE, and controlling trip ID 113 does not offer the possibility of an $ON_{reverse}$ state. Use of the second VALVE table will be illustrated in the next example.

6) The parameter FAVLVE = 1.0 is the initial flow-area fraction of the VALVE's adjustable flow-area interface. Because the TSV is initially in its fully-opened position, FAVLVE is set to 1.0.

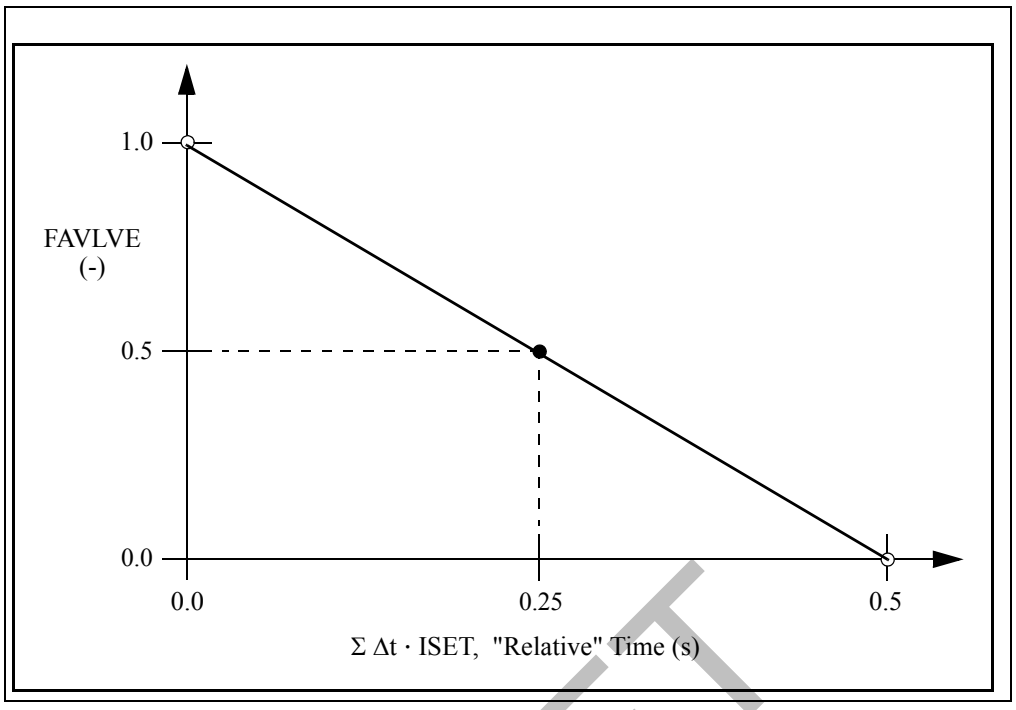



Figure. 3-86. Flow-area fraction vs time for the turbine stop valve.



7) The parameter NVTB1 = –2 absolute value specifies that there are two (x,y) pairs of data in the first VALVE component-action table. This implies that the total number of table values required is four (|NVTB1| × 2). The first, third, fifth, etc. (odd-numbered) data entries are the values of the independent variable (in our example, time since the trip status changes to $ON_{forward}$). The second, fourth, sixth, etc. (even-numbered) data entries are the values of the dependent variable (in our example, VALVE flow-area fractions). The input data for this table show the VALVE is fully open at 0.0 s and fully closed at 0.5 s after the set-status label of trip ID 113 is set to $ON_{forward.}$ At 3.35 s after the start of the transient calculation, in the example cited in note 4 above, the VALVE flow-area fraction would be 0.5 as shown in Figure 3-86 because the independent variable has a value of 0.25 s. With more table data entry pairs, the user can specify nonlinear (in time) valve movement. While problem time commonly is used for the independent variable of component-action tables, that parameter can be any parameter definable by a signal variable or control blocks.

## *Example 2: Two-way Open and Close VALVE-Component Action*

In this example, we will illustrate the use of two VALVE component-action tables, one to close the valve and one to open the valve. We will also illustrate usage of a more complex trip setpoint configuration and show how to define a signal variable that represents a pressure difference

between two different cells in a component. Finally, we will illustrate a very simple use of a control block.

The problem we will consider in this example is that of modeling the component-action of a VALVE, such as an accumulator check valve. When the pressure on the primary side of a PWR plant falls below a given value [typically of the order of $4.237\times10^{6}$ Pa], the accumulator check valve will open and coolant, driven by gravity and the pressurized nitrogen gas in the accumulator, will be injected into the primary-coolant system. For an LBLOCA, the accumulator check valve will open and all of the available liquid coolant in the accumulator tank will be quickly discharged into the primary system. For an SBLOCA, the primary-coolant side may depressurize slowly and even repressurize periodically due to liquid flashing elsewhere in the system model, in which case the accumulator may discharge a number of times for short periods. The accumulator check valve would open and close repeatedly during that time. For accidents in which the primary-coolant pressure decreases slowly, the pressure difference across the accumulator check valve may fall below that required to keep the check valve open. As a result, the accumulator check valve opens for short periods and then closes until the primary-side pressure decreases sufficiently to allow the check valve to reopen. It is this valve operation that we wish to simulate with the VALVE control procedure of this example.



The accumulator check valve will be modeled by a 1D hydraulic flow-channel VALVE component 91 with 5 fluid cells and the VALVE adjustable flow area located between cells 2 and 3 as shown in Figure 3-87. We will control the opening and closing of the VALVE adjustable flow area based upon the pressure difference between cells 1 and 5, that is $\Delta P = P_1 - P_5$. When $\Delta P$ rises above a specified value, the VALVE adjustable flow area starts to open. When $\Delta P$ falls below a specified value, the VALVE adjustable flow area starts to close. It is our responsibility to define the specific valve-movement characteristics using VALVE component-action tables.



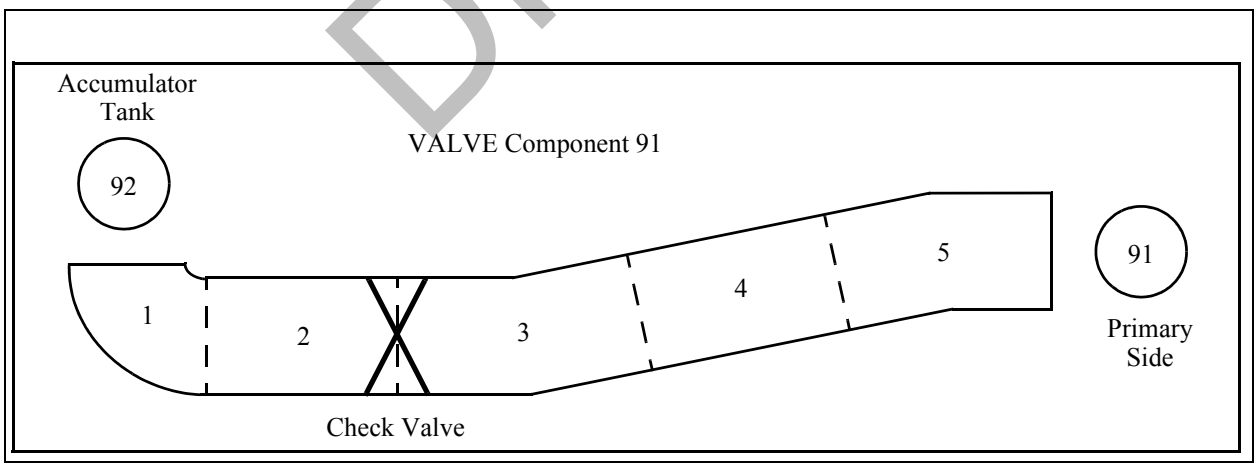



Figure. 3-87. Accumulator check-valve model.

As in Example 1, we first define the signal-variable parameters for the control procedure. In this case, we will define time as one signal variable for use as the independent variable in the VALVE component-action tables. We also define the pressure difference between cells 1 and 5 of VALVE component 91. This will be used as the incoming signal to the trip that controls

operation of the VALVE. The definition of time as a signal variable was illustrated in Example 1. We again assume that the identification number for this signal variable is IDSV = 1. Let us consider now how the difference in pressure between cells 1 and 5 can be specified directly as a signal variable. From Volume 1, we see that when ISVN > 0, the form of the signal variable may be any of the following: the parameter value in a mesh cell, the maximum or minimum over a range of cells, or the volume-weighted average parameter value in a series of contiguous cells. When ISVN < 0, the form of the signal variable may be either the difference in the parameter's values in two given cells or the difference in the parameter's value since the last timestep. In either case (ISVN < 0 or ISVN > 0), the exact functional form that gets used is further defined by what we set for ICN1 and ICN2. It is the ISVN < 0 form that is of interest for our example since we want our signal variable to represent the pressure difference between two different cells.

The signal-variable input data would be entered as follows:

```
* problem time
*           idsv          isvn          ilcn          icn1          icn2
               1             0             0             0             0
* dp = p(1) - p(5) in the accumulator check valve
*           idsv          isvn          ilcn          icn1          icn2
              39           -21            91             1             5
```

We have created a signal variable with an arbitrary ID number (IDSV) equal to 39. The signal variable type (ISVN) is set to -21 (indicating it is a pressure signal) and ILCN has been set to 91 to indicate that the accumulator check valve (VALVE 91) will be the component from which this pressure signal will be obtained. The negative sign in front of ISVN indicates this signal variable will represent either the pressure difference between two cells or the change in pressure since the last timestep. The values used for ICN1 and ICN2 determine whether the signal vairable represents the spatial pressure difference or temporal pressure difference. In this case. we set ICN1 = 1 and ICN2 = 5 to indicate the signal variable will represent the pressure difference between the first and last cell of the component. Note that the order in which the cell numbers are entered is important; reversing the order (ICN1 = 5 and ICN2 = 1) would define $\Delta P = P_5 - P_1$ instead of $\Delta P = P_1 - P_5$ as the desired signal-variable parameter. Had we set ICN1 or ICN2 to zero, the signal variable would have represented the change in pressure since the last timestep for the non-zero ICN1/ICN2 value.

We require the accumulator check valve to open when $\Delta P$ is greater than a trip setpoint $S_4$ and to close when $\Delta P$ is less than a trip setpoint $S_1$. There is to be no change in the VALVE adjustable flow-area state within the intermediate range of P. For this situation, we need three trip states, $ON_{reverse}$, OFF, and $ON_{forward}$ (or $ON_{forward}$, OFF, and $ON_{reverse}$ could be chosen as well). The trip $ON_{reverse}$, OFF, and $ON_{forward}$ trip-signal range diagram is shown in Figure 3-88. This corresponds to a ISRT = –3 trip signal-range type.

Early in the transient calculation, before the primary system has depressurized very much, $\Delta P = P_1 - P_5 < 0.0$ and the trip status will be $ON_{reverse}$. The VALVE component-action table will be evaluated to close. Because it is already closed, it will remain fully closed. As the primary

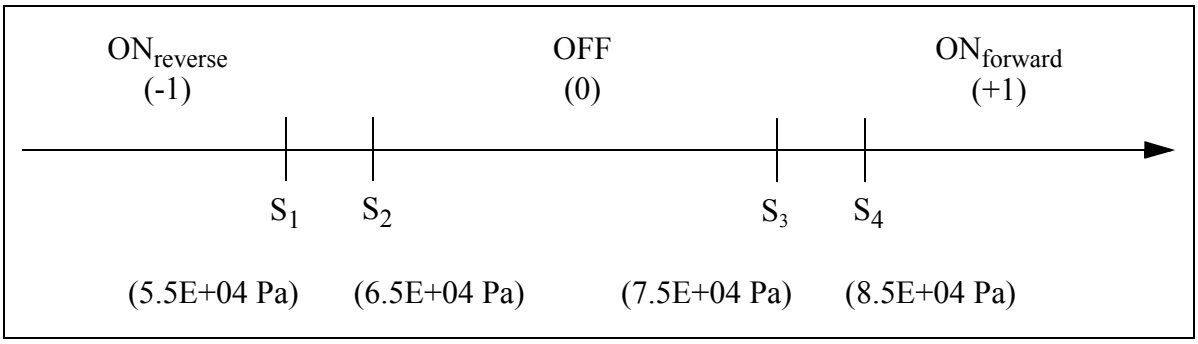



Figure. 3-88. Trip-signal-range-type diagram for accumulator check-valve control.



system depressurizes, $P_5$ will decrease and the value of $\Delta P = P_1 - P_5$ will increase and eventually become positive. When $\Delta P$ crosses $S_2 = 6.5\times10^4$ Pa, the trip status will be set to OFF and the VALVE component-action table will not be evaluated (remaining in its fully closed state). Finally, when $\Delta P$ crosses $S_4 = 8.5\times10^4$ Pa, the trip status will be set to $ON_{forward}$ and the VALVE component-action table will be evaluated to open the VALVE adjustable flow area.

For transients where the primary-system depressurization is slow, the pressure difference may fluctuate quite rapidly causing the VALVE to "chatter" (with open and close movements every few timesteps) because of rapid changes in the trip status between $ON_{reverse}$ and $ON_{forward}$. We can specify setpoint delay times to prevent this from happening. Then the trip signal must cross a setpoint and remain past the setpoint for the specified delay time before the trip set status is changed. This will prevent a momentary pressure drop or pressure spike from initiating valve closure action. Experience has shown that usually a delay time on the order of five timesteps is sufficient. The user must determine the setpoint values, associated delay times, and valve-movement rates based upon a knowledge of the accumulator-tank pressure and check-valve characteristics. The parameter values we have chosen are for illustrative purposes only and do not imply any general characteristics for check valves.



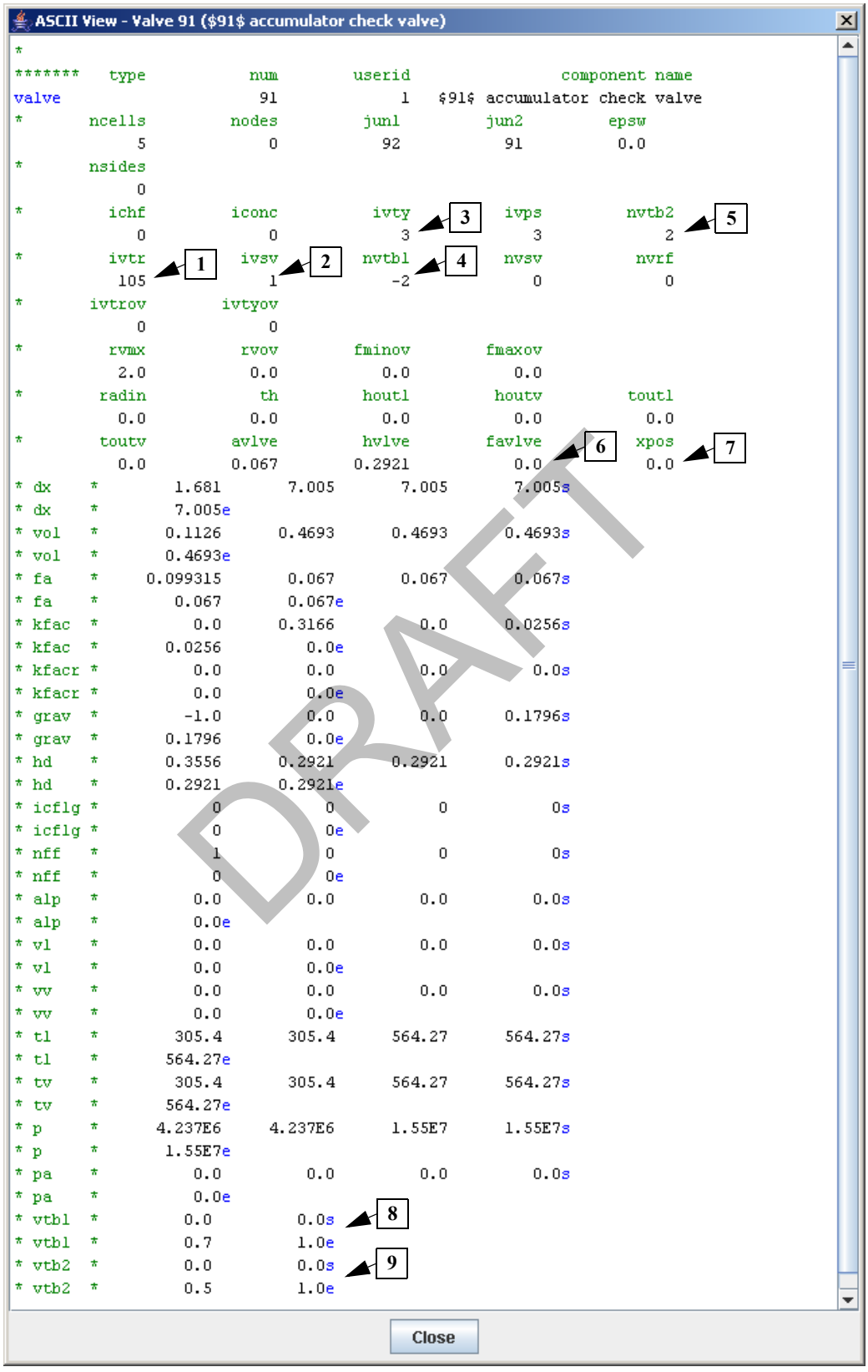
We assign to this trip the identification number IDTP = 105. The trip ID 105 input data are defined as follows:

```
* trip 105 accumulator check valve controlled by dp across valve
*            idtp            isrt            iset            itst           idsg
              105              -3              -1               1             39
*         setp(1)         setp(2)         setp(3)         setp(4)
       5.5000e+04      6.5000e+04      7.5000e+04      8.5000e+04
*         dtsp(1)         dtsp(2)         dtsp(3)         dtsp(4)
       2.0000e-01      2.0000e-01      2.0000e-01      2.0000e-01
*         ifsp(1)         ifsp(2)         ifsp(3)         ifsp(4)
               0               0               0               0
```

Because the pressure-difference trip-signal value is negative and in the $ON_{reverse}$ trip-signal subrange initially, ISET = –1 is specified to signify that the trip status initially is $ON_{reverse}$. We input ITST = 1 to identify the trip signal as signal variable IDSG = 39. The accumulator check valve will begin to open when the pressure difference across the check valve rises to $S_4 = 8.5\times10^4$ Pa; i.e., the pressure in cell 5 is $S_4 = 8.5\times10^4$ Pa below the accumulator-tank outlet cell 1 pressure of $4.237\times10^6$ Pa. Setpoint delay times of 0.2 s are specified to prevent valve "chatter." As in Example 1, the setpoints are constant values so that all setpoint entries for parameter array IFSP are set to zero

Let us consider Figure 3-89, which lists the VALVE component number 91 input data for modeling the accumulator check valve. The numbered annotations in Figure 3-89 are referred to in the discussion that follows. In this example, we define both VALVE component-action tables, and as before, |NVTB1| and |NVTB2| (notes 4 and 5) denote the number of (x,y) entry pairs in the first and second VALVE tables (notes 8 and 9), respectively. The tables need not have the same number of entry pairs and while their opening and closing times need not be the same, the numerical signs of NVTB1 and NVTB2 must be the same (implying that the same independent-variable must be used for both tables). As in Example 1, the VALVE tables are trip controlled by a trip IVTR = 105 (note 1) with a IVTY = 3 (note 3) valve-type option (where the trip-controlled component-action table defines the VALVE's adjustable flow-area fraction). Signal variable IVSV = 1 (note 2) defines the independent variable of both VALVE tables to be problem time. Because NVTB1 and NVTB2 are negative valued (notes 4 and 5), their independent-variable actually becomes the change in time since the trip status changes to ON. The first VALVE table (note 8) is evaluated when the trip status is $ON_{forward}$, and the second VALVE table (note 9) is evaluated when the trip status is $ON_{reverse}$. While the trip set status is $ON_{forward}$ (ISET = 1), the independent variable in the first VALVE table is moved a positive timestep increment to interpolate to the right in the table to open the valve. Similarly, if the trip set status is $ON_{reverse}$ (ISET = –1), the independent variable in the second VALVE table is moved a negative timestep increment to interpolate to the left in the table to close the valve. TRACE communicates the interpolated state of the valve action (flow-area fraction for IVTY = 1 or 3 or relative value-stem position for IVTY = 2 or 4) between the two VALVE tables so that their (potentially different) independent variable values define the same interpolated valve-closure state after each evaluation of either VALVE table..

It hopefully will be clearer to demonstrate this with an example. Assume the controlling trip IVTR = 105 (note 1) status is $ON_{forward}$ for 0.56 s. The VALVE will open from its input-specified initial FAVLVE = 0.0 state (note 6 where for consistency XPOS = 0.0 in note 7) to a FAVLVE flow-area fraction of 0.8 = 0.0 + (0.56 s – 0.0 s)/0.7 s based on evaluated interpolation in the first VALVE table. The VTB1-table independent variable will have a value of x = 0.0 s at y = FAVLVE = 0.8 because 0.56 s = (0.56 s – 0.0 s) · 1 will have been subtracted from each of the VTB1-table independent variable x values during that 0.56 s such that $x_1$ = 0.0 s – 0.56 s = –0.56 s and $x_{|NVTB1|=2}$ = 0.7 s – 0.56 s = 0.14 s. The VTB2-table independent variable will have a value of x = 0.0 s at y = FAVLVE = 0.8 as well, to keep the last interpolated state consistent in both tables. To achieve this, 0.4 s = 0.5 s · (0.8 – 0.0) will have been subtracted from each of the VTB2-table independent variable x values during that 0.56 s of valve opening such that $x_1$ = 0.0 s – 0.4 s = –




```
*
*******   type            num         userid              component name
valve                      91              1   $91$ accumulator check valve
*       ncells          nodes          junl          jun2          epsw
             5              0            92            91           0.0
*       nsides
             0
*         ichf          iconc          ivty          ivps          nvtb2
             0              0             3             3              2
*         ivtr          ivsv          nvtbl          nvsv          nvrf
           105             1            -2             0              0
*       ivtrov        ivtyov
             0              0
*         rvmx          rvov         fminov        fmaxov
           2.0           0.0            0.0           0.0
*        radin            th         houtl         houtv         toutl
           0.0           0.0            0.0           0.0           0.0
*        toutv         avlve         hvlve         favlve          xpos
           0.0         0.067        0.2921            0.0           0.0
* dx     *         1.681         7.005         7.005         7.005s
* dx     *         7.005e
* vol    *        0.1126        0.4693        0.4693        0.4693s
* vol    *        0.4693e
* fa     *      0.099315         0.067         0.067         0.067s
* fa     *         0.067         0.067e
* kfac   *           0.0        0.3166           0.0        0.0256s
* kfac   *        0.0256           0.0e
* kfacr  *           0.0           0.0           0.0           0.0s
* kfacr  *           0.0           0.0e
* grav   *          -1.0           0.0           0.0        0.1796s
* grav   *        0.1796           0.0e
* hd     *        0.3556        0.2921        0.2921        0.2921s
* hd     *        0.2921        0.2921e
* icflg  *             0             0             0             0s
* icflg  *             0             0e
* nff    *             1             0             0             0s
* nff    *             0             0e
* alp    *           0.0           0.0           0.0           0.0s
* alp    *           0.0e
* vl     *           0.0           0.0           0.0           0.0s
* vl     *           0.0           0.0e
* vv     *           0.0           0.0           0.0           0.0s
* vv     *           0.0           0.0e
* tl     *         305.4         305.4        564.27        564.27s
* tl     *        564.27e
* tv     *         305.4         305.4        564.27        564.27s
* tv     *        564.27e
* p      *       4.237E6       4.237E6       1.55E7        1.55E7s
* p      *       1.55E7e
* pa     *           0.0           0.0           0.0           0.0s
* pa     *           0.0e
* vtbl   *           0.0           0.0s
* vtbl   *           0.7           1.0e
* vtb2   *           0.0           0.0s
* vtb2   *           0.5           1.0e
```



Figure. 3-89. Component Input Data for the Accumulator Check Valve

0.4 s and $x_{|NVTB2|=2}$ = 0.5 s – 0.4 s = 0.1 s. Their independent variable values were shifted different amounts because the VTB1 table opens in 0.7 s and the VTB2 table closes in 0.5 s (notes 8 and 9). Next in our example scenario, the trip status changes from $ON_{forward}$ to OFF at 0.565 s (the beginning of the next timestep after a timestep of 0.005 s). The VALVE's FAVLVE flow-area fraction will remain at 0.8 and neither VALVE table is evaluated. Then later at 0.9 s, the trip set status changes to $ON_{reverse}$. At 1.0 s, the VALVE will have closed to a FAVLVE flow-area fraction of 0.6 = 0.8 – (1.0 s – 0.9 s)/0.5 s. The VTB2-table independent variable will have a value of x = 0.0 s at y = FAVLVE = 0.6 because –0.1 s = (1.0 s – 0.9 s) · –1 will have been subtracted from each of the VTB2-table independent variable x values during that 0.1 s so that $x_1$ = –0.4 s – (–0.1 s) = –0.3 s and $x_{|NVTB2|=2}$ = 0.1 s – (–0.1 s) = 0.2 s. The VTB1-table independent variable will have a value of x = 0.0 s at y = FAVLVE = 0.6 as well to keep the last interpolated state consistent in both tables. To achieve this, –0.14 s = 0.7 s · (0.6 – 0.8) will have been subtracted from each of the VTB1-table independent variable x values during that 0.1 s of valve closing such that $x_1$ = –0.56 s – (–0.14 s) = –0.42 s and $x_{|NVTB1|=2}$ = 0.14 s – (–0.14 s) = 0.28 s. To summarize the above procedure, the independent variable values of the evaluated VALVE table are decreased by Δt · ISET each timestep to keep its last interpolation point value at x = 0.0, and the independent variable values of the other VALVE table are shifted to define the same valve-closure state at x = 0.0.

When specifying both VALVE component-action tables, the slope of their data must be the same. That is because for one VALVE table to open the valve by interpolative movement in one direction and the other VALVE table to close the valve by interpolative movement in the other opposite direction, the numerical sign of the slope of their data must be the same. In our example, the VALVE movements that occur for the trip set-status labels $ON_{forward}$ and $ON_{reverse}$ are illustrated in Figure 3-90. The arrow shows the direction of valve adjustment by each VALVE table. We chose to have the $ON_{forward}$ trip status open the valve and the $ON_{reverse}$ trip status close the valve. Had we chosen the opposite ($ON_{reverse}$ opens the valve and $ON_{forward}$ closes the valve with a ISRT = 3 signal-range type for trip ID 105), the slope of the VALVE table data in Figure 3-90 would have to have been negative rather than positive to model the same VALVE adjustment.

A special case needs to be pointed out, particularly for TRACE users with some experience who may encounter this situation during a restart calculation. Let us assume that a TRACE model, having a valve controller similar to the one in this example, has been evaluated for a 1000 s transient with data dumps every 200 s. Assume further that a parametric study is to be done that requires a change be made to the VALVE-component input data beginning at one of the data dumps, for example at 800 s, for a restart calculation. To avoid reevaluating 80% of the transient, we would revise the VALVE-component model and include it in the transient-restart input-data TRACIN file. Its component data could be extracted from the TPR dump file (using SNAP) or obtained from the output file's large edit at 800.0 s.

Selected signal variables, control blocks, and trips controlling the VALVE also may need to be revised and supplied in the input file depending on the changes being made to the VALVE component. The initial conditions for all other components, signal variables, control blocks and trips will be read from the dump file at 800 s. The VALVE component-action tables, as originally

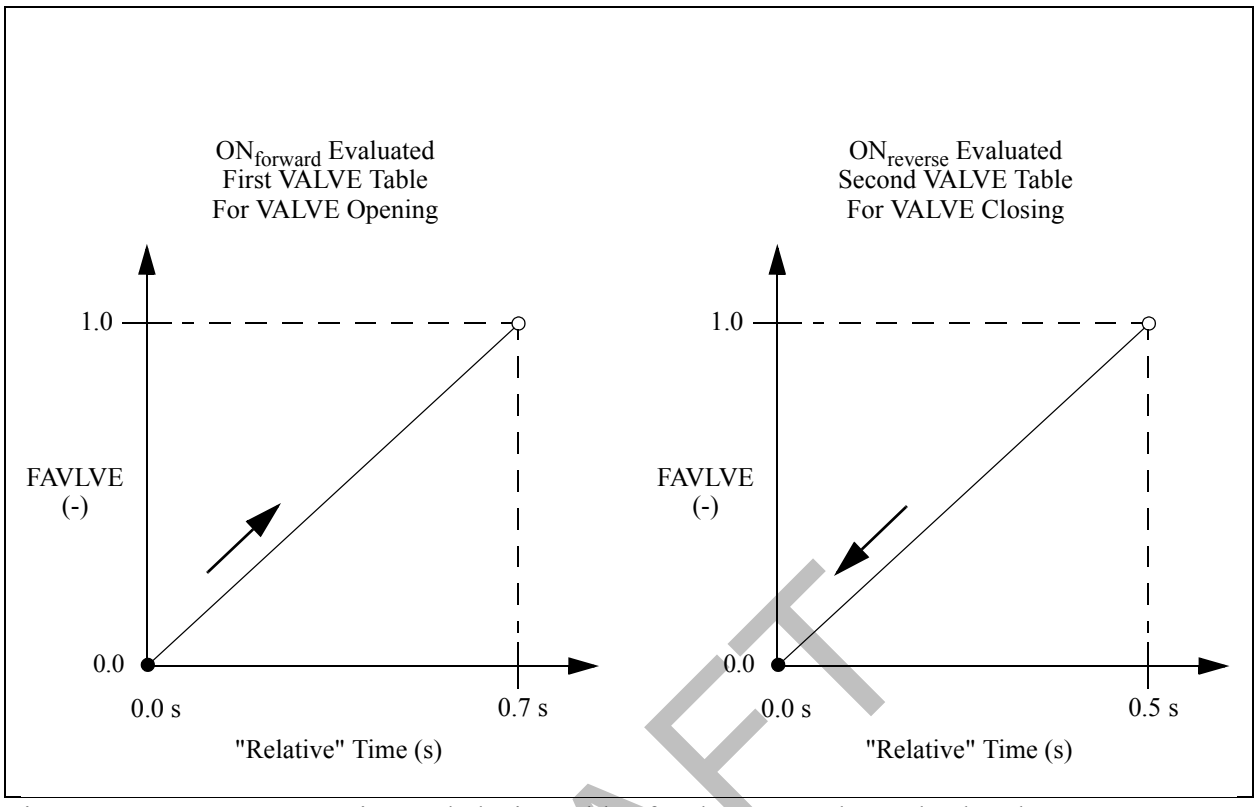
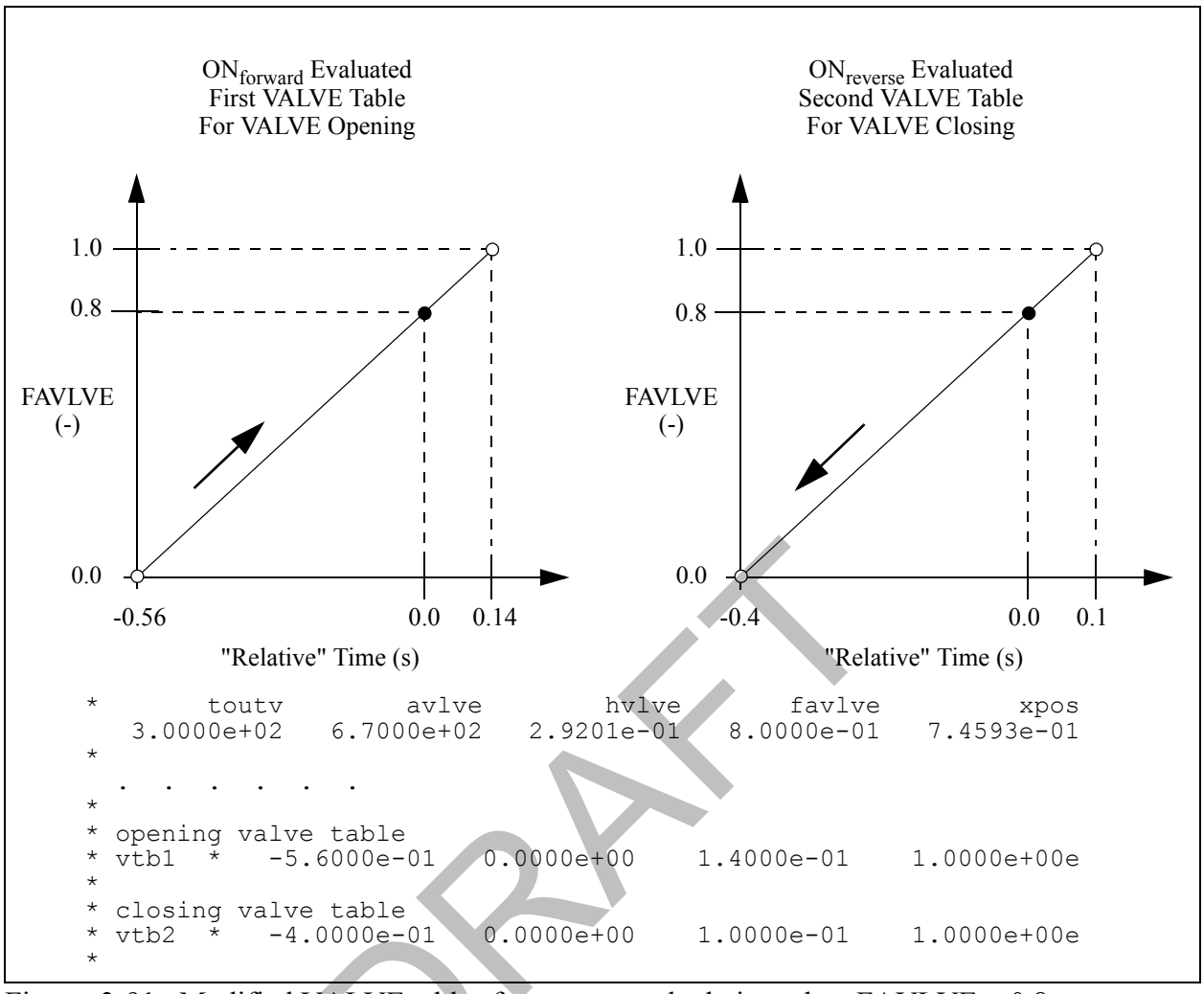



Figure. 3-90. VALVE opening and closing tables for the accumulator check valve.

input (as shown in Figure 3-89), would remain unchanged if the VALVE were fully closed at 800 s. However, if the VALVE were partially or fully open, each VALVE table's (x,y) entry pair values of x must be shifted to reflect that current valve-closure state. The input-specified valve-closure state FAVLVE value at the restart time must correspond to x = 0.0 s in each VALVE table when a "relative" value of the VALVE table's independent variable is defined. Note that the data shown in Figure 3-89 satisfies this requirement. A constant value is added or subtracted from all x values in the original VALVE table to make this shift. Figure 3-91 shows the results of making that shift in x values for FAVLVE = 0.8. VALVE table VTB1 has –0.4 s subtracted from all its x values, and VALVE table VTB2 has –0.56 s subtracted from all its x values. This results in both VALVE tables having FAVLVE = y = 0.8 at the "relative" time x = 0.0 s. Although the likelihood of encountering this situation is small, you need to be aware of how to re-input component-action tables such as this with "relative" value independent variables to the input file for a restart calculation.

Finally, in this example we will illustrate a very simple application of a control block. Let us assume that the pressure difference we wish to use as our trip signal is the difference in pressure in cell 1 of component 91, as before, but the second pressure is in cell 2 of component 90, which adjoins component 91. We cannot define this pressure difference directly as a signal variable, as we did previously, because the cells are in different components. Instead, we can use a control block to evaluate this pressure difference. First we define these two pressures by signal variables and then assign these signal variables as input to a control block that evaluates the subtraction function. The following signal-variable input data defines problem time by signal variable IDSV




```
*       toutv         avlve         hvlve        favlve          xpos
   3.0000e+02    6.7000e+02    2.9201e-01    8.0000e-01    7.4593e-01
*
  .   .   .   .   .   .
*
* opening valve table
* vtb1  *    -5.6000e-01   0.0000e+00    1.4000e-01    1.0000e+00e
*
* closing valve table
* vtb2  *    -4.0000e-01   0.0000e+00    1.0000e-01    1.0000e+00e
*
```

Figure. 3-91. Modified VALVE tables for a restart calculation when FAVLVE = 0.8.



= 1, the pressure in cell ICN1 = 1 of component ILCN = 91 by signal variable IDSV = 39, and the pressure in cell ICN1 = 2 of component ILCN = 90 by signal variable IDSV = 40:

```
* problem time
*            idsv          isvn          ilcn          icn1          icn2
                1             0             0             0             0
* pressure in component 91, cell 1
*            idsv          isvn          ilcn          icn1          icn2
               39            21            91             1             0
* pressure in component 90, cell 2
*            idsv          isvn          ilcn          icn1          icn2
               40            21            90             2             0
```

Note that ISVN for signal variables IDSV = 39 and 40 now are both 21 and not –21 to define individual cell pressures rather than the pressure difference between cells. This requires that no

values be input for ICN2. When only one cell number is defined for a signal variable, either ICN1 or ICN2 can define that cell number with the other defined as 0.

We now consider the control-block input data for this example.

```
* pressure difference (comp 91, cell 1) - (comp 90, cell 2)
*             idcb           icbn           icb1           icb2           icb3
              -100             54             39             40              0
*           lugain         luxmin         luxmax         lucon1         lucon2
          lunounit       lupressa       lupressa       lunounit       lunounit
*           cbgain         cbxmin         cbxmax         cbcon1         cbcon2
        1.0000e+00    -1.0000e+08     1.0000e+08     0.0000e+00     0.0000e+00
```

The user chooses the control-block identification number IDCB = –100 with the restriction that –9900 ≤ IDCB ≤ –1. From Volume 1, we see that ICBN = 54 defines the subtraction function operator. The control-block input-signal ID numbers are specified to be ICB1 = 39, ICB2 = 40, and ICB3 = 0. Only two input signals are required for the subtraction operator as shown by $X_1$ and $X_2$. No value is required for ICB3 so we simply input 0. Positive values for ICB1 and ICB2 indicate that they are signal variables and not the output signals of control blocks. The value for CBGAIN is set to 1.0 because we need to evaluate only the difference between the signal-variable values. A nonunity value of CBGAIN could be input if a multiple of the difference were required. The values of CBXMIN and CBXMAX limit the output-signal value of the control block to be greater than or equal to CBXMIN and CBXMAX. You should ensure that reasonable values for these limits are input. In our case, we need to set CBXMIN < $S_1$ and CBXMAX > $S_4$ so that at least the trip signal defined by this control block spans the trip-signal range that is tested. No values are required for constants CBCON1 and CBCON2 so we supply values of 0.0. Units-name labels LUNOUNIT and LUPRESSA are supplied to define the units of control-block parameters CBGAIN, CBXMIN, CBXMAX, CBCON1 and CBCON2. The units of control blocks are generally unknown to TRACE, so the user must define them through input. They become important when units conversion from SI to English is to be performed by TRACE (this behavior is controlled through namelist options).

The trip ID 105 input data must be modified so that the control-block output signal is used as the trip signal. This is done by changing a single parameter. The value of IDSG is set to –100 with ITST = 1 unchanged. The minus sign identifies to TRACE that a control block with ID –100 defines the trip signal. The trip 105 modified definition is:

```
* trip 105 accumulator check valve controlled by dp across valve
*             idtp           isrt           iset           itst           idsg
               105             -3             -1              1           -100
*          setp(1)        setp(2)        setp(3)        setp(4)
        5.5000e+04     6.5000e+04     7.5000e+04     8.5000e+04
*          dtsp(1)        dtsp(2)        dtsp(3)        dtsp(4)
        2.0000e-01     2.0000e-01     2.0000e-01     2.0000e-01
*          ifsp(1)        ifsp(2)        ifsp(3)        ifsp(4)
```

```
0              0              0              0
```

# *Example 3: Feedwater Control by a FILL Components*

In a PWR, following a reactor-core power trip on low pressure, the main feedwater flow into the steam generators (SG) will be terminated and auxiliary feedwater initiated to maintain a desired water level in the SG's. In this example, we will investigate some simple control procedures that will simulate this scenario. Specifically, we intend to show you how to a) configure a FILL component to simulate the main feedwater coastdown and b) model the initiation of auxiliary feedwater injection into a SG such that the proper water level is maintained. In the process, you will learn how the liquid level on the secondary side of a SG can be defined directly as a signal variable and how the use of a scale factor in a component-action table can simplify its input requirements.

Let us assume the reactor-core power is tripped off on a low pressure of $1.31\times10^{7}$ Pa and 1.0 s later the main feedwater pump is tripped off. Let us also assume that the mass flow rate as a function of time for the main feedwater-flow coastdown is known after the trip. Finally, we'll assume that the auxiliary feedwater flow is to start 20.0 s after the reactor-core power trip and is to be controlled automatically to maintain the SG liquid level in the downcomer at 0.76 m above the top of the tube sheet. Note that our assumptions afford us the flexibility of not having to directly model the main and auxiliary feedwater pumps but, instead, allow us to simulate their actions by specifying their mass flows as FILL-component boundary conditions.



We can recognize almost immediately that we will need three different signal variables for this modeling scenario - problem time (to serve as the independent variable for the mass flow vs. time table), the pressurizer pressure, and the liquid level in the downcomer of the SG. We assume that the pressurizer is modeled by component 22 and the SG downcomer is modeled by component 203 with 11 cells. We also assume that the user will use signal-variable IDSV values of 1 for problem time, 2 for the pressurizer pressure, and 3 for the SG collapsed liquid level within the downcomer. The signal-variable input data would appear as follows:

```
* problem time
*             idsv           isvn           ilcn           icn1           icn2
                1              0              0              0              0
* pressurizer pressure
*             idsv           isvn           ilcn           icn1           icn2
                2             21             22              1              0
* downcomer liquid level in the SG
*             idsv           isvn           ilcn           icn1           icn2
                3             20            203              1             11
```

The input data for problem time and the pressurizer pressure are identical to that in Example 1. ISVN = 20 is the collapsed liquid-level signal variable and will be used to define the steam

generator downcomer liquid level. ILCN = 203 identifies the 1D hydraulic component that models the downcomer. Specifying the component cell numbers ICN1 = 1 and ICN2 = 11 includes all downcomer cells in the evaluation of the collapsed liquid level in the downcomer. The TRACE signal variable for collapsed liquid level is evaluated in a somewhat nonstandard manner. TRACE evaluates the volume of liquid in each cell and sums it over all cells. Then all the liquid is assumed to drain to the lowest cells in the flow path. Starting with the lowest cell ICN1 and going to the highest cell ICN2, each cell in turn is filled fully with that liquid and its DX cell length is summed. When the remaining liquid only partially fills the next cell, its liquid fraction is multiplied by the DX cell length and is added to the DX summation to define the collapsed liquid level. Actually, this defines the collapsed liquid length in the component and becomes the collapsed liquid level (height) only when GRAV = ±1.0. A different liquid-level definition can be evaluated by TRACE, but it would require a signal variable to define each addend and factor for the add and multiply control blocks needed to evaluate its defining form.



The main and auxiliary feedwater mass flows need to have their FILL component-actions controlled by a trip whose setpoints are compared against the pressurizer pressure (defined by signal variable with IDSV=2). Initially this pressure is above the reactor-core power trip setpoint pressure. In this situation, we want the feedwater controlling trips defined with an OFF status so that their FILL component actions are not evaluated and their mass flows do not change from their initial values. When the pressurizer pressure falls equal to or below $1.31\times10^{7}$ Pa, then we want the trip status to be reset to $ON_{forward}$ so that a change in their component actions can be evaluated for both the main and auxiliary feedwater mass flows. Some users may confuse the controlling trip's status with the mass-flow condition of the FILL component action it controls. Don't make this mistake. A controlling-trip status of OFF only means that the component-action it controls is not evaluated. For example, it does not mean that the main-feedwater mass flow is zero because its controlling trip is OFF. If the main-feedwater mass flow is initially 700.0 kg-$s^{-1}$ and the controlling-trip's status is OFF, that mass flow will remain unchanged at 700.0 kg-$s^{-1}$ until the controlling-trip status is reset to $ON_{forward}$. At that time, the main-feedwater FILL component-action table would be evaluated and from that evaluation a possible change in the mass flow could occur. In this example, we want that evaluation to ramp the main feedwater mass flow to zero according to the component-action table's defined time dependence.



The trip signal range type for both main and auxiliary feedwater control is shown in Figure 3-92. The trip input data would be input specified as follows:

```
* trip 103 main feedwater tripped on low pressure after a 1.0 s delay
*              idtp              isrt             iset             itst             idsg
                103                 1                0                1                2
*           setp(1)           setp(2)
         1.3100e+07        1.0000e+08
*           dtsp(1)           dtsp(2)
         1.0000e+00        1.3000e+01
*           ifsp(1)           ifsp(2)
                0                 0
```

```
*
* trip 333 auxiliary feedwater tripped on low pressure after a 20.0 s delay
*              idtp             isrt            iset            itst            idsg
                333                1               0               1               2
*           setp(1)          setp(2)
         1.3100e+07       1.0000e+08
*           dtsp(1)          dtsp(2)
         2.0000e+01       2.0760e+01
*           ifsp(1)          ifsp(2)
                 0                0
```

The various input-data parameters for these trips were discussed in Example 2. Note that ISET = 0, and the initial set status is OFF for both trips so that both the main- and auxiliary-feedwater FILL component actions are not evaluated, and their initial mass flows remain unchanged until these trips are reset to $ON_{forward}$. Both trips have the ISRT = 1 trip signal-range type shown in Figure 3-92 and both trips define signal variable IDSG = 2 (the pressurizer pressure) to be their trip signal. The main-feedwater controlling trip has a 1.0 s delay time and the auxiliary-feedwater controlling trip has a 20 s delay time on its low pressure setpoint ($S_1 = 1.31\times10^7$ Pa) that will be tested for a change of status to $ON_{forward}$. The $S_2$ setpoint (= $1.0\times10^8$ Pa) for each trip is defined much larger than the initial pressurizer pressure, and its delay time is the sum of the $S_1$ setpoint delay time and the FILL component-action table adjustment time. This was defined so that after the pressurizer pressure crosses $S_1$, if a pressurizer pressure spike were to cross $S_2$, the trip would be reset to $ON_{forward}$ and all FILL component-action table mass-flow change would be evaluated before the trip would be reset to OFF.

We consider now the FILL-component input data shown in Figure 3-93 and Figure 3-94 for the main-and auxiliary-feedwater mass-flow boundary conditions. The numbered annotations in those figures are discussed below by notes of the same number.

1) IFTY = 8 is the FILL-type option for both the main-feedwater and auxiliary-feedwater FILL component actions. It defines an initial constant FLOWIN mass flow until the IFTR = 103 and 333 controlling trips for main- and auxiliary-feedwater, respectively, are reset to $ON_{forward}$, and their FILL component-action tables evaluate their boundary-condition mass flows.

2) IFSV = 1 and IFSV = 3 define the independent variable for the main- and auxiliary-feedwater FILL component-action tables, respectively. Signal variable IFSV = 1 is problem time for the main-feedwater mass-flow table. Signal variable IFSV = 3 is the "collapsed" liquid level in the SG downcomer for the auxiliary-feedwater mass-flow table.

3) NFTB = –7 and NFTB = 2 define the absolute number of (x,y) data pairs in the FILL component-action tables for main and auxiliary feedwater, respectively. The main-feedwater table has a "relative" value independent variable, $\Sigma\, \Delta t \cdot ISET$, for signal variable IFSV = 1 (problem time) because NFTB = –7 < 0. The auxiliary-feedwater

table has an “absolute” valueindependent variable for signal variable IFSV = 3 (“collapsed” liquid level in the downcomer) because NFTB = 4 > 0.

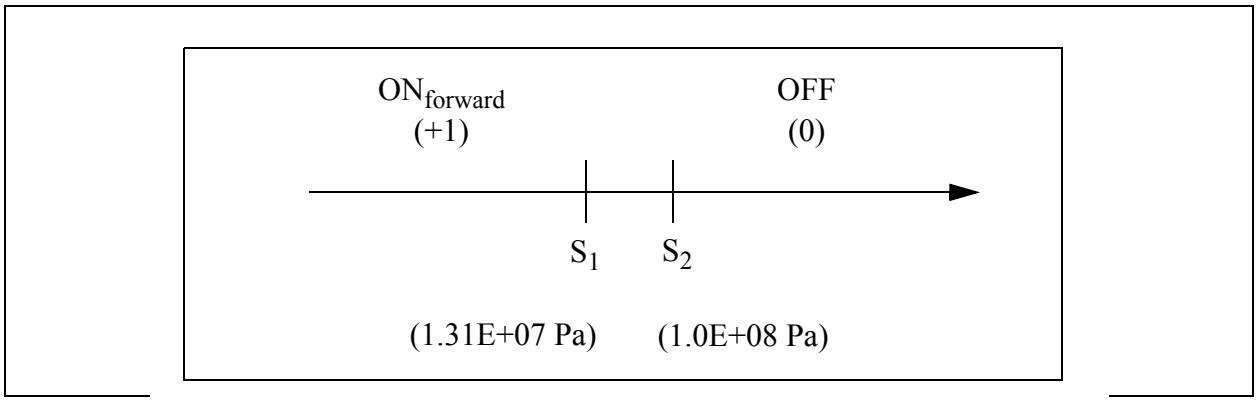



Figure. 3-92. Trip-signal-range-type diagram for main and auxiliary feedwater control.





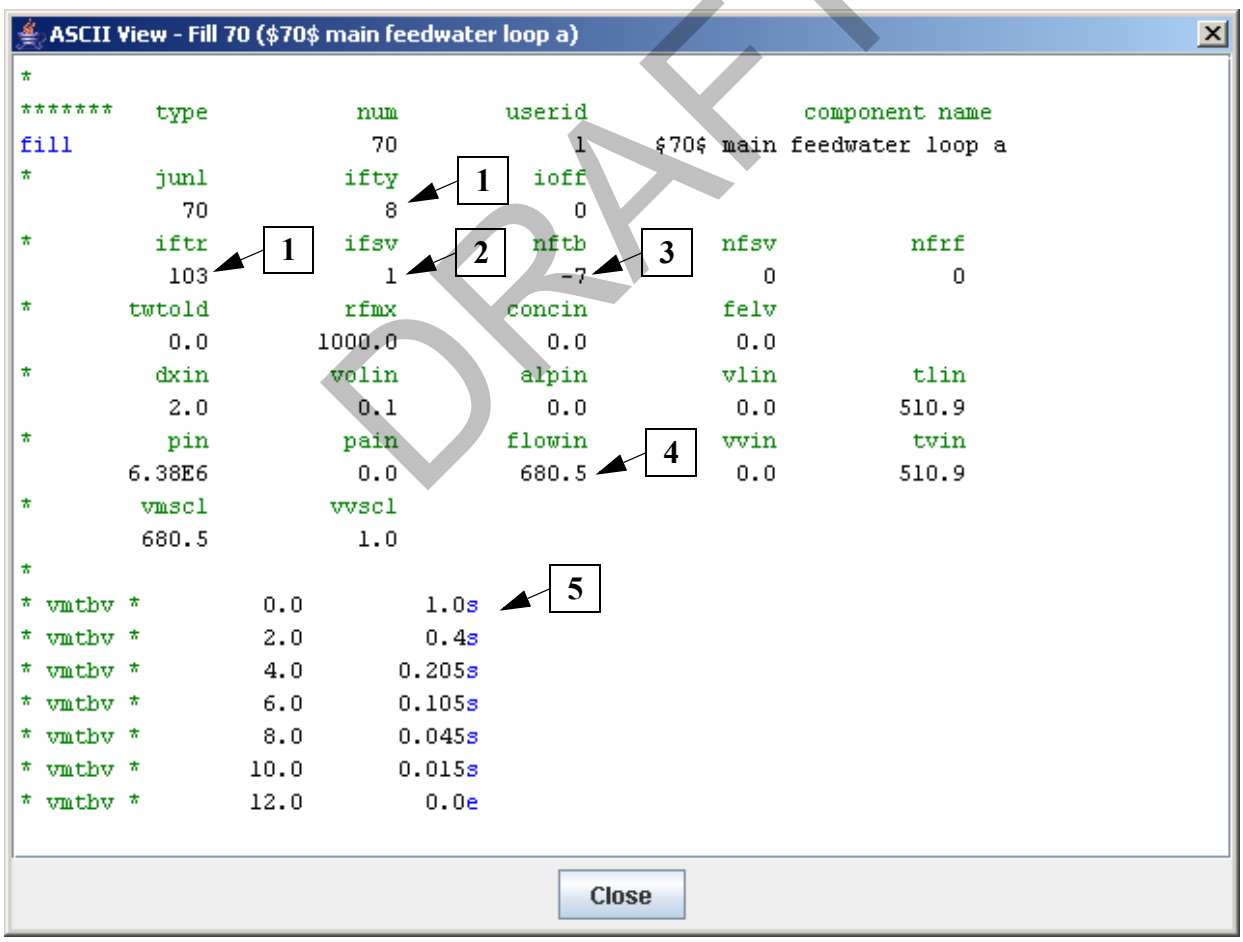



Figure. 3-93. Component Input Data For Main Feedwater FILL

4) The main- and auxiliary-feedwater initial mass flows are FLOWIN = 680.5 kg-s$^{-1}$ and 0.0 kg-s$^{-1}$, respectively.

5) The FILL component-action tables are defined for main feedwater and for auxiliary feedwater. The first column defines the independent variable x values ("relative" time and liquid level) and the second column defines the dependent-variable y values (relative mass flow and mass flow). Note that for the main-feedwater table, the dependent variable is not mass flow but the mass flow fraction. The parameter VMSCL = 680.5 kg-s$^{-1}$ on line 16 is the scale factor that the VMTB table y values are multiplied by after being input by TRACE. Also note that the VMTB table's scale-factor-multiplied mass flow at "relative" time x(1) = 0.0 s is y(1) · VMSCL = 1.0 · 680.5 = 680.5 kg-s$^{-1}$ = FLOWIN. The VMSCL scale factor can save time when you need to renormalize the dependent variable of tabular input data. The initial mass flow can be changed by changing only the value of VMSCL without having to change all of the table's y values. The tabular data for auxiliary feedwater specify a maximum mass flow of y(1) = 65.4 kg-s$^{-1}$ if the collapsed liquid level is 0.74 m and a minimum mass flow of y(2) = 0.0 kg-s$^{-1}$ if the collapsed liquid level is greater than or equal to 0.76 m. The auxiliary-feedwater mass flow varies linearly between these levels. More table entry pairs could be used to simulate a different functional relation between mass flow and liquid level. Figure 3-95 shows the plotted tabular data for both the VMTB main-feedwater and auxiliary-feedwater FILL component-action tables.

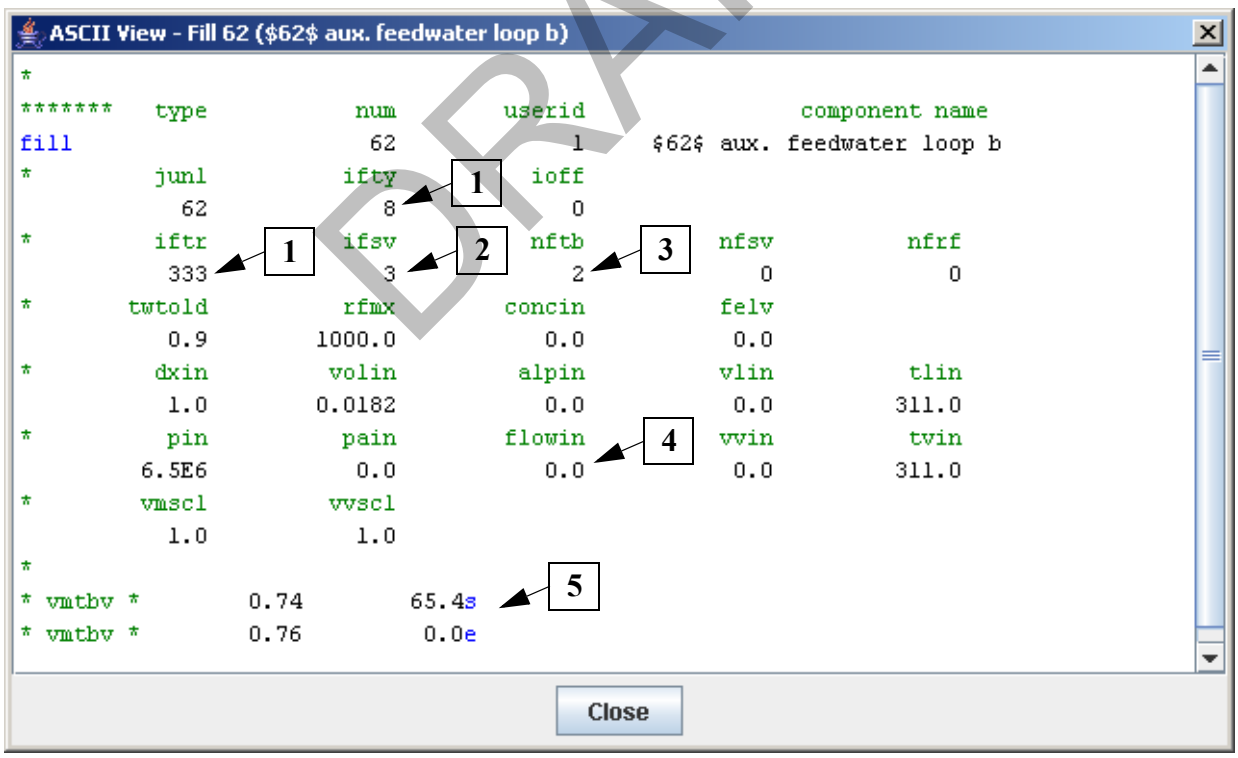



Figure. 3-94. Component Input Data for Auxiliary Feedwater FILL

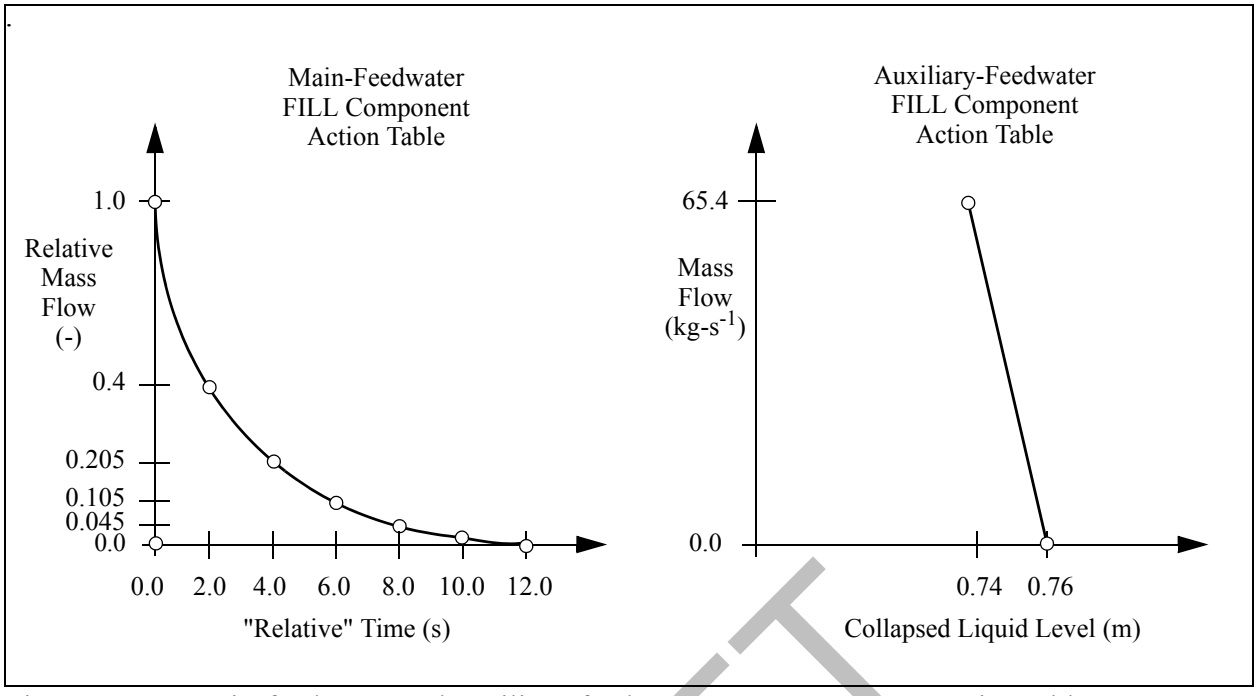



Figure. 3-95. Main-feedwater and auxiliary-feedwater FILL component-action tables.



## *Example 4: Use of Control Blocks to Model a Cooldown Rate Controller*



In some PWRs, the main-steam system is controlled by five types of valves: turbine stop valves (TSVs), turbine bypass valves (TBVs), main-steam isolation valves (MSIVs), safety relief valves (SRVs), and atmospheric dump valves (ADVs). The ADVs are reactor-core-power trip activated and controlled by the average reactor-core coolant temperature. They are designed to open fully on a reactor/turbine trip when the average reactor-core coolant temperature in our example exceeds 552.0 K. We are interested in a controller for the ADVs to cool and depressurize the primary-coolant system to conditions at which the shutdown decay-heat-removal heat exchangers are utilized to place the plant in a stable, long-term cooling mode.

Assume the desired cooldown rate of the primary-coolant system is 0.15432 K-s$^{-1}$. With the ADVs fully open after activating the reactor-core-power trip, if this cooldown rate is exceeded, possible damage could result to the reactor core. A controller is needed to regulate the ADV to maintain a cooldown rate of 0.15432 K-s$^{-1}$. We will develop such a control procedure for one loop only because the controllers for the other loops would be similar. There are undoubtedly a number of ways to accomplish this objective. The method described here is one such technique even though it is less than optimal. A better controller could be provided by a PI or PID control block (control block types ICBN = 200 or 201) where appropriate ADV adjustments would be evaluated and applied each timestep to drive the cooldown-rate monitored condition to its desired rate.

The control procedure will evaluate the cooldown rate, compare it with its desired rate, and adjust the ADV flow area as required. We obtain the cooldown rate by subtracting the hot-leg temperature, $T_1$, at transient time $t_1$ from the hot-leg temperature, $T_0$, at the time we initiate the control procedure, $t_0$. This temperature difference $(T_0 - T_1)$ will be divided by the time difference $(t_1 - t_0)$ to obtain the positive-valued overall cooldown rate

$$\frac{\Delta T}{\Delta t} = \frac{(T_0 - T_1)}{(t_1 - t_0)}. \tag{3-118}$$

Within some deviation limit $\Delta > 0.0$ K s$^{-1}$, from the desired cooldown rate, we will make corrective flow-area adjustments to the ADV. Opening the valve will increase steam release from the secondary side, decrease the secondary-side pressure and saturation temperature, and enhance primary-side cooldown. Closing the valve will act oppositely to decrease the primary-side cooldown rate. When the cooldown rate exceeds the desired rate + $\Delta$, the ADV is to be fully closed; when the cooldown rate is less than the desired rate – $\Delta$, the ADV is to be fully open. That is,

$$\frac{\Delta T}{\Delta t} \geq \text{1.5432E-01 K-s}^{-1} + \Delta, \qquad \text{ADV is fully closed;} \tag{3-119}$$

$$\frac{\Delta T}{\Delta t} \leq \text{1.5432E-01 K-s}^{-1} - \Delta, \qquad \text{ADV is fully open;} \tag{3-120}$$

$$\text{1.5432E-01 K-s}^{-1} - \Delta < \frac{\Delta T}{\Delta t} < \text{1.5432E-01 K-s}^{-1} + \Delta, \tag{3-121}$$

ADV is appropriately adjusted.



The question to answer is, how much should the ADV be adjusted if the cooldown rate is within the deviation limit? One method of determining the required valve motion is to find the error in the cooldown rate from the desired value and divide it by the deviation limit. This defines the following relative error that is constrained between –1.0 and +1.0

$$E = \max\left\{-1.0\ ,\ \min\left[1.0\ ,\left(\frac{\Delta T}{\Delta t} - \text{1.5432E-01}\,Ks^{-1}\right)/\Delta\right]\right\}. \tag{3-122}$$

As a reference point, we will set the VALVE adjustable flow-area fraction $FA = 0.5$ when $E = 0.0$. This arbitrarily provides for equal VALVE adjustment to increase or decrease the cooldown rate. Note the following relationship between $E$ and the $FA$ flow-area fraction of the VALVE that will be implemented in the control procedure

.

| E | FA | |
|---|---|---|
| -1.0 | 1.0 | Cooldown rate ≤ 0.15432 K-s$^{-1}$ - Δ, with ADV fully open |
| 0.0 | 0.5 | Cooldown rate = 0.15432 K-s$^{-1}$, with ADV at mid-position, |
| +1.0 | 0.0 | Cooldown rate ≥ 0.15432 K-s$^{-1}$ + Δ, with ADV fully closed |

From the VALVE-component's input description (see Volume 1), if the number of VALVE component-action table entry values NVTB1 = 0, the VALVE flow-area fraction *FA* (or valve-stem position XPOS) is defined directly by the table's independent variable IVSV parameter. IVSV < 0 indicates that the table's independent variable is defined by the output signal of control block IVSV.



We need to define a control block to evaluate *E* by Eq. (3-122). The min and max constraints on *E* are to be applied by the control block CBXMIN and CBXMAX limits on the control block's output signal. Then another control block would be used to evaluate *FA* based on *E* and the defined states (shown in the table above) with linear interpolation between the $E = \pm 1.0$ limit conditions. That relationship is

$$FA = 0.5 - 0.5 \cdot E. \tag{3-123}$$



Having thought through this relatively simple control procedure, we now put these ideas into the form of a control-block logic diagram that should simplify the input preparation for the control procedure. Figure 3-96 shows how we link control-block evaluations to provide the desired ADV cooldown-rate controller for evaluation by TRACE. The control blocks are indicated by rectangles with their IDCB control-block ID number, ICBN control-block function operation number, and function name defined inside each rectangle. The user should refer to Volume 1 for the control-block input format description and the control-block function operations and their required input data. Control-block operation 9 allows us to input the constant values for the reference temperature and time, desired cooldown rate, and allowable error in the cooldown rate (see control block IDCBs = –11, –12, –16, and –18). Two signal variables are required: problem time and the hot-leg temperature. The input data for these are similar to that in Examples 1, 2, and 3. The input data for the required signal variables, control blocks, and trip are shown in Table 3-41. You should review these input data carefully to understand the input requirements for the various control blocks so they can perform their desired function, as shown in Figure 3-96. Parameters ICB1, ICB2, and ICB3 should be examined to see how output signals from signal variables and control blocks are used as input signals to a control block.

At problem time 660.0 s, a 0.0 s divisor in control block IDCB= –15 is avoided by the CBXMIN = 1.0000E-10 limit constraint on control block IDCB = –14. Control block IDCB = –19 constrains its output signal *E* between –1.0 and 1.0 by CBXMIN = –1.0 and CBXMAX = 1.0. Parameter CBCON1 is used to define constants for the control-block function operators.

Specifying CBCON2 = 0.0 for all these control blocks results in TRACE internally initializing their output values at the start of the calculation based on the control block input-signal values and function operator. Such an internal evaluation procedure can be overrided by the TRACE user by defining the control block's initial output-signal value with CBCON2 ≠ 0.0.

The output signal of control block IDCB = –20 is the VALVE's adjustable flow-area fraction FA. This control-block output signal is applied to the ADV component by setting IVSV = –20 in the VALVE-component input data as shown in Table 3-42.

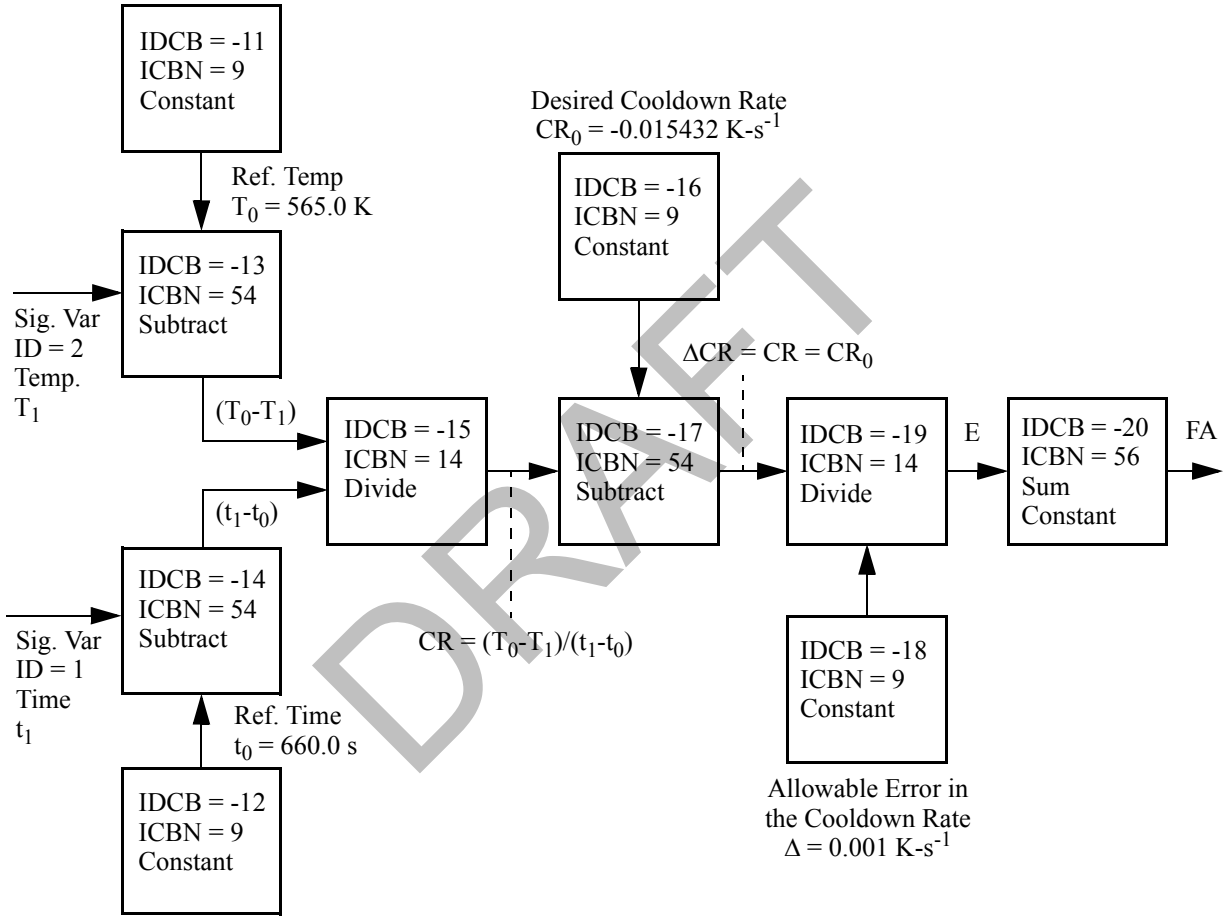





Figure. 3-96. Cooldown-rate controller for the atmospheric dump valves.

## Table 3-41. Input Data for the ADV Cooldown Rate Controller

```
*
************************
* signal variable data *
************************
*
* problem time
*                            idsv         isvn         ilcn         icn1         icn2
                               1            0            0            0            0
* hot let temperature in loop a
*                            idsv         isvn         ilcn         icn1         icn2
                               2           23           21            3            0
*
************************************
* user-defined units-name label data *
************************************
*
*                       lulabel      lunitsi     luniteng      ufactor       ushift
                         ludtdt        luk/s        luf/s   1.8000e+00   0.0000e+00
*
**********************
* control block data *
**********************
*
* cooldown-rate controller
* monitors the cooldown rate of loop a with adjustment of the
* atmospheric dump valves (adv) to achieve a desired cooldown rate
* reference temperature (set to the initial average hot-leg temperature)
*                            idcb         icbn         icb1         icb2         icb3
                             -11            9            0            0            0
*                         luxgain       luxmin       luxmax       lucon1       lucon2
                        lunounit       lutemp       lutemp       lutemp     lunounit
*                           cbgain       cbxmin       cbxmax       cbcon1       cbcon2
                      1.0000e+00   5.6500e+02   5.6500e+02   5.6500e+02   0.0000e+00
*
* reference time (set to the time for initiating adv control)
*                            idcb         icbn         icb1         icb2         icb3
                             -12            9            0            0            0
*                         luxgain       luxmin       luxmax       lucon1       lucon2
                        lunounit       lutime       lutime       lutime     lunounit
*                           cbgain       cbxmin       cbxmax       cbcon1       cbcon2
                      1.0000e+00   6.6000e+02   6.6000e+02   6.6000e+02   0.0000e+00
*
* loop a temperature deviation
*                            idcb         icbn         icb1         icb2         icb3
                             -13           54          -11            2            0
*                         luxgain       luxmin       luxmax       lucon1       lucon2
                        lunounit       lutemp       lutemp     lunounit     lunounit
*                           cbgain       cbxmin       cbxmax       cbcon1       cbcon2
                      1.0000e+00   0.0000e+00   1.0000e+03   0.0000e+00   0.0000e+00
*
* time interval
*                            idcb         icbn         icb1         icb2         icb3
                             -14           54            1          -12            0
*                         luxgain       luxmin       luxmax       lucon1       lucon2
                        lunounit       lutime       lutime     lunounit     lunounit
*                           cbgain       cbxmin       cbxmax       cbcon1       cbcon2
                      1.0000e+00   0.0000e+00   1.0000e+04   0.0000e+00   0.0000e+00
*
* loop a cooldown rate
*                            idcb         icbn         icb1         icb2         icb3
                             -15           14          -13          -14            0
*                         luxgain       luxmin       luxmax       lucon1       lucon2
```

```
63                          lunounit       ludtdt       ludtdt      lunounit      lunounit
64 *                          cbgain       cbxmin       cbxmax        cbcon1        cbcon2
65                        1.0000e+00   0.0000e+00   1.0000e+02   0.0000e+00   0.0000e+00
66 *
67 * desired cooldown rate
68 *                             idcb         icbn         icb1         icb2         icb3
69                               -16            9            0            0            0
70 *                           luxgain       luxmin       luxmax       lucon1       lucon2
71                          lunounit       ludtdt       ludtdt       ludtdt      lunounit
72 *                          cbgain       cbxmin       cbxmax       cbcon1        cbcon2
73                        1.0000e+00   1.5432e-02   1.5432e-02   1.5432e-02   0.0000e+00
74 *
75 * cooldown rate deviation in loop a
76 *                             idcb         icbn         icb1         icb2         icb3
77                               -17           54          -15          -16            0
78 *                           luxgain       luxmin       luxmax       lucon1       lucon2
79                          lunounit       ludtdt       ludtdt      lunounit      lunounit
80 *                          cbgain       cbxmin       cbxmax       cbcon1        cbcon2
81                        1.0000e+00  -1.0000e+00   1.0000e+00   0.0000e+00   0.0000e+00
82 *
83 * allowable deviation in the cooldown rate
84 *                             idcb         icbn         icb1         icb2         icb3
85                               -18            9            0            0            0
86 *                           luxgain       luxmin       luxmax       lucon1       lucon2
87                          lunounit       ludtdt       ludtdt       ludtdt      lunounit
88 *                          cbgain       cbxmin       cbxmax       cbcon1        cbcon2
89                        1.0000e+00   1.0000e-03   1.0000e-03   1.0000e-03   0.0000e+00
90 *
91 * fractional error e with constraint limits applied
92 *                             idcb         icbn         icb1         icb2         icb3
93                               -19           14          -17          -18            0
94 *                           luxgain       luxmin       luxmax       lucon1       lucon2
95                          lunounit      lunounit     lunounit     lunounit     lunounit
96 *                          cbgain       cbxmin       cbxmax       cbcon1        cbcon2
97                        1.0000e+00  -1.0000e+00   1.0000e+00   0.0000e+00   0.0000e+00
98 *
99 * valve flow-area fraction fa
100 *                            idcb         icbn         icb1         icb2         icb3
101                              -20           56          -19            0            0
102 *                          luxgain       luxmin       luxmax       lucon1       lucon2
103                         lunounit      lunounit     lunounit     lunounit     lunounit
104 *                          cbgain       cbxmin       cbxmax       cbcon1        cbcon2
105                       -5.0000e-01   0.0000e+00   1.0000e+00  -1.0000e+00   0.0000e+00
106 *
107 *************
108 * trip data *
109 *************
110 *
111 * trip 105 activates adv cooldown-rate controller at 660.0 s
112 *                             idtp         irst         iset         itst         idsg
113                              105            2            0            1            1
114 *                         setp(1)      setp(2)
115                       0.0000e+00   6.6000e+02
116 *                         dtsp(1)      dtsp(2)
117                       0.0000e+00   0.0000e+00
118 *                         ifsp(1)      ifsp(2)
119                                0            0
120 *
```

**Table 3-42. Component Input Data for Controller-Activated ADV**

```
1 *
2 ************************************************************************
3 *******                 type            num             id         ctitle
4 valve                                    53          53 $53$ atm. dump valve in loop a
5 *                     ncells          nodes           jun1           jun2           epsw
6                            1              1             53             54     0.0000e+00
7 *                       ichf          iconc           ivty           ivps          nvtb2
8                            0              1              3              2              0
9 *                       ivtr           ivsv          nvtb1          nvsv           nvrf
10                         105            -20              0              0              0
11 *                     iqp3tr         iqp3sv         nqp3tb         nqp3sv         nqp3rf
12                           0              0              0              0              0
13 *                     ivtrov         ivtyov
14                           0              0
15 *                       rvmx           rvov         fminov         fmaxov
16                  1.0000e+01     0.0000e+00     0.0000e+00     1.0000e+00
17 *                      radin             th          houtl          houtv          tout1
18                  4.0767e-01     2.4130e-02     0.0000e+00     0.0000e+00     2.9500e+02
19 *                      toutv          avlve          hvlve          favlve           xpos
20                  2.9500e+02     8.2130e-03     1.0226e-01     0.0000e+00     0.0000e+00
21 *                      qp3in          qp3off         rqp3mx         qp3scl
22                  0.0000e+00     0.0000e+00     0.0000e+00     0.0000e+00
23 *
24 * dx        *                1.6714e+00e
25 * vol       *                8.7269e-01e
26 * fa        * f              5.2212e-01e
27 * kfac      *                 0.0000e+00   1.1000e-01e
28 * rkfac     *                 0.0000e+00   5.5000e-02e
29 * grav      * f               0.0000e+00e
30 * hd        * f               8.1534e-01e
31 * icflg     * f                     0e
32 * nff       *                       1           -1e
33 * alp       *                1.0000e+00e
34 * vl        * f              0.0000e+00e
35 * vv        * f              0.0000e+00e
36 * tl        *                5.5120e+02e
37 * tv        *                5.5150e+02e
38 * p         *                6.2280e+06e
39 * pa        *                0.0000e+00e
40 * qppp      *                0.0000e+00e
41 * matid     *                       9e
42 * tw        *                5.5150e+02e
43 * iconc     *                0.0000e+00e
```

In this problem, the ADV controller is assumed to activate VALVE adjustment at 660.0 s into the transient with the ADV closed at that time. We do not want any ADV adjustment before that time. We accomplish this with a trip (IVTR = 105) whose trip signal is problem time. We define this trip to have a trip-signal-range type (ISRT) = 2 and setpoint $S_2 = 660.0$ s. In the VALVE component data of Table 3-42, we set IVTR = 105 for the controlling trip ID number, and set FAVLVE = 0.0 to indicate that the initial state of the VALVE is closed until trip 105 is set ON

and ADV adjustment is applied. Note that for all timesteps before problem time 660.0 s, the control blocks of the ADV controller are evaluated, but their FA output signal of control block IDCB = –20 is not applied to VALVE component 53 until trip 105 is set to $ON_{forward}$ at problem time 660.0 s. Thereafter, the VALVE's flow area (FAVLVE) is defined, at the beginning of each timestep, by the flow-area fraction calculated by control block –20. Note that NVTB1 = 0 entry data pairs which indicates that the table's independent variable (in this case, IVSV = -20) defines the table's dependent variable directly).

## *Example 5: Use of a Rate-Factor Table to Reduce Over-adjustment by an ON/OFF Switch Trip Controller*

In Example 2, we discussed the case of component-action adjustment by an ON/OFF switch trip controller. The VALVE flow-area fraction increased, remained unchanged, or decreased depending upon the value of its controlling trip set status. The VALVE component action was evaluated when the trip set status was ON and not evaluated when the trip set status was OFF. When the trip set status was ON, the rate at which the adjustable flow-area fraction changed was constant in Example 2.

For this type of controller, the monitored parameter affected by the VALVE adjustment generally will oscillate about its desired value. This is because of the time delay after the adjustment and before the monitored parameter is affected. Reducing the component-action adjustment rate reduces overshoot of the desired value and lengthens the period of oscillation, but it slows the rate of convergence to the desired value. This can be improved by applying an appropriate rate factor to the component-action table's independent variable to increase the rate of convergence while reducing overshoot of the desired solution state.

Let us consider the case where we desire a given SG secondary-side pressure. We will use an ON/OFF switch trip to control the adjustment of the steam-flow control valve to obtain the desired pressure. If we use a constant rate of adjustment for the VALVE, we find that the steam pressure can undergo rather large overshoots, while its controller attempts to converge to the desired pressure. Intuitively, the larger the monitored error (measured pressure minus desired pressure), the larger the component-action adjustment rate that should be applied. As the error approaches zero, the rate of adjustment of the VALVE should become small. The constant-rate adjustment is too small when the error is large, and too large (causing overshoot) when the error is small.

We correct for this by defining a rate-factor table for the component action in the VALVE component data. The rate-factor table is evaluated by tabular-data interpolation to determine a rate-factor value at the beginning of each timestep. That rate factor is multiplied to the change in the independent variable (when NVTB# < 0) or to the independent variable (when NVTB# ≥ 0) of the component-action table to increase or decrease the rate of VALVE adjustment. In this example, the rate factor should depend upon the magnitude of the pressure error (the rate-factor table's independent variable). NVSV (Word 4 on Card Number 4 of Section ) defines the ID number of the rate-factor table's independent variable, and NVRF (Word 5 on Card Number 4) defines the rate-factor table's number of entry data pairs. For this example, we desire the special

case of NVSV = 0, which defines the difference between the controlling trip's trip signal and the setpoint value that changes the trip set status to OFF for the rate-factor table's independent variable.

In this example, we have two VALVE component-action tables, one for opening the VALVE and one for closing the VALVE. The controlling trip's trip signal is the SG secondary-side pressure. The VALVE tables are shown in Figure 3-97. These VALVE component-action tables require relative time as the independent variable, so both NVTB1 and NVTB2 in the VALVE component data are prefixed with a minus sign. We define NVSV = 0 so that the rate-factor table's independent variable is the difference between the trip signal and the setpoint value that turns the trip OFF (the pressure error). In the trip-signal-range type ISRT = 3 diagram of Figure 3-97, the closer the trip signal is to the $S_2$ or $S_3$ setpoint when its set status is $ON_{reverse}$ or $ON_{forward}$, respectively, the smaller the rate factor (evaluated by the rate-factor table) should be. We wish to decrease the rate of VALVE adjustment as the trip signal approaches $S_2$ from below or $S_3$ from above. The rate-factor table in Figure 3-97 accomplishes this. The magnitude of will require the user to judge the time delay and coupling strength of the VALVE adjustment effect on the monitored parameter. The value of the rate factor, $f_{RF,}$ should have a maximum value of 2.0 to 5.0 when the magnitude of the monitored parameter error is $\geq \Delta$ and should become much smaller than 1.0 as that error goes to zero.

We see in Figure 3-97 that the change in FAVLVE corresponding to a $t \cdot ISET$ change in the component-action table's independent variable when no rate-factor table is applied can now be increased or decreased depending upon the value of $f_{RF}$ applied as a factor to $\Delta t \cdot ISET$. Be aware that the parameter RVMX in the VALVE component-action data determines the maximum rate of VALVE adjustment (1.0/RVMX is the minimum time required for the VALVE to be adjusted from closed to full open or vice versa). Regardless of how large $f_{RF}$ is from its rate-factor table evaluation, the VALVE adjustment rate cannot exceed RVMX.

Table 3-43 shows the steam-flow control valve's VALVE component 44 input data with the VALVE component-action and rate-factor tables shown in Figure 3-97. Figure 3-98 compares the results of three different rate-factor tables for the case of an ON/OFF switch trip adjustment of the steam-flow control valve. Note that when $f_{RF}$ =1.0 (with a constant valve-adjustment rate), there are initially large deviations from the desired pressure. The response of the steam-generator secondary-side pressure to the rate factor of Case C is much smoother than for Case B. Several user-adjustment iterations may be required before a satisfactory rate-factor table is developed for a component action.

This example illustrates how a simple ON/OFF switch trip controller can be improved by means of a rate-factor table to make the rate of component-action adjustment proportional to the error in the monitored parameter. Overshoot adjustment can be reduced, and a more rapid convergence to the desired value of the monitored parameter can be achieved.

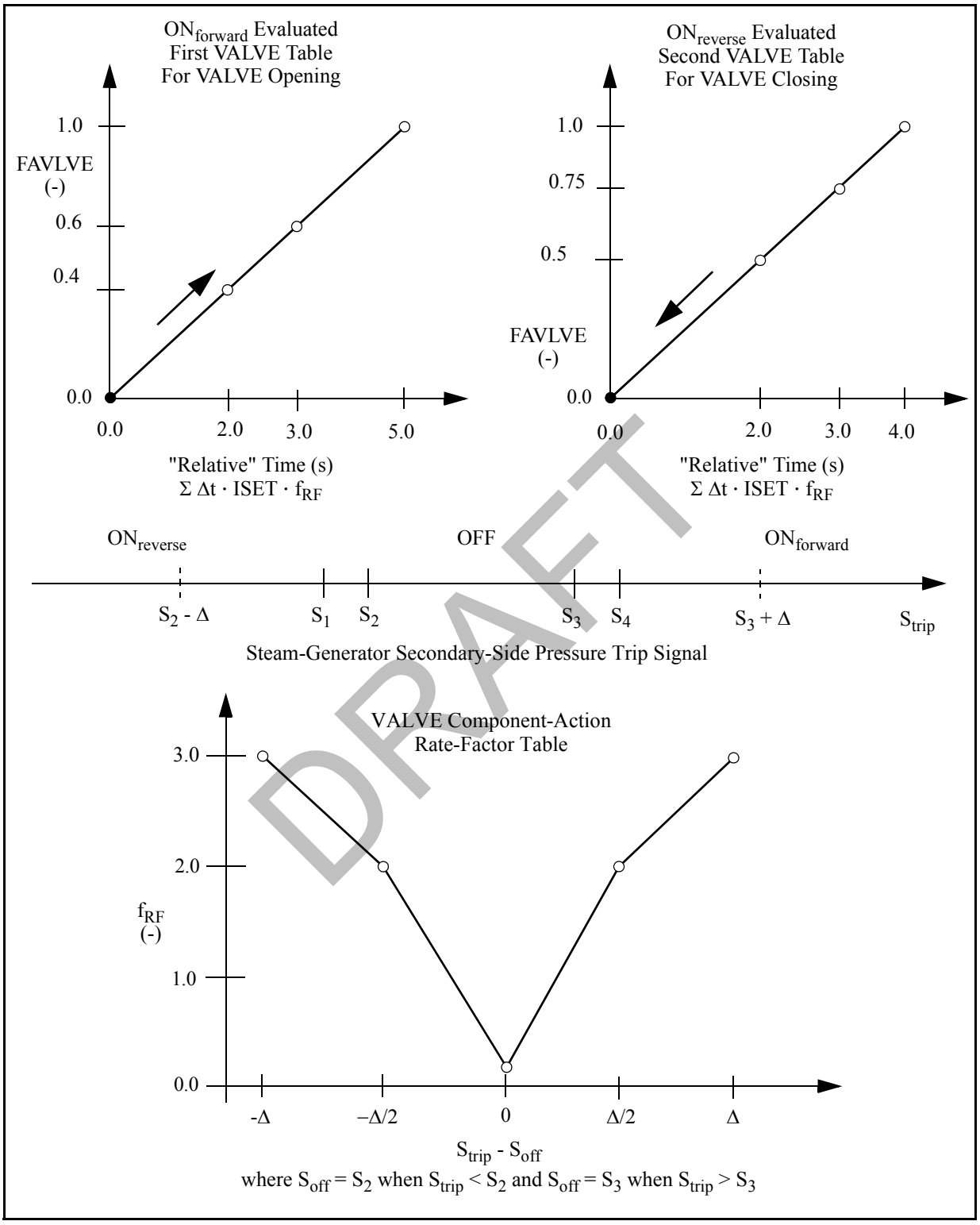





Figure. 3-97. ON/OFF switch trip controller with a rate-factor table.

**Table 3-43.** VALVE Component Input Data with a Rate-Factor Table

```
1 *
2 ************************************************************************
3 *******                 type            num             id        ctitle
4 valve                                    44             44 $44$ steam-flow control valve
5 *                     ncells          nodes           jun1           jun2           epsw
6                            1              1             54            182     0.0000e+00
7 *                       ichf          iconc          ivty           ivps          nvtb2
8                            1              0              3              2             -4
9 *                       ivtr           ivsv         nvtb1           nvsv           nvrf
10                         113              1             -4              0              5
11 *                     iqp3tr         iqp3sv        nqp3tb         nqp3sv         nqp3rf
12                           0              0             0              0              0
13 *                     ivtrov         ivtyov
14                           0              0
15 *                       rvmx           rvov         fminov         fmaxov
16                  1.0000e+01     0.0000e+00     0.0000e+00     1.0000e+00
17 *                      radin             th          houtl          houtv          toutl
18                  3.0960e-01     3.9600e-02     0.0000e+00     0.0000e+00     2.9500e+02
19 *                      toutv          avlve          hvlve          favlve          xpos
20                  2.9500e+02     5.8600e-01     6.0960e-01     1.0000e+00     1.0000e+00
21 *                      qp3in          qp3off         rqp3mx         qp3scl
22                  0.0000e+00     0.0000e+00     0.0000e+00     0.0000e+00
23 *
24 * dx        *                 1.0000e+00e
25 * vol       *                 5.8600e-01e
26 * fa        * f               5.8600e-01e
27 * fric      * f               0.0000e+00e
28 * grav      * f               0.0000e+00e
29 * hd        * f               6.0960e-01e
30 * icflg     * f                        0e
31 * nff       * f                        1e
32 * alp       *                 1.0000e+00e
33 * vl        * f               0.0000e+00e
34 * vv        * f               0.0000e+00e
35 * tl        *                 6.1000e+02e
36 * tv        *                 6.1000e+02e
37 * p         *                 6.3740e+06e
38 * pa        *                 0.0000e+00e
39 * qppp      *                 0.0000e+00e
40 * matid     *                          9e
41 * tw        *                 6.1000e+02e
42 *
43 * opening valve table
44 * vtb1      *                  0.0000e+00     0.0000e+00     2.0000e+00    4.0000e-01s
45 * vtb1      *                  3.0000e+00     6.0000e-01     5.0000e+00    1.0000e+00e
46 *
47 * closing valve table
48 * vtb2      *                  0.0000e+00     0.0000e+00     2.0000e+00    5.0000e-01s
49 * vtb2      *                  3.0000e+00     7.5000e-01     4.0000e+00    1.0000e+00e
50 *
51 * rate-factor table
52 * rftb      *                 -1.3000e+06     3.0000e+00    -6.5000e+05    2.0000e+00s
53 * rftb      *                  0.0000e+00     2.0000e-01     6.5000e+05    2.0000e+00s
54 * rftb      *                  1.3000e+06    3.0000e+00e
```

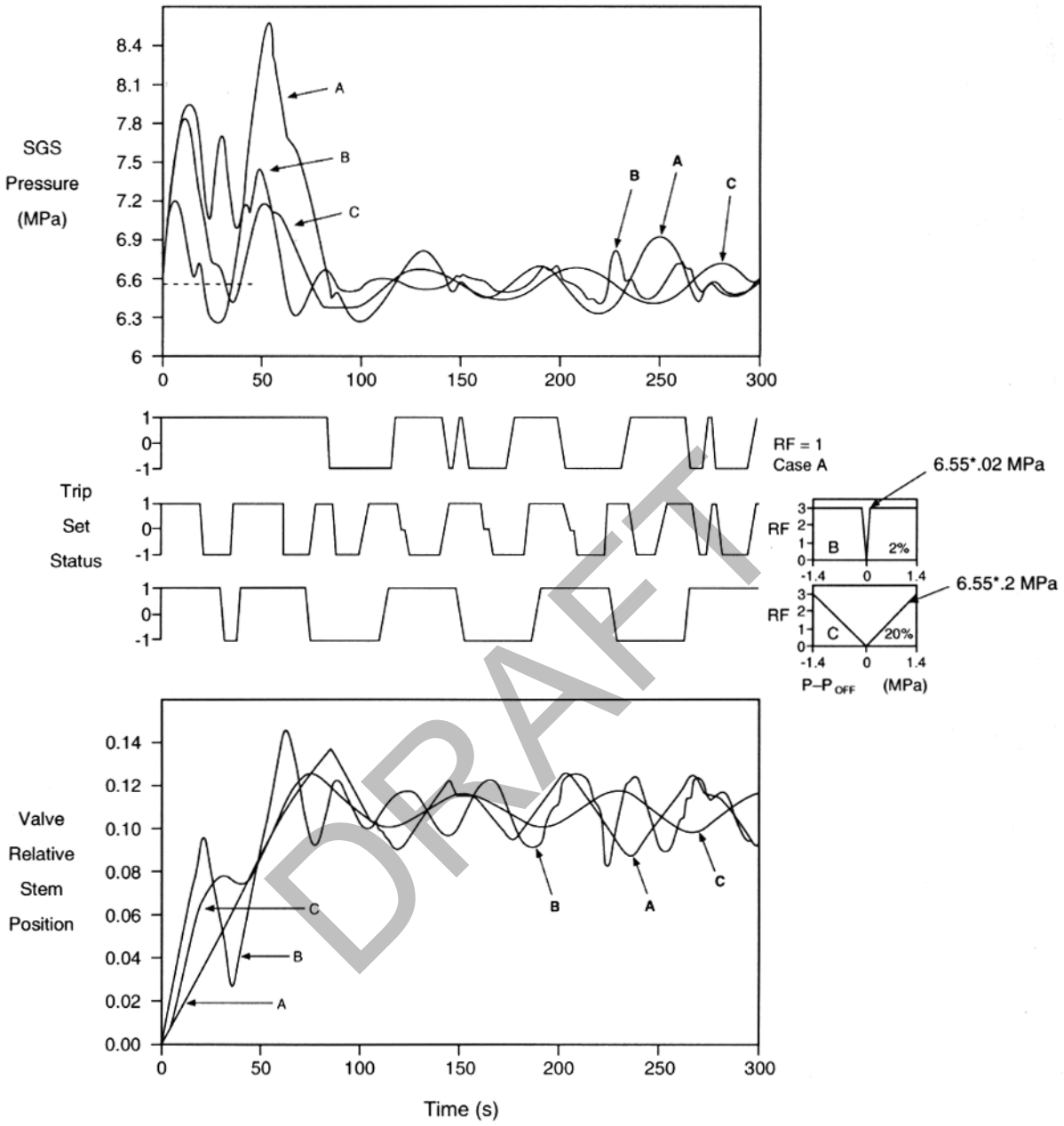





Figure. 3-98. ON/OFF switch trip controller adjustment of the steam flow control valve.

# 4

# *Modeling Guidelines*

All the information presented to this point has been directed toward preparatory activities. The information in this section is intended to help you construct a TRACE input model for a flow loop, experimental test facility, or power plant. We have divided our modeling guidelines into seven sections: (1) thermal-hydraulic components, (2) wall heat-transfer structures, (3) control procedures, (4) initial and boundary conditions, (5) model-selection parameters, (6) reactor-vessel geometry, and (7) heat-structure components. The reactor-vessel 3D VESSEL component is discussed separately because it is unique in its thermal-hydraulic component data requirements. The last section provides guidelines for the HTSTR component that provides heat-transfer paths between thermal-hydraulic components.

The guidelines contained in this chapter do not necessarily constitute all useful guidelines that are known by TRACE users. If you have additional guidelines that you believe should be included in subsequent revisions of this manual, you are encouraged to submit them.





## *Thermal-Hydraulic Components*

The geometry data for 1D thermal-hydraulic components are specified by six arrays. The geometry data are the cell length (DX), cell fluid volume (VOL), cell-edge fluid flow area (FA), vertical-orientation information (cell-edge GRAV or cell-centered ELEV), cell-edge flow-channel hydraulic diameter (HD), and cell-edge additive (form) loss coefficient (FRIC or KFAC). Please note that the DX and VOL arrays are identified with "cells," while the FA, HD, and FRIC or KFAC arrays are identified with the "cell edge." The elevation array may be either a cell-centered ELEV array or cell-edge GRAV array, depending on the value of the NAMELIST-variable IELV option. NAMELIST-variable IKFAC defines the cell-edge additive loss coefficient to be either a FRIC or KFAC array. The number of value entries in a cell-edge array always exceeds the number of value entries in the cell arrays by one. In **Chapter 1**, we presented general guidelines for preparing an input model. You were encouraged to develop noding diagrams for the fluid-flow channels of your system model. If you have done this, you should find that the physical identification of values for the DX, VOL, FA, GRAV or ELEV, HD, and FRIC/KFAC arrays is straightforward.

# *Common Guidelines*

The common guidelines that follow are applicable to all 1D thermal-hydraulic components.

## *Length array*

Each value in this array is equal to the fluid-flow length of the cell that it describes. In general, you should make each 1D cell as long as you can while justifying the requirement of an average homogeneous fluid condition over the length of each cell. Cell lengths should be shorter where the thermal-hydraulic conditions are expected to vary more per unit length. That generally results in 0.1 m to 3.0 m long cells. However, remember that the 1D flow equations are constructed by averaging across the width of the flow-channel. This means that selection of a cell length less than the hydraulic diameter of the flow-channel does not normally make sense. Exceptions to this rule may occur when it is important to limit the numerical diffusion associated with cell length. As you exercise modeling judgment, tradeoffs may be necessary. In general, more cells give more spatial detail for state variables such as the gas volume fraction and phasic temperature distributions along a flow-channel. However, more cells also imply higher computer costs and more computer storage memory.

## *Volume array*

Each cell volume in this array is equal to the fluid volume in the cell that it describes. For cells of constant fluid flow area, the fluid volume is equal to the product of the cell-edge fluid flow area (FA) and the cell length (DX). However, for cells having variable fluid flow area, the fluid volume generally is not equal to the product of the cell-edge fluid flow area and cell length. Therefore, the fluid volume data are required as an independent data array. Because the system-model fluid inventory and its spatial distribution are important for simulating the behavior of many transients, you should determine carefully the fluid volume of each cell. Particular care should be taken to conserve the fluid inventory of cells whose fluid flow area varies along the length of the cell.

TRACE computes a cell-average fluid-flow area (VOL/DX) that is used in calculating the cell-average pressure and in defining the momentum flux at the cell center (momentum-cell edge). This gives you the capability to accurately model the effect of flow-area change on fluid pressure. However, it also forces you to determine reasonable VOL/DX cell-average flow areas. If the TRACE input checking algorithm finds changes in VOL/DX and FA that are large (>10%) and there is no positive-valued cell-edge additive loss coefficient (when NFF $\geq$ 0) modeling its irreversible form loss, a warning message will be issued. To make this warning message disappear, you either need to set NFF < 0, or set NFF = 1 and supply a positive-valued additive wall loss (FRIC or KFAC) at that interface. You need to be aware of this when specifying geometric parameters for components with fluid-flow channels having a changing fluid flow area.

## *Flow area array*

Generally, you should define cell-edge boundaries at locations where the fluid flow area can be easily determined. You must input additive loss coefficients to model the irreversible form loss at a cell-edge interface for a flow orifice, a change in cell-average fluid flow area, or a change in flow direction. We **highly** recommend the NAMELIST-variable IKFAC = 1 option for the ease of specifying K-factors rather than FRIC additive loss coefficients. K-factors are based on the geometry of the orifice, the cell-average fluid flow areas, and the flow-direction turn, and are defined in the Crane Handbook (Ref. 4-30) or some similar handbook. Specifying NFF < 0 results in TRACE internally evaluating the irreversible form loss of an assumed abrupt flow-area change between mesh cells.

For steam generators and reactor vessels, most fluid flow areas are reduced by the presence of structural materials. Careful attention should be paid to the specification of fluid flow areas and HDs in these cases. It may be necessary to add additional loss coefficients (see the section ***Additive loss coefficient array*** below) to obtain the correct pressure drops across the component.

## *Gravity array*

There are two methods of providing elevation data to TRACE. The two are quite different although the same database is needed to develop either input form. The first input form is that used in the original TRAC code development; the cell elevation is specified by the gravity term of the GRAV array. The GRAV gravity term is defined as the ratio of the change in elevation to the length of the flow path between cell centers.

The following 5-step description is given to assist you in correctly evaluating the GRAV-array gravity term.

1) The change in elevation and length of the flow path is measured between two adjacent cell centers.
2) The resultant GRAV gravity term is defined at the cell-edge interface between the two cell centers.
3) For defining the numerical sign of the GRAV gravity term, the positive direction of travel needs to be established. The positive direction of travel is from the lowest-numbered cell (cell 1 as defined on your noding diagram) to the highest-numbered cell.
4) As you reach a cell-edge interface along the direction of travel, the sign of the GRAV gravity term is positive if the cell center ahead is at a higher elevation than the cell center behind. The sign is negative if the cell center ahead is at a lower elevation than the cell center behind. A zero value is assigned to the GRAV gravity term if the cell centers ahead and behind are at the same elevation.
5) The GRAV gravity term must be specified at the cell edge between any two cells. This also is true if the cells are in two different components that are joined together at a

junction interface. In this case, TRACE will check to see if the absolute values of the gravity terms specified for each component at the junction interface are identical. The numerical signs may be different because the directions of travel through each component (established by the sequential numbering of cells) may be opposite as the junction is approached from each component.

The above guidelines that we have provided for calculating the GRAV gravity term may appear to be complicated. Certainly this method of determining elevation data is more difficult than the second method; therefore, we have provided the example shown in Figure 4-99 that illustrates all the features discussed in the guidelines. There is one special case that requires additional explanation. This is the evaluation of the GRAV gravity term for the TEE component internal-junction interface as discussed in ***Gravity term evaluation in TEEs or Side Junctions***

The second-method input form was provided at the request of users who wished to input elevation data directly. Conceptually, this is the most direct approach and is generally recommended when developing new system models and you are not using SNAP as the basis for your model development activities[1]. The user selects this option by setting NAMELIST variable IELV = 1. You select a reference elevation and all other elevations are relative to that reference elevation. TRACE takes this cell-center ELEV elevation data and internally converts it to GRAV gravity-term data for use in the calculation. TRACE outputs a table of the internally evaluated GRAV gravity terms and the total elevation change of each component before the first timestep data set is echoed to the output file. This can be used as a debugging tool for the input-specified ELEV data. For example, if the magnitude of a gravity term is evaluated to be > 1.0, there is an error in the cell-centered elevation ELEV-array input data.



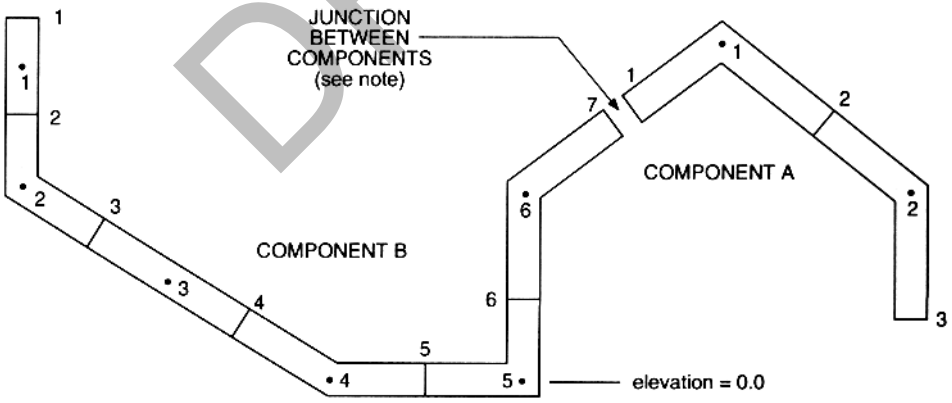



Figure. 4-99. Illustration of evaluating the GRAV gravity term.

1. When using SNAP for model development, you may find the use of the GRAV terms to be more convenient. When working with the ELEV array, small differences in elevation differences introduced by numerical round-off can make it difficult to achieve absolute loop closure. This is not generally a problem when using working with gravity vectors.

| Component B | | | | |
|---|---|---|---|---|
| **Cell** | **Cell edge** | **DX (m)** | **Elevation (m)** | **GRAV (–)** |
| | 1 | | | requires adjoining-cell data to evaluate |
| 1 | | 1.2 | 4.1 | |
| | 2 | | | –1.0000E+00 = (2.7–4.1)/(1.6/2+1.2/2) |
| 2 | | 1.6 | 2.7 | |
| | 3 | | | –6.6667E-01 = (1.5–2.7)/(2.0/2+1.6/2) |
| 3 | | 2.0 | 1.5 | |
| | 4 | | | –6.0000E-01 = (0.0–1.5)/(3.0/2+2.0/2) |
| 4 | | 3.0 | 0.0 | |
| | 5 | | | 0.0000E+00 = (0.0–0.0)/(1.8/2+3.0/2 |
| 5 | | 1.8 | 0.0 | |
| | 6 | | | 1.0000E+00 = (2.2–0.0)/(2.6/2+1.8/2) |
| 6 | | 2.6 | 2.2 | |
| | 7 | | | 6.6667E-01 = (4.2–2.2)/(3.4/2+2.6/2) |

| Component A | | | | |
|---|---|---|---|---|
| **Cell** | **Cell edge** | **DX (m)** | **Elevation (m)** | **GRAV[a] (–)** |
| | 1 | | | 6.6667E-01 = (4.2-2.2)/(3.4/2+2.6/6) |
| 1 | | 3.4 | 4.2 | |
| | 2 | | | –6.6667E-01 = (2.0–4.2)/(3.2/2+3.4/2) |
| 2 | | 3.2 | 2.0 | |
| | 3 | | | requires adjoining-cell data to evaluate |

a. If Component A had been numbered in the opposite direction (cell 2 becomes cell 1 and cell 1 becomes cell 2), an opposite direction of travel would have been established in Component A, and all GRAV values of Component A would have an opposite numerical sign. GRAV at the junction interface with Component B would have the same magnitude but be negative valued.





## *Hydraulic diameter array*

If your fluid-flow channel geometry is not circular in cross section, the hydraulic diameter, HD, should be evaluated based on

$$HD = 4 \cdot FA / WP \tag{4-124}$$

where FA is the flow area and WP is the wetted perimeter. Hydraulic diameters are used for the evaluation of pressure losses resulting from flow friction at wall (structure) surfaces. They are input to TRACE as cell-edge values. A special case arises when attempts are made to model a fluid-flow channel with an abrupt fluid flow-area change between mesh cells. The value of HD at cell edge $i$+1/2 between cells $i$ and $i$+1 should be determined (assuming a constant friction factor in a cell) based on Reference 4-31:

$$HD = \frac{(DX_i + DX_{i+1})}{\left[\left(\frac{FA_{i+1/2}}{FA_i}\right)^2 \left(\frac{DX_i}{HD_i}\right) + \left(\frac{FA_{i+1/2}}{FA_{i+1}}\right)^2 \left(\frac{DX_{i+1}}{HD_{i+1}}\right)\right]} \tag{4-125}$$

The quantities with subscripts $i$ and $i+1$ represent "volume-centered" or "cell-centered" quantities, whereas those with subscript $i+1/2$ are for the cell-edge interface between cells $i$ and $i$+1. The cell-centered hydraulic diameters $HD_i$ and $HD_{i+1}$ used to calculate $HD_{i+1/2}$ should not take into account any effect of "lumping" of flow paths, such as combining multiple intact loops into one loop or combining all the steam generator tubes into one fluid flow path.

## *Additive loss coefficient array*

The additive loss coefficient array may be specified in either of two forms, FRIC or KFAC. FRIC values are related to the $K_{i+1/2}$ irreversible form-loss K-factor at the $i+1/2$ cell-edge interface (where the fluid flow velocity is $V_{i+1/2}$) by the expression

$$FRIC_{i+1/2} = K_{i+1/2} \cdot \frac{HD_{i+1/2}}{(DX_i + DX_{i+1})}. \tag{4-126}$$

The FRIC form of the additive wall losses is largely a historical anachronism from a much earlier period in the TRAC code development. If you are developing a new input-data model, we strongly recommend that you enter the irreversible form-loss K-factors directly by the setting IKFAC = 1 in the NAMELIST input and using the KFAC array. TRACE takes the KFAC-array irreversible form-loss K factors and converts them with Eq. (4-126) to FRIC-array additive loss coefficients for use in the calculation. TRACE models all fluid flow-area changes as smooth flow-area changes and evaluates only the Bernoulli-equation reversible pressure loss or gain associated from a fluid flow-area change. Therefore, you must input additive loss coefficients for all irreversible form losses in the modeled system with the FRIC or KFAC array.

Fluid flow in opposite directions through a flow-area change have different K-factor values for flow expansion and flow contraction. Inputting a single FRIC or KFAC value for a mesh-cell interface assumes that you know, *a priori*, the direction of fluid flow in all 1D fluid-flow channels. When such is not the case in one or more 1D flow channels of the system model, the NAMELIST-variable NFRIC1 option should be set equal to two. When NFRIC1 = 2 for 1D thermal-hydraulic components, you must supply both the forward (FRIC or KFAC) and reverse (RFRIC or RKFAC) additive loss coefficient arrays. TRACE applies the forward additive loss

coefficient array when the component phasic velocity is positive (fluid flow is in the direction of increasing cell numbers) and the reverse additive loss coefficient array when the component phasic velocity is negative (fluid flow is in the direction of decreasing cell numbers). Both forward and reverse additive loss coefficients are needed when the liquid and gas velocities are in opposite directions during countercurrent flow.

TRACE is programmed to evaluate the irreversible form-loss for an abrupt flow-area change across mesh-cell interface *i+1/2* when $NFF_{i+1/2} < 0$ is specified. Based on the flow direction, TRACE evaluates an abrupt flow-expansion or flow-contraction K-factor and its FRIC from it. If the flow-area change is less than abrupt, the user needs to input a K-factor or FRIC additive loss coefficient with an appropriate lesser value than TRACE would evaluate internally for an abrupt flow-area change.

## *Gravity term evaluation in TEEs or Side Junctions*

Tee-connection flow channels modeled by the TEE component have two parts: the main or primary tube and the side or secondary tube. For both the main- and side-tube cell-edge interfaces, the GRAV gravity term is evaluated as described in the section ***Gravity array*** above; however, special attention must be paid to one-cell edge that is evaluated in a unique manner. That is the cell-edge interface between the main-tube cell JCELL and side tube cell 1 called the internal-junction interface.





Again, the GRAV gravity term is defined as the ratio of the change in elevation to the length of the flow path between cell centers. The change in elevation is evaluated in the normal manner. The direction of travel is associated with the side tube of the TEE component for the internal-junction interface such that the

$$\text{change in elevation} = ELEV_{\text{side-tube cell 1}} - ELEV_{\text{main-tube cell JCELL}}. \tag{4-127}$$

Using the nomenclature shown in Figure 4-100, the

$$\text{length of the flow path} = \left(\frac{DX_{\text{side-tube cell 1}}}{2}\right) + \left(\frac{DX_{\text{main-tube cell JCELL}}}{2}\right) \tag{4-128}$$

where

$$DX_{\text{main-tube cell JCELL}} = \min\left[\frac{HD_{\text{JCELL}}}{\sin\theta},\ \frac{DX_{\text{JCELL}}}{|\cos\theta|}\right], \text{ and} \tag{4-129}$$

$$HD_{\text{JCELL}} = \frac{(HD_{\text{JCELL-1/2}} + HD_{\text{JCELL+1/2}})}{2}. \tag{4-130}$$

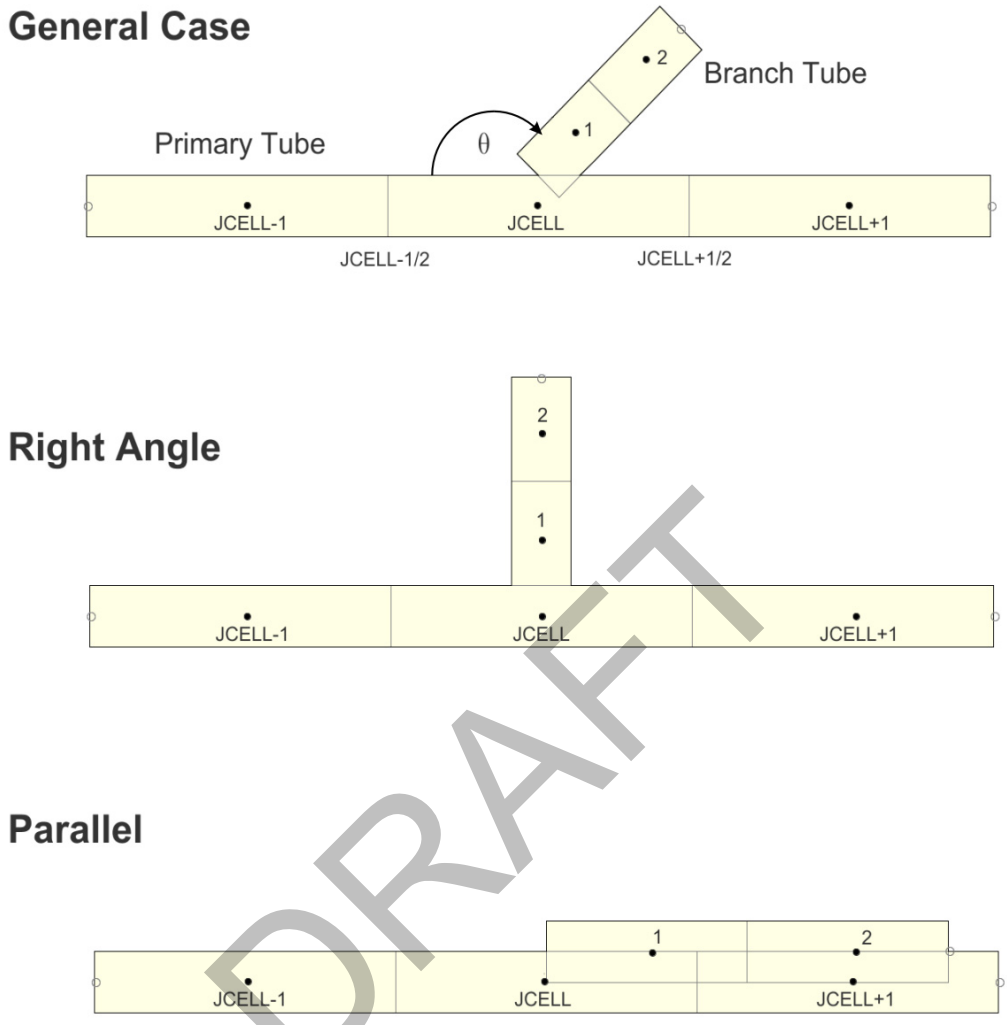





Figure. 4-100. GRAV gravity-term evaluation at the TEE internal-junction interface.

$\theta$ is defined as the connection angle for the TEE side-tube (obtained from the COST input variable), as measured from the lower-numbered portion of the main-tube. The fact that Eq. (4-129) is based on the minimum of two different expressions is a reflection of the fact that, as the side tube sweeps from a right angle configuration (θ = 90°) to a parallel configuration (θ = 0° or 180°), there is a point at which the cell edge (at JCELL-1/2 or JCELL+1/2) will begin to limit the JCELL contribution to the total flow path length. The point of this transition is

$$\theta = \mathrm{atan}\left(\frac{HD_{\mathrm{JCELL}}}{DX_{\mathrm{JCELL}}}\right) \tag{4-131}$$

The limiting two cases of interest, shown in Figure 4-100, are:

for a right-angle tee connection (θ = 90°),

$$DX_{\text{main-tube cell JCELL}} = \frac{(HD_{\text{JCELL-1/2}} + HD_{\text{JCELL+1/2}})}{2}, \tag{4-132}$$

and for a parallel tee connection (θ = 0° or 180°),

$$DX_{\text{main-tube cell JCELL}} = DX_{\text{JCELL}}. \tag{4-133}$$

## *Technique for combining loops*

As previously mentioned, there are incentives to minimize the number of components in the system model. If computing time were not a factor and computer memory was sufficient, we would model each plant feature in fine spatial detail. But CPU time and memory space generally are limited. They become incentives to keep the model as small as possible yet consistent with resolving the physical phenomena of interest. One technique for reducing the size of a model is to combine several coolant loops into a single loop. For example, Westinghouse manufactures two-loop, three-loop, and four-loop nuclear power plants. We have retained both loops in our model of a Westinghouse two-loop plant, but two loops could be modeled as one loop. We have retained three loops in our model of the three-loop plant, but two or three loops could be modeled as one loop. For the four-loop plant, we have combined three loops into one loop in our system model. We retained the loop with the pressurizer as the single loop. In this manner, the four-loop plant is modeled with two loops. There are compromises involved with this approach, but it is acceptable for many transients.





In the six guidelines that follow, we will assume that "N" identical coolant loops are being combined into one modeled loop. We assume that you have prepared the single-loop model and wish to modify it to represent N loops.

1) Retain all *DX* length, *HD*, *GRAV* or *ELEV* gravity term, and FRIC or KFAC additive loss coefficient array values for the single loop without change.

2) Multiply all VOL volume and FA flow area array values by *N*. The FILL (and possibly BREAK) component cell VOLIN volume must be multiplied by *N*.

3) The situation with 1D hydraulic-component wall heat transfer is more complex. In cylindrical geometry, it is not possible to preserve the inner-surface radius, inner-surface heat-transfer area, wall thickness, wall material volume, and outer-surface heat-transfer area simultaneously. We recommend that you preserve the inner-surface heat-transfer area by increasing the inner-surface heat-transfer radius (RADIN for a PIPE, PRIZER, PUMP, and VALVE; RADIN1 and RADIN2 for a SEPD and TEE) by a factor of N. Then preserve the wall volume and its heat capacity by entering a wall thickness "T" that is related to the single-loop wall thickness "t" and the single-loop inner-surface radius, $r_i$, by the equation

$$T = -N \cdot r_i + (N^2 \cdot r_i^2 + 2 \cdot N \cdot r_i \cdot t + N \cdot t^2)^{1/2}. \quad (4\text{-}134)$$

4) The number of actual HTSTR RDX elements must be multiplied by *N* for HTSTR components.

5) PUMP component input parameters EFFMI, TFR1, TFR2, RTORK, and RFLOW must be multiplied by *N*.

6) Tables in FILL components that define fluid mass flows (not velocity) must be multiplied by *N*. Examples are main feedwater, auxiliary feedwater, high-pressure injection, low-pressure injection, and accumulator mass flows. If only one of the loops being combined has a high-pressure injection, low-pressure injection and accumulator ECC system, its FILL component mass flows should not be changed.

Generally, only one loop has a pressurizer. If that loop is combined with other loops, the TEE side-tube flow channel to the pressurizer requires no change in the system model. We recommend combining loops that are identical or almost identical except for minor pipe-length differences. Combining loops where only one loop has a pressurizer or ECC system will simulate incorrect behavior when these features are activated.



## *Fine-noding guidelines*

This section is included to counterbalance the statements made thus far about minimizing the number of components and computational cells and nodes.

There are several examples of flow phenomena that may need a finely noded model to accurately resolve the physical phenomena of interest. If a precise estimate of the steam generator secondary-side dry-out time is important, you should consider a finer cell noding arrangement at the bottom of the steam generator secondary-side model. You should carefully consider the size of the cell upstream of a pipe break. If a 3.0 m cell length is used, the break outflow condition is defined at a point 1.5 m from the break that is averaged over a 3.0 m length. This is probably too far away and would have an overly homogenized cell-average fluid state. If calculated temperatures in the reactor core are to be compared with thermocouple data, the node centers in the core should be placed as close as practicable to the thermocouple locations for unambiguous interpretation of reactor-core heat transfer. Note that the hydraulic condition of a cell is indicative of the measured condition at its outflow interface (rather than cell center) because of upstream donor-cell evaluated convection. Other examples could be provided; however, the most important guideline is that you be thoughtful in your noding practices as the nature of the numerical solution and the measurements you may be comparing TRACE against.

There have not been sufficient noding studies completed for us to develop general noding guidelines appropriate for all circumstances. We recommend that you conduct noding studies for your model if you believe either finer or coarser noding compared with your base case would be appropriate. The laws of an impatient management chain generally dictate that there will not be

sufficient time for such noding studies, so when in doubt, err on the side of modeling with a finer mesh than needed. Today's fast and cheaper computers make the finer-mesh run-time penalty less significant than at any point in the past. If an input model is to be evaluated only a few times, your cost of preparing the input file probably will definitely overshadow the computer cost of the TRACE calculations.

We refer you to three Sandia National Laboratories studies that investigated noding for several applications with the TRAC-PF1/MOD1 computer code. The first examined noding for a once-through steam generator. The base model consisted of 85 cells. Sandia noted that most plant analyses would not be able to use a similar fine nodalization because of cost and storage limitations. The study found good agreement with experimental data when 51 cells were used, but 33 cells produced less satisfactory results. Sandia found that the total primary-to-secondary heat-transfer rate prediction was good using any of their three models; however, for plant simulations in which the secondary-side response is important, the coarse-noding model would not be appropriate.

The second study examined noding for a pressurizer model (Refs. 4-31 and 4-32). The experiment consisted of four pressurizer in surges and out surges combined with four cycles of spray. The PRIZER component was used with 13-cell and 4-cell noding. There were small differences in the maximum pressures during the in surges. The minimum pressures for the 4-cell model were slightly lower than for the 13-cell model.

The third study examined a 200% cold-leg break LOCA for an upper-head injection plant (Ref. 4-33). Two models were developed: a fine-node model with 776 mesh cells and a coarse-node model with 320 mesh cells. The study was performed to determine the effect of noding on predicted results and on computer execution time. It was found that the overall sequence of events and the important trends of the transient were predicted to be nearly the same with both the fine-node and coarse-node models. There were differences in the time-dependence of the cold-leg accumulator injection. The predicted peak cladding temperature for the coarse-node calculation was about 75.0 K less than that for the fine-node calculation. The complete (steady-state plus transient) coarse-node calculation required 13.5 h of Cyber 76 computer time compared with 68.3 h for the fine-node calculation, yielding an overall factor-of-five decrease in execution time. The Sandia researchers concluded that for any LBLOCA analysis in which only the overall trends are of concern, the loss of accuracy resulting from the use of such a coarse-node model will normally be inconsequential compared with the savings in resources that are realized. However, if the objective of the analysis is the investigation of the effects of multidimensional flows on cladding temperatures, a more detailed model is required.





## *Break-flow modeling*

In the past, studies have been performed with TRAC–P at the Los Alamos National Laboratory to determine small break modeling criteria for full-scale pressurized water reactor SBLOCA analyses (Ref. 4-34). Based on these studies (which carry over directly to TRACE), Los Alamos recommends that small breaks in TRACE be modeled with a single convergent cell in the side-tube of a TEE component, as shown in Figure 4-101. The cell length (DX) of this convergent cell

should model the pipe thickness plus the average length of blown out pipe wall that may still be intact, directed outward, and constraining fluid flow. The entrance to exit area ratio should be 3.0 (ratio of FA at the internal-junction interface with main-tube cell JCELL to FA at the side-tube cell 1 junction with the BREAK). Model the BREAK-cell flow area (VOLIN/DXIN) to equal the junction interface FA flow area of the BREAK and model the BREAK-cell DXIN length to equal the side-tube cell 1 DX length. This models no outflow expansion at the location of the BREAK-cell pressure. For small breaks, an atmospheric-pressure boundary condition is appropriate so close to the pipe-wall break; for pipe side-wall large breaks, a higher than atmospheric pressure boundary condition or VOLIN/DXIN > FA will need to be modeled.

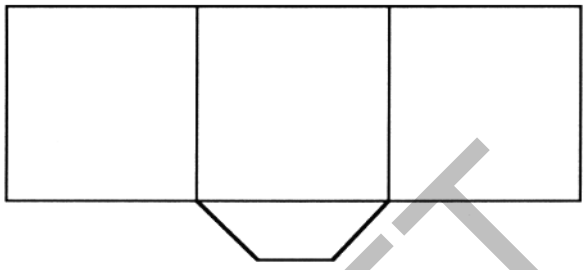


Figure. 4-101. TRACE small break noding diagram. It shows the recommended convergent one-cell small break model (the convergent cell entrance-to-exit flow-area ratio should be three and its length should model the pipe thickness plus the average length of blownout pipe wall that may still be intact, directed outward, and constraining fluid flow).



The choked-flow model should be evaluated at the BREAK-component junction either with NAMELIST variable ICFLOW = 1 (default value) or with ICFLOW = 2 and the choked-flow option flag ICFLG = 1 at the junction interface. With this recommended noding, the critical mass flux agrees reasonably well with the Burnell model and homogeneous-equilibrium model (HEM) in the appropriate fluid states. At highly subcooled liquid conditions [1.5E+07 Pa, 560.0 K)], the TRAC–P mass flux is 2.7% lower than that evaluated by the Burnell model; at saturated-liquid conditions [7.1E+06 Pa, 560.0 K], the TRAC–P mass flux is 6.5% lower than that evaluated by the Burnell model; at saturated-vapor conditions, the TRAC–P mass flux is 3% higher than that evaluated by the HEM model. We found this small break model to be applicable to break sizes ranging from 0.25% to 10% of the main-tube flow area. For situations where horizontal main-tube, two-phase flow conditions are expected to be stratified, the TEE-component offtake model (IENTRN = 1) should be used.

The explicit choked-flow model simulates fast transients more accurately and efficiently than the natural-choking calculation. Under conditions where thermal disequilibrium is probable due to a short flow path through the break, a natural choking fine nodalization may be more appropriate. Unfortunately, the uncertainty in modeling the geometry and size of an actual break (vs the circular flow area of an orifice in an experiment) will probably overshadow the few percent mass-flux errors of these other effects.

Gravity effects can be very important in break-flow modeling, particularly for small-break simulations. Careful attention should be paid to the modeling of flow channels thought to be horizontal but in reality are inclined slightly.

## *BREAK Component Input Guidance for Unchoked Flow Conditions*

In order to provide guidance for the DXIN and VOLIN inputs for an unchoked BREAK component, an assessment of the steady state results for the simple model shown in Figure 4-102 is provided. This problem represents a steady state flow condition between two BREAK components, 1 and 3, separated by a PIPE component consisting of a single volume. The bulk of the problem input definition is provided in the figure. However, in order to illustrate sensitivity to BREAK component inputs, solutions using different values of DXIN and VOLIN for the two BREAK components are provided for a direct hand calculation and from the TRACE code.

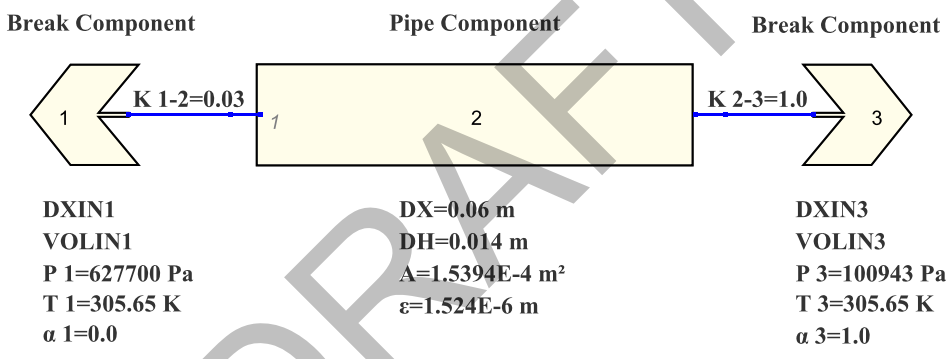





Figure. 4-102. BREAK verification test problem with unchoked flow

The flow and thermodynamic conditions for the sample model can be solved using the Bernoulli equation. The resulting equation for flowrate, which must be iteratively solved, is provided in the following equations:

$$\dot{m} = \sqrt{\frac{2\rho(P_1 - P_3)}{\frac{1}{A_3^2} - \frac{1}{A_1^2} + \frac{\left(K_{1\to 2} + K_{2\to 3} + f\,\frac{\left(dx_2 + \left(\frac{dx_1 + dx_3}{2}\right)\right)}{dh_2}\right)}{A_2^2}}} \tag{4-135}$$

$$V_2 = \frac{\dot{m}}{\rho A_2} \tag{4-136}$$

When the steady-state Bernoulli equation is applied to flow exiting BREAK component 1 and entering PIPE volume 2, the static pressure of the downstream volume, $P_2$, is defined as:

$$P_2 = P_1 + \left(\frac{\dot{m}^2}{2\rho}\right)\left(\frac{1}{A_1^2} + \frac{1 + K_{1\rightarrow 2} + f\dfrac{dx_2}{2\,dh_2}}{A_2^2}\right) \tag{4-137}$$

where

$\dot{m}$ is the flow from BREAK component 1 to BREAK component 3.

$\rho$ is the flow density.

$P_1$ is the static pressure of BREAK component 1.

$P_3$ is the static pressure of BREAK component 3.

$A_3$ is the flow area of BREAK component 3 defined by $VOLIN_3$ / $DXLIN_3$.

$A_1$ is the flow area of BREAK component 1 defined by $VOLIN_1$ / $DXLIN_1$.

$K_{1\rightarrow 2}$ is the irreversible loss coefficient between components 1 and 2.

$K_{2\rightarrow 3}$ is the irreversible loss coefficient between components 2 and 3.

$f$ is the wall loss coefficient calculated using the Churchill correlation.

$dx_2$ is the length of PIPE component 2.

$dh_2$ is the hydraulic diameter of PIPE component 2.

$A_2$ is the flow area of PIPE component 2.

$V_2$ is the flow velocity in PIPE component 2.

The results of the direct hand solution of the above equations and the TRACE solution using various input values of $DXIN_1$, $VOLIN_1$, $DXIN_3$ and $VOLIN_3$, and $K_{1\rightarrow 2} = 0.03$ and $K_{2\rightarrow 3} = 1.0$ are provided in Table 4-44. NFF was set equal to 1 for all the junctions in the TRACE model. This option instructs the code to calculate friction losses using the homogeneous flow friction factor plus the user input value for FRIC, the irreversible loss coefficients $K_{1\rightarrow 2}$ and $K_{2\rightarrow 3}$. Table 4-44 indicates that, depending on the inputs, the TRACE calculated results do not always agree with the direct hand calculation. The TRACE calculated results are dependent on the input values of DXIN and VOLIN. The tables indicate that the calculation of the pressure in the PIPE volume 2 is especially sensitive to inputs of the connected BREAK component. The cases where the TRACE calculations are closest to the direct hand calculations are highlighted on the two tables. After studying these tables, the following recommendations can be made:

1) If a TRACE volume, such as a PIPE component volume, is connected to a pressure source or sink which possesses the same flow area, the BREAK component values of DXIN and VOLIN should be set equal to the connecting volume values. That is:

   DXIN should be set equal to the DX of the connecting volume.

   VOLIN should be set equal to the volume of the connecting volume.

   For this situation, the pressure input for the BREAK component represents a static pressure. The BREAK dynamic pressure will be calculated by TRACE using the previously listed equation.

2) If a TRACE volume, such as a PIPE component volume, is connected to a large pressure source or sink volume, the source or sink boundary volume should be modeled as a BREAK component with a small value for DXIN (e.g. $10^{-6}$), and a large value for VOLIN (e.g. $10^{6}$). This input results in a large BREAK flow area (VOLIN / DXIN) and a very small velocity in the BREAK component volume. Consequently, the pressure input for the BREAK component represents a dynamic pressure. That is, if the BREAK flow area is large, the BREAK input pressure equals the static pressure which equals the BREAK dynamic pressure. This type of BREAK component input should be used for "pipe break" conditions where a ruptured pipe flows into a large, constant pressure volume. In the "pipe break" outflow example, the value of DXIN is kept small in order to minimize the contribution of DXIN in the calculation of the connecting junction thermodynamic properties during unchoked conditions.

## *BREAK Component Input Guidance for Choked Flow Conditions*

The TRACE computer code can check for critical flow at the connecting flow junction. In order to assess the importance of BREAK component inputs under choked flow conditions, the model shown on Figure 4-103 was analyzed for different input values of DXIN and VOLIN for BREAK

component 255. NFF was set equal to 1 for all the junctions in the TRACE model which instructed the code to calculate friction losses using the homogeneous flow friction factor plus the user input value for FRIC, the irreversible loss coefficients identified as K in Figure 4-103. The results of this assessment are shown on Table 4-45.

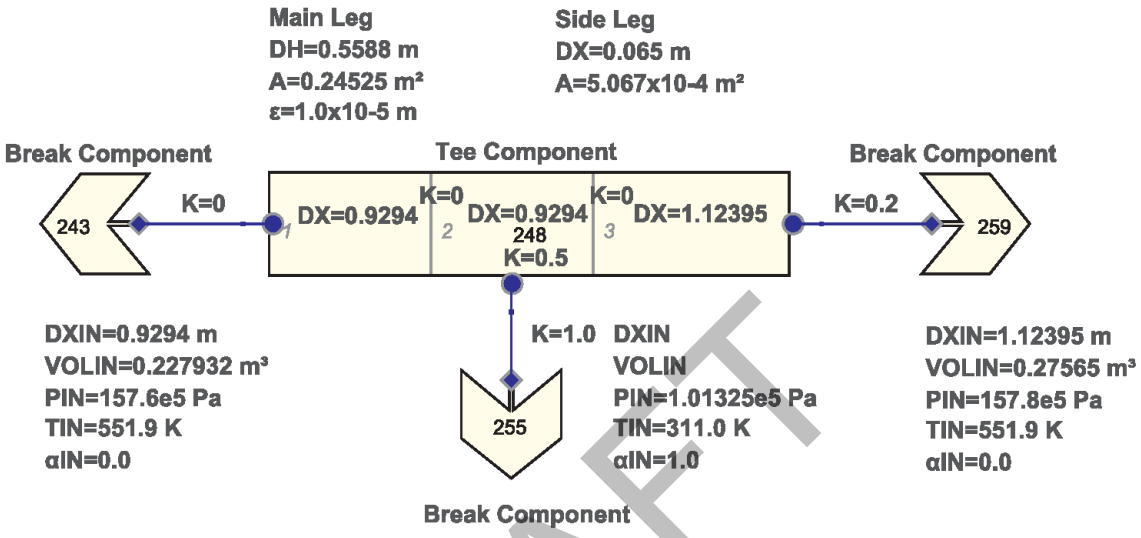



Figure. 4-103. BREAK verification test problem with choked flow

Table 4-45 indicates that, for choked flow conditions, the flowrate is not dependent on the value of VOLIN and only weakly dependent on the value of DXIN. This comparison indicates that the choked flowrate is primarily determined by the flow area of the break junction connected to the BREAK component. Consequently, the previously listed BREAK component input guidelines for unchoked flow also pertain to choked flow conditions.

## *BREAK Component Input Guidance*

Table 4-46 summarizes the input guidelines for BREAK components. As indicated by the results of the sensitivity studies, these guidelines will appropriately model the BREAK component irrespective of whether the connecting junction is choked or unchoked as long as the inputs for the connecting junction reflect the correct flow area and flow loss coefficient.

**Table 4-44. BREAK Component Input Sensitivity With Unchoked Flow (K12 = 0.03, K23 = 1.0)**

| Varying Inputs | | | | | | Direct Hand Calculation | | | TRACE Results | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $DXIN_1$ | $VOLIN_1$ | $A_1$ | $DXIN_3$ | $VOLIN_3$ | $A_3$ | Flow | Velocity $V_2$ | $P_2$ | Flow | Velocity $V_2$ | $P_2$ |
| 1 | 1.5394e-4 | 1.5394e-4 | 1 | 1.5394e-4 | 1.5394e-4 | 4.66872 | 30.466 | 588377 | 3.25158 | 21.22 | 493511 |
| .1 | 1.5394e-5 | 1.5394e-4 | .1 | 1.5394e-5 | 1.5394e-4 | 4.66872 | 30.466 | 588377 | 4.55179 | 29.71 | 578062 |
| .01 | 1.5394e-6 | 1.5394e-4 | .01 | 1.5394e-6 | 1.5394e-4 | 4.66872 | 30.466 | 588377 | 4.74793 | 30.99 | 595944 |
| 0.06 | 9.2364e-6 | 1.5394e-4 | 0.06 | 9.2364e-6 | 1.5394e-4 | 4.66872 | 30.466 | 588377 | 4.63714 | 30.26 | 585640 |
| 0.001 | 1.5394e-7 | 1.5394e-4 | 0.001 | 1.5394e-7 | 1.5394e-4 | 4.66872 | 30.466 | 588377 | 4.76833 | 31.12 | 597903 |
| 1.0e-6 | 1.5394e-10 | 1.5394e-4 | 1.0e-6 | 1.5394e-10 | 1.5394e-4 | 4.66872 | 30.466 | 588377 | 4.77068 | 31.14 | 598123 |
| 0.06 | 0.0001 | 0.0016667 | 0.06 | 0.0001 | 0.0016667 | 4.66872 | 30.466 | 130336 | 4.61213 | 30.11 | 139174 |
| 0.06 | 0.001 | 0.016667 | 0.06 | 0.001 | 0.016667 | 4.66872 | 30.466 | 126434 | 4.56729 | 29.81 | 144865 |
| 0.06 | 0.01 | 0.116667 | 0.06 | 0.01 | 0.116667 | 4.66872 | 30.466 | 126395 | 4.54745 | 29.68 | 149000 |
| 0.06 | 0.1 | 1.6667 | 0.06 | 0.1 | 1.6667 | 4.66872 | 30.466 | 126395 | 4.54379 | 29.66 | 149768 |
| 0.06 | 10 | 166.67 | 0.06 | 10 | 166.67 | 4.66872 | 30.466 | 126395 | 4.54321 | 29.66 | 149889 |
| 0.06 | 100 | 1666.7 | 0.06 | 100 | 1666.7 | 4.66872 | 30.466 | 126395 | 4.54321 | 29.66 | 149890 |
| 0.06 | 1000 | 16667. | 0.06 | 1000 | 16667. | 4.66872 | 30.466 | 126395 | 4.54321 | 29.66 | 149890 |
| 1.0e-5 | 1 | 100000. | 1.0e-5 | 1 | 100000. | 4.66872 | 30.466 | 126395 | 4.71792 | 30.80 | 127147 |
| 0.06 | 10000 | 166667. | 0.06 | 10000 | 166667. | 4.66872 | 30.466 | 126395 | 4.54321 | 29.66 | 149890 |
| 1.0e-5 | 100 | 1.0e+7 | 1.0e-5 | 100 | 1.0e+7 | 4.66872 | 30.466 | 126395 | 4.71788 | 30.80 | 127154 |
| 1.0e-5 | 1000 | 1.0e+8 | 1.0e-5 | 1000 | 1.0e+8 | 4.66872 | 30.466 | 126395 | 4.71788 | 30.80 | 127154 |
| 0.001 | 1.0e+6 | 1.0e+9 | 0.001 | 1.0e+6 | 1.0e+9 | 4.66872 | 30.466 | 126395 | 4.71485 | 30.78 | 127555 |
| 0.0001 | 1.0e+6 | 1.0e+10 | 0.0001 | 1.0e+6 | 1.0e+10 | 4.66872 | 30.466 | 126395 | 4.71761 | 30.80 | 127191 |
| 1.0e-5 | 1.0e+6 | 1.0e+11 | 1.0e-5 | 1.0e+6 | 1.0e+11 | 4.66872 | 30.466 | 126395 | 4.71788 | 30.80 | 127154 |
| 1.0e-6 | 1.0e+6 | 1.0e+12 | 1.0e-6 | 1.0e+6 | 1.0e+12 | 4.66872 | 30.466 | 126395 | 4.71791 | 30.80 | 127151 |

**Table 4-45. BREAK Component Input Sensitivity With Choked Flow**

| $DXIN_{255}$ | $VOLIN_{255}$ | $A_{255}$ | Choked Flow |
|---|---|---|---|
| 1.0e-6 | 1.0e6 | 1.0e12 | 20.1146 |
| 1.0e-5 | 1.0e6 | 1.0e11 | 20.1146 |
| 1.0e-5 | 1.0e5 | 1.0e10 | 20.1146 |
| 1.0e-5 | 1.0e3 | 1.0e8 | 20.1146 |
| 1.0e-5 | 10.0 | 1.0e6 | 20.1146 |
| 1.0e-4 | 1.0e6 | 1.0e10 | 20.1144 |
| 1.0e-4 | 1.0e5 | 1.0e9 | 20.1144 |
| 1.0e-4 | 1.0e3 | 1.0e7 | 20.1144 |
| 1.0e-4 | 10.0 | 1.0e5 | 20.1144 |
| 1.0e-3 | 1.0e6 | 1.0e9 | 20.1122 |
| 1.0e-3 | 1.0e5 | 1.0e8 | 20.1122 |
| 1.0e-3 | 1.0e3 | 1.0e6 | 20.1122 |
| 1.0e-3 | 10.0 | 1.0e4 | 20.1122 |
| 1.0e-2 | 1.0e6 | 1.0e8 | 20.0895 |
| 1.0e-2 | 1.0e5 | 1.0e7 | 20.0895 |
| 1.0e-2 | 1.0e3 | 1.0e5 | 20.0895 |
| 1.0e-2 | 10.0 | 1.0e3 | 20.0895 |
| 0.065 | 3.294e-5 | 5.067e-4 | 20.0337 |
| 1.0e-1 | 1.0e6 | 1.0e7 | 19.9503 |
| 1.0e-1 | 1.0e5 | 1.0e6 | 19.9503 |
| 1.0e-1 | 1.0e3 | 1.0e4 | 19.9503 |
| 1.0e-1 | 10.0 | 1.0e2 | 19.9503 |

**Table 4-46. BREAK Component Input Guideline Examples**

| Type of BREAK Component | DXIN (Note, the junction uses length weighted averages of BREAK and connecting cell properties.) | VOLIN (Note, the flow area equals VOLIN / DXIN.) | ISAT | ALPIN | TIN | PIN |
|---|---|---|---|---|---|---|
| Pipe Break Outflow | Input value much smaller than the connecting cell's length. | Input volume much larger than the connecting cell's value. | 3 | 1.0 | Code sets to $T_{sat}$ | PIN = $P_{static}$ = $P_{dynamic}$ ($V_{break}$ = 0) |
| Pipe Inflow/ Outflow (Boundary cell flow area equals connecting cell area.) | Input value equal to the connecting cell's length. | Input volume equal to the connecting cell's value. | 1 | 0.0 | $T_{liquid}$ | PIN = $P_{static}$ |
| | | | 3 | 0 - 1.0 | Code sets to $T_{sat}$ | |
| | | | 2 | 1.0 | $T_{vapor}$ | |
| Pipe Inflow/ Outflow (Boundary cell is very large tank.) | Input value much smaller than the connecting cell's length. | Input volume much larger than the connecting cell's value. | 1 | 0.0 | $T_{liquid}$ | PIN = $P_{static}$ = $P_{dynamic}$ ($V_{break}$ = 0) |
| | | | 3 | 0 - 1.0 | Code sets to $T_{sat}$ | |
| | | | 2 | 1.0 | $T_{vapor}$ | |

# *Sizing valves*

Valve characteristics and operating sequences need to be carefully modeled for the timing of critical situations. A VALVE component's adjustable flow area needs to be accurately determined for the TRACE model to predict correct fluid-flow conditions. We follow a standard process to size valves, as described below.

The adjustable flow area in the VALVE component (cell-edge interface IVPS) is set to obtain the correct rated steam mass flow under full-open conditions. The HD is defined to be fixed assuming smooth, circular geometry. We have found it helpful to construct a standalone TRACE model for sizing the VALVE-component adjustable flow area. That model is simple, consisting of only a VALVE component, a BREAK component at the exit, and a BREAK component at the entrance. A BREAK component is used at the entrance, rather than a FILL component, to specify the entry pressure rather than the fluid flow that the VALVE is to be sized to achieve. The thermodynamic properties of the steam also are specified for the BREAK component at the entrance. We have found it necessary to specify 1 to 2 K superheat at the inlet to insure that no liquid is present at the adjustable flow area. A low pressure is specified for the BREAK-component exit to induce choked-flow conditions at the adjustable flow area. You can easily check if choking occurs there. TRACE sets the output parameter "wf. liq." to a value of 1.111e-11 at each cell-edge interface where choking occurs (see the output file). The VALVE-component adjustable flow areas AVLVE and HD HVLVE are varied until the specified steam flow rate is obtained.

The TRACE input file listing of a standalone model for valve sizing is provided in **Appendix B,** *TRACE Standalone Model for VALVE Sizing*. To minimize the number of calculations required to approach the target steam mass-flow value for a fully open valve, we adjust the VALVE-component adjustable flow-area fraction (FA) with trip control (IVTR = 1). The signal variable ID for the trip signal (the steam mass flow at the cell edge defined by IVPS = 2 of VALVE component 120) is IDSG = 2. The VALVE-component flow area is adjusted using ON/OFF trip-control to keep the steam mass flow between upper and lower limits that closely bracket the desired steam mass flow of 5.2966E+01 kg/s. If the specified AVLVE flow area value is too large, the output file will identify the adjusted VALVE flow-area fraction (FA) and the percentage of full open. Then this adjusted VALVE flow area (and its related hydraulic diameter, HD) are used as AVLVE and HVLVE guesses for the next calculative iteration. If the specified AVLVE flow area value is too small, the adjustable flow area will be 100% of full open but discharging less than the target steam mass flow. The calculated mass flow also is available in the output file output for the entry and exit BREAK components. Increase the AVLVE flow area and corresponding HD HVLVE, and recalculate until the specified AVLVE flow area is too large. You then proceed as described above. Once you are close to the target steam mass flow for a near or full-open valve, if greater accuracy is required, you could continue this process or modify the valve model by eliminating trip control and selecting the VALVE component's constant flow-area option (IVTY = 0) with FAVLVE = 1.0. You will need to remove the valve-open VTB1 table and close-table VTB2 table as well. Interpolated values of AVLVE and HVLVE would be evaluated to iteratively converge to the desired steam mass flow with repeated calculations.

We have also examined how well a valve modeled in this manner predicts off-normal conditions such as two-phase or liquid mass flow. As reported in Reference 4-35, a valve sized, using the procedure just described, predicts two-phase and liquid mass flows within ±25%.

## *Avoiding "Chattering" Valves*

For transients where the depressurization rate is slow, the pressure difference across a VALVE may fluctuate quite rapidly causing it to "chatter" (with open and close movements every few timesteps) because of rapid changes in the trip status between $ON_{reverse}$ and $ON_{forward}$. You can specify setpoint delay times to prevent this from happening. Then the trip signal must cross a setpoint and remain past the setpoint for the specified delay time before the trip set status is changed. This will prevent a momentary pressure drop or pressure spike from initiating valve closure action. Experience has shown that usually a delay time on the order of five timesteps is sufficient. You must determine the setpoint values, associated delay times, and valve-movement rates based upon a knowledge of the pressure signal and the valve characteristics.

## *Modeling an Accumulator*

The ACCUM component was eliminated from TRACE's predecessor code TRAC-P because an accumulator can be modeled better with a PIPE component using the PIPETYPE accumulator option.

Accumulator flow has a first-order effect on the simulation results obtained with TRACE, so this PIPE-component model of an accumulator should be carefully modeled in integral-system simulations. Some inaccuracy has occurred in previous calculations when nitrogen gas appears in the bottom PIPE cell of the accumulator. TRACE convects it into the adjacent component cell before this bottom cell empties when the PIPETYPE = 1 accumulator-model option is used. This nonphysical behavior can be significantly reduced if the PIPE cell at the bottom of the accumulator is made as small as practical. Gas outflow can be prevented with the PIPETYPE = 2 option, but this is nonphysical when the accumulator empties of liquid.

## *Modeling a Pump*

In TRACE, the pump momentum-source expression includes the gravitational head (if any) and the frictional losses in the momentum equation applied at the second cell-edge interface. The result is that the elevation change across the interface and the frictional losses (both wall friction and additive losses) are considered to be identically zero regardless of the input values for GRAV(2) or ELEV(2), FRIC(2) or KFAC(2), and NFF(2). In addition, the liquid and gas velocities at this cell-edge interface are forced to be equal (no slip). If this is not acceptable in a particular application, you will need to investigate alternative approaches. You should input all elevation changes (GRAV or ELEV) at other interfaces to achieve the correct elevation gravitational-head balance around the loop. The net elevation change will be nonzero if an

elevation change occurs across the pump-impeller interface between the fluid volumes on each side. Additive loss coefficients should be applied at other cell-edge interfaces to obtain the correct pressure drops around a loop containing a PUMP component; therefore, you should set GRAV(2) = 0.0 or ELEV(2) = 0.0 m, FRIC(2) = 0.0 or KFAC = 0.0, and NFF(2) > 0 for all PUMP components. Some users choose to input GRAV(2) or ELEV(2) with the elevation change across the pump-impeller interface to show that the net elevation change around the loop is zero. An input-data comment to indicate this understanding is recommended. Check that the remaining GRAV or ELEV, FRIC or KFAC, and NFF values around the loops yield the desired elevation changes and pressure drops.

# *Modeling a Pressurizer*

We recommend that the PRIZER component be used in combination with other TRACE components to model a complete pressurizer. Although the PRIZER component was originally intended to model the entire pressurizer, it has several shortcomings that limit the accuracy of its model for a complete pressurizer. Specifically, it does not adequately model the heater power and the spray as separate items, the spray as a liquid mass flow rather than a heat sink, and the actual locations of the heaters and the spray in the pressurizer.

We have found that a three-component model of the pressurizer provides the needed features to successfully model a complete pressurizer. Such a model is contained **Appendix B,** *Sample 3-Component Pressurizer Input Listing* and shown in Figure 1-10. The lower portion of the pressurizer, containing the proportional and backup heaters, was modeled using PIPE component 40. The logic for its control is shown in Figure 4-104. You should use a small cell at the bottom of the pressurizer [DX(3) = 5.31E-01 m] to ensure proper liquid draining of the pressurizer. The middle section of the pressurizer was modeled with TEE component 41 that provides a side-tube JUN3 connection outlet to the power-operated relief valves and the primary safety-relief valves and a JUN1 inlet for the spray. We believe the eight main-tube cells in this component are adequate to model the liquid-steam interface. The upper portion of the pressurizer was modeled with PRIZER component 42. This component is used to fix the system pressure during the steady-state calculation. The pressurizer spray is modeled by FILL component 43 connected to the top of the PRIZER component. You must size its inlet flow area so that the liquid velocity at the PRIZER-component top cell edge exceeds 4.0 m/s. This will ensure that the condensation model in the PRIZER component is activated to provide a more accurate pressure response during spraying. The logic control for the pressurizer spray is shown in Figure 4-104 as well.

Several alternative pressurizer modeling approaches were examined by Sandia National Laboratories (Ref. 4-32). Similar results were calculated when the test pressurizer was modeled with a single PRIZER component (both 4 and 13 cells), two PRIZER components and one PIPE component, and three PIPE components. However, we believe the recommended configuration provides the general modeling capabilities needed and should be used unless you have specific reasons for another modeling approach.

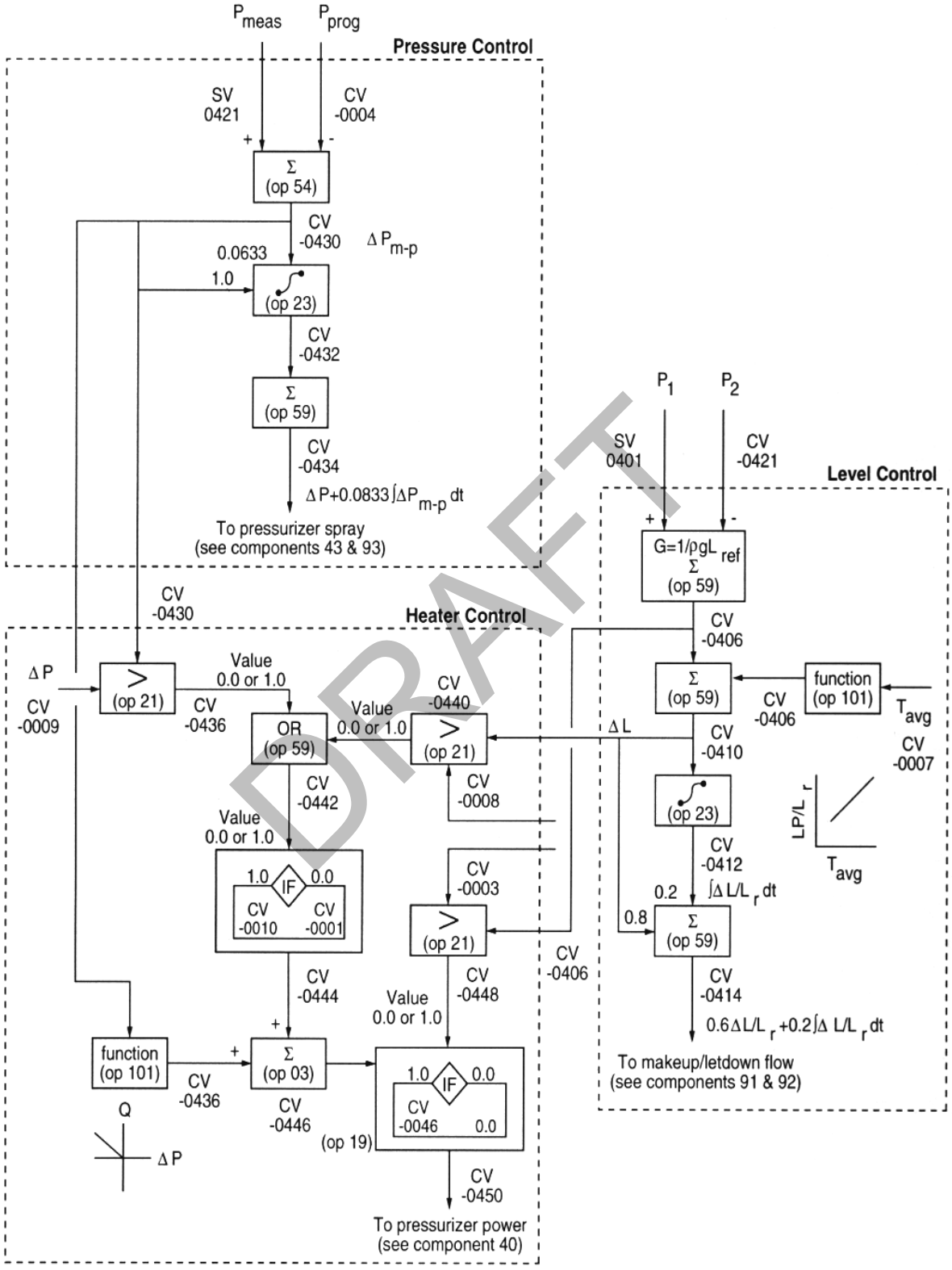



Figure. 4-104. Pressurizer control procedure.

# *Modeling a Steam Generator (SG)*

A generalized SG modeling capability is provided in TRACE. The user must build a SG model in much the same manner as the full-plant model is developed. Again, a good database is necessary. An acceptable SG model will closely approximate both its steady-state and transient performance. Steady-state operating data usually are available, whereas transient data may not be available.

The primary-side performance parameters of interest at rated mass flow are the pressure and temperature changes from inlet to outlet. Primary-side modeling is straightforward; the primary-side flow field generally is modeled with an effective combined-tubes single flow channel modeled by a single PIPE or TEE component. The secondary-side parameters of interest are more diverse. They include the outlet pressure, temperature, and moisture content for rated inlet conditions, recirculation mass flow, steady-state liquid inventory; and the distribution of that inventory (to match the pressure distribution as measured by pressure taps in a real facility). The secondary side generally is modeled by a combination of TEE and PIPE components as specified by the user. Heat transfer between these primary- and secondary-side hydraulic components is modeled by HTSTR components. Although we have been able to develop acceptable SG models, we have not always matched all secondary-side parameters as closely as desired (e.g., the secondary-side fluid mass distribution based on a pressure tap simulation). This is due, in part, to real plant elements such as tube-support plates and separator vanes not being included explicitly in the model. These elements can be modeled, but the cost of developing the model and its calculative effort increases because of the finer noding and detailed heat-transfer coupling required.

The generic 3-loop plant model presented in **Chapter 1** contains three U-tube SGs. The following discusses the loop 3 SG shown in Figure 1-10. The model consists of 4 hydraulic components and 9 heat-structure components. The primary-coolant side is modeled by PIPE component 32. Three hydraulic components comprise the secondary-side fluid model. The boiler region is modeled by PIPE component 300, the moisture-separator and steam-dome regions are modeled by TEE component 305, and the downcomer region is modeled by TEE component 390. Heat transfer through the SG tubes from the primary-side fluid to the secondary-side fluid in the boiler region is modeled by HTSTR component 930. The third element of HTSTR component 931 and HTSTRs 932, 933, and 938 models secondary-side structure heat transfer between the fluids of the boiler and downcomer, moisture-separator and downcomer, and boiler/moisture-separator/steam-dome/ downcomer and outside air. The third element of HTSTR components 934, 935, 936, and 937 model the primary-side inlet-plenum and outlet-plenum heat transfer between the primary-side fluid and the outside air. All these heat-transfer path nodes between hydraulic cells and outside air through solid structures are shown in Figure 1-7.

Several points need to be emphasized. First, the secondary-side coolant recirculation flow rate through the downcomer region is a function of the secondary-side fluid flow areas and frictional losses. We model the geometry as closely as possible and use frictional losses as appropriate. The large forward-flow additive loss coefficient form-loss K factor = 215.0 (1000.0 for reverse flow) specified at the tube-support plate cell-edge interface between the downcomer and boiler regions was selected to produce the target recirculation boiler fluid flow to steam outflow ratio of 4±1.

Second, some effort may be required to model the moisture-separator and steam-dome regions of the SG in an acceptable fashion. Actual fluid-flow and heat-transfer areas as specified by the vendor were used in the model; however, sometimes database drawings are not sufficiently detailed to permit an accurate estimate of these areas. Secondary-side coolant behavior has a strong model dependency, so we encourage you to review your results critically to see that moisture separation is occurring appropriately for the moisture (liquid) content of steam outflow and the steam content of liquid recirculation. Within TRACE, the user may specify an additive loss coefficient > 1.0000E+20 at a cell-edge interface. This applies a "perfect" separator model that will not convect liquid across the interface. An additive loss coefficient < -1.0000E+20 will not convect gas (steam) across the interface. This option of FRIC > 1.0000E+20 in the steam dome and FRIC < –1.0000E+20 in the downcomer should be used with caution (if at all) to ensure that this "perfect" separator concept matches the physical phenomena expected. The separator SEPD component (rather than a TEE component) can be used to model mechanistic or control-procedure defined liquid carryover and vapor carryunder at a tee connection in a SG. Generally, this requires knowledge of the separator behavior of the tee connection.

We have noted a tendency for TRACE to underpredict the secondary-side pressure at steady state when the desired primary-side conditions are achieved. It appears that this may be due, in part, to use of the Chen correlation that is based on flow inside tubes for SG secondaries. We have found that the Chen nucleate boiling correlation shows a strong dependence on HD as it becomes small. Normally, the secondary-side HD would be evaluated using the standard (Eq. Figure 4-124 formula (four times the flow area divided by the wetted perimeter). For the secondary-side boiler region, the resultant HD corresponds closely to the pitch of the tube array. However, if HDs on the order of the outer-surface wall-to-wall minimum distance are used, considerable improvement in the predicted secondary-side pressure can be achieved (Ref. 4-37).

A flexible modeling approach is to use separate hydraulic-diameter input for the hydraulic and heat-transfer calculations. This may be done by setting NAMELIST variable ITHD = 1 for HTSTR components and NAMELIST variable NDIA1 = 2 for 1D hydraulic components. Then input HDRI and HDRO for the inner- and outer-surface heat-transfer diameters for HTSTR components, and input another HD array for the wall inner-surface heat-transfer diameters for 1D hydraulic components. The use of heat-transfer diameters in a once-through SG model is described in Reference 4-32.

A generic model of a once-through SG is presented in Figure 4-105. The figure illustrates the design details, flow paths, heat-transfer regimes, and a TRACE noding diagram. Again, the model is assembled from four 1D hydraulic components. The feedwater-downcomer annulus and steam-exit annulus are modeled with the main-tube flow channels of two TEE components. The boiler and superheater regions are modeled by the main-tube flow channel of another TEE component.

The aspirator flow path is formed using the side-tube TEE connection that is normally used to model an auxiliary-feedwater inlet. This required placing the auxiliary-feedwater inlet in the steam-exit annulus. All once-through SG dimensions are correctly modeled. The HDs on the secondary side for the boiler and superheater regions are based on the minimum wall-to-wall distance for the tube array.

More complex models of the SG secondary side may be required to accurately simulate design data. We have developed the split-bundle once-through SG model shown in Figure 4-106 to simulate the partial wetting of SG tubes by auxiliary feedwater.

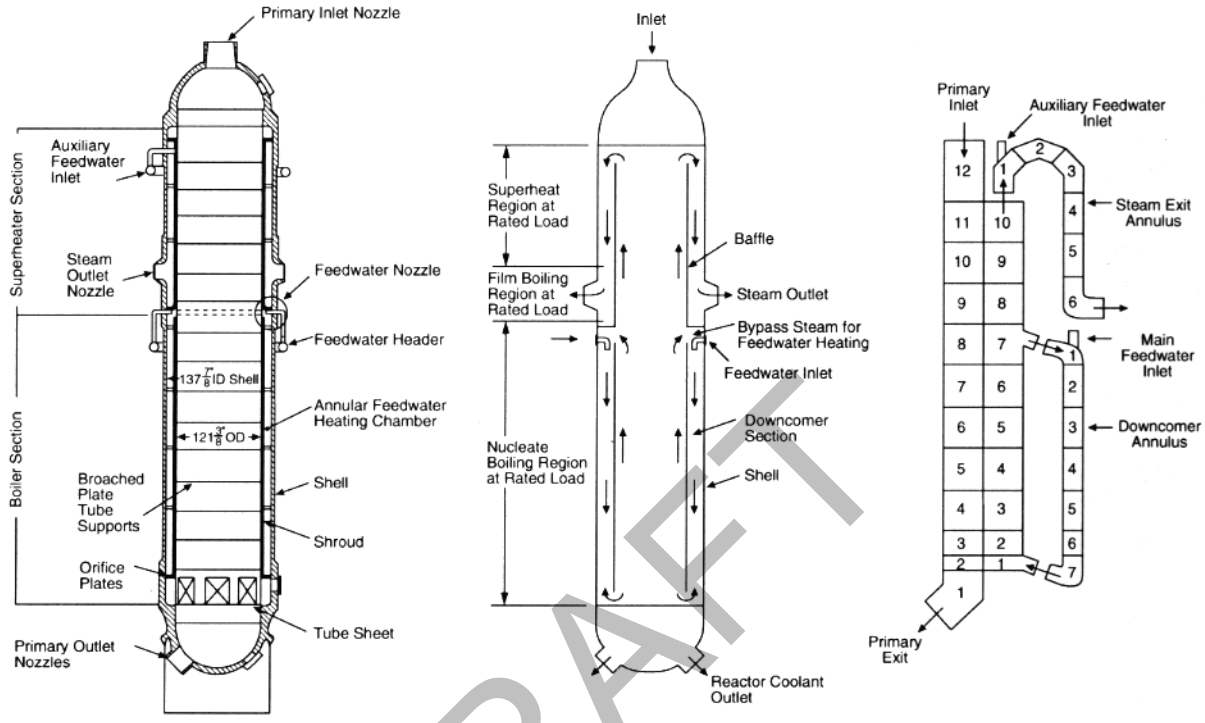



Figure. 4-105. TRACE model of a once-through SG with aspirator flow.



# *Wall Heat-Transfer Structures*

The heat-transfer calculation in TRACE is based on conduction through solid structures and convection at structure surfaces to the hydraulic-channel contacting fluid. One-dimensional heat-transfer may be evaluated across the cylindrical wall of almost all 1D hydraulic components. Modeling wall heat transfer is simply a matter of setting the number of radial heat-transfer nodes in the wall to be greater than zero (i.e. NODES > 0). The remaining input data are the radius of the wall inner surface (RADIN), wall thickness (TH), wall outer-surface liquid and gas heat transfer coefficients and temperatures (HOUTL, HOUTV, TOUTL, and TOUTV), wall material identifier (MATID), volumetric heat source/sink (QPPP), and 2D wall temperature distributions (TW). This process is straightforward because there is a one-to-one correspondence between the 1D heat-transfer node rows in the wall and the hydraulic cells they are coupled to. A guideline for wall heat-transfer input-data preparation when combining two or more coolant-flow loops into one modeled flow low is presented in ***Technique for combining loops*** above

Modeling heat transfer through solid structures in the reactor vessel, SGs, or other complicated hardware structures should be done using HTSTR components with cylindrical or Cartesian

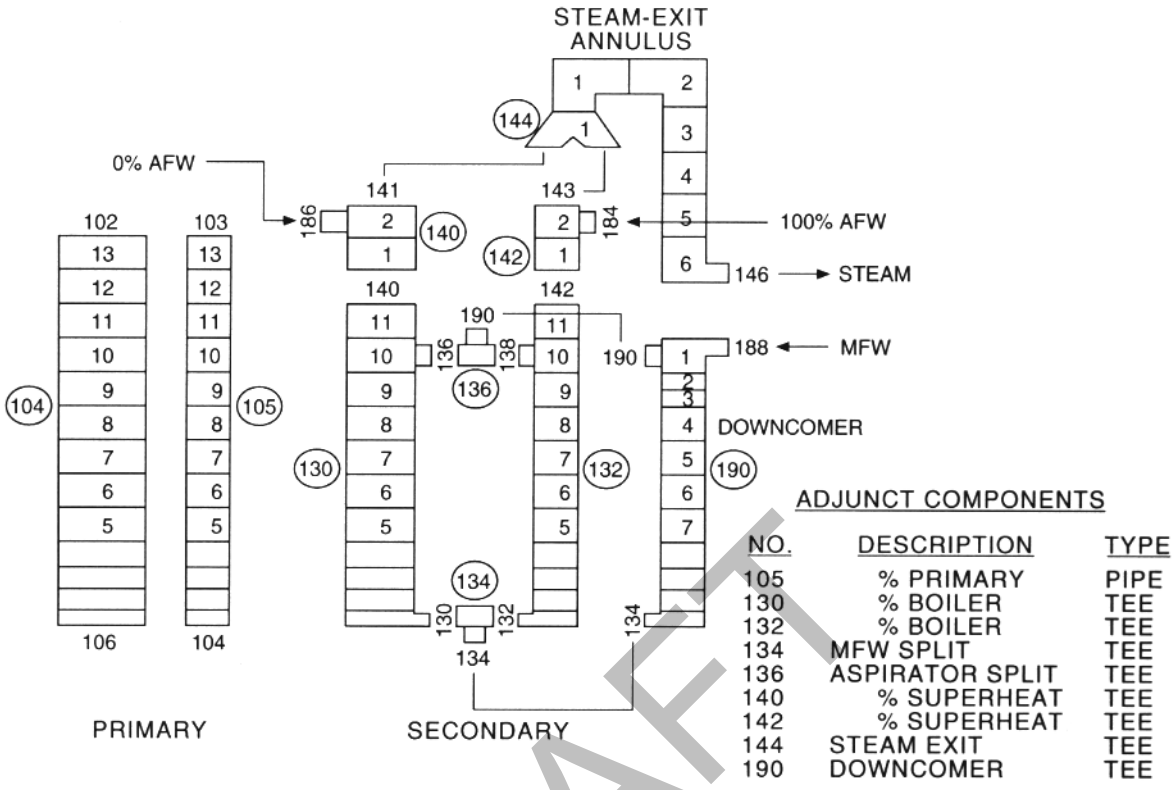



Figure. 4-106. Diagram of a TRACE once-through SG with dual-channel modeling.

geometry elements. Convection heat-transfer coupling to the fluid of hydraulic components can be evaluated on both the inner and outer surfaces of the HTSTR element. The actual geometry of a single physical element is modeled and evaluated by a calculative HTSTR element with the combining of identical elements defined by the RDX-array number of such physical elements. HTSTR components have significantly more modeling features and options than the wall heat-transfer calculation of 1D hydraulic components, but the latter is more convenient if only a simple 1D heat-transfer model is needed having an adiabatic or constant convection-parameter outer-surface condition.

# *Initial and Boundary Conditions*

The starting point of a transient is determined by its initial conditions; the course of a transient is determined by its boundary conditions. Accurate specification of each is necessary if the calculated transient is to simulate reality. For example, consider a total loss of feedwater to the steam-generator secondary in a PWR. If the initial SG-secondary inventory is either high or low, the predicted timing of key events will be either delayed or accelerated relative to the correct timing of these events. Similar statements apply to the boundary conditions for a specific transient. If valves open at the wrong pressure, or do not open at all when they should, the correct course of the transient will not be simulated.

# *Initial Conditions*

You have several approaches and options for developing the initial conditions for a transient calculation. First, you can directly specify the detailed initial state of the plant or facility you are modeling. This is a tedious and time-consuming process for even moderate-size models, and frequently the distribution of each parameter's values throughout the system being modeled is not known. This approach is not recommended unless (1) the model is small, (2) TRACE cannot readily calculate the numerical solution without reasonable initial conditions, or (3) the initial condition is not at steady state.

The second approach to provide a complete but approximate specification of the initial conditions and let TRACE calculate an accurate set of steady-state initial conditions. The TRACE-calculated initial conditions or steady-state solution should be compared with plant performance specifications or operational data to validate the calculated results. We refer you to **Chapter 3** for additional information regarding the TRACE steady-state calculation.

Two improvements can be made to the second approach. Constrained steady-state controllers (conveniently defined through input, as described in Volume 1) can be applied to adjust the uncertain state of component actions to achieve known or desired conditions in hydraulic parameters that the adjusted actions affect. This adjusts uncertain hardware conditions to achieve hydraulic conditions in the steady-state solution that are known or measured. The second improvement is to conveniently input isothermal, no-flow initial conditions in the component data and have TRACE internally initialize the phasic cell temperature and interface velocity distributions throughout the modeled system by its hydraulic-path steady-state initialization procedure described in Volume 1. This approximately halves the calculative effort of the steady-state calculation to converge to the steady-state solution.

After you have completed your system model, but before you calculate your first steady-state solution, we recommend that you make a special static-check steady-state calculation. When this option is selected, all heat sources and pumps are automatically deactivated. If the gravity terms or elevations have been entered correctly, all fluid motion should stop in the model. The conversion of elevations to gravity terms is output to the output file along with the elevation changes across each hydraulic component. These can be added to see if the loop elevations add to zero. To achieve the best results with this option, we recommend that you make the initial temperatures uniform in all cells that are coupled hydraulically (e.g., in the primary-coolant system and in the secondary-coolant system).

# *Boundary Conditions*

Boundary conditions that determine the course of a transient can be specified in TRACE either explicitly, implicitly, or (usually) in combination. Examples of explicit specification of boundary conditions would be the pre-defined phasic velocity or mass flow specified by a FILL component or the fluid pressure specified by a BREAK component. Both components define their composition phasic temperatures and gas volume fraction for inflow to their adjacent component.

The valve-sizing input model discussed in ***Sizing valves*** and presented in **Appendix B,** *TRACE Standalone Model for VALVE Sizing* is based solely on the explicit statement of its closure state boundary condition.

A user-specified control procedure can be used in TRACE to define implicit boundary conditions. The user defines the boundary conditions but does not know in advance whether or not these conditions will be invoked during the course of the transient. For example, the injection of emergency core-cooling liquid into the primary will occur only if certain prespecified conditions (defined by control block and trip logic) are satisfied. Our objective here is to ensure that you understand that the definition and provision of TRACE control procedures is the manner in which boundary conditions are implicitly defined in a TRACE model. We refer you to **Chapter 3** for a discussion on control procedure examples.

As previously mentioned, a combination of explicit and implicit specifications usually is found in a plant or facility system model. TRACE is sufficiently general in its formulation and capabilities to permit a wide range of realistic boundary conditions to be modeled.

# *Closure Model Selection Guidelines*



For the most part, you need not have a detailed knowledge of the various constitutive models in TRACE to use the code. Please note that this is not a recommendation that you apply TRACE without understanding its models. It is a recognition that a full understanding of its models is not required to use TRACE. However, there are several parameters that you must specify which have a direct effect on how the solution of the field equations achieves closure. Here, we briefly describe some of these model-selection parameters and recommend input values.



## *ICHF*

ICHF is the critical-heat-flux option flag. If ICHF = 1, the entire boiling curve is used by TRACE as needed during the course of a steady-state or transient calculation. If ICHF = 0, the nucleate-boiling portion of the boiling curve is not available and forced convection of the fluid is assumed. We recommend that you always use ICHF = 1.

## *NFF*

NFF is the friction-factor correlation option flag. Several options are available. NFF = 1 applies a homogeneous-flow friction factor for wall and structure drag. NFF = –1 is the same but adds an internal form-loss computation for abrupt changes in flow area between mesh cells. NFF = –100 applies the form-loss computation only. We recommend that NFF = 1 or –1 be applied at mesh-cell interfaces everywhere except at a interface where flow choking is anticipated. NFF = 0 is recommended for this case. The reason for setting NFF = 0 at the flow-choking interface is to avoid becoming friction limited as the onset of flow choking is approached. We also recommend

that the user account for gradual flow-area change, flow turning, and orifice form losses by specifying FRIC or KFAC additive form-loss coefficients as well.

## *Choosing an Equation-of-State Model*

TRACE currently offers the choice of two different equation of state (EOS) models - the legacy built-in curve fit formulation inherited from TRAC-PF1, and an interploation scheme based on the 1997 International Association for the Properties of Water and Steam (IAPWS) Industrial Formulation (IF97) standard. While the curve fit formulation currently tends to perform, on the whole, somewhat faster (~10-15%) than the IAPWS standard[2], that speed advantage comes at the cost of lower accuracy in certain regions of the phase diagram for water. This loss in accuracy can have a significant impact on the predictions of certain reactivity feedback transients[3], and has been found, through assessments against break flow experiments, to detrimentally impact the robustness of the choked flow model. As such, the TRACE development team generally recommends use of the IAPWS formulation in most instances. Details on how to engage this option are provided in **Volume 1, Chapter 1** of the TRACE User's Guide.

Having said this, we must, however, caution you to beware. The IAPWS formulation currently behaves very badly when conditions of the fluid reach far into the metastable region (i,e. liquid becomes highly superheated or vapor becomes highly subcooled). In these situations, the violence of water packing events, even after correction, will have an abnormal tendency to drive the fluid into odd states during iteration. Our current best guidance is that any input model which fails with water packing and iteration failure messages in close proximity needs to be tried with the legacy curve-fit EOS formulation. Unfortunately, there are going to be LOCA simulations where this advice conflicts with previous advice to use the IAPWS formulation for best behavior of the choked flow model.



# *Reactor Geometry*

The VESSEL component in TRACE models a PWR vessel, its internal structures, and the reactor core. The VESSEL is the only TRACE hydraulic component that is 2- or 3D. As you might expect, a different form is used to define the required input parameters in two or three dimensions. Heat-transfer structures, previously a part of the VESSEL component in TRAC-PF1/MOD1, now are modeled separately using HTSTR components. For example, specification of the power generation in the reactor-core region is done by HTSTR rather than VESSEL input data. In this section, we present guidelines for specifying the VESSEL-component geometry. In the next

2. We expect that this difference in run-time will continue to decrease and eventually favor the IAPWS scheme as computer architectures move to larger and larger sizes of cache memory.
3. One such scenario would be the OECD main steam line break benchmark in which the reactivity of sub-cooled water plays a key role. A difference of just 5% in the subcooled water density as compared to the IAPWS standard values can affect the predicted power shape and whether the code will predict an actual return-to-power or not.

section, we present guidelines for HTSTR modeling including heat transfer, core reflood, and neutronics.

We refer you to **Chapter 2** for a description of the VESSEL component; to **Volume 1, Chapter 6** for the VESSEL-component input-data description; and the TRACE Theory Manual for a detailed discussion on the fluid-dynamics, heat-transfer, and point-kinetics equations and solution methods for the multi-dimensional VESSEL component.

As discussed in **Chapter 1**, it is important that you prepare a noding diagram for the VESSEL component. The noding guidelines that follow are intended to help you decide how to subdivide (nodalize) the VESSEL with mesh-cell volumes.

1) The number of node volumes you select is dependent on the phenomena you are trying to study. For facilities in which an accurate simulation of the overall-plant system response is desired, the VESSEL mesh-cell noding selected for the full-plant model depicted in **Chapter 1**, Figure 1-5 is adequate. If you wish to focus on specific flow phenomena within the VESSEL, finer noding may be required locally or globally. For example, you should use two or more axial levels in the lower plenum if the phenomenon of liquid coolant sweep-out is important.

2) We re-emphasize that a price is paid for small mesh-cell sizes in the VESSEL. Doubling the number of VESSEL cells can result in doubling the computation effort when the VESSEL component/s contain most of the mesh cells of the system model. However, the greater computational effort may be a necessary and an acceptable tradeoff for resolving the physical phenomena of interest with appropriate accuracy.

3) You are cautioned against connecting to the VESSEL any component (usually a PIPE or TEE) with a connecting flow area that is greater than the flow area of the mesh-cell face to which it is connected because erroneous pressure gradients may result. The flow area of the connecting component should never exceed the available VESSEL mesh-cell face area to which it is connected. You can avoid this modeling difficulty by proper selection of the VESSEL geometry coordinate spacings in the axial and azimuthal directions.





As shown in Figure 1-5, the user typically defines a 3D cylindrical mesh to represent the internal volume of the reactor vessel. Variable-mesh spacings in all three directions are possible. In Figure 1-5, variable-mesh spacing is used in the axial and radial directions while a regular-mesh spacing is used in the azimuthal direction. The user first describes the mesh by specifying the NASX number of z-direction axial cells (levels), NRSX number of x- or r-direction cells (rings), and NTSX number of y- or θ-direction cells (azimuthal sectors). The VESSEL geometry is defined by IGEOM = 0 (cylindrical) or 1 (Cartesian). Setting NASX, NRSX, or NTSX = 1 eliminates the dimensionality of the VESSEL in that direction. In this manner, the three-, two-, one-, or zero-dimensional mesh cells that model the VESSEL are defined. The mesh cells are identified by an axial level number and a relative cell number at each level (where the same relative cell numbering repeats at each axial level). In addition to numbering the cells, the cell faces also are numbered using the convention shown in Figure 4-107. This cell and face numbering convention is used to define where external 1D hydraulic connections are made to VESSEL cell faces.

Connections of 1D hydraulic component to the VESSEL are made perpendicular to the faces of the its mesh cells. Connections can be made to any and all of its six faces with multiple connections to any face. They can be external connections, such as to coolant loops, and internal connections, such as to guide tubes, as shown in Figure 1-5. Four input parameters are used to specify a VESSEL cell-face connection to a 1D hydraulic component. The parameter ISRL defines the axial level, ISRC defines the relative cell number at the given level, and ISRF defines the face number where the connection is made as shown in Figure 4-107. The connected 1D hydraulic component is always located outside of the VESSEL cell that it is connected to. For example, for an axial connection, the top face is specified if ISRF = 2 (positive value in Figure 4-107) and the bottom face is specified if ISRF = –2 (negative value). For a radial connection, the outer face is specified if ISRF = 3 and the inner face if ISRF = –3. For an azimuthal connection, the counterclockwise-direction face is specified if ISRF = 1 and the clockwise-direction face is specified if ISRF = –1. The fourth input parameter JUNS defines the 1D component junction number that the VESSEL-cell face is connected to.

Cell fluid volumes and face flow areas are internally evaluated by TRACE on the basis of the geometric and directional mesh-cell spacings and the fluid volume and flow-area fractions specified by the user. These are the FRVOL fraction of cell volume occupied by coolant; and the FRFAYT, FRFAZ, and FRFAXR fractions of each cell's face flow area in the azimuthal, axial, and radial directions, respectively, that are open to fluid flow. For example, the downcomer wall can be modeled by setting the appropriate FRFAZ and FRFAXR flow-area fractions to 0.0. An option is provided to do this internally in the code if the upper, lower, and radial downcomer position parameters IDCU, IDCL, and IDCR are specified with nonzero values. NAMELIST variable IGEOM3 can be used to allow nonzero flow-area fractions to be specified in the downcomer wall to model leakage flow paths.

There are restrictions on interface flow areas in TRACE. This was required when cell-to-cell flow-area ratios were applied to the momentum-convection term in TRAC-PF1/MOD2 (and carried over into TRACE) to model Bernoulli-equation reversible flow losses correctly. Now the interface flow area specified cannot be > 1.1 times the maximum VOL/DX (where DX = $\Delta Z$, $\Delta Y$ or $R\Delta\theta$, and $\Delta X$ or $\Delta R$ for a VESSEL cell and DX = $\Delta X$ for a 1D hydraulic component cell) average flow area of the cells on each side of the interface. This is done to prevent nonphysical modeling and to avoid an unstable numerical solution from the application of flow-area ratios in the momentum-convection term.

The Babcock & Wilcox vent valves that are located in the wall between the upper plenum and downcomer are modeled by a VESSEL option. These vent valves permit flow directly from the upper plenum to the downcomer and out the cold leg during a cold-leg break. They are modeled as constant flow areas in the outer radial face of a VESSEL cell (which models the downcomer) with a variable additive loss-coefficient FRIC term to model the variable irreversible form loss of different closure states. The user specifies the cells that have vent valves by giving the axial level, relative cell number, and total flow area of the vent valve. The user also specifies for each cell with a vent valve: (1) the DPCVN pressure drop for the valve to be closed, (2) the DPOVN pressure drop for the valve to be opened, (3) the FRIC value FRCVN to model leakage when the valve is closed, and (4) the FRIC value FROVN when the valve is open. The pressure drop is defined as the pressure of the inner radial cell minus the pressure of the outer radial cell. TRACE

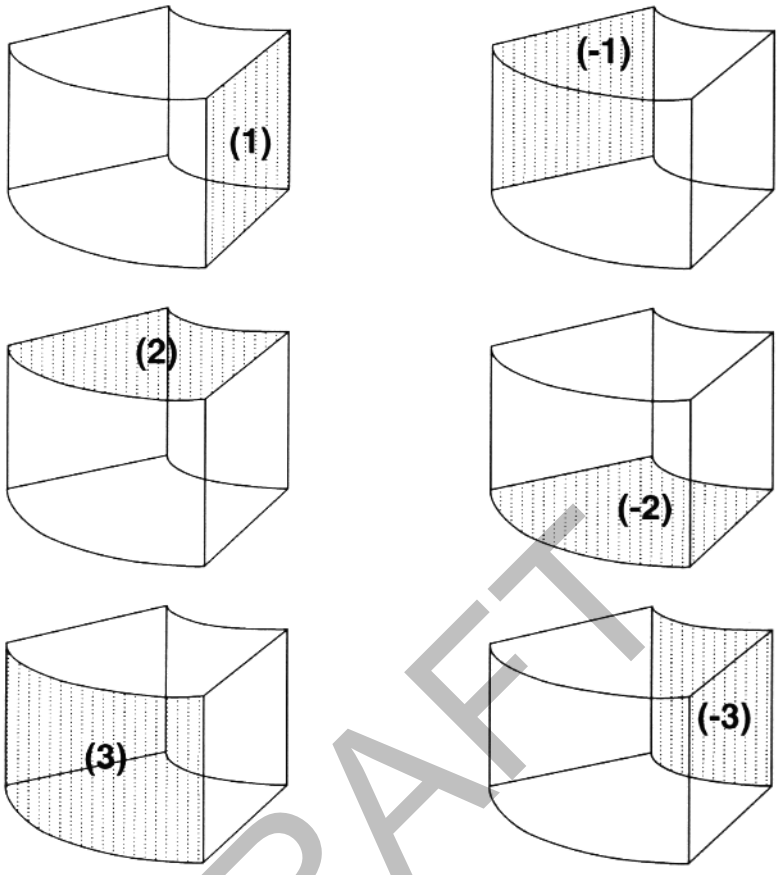



Figure. 4-107. Numbering convention for VESSEL-cell faces.





uses FRCVN when the pressure drop is less than DPCVN, uses FROVN when the pressure drop is greater than DPOVN, and interpolates for an intermediate pressure drop.

The reactor-core region in the VESSEL component is specified by input parameters ICRU, ICRL, and ICRR. These parameters define the directional-cell numbers of the upper, lower, and radial positive-interface boundaries, respectively, of the cylindrical or Cartesian reactor-core region in the VESSEL. Each axial stack of mesh cells in the reactor-core region may contain an arbitrary number of RDX fuel rods modeled by a HTSTR component. The HTSTR's average thermal calculation couples directly to the fluid thermal-dynamics of the VESSEL's axial stack of cells. One average HTSTR element models the average power of the ensemble of fuel rods in each axial stack of mesh cells. One or more supplemental HTSTR elements model the average power times an RPKF peaking factor. The thermal analysis of supplemental HTSTR elements does not feed back or couple directly to the fluid-dynamics analysis. However, the local fluid condition in the axial stack of cells is used to evaluate the temperature distributions in the supplemental as well as average HTSTR elements.

An analytical procedure has been developed for determining additive-friction-loss coefficients for liquid- and vapor-phase rod-bundle cross flow in the VESSEL. The procedure was verified

through excellent comparisons of TRAC–P calculations with three independent sets of data for liquid, vapor, and two-phase flows (Ref. 4-38). In a 3D VESSEL model, one dimension is aligned with the rod bundle (usually the axial coordinate) and two dimensions define cross flow (usually the radial and azimuthal coordinates). The x- or r-direction additive-friction-loss coefficients for liquid and vapor at interface *i+1/2* are defined by

$$CFZLXR_{i+1/2} = CFZVXR_{i+1/2} = 4Nf_{dt}/(\Delta X_i + \Delta X_{i+1}), \quad \text{or} \tag{4-138}$$

$$4Nf_{dt}/(\Delta R_i + \Delta R_{i+1}) \tag{4-139}$$

where $N$ is the number of transverse rows of rods from the center of cell $i$ to the center of cell $i+1$, $\Delta X_i$ and $\Delta X_{i+1}$ or $\Delta R_1$ and $\Delta R_2$ are the x- or r-direction cell lengths on each side of the *i+1/2* interface, and $f_{dt}$ is a special friction factor evaluated from Figure 4-108. The y- or θ-direction additive-friction-loss coefficients for liquid and vapor at interface *j+1/2* are defined by

$$CFZLYT_{j+1/2} = CFZVYT_{j+1/2} = \begin{cases} (4Nf_{dt}/\Delta Y_j + \Delta Y_{j+1}) \text{, or} \\ (4Nf_{dt})/(R_i\Delta\theta_j + R_i\Delta\theta_{j+1}) \end{cases} \tag{4-140}$$

where $\Delta Y_j$ and $\Delta Y_{j+1}$ or $R_i\Delta\theta_j$ and $R_i\Delta\theta_{j+1}$ are the y- or θ-direction cell lengths on each side of the *j+1/2* interface. The z-direction axial additive-friction-loss coefficients for liquid and vapor are defined using the basic FRIC definition

$$CFZLZ_{k+1/2} = CFZVZ_{k+1/2} = \frac{K_{k+1/2}D_{k+1/2}}{(\Delta Z_k + \Delta Z_{k+1})}, \tag{4-141}$$

where $K_{k+1/2}$ and $D_{k+1/2}$ are the input-specified K-factor irreversible form loss and hydraulic diameter of interface *k+1/2*, and $Z_k$ and $Z_{k+1}$ are the z-direction cell lengths on each side of the *k+1/2* interface.

TRACE requires that positive additive-friction-loss coefficients be input for interfaces between cells where the change in the VOL/DX average flow area (where $DX = \Delta Z$, $\Delta Y$ or $R\Delta\theta$, and $\Delta X$ or $\Delta R$ for a VESSEL cell, and $DX = X$ for a 1D hydraulic component cell) is greater than a factor of 2.0 or less than a factor of 0.5. An irreversible form loss must be input either by specifying CFZL# < 0.0 (# represents *Z*, *YT*, or *XR*) with the negative sign flagging TRACE to internally evaluate an abrupt flow-area-change irreversible form loss (like that done by NFF for 1D hydraulic components) and/or by specifying an additive-friction-loss coefficient, |CFZL#| > 0.0 and CFZV# > 0.0. This is defined in Volume 1 by the additive-friction-loss coefficient input data for the VESSEL component and discussed in the TRACE Theory Manual.

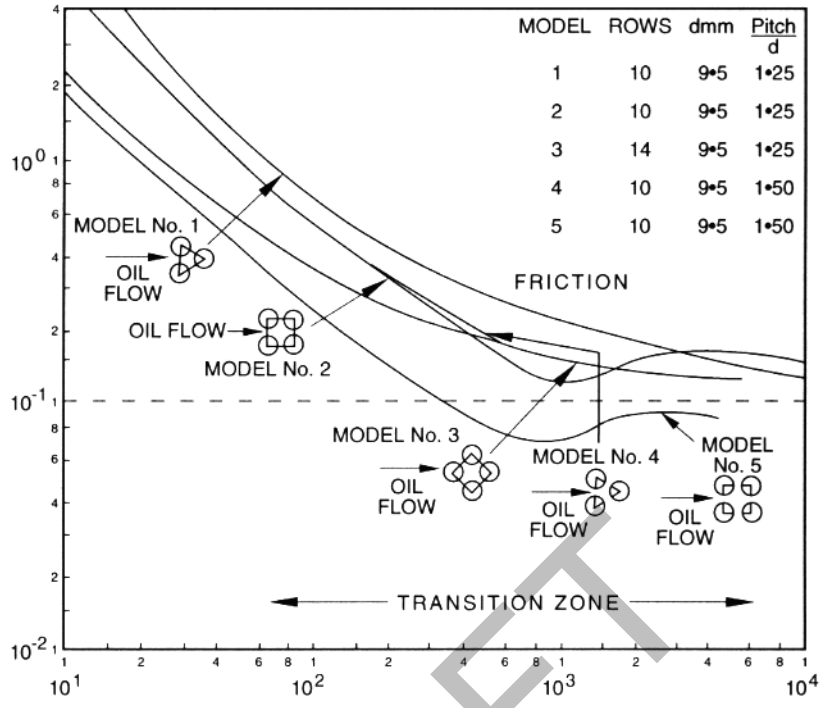



Figure. 4-108. Special friction factor $f_{dt}$ for cross flow in rod bundles (Ref. 4-36).





# *Heat-Structure Components*

Heat transfer in fuel rods and structural hardware, thermally coupled to the fluid in the hydraulic components, can be modeled using the HTSTR (heat-structure) component. Reactor core to downcomer heat transfer in a VESSEL can be modeled because the HTSTR component provides a two-sided conductor with each side thermally coupled to a different hydraulic cell. The VESSEL outer wall can now be modeled with external heat-transfer losses to the environment. Thermal analysis of the cylindrical wall of 1D hydraulic components either may be evaluated by those components or by a HTSTR component with more flexibility in modeling. Note that neither heat-transfer calculation can be done for a BREAK, FILL, or PLENUM component.

The HTSTR component is discussed in **Chapter 2**. In this section, we present some guidelines for geometric modeling, use of the core-reflood option, and specification of neutronics.

## *Geometry*

Heat structures in TRACE are modeled by the geometry of a HTSTR component. HTSTR components can have a Cartesian, cylindrical, or spherical geometry. A cylindrical HTSTR may be a hollow annular region so that pipe and vessel outer walls, or the wall separating the vessel core or steam-generator boiler and their downcomer, can be modeled. Other structural

components may be modeled by HTSTRs in Cartesian geometry. In evaluating energy exchange by heat transfer between the fluid and structure, two basic criteria are satisfied. First, the available energy content of all structural materials and the fluid within a cell must be conserved. Second, during a transient analysis, the rate at which the available energy is exchanged between the fluid and the structural material as predicted via the TRACE model should match the actual physical rate that would occur.

Both of these requirements can be accomplished by proper input specifications. A method for preparing HTSTR input specifications is presented in this section. The method is divided into two general categories. The first category describes the procedure to be used if a Cartesian HTSTR element consists of only one structural material. The second category describes the procedure to be used if several structural materials are to be combined into one Cartesian HTSTR element.

## *Single Structural Material*

Regardless of the shape of the structural material, the volume (or portion of the volume) of the material that is within a cell must be determined. The user can then follow one of two options depending upon the actual shape of the material. The user can choose to conserve volume and the characteristic thickness (i.e., distance to an adiabatic surface) of the component and calculate the corresponding heat-transfer area if the characteristic thickness is well defined. The user also can conserve volume and heat-transfer area, and calculate the corresponding characteristic thickness if the characteristic thickness is not well defined. In either case, the volume of the material within a cell must be conserved, and the following relationship maintained:

$$V = A \cdot L\,, \tag{4-142}$$

where

$V$ = volume of single material within a cell,
$A$ = heat-transfer area, and
$L$ = characteristic thickness distance to an adiabatic surface.

The area of a slab is defined in TRACE as the product of the height (of the hydraulic cell) and width (WIDTH) specified by the user. This area must equal A. The thermal diameters of the inner and outer surfaces are input as HDRI and HDRO, and the slab thickness is (HDRO – HDRI)/2. If this value is equal to L, the surface boundary conditions should be input as IDBCI = 2 (surface coupled to a hydraulic cell) and IDBCO = 0 (adiabatic boundary condition).

For a single material, conserving volume is analogous to conserving available heat content of the material. Using the characteristic distance to an adiabatic surface maintains the proper time constant for energy exchange.

For most cases where the characteristic thickness is well defined, the flexibility of the HTSTR component allows a straightforward approach. For the wall of a vessel, for example, you simply input the correct geometry (WIDTH, HDRI, and HDRO) and specifiy IDBC1 = 2 (inner surface

connected to a hydraulic cell) and IDBCO = 1 (user-specified ambient temperature and film coefficient) at the outer surface.

As an example in which the characteristic thickness is not well defined, consider the circular flow-skirt baffle in a PWR vessel. The volume of the baffle is calculated to be 1.8768E-01 $m^3$ and has a surface area of 1.5488E+01 $m^2$. The thickness of the baffle wall is 3.175E-02 m and has 981 holes of 7.3025E-02 m diameter spaced evenly about the skirt. The average distance to an adiabatic surface is not well known. Hence, the second approach of conserving volume and area would be most appropriate. The characteristic thickness would be calculated from

$$L = 1.8768\text{E-}01\ \mathrm{m}^3 / 1.5488\text{E+}01\ \mathrm{m}^2 = 1.2118\text{E-}02\ \mathrm{m} \tag{4-143}$$

and, for six symmetric azimuthal cells, the corresponding surface area per cell would be

$$A = 1.5488\text{E+}01\ \mathrm{m}^2 / 6 = 2.5813\text{E+}00\ \mathrm{m}^2 \tag{4-144}$$

## *Several Structural Materials*

If several structural materials are associated with one computational cell, an accurate slab model becomes more difficult to define. One useful technique first defines an effective volume, V:

$$V = \frac{1}{\rho \cdot C_p} \sum_i \rho_i \cdot C_{p,i} \cdot V_i, \tag{4-145}$$

where the sum includes all material structures within the computational cell, and ρ and $C_p$ are the input-specified density and specific heat (typically equal to those of one of the cell materials). The rate of energy exchange between the fluid and the structures then may be modeled by calculating a characteristic thickness, *L*. The *L* value for an important time during the transient under consideration may be obtained from the transcendental equation

$$\rho c_p V \left( 1 - \sum_n^N D_n e^{-\gamma_n^2 Fo} \right) = \sum_i \rho_i c_{pi} V_i \left[ \sum_n^N D_{ni} e^{-\gamma_{ni}^2 Fo_i} \right]. \tag{4-146}$$

This equation represents a series solution (composed of N terms) to the transient 1D conduction heat-transfer equation. In this equation *Fo* is the Fourier Number,

$$Fo = (\alpha t) / L^2, \tag{4-147}$$

where $\alpha = k / (\rho C_p)$. The $\gamma_n$ is a constant obtained from the transcendental equation,

$$\gamma_n = \gamma_n \tan(\gamma_n) = Bi, \tag{4-148}$$

where $Bi = h\,L\,/\,k$ is the Biot number, and

$$D_n = \frac{2\sin^2\gamma_n}{(\gamma_n^2 + \gamma_n \sin\gamma_n \cos\gamma_n)}, \tag{4-149}$$

where $\alpha$, $k$, and $h$ are the material thermal diffusivity, material thermal conductivity, and the convective heat transfer coefficient, respectively. The right side of the transcendental equation is the total energy exchange for the time interval the user selects as appropriate for his problem for each structure (i). The left side is the energy exchange for the effective slab. Again, the material and thermal properties for the effective slab are specified by the user. With the effective length L determined from the transcendental equation, the calculated volume for all structures in the cell, $V$, and the user-specified properties, the remaining variable, the $A$ surface area per cell, may be calculated by $A = V/L$.

The user has four options for calculating conduction in a HTSTR component. These are (1) a lumped-parameter solution, (2) an implicit x or r calculation with no axial heat transfer, (3) a x- or r-implicit axial-explicit calculation, and (4) a fully-implicit 2D (x,z) or (r,z) calculation. These are listed in the order of increasing complexity and computational cost. The user should select the simplest method consistent with the required accuracy. If the temperature distribution is unimportant but the thermal storage capacity of a structure is judged to be significant, the lumped-parameter solution may be sufficient. If the radial temperature is important but the axial heat transfer is not likely to be significant (e.g., no reflood), the x- or r-implicit calculation with no axial conduction should be chosen. For cases with reactor-core reflood, one of the last two cases should be selected. The fully implicit (x,z) or (r,z) calculation should be used for solid fuel rods when reflood or uncovering is likely to occur. Note that the fully implicit method cannot be used for hollow HTSTRs having different boundary conditions on its two surfaces. For those cases, the x- or r-implicit axial-explicit calculation may be the best choice. The fully implicit method can be applied to a HTSTR that is connected to only one hydraulic cell if symmetry considerations are used and a connection to only one hydraulic cell is applied as a boundary condition. For this case, the specified slab thickness is one half the actual thickness, and the surface area is twice the surface area of one side of the HTSTR.



# *Reactor-Core Reflood*

TRACE contains a unified heat transfer package that includes models for reflood heat transfer. The term 'unified' is used because from the user's standpoint, there is no special set of physical models that you need to arrange for TRACE to use when you expect reflood to occur (seasoned TRAC users may recall the need to create a special fine mesh and reflood trip that would act as the code's cue to use the special core reflood heat transfer package).

A correctly predicted thermal response from the fuel rods during core reflood requires a numerical technique that can model the rewetting phenomena associated with the quench-front motion. The leading edge of the rewetting region is characterized by large variations of temperatures and heat fluxes within small axial distances. To model these steep thermal gradients, supplemental rows of conduction nodes are inserted in the HTSTR's fuel-rod model by using the fine-mesh rezoning option by setting its FMON flag to a nonzero value. The rows are uniformly spaced within each fluid cell. These transitory nodes are added whenever the temperature difference between adjacent fuel-rod surface nodes exceeds a value based on the heat transfer regime and the wall superheat. The user input parameters that define the geometry of the fine-mesh noding are NFAX, the number of fine-mesh intervals per (cell) coarse-mesh interval added at the start of evaluating the fine-mesh noding option; DZNHT, the minimum axial spacing below to which no additional renoding is added; and NZMAX, the maximum number of additional nodes related to NFAX and the number of reactor-core region axial (cells) levels. The recommended user input parameters defining the fine-mesh noding are:

$$\text{DZNHT} = 1.0\text{E-}03\ \text{m}\,, \text{ and} \tag{4-150}$$

$$\text{NZMAX} = 100 \text{ to } 250\,. \tag{4-151}$$

If NZMAX is chosen too small, propagation rates of the quench front have been observed to be inconsistent. The model runs out of available fine-mesh node rows and has to wait until some nucleate-boiling region node rows are eliminated. This elimination and reinsertion into the film-boiling region have a significant effect on the thermal response of the calculation.

The conduction heat-transfer calculation in the axial direction could be performed as implicit or explicit. If NAMELIST variable NRSLV is set to 1, the axial-conduction heat-transfer calculation is implicit; otherwise, a NRSLV = 0 default option explicit calculation is used to evaluate axial conduction. NRSLV = 1 is recommended.

The user should select the characteristic length of the structure (the hydraulic diameter HDRO) as the hydraulic diameter of the rod-bundle unit cell. The hydraulic diameter for the hydraulic cells should consider all of the wetted surfaces.

## *Reactor-Core Fuel Rods*

The total power level in the HTSTR-component in the reactor core may be specified by one of two methods. In the first method, the user specifies the total power to be constant or defined by a power component-action table. The table is a tabular function of a system signal-variable or control-block independent-variable parameter. Values between data entry pairs in the table are determined by linear interpolation with no extrapolated evaluated beyond the defined range of the table. The total power determination can be trip controlled by evaluating the power table when the controlling trip is ON and by not evaluating the power table and holding the power constant when the trip is OFF.

In the second point-reactor kinetics method, TRACE determines the total prompt-fission power from the solution of the point-reactor kinetics equations. These equations define the time behavior of the reactor-core fission power level with neutronic reactivity (the sum of programmed and feedback reactivities) as the driving function. The user specifies programmed reactivity to account for reactivity effects not accounted for by feedback reactivity such as control-rod movement. TRACE evaluates feedback reactivity based on changes in the core-averaged fuel temperature, coolant temperature, gas volume fraction, and dissolved and plated solute (boron) concentration. The total thermal power generated in the reactor core is the sum of prompt fission, fission-product precursor decay, and delayed fission.

The required input data for the second method are the NDGX number of delayed-neutron groups, the delayed-neutron BETA and LAMBDA constants for each delayed-neutron group, the NDHX number of decay-heat groups, the decay-heat LAMDH and EDH constants for each decay-heat group, and the NHIST number of entry-pair values in the PHIST power-history table or the CDGN initial delayed-neutron precursor and CDHN decay-heat precursor power concentrations. If NDGX ≤ 0 is input, TRACE internally defines the 6-group delayed-neutron constants presented in the TRACE/F90 Theory Manual. If NDHX ≤ 0 is input, TRACE internally defines the 69-group decay-heat constants presented in the TRACE/F90 Theory Manual. If both NDGX ≤ 0 and NDHX ≤ 0 and no prompt-fission power history is input with NHIST = 0, TRACE assumes that initially steady-state conditions exist to initialize the CDGN and CDHN precursor power concentrations internally in TRACE based on the initial power, RPOWRI. The above internally defined data used in TRACE closely approximate the standard American Nuclear Society decay-heat curve (Ref. 4-39).

The Westinghouse three-loop full-plant model in Appendix A uses IRPWTY = 4, which selects the option to calculate the reactor-core power based on the point-reactor kinetics equations with a trip-controlled programmed-reactivity table. NDGX = 0 and NDHX = 0, so the TRACE internally-defined 6-group delayed-neutron constants and 69-group decay-heat constants are used. In this example, the thermal-hydraulic feedback-reactivity contribution is not calculated because 10 needs to be added to IRPWTY to evaluate reactivity feedback. With NDGX = 0, NDHX = 0, and NHIST = 0, the CDGN and CDHN precursor power concentrations are defined internally in TRACE based on the RPOWRI initial steady-state power level.

The reactivity-feedback model for the point-reactor kinetics equations is based on the assumption that only changes in the reactor-core-averaged fuel temperature, coolant temperature, gas volume fraction, and dissolved and plated solute (boron) concentration affect the neutron-multiplication reactivity of the reactor core. The user specifies a reactivity coefficient for each of these reactivity-feedback parameters by choosing one of the reactivity-coefficient forms in the TRACE/F90 Theory Manual. Each reactivity coefficient is defined through input by a table of reactivity-coefficient values that are dependent on 0, 1, 2, 3, or all 4 reactivity-feedback parameters. Determining the feedback-reactivity contribution to the total reactivity can be complex. Reaction-rate, cross-section generation and multidimensional, neutron-diffusion software programs are needed to evaluate the reactivity coefficients directly. Reactivity coefficients for the initial reactor-core condition usually are provided in the safety analysis report for the reactor plant. We encourage you to review the TRACE/F90 Theory Manual for additional information about this analytical model and its many options.

There are two types of user-specified fuel rods in TRACE: the "average" fuel rods and the "additional" supplemental fuel rods. One average fuel rod is associated with each fluid-cell axial stack within the reactor-core region. Only the average fuel rod is coupled thermally to its surrounding coolant. The thermal power generated within the reactor core is transferred to the coolant from the average rods. The additional supplemental fuel rods permit the user to apply power peaking factors to rods other than the average rods to determine power-peaking temperature condition. Such supplemental fuel rods base their heat-transfer calculation on the fluid condition determined by the average fuel rod but do not affect the thermal-hydraulic condition of the reactor core.

The spatial power-density distribution in the reactor core is specified by separate fuel-element, horizontal-plane, and axial power-density shapes that are superimposed. These spatial distributions ensure that the local power density is correct in magnitude relative to the power density elsewhere in the reactor core. Their shapes are held constant throughout the calculation except for the axial-power shape, which can be defined by a table of shapes with dependence on a signal-variable or control-block parameter. For example, the axial power-density shape can vary during the calculation as a function of the programmed reactivity of control-rod movement or the gas volume fraction liquid-voiding of the reactor core.





The power density in fuel-element node i, horizontal-plane relative cell j, and axial level cell k is given by the expression,

$$P(i,j,k) = S \cdot POWAVG \cdot RDPWR(i) \cdot CPOWR(j) \cdot ZPWTB(k), \tag{4-152}$$

where POWAVG = (RPOWR($t^n$) + RPOWR($t^{n+1}$))/2 is the approximate average total reactor-core power level between times $t^n$ and $t^{n+1}$ of timestep n+1 (initially POWAVG = RPOWRI), RDPWR(i) is the relative power density in fuel-element node i, CPOWR(j) is the relative power density in horizontal-plane relative cell j, ZPWTB(k) is the relative power density in axial-level cell *k*, and *S* is a TRACE calculated scale factor that normalizes the three superimposed relative power density shapes over the volume of the reactor core to a total power of POWAVG:

$$S = 1/\sum_{i,j,k} RDPWR(i) \cdot CPOWR(j) \cdot ZPWTB(k) \cdot Volume(i,j,k). \tag{4-153}$$

All three user-specified power-density shapes are normalized after input to have a spatially average value of unity.

$$1.0 = \sum_i RDPWR(i) \cdot Volume(i) / \sum_i Volume(i), \tag{4-154}$$

$$1.0 = \sum_j CPOWR(j) \cdot Volume(j) / \sum_j Volume(j), \text{ and} \quad (4\text{-}155)$$

$$1.0 = \sum_k ZPWTB(k) \cdot Volume(k) / \sum_k Volume(k). \quad (4\text{-}156)$$

For the analysis of supplemental fuel rods, the average fuel rod power density $P(i,j,k)$ is multiplied by a specified power-peaking factor RPKF($j$) to obtain the power density for the supplemental fuel rod in horizontal-plane relative cell $j$.

Historically, when defining the reactor-core power directly rather than evaluating the point-reactor kinetics equations, the fission power after a control-rod insertion scram has been ignored for a TRAC–P LBLOCA calculation. The historical approach is to delay scram for some fixed amount of time and then, after scram, to decrease the power to the fission-product decay power, as predicted by the 1979 ANS decay-heat standard (Ref. 4-39). According to Reference 4-40, the thermal-neutron flux, which is proportional to the fission power, can be approximated after a scram at $t = 0$ by a prompt drop to

$$\overline{\Phi}_T(t) \rightarrow \frac{\beta}{\beta - \rho_s} \cdot \Phi_T(0) \quad (4\text{-}157)$$

where

$\overline{\Phi}_T(0)$ = steady-state reactor-core-averaged thermal-neutron flux,

$\overline{\Phi}_T(t)$ = reactor-core-averaged thermal-neutron flux after scram,

$\beta$ = delayed-neutron fraction, and

$\rho_s$ = scram reactivity, where $\rho_s < -\beta < 0$,

followed by an ~80.0 s thermal-neutron flux decay. For a large scram reactivity where $\rho_s \rightarrow -1.0 + \beta$, $\overline{\Phi}_T(t)$ can be approximated by $\beta \cdot \overline{\Phi}_T(0)$. The delayed-neutron fraction for a typical US PWR is $\beta$ = ~0.0065. Therefore, the fission power after a scram is on the order of 0.65% of the steady-state power level before a large-reactivity scram. After scram, the fission-product decay power is initially ~6% of the steady-state power level. Neglecting the fission power after a scram results in an ~10% error in the total power level immediately after a scram. Of course, this error decays away after ~80.0 s. For a best-estimate analysis of LBLOCAs, the peak cladding temperature typically occurs early during the blowdown; therefore, correct modeling of the early transient power can be important.

**Table 4-47. Typical US PWR Reactor-Kinetics Parameters**

| | |
|---|---|
| Coolant-temperature coefficient, $(\Delta k/\Delta T_m)$ = | $-1.6667E-05\ K^{-1}$ |
| | $(-3.0000E-05°F^{-1})$ |
| Fuel-temperature doppler coefficient, $\Delta k/\Delta T_f$ = | $-9.4444E-06\ K^{-1}$ |
| | $(-1.7000E-05°F^{-1})$ |
| Gas volume fraction coefficient, $\Delta k/(k\Delta\ \alpha_g)$ = | –1.8500E-02 |
| Prompt-neutron lifetime, $\Lambda_p$ = | 2.0000E-05 s |

Scram Reactivity as a Function of Time after the Scram Signal

| Time After Scram Signal (s) | Inserted Control-Rod Reactivity Worth $\rho_s$ (–) |
|---|---|
| 0.1 | 0.0 |
| 0.4 | –0.0003515 |
| 0.8 | –0.000723 |
| 1.2 | –0.003615 |
| 1.6 | –0.013737 |
| 2.0 | –0.06 |
| 2.4 | –0.0723 |
| inf. | –0.0723 |





To estimate the magnitude of this error, a TRAC-P 1D reactor-core model was developed for a typical US PWR. This model was driven with transient boundary conditions obtained from the TRAC-PF1 analysis given in Reference 4-41. Two calculations were performed: one with the power specified as a function of time assuming a 0.5 s delay in the scram and no fission power after scram, and the other with a point-reactor kinetics calculation. The input data for the point-reactor kinetics with reactivity feedback model, which were obtained from References 4-42 and 4-43, are listed in Table 4-47.

The transient reactor-core total power for both calculations is given in Figure 4-109. For the point-reactor kinetics calculation, control-rod movement begins at 0.1 s; however, the power begins to decrease immediately because of blowdown voiding in the reactor core. At about 0.5 s, the reactor core essentially has lost its liquid coolant and is dried out, so no additional negative reactivity can be added to the reactor core because of coolant voiding. Decreasing fuel and moderator temperatures add positive reactivity to the reactor core and, from 0.5 s to 1.0 s, the reactor-core power tends to stabilize. After ~1.0 s, the control-rod movement scram reactivity

becomes large enough to cause the reactor-core power to start decreasing again. Even after ~2.0 s, fission power is a significant fraction of the total power.

The effect of these two transient reactor-core powers is illustrated in Figure 4-110 for the reactor-core midplane cladding temperature. The point-reactor kinetics calculation results in a slightly higher peak cladding temperature and a slightly higher heating rate after the peak. This result is not surprising when the integrated powers (total fuel-rod energy generation) in Figure 4-111 are compared. The user-specified power-vs-time calculation begins with more fuel-rod energy generation because of the ~0.5 s delay in scram. However, the point-reactor-kinetics calculated fuel-rod energy generation overtakes the power-vs-time calculated fuel-rod energy generation at ~1.5 s because of fission power generated after scram. .

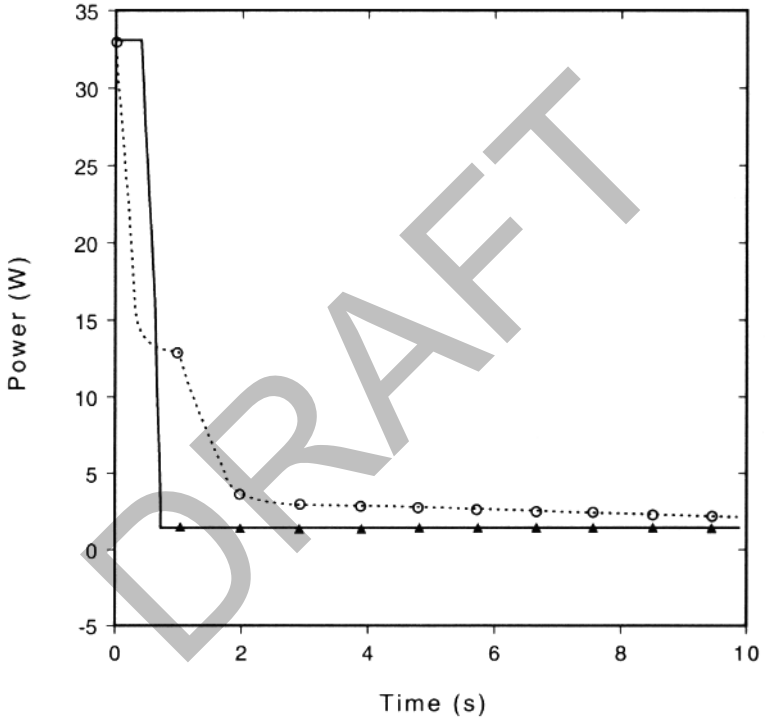





Figure. 4-109. Transient reactor power for the power-vs-time calculation (solid line) and the point-reactor kinetics calculation (dashed line).

This TRAC–P point-reactor kinetics calculation used the 1979 ANS decay-heat standard and the TRAC–P point-reactor kinetics solution with reactivity feedback (the same models are in TRACE). This was accomplished by using the 23 decay-heat groups for $^{235}U$ fissions given in Reference 4-39. The 23 decay-heat groups in TRAC-consistent units are given in Table 4-48. To verify that TRAC–P reproduced the 1979 ANS decay-heat standard accurately, a TRAC–P calculation was performed with essentially no fission power so that the calculated power was the decay-heat power only. In Table 4-49, the TRAC–P calculation is compared with the infinite operating-period example in the ANS 5.1 standard. From this comparison, it is apparent that TRAC–P was reproducing the ANS 5.1 decay-heat power vs time accurately.

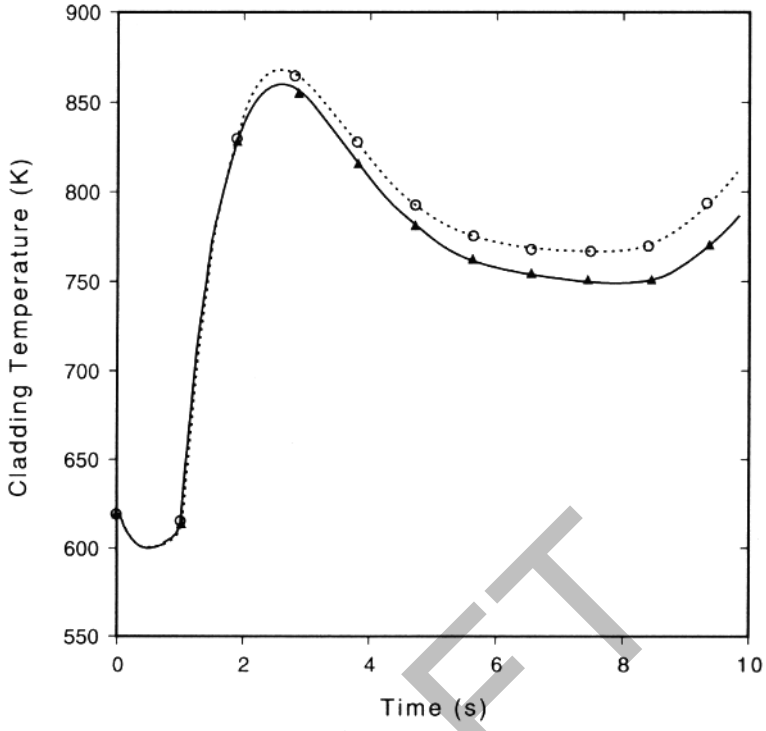



Figure. 4-110. Cladding temperature at the reactor-core midplane for the power-vs-time calculation (solid line) and the point-reactor kinetics calculation (dashed line)





Also, the TRAC-P (and TRACE) method for initializing the decay-heat group precursor concentrations for a finite operating period is consistent with the 1979 ANS decay-heat-standard method for finite operating periods. Again, a TRAC–P calculation with decay heat only was evaluated using the operating history given in Table 4-50. In Table 4-51, the TRAC–P results are compared with the results given in the 1979 ANS decay-heat standard for the same problem. Again, the comparison is excellent.

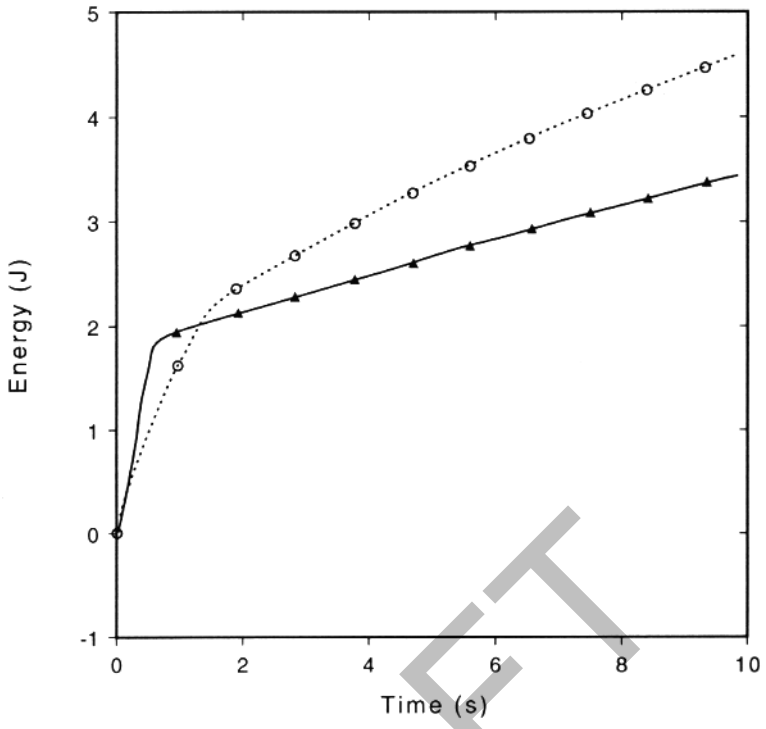



Figure. 4-111. Integrated reactor power for the power-vs-time calculation (solid line) and the point-reactor kinetics calculation (dashed line).



**Table 4-48. Expanded Set of Decay-Heat Constants**

| Group j | Decay Constant $\lambda_j^H$ ($s^{-1}$) | Energy Fraction $E_j$ |
|---|---|---|
| 1 | 2.2138E+01 | 1.4694E-04 |
| 2 | 5.1587E-01 | 4.9687E-03 |
| 3 | 1.9594E-01 | 6.2223E-03 |
| 4 | 1.0314E-01 | 6.7142E-03 |
| 5 | 3.3656E-02 | 8.2363E-03 |
| 6 | 1.1681E-02 | 9.5133E-03 |
| 7 | 3.5780E-03 | 4.6122E-03 |
| 8 | 1.3930E-03 | 3.3387E-03 |
| 9 | 6.2630E-04 | 6.4620E-03 |
| 10 | 1.8906E-04 | 5.1748E-03 |
| 11 | 5.4988E-05 | 2.9584E-03 |
| 12 | 2.0958E-05 | 1.8035E-03 |
| 13 | 1.0010E-05 | 1.2603E-03 |
| 14 | 2.5438E-06 | 9.8176E-04 |
| 15 | 6.6361E-07 | 1.3962E-03 |
| 16 | 1.2290E-07 | 1.0825E-03 |
| 17 | 2.7213E-08 | 4.1153E-04 |

**Table 4-48. Expanded Set of Decay-Heat Constants**

| Group j | Decay Constant $\lambda_j^H$ ($s^{-1}$) | Energy Fraction $E_j$ |
|---|---|---|
| 18 | 4.3714E-09 | 9.3381E-06 |
| 19 | 7.5780E-10 | 5.7290E-04 |
| 20 | 2.4786E-10 | 5.0696E-07 |
| 21 | 2.2384E-13 | 7.1873E-06 |
| 22 | 2.4600E-14 | 9.1540E-06 |
| 23 | 1.5699E-14 | 2.3820E-05 |

**Table 4-49. Comparison of TRAC-P Decay Power to ANS 5.1 Decay Power for Infinite Operating Period**

| Time (s) | TRAC-P P(t)/P(0) | ANS 5.1 P(t)/P(0) |
|---|---|---|
| 1.0 | 0.06151 | 0.06155 |
| 2.0 | 0.05843 | 0.05845 |
| 4.0 | 0.05415 | 0.05415 |
| 8.0 | 0.04916 | 0.04915 |
| 10.0 | 0.04748 | 0.04747 |
| 20.0 | 0.04230 | 0.04228 |
| 40.0 | 0.03732 | 0.03730 |
| 80.0 | 0.03249 | 0.03247 |
| 100.0 | 0.03102 | 0.03099 |



**Table 4-50. Typical Operating History**

| Operating Period (days) | Power (MW) |
|---|---|
| 300.0 | 3315.0 |
| 60.0 | 0.0 |
| 300.0 | 3315.0 |
| 60.0 | 0.0 |
| 300.0 | 3315.0 |

**Table 4-51. Comparison of TRAC-P Decay Power To ANS 5.1 Decay Power for Finite Operating Period**

| Time (s) | TRAC-P P(t)/P(0) | ANS 5.1 P(t)/P(0) |
|---|---|---|
| 1.0 | 0.06082 | 0.06090 |
| 10.0 | 0.04679 | 0.04681 |
| 100.0 | 0.03033 | 0.03033 |

The effect of neutron capture in fission products is to increase the fission-product decay heat by a small factor that ranges from 1.00 to 1.13 depending upon the time after shutdown and the operating history before shutdown. In the ANS 5.1 standard, a formula for calculating this factor [G(t,T)] is given as

$$G(t,T) = 1.0 + (3.24\times10^{-6} + 5.23\times10^{-10}\,t)\,T^{0.4}\,Y, \tag{4-158}$$

where

G(t,T) = neutron-capture effect ratio,

t = time after shutdown (s), $t < 10^4$ s,

T = operating period (s), $T < 1.26 \cdot 10^8$ s, and

Y = fissions per initial fissile atom, $Y < 3.0$.

This equation cannot be implemented into TRACE through input; however, a conservative approximation can be obtained by using Table 4-52, which was obtained from Reference 4-39. Given the length of the transient to be evaluated after shutdown, the G(t) factor can be estimated from Table 4-52 and applied uniformly to the $E_j$s for the 23 decay-heat groups in Table 4-48.

Heavy-element decay heating also can be included in a TRACE point-reactor kinetics model. According to ANS 5.1, heavy-element decay heating is

$$\frac{P_{HE}(t,T)}{P(0)} = \frac{R}{Q}\left\{E_{24}[1-e^{-\lambda_{24}T}]e^{-\lambda_{24}T} + E_{25}\left[\frac{\lambda_{24}}{\lambda_{24}-\lambda_{25}}(1-e^{-\lambda_{25}T})e^{-\lambda_{25}T} - \frac{\lambda_{25}}{\lambda_{24}-\lambda_{25}}(1-e^{-\lambda_{24}T})e^{-\lambda_{24}T}\right]\right\} \tag{4-159}$$

where

$P_{HE}(t, T)$ = heavy-element decay power at time $t$ after shutdown for a reactor core operating at power $P(0)$ for length of time $T$,

$R$ = number of $^{239}$U atoms produced per fission (0.4 to 0.9),

$Q$ = 200 MeV per fission,

$E_{24}$ = available decay energy from a single $^{239}$U atom (0.474 MeV),

$E_{25}$ = available decay energy from a single $^{239}$Np atom (0.419 MeV),

$\lambda_{24}$ = decay constant for $^{239}$U ($4.91 \times 10^{-4}$ s$^{-1}$), and

$\lambda_{25}$ = decay constant for $^{239}$Np ($3.41 \times 10^{-6}$ s$^{-1}$).

The previous equation can be rewritten in a form consistent with the TRACE decay-heat model,

$$\frac{P_{HE}(t,T)}{P(0)} = \frac{R}{Q}\left[E_{24} - E_{25}\frac{\lambda_{24}}{\lambda_{24}-\lambda_{25}}\right][1-e^{-\lambda_{24}T}]e^{-\lambda_{24}t} + \frac{R}{Q}\left[E_{25}\frac{\lambda_{24}}{\lambda_{24}-\lambda_{25}}\right][1-e^{-\lambda_{25}T}]e^{-\lambda_{25}t}. \tag{4-160}$$

Evaluation of this equation yields two additional decay-heat groups that are listed in Table 4-53. From Table 4-53, it is apparent that the $E_j$s for these two groups still are dependent upon R. The parameter R is a function of initial fuel enrichment and fuel

**Table 4-52. Ratio of Decay Heat with Neutron Absorption to Values w/o Absorption for $^{235}U$ Thermal Fissions for Four Years of Operating History with Typical LWR Neutron Spectrum**

| Time After Shutdown (s) | G(t) (–) |
|---|---|
| 1.0 | 1.02 |
| 10.0 | 1.022 |
| 100.0 | 1.023 |
| 1000.0 | 1.033 |
| 10000.0 | 1.064 |
| 100000.0 | 1.124 |

exposure and should be determined for the specific reactor core that the calculation will simulate.

If the user wants to perform a calculation with the ANS decay-heat curve plus 20%, then the $E_j$s given in Table 4-48 and Table 4-53 should be multiplied by 1.20 and input to TRACE. Two TRAC-P calculations were performed to verify this method. The transient fission-product decay power from a TRAC–P calculation that uses the 23 groups in Table 4-48 and the 2 groups in Table 4-53 is given in Figure 4-112. The results from using 1.2 times the $E_j$s for the 23+2 decay-heat groups is plotted in Figure 4-113. The transient fission-product decay-heat power after scram at time zero is divided by the initial reactor-core power plotted in both Figure 4-112 and Figure 4-113. The results using 1.2 times the $E_j$s were divided by the results using the $E_j$s and plotted in Figure 4-114. From Figure 4-114, it can be seen that this method yields the ANS decay heat plus 20%. Also note that this method is independent of the initial reactor-core power level.





**Table 4-53. TRACE Input for the Heavy Element Decay Heat Groups**

| j | Energy Fraction $E_j$ | Decay Constant $\lambda_j^H$ ($s^{-1}$) |
|---|---|---|
| 24 | 2.3553E-03 | 4.91E-04 |
| 25 | 2.1097E-03 | 3.41E-06 |

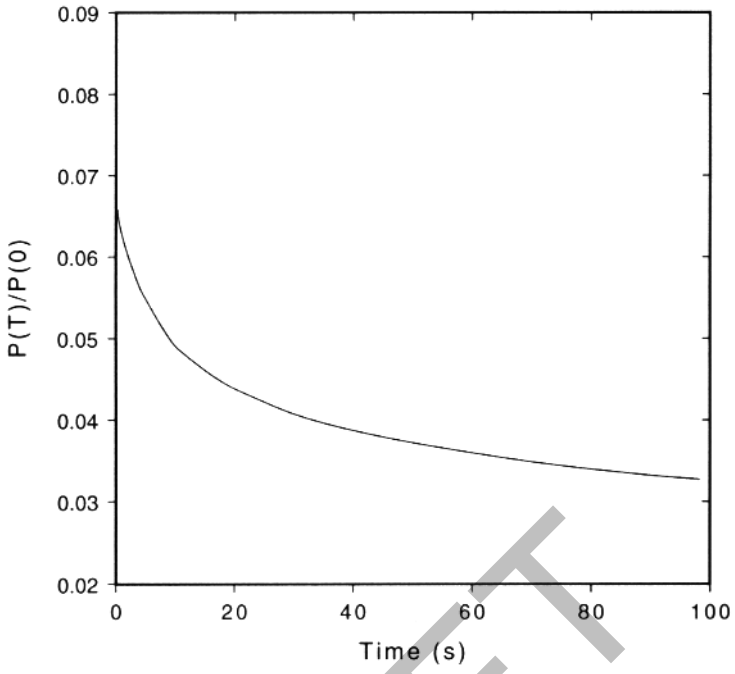



Figure. 4-112. TRAC–P calculated ANS power curve.

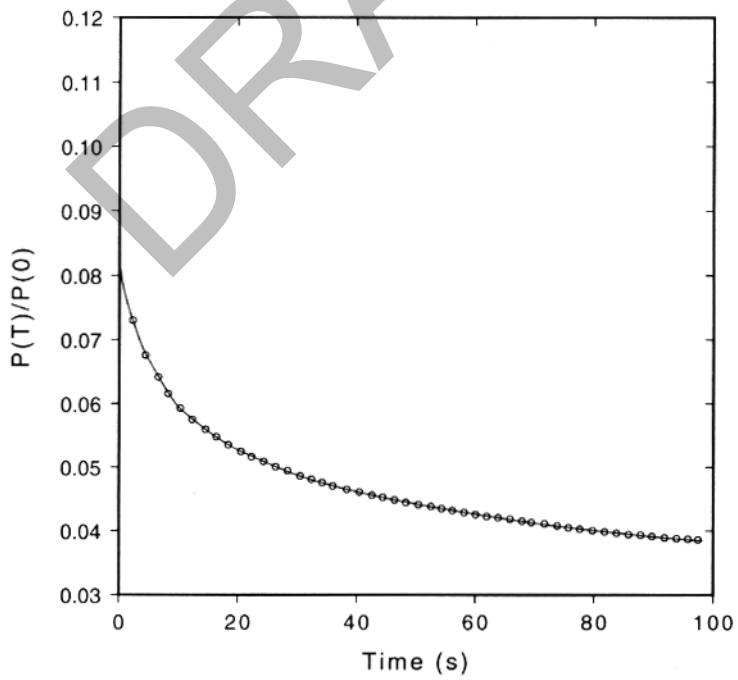



Figure. 4-113. TRAC–P calculated 1.2 times ANS power curve.

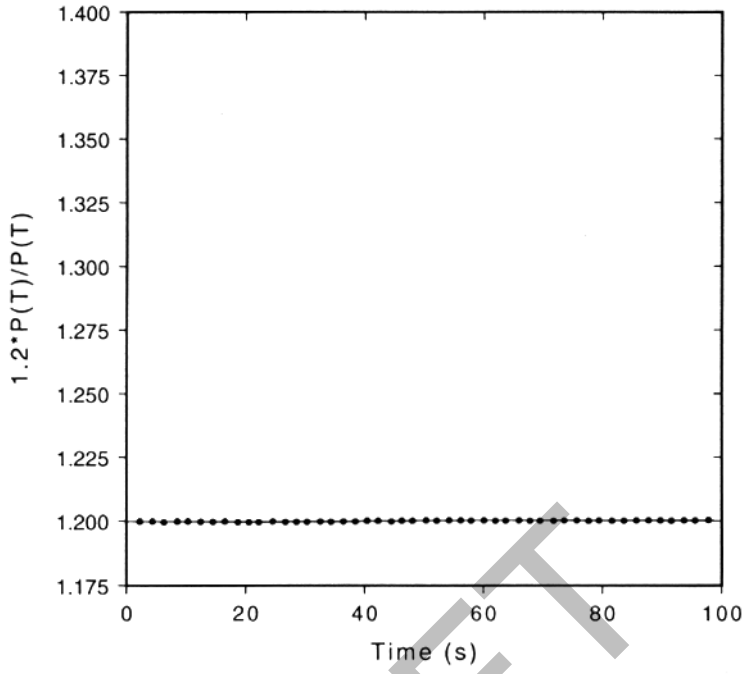



Figure. 4-114. Ratio of the TRAC–P 1.2 times ANS divided by ANS power curve.





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# A

# *Sample Calculation Notes*

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| DB No. | Description | Sender | Date | Volume |
|---|---|---|---|---|
| 1 | Training notes by plant personnel from plant visit (date) | Utility | Date 1 | I |
| 2 | Steam-dump-control notes from plant visit | Utility | Date 2 | I |
| 3 | Utility letter on homogeneous number-density calculations for fuel-cycle calculations. | NRC | Date 4 | Filed separately |
| 4 | Updated FSAR | NRC | Date 4 | Filed separately |
| 5 | P&IDs and Logic Diagrams. See Table A-2 for a listing | Utility | Date 5 | Filed separately |
| 6 | Utility letter dated x/x/xx documenting information transmitted. Also enclosed - plant information on FW heater 4 and Q & A on steam generator (SG) and Vessel | Utility | Date 6 | 1 |
| 7 | System Descriptions. See Table A-3 and Table A-4 for listings of relevant information. | NRC | Date 7 | I&II |
| 8 | Precautions, Limitations, and Set Points | NRC | Date 8 | II |
| 9 | Plant Isometric Sketches | NRC | Date 9 | III |

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| | | | | |
|---|---|---|---|---|
| | 1) SG blowdown system<br>2) Chemical and volume control system<br>3) Primary coolant system<br>4) Feedwater system<br>5) Main steam system<br>6) Auxiliary feed steam system<br>7) Safety-injection system<br>8) Residual heat removal system | | | |
| 10 | Reactor pressure vessel manual (parts) | NRC | Date 10 | III |
| 11 | Pressurizer manual (parts) | NRC | Date 10 | III |
| 12 | Net unit heat rates report | NRC | Date 10 | III |
| 13 | Revised sketch of instrument and station air from EDS Nuclear work | NRC | Date 10 | III |
| 14 | New condenser data and curves | NRC | Date 10 | III |
| 15 | Moisture separator reheater data | NRC | Date 10 | III |
| 16 | Feedwater heater data on the original heaters 1, 2, and 5, and on the new feedwater heaters 3 and 6 | NRC | Date 10 | III |
| 17 | Pump curves for:<br>1) A&B condensate pumps<br>2) A&B heater-drain-tank pumps<br>3) A&B feedwater pumps | NRC | Date 10 | III |
| 18 | Drawing xxx xxxx on the reactor vessel | NRC | Date 10 | III |
| 19 | Telecon listing feedwater heaters MSR replacement information | NRC | Date 10 | III |
| 20 | Flux map data from fuel cycle listing radial and axial power distributions | NRC | Date 10 | III |
| 21 | Missing pages of XX-1 and revised pages of XX-7 | ORNL | Date 11 | III |
| 22 | Telecon info on vessel volumes, upper-head flow, ΔPs, and reactivity insertion rate | ORNL | Date 11 | III |
| 23 | WCAP-xxx “Set Point Study for Utility Steam Electric Plant” dated x/xx/xx | ORNL | Date 12 | III |
| 24 | Operating Procedures. See Table A-5 for a listing | ORNL | Date 12 | IV |

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| | | | | |
|---|---|---|---|---|
| 25 | General Procedures. See Table A-6 for a listing | ORNL | Date 12 | IV |
| 26 | Abnormal Procedures. See Table A-7 for a | ORNL | Date 12 | IV |
| 27 | Emergency Instructions. See Table A-8 for a listing | ORNL | Date 12 | IV |
| 28 | SI Pump data, HPSI and RHR | Utility | Date 13 | IV |
| 29 | Replacement Steam-Generator Data | Utility | Date 13 | IV |
| 30 | SI Data Book 1:~Contains later SI pump data, RHR system, HPSI system, isometrics, P&IDS, and other data | Utility | Date 13 | V |
| 31 | Drawings. See Table A-9 for a listing | Utility | Date 14 | Filed separately |
| 32 | Report: Set Point Revision for xxxx MWt Operations | Utility | Date 15 | V |
| 33 | Master instrument list | Utility | Date 15 | V |
| 34 | WCAP xxxx plant justification for operation at xxxx MWt | Utility | Date 16 | Filed separately |
| 35 | Replacement SG Data — copy of DB-29 | ORNL | Date 16 | Filed with DB-29 |
| 36 | Drawing X-xxxxxx heater drain vent system | ORNL | Date 16 | Filed separately |
| 37 | Auxiliary FW head curves, both motor driven and steam driven | Utility | Date 18 | V |
| 38 | AO Training Manual Handouts:<br>CVCS<br>Turbine & Control<br>Condensate | Utility | Date 18 | V |
| 39 | RO Training Manual Handout:<br>Turbine Control | Utility | Date 18 | V |
| 40 | xxxx MWt PLS | Utility | Date 18 | V |
| 41 | Drawing X-xxxxxxx vessel | Utility | Date 19 | Filed separately |
| 42 | Control-Block Diagrams<br>$\Delta T/T_{ave}$<br>Steam-dump control<br>Drawing $T_{ave}$–DT protection system<br>Pressurizer level control<br>Numbers & Pressurizer pressure control<br>S/G level control<br>S/G break protection | Utility | Date 19 | V |

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| | | | | |
|---|---|---|---|---|
| 43 | Isometrics without dimensions (EBASCO drawings)<br>Main Steam Piping (2)<br>Feedwater Piping (3)<br>Condensate Piping (10)<br>Safety Vent Valves (2)<br>Safety Injection (10)<br>Reactor Coolant (1)<br>Residual Heat (1) | Utility | Date 19 | Filed separately |
| 44 | Plant Technical Specifications | ORNL | Date 20 | VI |
| 45 | SG Drawing xxxxxxx for MOD44F | ORNL | Date 21 | Filed |
| 46 | Value Data:<br>1) Main-steam isolation<br>2) Flow elements (FE) -474, -484, -494<br>3) Main-steam SRV schedule<br>4) Feedwater control<br>5) Pressurizer PORV<br>6) Main-steam safety | Utility | Date 22 | VII |
| 47 | Heat loss calculation of 3-loop MSSS | Utility | Date 22 | VII |
| 48 | AO student handouts:<br>1) Feedwater system<br>2) Auxiliary-feedwater system<br>3) CVCS<br>4) Heater vents<br>5) Turbine controls | Utility | Date 22 | VII |
| 49 | Westinghouse RC pumps manual | Utility | Date 22 | VII |
| 50 | ORNL information transfer of 5/20/83 | ORNL | Date 23 | VII |
| 51 | 3-pump SI delivery curve by vendor | ORNL | Date 24 | VII |
| 52 | Auxiliary-feedwater component test report | Utility | Date 25 | VII |
| 53 | RO student handouts:<br>1) Feedwater system<br>2) Condensate system<br><br>Extraction steam, feedwater heater, and vents and drains | Utility | Date 25 | VII |

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| | | | | |
|---|---|---|---|---|
| 54 | Westinghouse SB technical manual (parts of) | Utility | Date 25 | VII |
| 55 | Drawings X-xxxxxx and X-xxxxxx on main-stream and feedwater piping | Utility | Date 25 | VII |
| 56 | Piping schedule list | Utility | Date 25 | VII |
| 57 | ORNL letter 6/3/83 — four attachments:<br>1) Q and A from plant meeting x/x/xx<br>2) Marked-up steam-dump notes<br>3) Marked-up copy of control system questions to utility on x/x/xx<br>4) ORNL documentation list of plant data received | ORNL | Date 26 | VII |
| 58 | Thermal-hydraulic report for MOD44FSG | W | Date 27 | VII |
| 59 | ORNL letter x/x/xx information transfer on SG (s/s/ss call) and on vessel (x/x/xx call) | ORNL | Date 28 | VII |
| 60 | ORNL letter x/x/xx — System State Trees | ORNL | Date 29 | VII |
| 61 | ORNL letter x/x/xx — Information Transfer on SG data for plant MOD44F SG | ORNL | Date 30 | VII |
| 62 | Two items from XXXXXXXXX<br>1) Core-normalized axial power profile<br>2) Main-steam PORV data sheet | Utility | Date 31 | VII |
| 63 | EG&G teleconference memo x/x/xx Questions and answers on:<br>1) Feedline polishers and demineralizers<br>2) Steam-line PORVs<br>3) DPs along feed and steam lines<br>4) HP heater bypass lines | EG&G | Date 32 | VII |

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| | | | | |
|---|---|---|---|---|
| | ORNL letter x/xx/xx teleconference call about:<br>1. Maximum steam-line flow<br>1) Percent moisture carryover<br>2) Upper-head temperature<br>3) Upper-head volume<br>4) Vessel metal masses<br>5) Core DP | | | |
| 64 | | | Date 33 | VII |
| 65 | EG&G memo on x/x/xx cell:<br>SG and Vessel data | EG&G | Date 34 | VII |
| 66 | EG&G memo on x/x/xx call on feedlinne polishers | EG&G | Date 35 | VII |
| | ORNL letter on x/x/xx meeting<br>1) Summary of x/x/xx meeting<br>2) Utility data commitments<br>3) Steam-line break scenarios<br>4) Transient scenarios (8)<br>5) Q and A from plant meeting on x/x/xx<br>6) Meeting agenda | | | |
| 67 | | ORNL | Date 36 | VII |
| 68 | Graphs of Tave and DT program. Also same data received from ORNL x/x/xx | Utility | Date 37 | VII |
| | ORNL letter x/x/xx — Information transfer:<br>1) Steam-dump valve specifications<br>2) Pressurizer pressure-tab location<br>3) MFW flow DP<br>4) AFW information<br>5) Modifications to MFW flow<br>6) SG level calibration<br>7) SG data correction<br>8) RCP trip<br>9) Updated documentation list | | | |
| 69 | | ORNL | Date 38 | VII |
| 70 | Westinghouse summary of all vessel data | Utility | Date 39 | VII |

**Table A-1.** Westinghouse Three-Loop Plant Database Listing

| | | | | |
|---|---|---|---|---|
| 71 | EG&G memo on x/x/xx call on water temperature for HPI, LPI, accumulator, and AFW | ORNL | Date 40 | VII |

**Table A-2. P&ID Drawing Listing for DB No. 5 in Table A-1**

| Number | Sheets | Title |
|---|---|---|
| P&IDs | 1 | Legend |
| | 3 | Main, Extraction, and Auxiliary Steam System |
| | 3 | Feed and Condensate |
| | 4 | Service and Cooling Water |
| | 3 | Fire and Makeup Water System |
| | 3 | Emergency Diesel Generator |
| | 3 | Auxiliary Steam System |
| | 2 | Blowdown System |
| | 3 | Instrument and Service Air |
| | 4 | Penetration Pressurization System |
| | 1 | Isol. Valve Seal Water |
| | 2 | Heating, ventilating, and air conditioning (HVAC) |
| | 3 | Component Cooling System |
| | 1 | Sample System |
| | 1 | Chemical and volume control system (CVCS) |
| | 3 | Nuclear Instrumentation System |
| | 4 | Liquid Waste Disposal |
| | 2 | Gaseous Waste Disposal |
| | 1 | Chemical Fuel System |
| | 1 | Postaccident Sampling System |
| | 1 | RHRS |
| Logic Diagrams | 1 | (all diagrams) |

**Table A-3. System Description Listing for DB No. 6 in Table A-1**

| SD No. | Revision | System | |
|---|---|---|---|
| 1 | 9 | Reactor-coolant system | 1 |
| 2 | 7 | Safety injection | 1 |
| 3 | 3 | Residual heat removal | 1 |
| 4 | 7 | Service water | I |
| 6 | 4 | Reactor safeguards | I |

**Table A-3. System Description Listing for DB No. 6 in Table A-1**

| | | | |
|---|---|---|---|
| 7 | 2 | Rod control system | I |
| 11 | 7 | Reactor protection | I |
| 13 | 3 | Component cooling | I |
| 16 | 25 | Electrical | I |
| 17 | 6 | Instrument and station air | II |
| 18 | 0 | Nitrogen and hydrogen systems | II |
| 20 | 7 | SG blowdown | II |
| 21 | 3 | Chemical and volume control system | II |
| 25 | 4 | Main steam | II |
| 26 | 3 | Condensate | II |
| 27 | 5 | Feedwater | II |
| 28 | 3 | Heater vents and drains | II |
| 33 | 2 | Turbine controls | II |

**Table A-4. System Description Listing for DB No. 6 in Table A-1**

| PLS No. | Revision | System |
|---|---|---|
| 1 | 20 | Reactor control and protection |
| 2 | 7 | Reactor-coolant system |
| 3 | 7 | Chemical and volume control system |
| 4 | 4 | Auxiliary coolant system |
| 6 | 6 | Nuclear instrumentation system |
| 7 | 4 | Safety-injection system |
| 9 | 2 | Electrical system |
| 10 | 1 | Instrument and station air system |
| 11 | 3 | Heating, ventilating, and air conditioning systems |
| 12 | 4 | Isolation valve seal water system |
| 13 | 5 | Condensate and feedwater system |
| 14 | 4 | Main, reheat, and dump steam system |
| 15 | 5 | Auxiliary-feedwater system |
| 16 | 1 | Auxiliary-steam system |
| 17 | 2 | Primary water and demineralizer water makeup system |
| 18 | 2 | Service water system |

**Table A-5. Operating Procedures Listing for DB No. 24 in Table A-1**

| Number | Revision | Title |
|---|---|---|
| OP-1 | 1 | DC Supply |
| OP-3 | 6 | Electrical Distributions |

**Table A-5. Operating Procedures Listing for DB No. 24 in Table A-1**

| | | |
|---|---|---|
| OP-6 | 18 | Service Water System |
| OP-7 | 13 | Diesel Generator “A” and “B” |
| OP-9 | 4 | Instrument and Station Air System |
| OP-14 | 22 | Auxiliary-Feedwater System |
| OP-15 | 6 | Circulating Water System |
| OP-16 | 13 | Condensate and Feedwater |
| OP-16-1 | 3 | Steam-Generators and Generator Level Control |
| OP-17 | 10 | Main and Reheat Steam |
| OP-17-1 | 8 | Steam-Generator Blowdown System |
| OP-19 | 2 | Gland Seal Steam and Drain |
| OP-20 | 8 | Heater Drains and Vents |
| OP-20-1 | 4 | Miscellaneous Drains System |
| OP-21 | 8 | Turbine, Generator, and Control |
| OP-23 | 14 | Nuclear Instrumentation System |
| OP-24 | 6 | Reactor-Coolant System Operation |
| OP-26 | 10 | Rod Control and Position Indication |
| OP-28 | 18 | Charging and Volume Control |
| OP-29 | 8 | Reactor Coolant Pump Operation |
| OP-30 | 6 | Pressurizer Pressure and Spray Control |
| OP-40 | 6 | Component Cooling System |
| OP-42 | 18 | Safety Injection and Containment Spray |
| OP-49 | 4 | Post-accident Containment Venting System |
| OP-50 | 0 | Low-Temperature Overpressure Protection System |
| OP-53 | 1 | Condenser Drain System |
| OP-54 | 4 | Core-Cooling Monitor |





**Table A-6. General Procedures Listing for DB No. 25 in Table A-1**

| Number | Revision | Title |
|---|---|---|
| GP-2 | 41 | Cold Solid to Hot Subcritical at No Load $T_{ave}$ |
| GP-3A | 21 | Normal Plant SU from Hot SD to Critical |
| GP-3B | 12 | Reactor Trip Recovery |
| GP-40 | 10 | Power Operation |
| GP-5 | 9 | Shutdown from Power to Hot Shutdown |
| GP-5A | | Temperature and Pressure Control Using Natural Circulation |
| GP-6 | 18 | Plant Cooldown from Hot SD to Cold SD |

**Table A-7. Abnormal Procedures Listing for DB No. 26 in Table A-1**

| Number | Revision | Title |
|---|---|---|
| AP-1 | 3 | Malfunction of Reactor Control System |
| AP-2 | 3 | Emergency Boration |
| AP-3 | 2 | Malfunction of Reactor Makeup Control |
| AP-9 | 2 | Loss of One Feedwater Pump |
| AP-10 | 2 | Loss of One Condensate Pump |
| AP-11 | 5 | Loss of One Circulating Pump |
| AP-12 | 4 | Partial Loss of Condenser Vacuum |
| AP-14 | 7 | Loss of Auxiliary Cooling |
| AP-15 | 4 | Secondary Load Rejection |
| AP-16 | 2 | Excessive Primary Plant Leakage |
| AP-17 | 4 | Loss of Instrument Air |
| AP-18 | 4 | Reactor Coolant Pump Abnormal Conditions |
| AP-19 | 4 | Malfunction of RCS Pressure Control System |
| AP-20 | 1 | Loss of Residual Heat Removal System (Shutdown Cooling) |
| AP-22 | 1 | Loss of Service Water |
| AP-23 | 1 | Loss of Containment Integrity |
| AP-24 | 0 | Loss of Instrument Bus |
| AP-25 | 1 | Spurious Safeguards Actuation |
| AP-8 | 7 | Loss of One Heater Drain Pump |



**Table A-8. Emergency Instructions Listing for DB No. 27 in Table A-1**

| Number | Revision | Title |
|---|---|---|
| EI-4 | 32 | Incident Involving Reactor Coolant System Depressurization |
| EI-4 | 2 | Loss of Reactor-Coolant Flow |
| EI-6 | 9 | Loss of Feedwater |
| EI-7 | 14 | Station Blackout Operation |
| EI-14 | 7 | Reactor Trip (Part A) Turbine and Generator Trip (Part B) |
| EI-15 | 7 | Control Room Inaccessibility |
| EI-16 | 5 | Post-accident Containment Venting System |
| EI-17 | 3 | Emergency Diesels Failure to Start on Automatic Safety-Injection Signal or Station Blackout |

**Table A-8. Emergency Instructions Listing for DB No. 27 in Table A-1**

| | | |
|---|---|---|
| EI-18 | 2 | Loss of Emergency Busses (480V) and/or Station DC Batteries |

**Table A-9. Miscellaneous Drawings Listing for DB No. 31 in Table A-1**

| DWG. No. | Title |
|---|---|
| | Flow Diagram of Feedwater condensate and air evacuation system |
| | Safety-Injection System, Sheet 1 |
| | Reactor-Coolant System Piping |
| | RHR System Piping |
| | SI System, Sheet 2 |
| | SI System Sections |
| | Reactor-Coolant Loop Piping |
| | Flow diagram of heater drains and vents |
| | Main Steam and Feedwater |
| | Piping, Sheet 1 |
| | MS & FW Piping, Sheet 2 |
| | MS & FW Piping, Sections |
| | Turbine & Ext.~Steam Piping |
| | Condensate Piping Section |
| | SG General Arrangement |
| | Vessel cross-sectional views |





**Table A-10. ZION-1 Nuclear Power Plant FSAR Database Listing**

| No. | Item | Description |
|---|---|---|
| 1 | Table 4.1-5 | SG design data |
| 2 | Fig. 6.7-1 | Auxiliary-feedwater system |
| 3 | Fig. 4.2-1 | Reactor-coolant system |
| 4 | Table 4.1-4 | Pressurizer and pressurizer-relief tank design data |
| 5 | Table 4.1-3 | Reactor-vessel design data |
| 6 | Fig. 4.2-2 | Reactor-vessel schematic |
| 7 | Table 3.2.3-1 | Core mechanical-design properties |
| 8 | Fig. 3.2.3-6 | Upper-core support structure |
| 9 | Fig. 3.2.3-9 | Fuel assembly |
| 10 | Section 3-2 | Mechanical design and evaluation |

**Table A-10. ZION-1 Nuclear Power Plant FSAR Database Listing**

| | | |
|---|---|---|
| 11 | Table 4.1-1 | System design and operating parameters |
| 12 | Table 4.2-1 | Construction materials of the reactor-system components |
| 13 | Table 4.1-7 | Reactor-coolant piping design parameters |
| 14 | Table 4.1-2 | Reactor-coolant system design pressure settings |
| 15 | Table 6.2-2 | Accumulator-design parameters |
| 16 | Table 6.2-3 | Boron-injection tank design parameters |
| 17 | Table 6.2-4 | Refueling water-storage tank design parameters |
| 18 | Fig. 14.3.2-14 | Safety-injection delivery |
| 19 | Table 4.1-9 | Reactor-coolant system design pressure drop |
| 20 | Table 4.1-8 | Pressurizer-valves design parameters |
| 21 | Table 4.1-6 | Reactor-coolant pumps design data |

# B

# *Sample Input Listings*

## *W4LOOP Test Problem*



```
free format
*
*************
* main data *
*************
*
*       numtcr          ieos          inopt          nmat           d2o
           10             0              1             0             0
*-*-*TEST PROBLEM W4LOOP , Time = 500.0 s all heat structures type HTSTR
Steady-state calculation test problem use new POWER component.
Zion 4-loop pressurized water reactor (PWR)
Fuel-rod average linear power of 3.9370e+04 W/m (4.0946e+04 Btu/hr/ft)
Coarse-node version with a broken loop and an intact (3 combined) loop
Constrained steady state with type 1, 3, and 5 controllers
Two Stgen components replaced by four Htstr, Pipe, and Tee components
Based on an isothermal (primary, secondary, & ecs temperatures differ),
isobaric (pressurizer pressure), no-flow, and no-power input condition
The solution estimate is initialized by hydraulic-path steady-state data
*
*  ########          ########                                  ########
*  # fill #          # fill #                                  # fill #
*  #  23  #          #  22  #                                  #   8   #
*  ########          ########                                  ########
*     24                23                                       9
*  ########          ########                                  ########
*  #  tee #          #prizer#                                  #  tee #
*  #  18  #          #  19  #                                  #  17  #
*  ########  rods    ########                              rods ########
*   33  34 128&129       20                                126&127 19  18
*  ########--########  ########  ########  ########  ########--########
*  #      #--# pipe #  #  tee #  #vessel#  # pipe #  # pipe #--#      #
*  #      #--#  11  #12#  10  #11#  26  # 1#   1  # 2#   2  #--#      #
*  #  tee #--########  ########  #      #  ########  ########--#  tee #
*  #  28  #     13               #vessel#               3     #  27  #
*  # slabs#--########  ########  # slabs#             ########--# slabs#
*  #      #--# pipe #  # fill #  #130 to#   broken    # pipe #--#130 to#
*  #      #--#  12  #  #  31  #  #  139 #    loop     #   3  #--#      #
*  ########--########  ########  #      #             ########--########
*     25        14        31     # core #                4        10
*  ########  ########  ########  # fuel #  ########  ########  ########
*  # break#  # pump #  # pipe #  #  rod #  #  tee #  # pump #  # break#
*  #  24  #  #  13  #  #  21  #  #  140 # 6#   5  # 5#   4  #  #   9  #
```

```
*  ########  ########  ########  #  171 #  ########  ########  ########
*               15        22     #  172 #       7
*             ########  ########  #  173 #  ########
*             #  tee #  # valve#  #       #  # valve#
*             #  14  #21#  20  #  #power #  #    6  #
*             ########  ########  #  174 #  ########
*               16       intact   #       #       8
*  ########  ########    loop     #       #  ########
*  # fill #  #  tee #  modeling   #       #  # break#
*  #  25  #26#  15  #   three     #       #  #    7  #
*  ########  ########   loops     #       #  ########
*               17                #       #
*             ########  ########  #       #
*             #       #  # pipe #  #       #
*             #       #41#  41  #27#       #
*             #       #  ########  #       #
*             #       #  ########  #       #
*             #       #  # pipe #  #       #
*             #plenum#42#  42  #28#       #
*             #  16  #  ########  #       #
*             #       #  ########  #       #
*             #       #  # pipe #  #       #
*             #       #43#  43  #29#       #
*             #       #  ########  #       #
*             #       #  ########  #       #
*             #       #  # pipe #  #       #
*             #       #44#  44  #30#       #
*             ########  ########  ########
*
******************
* namelist data *
******************
*
 &inopts
  cpuflg=1, iadded=10, idiag=4, inlab=3, iolab=1,
  ioout=1,  noair=0, nsdl=0,  nsdu=5,  nspl=0,  nspu=5
 nhtstr = 48,
 npower = 1,
 &end
*
*        dstep          timet
             0    0.0000e+00
*       stdyst          transi          ncomp           njun           ipak
             4               0             82             37              1
*         epso           epss
    1.0000e-03    1.0000e-04
*       oitmax          sitmax         isolut         ncontr          nccfl
            10              10              0              8              0
*         ntsv           ntcb           ntcf           ntrp           ntcp
             4               0              0              2              1
*  iorder array
             1               2              3              4              5s
             6               7             10             11             12s
            13              14             15             41             19s
            20              21             42             43             44s
            16              22             31             25             17s
            27               8              9             18             28s
            24              23             26            126            127s
           128             129            130            131            132s
           133             134            135            136            137s
           138             139            140            141            142s
           143             144            145            146            147s
           148             149            150            151            152s
           153             154            155            156            157s
```

```
          158          159          160          161          162s
          163          164          165          166          167s
          168          169          170          171          172s
          173          174e
*
************************************
* hydraulic-path steady-state data *
************************************
*
*       npaths          nfpi          ntpi
           11             0             1
*
* broken-loop primary side
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         1001          5005          5005          2002          3004
*         pmvl          pmvv           ptl           ptv        ppower
    4.2520e+03    0.0000e+00    5.5000e+02    0.0000e+00   -8.1250e+08
*
* broken-loop secondary side with an assumed 5.0 recirculation ratio
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
        -27005         27004        -27003         27001         27002
*         pmvl          pmvv           ptl           ptv        ppower
    1.5540e+03    0.0000e+00    0.0000e+00    0.0000e+00    8.1250e+08
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         8002        -17006        -17002             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    3.8850e+02    0.0000e+00    4.4000e+02    0.0000e+00    0.0000e+00
*
* intact-loop primary side
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
        10001         15004         15004         11002         12004
*         pmvl          pmvv           ptl           ptv        ppower
    1.2756e+04    0.0000e+00    5.5000e+02    0.0000e+00   -2.4375e+09
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
        -10006         19001        -10002             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         41001         41003         41001             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    4.2520e+03    0.0000e+00    5.5000e+02    0.0000e+00    0.0000e+00
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         42001         42003         42001             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    4.2520e+03    0.0000e+00    5.5000e+02    0.0000e+00    0.0000e+00
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         43001         43003         43001             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    2.1260e+03    0.0000e+00    5.5000e+02    0.0000e+00    0.0000e+00
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         44001         44003         44001             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    2.1260e+03    0.0000e+00    5.5000e+02    0.0000e+00    0.0000e+00
*
* intact-loop secondary side with an assumed 5.0 recirculation ratio
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
        -28005         28004        -28003         28001         28002
*         pmvl          pmvv           ptl           ptv        ppower
```

```
    4.6620e+03    0.0000e+00    0.0000e+00    0.0000e+00    2.4375e+09
*
*       idcinf        idcouf        idcloc        idcpwi        idcpwo
         23002        -18006        -18002             0             0
*         pmvl          pmvv           ptl           ptv        ppower
    1.1655e+03    0.0000e+00    4.4000e+02    0.0000e+00    0.0000e+00
*
********************************
* constrained steady-state data *
********************************
*
* broken-loop pump type-1 controller adjusts impeller rotational speed
*       numcss        amncss        amxcss        nmpcss        napcss
            4    0.0000e+00    2.0000e+02             0             0
*
* intact-loop pump type-1 controller adjusts impeller rotational speed
*       numcss        amncss        amxcss        nmpcss        napcss
           13    0.0000e+00    2.0000e+02             0             0
*
* broken-loop fill type-3 controller adjusts feedwater mass flow
*       numcss        amncss        amxcss        nmpcss        napcss
            8    0.0000e+00    1.0000e+04         27004             1
*
* intact-loop fill type-3 controller adjusts feedwater mass flow
*       numcss        amncss        amxcss        nmpcss        napcss
           23    0.0000e+00    3.0000e+04         28004             1
*
* broken-loop htstr type-5 controller adjusts surface areas & th.cond.
*       numcss        amncss        amxcss        nmpcss        napcss
          126    8.0000e-01    1.2500e+00          3003            14
          127    8.0000e-01    1.2500e+00          3003            14
*
* intact-loop htstr type-5 controller adjusts surface areas & th.cond.
*       numcss        amncss        amxcss        nmpcss        napcss
          128    8.0000e-01    1.2500e+00         12003            14
          129    8.0000e-01    1.2500e+00         12003            14
*
*************************
* control-parameter data *
*************************
*
* signal variables
*         idsv          isvn          ilcn          icn1          icn2
            1             0             0             0             0
            2            21            15             3             0
            3            21            19             2             0
            4            21            26          1003             0
*
* trips
*         ntse          ntct          ntsf          ntdp          ntsd
            0             0             0             0             0
*
*         idtp          isrt          iset          itst          idsg
           11             1             0             1             3
*      setp(1)       setp(2)
    4.0800e+06    4.0900e+06
*      dtsp(1)       dtsp(2)
    0.0000e+00    0.0000e+00
*      ifsp(1)       ifsp(2)
            0             0
*
*         idtp          isrt          iset          itst          idsg
           12             1             0             1             4
*      setp(1)       setp(2)
```

```
    1.0000e+06    1.0100e+06
*      dtsp(1)       dtsp(2)
    0.0000e+00    0.0000e+00
*      ifsp(1)       ifsp(2)
             0             0
*
******************
* component data *
******************
*
*******   type           num            id        ctitle
pipe                       1             1 $1$ bkn-loop hot-leg pipe
*       ncells         nodes          jun1          jun2          epsw
             2             1             1             2    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*        radin            th         houtl         houtv         toutl
    3.6830e-01    6.2000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    *     7.2400e+00    1.5000e+00e
* vol   *     3.1246e+00    6.3900e-01e
* fa    *     6.0300e-01r02 4.2600e-01e
* fric  * f   0.0000e+00e
* grav  * r02 0.0000e+00    1.0000e+00e
* hd    *     8.7630e-01r02 7.3660e-01e
* nff   *             -1            1            -1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *             6e
* tw    * f   5.5000e+02e
*
*******   type           num            id        ctitle
pipe                       2             2 $2$ bkn-loop st-gen primary
*       ncells         nodes          jun1          jun2          epsw
             3             0             2             3    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*        radin            th         houtl         houtv         toutl
    9.8500e-03    1.2700e-03    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*
* dx    *     1.0000e+00r02 4.3500e+00e
* vol   *     5.5900e+00r02 4.7175e+00e
* fa    *     4.2600e-01r03 1.0050e+00e
* fric  * f   0.0000e+00e
* grav  * r03 1.0000e+00    0.0000e+00e
* hd    *     7.3660e-01r03 1.4800e-02e
* nff   * r02         -1r02          1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
```

```
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
*
*******   type           num             id        ctitle
pipe                       3              3 $3$ bkn-loop pump-suct pipe
*       ncells         nodes          jun1          jun2          epsw
             5             0             4             3    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*        radin           th         houtl         houtv         toutl
    9.8500e-03    1.2700e-03    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*
* dx    *     4.0000e+00    1.5000e+00    1.0000e+00r02 4.3500e+00e
* vol   *     1.9480e+00    7.3050e-01    5.9800e+00r02 4.7175e+00e
* fa    * r03 4.8700e-01r03 1.0050e+00e
* fric  * f   0.0000e+00e
* grav  * r02 0.0000e+00r03 1.0000e+00    0.0000e+00e
* hd    * r03 7.8740e-01r03 1.4800e-02e
* nff   * r02          1r02         -1r02          1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
*
*******   type           num             id        ctitle
pump                       4              4 $4$ bkn-loop pump
*       ncells         nodes          jun1          jun2          epsw
             2             1             4             5    0.0000e+00
*         ichf         iconc       ipmpty           irp           ipm
             0             0             1             0             1
*       ipmptr        ipmpsv        npmptb        npmpsv        npmprf
             0             0             0             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*        radin           th         houtl         houtv         toutl
    2.5400e-01    1.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv         effmi
    3.0000e+02    3.4600e+03
*         tfr0          tfr1          tfr2          tfr3          tfrb
            0.0           0.0           0.0           0.0           0.0
*        tfrl0         tfrl1         tfrl2         tfrl3
            0.0           0.0           0.0           0.0
*        rhead         rtork         rflow          rrho        romega
    8.4300e+02    4.2850e+04    5.5800e+00    1.0000e+03    1.2440e+02
*       omegan        omgoff        romgmx        omgscl        npmpsd
    1.2440e+02    0.0000e+00    0.0000e+00    0.0000e+00             0
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*       option
             1
*
* dx    *     2.2400e+00    1.1200e+00e
* vol   *     1.0908e+00    4.8720e-01e
* fa    * r02 4.8700e-01    3.8300e-01e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * r02 7.8740e-01    6.9850e-01e
```

```
* nff    * f            1e
* alp    * f    0.0000e+00e
* vl     *      0.0000e+00    1.1312e+01    0.0000e+00e
* vv     *      0.0000e+00    1.1312e+01    0.0000e+00e
* tl     * f    5.5000e+02e
* tv     * f    5.5000e+02e
* p      * f    1.5513e+07e
* pa     * f    0.0000e+00e
* qppp   * f    0.0000e+00e
* matid  *              6e
* tw     * f    5.5000e+02e
*
*******   type           num            id        ctitle
tee                        5             5 $5$ bkn-loop cold-leg & break
*         jcell         nodes          ichf          cost          epsw
               3             1             0    0.0000e+00    0.0000e+00
*        iconc1        ncell1          jun1          jun2          ipow1
               0             4             5             6             0
*        iqptr1        iqpsv1        nqptb1        nqpsv1        nqprf1
               0             0             0             0             0
*        radin1           th1        houtl1        houtv1        toutl1
     3.4925e-01    5.8400e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv1
     3.0000e+02
*         qpin1        qpoff1        rqpmx1        qpscl1
     0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*        iconc2        ncell2          jun3          ipow2
               0             1             7             0
*        iqptr2        iqpsv2        nqptb2        nqpsv2        nqprf2
               0             0             0             0             0
*        radin2           th2        houtl2        houtv2        toutl2
     3.6830e-01    6.2000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv2
     3.0000e+02
*         qpin2        qpoff2        rqpmx2        qpscl2
     0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx     *      4.4200e+00r03 1.4733e+00e
* vol    *      1.8084e+00r03 5.8123e-01e
* fa     * r02  3.8300e-01r02 3.9451e-01    5.5200e-01e
* fric   * f    0.0000e+00e
* grav   * f    0.0000e+00e
* hd     * r02  6.9850e-01r02 7.0874e-01    8.3820e-01e
* nff    * r04            1            -1e
* alp    * f    0.0000e+00e
* vl     * f    0.0000e+00e
* vv     * f    0.0000e+00e
* tl     * f    5.5000e+02e
* tv     * f    5.5000e+02e
* p      * f    1.5513e+07e
* pa     * f    0.0000e+00e
* qppp   * f    0.0000e+00e
* matid  *              6e
* tw     * f    5.5000e+02e
*
* dx     *      1.0000e-01e
* vol    *      6.0300e-02e
* fa     * f    6.0300e-01e
* fric   *      1.0000e-10    0.0000e+00e
* grav   * f    0.0000e+00e
* hd     * f    8.7630e-01e
* nff    * f            1e
* alp    *      0.0000e+00e
* vl     * f    0.0000e+00e
```

```
* vv    * f   0.0000e+00e
* tl    *     5.5000e+02e
* tv    *     5.5000e+02e
* p     *     1.5513e+07e
* pa    *     0.0000e+00e
* qppp  *     0.0000e+00e
* matid *              6e
* tw    *     5.5000e+02e
*
*******   type           num            id        ctitle
valve                     6             6 $6$ bkn-loop break valve
*       ncells         nodes          jun1          jun2          epsw
             1             1             7             8    0.0000e+00
*         ichf         iconc          ivty          ivps         nvtb2
             0             0             1             2             0
*         ivtr          ivsv         nvtb1          nvsv          nvrf
             0             1            -2             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*       ivtrov        ivtyov
             0             0
*         rvmx          rvov        fminov        fmaxov
    1.0000e+01    0.0000e+00    0.0000e+00    0.0000e+00
*        radin            th         houtl         houtv         toutl
    3.6830e-01    6.2000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv          avlve         hvlve         favlve          xpos
    3.0000e+02    6.0300e-01    8.7630e-01    0.0000e+00    0.0000e+00
*         qp3in        qp3off        rqp3mx        qp3scl
    1.0000e-01    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    *     1.0000e-01e
* vol   *     6.0300e-02e
* fa    * f   6.0300e-01e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   8.7630e-01e
* nff   * f            1e
* alp   *     0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     5.5000e+02e
* tv    *     5.5000e+02e
* p     *     1.5513e+07e
* pa    *     0.0000e+00e
* qppp  *     0.0000e+00e
* matid *              6e
* tw    *     5.5000e+02e
* vtb1  * r02 0.0000e+00    1.0000e-01    1.0000e+00e
*
*******   type           num            id        ctitle
break                     7             7 $7$ bkn-loop containment
*         jun1          ibty          isat          ioff
             8             0             0             0
*         dxin         volin         alpin          tin           pin
    1.0000e-01    1.0000e+01    1.0000e+00    3.0000e+02    1.0000e+05
*         pain         concin          rbmx          poff          belv
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
*******   type           num            id        ctitle
fill                      8             8 $8$ bkn-loop sec-side feedwater
*         jun2          ifty          ioff
             9             1             0
*       twtold          rfmx        concin          felv
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
```

```
*         dxin         volin         alpin          vlin          tlin
    1.0000e+00    5.0000e-01    0.0000e+00    0.0000e+00    4.4000e+02
*          pin          pain         flowin          vvin          tvin
    4.8500e+06    0.0000e+00    0.0000e+00    0.0000e+00    4.4000e+02
*
*******   type           num            id        ctitle
break                      9             9 $9$ bkn-loop sec pressure bc
*         jun1          ibty          isat          ioff
            10             0             0             0
*         dxin         volin         alpin           tin           pin
    4.3500e+00    2.4800e+01    1.0000e+00    5.3514e+02    4.8500e+06
*         pain        concin         rbmx          poff          belv
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
*******   type           num            id        ctitle
tee                       10            10 $10$ int-loop hot-leg & prizer
*        jcell         nodes          ichf          cost          epsw
            2             1             0    0.0000e+00    0.0000e+00
*       iconc1        ncell1         jun1          jun2         ipow1
            0             4            11            12             0
*       iqptr1        iqpsv1        nqptb1        nqpsv1        nqprf1
            0             0             0             0             0
*       radin1           th1        houtl1        houtv1        toutl1
    6.3780e-01    2.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv1
    3.0000e+02
*        qpin1        qpoff1        rqpmx1        qpscl1
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*       iconc2        ncell2         jun3         ipow2
            0             2            20             0
*       iqptr2        iqpsv2        nqptb2        nqpsv2        nqprf2
            0             0             0             0             0
*       radin2           th2        houtl2        houtv2        toutl2
    1.7760e-01    3.0000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv2
    3.0000e+02
*        qpin2        qpoff2        rqpmx2        qpscl2
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    * r03 2.4133e+00    1.5000e+00e
* vol   * r03 3.1246e+00    1.9170e+00e
* fa    *     1.8090e+00r02 1.2947e+00r02 1.2780e+00e
* fric  * f   0.0000e+00e
* grav  * r04 0.0000e+00    1.0000e+00e
* hd    *     8.7630e-01r02 7.4135e-01r02 7.3660e-01e
* nff   *             -1r03          1            -1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
* dx    * f   1.0800e+01e
* vol   * f   1.0702e+00e
* fa    * f   9.9100e-02e
* fric  *     1.0000e-10r02 0.0000e+00e
* grav  *    -1.0000e+00    0.0000e+00    1.0000e+00e
* hd    * f   1.0000e-02e
* nff   * r02          1            -1e
```

```
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
*******   type           num            id        ctitle
pipe                      11            11 $11$ int-loop st-gen primary
*       ncells         nodes          jun1          jun2          epsw
             3             0            12            13    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*        radin            th         houtl         houtv         toutl
    9.8500e-03    1.2700e-03    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*
* dx    *     1.0000e+00r02 4.3500e+00e
* vol   *     1.6770e+01r02 1.4153e+01e
* fa    *     1.2780e+00r03 3.0150e+00e
* fric  * f   0.0000e+00e
* grav  * r03 1.0000e+00    0.0000e+00e
* hd    *     7.3660e-01r03 1.4800e-02e
* nff   * r02         -1r02          1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
*
*******   type           num            id        ctitle
pipe                      12            12 $12$ int-loop pump-suct pipe
*       ncells         nodes          jun1          jun2          epsw
             5             0            14            13    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*        radin            th         houtl         houtv         toutl
    9.8500e-03    1.2700e-03    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*
* dx    *     4.0000e+00    1.5000e+00    1.0000e+00r02 4.3500e+00e
* vol   *     5.8440e+00    2.1915e+00    1.7940e+01r02 1.4153e+01e
* fa    * r03 1.4610e+00r03 3.0150e+00e
* fric  * f   0.0000e+00e
* grav  * r02 0.0000e+00r03 1.0000e+00    0.0000e+00e
* hd    * r03 7.8740e-01r03 1.4800e-02e
* nff   * r02         1r02         -1r02          1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
*
*******   type           num            id        ctitle
```

```
pump                    13          13 $13$ int-loop pump
*       ncells         nodes         jun1         jun2         epsw
             2             1           14           15   0.0000e+00
*         ichf         iconc       ipmpty          irp          ipm
             0             0            1            0            1
*       ipmptr        ipmpsv       npmptb       npmpsv       npmprf
             0             0            0            0            0
*       iqp3tr        iqp3sv       nqp3tb       nqp3sv       nqp3rf
             0             0            0            0            0
*        radin            th        houtl        houtv        toutl
    6.8000e-01   2.0000e-01   0.0000e+00   0.0000e+00   3.0000e+02
*        toutv         effmi
    3.0000e+02   1.0380e+04
*         tfr0          tfr1         tfr2         tfr3         tfrb
          0.0           0.0          0.0          0.0          0.0
*        tfrl0         tfrl1        tfrl2        tfrl3
          0.0           0.0          0.0          0.0
*        rhead         rtork        rflow         rrho        romega
    8.4300e+02   1.2855e+05   1.6740e+01   1.0000e+03   1.2440e+02
*       omegan        omgoff       romgmx       omgscl       npmpsd
    1.2440e+02   0.0000e+00   0.0000e+00   0.0000e+00            0
*        qp3in        qp3off       rqp3mx       qp3scl
    0.0000e+00   0.0000e+00   0.0000e+00   0.0000e+00
*       option
             1
*
* dx    *     2.2400e+00    1.1200e+00e
* vol   *     3.2724e+00    1.4616e+00e
* fa    * r02 1.4610e+00    1.1490e+00e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * r02 7.8740e-01    6.9850e-01e
* nff   * f             1e
* alp   * f   0.0000e+00e
* vl    *     0.0000e+00    1.1312e+01    0.0000e+00e
* vv    *     0.0000e+00    1.1312e+01    0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *               6e
* tw    * f   5.5000e+02e
*
*******   type           num            id        ctitle
tee                      14            14 $14$ int-loop cold-leg & accum
*        jcell         nodes         ichf         cost         epsw
             3             1            0   5.0000e-01   0.0000e+00
*       iconc1        ncell1         jun1         jun2         ipow1
             0             4           15           16            0
*       iqptr1        iqpsv1       nqptb1       nqpsv1       nqprf1
             0             0            0            0            0
*       radin1           th1       houtl1       houtv1       toutl1
    6.0480e-01   2.0000e-01   0.0000e+00   0.0000e+00   3.0000e+02
*       toutv1
    3.0000e+02
*        qpin1        qpoff1       rqpmx1       qpscl1
    0.0000e+00   0.0000e+00   0.0000e+00   0.0000e+00
*       iconc2        ncell2         jun3         ipow2
             0             2           21            0
*       iqptr2        iqpsv2       nqptb2       nqpsv2       nqprf2
             0             0            0            0            0
*       radin2           th2       houtl2       houtv2       toutl2
    2.2000e-01   6.0000e-02   0.0000e+00   0.0000e+00   3.0000e+02
```

```
*       toutv2
    3.0000e+02
*        qpin2        qpoff2        rqpmx2        qpscl2
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    *     9.9210e-01r03 3.3070e-01e
* vol   *     1.1400e+00r03 3.8000e-01e
* fa    * f   1.1490e+00e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   6.9850e-01e
* nff   * f            1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
* dx    * f   8.5000e+00e
* vol   * f   1.2930e+00e
* fa    * f   1.5210e-01e
* fric  *     1.0000e-10r02 0.0000e+00e
* grav  *    -8.6600e-01   -1.0000e+00    0.0000e+00e
* hd    * f   2.5400e-01e
* nff   * f            1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
*******   type          num           id        ctitle
tee                      15           15 $15$ int-loop c-leg & hpis/lpis
*        jcell        nodes         ichf         cost         epsw
               2            1            0    5.0000e-01    0.0000e+00
*       iconc1        ncell1         jun1         jun2         ipow1
               0            3           16           17            0
*       iqptr1        iqpsv1       nqptb1       nqpsv1       nqprf1
               0            0            0            0            0
*       radin1           th1       houtl1       houtv1       toutl1
    6.0480e-01    2.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv1
    3.0000e+02
*        qpin1        qpoff1        rqpmx1        qpscl1
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*       iconc2        ncell2         jun3         ipow2
               0            1           26            0
*       iqptr2        iqpsv2       nqptb2       nqpsv2       nqprf2
               0            0            0            0            0
*       radin2           th2       houtl2       houtv2       toutl2
    4.3700e-02    3.0000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv2
    3.0000e+02
*        qpin2        qpoff2        rqpmx2        qpscl2
```

```
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    * f   1.1427e+00e
* vol   * f   1.3524e+00e
* fa    *     1.1490e+00r02 1.1835e+00    1.1490e+00e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   6.9850e-01e
* nff   * f            1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
* dx    *     1.0000e+00e
* vol   *     6.0000e-03e
* fa    * f   6.0000e-03e
* fric  *     1.0000e-10    0.0000e+00e
* grav  * f  -8.6600e-01e
* hd    * f   5.0800e-02e
* nff   * f            1e
* alp   *     0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     5.5000e+02e
* tv    *     5.5000e+02e
* p     *     1.5513e+07e
* pa    *     0.0000e+00e
* qppp  *     0.0000e+00e
* matid *              6e
* tw    *     5.5000e+02e
*
*******   type           num           id        ctitle
plenum                    16           16 $16$ int-loop c-leg flow split
*         npljn         iconc         juns1         juns2
              5             0             1             4
*
* junj  *            17s
* junj  *            41            42            43            44e
* dx    * f   1.9280e+00e
* vol   *     2.5442e+00e
* elev  *     0.0000e+00e
* alp   *     0.0000e+00e
* tl    *     5.5000e+02e
* tv    *     5.5000e+02e
* p     *     1.5513e+07e
* pa    *     0.0000e+00e
*
*******   type           num           id        ctitle
tee                       17           17 $17$ bkn-loop sec-side downcomer
*         jcell        nodes         ichf         cost         epsw
              2            0            0    0.0000e+00    0.0000e+00
*        iconc1       ncell1         jun1         jun2         ipow1
              0            4           18           19             0
*        radin1          th1       houtl1       houtv1       toutl1
    1.4600e+00    3.0000e-03    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv1
    3.0000e+02
```

```
*       iconc2        ncell2          jun3         ipow2
             0             1             9             0
*       radin2           th2        houtl2        houtv2        toutl2
    5.6420e-01    2.0000e-03    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv2
    3.0000e+02
*
* dx    *     1.0000e+00r02 3.3500e+00    1.0000e+00e
* vol   *     1.0000e+00r02 3.3500e+00    1.0000e+00e
* fa    *     1.5000e+00r04 1.0000e+00e
* fric  *     3.0000e-03r03 0.0000e+00    2.0000e-01e
* grav  * r04-1.0000e+00    6.2617e-01e
* hd    * r04 1.0000e-01    3.4170e-02e
* nff   * f             1e
* alp   *     1.0000e+00r03 0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.3514e+02e
* tv    * f   5.3514e+02e
* p     * f   4.8500e+06e
* pa    * f   0.0000e+00e
*
* dx    *     1.0000e+00e
* vol   *     5.0000e-01e
* fa    * f   5.0000e-01e
* fric  *     1.0000e-10    0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   1.0000e-01e
* nff   * f             1e
* alp   *     0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     4.4000e+02e
* tv    *     4.4000e+02e
* p     *     4.8500e+06e
* pa    *     0.0000e+00e
*
*******   type             num             id        ctitle
tee                         18             18 $18$ int-loop sec-side downcomer
*        jcell          nodes          ichf          cost          epsw
             2              0             0    0.0000e+00    0.0000e+00
*       iconc1        ncell1          jun1          jun2         ipow1
             0              4            33            34             0
*       radin1           th1        houtl1        houtv1        toutl1
    1.4600e+00    3.0000e-03    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv1
    3.0000e+02
*       iconc2        ncell2          jun3         ipow2
             0             1            24             0
*       radin2           th2        houtl2        houtv2        toutl2
    5.6420e-01    2.0000e-03    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv2
    3.0000e+02
*
* dx    *     1.0000e+00r02 3.3500e+00    1.0000e+00e
* vol   *     3.0000e+00r02 1.0050e+01    3.0000e+00e
* fa    *     4.5000e+00r04 3.0000e+00e
* fric  *     3.0000e-03r03 0.0000e+00    2.0000e-01e
* grav  * r04-1.0000e+00    6.2617e-01e
* hd    * r04 1.0000e-01    3.4170e-02e
* nff   * f             1e
* alp   *     1.0000e+00r03 0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
```

```
* tl    * f   5.3514e+02e
* tv    * f   5.3514e+02e
* p     * f   4.8500e+06e
* pa    * f   0.0000e+00e
*
* dx    *     1.0000e+00e
* vol   *     1.5000e+00e
* fa    * f   1.5000e+00e
* fric  *     1.0000e-10    0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   1.0000e-01e
* nff   * f           1e
* alp   *     0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     4.4000e+02e
* tv    *     4.4000e+02e
* p     *     4.8500e+06e
* pa    *     0.0000e+00e
*
*******   type           num            id        ctitle
prizer                    19            19 $19$ int-loop hot-leg prizer
*       ncells         nodes          jun1          jun2
             3             0            23            20
*         ichf         iconc         qp3in
             0             0    0.0000e+00
*        radin            th         houtl         houtv         toutl
    1.0420e+00    1.0000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv         qheat         pset         dpmax          zhtr
    3.0000e+02    1.7000e+06    1.5500e+07    2.0000e+05    3.0000e+00
*
* dx    *     6.0107e+00    8.6893e+00    2.0000e-01e
* vol   *     2.0580e+01    2.9665e+01    6.8280e-01e
* fa    * r03 3.4140e+00    9.9100e-02e
* fric  * f   0.0000e+00e
* grav  * f  -1.0000e+00e
* hd    * f   1.0000e-02e
* nff   * r03           1          -1e
* alp   *     1.0000e+00r02 0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     6.1797e+02r02 5.5000e+02e
* tv    *     6.1797e+02r02 5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
*
*******   type           num            id        ctitle
valve                     20            20 $20$ int-loop accum check valve
*       ncells         nodes          jun1          jun2          epsw
             2             1            22            21    0.0000e+00
*         ichf         iconc          ivty          ivps         nvtb2
             0             0             3             2             0
*         ivtr          ivsv         nvtb1          nvsv          nvrf
            11             1            -2             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*       ivtrov        ivtyov
             0             0
*         rvmx          rvov        fminov        fmaxov
    1.0000e+05    0.0000e+00    0.0000e+00    0.0000e+00
*        radin            th         houtl         houtv         toutl
    2.2000e-01    4.0000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv         avlve         hvlve         favlve          xpos
    3.0000e+02    1.5210e-01    2.5400e-01    0.0000e+00    0.0000e+00
```

```
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    * f   2.0000e+00e
* vol   * f   3.0420e-01e
* fa    * f   1.5210e-01e
* fric  * f   0.0000e+00e
* grav  * r02-1.0000e+00    0.0000e+00e
* hd    * f   2.5400e-01e
* nff   *             -1r02          1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     3.2500e+02    5.5000e+02e
* tv    *     3.2500e+02    5.5000e+02e
* p     *     4.0800e+06    1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *               6e
* tw    *     3.2500e+02    5.5000e+02e
* vtb1  * r02 0.0000e+00    1.0000e-05    1.0000e+00e
*
*******   type           num            id        ctitle
pipe                      21            21 $21$ int-loop accumulator
*       ncells         nodes          jun1          jun2          epsw
             3             0            31            22    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             2             0
*        radin            th         houtl         houtv         toutl
    1.6821e+00    1.0000e-02    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv         powin        powoff        rpowmx        powscl
    3.0000e+02    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    *     1.5000e+00    3.0580e+00    2.0000e-01e
* vol   *     4.0000e+01    8.1560e+01    5.3410e+00e
* fa    * r03 2.6670e+01    1.5210e-01e
* fric  * f   0.0000e+00e
* grav  * f  -1.0000e+00e
* hd    * r03 3.3650e+00    2.5400e-01e
* nff   * r03           1             -1e
* alp   *     1.0000e+00r02 0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   3.2500e+02e
* tv    * f   3.2500e+02e
* p     * f   4.0800e+06e
* pa    *     4066454.05r02 0.0000e+00e
*
*******   type           num            id        ctitle
fill                      22            22 $22$ int-loop prizer top
*         jun2          ifty          ioff
            23             1             0
*       twtold         rfmx        concin          felv
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*         dxin         volin         alpin         vlin          tlin
    6.0107e+00    2.0580e+01    1.0000e+00    0.0000e+00    6.1797e+02
*          pin         pain        flowin         vvin          tvin
    1.5513e+07    0.0000e+00    0.0000e+00    0.0000e+00    6.1797e+02
*
*******   type           num            id        ctitle
fill                      23            23 $23$ int-loop sec-side feedwater
*         jun2          ifty          ioff
            24             1             0
*       twtold         rfmx        concin          felv
```

```
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*         dxin          volin          alpin          vlin          tlin
    1.0000e+00    1.5000e+00    0.0000e+00    0.0000e+00    4.4000e+02
*          pin          pain         flowin          vvin          tvin
    4.8500e+06    0.0000e+00    0.0000e+00    0.0000e+00    4.4000e+02
*
*******   type           num            id        ctitle
break                     24            24 $24$ int-loop sec pressure bc
*         jun1          ibty          isat          ioff
            25             0             0             0
*         dxin          volin          alpin           tin           pin
    4.3500e+00    7.4400e+01    1.0000e+00    5.3514e+02    4.8500e+06
*         pain         concin          rbmx          poff          belv
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
*******   type           num            id        ctitle
fill                      25            25 $25$ int-loop hpis & lpis
*         jun2          ifty          ioff
            26             4             0
*         iftr          ifsv          nftb          nfsv          nfrf
              0             2            17             0             0
*       twtold          rfmx         concin          felv
    0.0000e+00    1.0000e+05    0.0000e+00    0.0000e+00
*         dxin          volin          alpin          vlin          tlin
    1.0000e+00    6.0000e-03    0.0000e+00    0.0000e+00    3.2500e+02
*          pin          pain         flowin          vvin          tvin
    1.0200e+07    0.0000e+00    0.0000e+00    0.0000e+00    3.2500e+02
*        vmscl         vvscl
    1.0000e+00    0.0000e+00
*
* vmtb  *     0.0000e+00    3.2800e+01    2.0000e+05    3.3600e+01
4.0000e+05
* vmtb  *     3.3800e+01    6.0000e+05    3.2200e+01    8.0000e+05
2.6800e+01
* vmtb  *     9.0000e+05    2.5000e+01    1.0000e+06    1.9700e+01
1.1000e+06
* vmtb  *     1.5000e+01    1.2000e+06    9.4000e+00    1.2300e+06
7.8000e+00
* vmtb  *     1.2700e+06    7.2000e+00    1.5000e+06    7.2000e+00
4.0000e+06
* vmtb  *     3.5000e+00    6.0000e+06    3.3000e+00    8.0000e+06
2.6000e+00
* vmtb  *     1.0000e+07    1.0000e+00    1.0200e+07    0.0000e+00e
*
*******   type           num            id        ctitle
vessel                    26            26 $26$ 3-d vessel
*         nasx          nrsx          ntsx          ncsr        ivssbf
              7             2             4             7             0
*         idcu          idcl          idcr          icru          icrl
              6             2             1             5             2
*         icrr         ilcsp         iucsp          iuhp         iconc
              1             0             0             0             0
*        igeom         nvent         nvvtb
              0             0             0
*        shelv          epsw          nolt     rfldinput
    0.0000e+00    0.0000e+00             0             1
*
* z     *     1.7900e+00    2.9750e+00    4.1891e+00    5.4033e+00
6.6174e+00
* z     *     1.0820e+01    1.2510e+01e
* rad   *     1.9411e+00    2.1971e+00e
* th    *     1.5708e+00    3.1416e+00    4.7124e+00    6.2832e+00e
* unheatFr* f        0.0 e
* nhsca *            140           171           172           173 f 0 e
```

```
*
*        lisrl         lisrc         lisrf         ljuns
             6             1             3             1
             6             3             3            11
             6             5             3             6
             6             6             3            27
             6             7             3            28
             6             8             3            29
             6             8             3            30
*
* level   1
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   3.7000e-03e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   3.7000e-03e
* cfzv-r* f   0.0000e+00e
* vol   * r04 6.6390e-01r04 3.6510e-01e
* fa-t  * r04 4.4000e-01r04 3.3000e-01e
* fa-z  * r04 6.6390e-01r04 5.7132e-01e
* fa-r  * r04 3.8917e-01r04 0.0000e+00e
* hd-t  * r04 7.4000e-01r04 8.2000e-01e
* hd-z  * r04 7.4000e-01r04 8.2000e-01e
* hd-r  * r04 7.4000e-01r04 8.2000e-01e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
* level   2
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* r04 1.3025e-02r04 0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* r04 1.3025e-02r04 0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * r04 7.1920e-01r04 8.6300e-01e
* fa-t  * r04 6.0000e-01r04 6.5000e-01e
* fa-z  * r04 2.5000e-01r04 8.5000e-01e
* fa-r  * r04 5.0000e-01r04 0.0000e+00e
* hd-t  * r04 2.3000e-01r04 4.1000e-01e
* hd-z  * r04 1.3000e-02r04 4.1000e-01e
* hd-r  * r04 2.3000e-01r04 4.1000e-01e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
```

```
* level   3
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * r04 3.9020e-01r04 9.3700e-01e
* fa-t  * r04 3.9020e-01r04 6.9250e-01e
* fa-z  * r04 3.9020e-01r04 9.3700e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * r04 1.3000e-02r04 1.7800e-01e
* hd-z  * r04 1.3000e-02r04 1.7800e-01e
* hd-r  * r04 1.3000e-02r04 1.7800e-01e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
* level   4
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * r04 3.9020e-01r04 9.3700e-01e
* fa-t  * r04 3.9020e-01r04 6.9250e-01e
* fa-z  * r04 3.9020e-01r04 9.3700e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * r04 1.3000e-02r04 1.7800e-01e
* hd-z  * r04 1.3000e-02r04 1.7800e-01e
* hd-r  * r04 1.3000e-02r04 1.7800e-01e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
* level   5
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* r04 5.1380e-03r04 0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* r04 5.1380e-03r04 0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * r04 3.9020e-01r04 9.3700e-01e
* fa-t  * r04 3.9020e-01r04 6.9250e-01e
```

```
* fa-z  * r04 2.5000e-01r04 9.3700e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * r04 1.3000e-02r04 1.7800e-01e
* hd-z  * r04 1.3000e-02r04 1.7800e-01e
* hd-r  * r04 1.3000e-02r04 1.7800e-01e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
* level   6
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   1.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   1.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * r04 9.5000e-01r04 9.0000e-01e
* fa-t  * r04 6.0000e-01r04 3.0000e-01e
* fa-z  * r04 7.2000e-02r04 0.0000e+00e
* fa-r  * f   0.0000e+00e
* hd-t  * r04 2.3000e-01r04 1.7800e-01e
* hd-z  * r04 2.3000e-01r04 1.7800e-01e
* hd-r  * r04 2.3000e-01r04 1.7800e-01e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
* level   7
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * r04 8.0000e-01r04 7.0000e-01e
* fa-t  * r04 8.0000e-01r04 2.9000e-01e
* fa-z  * f   0.0000e+00e
* fa-r  * r04 5.0000e-01r04 0.0000e+00e
* hd-t  * r04 3.5000e-01r04 1.6900e+00e
* hd-z  * r04 3.5000e-01r04 1.6900e+00e
* hd-r  * r04 3.5000e-01r04 1.6900e+00e
* alpn  * f   0.0000e+00e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
```

```
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.5000e+02e
* tln   * f   5.5000e+02e
* pn    * f   1.5513e+07e
* pan   * f   0.0000e+00e
*
*******   type           num            id        ctitle
tee                       27            27 $27$ brk-loop sec boiler/stdome
*        jcell         nodes          ichf          cost          epsw
               3             0             0    6.1248e-01    0.0000e+00
*       iconc1        ncell1          jun1          jun2          ipow1
               0             3            19            10             0
*        radin            th         houtl         houtv         toutl
    9.8500e-03    1.2700e-03    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*       iconc2        ncell2          jun3         ipow2
               0             1            18             0
*       radin2           th2        houtl2        houtv2        toutl2
    1.4600e+00    3.0000e-03    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv2
    3.0000e+02
*
* dx    * f   4.3500e+00e
* vol   * f   2.4800e+01e
* fa    *     1.0000e+00r03 5.7011e+00e
* fric  *     2.0000e-01r02 0.0000e+00    1.0000e+30e
* grav  *     6.2617e-01r03 1.0000e+00e
* hd    * r03 3.4170e-02    2.6942e+00e
* nff   * f             1e
* alp   *     0.0000e+00    2.3000e-01    1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.3514e+02e
* tv    * f   5.3514e+02e
* p     * f   4.8500e+06e
* pa    * f   0.0000e+00e
*
* dx    *     2.1750e+00e
* vol   *     6.5250e+00e
* fa    *     5.0000e+00    1.5000e+00e
* fric  *     1.0000e-10    3.0000e-03e
* grav = -1.0875/(0.5x(1.7258+2.175)) = -0.55758
* where 1.7258 = 0.5x(0.03417+2.6942)/sqrt(1.0-costxcost)
* grav  *    -5.5758e-01   -1.0000e+00e
* hd    * f   1.0000e-01e
* nff   * f             1e
* alp   *     1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     5.3514e+02e
* tv    *     5.3514e+02e
* p     *     4.8500e+06e
* pa    *     0.0000e+00e
*
*******   type           num            id        ctitle
tee                       28            28 $28$ int-loop sec boiler/stdome
*        jcell         nodes          ichf          cost          epsw
               3             0             0    6.1248e-01    0.0000e+00
*       iconc1        ncell1          jun1          jun2          ipow1
               0             3            34            25             0
*        radin            th         houtl         houtv         toutl
    9.8500e-03    1.2700e-03    0.0000e+00    0.0000e+00    3.0000e+02
```

```
*        toutv
    3.0000e+02
*       iconc2        ncell2          jun3         ipow2
             0             1            33             0
*       radin2           th2        houtl2        houtv2        toutl2
    1.4600e+00    3.0000e-03    0.0000e+00    0.0000e+00    3.0000e+02
*       toutv2
    3.0000e+02
*
* dx    * f   4.3500e+00e
* vol   * f   7.4400e+01e
* fa    *     3.0000e+00r03 1.7103e+01e
* fric  *     2.0000e-01r02 0.0000e+00    1.0000e+30e
* grav  *     6.2617e-01r03 1.0000e+00e
* hd    * r03 3.4170e-02    2.6942e+00e
* nff   * f             1e
* alp   *     0.0000e+00    2.3000e-01    1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.3514e+02e
* tv    * f   5.3514e+02e
* p     * f   4.8500e+06e
* pa    * f   0.0000e+00e
*
* dx    *     2.1750e+00e
* vol   *     1.9575e+01e
* fa    *     1.5000e+01    4.5000e+00e
* fric  *     1.0000e-10    3.0000e-03e
* grav  *    -5.5758e-01   -1.0000e+00e
* hd    * f   1.0000e-01e
* nff   * f             1e
* alp   *     1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     5.3514e+02e
* tv    *     5.3514e+02e
* p     *     4.8500e+06e
* pa    *     0.0000e+00e
*
*******   type            num            id        ctitle
fill                       31            31 $31$ int-loop accum top
*         jun2          ifty          ioff
            31             1             0
*       twtold          rfmx        concin          felv
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*         dxin          volin         alpin          vlin          tlin
    1.5000e+00    4.0000e+01    1.0000e+00    0.0000e+00    3.2500e+02
*          pin          pain        flowin          vvin          tvin
    4.0800e+06    4066454.05    0.0000e+00    0.0000e+00    3.2500e+02
*
*******   type            num            id        ctitle
pipe                       41            41 $41$ int-loop c-leg vssl c6
*       ncells         nodes          jun1          jun2          epsw
             2             1            41            27    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*        radin           th         houtl         houtv         toutl
    4.7700e-01    1.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
```

```
*
* dx     * f   7.4990e-01e
* vol    * f   2.9584e-01e
* fa     * r02 3.8300e-01    5.5200e-01e
* fric   * f   0.0000e+00e
* grav   * f   0.0000e+00e
* hd     * r02 6.9850e-01    8.3820e-01e
* nff    * r02          1           -1e
* alp    * f   0.0000e+00e
* vl     * f   0.0000e+00e
* vv     * f   0.0000e+00e
* tl     * f   5.5000e+02e
* tv     * f   5.5000e+02e
* p      * f   1.5513e+07e
* pa     * f   0.0000e+00e
* qppp   * f   0.0000e+00e
* matid  *              6e
* tw     * f   5.5000e+02e
*
*******   type           num            id        ctitle
pipe                      42            42 $42$ int-loop c-leg vssl c7
*       ncells         nodes          jun1          jun2          epsw
             2             1            42            28    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*        radin            th         houtl         houtv         toutl
    4.7700e-01    1.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx     * f   7.4990e-01e
* vol    * f   2.9584e-01e
* fa     * r02 3.8300e-01    5.5200e-01e
* fric   * f   0.0000e+00e
* grav   * f   0.0000e+00e
* hd     * r02 6.9850e-01    8.3820e-01e
* nff    * r02          1           -1e
* alp    * f   0.0000e+00e
* vl     * f   0.0000e+00e
* vv     * f   0.0000e+00e
* tl     * f   5.5000e+02e
* tv     * f   5.5000e+02e
* p      * f   1.5513e+07e
* pa     * f   0.0000e+00e
* qppp   * f   0.0000e+00e
* matid  *              6e
* tw     * f   5.5000e+02e
*
*******   type           num            id        ctitle
pipe                      43            43 $43$ int-loop c-leg vssl c8
*       ncells         nodes          jun1          jun2          epsw
             2             1            43            29    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*        radin            th         houtl         houtv         toutl
    4.7700e-01    1.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
```

```
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    * f   7.4990e-01e
* vol   * f   1.4792e-01e
* fa    * r02 1.9150e-01    2.7600e-01e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * r02 6.9850e-01    8.3820e-01e
* nff   * r02          1            -1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
*******   type           num            id        ctitle
pipe                      44            44 $44$ int-loop c-leg vssl c8
*       ncells         nodes          jun1          jun2          epsw
             2             1            44            30    0.0000e+00
*         ichf         iconc      pipeType          ipow
             0             0             0             0
*       iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*        radin            th         houtl         houtv         toutl
    4.7700e-01    1.0000e-01    0.0000e+00    0.0000e+00    3.0000e+02
*        toutv
    3.0000e+02
*        qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    * f   7.4990e-01e
* vol   * f   1.4792e-01e
* fa    * r02 1.9150e-01    2.7600e-01e
* fric  * f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * r02 6.9850e-01    8.3820e-01e
* nff   * r02          1            -1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   5.5000e+02e
* tv    * f   5.5000e+02e
* p     * f   1.5513e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid *              6e
* tw    * f   5.5000e+02e
*
*******   type           num            id        ctitle
*         type           num            id        ctitle
htstr                     126           126 $126$ bkn-loop st-gen tubes
*      nzhtstr          ittc         hscyl          ichf
             2             0             1             1
*    nofuelrod        plane         liqlev        iaxcnd
             1             3             0             0
*        nmwrx         nfci          nfcil         hdri          hdro
             0             0             0    1.4800E-02    3.4170E-02
*         nhot         nodes          fmon         nzmax     refloodon
```

```
              0             3             0             3             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    3.0000E+00    1.0000E+01    4.3500E+00    0.0000E+00    0.0000E+00
*       idbciN
f             2e
*       idbcoN
f             2e
*       nhcomi        nhcelii       nhcelji       nhcelki
              2             2             0            0e
              2             3             0            0e
*       nhcomo        nhcelio       nhceljo       nhcelko
             27             1             0            0e
             27             2             0            0e
*      dhtstrz
    4.3500E+00    4.3500E+00e
*          rdx
    4.4430E+03e
*        radrd
    9.8500E-03    1.0485E-02    1.1120E-02e
*        matrd
             10            10e
*         nfax
              0             0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id         ctitle
htstr                    127           127 $127$ bkn-loop st-gen tubes
*      nzhtstr          ittc         hscyl          ichf
              2             0             1             1
*    nofuelrod         plane        liqlev        iaxcnd
              1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
              0             0             0    1.4800E-02    3.4170E-02
*         nhot         nodes          fmon         nzmax     refloodon
              0             3             0             3             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    3.0000E+00    1.0000E+01    4.3500E+00    0.0000E+00    0.0000E+00
*       idbciN
f             2e
*       idbcoN
f             2e
*       nhcomi        nhcelii       nhcelji       nhcelki
              3             4             0            0e
              3             5             0            0e
*       nhcomo        nhcelio       nhceljo       nhcelko
             27             1             0            0e
             27             2             0            0e
*      dhtstrz
    4.3500E+00    4.3500E+00e
*          rdx
    4.4430E+03e
*        radrd
    9.8500E-03    1.0485E-02    1.1120E-02e
*        matrd
             10            10e
*         nfax
              0             0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id         ctitle
htstr                    128           128 $128$ int-loop st-gen tubes
*      nzhtstr          ittc         hscyl          ichf
```

```
              2             0             1             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    1.4800E-02    3.4170E-02
*          nhot         nodes          fmon         nzmax      refloodon
              0             3             0             3             0
*        dtxht1        dtxht2         dznht         hgapo         radin
     3.0000E+00    1.0000E+01    4.3500E+00    0.0000E+00    0.0000E+00
*        idbciN
f             2e
*        idbcoN
f             2e
*        nhcomi        nhcelii        nhcelji        nhcelki
             11             2             0            0e
             11             3             0            0e
*        nhcomo        nhcelio        nhceljo        nhcelko
             28             1             0            0e
             28             2             0            0e
*       dhtstrz
     4.3500E+00    4.3500E+00e
*           rdx
     1.3329E+04e
*         radrd
     9.8500E-03    1.0485E-02    1.1120E-02e
*         matrd
             10           10e
*          nfax
              0            0e
*          rftn
     5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
     5.5000E+02e
*          type           num            id         ctitle
htstr                     129           129 $129$ int-loop st-gen tubes
*       nzhtstr          ittc         hscyl          ichf
              2             0             1             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    1.4800E-02    3.4170E-02
*          nhot         nodes          fmon         nzmax      refloodon
              0             3             0             3             0
*        dtxht1        dtxht2         dznht         hgapo         radin
     3.0000E+00    1.0000E+01    4.3500E+00    0.0000E+00    0.0000E+00
*        idbciN
f             2e
*        idbcoN
f             2e
*        nhcomi        nhcelii        nhcelji        nhcelki
             12             4             0            0e
             12             5             0            0e
*        nhcomo        nhcelio        nhceljo        nhcelko
             28             1             0            0e
             28             2             0            0e
*       dhtstrz
     4.3500E+00    4.3500E+00e
*           rdx
     1.3329E+04e
*         radrd
     9.8500E-03    1.0485E-02    1.1120E-02e
*         matrd
             10           10e
*          nfax
              0            0e
```

```
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id        ctitle
htstr                    130           130 $130$ vessel slabs (R1,L1)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    7.4000E-01
*        width        ipatch
    9.1400E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             1             1            1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    141           141 $130$ vessel slabs (R1,L1)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    7.4000E-01
*        width        ipatch
    9.1400E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             1             2            1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
```

```
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    142           142 $130$ vessel slabs (R1,L1)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod        plane         liqlev        iaxcnd
             1             3             0             0
*        nmwrx         nfci          nfcil          hdri          hdro
             0             0             0    0.0000E+00    7.4000E-01
*        width        ipatch
    9.1400E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             3            1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    143           143 $130$ vessel slabs (R1,L1)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod        plane         liqlev        iaxcnd
             1             3             0             0
*        nmwrx         nfci          nfcil          hdri          hdro
             0             0             0    0.0000E+00    7.4000E-01
*        width        ipatch
    9.1400E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             4            1e
*      dhtstrz
```

```
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type            num             id         ctitle
htstr                     131            131 $131$ vessel slabs (R2,L1)
*      nzhtstr           ittc          hscyl           ichf
             1              0              0              1
*    nofuelrod         plane         liqlev         iaxcnd
             1              3              0              0
*        nmwrx          nfci          nfcil           hdri           hdro
             0              0              0    0.0000E+00    8.2000E-01
*        width         ipatch
    8.1000E-01              0
*         nhot          nodes           fmon          nzmax     refloodon
             0              2              0              2              0
*       dtxht1         dtxht2         dznht          hgapo          radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo        nhcelio        nhceljo        nhcelko
            26              2              1             1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type            num             id         ctitle
htstr                     144            144 $131$ vessel slabs (R2,L1)
*      nzhtstr           ittc          hscyl           ichf
             1              0              0              1
*    nofuelrod         plane         liqlev         iaxcnd
             1              3              0              0
*        nmwrx          nfci          nfcil           hdri           hdro
             0              0              0    0.0000E+00    8.2000E-01
*        width         ipatch
    8.1000E-01              0
*         nhot          nodes           fmon          nzmax     refloodon
             0              2              0              2              0
*       dtxht1         dtxht2         dznht          hgapo          radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
```

```
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
           26             2             2            1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
           6e
*         nfax
           0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type          num           id        ctitle
htstr                   145          145 $131$ vessel slabs (R2,L1)
*      nzhtstr         ittc         hscyl          ichf
           1            0             0            1
*    nofuelrod        plane        liqlev        iaxcnd
           1            3             0            0
*        nmwrx         nfci         nfcil          hdri          hdro
           0            0             0    0.0000E+00    8.2000E-01
*        width        ipatch
    8.1000E-01            0
*         nhot        nodes          fmon         nzmax     refloodon
           0            2             0            2             0
*       dtxht1       dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
f           0e
*       idbcoN
f           2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
           26             2             3            1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
           6e
*         nfax
           0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type          num           id        ctitle
htstr                   146          146 $131$ vessel slabs (R2,L1)
*      nzhtstr         ittc         hscyl          ichf
           1            0             0            1
*    nofuelrod        plane        liqlev        iaxcnd
           1            3             0            0
*        nmwrx         nfci         nfcil          hdri          hdro
           0            0             0    0.0000E+00    8.2000E-01
*        width        ipatch
    8.1000E-01            0
*         nhot        nodes          fmon         nzmax     refloodon
           0            2             0            2             0
*       dtxht1       dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    0.0000E+00
*       idbciN
```

```
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             2             4            1e
*      dhtstrz
    1.7900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
            6e
*         nfax
            0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                   132           132 $132$ vessel slabs (R1,L2)
*      nzhtstr          ittc         hscyl          ichf
            1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    1.3000E-02
*        width         ipatch
    1.1300E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
            0             2             0             2             0
*       dtxht1        dtxht2         dznht          hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             1            2e
*      dhtstrz
    1.1850E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
            6e
*         nfax
            0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                   147           147 $132$ vessel slabs (R1,L2)
*      nzhtstr          ittc         hscyl          ichf
            1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    1.3000E-02
*        width         ipatch
    1.1300E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
```

```
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             2            2e
*       dhtstrz
    1.1850E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
             6e
*          nfax
             0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                     148           148 $132$ vessel slabs (R1,L2)
*       nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*     nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    1.3000E-02
*         width        ipatch
    1.1300E+01             0
*          nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             3            2e
*       dhtstrz
    1.1850E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
             6e
*          nfax
             0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                     149           149 $132$ vessel slabs (R1,L2)
*       nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*     nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
```

```
              0             0             0    0.0000E+00    1.3000E-02
*         width        ipatch
    1.1300E+01             0
*          nhot         nodes          fmon          nzmax     refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht          hgapo          radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             1             4             2e
*       dhtstrz
    1.1850E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
             6e
*          nfax
             0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                    133           133 $133$ vessel slabs (R2,L2)
*       nzhtstr          ittc         hscyl          ichf
              1             0             0             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
              0             0             0    0.0000E+00    4.1000E-01
*         width        ipatch
    8.5700E+00             0
*          nhot         nodes          fmon          nzmax     refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht          hgapo          radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             2             1             2e
*       dhtstrz
    1.1850E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
             6e
*          nfax
             0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                    150           150 $133$ vessel slabs (R2,L2)
*       nzhtstr          ittc         hscyl          ichf
```

```
              1             0             0             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    0.0000E+00    4.1000E-01
*         width         ipatch
    8.5700E+00             0
*          nhot         nodes          fmon         nzmax      refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*        nhcomo        nhcelio        nhceljo        nhcelko
             26              2              2             2e
*       dhtstrz
    1.1850E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
              6e
*          nfax
              0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                     151           151 $133$ vessel slabs (R2,L2)
*       nzhtstr          ittc         hscyl          ichf
              1             0             0             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    0.0000E+00    4.1000E-01
*         width         ipatch
    8.5700E+00             0
*          nhot         nodes          fmon         nzmax      refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*        nhcomo        nhcelio        nhceljo        nhcelko
             26              2              3             2e
*       dhtstrz
    1.1850E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
              6e
*          nfax
              0e
*          rftn
```

```
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    152           152 $133$ vessel slabs (R2,L2)
*      nzhtstr          ittc         hscyl          ichf
              1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
              1             3             0             0
*        nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    0.0000E+00    4.1000E-01
*        width         ipatch
    8.5700E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
              0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.7900E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             2             4            2e
*      dhtstrz
    1.1850E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    134           134 $134$ vessel slabs (R1,L3/4/5)
*      nzhtstr          ittc         hscyl          ichf
              3             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
              1             3             0             0
*        nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    0.0000E+00    1.3000E-02
*        width         ipatch
    1.0000E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
              0             2             0             4             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    2.9750E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             1             1            3e
             26             1             1            4e
             26             1             1            5e
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*          rdx
```

```
    1.0000E+00e
*        radrd
    0.0000E+00    7.0000E-03e
*        matrd
             6e
*         nfax
             0             0             0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id        ctitle
htstr                    153           153 $134$ vessel slabs (R1,L3/4/5)
*      nzhtstr          ittc         hscyl          ichf
             3             0             0             1
*    nofuelrod         plane         liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci          nfcil          hdri          hdro
             0             0             0    0.0000E+00    1.3000E-02
*        width         ipatch
    1.0000E+00             0
*         nhot         nodes          fmon          nzmax     refloodon
             0             2             0              4             0
*       dtxht1        dtxht2         dznht          hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    2.9750E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             2             3e
            26             1             2             4e
            26             1             2             5e
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    7.0000E-03e
*        matrd
             6e
*         nfax
             0             0             0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id        ctitle
htstr                    154           154 $134$ vessel slabs (R1,L3/4/5)
*      nzhtstr          ittc         hscyl          ichf
             3             0             0             1
*    nofuelrod         plane         liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci          nfcil          hdri          hdro
             0             0             0    0.0000E+00    1.3000E-02
*        width         ipatch
    1.0000E+00             0
*         nhot         nodes          fmon          nzmax     refloodon
             0             2             0              4             0
*       dtxht1        dtxht2         dznht          hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    2.9750E+00
*       idbciN
```

```
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             3            3e
            26             1             3            4e
            26             1             3            5e
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    7.0000E-03e
*        matrd
            6e
*         nfax
            0             0            0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id         ctitle
htstr                   155           155 $134$ vessel slabs (R1,L3/4/5)
*      nzhtstr          ittc         hscyl          ichf
            3             0             0             1
*    nofuelrod         plane         liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    1.3000E-02
*        width        ipatch
    1.0000E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
            0             2             0             4             0
*       dtxht1       dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    2.9750E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             4            3e
            26             1             4            4e
            26             1             4            5e
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    7.0000E-03e
*        matrd
            6e
*         nfax
            0             0            0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id         ctitle
```

```
htstr                   135          135 $135$ vessel slabs (R2,L3/4/5)
*      nzhtstr         ittc         hscyl          ichf
             3            0             0             1
*    nofuelrod        plane        liqlev        iaxcnd
             1            3             0             0
*        nmwrx         nfci         nfcil          hdri          hdro
             0            0             0  0.0000E+00  1.7800E-01
*        width        ipatch
  1.9100E+01             0
*         nhot        nodes         fmon         nzmax     refloodon
             0            2             0             4             0
*       dtxht1       dtxht2       dznht         hgapo         radin
  4.0000E+00  5.0000E+01  5.0000E-03  0.0000E+00  2.9750E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
  0.0000E+00e
  0.0000E+00e
  0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             2             1            3e
            26             2             1            4e
            26             2             1            5e
*      dhtstrz
  1.2141E+00  1.2142E+00  1.2141E+00e
*          rdx
  1.0000E+00e
*        radrd
  0.0000E+00  1.0000E-02e
*        matrd
             6e
*         nfax
             0            0            0e
*         rftn
  5.5000E+02  5.5000E+02  5.5000E+02  5.5000E+02  5.5000E+02s
  5.5000E+02e
*         type          num           id        ctitle
htstr                   156          156 $135$ vessel slabs (R2,L3/4/5)
*      nzhtstr         ittc         hscyl          ichf
             3            0             0             1
*    nofuelrod        plane        liqlev        iaxcnd
             1            3             0             0
*        nmwrx         nfci         nfcil          hdri          hdro
             0            0             0  0.0000E+00  1.7800E-01
*        width        ipatch
  1.9100E+01             0
*         nhot        nodes         fmon         nzmax     refloodon
             0            2             0             4             0
*       dtxht1       dtxht2       dznht         hgapo         radin
  4.0000E+00  5.0000E+01  5.0000E-03  0.0000E+00  2.9750E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
  0.0000E+00e
  0.0000E+00e
  0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             2             2            3e
            26             2             2            4e
            26             2             2            5e
```

```
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*         rdx
    1.0000E+00e
*       radrd
    0.0000E+00    1.0000E-02e
*       matrd
           6e
*        nfax
           0             0             0e
*        rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num           id        ctitle
htstr                    157          157 $135$ vessel slabs (R2,L3/4/5)
*      nzhtstr          ittc         hscyl          ichf
           3              0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
           1              3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
           0              0             0    0.0000E+00    1.7800E-01
*        width        ipatch
    1.9100E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
           0              2             0             4             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    2.9750E+00
*       idbciN
f           0e
*       idbcoN
f           2e
*       qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
           26             2             3             3e
           26             2             3             4e
           26             2             3             5e
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*         rdx
    1.0000E+00e
*       radrd
    0.0000E+00    1.0000E-02e
*       matrd
           6e
*        nfax
           0             0             0e
*        rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num           id        ctitle
htstr                    158          158 $135$ vessel slabs (R2,L3/4/5)
*      nzhtstr          ittc         hscyl          ichf
           3              0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
           1              3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
           0              0             0    0.0000E+00    1.7800E-01
*        width        ipatch
    1.9100E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
           0              2             0             4             0
```

```
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    2.9750E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             2             4             3e
             26             2             4             4e
             26             2             4             5e
*      dhtstrz
    1.2141E+00    1.2142E+00    1.2141E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0             0             0e
*         rftn
    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02    5.5000E+02s
    5.5000E+02e
*         type           num            id         ctitle
htstr                    136           136 $136$ vessel slabs (R1,L6)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev         iaxcnd
             1             3             0             0
*        nmwrx         nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    2.3000E-01
*        width        ipatch
    2.4900E+01             0
*         nhot        nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             1             1             6e
*      dhtstrz
    4.2026E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    9.0000E-03e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id         ctitle
htstr                    159           159 $136$ vessel slabs (R1,L6)
*      nzhtstr          ittc         hscyl          ichf
```

```
              1             0             0             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    0.0000E+00    2.3000E-01
*         width         ipatch
     2.4900E+01             0
*          nhot         nodes          fmon         nzmax      refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht         hgapo         radin
     4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
     0.0000E+00e
*        nhcomo        nhcelio        nhceljo        nhcelko
             26              1              2             6e
*       dhtstrz
     4.2026E+00e
*           rdx
     1.0000E+00e
*         radrd
     0.0000E+00    9.0000E-03e
*          matrd
             6e
*          nfax
             0e
*          rftn
     5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                     160           160 $136$ vessel slabs (R1,L6)
*       nzhtstr          ittc         hscyl          ichf
              1             0             0             1
*     nofuelrod         plane         liqlev         iaxcnd
              1             3             0             0
*         nmwrx          nfci          nfcil          hdri          hdro
              0             0             0    0.0000E+00    2.3000E-01
*         width         ipatch
     2.4900E+01             0
*          nhot         nodes          fmon         nzmax      refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht         hgapo         radin
     4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
     0.0000E+00e
*        nhcomo        nhcelio        nhceljo        nhcelko
             26              1              3             6e
*       dhtstrz
     4.2026E+00e
*           rdx
     1.0000E+00e
*         radrd
     0.0000E+00    9.0000E-03e
*          matrd
             6e
*          nfax
             0e
*          rftn
```

```
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    161           161 $136$ vessel slabs (R1,L6)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci          nfcil          hdri          hdro
             0             0             0    0.0000E+00    2.3000E-01
*        width         ipatch
    2.4900E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             4            6e
*      dhtstrz
    4.2026E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    9.0000E-03e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    137           137 $137$ vessel slabs (R2,L6)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci          nfcil          hdri          hdro
             0             0             0    0.0000E+00    1.7800E-01
*        width         ipatch
    7.5400E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             2             1            6e
*      dhtstrz
    4.2026E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
```

```
              6e
*          nfax
              0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id        ctitle
htstr                      162           162 $137$ vessel slabs (R2,L6)
*       nzhtstr          ittc         hscyl          ichf
              1             0             0             1
*     nofuelrod         plane        liqlev        iaxcnd
              1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
              0             0             0    0.0000E+00    1.7800E-01
*         width         ipatch
    7.5400E+00             0
*          nhot         nodes          fmon         nzmax     refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             2             2             6e
*       dhtstrz
    4.2026E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
              6e
*          nfax
              0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id        ctitle
htstr                      163           163 $137$ vessel slabs (R2,L6)
*       nzhtstr          ittc         hscyl          ichf
              1             0             0             1
*     nofuelrod         plane        liqlev        iaxcnd
              1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
              0             0             0    0.0000E+00    1.7800E-01
*         width         ipatch
    7.5400E+00             0
*          nhot         nodes          fmon         nzmax     refloodon
              0             2             0             2             0
*        dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             2             3             6e
*       dhtstrz
    4.2026E+00e
*           rdx
```

```
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
            6e
*         nfax
            0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                   164           164 $137$ vessel slabs (R2,L6)
*      nzhtstr          ittc         hscyl          ichf
            1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    1.7800E-01
*        width        ipatch
    7.5400E+00             0
*         nhot         nodes          fmon         nzmax     refloodon
            0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    6.6174E+00
*       idbciN
f           0e
*       idbcoN
f           2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
           26             2             4            6e
*      dhtstrz
    4.2026E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
            6e
*         nfax
            0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                   138           138 $138$ vessel slabs (R1,L7)
*      nzhtstr          ittc         hscyl          ichf
            1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    3.5000E-01
*        width        ipatch
    1.9500E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
            0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f           0e
*       idbcoN
f           2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
```

```
            26             1             1            7e
*      dhtstrz
    1.6900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    165           165 $138$ vessel slabs (R1,L7)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    3.5000E-01
*        width         ipatch
    1.9500E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             2            7e
*      dhtstrz
    1.6900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    166           166 $138$ vessel slabs (R1,L7)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    3.5000E-01
*        width         ipatch
    1.9500E+01             0
*         nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f            0e
*       idbcoN
```

```
f            2e
*       qflxbci
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             1             3            7e
*       dhtstrz
    1.6900E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
             6e
*          nfax
             0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                     167           167 $138$ vessel slabs (R1,L7)
*       nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*     nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    3.5000E-01
*         width        ipatch
    1.9500E+01             0
*          nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*        dtxht1        dtxht2        dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*        idbciN
f            0e
*        idbcoN
f            2e
*       qflxbci
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             1             4            7e
*       dhtstrz
    1.6900E+00e
*           rdx
    1.0000E+00e
*         radrd
    0.0000E+00    1.0000E-02e
*         matrd
             6e
*          nfax
             0e
*          rftn
    5.5000E+02    5.5000E+02e
*          type           num            id         ctitle
htstr                     139           139 $139$ vessel slabs (R2,L7)
*       nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*     nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*         nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    1.6900E+00
*         width        ipatch
    8.2800E-01             0
*          nhot         nodes          fmon         nzmax     refloodon
             0             2             0             2             0
*        dtxht1        dtxht2        dznht         hgapo         radin
```

```
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             2             1            7e
*      dhtstrz
    1.6900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
            6e
*         nfax
            0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    168           168 $139$ vessel slabs (R2,L7)
*      nzhtstr          ittc         hscyl          ichf
            1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    1.6900E+00
*        width        ipatch
    8.2800E-01             0
*         nhot         nodes          fmon         nzmax     refloodon
            0             2             0             2             0
*       dtxht1        dtxht2         dznht         hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f            0e
*       idbcoN
f            2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             2             2            7e
*      dhtstrz
    1.6900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
            6e
*         nfax
            0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id        ctitle
htstr                    169           169 $139$ vessel slabs (R2,L7)
*      nzhtstr          ittc         hscyl          ichf
            1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
            1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
            0             0             0    0.0000E+00    1.6900E+00
*        width        ipatch
```

```
    8.2800E-01             0
*         nhot         nodes          fmon         nzmax     refloodon
              0             2             0             2             0
*       dtxht1        dtxht2         dznht          hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             2             3             7e
*      dhtstrz
    1.6900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id         ctitle
htstr                    170           170 $139$ vessel slabs (R2,L7)
*      nzhtstr          ittc         hscyl          ichf
             1             0             0             1
*    nofuelrod         plane        liqlev        iaxcnd
             1             3             0             0
*        nmwrx          nfci         nfcil          hdri          hdro
             0             0             0    0.0000E+00    1.6900E+00
*        width        ipatch
    8.2800E-01             0
*         nhot         nodes          fmon         nzmax     refloodon
              0             2             0             2             0
*       dtxht1        dtxht2         dznht          hgapo         radin
    4.0000E+00    5.0000E+01    5.0000E-03    0.0000E+00    1.0820E+01
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
             26             2             4             7e
*      dhtstrz
    1.6900E+00e
*          rdx
    1.0000E+00e
*        radrd
    0.0000E+00    1.0000E-02e
*        matrd
             6e
*         nfax
             0e
*         rftn
    5.5000E+02    5.5000E+02e
*         type           num            id         ctitle
htstr                    140           140 $140$ reactor-core fuel rods
*      nzhtstr          ittc         hscyl          ichf
             3             0             1             1
*       nopowr         plane         liqlev        iaxcnd
```

```
              0             3             1             1
*         nmwrx          nfci         nfcil          hdri          hdro
              1             1             1  0.0000E+00  1.3000E-02
*          nhot         nodes         irftr         nzmax        irftr2
              1             8            12           100             0
*        dtxht1        dtxht2         dznht         hgapo         shelv
    4.0000E+00  5.0000E+01  5.0000E-03  6.0000E+03  2.9750E+00
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*        nhcomo       nhcelio       nhceljo       nhcelko
             26             1             1            3e
             26             1             1            4e
             26             1             1            5e
*       dhtstrz
f   1.2141E+00e
*           rdx
    9.8430E+03e
*         radrd
    0.0000E+00  2.0000E-03  3.0000E-03  4.0000E-03  4.6427E-03s
    4.7422E-03  5.0500E-03  5.3594E-03e
*         matrd
r04           1             3             2            2e
*          nfax
f             5e
*          rftn
f   5.5000E+02e
f   5.5000E+02e
*         fpuo2
f    0.0000E+00e
*           ftd
f    9.4500E-01e
*          gmix
    1.0000E+00 f  0.0000E+00e
*         gmles
f    0.0000E+00e
*          pgapt
f    1.0000E+07e
*          plvol
f    0.0000E+00e
*          pslen
f    0.0000E+00e
*          clenn
f    0.0000E+00e
*          burn
f   1.5400E+04e
f   1.5400E+04e
*          type           num            id        ctitle
htstr                    171           171 $140$ reactor-core fuel rods
*      numOrgHS
            -140
*        idbciN
f             0e
*        idbcoN
f             2e
*       qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
```

```
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             2            3e
            26             1             2            3e
            26             1             2            4e
            26             1             2            5e
            26             1             2            5e
*         type           num            id         ctitle
htstr                    172           172 $140$ reactor-core fuel rods
*     numOrgHS
           -140
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             3            3e
            26             1             3            3e
            26             1             3            4e
            26             1             3            5e
            26             1             3            5e
*         type           num            id         ctitle
htstr                    173           173 $140$ reactor-core fuel rods
*     numOrgHS
           -140
*       idbciN
f             0e
*       idbcoN
f             2e
*      qflxbci
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
    0.0000E+00e
*       nhcomo       nhcelio       nhceljo       nhcelko
            26             1             4            3e
            26             1             4            3e
            26             1             4            4e
            26             1             4            5e
            26             1             4            5e
*
*         type           num            id         ctitle
power                    174           174  Power Comp for reactor power
*          npwr
             4
*        htnid
           140           171           172          173e
*       irpwty         ndgx          ndhx          nrts         nhist
             6            0             0            10             0
*       irpwtr        irpwsv        nrpwtb        nrpwsv        nrpwrf
             0            1            20             0             0
*       izpwtr        izpwsv        nzpwtb        nzpwsv        nzpwrf
             0            1             1             0             0
*        ipwrad        ipwdep
             0             0
*         nzpwz         nzpwi         nfbpwt         nrpwr         nrpwi
```

```
              0             0             0             1             0
*         react         tneut         rpwoff        rrpwmx        rpwscl
    0.0000E+00    0.0000E+00    0.0000E+00    1.0000E+20    1.0000E+00
*        rpowri         zpwin        zpwoff        rzpwmx
    3.2500E+09    0.0000E+00    0.0000E+00    0.0000E+00
*        extsou          pldr         pdrat        fucrac
    0.0000E+00    0.0000E+00    1.3340E+00    1.0000E+00
*         rdpwr
    1.2109E+00    1.2371E+00    1.2703E+00    1.3201E+00    1.3823E+00s
    0.0000E+00    0.0000E+00    0.0000E+00e
*         cpowr
    1.0000E+00    1.0000E+00    1.0000E+00    1.0000E+00e
*          rpkf
           1.1           1.2           1.3           1.4e
*         zpwtb
     0.0000e+00    0.93748  0.93748     1.20535     0.83715s
     0.83715e
*         rpwtb
    0.0000E+00    3.2500E+09    1.0000E-01    2.2700E+08    1.0000E+00s
    1.9500E+08    2.0000E+00    1.8800E+08    5.0000E+00    1.7500E+08s
    1.0000E+01    1.6200E+08    1.5000E+01    1.5200E+08    2.0000E+01s
    1.4600E+08    5.0000E+01    1.2300E+08    7.5000E+01    1.1300E+08s
    1.0000E+02    1.0700E+08    1.2500E+02    1.0400E+08    1.5000E+02s
    1.0000E+08    2.0000E+02    9.4000E+07    2.5000E+02    8.8000E+07s
    3.0000E+02    8.4000E+07    3.5000E+02    8.0000E+07    4.0000E+02s
    7.7000E+07    5.0000E+02    7.2500E+07    9.0000E+02    5.5000E+07e
end
*
******************
* time-step data *
******************
*
*         dtmin         dtmax          tend          rtwfp
    4.0000e-04    4.0000e-04    2.0000e-03    1.0000e+01
*         edint         gfint         dmpint         sedint
    2.8000e-03    2.8000e-03    2.8000e-03    2.8000e-03
*
*         dtmin         dtmax          tend          rtwfp
    5.0000e-02    1.0000e+00    1.0000e+01    1.0000e+01
*         edint         gfint         dmpint         sedint
    1.2000e+01    5.0000e-01    1.2000e+01    1.2000e+01
*
*         dtmin         dtmax          tend          rtwfp
    5.0000e-02    2.0000e+00    5.0000e+01    1.0000e+01
*         edint         gfint         dmpint         sedint
    4.4000e+01    1.0000e+00    4.4000e+01    4.4000e+01
*
*         dtmin         dtmax          tend          rtwfp
    5.0000e-02    2.0000e+00    5.0000e+02    1.0000e+01
*         edint         gfint         dmpint         sedint
    4.5400e+02    2.0000e+00    4.5400e+02    4.5400e+02
*
*       endflag
   -1.0000e+00
```

# 3 CHANs & POWER Comp. Test Problem

```
free format
*************
* main data *
*************
*
*       numtcr          ieos         inopt          nmat
            1             0             1             0
*-*-*Power PROBLEM Req11. CHAN 25 in VESSEL. irpwty=7
*
*                                 #########
*                                 # break #
*                                 #   5   #  p= 7.0 mpa
*                                 #########
*                                     4
*                                 #########
*                                 # valve #
*                                 #   4   #
*                  favlve=0.95    #-------#
*                                 #  cell #
*                                 #   1   #
*                                 #########
*                                     3
*                                 #########
*                   node          # vessel#    node
*                   row           #   6   #     row
*                    5+++++++++---#-------#-----+5
*                     +       +---#  cell #---+  +
*                     +       +---#   5   #---+  +
*                    4+++++++++---#-------#-----+4
*                     +       +---#  cell #---+  +
*                     +       +---#   4   #---+  +
*                    3+++++++++---#-------#-----+3 ###########
*                     +       +---#  cell #---+  +  # chan    #
*                     +       +---#   3   #---+  +  #25,26,27 #
*                    2+++++++++---#-------#-----+2 ###########
*                     +       +---#  cell #---+  +
*                     +       +---#   2   #---+  +
*                    1+++++++++---#-------#-----+1
*                                 #  cell #
*                                 #   1   #
*                                 #########
*                                     2
*                                 #########
*                                 #  pipe #
*                    omegan=      #   2   #  tl=550.00k
*                   370.0rad/s    #-------#  ----------
*                                 #  cell #  tl=550.00k
*                                 #   1   #
*                                 #########
*                                     1       lmfw=17007.0kg/s
*                                 #########
*                                 # fill  # tl=554 K
*                                 #   1   #
*                                 #########
*
*****************
* namelist data *
*****************
*
 &inopts
```

```
    useSJC = 2, ikfac = 1, npower =   1,
 &end
*
*        dstep         timet
               0    0.0000e+00
*       stdyst        transi         ncomp          njun          ipak
               1             0             9            10             0
*         epso          epss
    1.0000e-04    1.0000e-04
*       oitmax        sitmax        isolut        ncontr         nccfl
              10            10             0             0             0
*         ntsv          ntcb          ntcf          ntrp          ntcp
              1             0             0             1             1
*
************************
* component-number data *
************************
*
* iorder*              1s     fill inlet mass-flow bc
* iorder*              2s     pump lower-plenum region
* iorder*              3s     vessel 1-d core region
* iorder*              4s     valve upper-plenum region
* iorder*              5s     break outlet pressure bc
* iorder*             25s     chan in vessel
* iorder*             26s     chan in vessel
* iorder*             27s     chan in vessel
* iorder*             28e     power component
*************************
* control-parameter data *
*************************
********************
* signal variables *
********************
*
*         idsv          isvn          ilcn          icn1          icn2
              1             0             0             0             0
*
*********
* trips *
*********
*         ntse          ntct          ntsf          ntdp          ntsd
              0             0             0             0             0
*1        idtp          isrt          iset          itst          idsg
            101             2             0             1             1
*3     setp(1)       setp(2)
         300.0         300.0
*4     dtsp(1)       dtsp(2)
    0.0000e+00    0.0000e+00
*5     ifsp(1)       ifsp(2)
               0             0
*
******************
* component data *
******************
*
*******   type           num            id        ctitle
fill                         1             1 fill inlet mass flow bc
*         jun1          ifty          ioff
              1             5             0
*             1             2             0
*         iftr          ifsv          nftb          nfsv          nfrf
              0             1             3             0             0
*       twtold          rfmx        concin          felv
    0.0000e+00    1.0000e+11    1.0000e-04    0.0000e+00
```

```
*         dxin          volin          alpin          vlin          tlin
          0.9106    1.0000e+00            0.0    0.0000e+00    5.000e+02
*           pin           pain         flowin          vvin          tvin
*     7.0000e+06       1.0e+03            0.0    0.0000e+00    5.5900e+02
      7.0000e+06       1.0e+03        51000.0    0.0000e+00    5.5900e+02
*         vlscl   vvscl
            1.0     1.0
*         time  mflow(kg/s)
            0.0         0.0s
          100.0      51000.0s
          1.e6       51000.0e
*
*******   type            num            id        ctitle
pipe                        2             2   pipe to vessel LP
*       ncells          nodes          jun1          jun2          epsw
              2              0             1             2    1.0000e-05
*       nsides
              0
*         ichf          iconc      pipeType          ipow
              0              0             0             0
*         radin             th         houtl         houtv         toutl
     5.0000e-01    5.0000e-02    0.0000e+00    0.0000e+00    5.0000e+02
*         toutv
     5.0000e+02
*
* dx    * f   0.9106e
 * vol   * f   1.0000e+00e
* fa    * f   1.0982e
* fric  * f   1.0000e+00e
* grav  * f   1.0000e+00e
* hd    * f   1.0000e+00e
* nff   * f           -1e
* alp   * f   0.0200e+00e
* vl    * f   5.5000e+01e
* vv    * f   5.5000e+01e
* tl    * f   5.0000e+02e
* tv    * f   5.5900e+02e
* p     * f   7.0e+06e
* pa    * f   0.0000e+00e
*
*******   type            num            id            ctitle
chan                        25            25            chan medium
*2      ncells          nodes          jun1          jun2          epsw
              4              4            60            61         1.e-5
*       nsides
              2
*      cellInd         JunID
              2           201
              3           301
*6        ichf          iconc        iaxcnd          liqlev         nhcom
              2              0             0               0             3
*7       width             th         houtl          houtv         toutl
         0.78224         .0077           0.0            0.0           0.0
*8       toutl     advBWRFuel       quadSym    numWaterRods       nVFRays
           0.0              1             0               1             0
*9        ngrp         nchans        nodesr          nrows          ncrz
              3              2             5              12             3
*10       icrnk          icrlh         nmwrx          nfci          nfcil
              1              0             0               0             0
*11       irfdt         irfdt2         nzmax          nzmaxw         ibeam
              0              0             5               5             0
*12       dznht         dznhtw        dtxht1         dtxht2
            0.1            0.1           5.0            10.0
*13       hgapo          pdrat          pldr          fucrac        notRad
```

```
        1000.0          1.33           0.0            1.0              0
*14     emcif1        emcif2         emcif3         notAni
          0.67           0.0            0.0             0
*15     emcof1        emcof2         emcof3
          0.67           0.0            0.0
*array data
*15 dx    * f   0.9106e
*16 vol   * f   1.0000e+00e
*17 fa    * f   1.7000e+00e
*18 fric  * f   0.0000e+00e
*19 grav  * f   1.0000e+00e
*20 hd    * f   1.1111e+00e
*22 nff   * f          -1e
*24 alp   * f   0.02e
*25 vl    * f   0.0000e+00e
*26 vv    * f   0.0000e+00e
*27 tl    * f   5.5000e+02e
*28 tv    * f   5.5900e+02e
*29 p     * f   7.0000e+06e
*30 pa    * f   0.0000e+00e
*31 qppp  * f   0.0000e+00e
*32 matid * f   6 e
*33 tw    * f   549.0 e
*37 idrodo* f           1 e
*38 nhcelo*        2     3    4    5e
*44 rdx   * 112.0 16.0 4.0 e
*45 radrd *  0.0 0.003 0.004 0.005 0.006 e
*46 matrd *  1 1 3 2 e
*47 nfax  *  f 2 e
*49 rftn  * f 560.0 e
*49 rftn  * f 560.0 e
*50 rdpwr *   1.2 1.0 0.6 0.0 0.0 e
*51 cpowr * 1.0 0.8 e
*   radpw * f 1.0 e
*52 fpuo2 * f   0.0001e
*53 ftd   * f   9.4000e-01e
*54 gmix  * f   1.0000e+00e
*55 pgapt * f 1.5e6 e
*
*  Replaced cell edge burn values with cell centered ones
*  Chris Murray - 8/21/03
*56 burn  * 0.015 0.025 0.035e
*56 burn  * 0.055 0.065 0.075e
*57 mrod  * r12 1 s
*57 mrod  * r12 1 s
*57 mrod  * r04 1 r04 3 r04 1s
*57 mrod  * r04 1 r04 3 r04 1s
*57 mrod  * r04 1 r04 2 r04 1s
*57 mrod  * r04 1 r04 2 r04 1s
*57 mrod  * r04 1 r04 2 r04 1s
*57 mrod  * r04 1 r04 2 r04 1s
*57 mrod  * r04 1 r04 3 r04 1s
*57 mrod  * r04 1 r04 3 r04 1s
*57 mrod  * r12 1 s
*57 mrod  * r12 1 s
*57 mrod  * 4e
*    Non-Default LevRods (i.e. partial length rods)
*    i     j   LevRod
     5     5     3
     6     5     3
     7     5     3
     8     5     3
     5     6     3
     6     6     3
```

```
      7     6     3
      8     6     3
      5     7     3
      6     7     3
      7     7     3
      8     7     3
      5     8     3
      6     8     3
      7     8     3
      8     8     3
     -1
*     Non-Default WaterRodFlgs
*     nRows = 12
*     radius = 0.006 m
*     dRod = 2x0.006 = 0.012 m
*     pitch = 1.33x0.12 = 0.01596 m
*     Min distance between edge of fuel rod and inside of channel box =
0.004 m
*     bundw = 11xpitch + dRod + 2x0.004 = 11x0.01596 + 0.012 + 0.008 =
0.19556 m
*     width = 4xbundw = 0.78224 m
*     xLoc for first water rod
*     0.004 + 4.5xpitch + radius
*     0.01 + 4.5x0.01596 = 0.08182 m
*     yLoc for first water rod
*     -0.004 - 2.5xpitch - radius
*     -0.01 - 2.5x0.01596 = 0.0499 m
*     xLoc for second water rod
*     0.004 + 6.5xpitch + radius
*     0.01 + 6.5x0.01596 = 0.11374 m
*     yLoc for second water rod
*     -0.004 - 2.5xpitch - radius
*     -0.01 - 2.5x0.01596 = -0.0499 m
*     xLoc for third water rod
*     0.01 + 4.5x0.01596 = 0.08182 m
*     yLoc for third water rod
*     -0.01 - 8.5x0.01596 = -0.14566 m
*     xLoc for fourth water rod
*     0.01 + 6.5x0.01596 = 0.11374 m
*     yLoc for fourth water rod
*     -0.01 - 8.5x0.01596 = -0.14566 m
*     i     j    WaterRodFlgs  xLoc      yLoc
      5     3       1          0.08182  -0.0499
      6     3       1          0.0       0.0
      5     4       1          0.0       0.0
      6     4       1          0.0       0.0
      7     3       1          0.11374  -0.0499
      8     3       1          0.0       0.0
      7     4       1          0.0       0.0
      8     4       1          0.0       0.0
      5     9       1          0.08182  -0.14566
      6     9       1          0.0       0.0
      5    10       1          0.0       0.0
      6    10       1          0.0       0.0
      7     9       1          0.11374  -0.14566
      8     9       1          0.0       0.0
      7    10       1          0.0       0.0
      8    10       1          0.0       0.0
     -1
*
*       geoType   rNodes
           1        3
*
* WR dia = 0.024 m
```

```
*     wRInlet  wROutlet     dia       sideA      sideB
         2        3       0.024
*
* 0.1" = 0.00254 m
*        th       rCorner     flowArea   flowAreaI   flowAreaO
         0.00254
*
*        hyDia    hyDiaI      hyDiaO     thermDiaI   thermDiaO
         0.0       0.01        0.01
*
*        FLossI    FLossO     RLossI     RLossO
         2.0       1.0        1.5        0.5
*
*     matId
      f 6 e
*
*       TW
      f 550.0 e
*
*
*******   type            num            id          ctitle
chan                       26            26          chan low
*2      ncells           nodes          jun1          jun2          epsw
            4               4            62            63         1.e-5
*       nsides
            0
*6        ichf          iconc       iaxcnd       liqlev        nhcom
            2              0            0            0            3
*7       width             th        houtl        houtv        toutl
         0.52           .0077          0.0          0.0          0.0
*8       toutl     advBWRFuel      quadSym  numWaterRods      nVFRays
          0.0              1            0            0            0
*9        ngrp         nchans       nodesr        nrows         ncrz
            2              2            5            8            3
*10      icrnk          icrlh       nmwrx         nfci         nfcil
            1              0            0            0            0
*11      irfdt         irfdt2        nzmax       nzmaxw        ibeam
            0              0            5            5            1
*12      dznht         dznhtw       dtxht1       dtxht2
          0.1            0.1          5.0         10.0
*13      hgapo          pdrat         pldr        fucrac       notRad
        1000.0           1.33          0.0          1.0            0
*14      emcif1         emcif2       emcif3       notAni
          0.67            0.0          0.0            0
*15      emcof1         emcof2       emcof3
          0.67            0.0          0.0
*array data
*15 dx    * f   0.9106e
*16 vol   * f   1.0000e+00e
*17 fa    * f   1.7000e+00e
*18 fric  * f   0.0000e+00e
*19 grav  * f   1.0000e+00e
*20 hd    * f   1.1111e+00e
*22 nff   * f          -1e
*24 alp   * f   0.02e
*25 vl    * f   0.0000e+00e
*26 vv    * f   0.0000e+00e
*27 tl    * f   5.5000e+02e
*28 tv    * f   5.5900e+02e
*29 p     * f   7.0000e+06e
*30 pa    * f   0.0000e+00e
*31 qppp  * f   0.0000e+00e
*32 matid * f   6 e
*33 tw    * f   549.0 e
```

```
*37 idrodo* f            1 e
*38 nhcelo*       2      3    4    5e
*44 rdx   * 48.0 16.0 e
*45 radrd *  0.0 0.003 0.004 0.005 0.006 e
*46 matrd *  1 1 3 2 e
*47 nfax  *  f 2 e
*49 rftn  *  f 560.0 e
*49 rftn  *  f 560.0 e
*50 rdpwr *   1.2 1.0 0.6 0.0 0.0 e
*51 cpowr * 1.0 0.8 e
*   radpw * f 0.8 e
*52 fpuo2 * f   0.0001e
*53 ftd   * f   9.4000e-01e
*54 gmix  * f   1.0000e+00e
*55 pgapt * f 1.5e6 e
*
*  Replaced cell edge burn values with cell centered ones
*  Chris Murray - 8/21/03
*56 burn  * 0.015 0.025 0.035e
*56 burn  * 0.055 0.065 0.075e
*56 burn  0.01 0.02 0.03 0.04e
*56 burn  0.05 0.06 0.07 0.08e
*57 mrod    r08 1 s
*57 mrod    r08 1 s
*57 mrod    r02 1 r04 2 r02 1 s
*57 mrod    r02 1 r04 2 r02 1 s
*57 mrod    r02 1 r04 2 r02 1 s
*57 mrod    r02 1 r04 2 r02 1 s
*57 mrod    r08 1 s
*57 mrod    r08 1 s
*57 mrod    3e
*
*           level 1
*           viewgrp(1:3,1:3)
    0.71481       0.61203E-01   0.22399     s
    0.18361       0.80826       0.81291E-02 s
    0.44199E-01   0.53470E-03   0.95527     e
*           beamgrp(1:3,1:3)
    0.44331E-02   0.14665E-01    1.0904 s
    0.14665E-01   0.39524E-02    1.1237 s
     1.0904        1.1237       0.40579 e
*
*           level 2
*           viewgrp(1:3,1:3)
    0.71481       0.61203E-01   0.22399     s
    0.18361       0.80826       0.81291E-02 s
    0.44199E-01   0.53470E-03   0.95527     e
*           beamgrp(1:3,1:3)
    0.44331E-02   0.14665E-01    1.0904 s
    0.14665E-01   0.39524E-02    1.1237 s
     1.0904        1.1237       0.40579 e
*
*           level 3
*           viewgrp(1:3,1:3)
    0.72          0.0           0.28     s
    0.0           1.0           0.0 s
    0.04          0.0           0.96     e
*           beamgrp(1:3,1:3)
    0.44331E-02   0.0           1.0904 s
    0.0           0.0           0.0 s
    1.0904        0.0           0.40579 e
*
*   levRodGs(i.e. partial length rods)
     4     3 e
```

```
*
*   wRodFlgG(i.e. water rod geometry type)
     0     0 e
*******   type            num             id        ctitle
chan                       27             27        chan  high
*2      ncells          nodes           jun1           jun2    epsw
             4              4             64             65    1.e-5
*       nsides
             4
*    cellInd        JunID
             2          401
             3          501
             2          601
             3          701
*6         ichf         iconc          iaxcnd         liqlev      nhcom
             2             0              0              0          3
*7       width            th         houtl           houtv     toutl
          0.64         .0077             0.             0.        0.
*8       toutl     advBWRFuel       quadSym  numWaterRods    nVFRays
           0.0             1             0              2          0
*9       ngrp         nchans          nodesr         nrows          ncrz
            4              2             5             10             3
*10       icrnk         icrlh           nmwrx          nfci          nfcil
             1             0              0              0             0
*11      irfdt         irfdt2          nzmax    nzmaxw          ibeam
             0             0              5              5          0
*12       dznht        dznhtw         dtxht1         dtxht2
           .1            .1             5.             10.
*13      hgapo       pdrat            pldr         fucrac          notRad
         1000.       1.33              0.0            1.0               0
*14      emcif1         emcif2         emcif3       notAni
          0.67             0.0            0.0            0
*15      emcof1         emcof2         emcof3
          0.67             0.0            0.0
*array data
*15 dx    * f   0.9106e
*16 vol   * f   1.0000e+00e
*17 fa    * f   1.7000e+00e
*18 fric  * f   0.0000e+00e
*19 grav  * f   1.0000e+00e
*20 hd    * f   1.1111e+00e
*22 nff   * f          -1e
*24 alp   * f   0.02e
*25 vl    * f   0.0000e+00e
*26 vv    * f   0.0000e+00e
*27 tl    * f   5.5000e+02e
*28 tv    * f   5.5900e+02e
*29 p     * f   7.0000e+06e
*30 pa    * f   0.0000e+00e
*31 qppp  * f   0.0000e+00e
*32 matid * f   6 e
*33 tw    * f   549.0 e
*37 idrodo* f           1 e
*38 nhcelo*          2    3 4 5 e
*44 rdx   * 78.0 14.0 1.0 1.0e
*45 radrd *  0.0 0.003 0.004 0.005 0.006 e
*46 matrd *  1 1 3 2 e
*47 nfax  *  f 2 e
*49 rftn  *  f 560.0 e
*49 rftn  *  f 560.0 e
*50 rdpwr *   1.2 1.0 0.6 0.0 0.0 e
*51 cpowr * 1.0 0.8 e
*   radpw * f 1.2 e
*52 fpuo2 * f   0.0001e
```

```
*53 ftd   * f   9.4000e-01e
*54 gmix  * f   1.0000e+00e
*55 pgapt * f 1.5e6 e
*
*  Replaced cell edge burn values with cell centered ones
*  Chris Murray - 8/21/03
*56 burn  * 0.015 0.025 0.035e
*56 burn  * 0.055 0.065 0.075e
*56 burn  0.01 0.02 0.03 0.04e
*56 burn  0.05 0.06 0.07 0.08e
* mrod  * r10 1 s
              1     2     1     2     1 s
              1     2     1     2     1 s
          r10 1 s
              1     2     1     1     1 s
              3     3     1     2     1 s
              1     1     1     1     2 s
              3     3     1     1     1 s
              1     1     1     4     4 s
              2     1     1     1     1 s
              1     2     1     4     4 s
              1     1     1     2     1 s
          r10 1 s
              1     2     1     2     1 s
              1     2     1     2     1 s
          r10 1     5 e
*    Non-Default LevRods (i.e. partial length rods)
*    i     j   LevRod
     2     2     3
     2     4     3
     2     7     3
     2     9     3
     4     2     3
     4     9     3
     5     5     3
     6     6     3
     7     2     3
     7     9     3
     9     2     3
     9     4     3
     9     7     3
     9     9     3
    -1
*    Non-Default WaterRodFlgs
*    nRows = 10
*    radius = 0.006 m
*    dRod = 2x0.006 = 0.012 m
*    pitch = 1.33x0.12 = 0.01596 m
*    bundw = width/4 = 0.16 m
*    Min distance between edge of fuel rod and inside of channel box
*    0.5x(bundw - (nRows-1)xpitch - dia) = 0.5x(0.16 - 9x0.01596 - 0.012)
= 0.00
*    width = 4xbundw = 0.64 m
*    xLoc for first water rod
*    0.00218 + 5.5xpitch + radius
*    0.00818 + 5.5x0.01596 = 0.09596 m
*    yLoc for first water rod
*    -0.00218 - 3.5xpitch - radius
*    -0.00818 - 3.5x0.01596 = -0.06404 m
*    xLoc for second water rod
*    0.00218 + 3.5xpitch + radius
*    0.00818 + 3.5x0.01596 = 0.06404 m
*    yLoc for second water rod
*    -0.00218 - 5.5xpitch - radius
```

```
*    -0.00818 - 5.5x0.01596 = -0.09596 m
*    i     j   WaterRodFlgs  xLoc      yLoc
     4     6       1         0.06404  -0.09596
     4     7       1         0.0       0.0
     5     6       1         0.0       0.0
     5     7       1         0.0       0.0
     6     4       2         0.09596  -0.06404
     6     5       2         0.0       0.0
     7     4       2         0.0       0.0
     7     5       2         0.0       0.0
    -1
*
*      geoType   rNodes
          1        2
*
* WR dia = 0.024 m
*     wRInlet  wROutlet     dia       sideA      sideB
          2        3      0.024
*
* 0.1" = 0.00254 m
*        th       rCorner     flowArea   flowAreaI   flowAreaO
         0.00254
*
*        hyDia    hyDiaI      hyDiaO     thermDiaI   thermDiaO
         0.0       0.01        0.01
*
*        FLossI    FLossO     RLossI     RLossO
         2.0       1.0        1.5        0.5
*
*     matId
      f 6 e
*
*       TW
      f 500.0 e
*
*      geoType   rNodes
          1        3
*
* WR dia = 0.024 m
*     wRInlet  wROutlet     dia       sideA      sideB
          2        3       0.024       0.02       0.02
*
* 0.1" = 0.00254 m
*        th       rCorner     flowArea   flowAreaI   flowAreaO
         0.00254
*
*        hyDia    hyDiaI      hyDiaO     thermDiaI   thermDiaO
         0.0       0.01        0.01
*
*        FLossI    FLossO     RLossI     RLossO
         2.0       1.0        1.5        0.5
*
*     matId
      f 6 e
*
*       TW
      f 500.0 e
*
*
*******   type           num            id        ctitle
vessel                     3             3 vessel 1-d core region
*         nasx          nrsx          ntsx          ncsr        ivssbf
             6             1             1             8             0
*         idcu          idcl          idcr          icru          icrl
```

```
             0             0             0             5             0
*         icrr         ilcsp         iucsp         iuhp         iconc
             1             0             0             0             0
*        igeom         nvent         nvvtb
             0             0             0
*        shelv          epsw
    0.0000e+00    1.0000e-05
*
* z     *     9.1060e-01    1.8212e+00    2.7318e+00 3.6424  4.553s
* z     *     5.463e
* rad   *     1.4595e+00e
* th    *     3.6000e+02e
*
*        lisrl         lisrc         lisrf         ljuns
             1             1            -2             2
             1             1             2            60
             5             1            -2            61
             1             1             2            62
             5             1            -2            63
             1             1             2            64
             5             1            -2            65
             6             1             2             3
*
* level 1
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   1.0000e+20e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   1.0000e+20e
* cfzv-r* f   0.0000e+00e
* vol   * f   7.1000e-01e
* fa-t  * f   0.0000e+00e
* fa-z  * f   1.e-20e
* fa-r  * f   0.0000e+00e
* hd-t  * f   0.0000e+00e
* hd-z  * f   1.3000e-02e
* hd-r  * f   0.0000e+00e
* alpn  * f   0.0e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.00e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.00e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.590e+02e
* tln   * f   5.50e+02e
* pn    * f   7.0e+06e
* pan   * f   0.0e
* conc   f   1.0000e-04e
*
* level 2
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * f   7.1000e-01e
* fa-t  * f   0.0000e+00e
* fa-z  * f   7.1000e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * f   0.0000e+00e
```

```
* hd-z  * f   1.3000e-02e
* hd-r  * f   0.0000e+00e
* alpn  * f   0.0e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.590e+02e
* tln   * f   5.50e+02e
* pn    * f   7.00e+06e
* pan   * f   0.0e
* conc   f   1.0000e-04e
*
* level 3
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * f   7.1000e-01e
* fa-t  * f   0.0000e+00e
* fa-z  * f   7.1000e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * f   0.0000e+00e
* hd-z  * f   1.3000e-02e
* hd-r  * f   0.0000e+00e
* alpn  * f   0.0e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.00e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.590e+02e
* tln   * f   5.500e+02e
* pn    * f   7.0e+06e
* pan   * f   0.0e
* conc   f   1.0000e-04e
*
* level 4
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * f   7.1000e-01e
* fa-t  * f   0.0000e+00e
* fa-z  * f   7.1000e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * f   0.0000e+00e
* hd-z  * f   1.3000e-02e
* hd-r  * f   0.0000e+00e
* alpn  * f   0.0e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.00e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0+00e
```

```
* vln-r * f   0.0000e+00e
* tvn   * f   5.590e+02e
* tln   * f   5.500e+02e
* pn    * f   7.0e+06e
* pan   * f   0.0e
* conc   f   1.0000e-04e
*
* level 5
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f  -1.0000e-20e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * f   7.1000e-01e
* fa-t  * f   0.0000e+00e
* fa-z  * f   7.1000e-01e
* fa-r  * f   0.0000e+00e
* hd-t  * f   0.0000e+00e
* hd-z  * f   1.3000e-02e
* hd-r  * f   0.0000e+00e
* alpn  * f   0.0e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0 e
* vln-r * f   0.0000e+00e
* tvn   * f   5.590e+02e
* tln   * f   5.500e+02e
* pn    * f   1.5230e+07e
* pan   * f   0.0e
* conc   f   1.0000e-04e
*
* level 6
*
* cfzl-t* f   0.0000e+00e
* cfzl-z* f   0.0000e+00e
* cfzl-r* f   0.0000e+00e
* cfzv-t* f   0.0000e+00e
* cfzv-z* f   0.0000e+00e
* cfzv-r* f   0.0000e+00e
* vol   * f   1.0000e+00e
* fa-t  * f   0.0000e+00e
* fa-z  * f   0.0000e+00e
* fa-r  * f   0.0000e+00e
* hd-t  * f   0.0000e+00e
* hd-z  * f   1.3000e-02e
* hd-r  * f   0.0000e+00e
* alpn  * f   0.0e
* vvn-t * f   0.0000e+00e
* vvn-z * f   0.0000e+00e
* vvn-r * f   0.0000e+00e
* vln-t * f   0.0000e+00e
* vln-z * f   0.0000e+00e
* vln-r * f   0.0000e+00e
* tvn   * f   5.590e+02e
* tln   * f   5.500e+02e
* pn    * f   7.0e+06e
* pan   * f   0.0e
* conc   f   1.0000e-04e
*
*******   type           num            id        ctitle
```

```
valve                     4            4 valve upper-plenum region
*2      ncells         nodes          jun1          jun2          epsw
             2             3             3             4    1.0000e-05
*       nsides
             0
*3        ichf         iconc          ivty          ivps         nvtb2
             0             0             0             2             0
*4        ivtr          ivsv         nvtb1          nvsv          nvrf
             0             0             0             0             0
*5      iqp3tr        iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0             0             0             0             0
*6      ivtrov        ivtyov
             0             0
*7        rvmx          rvov        fminov        fmaxov
    0.0000e+00    0.0000e+00    0.0000e+00    1.0000e+00
*8       radin            th         houtl         houtv         toutl
    1.4595e+00    7.7136e-03    0.0000e+00    0.0000e+00    0.0000e+00
*9       toutv         avlve         hvlve        favlve          xpos
    0.0000e+00      20.0763          2.22    9.5000e-01    9.0000e-01
*10      qp3in        qp3off        rqp3mx        qp3scl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*
* dx    * f   1.4000e+00e
* vol   * f   28.1064e
* fa    * f   20.076e
* fric  * f   1.0000e+00e
* grav  * f   1.0000e+00e
* hd    * f   7.4000e-01e
* nff   * f            1e
* alp   * f   0.0e
* vl    * f   0.0e
* vv    * f   0.0e
* tl    * f   5.500e+02e
* tv    * f   5.590e+02e
* p     * f   7.0e+06e
* pa    * f   0.0e
* qppp  * f   0.0000e+00e
* matid * f            6e
* tw    * f   5.50e+02e
* conc   f   1.0000e-04e
*
*******   type           num            id        ctitle
break                     5             5 break outlet pressure bc
*         jun1          ibty          isat          ioff
             4             0             0             0
*         dxin         volin         alpin           tin           pin
    1.4000e+00    9.3688e+00           0.0      5.540e+02       7.0e+06
*         pain         concin          rbmx          poff          belv
              0    1.0000e-04    0.0000e+00    0.0000e+00    0.0000e+00
*
*         type           num            id        ctitle
power                    28            28 chan medium
*         npwr       chanPow
             3             1
*        htnum
            25            26            27e
*       irpwty          ndgx          ndhx          nrts          nhist
             7             0             0            10             0
*       irpwtr         irpwsv        nrpwtb        nrpwsv        nrpwrf
           101             1             3             1             0
*       izpwtr         izpwsv        nzpwtb        nzpwsv        nzpwrf
             0             1             1             0             0
*       ipwrad         ipwdep      promHeat      decaHeat      wtBypass
             0             0    0.0000E+00    0.0000E+00    0.0000E+00
```

```
*        nzpwz          nzpwi         nfbpwt          nrpwr          nrpwi
             4             -1              0              1              0
*        react          tneut         rpwoff         rrpwmx         rpwscl
    0.0000E+00    0.0000E+00    0.0000E+00    1.0000E+20    1.0000E+00
*        rpowri         zpwin         zpwoff         rzpwmx
   1.50000E+07   0.00000E+00   0.00000E+00   1.00000E+20
*        extsou          pldr          pdrat         fucrac
    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
*        zpwzt
   0.00000E+00   9.10600E-01   1.82120E+00   2.73180E+00e
*        zpwtb
   0.00000E+00   6.92308E-01   1.03846E+00   1.26923E+00   1.03846E+00e
*        rpwtb
   0.00000E+00   1.50000E+07   5.00000E+02   1.50000E+07   2.00000E+03s
   1.50000E+07e
end
*
******************
* time-step data *
******************
*
*        dtmin          dtmax           tend          rtwfp
    1.0000e-06          0.001            0.1    1.0000e+00
*        edint          gfint         dmpint         sedint
           50.0          0.1             50.          100.0
*
*        dtmin          dtmax           tend          rtwfp
    1.0000e-06           0.25            0.5    1.0000e+00
*        edint          gfint         dmpint         sedint
           50.0         0.1           50.          100.0
*
*        dtmin          dtmax           tend          rtwfp
    1.0000e-03           0.25           20.0    1.0000e+00
*        edint          gfint         dmpint         sedint
           50.0         1.0           50.          100.0
*
*        dtmin          dtmax           tend          rtwfp
   1.0000e-03            5.0          1994.0    1.0000e+00
*        edint          gfint         dmpint         sedint
         100.0          10.0        1.000e+03    5.1000e+02
*
*      endflag
   -1.0000e+00
```

# *RadEncCylinder Test Problem*

```
free format
*
*************
* main data *
*************
*
*       numtcr          ieos         inopt          nmat
           10             0             1             1
* TEST PROBLEM  RadEncCylinder testing radiation heat transfer
 in cylindrical geometry.
 Rad inside of a hollow cylinder radiation HT test.
 For this problem qfluxRadiation(1) = sigma*(Tsurf(1)**4 - Tsurf(2)**4)/
          (1/emiss(1) + (Asurf(1)/Asurf(2))*(1/emiss(2) - 1))
  qfluxRadiation(1)= 5.67e-8*(500.46607**4-1000**4)/(1/0.8+0.5*(1/0.8 -1))
                   =-3.86495E+04 w/m**2
  qfluxConvection = 1.0e+05*(500.46607 - 500) = 4.6607e+04 w/m**2
  total flux on outside of inner cylinderical HS = 7957.5 w/m**2
  Total power leaving fuel rod = 7957.5 * 2 * pi * 1 * 2 = 100 Kw
*
*****************
* namelist data *
*****************
*
 &inopts
 nhtstr=2, cpuflg=1, npower=1, ipowr=1, nEnclosure=1,
 &end
*
*        dstep          timet
             0    0.0000e+00
*       stdyst         transi          ncomp          njun          ipak
             1              0              4             0             1
*         epso           epss
    1.0000e-03    1.0000e-10
*       oitmax         sitmax        isolut        ncontr
            10             10             0             0
*         ntsv           ntcb          ntcf          ntrp          ntcp
             1              0             0             0             0
*
*************************
* component-number data *
*************************
*
* iorder
             1s  * Solid cylindrical powered HS.
             2s  * Unpowered hollow cylinderical HS.
             3s  * Power component.
           901e  * RADENC component.
*
****************************
* material-properties data *
****************************
*
* matb  *             51e
* ptbln *              2e
*
*   prptb(1,i)    prptb(2,i)    prptb(3,i)    prptb(4,i)    prptb(5,i)
    2.0000e+02    1.0000e+00    1.0000e+00    2.0000e+00    1.0000e+00
    4.0000e+05    1.0000e+00    1.0000e+00    2.0000e+00    1.0000e+00
e
*
```

```
*************************
* control-parameter data *
*************************
*
*
* signal variables
*         idsv          isvn          ilcn          icn1          icn2
             1             0             0             0             0
*
******************
* component data *
******************
*
*******   type           num            id        ctitle
htstr                      1             1 powered-rod conductor
*         nzhtstr         ittc       hscyl          ichf
             1             0             1             1
*       nopowr          plane        liqlev        iaxcnd
             0             2             0             0
*       nmwrx           nfci         nfcil          hdri          hdro
             0             0             0       0.25231       0.35231
*      ifradi         ifrado
             0             1
*      emcof1         emcof2        emcof3
          0.8           0.0           0.0
*        nhot          nodes         irftr         nzmax
             0            26             0             4
*     dtxht(1)      dtxht(2)         dznht          hgapo          shelv
    5.0000e+00    1.0000e+01    5.0000e-02    0.0000e+00    0.0000e+00
* idbciN * 0e
* idbcoN * 1e
* qsurfi
  0.0   e
* hsurfo   tsinko
  100000.0 500.0   e
* dzhtstr * f 2.0 e
* rdx   *     1.0e
* radrd * 0.000  0.025   0.050   0.075   0.100
          0.125  0.150s
          0.175  0.200   0.250   0.300   0.325
          0.350  0.375   0.400   0.425   0.450
          0.475  0.500   0.550   0.600   0.650
          0.700  0.800   0.900   1.000e
* matrd * f            51e
* nfax  * f            0e
* rftn  * f   3.5000e+02e
* fpuo2 *     0.0000e+00e
* ftd   *     9.2500e-01e
* gmix  * f   0.0000e+00e
* gmles *     0.0000e+00e
* pgapt *     0.0000e+00e
* plvol *     2.0000e-05e
* pslen *     3.6576e+00e
* clenn *     3.9576e+00e
* burn  * f   2.6620e+03e
*
*
*******   type           num            id        ctitle
htstr                      2             2 non-powered-rod conductor
*         nzhtstr         ittc       hscyl          ichf
             1             0             1             1
*       nopowr          plane        liqlev        iaxcnd
             0             2             0             0
*       nmwrx           nfci         nfcil          hdri          hdro
```

```
            0              0              0       0.25231      0.35231
*      ifradi         ifrado
            1              0
*      emcof1         emcof2         emcof3
           0.8            0.0            0.0
*        nhot          nodes         irftr          nzmax
            0              3              0              4
*     dtxht(1)       dtxht(2)        dznht         hgapo          shelv
    5.0000e+00    1.0000e+01    5.0000e-02    0.0000e+00    0.0000e+00
* idbciN * 5e
* idbcoN * 0e
* tsurfi
  1000.0   e
* qsurf0
  0.0   e
* dzhtstr * f 2.0 e
* rdx   *     1.0e
* radrd * 2.000  2.500  3.000e
* matrd * f            51e
* nfax  * f            0e
* rftn  * f   3.5000e+02e
* fpuo2 *     0.0000e+00e
* ftd   *     9.2500e-01e
* gmix  * f   0.0000e+00e
* gmles *     0.0000e+00e
* pgapt *     0.0000e+00e
* plvol *     2.0000e-05e
* pslen *     3.6576e+00e
* clenn *     3.9576e+00e
* burn  * f   2.6620e+03e
*
*
*******   type           num            id        ctitle
  power         901            901 power data input test1
* npowr
   1
* htnid
   1e
*       irpwty          ndgx          ndhx          nrts          nhist
            5             0           -11             5              0
*       izpwtr        izpwsv        nzpwtb        nzpwsv        nzpwrf
            0             1             1             0              0
*        ipwrad        ipwdep
            0             0
*        nzpwz         nzpwi        nfbpwt
            0             0             0
*        react         tneut        rpwoff        rrpwmx        rpwscl
    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00    1.0000e+00
*       rpowri         zpwin        zpwoff        rzpwmx
    1.0000e+05    0.0000e+00    0.0000e+00    0.0000e+00
*       extsou          pldr         pdrat        fucrac
    0.0000e+00    0.0000e+00    1.3000e+00    7.0000e-01
* rdpwr * f   1.0000e+00e
* cpowr *     1.0000e+00e
* zpwtb * f   1.0000e+00e
*
*******   type           num            id        ctitle
radenc                    3             3        Radiation HT enclosure
*      nzlevel          nhss
            1             2
*       numhss         rnHSS         znHSS
            1            26             1
            2             1             1
*       Upper diagonal view fraction matrix array.
```

```
           1.0 e
*        Diagonal and upper off-diagonals for path length.
           f 0.0 e
           f 0.0 e
*
end
*
******************
* time-step data *
******************
*
*         dtmin          dtmax          tend          rtwfp
    1.0000e-02    5.0000e+00    3.0000e+03    1.0000e+02
*         edint          gfint         dmpint         sedint
    1.0000e+02    1.0000e+01    1.0000e+03    5.0000e+01
*
******************
* time-step data *
******************
*
*       endflag
   -1.0000e+00
```

# *TRACE Standalone Model for VALVE Sizing*

```
1 free format
2 *
3 *************
4 * main data *
5 *************
6 *
7 *                            numtcr          ieos         inopt          nmat         id2o
8                                   3             0             1             0            0
9 driver to size pressure-operated relief valves
10 target mass flow is 2.0 * 2.6483e+01 kg/s
11 inlet pressure at 1.6304e+07 pa
12 *
13 *****************
14 * namelist data *
15 *****************
16 *
17 $inopts inlab=3
18 $end
19 *
20 *                             dstep          timet
21                                  0    0.0000e+00
22 *                            stdyst         transi         ncomp          njun         ipak
23                                  0              1             3             2            1
24 *                              epso           epss
25                         1.0000e-03     1.0000e-04
26 *                            oitmax         sitmax        isolut        ncontr       nccfl
27                                 10             10             0             0            0
28 *                              ntsv           ntcb          ntcf          ntrp         ntcp
29                                  2              0             0             1            0
30 *
31 *************************
32 * component-number data *
33 *************************
34 *
35 * iorder*                     110            120          130e
36 *
37 *************************
38 * control-parameter data *
39 *************************
40 *
41 *
42 * signal variables
43 *                             idsv           isvn          ilcn          icn1         icn2
44                                  1              0             0             0            0
45                                  2             30           120             2            0
46 *
47 * trips
48 *                             ntse           ntct          ntsf          ntdp         ntsd
49                                  0              0             0             0            0
50 *                             idtp           isrt          iset          itst         idsg
```

```
                                1           3           0           1           2
* setp(1)      setp(2)      setp(3)      setp(4)
                         5.2700e+01  5.2800e+01  5.3000e+01  5.3100e+01
* dtsp(1)      dtsp(2)      dtsp(3)      dtsp(4)
                         0.0000e+00  0.0000e+00  0.0000e+00  0.0000e+00
* ifsp(1)      ifsp(2)      ifsp(3)      ifsp(4)
                                0           0           0           0
*
******************
* component data *
******************
*
*******                      type          num          id       ctitle
break                                      110         110 $110$ inlet pressure bc
*                          jun1         ibty         isat         ioff
                            110            0            0            0
*                          dxin        volin        alpin          tin          pin
                        1.0000e+00  1.3640e-02  1.0000e+00  6.2300e+02  1.6304e+07
*                          pain       concin         rbmx         poff         belv
                        0.0000e+00  0.0000e+00  0.0000e+00  0.0000e+00  0.0000e+00
*
*******                      type          num          id       ctitle
break                                      130         130 $130$ outlet pressure bc
*                          jun1         ibty         isat         ioff
                            130            0            0            0
*                          dxin        volin        alpin          tin          pin
                        1.0000e+00  1.8640e-02  1.0000e+00  4.9800e+02  2.5145e+06
*                          pain       concin         rbmx         poff         belv
                        0.0000e+00  0.0000e+00  0.0000e+00  0.0000e+00  0.0000e+00
*
*******                      type          num          id       ctitle
valve                                      120        120 $120$ press-op relief valve
*                        ncells        nodes         jun1         jun2         epsw
                              2            0          110          130  0.0000e+00
*                          ichf        iconc         ivty         ivps        nvtb2
                              1            0            4            2           -2
*                          ivtr         ivsv        nvtb1         nvsv         nvrf
                              1            1           -2            0            0
*                         ivtrov       ivtyov
                              0            0
*                          rvmx         rvov        fminov       fmaxov
                        2.0000e-01  0.0000e+00  0.0000e+00  0.0000e+00
*                           radin           th        houtl        houtv       toutl
                        6.5900e-02  1.8200e-02  0.0000e+00  0.0000e+00  2.9500e+02
*                           toutv        avlve        hvlve        favlve       xpos
                        2.9500e+02  1.9134e-03  4.9358e-02  0.0000e+00  0.0000e+00
*
* dx    * f          1.0000e+00e
* vol   *            1.3640e-02  1.8640e-02e
* fa    *            1.3640e-02  1.9134e-03  1.8640e-02e
* fric * f           0.0000e+00e
* grav *             4.0070e-01  0.0000e+00 -8.3980e-01e
* hd    *            1.3180e-01  4.9358e-02  1.5410e-01e
* nff   * f                  1e
* alp   * f          1.0000e+00e
```

```
106 * vl     * f          0.0000e+00e
107 * vv     * f          0.0000e+00e
108 * tl     *             6.1800e+02   4.9800e+02e
109 * tv     *             6.1800e+02   4.9800e+02e
110 * p      *             1.5500e+07   2.5200e+06e
111 * pa     * f          0.0000e+00e
112 * vtb1 * r02          0.0000e+00    5.0000e+00   1.0000e+00e
113 * vtb2 * r02          0.0000e+00    6.0000e+00   1.0000e+00e
114 *
115 end
116 *
117 ******************
```

# *Sample 3-Component Pressurizer Input Listing*

```
*************************************************************************
*******   type            num             id        ctitle
pipe                      40             40 $40$ prizer heater section
*       ncells          nodes          jun1          jun2          epsw
             3              5            41            40    0.0000e+00
*         ichf          iconc      pipeType          ipow
             1              1             0             1
*       ipowtr         ipowsv        npowtb        npowsv        npowrf
          -407           -450             0             0             0
*       iqp3tr         iqp3sv        nqp3tb        nqp3sv        nqp3rf
             0              0             0             0             0
*        radin             th         houtl         houtv         toutl
    1.0855e+00    1.0922e-01    0.0000e+00    4.0000e+01    3.0000e+02
*        toutv          powin         powoff         rpowmx         powscl
    3.1000e+02    2.0000e+05    0.0000e+00    1.0000e+10    1.0000e+00
*         qp3in         qp3off         rqp3mx         qp3scl
    0.0000e+00    0.0000e+00    1.0000e+10    1.0000e+00
*
* dx    *     1.1400e+00r02 5.3100e-01e
* vol   *     3.9519e+00    1.6871e+00    7.6739e-01e
* fa    * r02 3.5434e+00    2.6570e+00    6.7000e-02e
* kfac  * r02 0.0000e+00    1.0000e-02    0.0000e+00e
* rkfac * r02 0.0000e+00    2.0000e-02    0.0000e+00e
* grav  * f  -1.0000e+00e
* hd    * r02 2.1240e+00    1.8393e+00    2.9210e-01e
* icflg * f             0e
* nff   * r03           1          -1e
* alp   * f   0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   6.1800e+02e
* tv    * f   6.1800e+02e
* p     * f   1.5500e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid * f             9e
* tw    * f   6.1800e+02e
* conc  * f   0.0000e+00e
*
*************************************************************************
*******   type            num             id        ctitle
tee                       41             41 $41$ prizer middle section
*        jcell          nodes          ichf          cost          epsw
             2              5             1    0.0000e+00    0.0000e+00
*       iconc1         ncell1          jun1          jun2         ipow1
             1             10            42            41             0
*       iqptr1         iqpsv1        nqptb1        nqpsv1        nqprf1
             0              0             0             0             0
*       radin1           th1         houtl1         houtv1         toutl1
    1.0620e+00    1.0922e-01    0.0000e+00    4.0000e+01    3.0000e+02
*       toutv1          pwin1         pwoff1         rpwmx1         pwscl1
    3.0000e+02    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*        qpin1         qpoff1         rqpmx1         qpscl1
    0.0000e+00    0.0000e+00    1.0000e+10    1.0000e+00
*       iconc2         ncell2          jun3          ipow2
             1              1            44             0
*       iqptr2         iqpsv2        nqptb2        nqpsv2        nqprf2
             0              0             0             0             0
*       radin2           th2         houtl2         houtv2         toutl2
    1.0000e+00    1.0000e-02    0.0000e+00    0.0000e+00    3.0000e+02
```

```
*       toutv2          pwin2         pwoff2         rpwmx2         pwscl2
    3.0000e+02    0.0000e+00    0.0000e+00    0.0000e+00    0.0000e+00
*        qpin2         qpoff2         rqpmx2         qpscl2
    0.0000e+00    0.0000e+00    1.0000e+10    1.0000e+00
*
* main-cell arrays
* dx    * r03 1.7700e-01r07 1.1222e+00e
* vol   * r03 5.7483e-01r07 3.9763e+00e
* fa    *     2.6570e+00r02 3.2476e+00r08 3.5434e+00e
* kfac  *     2.0000e-02r10 0.0000e+00e
* rkfac *     1.0000e-02r10 0.0000e+00e
* grav  * f  -1.0000e+00e
* hd    *     1.8393e+00r10 2.1240e+00e
* icflg * f           0e
* nff   * f           1e
* alp   * r07 1.0000e+00    5.0000e-01r02 0.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    * f   6.1800e+02e
* tv    * f   6.1800e+02e
* p     * f   1.5500e+07e
* pa    * f   0.0000e+00e
* qppp  * f   0.0000e+00e
* matid * f           9e
* tw    * f   6.1800e+02e
* conc  * f   0.0000e+00e
*
* side-cell arrays
* dx    *     1.0000e+00e
* vol   *     5.8000e-02e
* fa    * f   5.8000e-02e
* kfac  *     1.0000e-10    0.0000e+00e
* rkfac *     1.0000e-10    0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   2.7200e-01e
* icflg * f           0e
* nff   * f           1e
* alp   *     1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     6.1800e+02e
* tv    *     6.1800e+02e
* p     *     1.5500e+07e
* pa    *     0.0000e+00e
* qppp  * f   0.0000e+00e
* matid * f           9e
* tw    * f   6.1800e+02e
* conc  *     0.0000e+00e
*
**********************************************************************
*******   type          num           id        ctitle
prizer                   42           42 $42$ prizer sprayer section
*       ncells         nodes         jun1          jun2
             1             5           43            42
*         ichf         iconc         qp3in
             1             1    0.0000e+00
*        radin            th         houtl         houtv         toutl
    1.0929e+00    1.0922e-01    0.0000e+00    4.0000e+01    3.0000e+02
*        toutv         qheat          pset         dpmax          zhtr
    3.1000e+02    0.0000e+00    1.5500e+07    3.4400e+05    0.0000e+00
*
* dx    *     5.3100e-01e
* vol   *     7.8438e-01e
* fa    *     6.3200e-03    2.6570e+00e
```

```
* kfac  *     0.0000e+00    2.0000e-02e
* rkfac *     0.0000e+00    1.0000e-02e
* grav  * f  -1.0000e+00e
* hd    *     8.9610e-02    1.8393e+00e
* icflg * f             0e
* nff   * f             1e
* alp   *     1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     6.1800e+02e
* tv    *     6.1800e+02e
* p     *     1.5500e+07e
* pa    *     0.0000e+00e
* qppp  * f   0.0000e+00e
* matid * f             9e
* tw    * f   6.1800e+02e
* conc  *     0.0000e+00e
*
```