7.0. DETAILED 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 the input-data model for a TRAC-M input-data TRACIN file. The input data will be assembled from the specific component models available in TRAC-M, which are tailored to your specific plant or facility description by the values that you enter into the data template of each component model. A list of the available TRAC-M component models, accompanied by a brief description of their function, is found in Table 5-1. We have divided our detailed 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 generalized HTSTR component that provides heat-transfer paths between thermal-hydraulic components.

7.1. Thermal-Hydraulic Components

The geometry data for 1D thermal-hydraulic components are input specified by six arrays. The geometry data are the cell length (DX), cell fluid volume (VOL), cell-edge fluid flow area (FA), cell-edge vertical-orientation (GRAV) from which elevation can be defined or cell-center elevation (ELEV), cell-edge flow-channel hydraulic diameter (HD), and cell-edge additive (form) loss coefficient (FRIC or KFAC). These array data are input specified for the PIPE, PRIZER, PUMP, SEPD, TEE, TURB, and VALVE thermal-hydraulic components. 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 ELEV array or cell-edge GRAV array, depending on the NAMELIST-variable IELV option selected for this variable. 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 Section 5, we presented general modeling guidelines. 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 or KFAC arrays is straightforward.

7.1.1. Common Guidelines

The common guidelines that follow are applicable to all 1D thermal-hydraulic components.

7.1.1.1. Length array. Each value in this array is equal to the fluid-flow length of the cell that it describes. As discussed in the General Guidelines of Section 5, 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 condition is expected to vary more per unit length. That generally results in 0.1-m- (0.32808 ft) to 3.0-m- (9.8425 ft) long cells while requiring that the cell length to diameter ratio L/D > 1.0. As you exercise modeling judgment, tradeoffs may be necessary. In general, more cells give more spatial detail that is desired in the gas volume fraction and phasic temperature flow-channel distributions. However, more cells also imply higher computer costs and more computer storage memory.

7.1.1.2. 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.

TRAC-M 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 the user the capability to model accurately the effect of flow-area change on fluid pressure. However, it also forces the user to determine reasonable VOL/DX cell-average flow areas. If the TRAC-M input-data checking algorithm finds changes in VOL/DX and FA that are large (>10%) and there is no positive-value cell-edge additive loss coefficient (or NFF < 0) modeling its irreversible form loss, a warning message will be given and the user will be forced to change this input data before TRAC-M can proceed with its calculation. The user needs to be aware of this when specifying geometric parameters for components with fluid-flow channels having a changing fluid flow area.

7.1.1.3. Flow area array. Generally, you should define cell-edge boundaries at locations where the fluid flow area can be easily determined. The user 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 recommend the NAMELIST-variable IKFAC = 1 option for the ease of input 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. 7-1) or some similar handbook. Specifying NFF < 0 results in TRAC-M 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 (Section 7.1.1.6.) to obtain the correct pressure drops across the component.

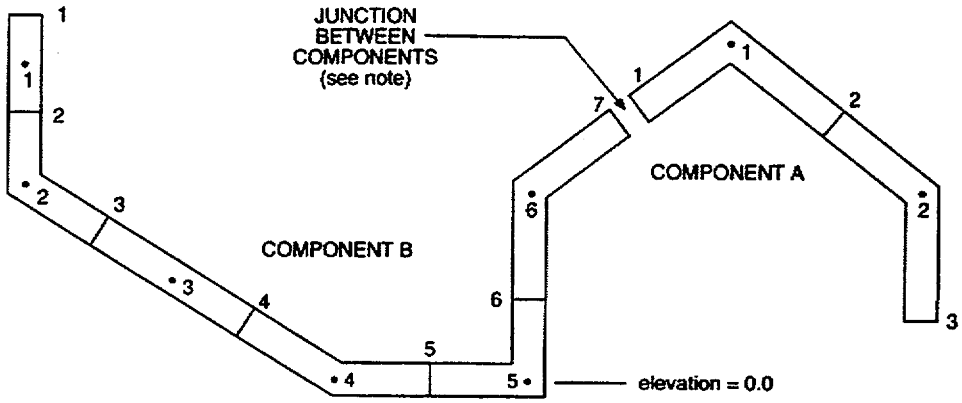
7.1.1.4. Gravity array. There are two methods of providing elevation data to TRAC-M. The two are quite different although the same database is needed to develop either input form. The first input form is that used in the original TRAC-code development; the cell elevation is specified by the gravity term 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 direction of travel needs to be established. The 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, TRAC-M will check to see if the absolute values of the gravity terms input 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 inputting elevation data is more difficult than the second method; therefore, we have provided the example shown in Fig. 7-1 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 Section 7.1.2.1.

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 it is recommended for new system-model development. 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. TRAC-M takes this cell-center ELEV elevation data and internally converts it to GRAV gravity-term data for use in the calculation. TRAC-M 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 TRCOUT 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.



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 (–)
	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

Note: 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.

Fig. 7-1. Illustration of evaluating the GRAV gravity term.

7.1.1.5. Hydraulic diameter array. If your fluid-flow channel geometry is not circular in cross section, the HD should be evaluated based on

$$HD = 4 \cdot FA/WP \tag{7-1}$$

where 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 TRAC-M 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 (Ref. 7-2)

$$HD = (DX_i + DX_{i+1}) / [(FA_{i+1/2}/FA_i)^2(DX_i/HD_i) + (FA_{i+1/2}/FA_{i+1})^2(DX_{i+1}/HD_{i+1})] \; . \tag{7-2}$$

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.

7.1.1.6. Additive loss coefficient array. The additive loss coefficient array may be input specified in either of two forms, FRIC or KFAC. Originally, only FRIC additive loss coefficients were input. They are related to the $K_{i+1/2}$ irreversible form-loss K factor at the cell-edge interface i+1/2 where the fluid flow velocity is $V_{i+1/2}$ by the expression

$$FRIC_{i+1/2} = K_{i+1/2} \cdot HD_{i+1/2}/(DX_i + DX_{i-1}) \; . \tag{7-3}$$

Later, the NAMELIST-variable IKFAC = 1 option was provided to input specify irreversible form-loss K factors directly by the KFAC array. If you are developing a new input-data model, we strongly recommend that you use the IKFAC = 1 option and enter the irreversible form-loss K factors directly. TRAC-M takes the KFAC-array irreversible form-loss K factors and converts them with Eq. (7-3) to FRIC-array additive loss coefficients for use in the calculation. TRAC-M 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, the user 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 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 = 2 option needs to be specified. When

NFRIC1 = 2 for 1D thermal-hydraulic components, both forward (FRIC or KFAC) and reverse (RFRIC or RKFAC) additive loss coefficient arrays are input specified. TRAC-M applies the forward additive loss coefficient array when the component phasic velocity is positive valued (fluid flow is in the direction of increasing cell numbers) and the reverse additive loss coefficient array when the component phasic velocity is negative valued (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.

TRAC-M is programmed to evaluate the irreversible form-loss K factor (FRIC) for an abrupt flow-area change across mesh-cell interface $i+1/2$ when $NFF_{i+1/2} < 0$ is input specified. Based on the flow direction, TRAC-M 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 TRAC-M would evaluate internally for an abrupt flow-area change.

7.1.2. Specific Guidelines

The common guidelines discussed above are applicable to all 1D hydraulic components. However, there are specific guidelines for either special applications or specific components. The specific guidelines that follow do not constitute all useful guidelines that are known by TRAC-M users. If you have additional guidelines that you believe should be included in subsequent revisions of this User's Manual , you are encouraged to submit them using the form found in Appendix C.

7.1.2.1. Gravity term evaluation in TEEs. 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 Section 7.1.1.4.; however, special attention must be paid to one-cell edge that is evaluated in a unique manner. That is the cell-edge interface between 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

$$\text{change in elevation} = ELEV_{\text{side-tube cell 1}} - ELEV_{\text{main-tube cell JCELL}} \, . \qquad (7\text{-}4)$$

Using the nomenclature shown in Fig. 7-2, the

$$\text{length of the flow path} = (DX_{\text{side-tube cell 1}}/2) + (DX_{\text{main-tube cell JCELL}}/2) \qquad (7\text{-}5)$$

where

$$DX_{\text{main-tube cell JCELL}} = \min[(HD_{\text{JCELL-1/2}} + HD_{\text{JCELL+1/2}})/(2 \cdot \sin\theta), DX_{\text{JCELL}}/|\cos\theta|] \, .$$

The limiting two cases of interest, shown in Fig. 7-2, are:
for a right-angle tee connection (θ = 90°),

$$DX_{\text{main-tube cell JCELL}} = (HD_{\text{JCELL-1/2}} + HD_{\text{JCELL+1/2}})/2 \,, \tag{7-6}$$

and for a parallel tee connection (θ = 0° or 180°),

$$DX_{\text{main-tube cell JCELL}} = DX_{\text{JCELL}} \,. \tag{7-7}$$

7.1.2.2. Technique for combining loops. As previously mentioned, there are incentives to minimize the number of components in the system model. If computing costs and time were not a factor and computer memory was sufficient, we would model each plant feature in fine spatial detail. But cost, 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 BREAK- and FILL-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

$$T = -N \cdot r_i + (N^2 \cdot r_i^2 + 2 \cdot N \cdot r_i \cdot t + N \cdot t^2)^{1/2} \quad . \tag{7-8}$$

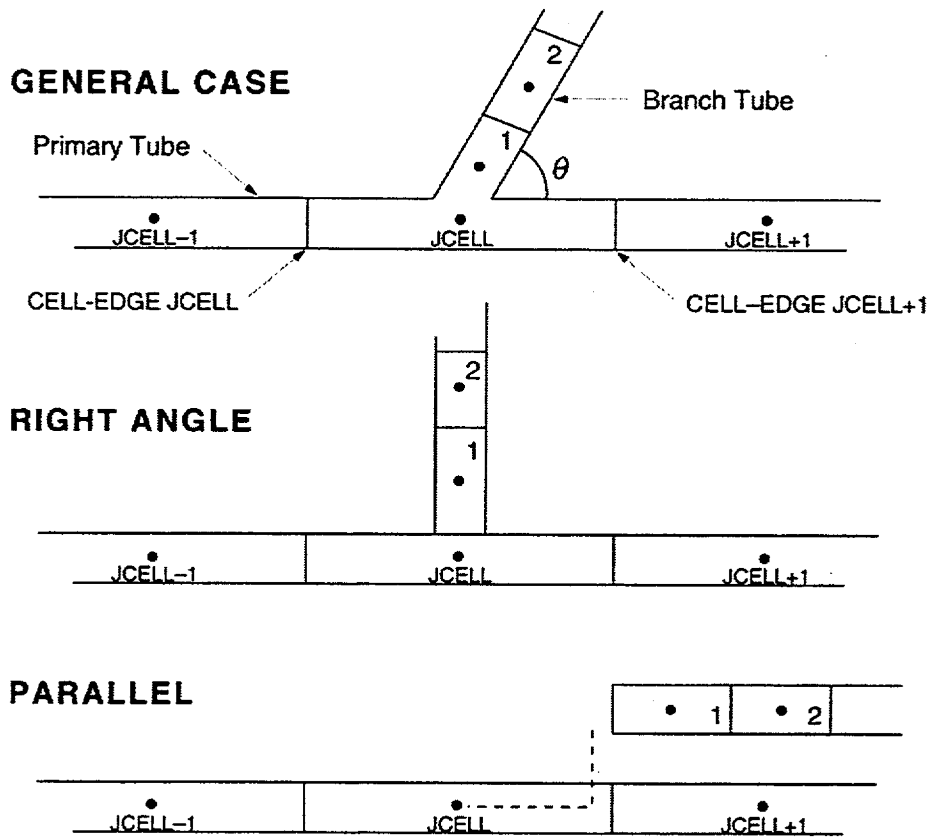


Fig. 7-2. GRAV gravity-term evaluation at the TEE internal-junction interface.

4. The number of actual ROD or SLAB 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.

7.1.2.3. 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 take a finely noded model to resolve the physical phenomena to the accuracy desired. 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 (9.8425 ft) cell length is used, the break outflow condition is defined at a point 1.5 m (4.9213 ft) from the break that is averaged over a 3.0-m (9.8425 ft) 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 to measurements compared with and the nature of the numerical solution.

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. Generally there isn't sufficient time for such noding studies, so when in doubt, error on the side of modeling with a finer mesh than needed. Today's faster and cheaper computers make the finer-mesh run-time penalty less significant than 5 or 10 years ago. If an input-data model is to be evaluated only a few times, your cost of preparing the input-data TRACIN file probably will overshadow the computer cost of the TRAC-M 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.

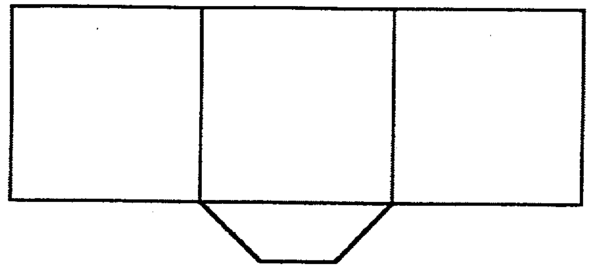
The second study examined noding for a pressurizer model (Refs. 7-2, 7-3). The experiment consisted of four pressurizer in surges and out surges combined with four cycles of spray. The PRIZER component was used with 13-cell and 4-cell noding. There were small differences in the maximum pressures during 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. 7-4). 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 (135.0 °F) 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.

It should be noted that with the improved run times of the TRAC-PF1/MOD2 code using SETS3D numerics, 10,000 s small-break as well as 100 s large-break LOCA calculations with fine to intermediate noding have been computed within several hours of CPU time on Cray X-MP and Y-MP computers. Now Pentium, SUN, HP, and Silicon-Graphics computers can perform such calculations in less than 24 h execution time with significantly less cost than a mainframe computer. Further versions of TRAC-M/F90 will have a prallel-computation capability.

7.1.2.4. Break-flow modeling. 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. 7-5). Based on these studies (which carry over directly to TRAC-M), Los Alamos recommends that small breaks in TRAC-M be modeled with a single convergent cell in the side-tube of a TEE component, as shown in Fig. 7-3. The DX cell length of this convergent cell should model the pipe thickness plus the average length of blown out pipe wall that may still be intact, directedoutward, 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.

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



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).

Fig. 7-3. TRAC-M small break noding diagram.

subcooled-liquid conditions [1.5000E+07 Pa (2.1756E+03 psia), 560.0 K (548.3 °F)], theTRAC–P mass flux is 2.7% lower than that evaluated by the Burnell model; at saturated-liquid conditions [7.1000E+06 Pa (1.0298E+03 psia), 560.0 K (548.3 °F)], 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.

7.1.2.5. Sizing valves. Valve characteristics and operating sequences need to be carefully modeled for the timing of critical situations. The VALVE-component adjustable flow area needs to be accurately determined for the TRAC-M model to predict correct fluid-flow conditions. We follow a standard process to size valves. The procedure generally used to adjust valve characteristics for TRAC-M systems modeling is the following. 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 TRAC-M 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 (1.8 to 3.6°F) 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. TRAC-M sets the output parameter "wf. liq." to a value of 1.111e-11 at each cell-edge interface where choking occurs (see the TRCOUT file). The VALVE-component adjustable flow areas AVLVE and HD HVLVE are varied until the specified steam flow rate is obtained.

The TRAC-M TRACIN-file listing of a standalone model for valve sizing is provided in Table 7-1. 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 FA flow-area fraction with trip IVTR = 1 control. The signal variable ID for the trip signal (the steam mass flow at cell edge IVPS = 2 of VALVE component 120) is IDSG = 2. The VALVE-component flow area is ON/OFF trip-control adjusted 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^{-1} (4.2037E+05 lb_m h^{-1}). If the AVLVE flow area specified is too large, the TRCOUT-file output will identify the adjusted VALVE adjustable FA flow-area fraction and the percentage of full open. Then this adjusted VALVE flow area (and its related HD) are used as AVLVE and HVLVE guesses for the next calculative iteration. If the AVLVE flow area specified 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 TRCOUT-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 Ref. 7-6, a valve sized, using the procedure just described, predicts two-phase and liquid mass flows within ±25%.

7.1.2.6. Accumulator. The ACCUM component was eliminated from TRAC-M's predecessor code TRAC-P because an accumulator can be modeled better with a PIPE component using the accumulator option IACC > 0. An example of how to remodel an existing ACCUM component with a FILL component and a PIPE component is discussed in Appendix J.

TABLE 7-1
TRAC-M STANDALONE MODEL FOR VALVE SIZING

```
free format
*
*************
* main data *
*************
*
*                           numtcr       ieos       inopt       nmat       id2o
                                 3          0           1          0          0
driver to size pressure-operated relief valves
target mass flow is 2.0 * 2.6483e+01 kg/s
inlet pressure at 1.6304e+07 pa
*
*****************
* namelist data *
*****************
*
$inopts inlab=3
$end
*
*                            dstep        timet
                                 0   0.0000e+00
*                           stdyst       transi       ncomp       njun       ipak
                                 0            1           3          2          1
*                             epso         epss
                        1.0000e-03   1.0000e-04
*                           oitmax       sitmax      isolut     ncontr      nccfl
                                10           10           0          0          0
*                             ntsv         ntcb        ntcf       ntrp       ntcp
                                 2            0           0          1          0
*
************************
* component-number data *
************************
*
* iorder*                      110          120        130e
*
*************************
* control-parameter data *
*************************
*
*
* signal variables
*                             idsv         isvn        ilcn       icn1       icn2
                                 1            0           0          0          0
                                 2           30         120          2          0
*
* trips
*                             ntse         ntct        ntsf       ntdp       ntsd
                                 0            0           0          0          0
*                             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
```

TABLE 7-1 (cont)
TRAC-M STANDALONE MODEL FOR VALVE SIZING

```
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
* vl    * f  0.0000e+00e
* vv    * f  0.0000e+00e
* tl    *    6.1800e+02  4.9800e+02e
* tv    *    6.1800e+02  4.9800e+02e
* p     *    1.5500e+07  2.5200e+06e
* pa    * f  0.0000e+00e
* vtb1  * r02  0.0000e+00  5.0000e+00  1.0000e+00e
* vtb2  * r02  0.0000e+00  6.0000e+00  1.0000e+00e
*
end
*
```

Accumulator flow has a first-order effect on the simulation results obtained with TRAC-M, 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. TRAC-M convects it into the adjacent component cell before this bottom cell empties when the IACC = 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 IACC = 2 option, but this is nonphysical when the accumulator empties of liquid.

7.1.2.7. Pump. In TRAC-M, 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 (0.0 ft), 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.

7.1.2.8. Pressurizer. We recommend that the PRIZER component be used in combination with other TRAC-M 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 in the annotated steady-state input-data TRACIN file presented in Appendix E (see components 40, 41 and 42) and shown in Fig. 5-11. 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 Fig. E-1. You should use a small cell at the bottom of the pressurizer [DX(3) = 5.3100E-01 m (1.7421 ft)] 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^{-1} (13.123 ft s^{-1}). 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 Fig. E-1 as well.

Several alternative pressurizer modeling approaches were examined by Sandia National Laboratories and reported in Ref. 7-3. 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.

7.1.2.9. Steam Generator (SG). A generalized SG modeling capability is provided in TRAC-M. 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 with ROD or SLAB elements. 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 plant model presented in Appendix E contains three U-tube SGs. The following discusses the loop 3 SG shown in Fig. 5-11. 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 ROD 930. The third element of HTSTR component SLAB 931 and RODs 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 component RODs 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 Fig. 5-8.

The above SG model was originally defined by STGEN component 32. Elimination of the STGEN component in TRAC-M's predecessor code resulted in its replacement by the above equivalent model defined by four hydraulic components and nine heat-structure components. How this was done is described in Appendix J.

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 = 2.1500E+02 (1.0000E+03 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 Appendix E 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 TRAC-M, 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 a database knowledge of the separator behavior of the tee connection.

Note: **SEPD Component**. See Sections 5 and 6 for the current status of the TRAC-M SEPD component.

We have noted a tendency for TRAC–P to underpredict the secondary-side pressure at steady state when the desired primary-side conditions are achieved (this would also apply to TRAC-M). 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. 7-1) 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. 7-8).

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 Ref. 7-3.

A generic model of a once-through SG is presented in Fig. 7-4. The figure illustrates the design details, flow paths, heat-transfer regimes, and a TRAC-M 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 Fig. 7-5 to simulate the partial wetting of SG tubes by auxiliary feedwater.

7.2. Wall Heat-Transfer Structures

The heat-transfer calculation in TRAC-M 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 PIPE, PRIZER, PUMP, SEPD, TEE, and VALVE hydraulic components. Modeling wall heat transfer requires input specifying the NODES number of radial heat-transfer nodes in the wall to be >0. The remaining input data are the RADIN radius of the wall inner surface, TH wall thickness, wall outer-surface liquid HOUTL and TOUTL, gas HOUTV and TOUTV heat-transfer coefficients and temperatures, MATID wall material identifier,

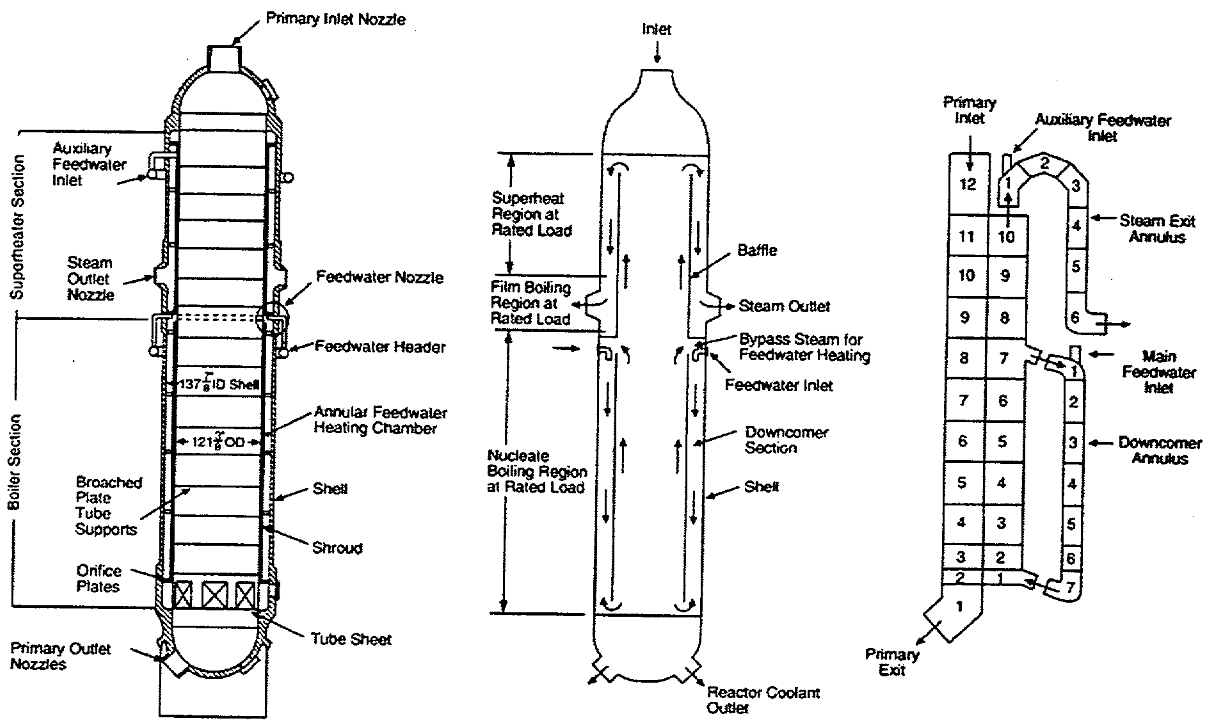
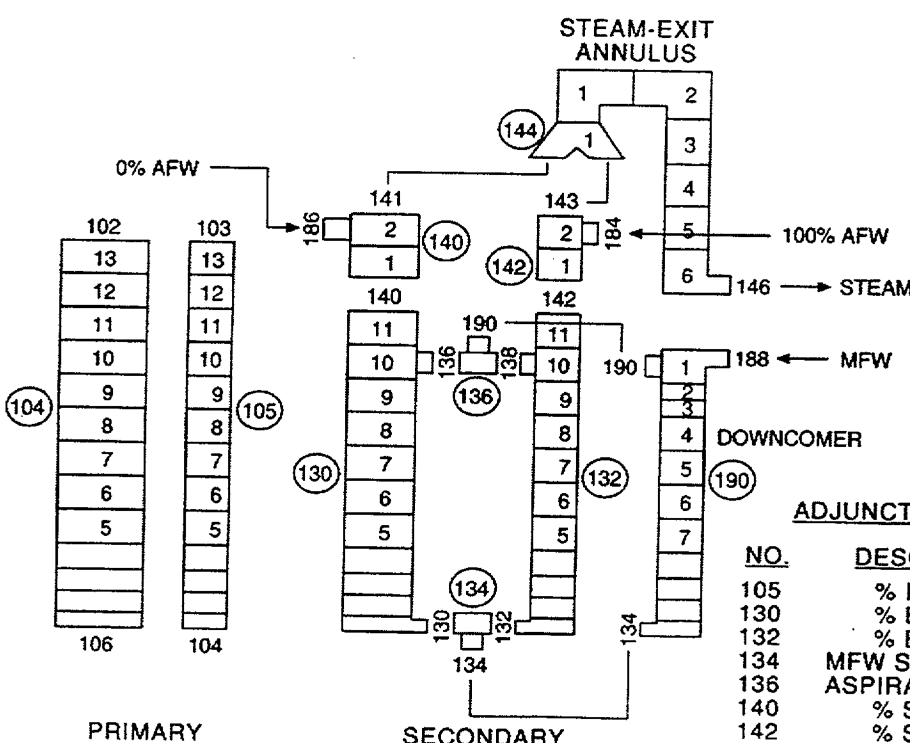


Fig. 7-4. TRAC-M model of a once-through SG with aspirator flow.



ADJUNCT COMPONENTS

NO.	DESCRIPTION	TYPE
105	% PRIMARY	PIPE
130	% BOILER	TEE
132	% BOILER	TEE
134	MFW SPLIT	TEE
136	ASPIRATOR SPLIT	TEE
140	% SUPERHEAT	TEE
142	% SUPERHEAT	TEE
144	STEAM EXIT	TEE
190	DOWNCOMER	TEE

Fig. 7-5. Diagram of a TRAC-M once-through SG with dual-channel modeling.

and QPPP volumetric heat source (sink), and TW temperature 2D distributions. 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 Section 7.1.2.2.

Modeling heat transfer through solid structures in the reactor vessel, SGs, or other complicated hardware structures should be done using HTSTR components with ROD (cylindrical geometry) or SLAB (Cartesian geometry) elements. Convection heat-transfer coupling to the fluid of hydraulic components can be evaluated on both the inner and outer surfaces of the ROD or SLAB element. The actual geometry of a single physical element is modeled and evaluated by a calculative ROD or SLAB 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.

7.3. Control Procedures

The control procedure in TRAC-M is discussed in Section and in the TRAC-M/F90 Theory Manual. The description and use of signal variables, control blocks, trips, and component-action tables are covered there in some detail. 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 TRAC-M control procedure. You should become familiar with Section 3, the Section control-procedure input data, and the TRAC-M full-plant annotated input-data TRACIN file in Appendix E because we will frequently refer to them.

7.3.1. Example 1: Trip-Controlled Valve Closure

We begin with a word statement of the control-procedure specification. 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 required 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 s 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 TRAC-M input-data TRACIN 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 it by 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 based on problem-time dependence. This signal-variable input data would be placed in the signal-variable section of the control-procedure input data (see the full-plant signal-variable section input data in Section E.8 and the definition of signal-variable parameter ISVN numbers and descriptions in Table 6-1). Assuming that the pressurizer is modeled by component 22 and its pressure is monitored in cell 1, the signal-variables input data (described in Section 6.3.5.3.) 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 of 1 IDSV 9900 is chosen by the user. We have identified signal variable ID = 1 to be problem time (ISVN = 0 in Table). Because problem time is not associated with any component, the other component-parameter entries, ILCN, ICN1, and ICN2 are 0. We have identified signal variable ID = 2 to be pressure (ISVN = 21 in Table). The value of ILCN is 22, which is the component identifier number NUM for the pressurizer it models, and 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. Note that by choosing the FREE-format option, we can comment the input data to identify the input-data FORTRAN-variable names and the parameter of each signal variable as shown above (see Section , Main-Data Card 1 for the FREE-format specification). The user should use 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 input-data developer.

The trip input data for our control procedure (described in Section) with comments and FORTRAN-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 1 |IDTP| 9999, 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 defining form.

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. From our previous discussion on trips in Section , we recall that when no evaluation of a component action is desired, the set-status label of its controlling trips should be OFF with a corresponding ISET value of 0. Thus, we input ISET = 0 for the initial set status of trip ID 113.

For our desired control procedure, we will need only two set-status label states for trip ID 113 (i.e., OFF and $ON_{forward}$). Initially ISET = 0 defines the set-status label to be OFF, and the trip-controlled valve-closure state is not evaluated. When the pressurizer pressure falls below a specified setpoint value, we want the set-status label for the trip to be set to $ON_{forward}$ and ISET set to 1 by TRAC-M. With ISET = 1 for the TSV controlling trip, the TSV component action is evaluated at the start of each timestep. We want that evaluation to close the TSV. Figure 7-6 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 = 1.3100E+07 Pa (1.9000E+03 psia) and S_2 = 1.0000E+08 Pa (1.4504e+04 psia). Trips have two setpoints between subranges to model hysteresis and to avoid an oscillating change in set status between timesteps. The trip signal is compared with the setpoint closest to the subrange that it is testing for a change of set status to. For trip ID 113, when ISET = 0, trip signal S_1 is tested for a change of set status to $ON_{forward}$ and when ISET = 1, trip signal Š S_2 is tested for a change of set status to OFF. From Table , we see that the Fig. 7-6 trip signal-range type to be input specified is ISRT = 1. S_1 = 1.3100E+07 Pa (1.9000E+03 psia) is our desired trip-signal setpoint pressurizer pressure for tripping the reactor-core power off and closing the TSV. Initially, the pressurizer pressure is greater than S_1, and when it falls to or below S_1 the set-status label of trip ID 113 is changed to $ON_{forward}$, ISET is changed to 1, and the TSV component action 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 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) = 1.0000E+08 Pa (1.4504E+04 psia)].

In the trip input data above, setpoint delay time DTSP(1) = 1.0000E+00 s requires a 1.0 s delay after the trip signal falls to or below S_1 before the set-status label of trip ID 113 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

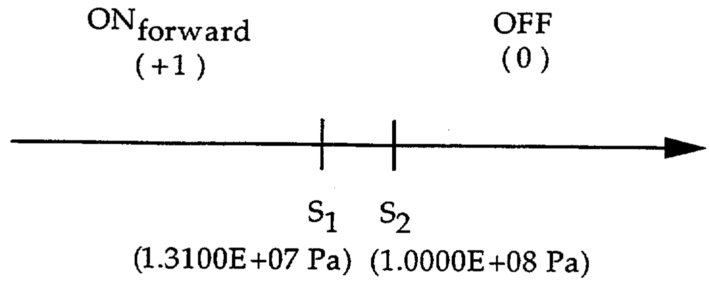


Fig. 7-6. Trip-signal-range-type diagram for turbine stop valve control.

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. Setpoint delay time DTSP(2) = 1.0000E+04 s requires a 10 000.0 s time delay after the trip signal rises to or above S_2 before the set-status label of trip ID 113 changes to OFF. For calculation problem times < 10 000.0 s, this definitely prevents ISET from being reset to 0 and stopping TSV closure. Actually, a DTSP(2) delay time Š 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 we set IFSP(1) and IFSP(2) equal to zero.

To show how the set status of controlling trip ID 113 is communicated to VALVE component 44, we look at the input data shown in Table 7-2 that models the TSV. Section should be referred to for a detailed description of the VALVE-component input-data format. The numbered annotations on Table 7-2 are discussed in the items that follow with the same number.

1. The parameter IVTR = 113 is the ID identifying number of the trip that controls the VALVE component-action table evaluation. Inputting the value of IVTR to be the trip ID number assigned to IDTP in the trip input data, for the trip that is to control the VALVE component's adjustable flow-area action, provides the control-procedure link between this trip and the VALVE's component-action table whose evaluation it controls.
2. The parameter IVSV = 1 is the ID identifying number of the independent variable for the VALVE component-action table. It is the positive ID number assigned to IDSV for the signal variable defining problem time.
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 set status of the controlling trip is ON$_{forward}$. Referring to the VALVE-component input-data format in Section , we see that IVTY = 3 (word 3 on Card Number 3) for this type of VALVE control and adjustment.
4. The parameter NVTB1 = –2 absolute value is the number of table (x,y) pairs in the (first) VALVE component-action table. Because we do not know

TABLE 7-2
INPUT COMPONENT DATA FOR THE TURBINE STOP VALVE

```
*
*************************************************************************
*******   type          num           id       ctitle
valve                    44           44 $44$ turbine stop valve
*      ncells         nodes         jun1         jun2         epsw
            1             1           54          182   0.0000e+00
*        ichf         iconc         ivty         ivps        nvtb2
            1             0            3            2            0
*        ivtr          ivsv        nvtb1         nvsv         nvrf
          113             1           -2            0            0
*      iqp3tr        iqp3sv       nqp3tb       nqp3sv       nqp3rf
            0             0            0            0            0
*      ivtrov        ivtyov
            0             0
*        rvmx          rvov       fminov       fmaxov
   2.0000e+00    0.0000e+00   0.0000e+00   1.0000e+00
*       radin            th        houtl        houtv        toutl
   3.0960e-01    1.0000e-02   0.0000e+00   0.0000e+00   2.9500e+02
*       toutv         avlve        hvlve       favlve         xpos
   2.9500e+02    5.8600e-01   6.0960e-01   1.0000e+00   1.0000e+00
*       qp3in        qp3off       rqp3mx       qp3scl
   0.0000e+00    0.0000e+00   0.0000e+00   1.0000e+00
*
* dx     *     1.0000e+00e
* vol    *     5.8600e-01e
* fa     * f   5.8600e-01e
* kfac   * f   0.0000e+00e
* rkfac  * f   0.0000e+00e
* grav   * f   0.0000e+00e
* hd     * f   6.0960e-01e
* icflg  * f            0e
* nff    * f            1e
* alp    *     1.0000e+00e
* vl     * f   0.0000e+00e
* vv     * f   0.0000e+00e
* tl     *     6.1000e+02e
* tv     *     6.1000e+02e
* p      *     6.3746e+06e
* pa     *     0.0000e+00e
* qppp   *     0.0000e+00e
* matid  *              9e
* tw     *     6.1000e+02e
*
* vtbl   *     0.0000e+00    1.0000e+00    5.0000e-01    0.0000e+00e
*
```

when the pressurizer pressure will fall to or below setpoint S_1 = 1.3100E+07 Pa (1.9000E+03 psia), 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 (when NVTB1 < 0) rather than "absolute" value (when NVTB1 > 0). Its "relative" value is the change in the IVSV parameter (in this case, problem time) from when the controlling trip was activated (set to $ON_{forward}$). When the trip ID 113 set-status value changes to ISET = 1, the independent variable sums the timestep size (change in problem time) multiplied by ISET for each timestep. Actually, it does this every timestep, but the addend is 0.0 when the trip is OFF with ISET = 0. Figure 7-7 shows the VALVE component-action table (defined on line 44 of Table 7-2, note 7) with its "relative" value independent variable. With ISET = 1 ($ON_{forward}$), the table's independent variable is evaluated to be the time interval since the trip was activated to an $ON_{forward}$ set status. For our example, if the pressurizer pressure fell to or below setpoint S_1 at 2.1 s after the start of the transient calculation, the trip ID 113 set status is set to ISET = 1 at 3.1 s because the trip setpoint S_1 has a 1.0 s time delay assigned to it [DTSP(1) = 1.0000E+00 s]. At problem time 3.35 s, the value of the independent variable for the VALVE component-action table would be $(3.1\ s - 0.0\ s) \cdot 0.0 + (3.35\ s - 3.1\ s) \cdot 1.0 = 0.25\ s$.

5. The parameter NVTB2 = 0 is the number of table (x,y) pairs in the (second) VALVE component-action table. If NVTB2 is nonzero with the same numerical sign as NVTB1, it would be evaluated when the set-status label of the controlling trip is $ON_{reverse}$ with ISET = –1. This VALVE table, for example, could be used to open (close) the VALVE with a different time dependence when the first VALVE table is used to close (open) 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 have an $ON_{reverse}$ set status. Use of the second VALVE table will be illustrated in the next eample.
6. The parameter FAVLVE = 1.0000E+00 is the initial flow-area fraction of the VALVE's adjustable flow-area interface. Because the turbine stop valve initially is in its full-open position, FAVLVE is set to 1.0.
7. The parameter NVTB1 = –2 absolute value specifies that there are two (x,y) pairs of data in the first VALVE component-action table. The number of table entry values is $|NVTB1| \times 2$ (four in our case). The first, third, fifth, etc. (odd numbered) data entries are the values of the independent variable (in our example, time since the trip set status changed to ISET = 1). 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

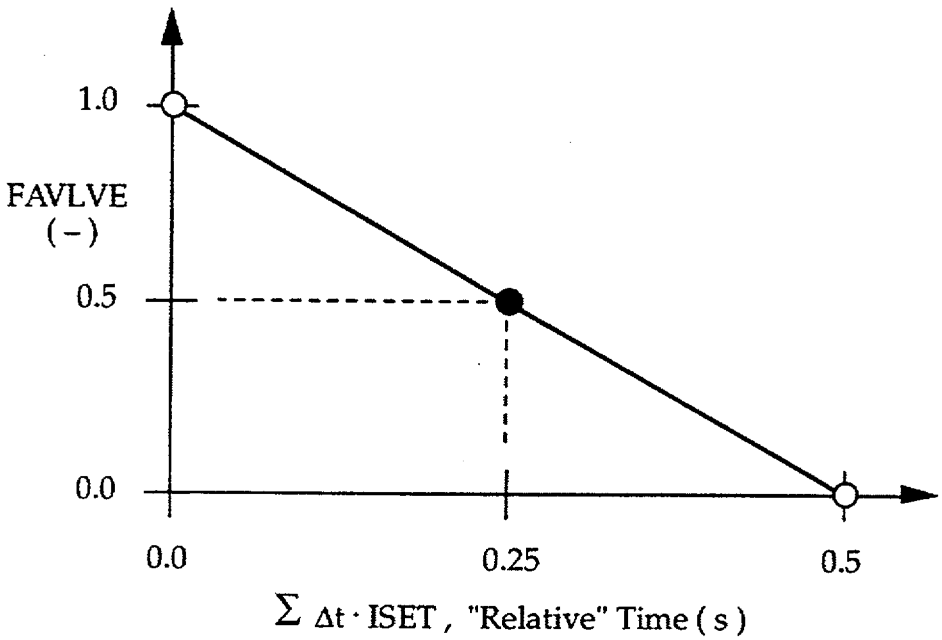


Fig. 7-7. Flow-area fraction vs time for the turbine stop valve.

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 Fig. 7-7 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. For a discussion of the other parameters appearing in the VALVE component data, you should refer to the VALVE-component input-data format in Section and the VALVE-component description in Section 4.10.

A clarification is needed on the defining form for the "relative" independent variable of component action tables. While it can be thought of as defined by

$$\sum_{i=1}^{i=n} (\text{independent variable change over timestep i}) \cdot ISET \quad , \tag{7-9}$$

TRAC-M evaluates this independent variable in a different but equivalent manner. The summation is accomplished by shifting all independent variable (x) values in the table by –(independent variable change over timestep i) · ISET each timestep. This always leaves the last interpolated value from the table with an independent variable value of x = 0.0. Note that the input VALVE table (note 7) has x = 0.0 at y = FAVLVE = 1.0 for the initial closure state of the VALVE. TRAC-M doesn't allow extrapolated evaluation outside the defined range of the table so $x_1 \leq 0.0 \leq x_{|NVTB1|}$.

7.3.2. 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 the use of a more complex trip signal-range type and show how signal-variable input data can be used to define a pressure difference between cells of a component as a signal variable. 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 4.2370E+06 Pa (6.1452E+02 psia)], 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 at interface 3 as shown in Fig. 7-8. 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 ΔP rises above a specified value, the VALVE adjustable flow area starts to open. When ΔP falls below a specified value, the VALVE adjustable flow area starts to close. The specific valve-movement characteristics must be defined by the user in the VALVE component-action table.

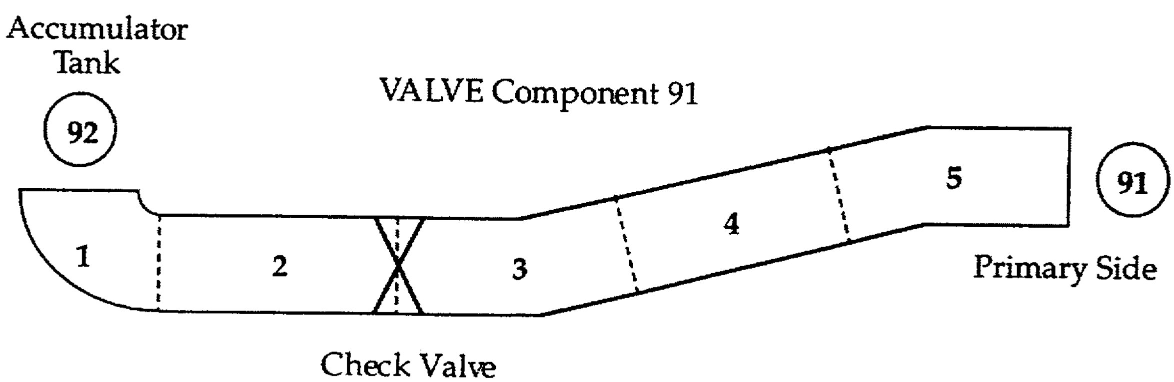


Fig. 7-8. Accumulator check-valve model.

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 as a signal variable for use as the controlling trip signal. 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. At the end of Section , we see that there are 5 different forms for defining signal variable parameters when they are cell or interface location dependent, as shown in Table for |ISVN| parameter numbers 20 to 40, 65 to 101, and 104. In these cases when ISVN > 0, the form of the signal variable is the parameter value in a mesh cell or the maximum, minimum, or volume-weighted average parameter value in a series of contiguous cells. When ISVN < 0, the form of the signal variable is the difference in the parameter's values in two given cells or over the last timestep. Note that these cells must be in the same component. It is the ISVN < 0 form that is of interest for our example.

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
```

The user has identified the accumulator check valve as component number ILCN = 91, identified signal variable IDSV = 39 as a ISVN = –21 pressure difference, and defined the cells in VALVE component 91 from which the pressure difference is to be determined as cells ICN1 = 1 and ICN2 = 5. From Table 6-1 we see that ISVN = 21 defines the signal-variable parameter to be the fluid pressure. Prefixing the parameter number with a minus sign selects the difference option for the parameter. It is the spatial difference between the parameter values in cells ICN1 > 0 and ICN2 > 0 (for our example) or the previous timestep difference when either ICN1 = 0 or ICN2 = 0. 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.

We require the accumulator check valve to open when ΔP is greater than a trip setpoint S_4 and to close when ΔP 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 set-status 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 Fig. 7-9. Referring to Table , we see that this corresponds to a ISRT = –3 trip signal-range type.

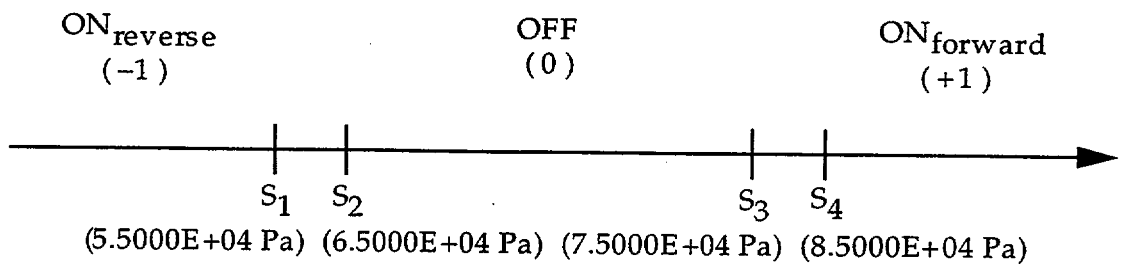


Fig. 7-9. Trip-signal-range-type diagram for accumulator check-valve control.

Early in the transient calculation, before the primary system has depressurized very much, $\Delta P = P_1 - P_5 < 0.0$ and the trip set-status label 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 system depressurizes, P_5 will decrease and the value of $\Delta P = P_1 - P_5$ will increase and eventually become positive valued. When ΔP crosses S_2 = 6.5000E+04 Pa (9.4275E+00 psia), the trip set status will be set to OFF and the VALVE component-action table will not be evaluated (remaining in its fully closed state). Finally, when ΔP crosses S_4 = 8.5000E+04 Pa (1.2328E+01 psia), the trip set 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 set 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. 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 set-status label 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 = 8.5000E+04 Pa (1.2328E+01 psia); i.e., the pressure in cell 5 is S_4 = 8.5000E+04 Pa (1.2328E+01 psia) below the accumulator-tank outlet cell 1 pressure of 4.2370E+06 Pa (6.1452E+02 psia). Setpoint delay times of 2.0000E-01 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 Table 7-3, which lists the VALVE component number 91 input data for modeling the accumulator check valve. The numbered note annotations in Table 7-3 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 their opening, and closing times for the VALVE adjustable flow area need not be the same, but the numerical signs of NVTB1 and NVTB2 must be the same. 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 is the summed change of signal variable IVSV = 1 during the previous timestep (the timestep size) multiplied by ISET of the controlling trip (and evaluated by TRAC-M as described in the last paragraph of the previous example). The first VALVE table (note 8) is evaluated when the trip set-status label is $ON_{forward}$, and the second VALVE table (note 9) is evaluated when the trip set-status label is $ON_{reverse}$. While the trip set status is $ON_{forward}$ and 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 $ON_{reverse}$ and 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. TRAC-M 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) set status is $ON_{forward}$ for 0.56 s. The VALVE will open from its input-specified initial FAVLVE = 0.0000E+00 state (note 6 where for consistency XPOS = 0.0000E+00 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 =

TABLE 7-3
INPUT COMPONENT DATA FOR THE ACCUMULATOR CHECK VALVE

```
*
*************************************************************************
*******     type            num              id          ctitle
valve                        91              91 $91$ accumulator check valve
*          ncells          nodes            jun1         jun2          epsw
                5              0              92           91     0.0000e+00
*            ichf          iconc            ivty  [3]    ivps          nvtb2
                0              0               3            3              2
*            ivtr  [1]     ivsv  [2]      nvtb1  [4]     nvsv   [5]     nvrf
              105              1              -2            0              0
*          ivtrov         ivtyov
                0              0
*            rvmx           rvov          fminov       fmaxov
       2.0000e+00     0.0000e+00      0.0000e+00   0.0000e+00
*           radin             th           houtl        houtv          toutl
       2.9210e-01     5.0000e-03      0.0000e+00   0.0000e+00     3.0000e+02
*           toutv          avlve           hvlve       favlve           xpos
       3.0000e+02     6.7000e-02      2.9210e-01   0.0000e+00     0.0000e+00
*                                                         [6]   [7]
* dx     *      1.6810e+00r04 7.0050e+00e
* vol    *      1.1260e-01r04 4.6930e-01e
* fa     *      9.9315e-02r05 6.7000e-02e
* kfac   *      0.0000e+00    3.1660e-01    0.0000e+00r02 2.5600e-02s
* kfac   *      0.0000e+00e
* rkfac  * f    0.0000e+00e
* grav   *     -1.0000e+00r02 0.0000e+00r02 1.7960e-01    0.0000e+00e
* hd     *      3.5560e-01r05 2.9210e-01e
* icflg  * f              0e
* nff    *              1r05            0e
* alp    *      0.0000e+00e
* vl     * f    0.0000e+00e
* vv     * f    0.0000e+00e
* tl     * r02 3.0540e+02r03 5.6427e+02e
* tv     * r02 3.0540e+02r03 5.6427e+02e
* p      * r02 4.2370e+06r03 1.5500e+07e
* pa     *     0.0000e+00e
*
* opening valve table
* vtb1   * r02 0.0000e+00    7.0000e-01    1.0000e+00e   <-- [8]
*
* closing valve table
* vtb2   * r02 0.0000e+00    5.0000e-01    1.0000e+00e   <-- [9]
*
```

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 = –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 set 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 Fig. 7-10. The arrow shows the direction of valve adjustment by each VALVE table. We chose to have the $ON_{forward}$ trip set status open the valve and the $ON_{reverse}$ trip set 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 Fig. 7-10 would have been negative rather than positive to model the same VALVE adjustment.

A special case situation needs to be pointed out, particularly for TRAC-M users with some experience who may encounter this situation during a restart calculation. Let us assume that a TRAC-M 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 restart-data TRCRST file or obtained from the TRCOUT file large edit at 800.0 s.

Note: The EXTRACT support code, which generates input in TRACIN format from a TRCDMP/TRCRST dump file, is currently not available.

Selected signal variables, control blocks, and trips controlling the VALVE also may need to be revised and input in the TRACIN file depending on the changes being made to the VALVE component. The initial conditions for all other components, signal variables, control blocks and trips are to be read from the restart-data TRCRST file data dump at 800 s. The VALVE component-action tables, as originally input (as shown in Table 7-3), 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 Table 7-3 data satisfies this requirement. A constant value is added or subtracted from all x values in the original VALVE table to make this shift. Figure 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 reinput component-action tables such as this with "relative" value independent variables to the TRACIN 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

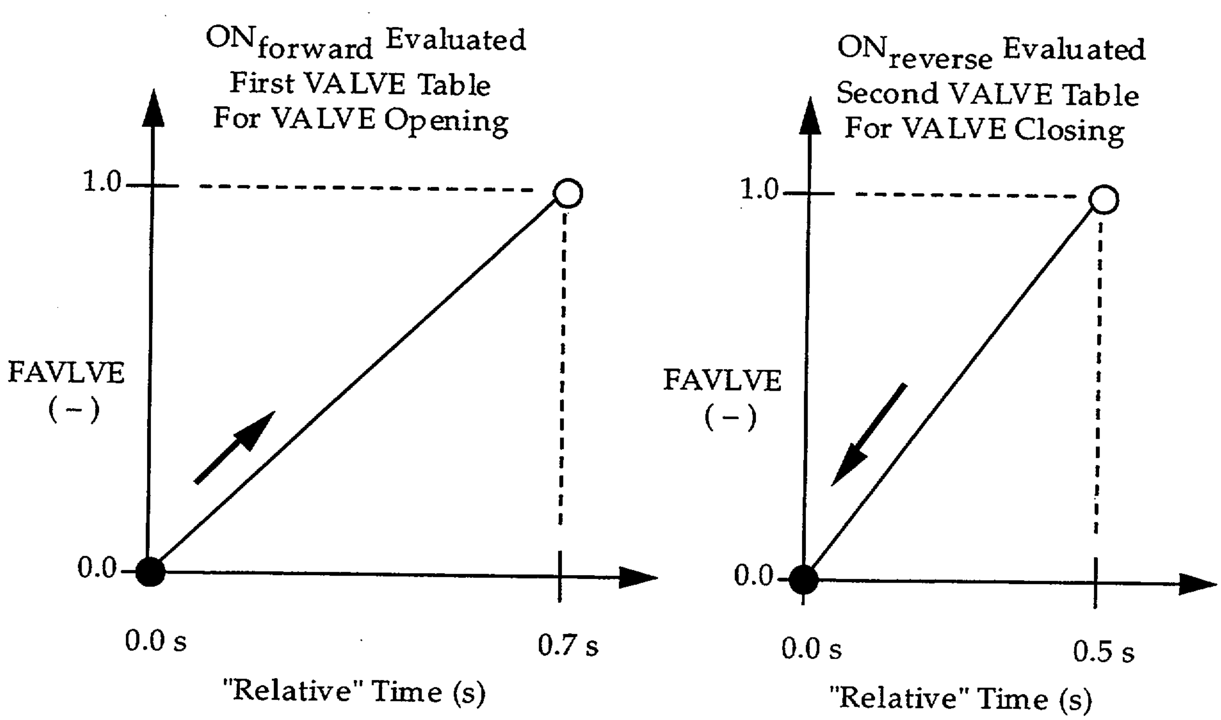


Fig. 7-10. VALVE opening and closing tables for the accumulator check valve.

directly as a signal variable, as we did previously, because the cells are in different components. We need 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 = 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
```

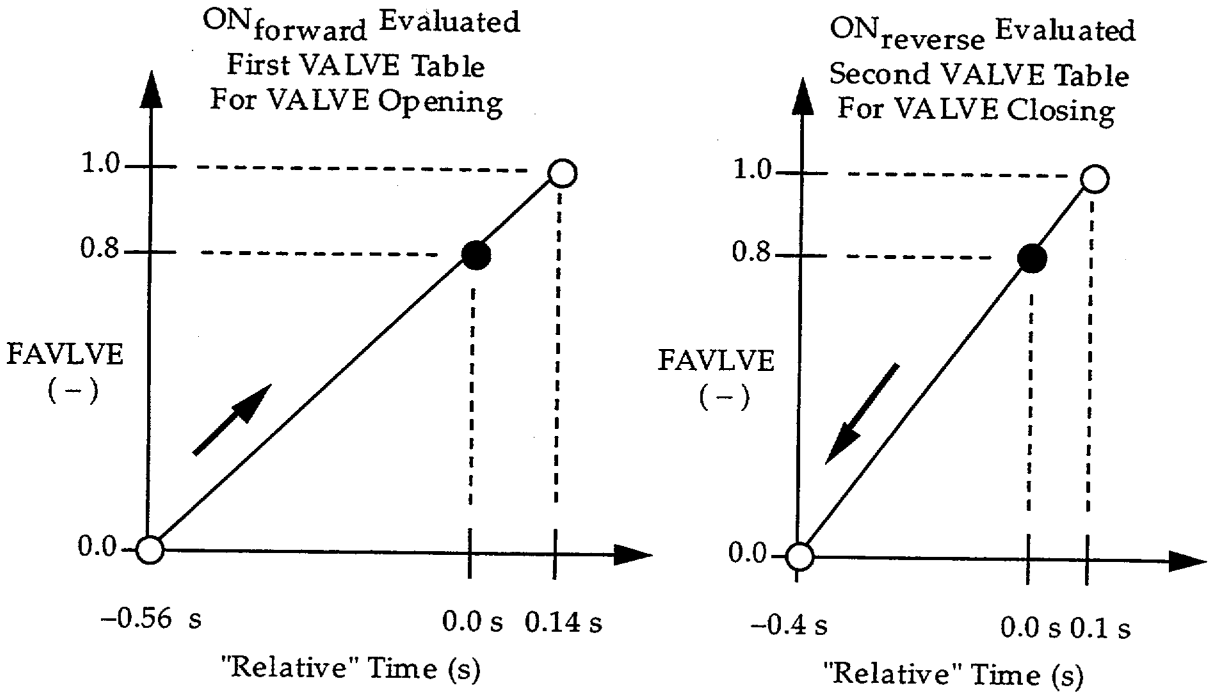
These signal-variable parameter definitions were discussed above. Note that ISVN for signal variables IDSV = 39 and 40 now are both 21 and not –21 to define individual cell pressures rather than the pressure difference between cells. This requires no values be input for ICN2. When only one cell number is defined for a signal variable, either ICN1 or ICN2 can define that cell number with the other defining 0.

We now consider the control-block input data for this example. You may wish to refer to the Westinghouse three-loop full-plant model in Appendix E for a much more extensive set of control-block input data with annotated comments on the different control-block functions that are used.

These signal-variable parameter definitions were discussed above. 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 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 defining 0.

We now consider the control-block input data for this example. You may wish to refer to the Westinghouse three-loop full-plant model in Appendix E for a much more extensive set of control-block input data with annotated comments on the different control-block functions that are used. The control block input is as follows:

```
* 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
```




```
*          toutv           avlve          hvlve          favlve           xpos
     3.0000e+02     6.7000e-02     2.9210e-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
*
```

Fig. 7-11. Modified VALVE tables for a restart calculation when FAVLVE = 0.8.

The user chooses the control-block identification number IDCB = –100 with the restriction that –9900 ≤ IDCB ≤ –1. From Table , 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 X1 and X2 in Table . No value is required for ICB3 even though 0 is input. Positive values for ICB1 and ICB2 indicate that they are signal variables and not the output signals of control blocks. The value for CBGAIN (G in Table) 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 XOUT output-signal value of the control block to be Š 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 (even though 0.0000E + 00 is input for each) because C1 and C2 are not shown in Table as required for the subtraction function. Units-name labels LUNOUNIT and LUPRESSA are input from Table to define the units of control-block parameters CBGAIN, CBXMIN, CBXMAX, CBCON1 and CBCON2. Their units are unknown to TRAC-M, and the user must define them through input when units conversion from metric SI to English is to be done by TRAC-M. That occurs when one or more NAMELIST variables IOGRF, IOINP, IOLAB, and IOOUT are defined with the value 1 for IOINP input and IOGRF, IOLAB, and IOOUT output in English units. When all 4 of these NAMELIST variables have their default value of 0, no input/output conversion to English units is done by TRAC-M, and the FORTRAN variable-name comment line and units-name labels line are not input. This situation allows older TRACIN files to be used by TRAC-M without the need to add control-block units-name labels data.

The trip ID 105 input data now 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 TRAC-M 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
```

7.3.3. Example 3: Feedwater Control by FILL Components

In this example, we will investigate some simple control procedures for FILL components to simulate main feedwater coastdown and the initiation of auxiliary feedwater injection into a SG following a reactor-core power trip. We also will show how the liquid level on the secondary side of a SG can be defined directly as a signal variable through use of one of the signal variable defining options and how a scale factor can be applied to a component-action table to simplify its input data.

Following a reactor-core power trip on low pressure, the main feedwater flow into a SG is to be terminated, and auxiliary feedwater is to be initiated to maintain a desired water level in the SG. Let us assume the reactor-core power is tripped off on a low pressure of 1.3100E+07 Pa (1.9000E+03 psia) and 1.0 s later the main feedwater pump is tripped off. We wish to simulate the main feedwater-flow coastdown and assume that mass flow as a function of time is known after the trip. 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 7.6000E-01 m (2.4934E+00 ft) above the tube sheet. Note that we will not be modeling the main and auxiliary feedwater pumps but will be simulating their action by specifying their mass flows as FILL-component boundary conditions.

The signal variables required are problem time, 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 the user has assigned signal-variable identity-number IDSV values of 1 for problem time, 2 for the pressurizer pressure, and 3 for the SG liquid level (height of collapsed liquid above the SG tube sheet) 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 signal-variable "collapsed" liquid-level parameter in Table that will be used to define the SG downcomer liquid level. ILCN = 203 identifies the 1D hydraulic component modeling 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 TRAC-M signal variable for "collapsed" liquid level is evaluated in a nonstandard manner. It is different from evaluating the liquid level by multiplying each cell i height ~$[(GRAV_{i-1/2} + GRAV_{i+1/2}) \cdot DX_i)]$ by the liquid fraction $(1.0 - ALPHA_i)$ and summing overall cells. Note that the height of each cell i is approximated because the GRAVs are defined at the cell-edge interfaces. TRAC-M instead 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 evaluate by TRAC-M, 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 trip controlled by the pressurizer pressure defined by signal variable ID 2. Initially this pressure is above the reactor-core power trip setpoint pressure. In this situation, we want the feedwater controlling trips defined with OFF set-status labels 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 to or below 1.3100E+07 Pa (1.9000E+03 psia), then we want their controlling-trip set 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 set-status label with the mass-flow condition of the FILL component action it controls. Don't make this mistake. A controlling-trip set-status label 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 7.0000E+02 kg s^{-1} (5.5556E+06 lb_m h^{-1}) and the controlling-trip set-status label is OFF, that mass flow will remain unchanged at 7.0000E+02 kg s^{-1} (5.5556E+06 lb_m h^{-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 FILL component action table's defined time dependence.

The trip signal range type for both main and auxiliary feedwater control is shown in Fig. 7-12. 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 Fig. 7-12 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 20.0 s delay time on its low pressure S_1 = 1.3100E+07 Pa (1.9000E+03 psia) setpoint that will be tested for a change of set status to $ON_{forward}$. The S_2 = 1.0000E+08 Pa (1.4504E+04 psia) setpoint 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 Table 7-4 for the main-and auxiliary-feedwater mass-flow boundary conditions. The Table 7-4 numbered annotations 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. Its control form in Section 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.

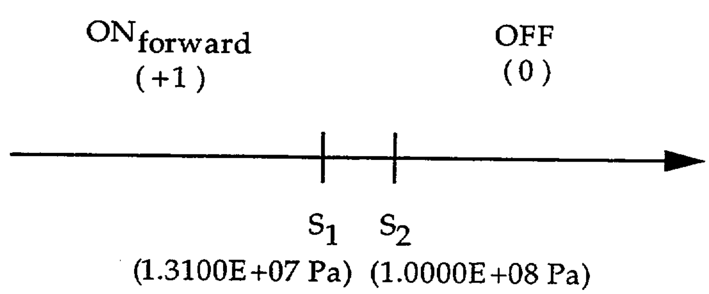


Fig. 7-12. Trip-signal-range-type diagram for main and auxiliary feedwater control.

TABLE 7-4
COMPONENT INPUT DATA FOR MAIN AND AUXILIARY FEEDWATER

```
*
*************************************************************************
*******    type               num              id       ctitle
fill                           70              70 $70$ main feedwater loop a
*            jun1           ifty            ioff
               70              8               0
*            iftr           ifsv            nftb            nfsv            nfrf
              103              1              -7               0               0
*          twtold           rfmx          concin            felv
       0.0000e+00     1.0000e+03      0.0000e+00      0.0000e+00
*            dxin          volin           alpin            vlin            tlin
       2.0000e+00     1.0000e-01      0.0000e+00      0.0000e+00      5.1090e+02
*             pin           pain          flowin            vvin            tvin
       6.3800e+06     0.0000e+00      6.8050e+02      0.0000e+00      5.1090e+02
*           vmscl          vvscl
       6.8050e+02     1.0000e+00
*
* vmtb          rel.time      rel.mass flow
* vmtb   *     0.0000e+00     1.0000e+00s
* vmtb   *     2.0000e+00     4.0000e-01s
* vmtb   *     4.0000e+00     2.0500e-01s
* vmtb   *     6.0000e+00     1.0500e-01s
* vmtb   *     8.0000e+00     4.5000e-02s
* vmtb   *     1.0000e+01     1.5000e-02s
* vmtb   *     1.2000e+01     0.0000e+00e
*
*************************************************************************
*******    type               num              id       ctitle
fill                           62              62 $62$ aux. feedwater loop b
*            jun1           ifty            ioff
               62              8               0
*            iftr           ifsv            nftb            nfsv            nfrf
              333              3               2               0               0
*          twtold           rfmx          concin            felv
       9.0000e-01     1.0000e+03      0.0000e+00      0.0000e+00
*            dxin          volin           alpin            vlin            tlin
       1.0000e+00     1.8200e-02      0.0000e+00      0.0000e+00      3.1100e+02
*             pin           pain          flowin            vvin            tvin
       6.5000E+06     0.0000e+00      0.0000e+00      0.0000e+00      3.1100e+02
*           vmscl          vvscl
       1.0000e+00     1.0000e+00
*
* vmtb          liq.level      mass flow
* vmtb   *     7.4000e-01     6.5400e+01s
* vmtb   *     7.6000e-01     0.0000e+00e
*
```

4. The main- and auxiliary-feedwater initial mass flows are FLOWIN = 6.8050E+02 kg s^{-1} (5.4009E+06 lb_m h^{-1}) and 0.0000E+00 kg s^{-1} (0.0000E+00 lb_m h^{-1}), respectively.
5. The FILL component-action tables are defined in lines 18 to 25 for main feedwater and lines 43 to 45 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 = 6.8050E+02 kg s^{-1} (5.4009E+06 lb_m h^{-1}) on line 16 is the scale factor that the VMTB-table dependent-variable y values are multiplied by after being input by TRAC-M. Also note that the VMTB table's scale-factor-multiplied mass flow at "relative" time x(1) = 0.0 s is y(1) · VMSCL = 1.0 680.50 = 6.8050E+02 kg s^{-1} = FLOWIN. The VMSCL scale factor can save time when the user needs 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 dependent-variable y values. The tabular data for auxiliary feedwater specify a maximum mass flow of y(1) = 6.5400E+01 kg s^{-1} (5.1906E+05 lb_m h^{-1}) if the "collapsed" liquid level is 7.4000E-01 m (2.4278E+00 ft) and a minimum mass flow of y(2) = 0.0000e+00 kg s^{-1} (0.0000E+00 lb_m h^{-1}) if the "collapsed" liquid level is Š 7.6000E-01 m (Š 2.4934E+00 ft). 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 7-13 shows the plotted tabular data for both the VMTB main-feedwater and auxiliary-feedwater FILL component-action tables.

7.3.4. 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 (533.93°F). 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 1.5432E-01 K s^{-1} (2.7778E-01°F 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 1.5432E-01 K s^{-1} (2.7778E-01°F 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

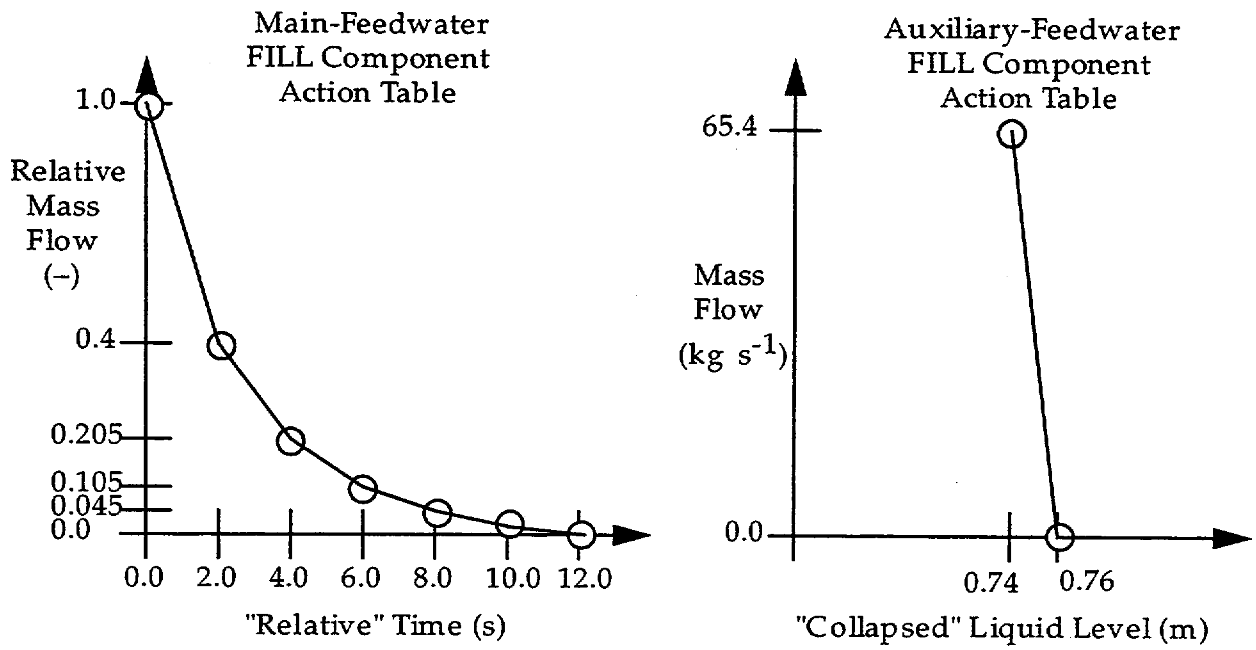


Fig. 7-13. Main-feedwater and auxiliary-feedwater FILL component-action tables.

even though it is less than optimum. A better controller could be provided by a PI or PID control block (operation numbers 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-value overall cooldown rate

$$DT/Dt = (T_0 - T_1)/(t_1 - t_0) \ . \tag{7-10}$$

Within some deviation limit $\Delta > 0.0$ K s^{-1} (0.0°F 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 + Δ, the ADV is to be fully closed; when the cooldown rate is less than the desired rate – Δ, the ADV is to be fully open. That is,

$DT/Dt \geq 1.5432\text{E-}01 \text{ K s}^{-1} + \Delta$, ADV is fully closed;

$(DT)/(Dt) \leq 1.5432\text{E-}01 \text{ K s}^{-1} - \Delta$, ADV is fully open;

$1.5432\text{E-}01 \text{ K s}^{-1} - \Delta < DT/Dt < 1.5432\text{E-}01 \text{ K s}^{-1} + \Delta$, ADV is appropriately adjusted. (7-11)

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

$$E = \max\{-1.0, \min[1.0, (DT/Dt - 1.5432\text{E-}01 Ks^{-1})/\Delta]\} . \tag{7-12}$$

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 $\leq$ 1.5432E-01 K $s^{-1} - \Delta$ with ADV fully open,	
0.0	0.5	Cooldown rate = 1.5432E-01 K s^{-1} with ADV at mid position, and	
+1.0	0.0	Cooldown rate $\geq$ 1.5432E-01 K $s^{-1} + \Delta$ with ADV fully closed.	(7-13)

In the VALVE-component input-data format description (see Section), 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. (7-12). 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 of Eq. (7-13) with linear interpolation between the $E = \pm 1.0$ limit conditions. That relationship is

$$FA = 0.5 - 0.5 \cdot E . \tag{7-14}$$

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 7-14 shows how we link control-block evaluations to provide the desired ADV cooldown-rate controller for evaluation by TRAC-M. 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 Section for the control-block input-data format description and to Table , which lists 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. These input data 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 7-5. The user 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 Fig. 7-14, according to their Table defining form. 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 SCBMIN = 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 = –1.0000E+00 and CBXMAX = 1.0000E+00. Parameter CBCON1 is used to define constants for the control-block function operators. Specifying CBCON2 = 0.0000E+00 for all these control blocks results in TRAC-M internally initializing their output-signal value at the start of the calculation based on the control block input-signal values and function operator. The TRAC-M user could have done this for any of these control blocks by defining the control block's initial output-signal value with CBCON2 ≠ 0.0000E+00.

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 7-6.

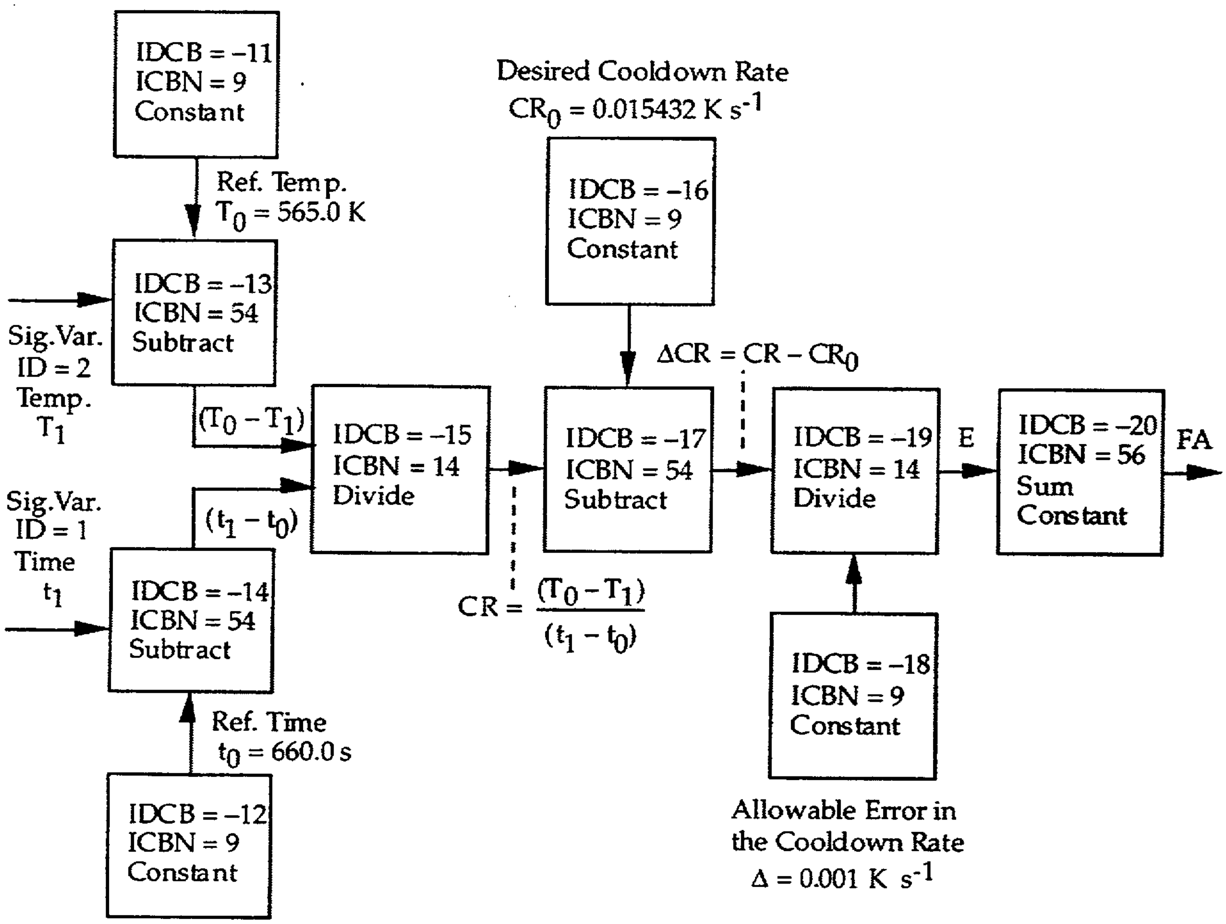


Fig. 7-14. Cooldown-rate controller for the atmospheric dump valves.

TABLE 7-5
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
```

TABLE 7-5 (cont)
INPUT DATA FOR THE ADV COOLDOWN-RATE CONTROLLER

```
              lunounit       ludtdt       ludtdt     lunounit     lunounit
*               cbgain       cbxmin       cbxmax       cbcon1       cbcon2
            1.0000e+00   0.0000e+00   1.0000e+02   0.0000e+00   0.0000e+00
*
* desired cooldown rate
*                 idcb         icbn         icb1         icb2         icb3
                   -16            9            0            0            0
*              luxgain       luxmin       luxmax       lucon1       lucon2
              lunounit       ludtdt       ludtdt       ludtdt     lunounit
*               cbgain       cbxmin       cbxmax       cbcon1       cbcon2
            1.0000e+00   1.5432e-02   1.5432e-02   1.5432e-02   0.0000e+00
*
* cooldown rate deviation in loop a
*                 idcb         icbn         icb1         icb2         icb3
                   -17           54          -15          -16            0
*              luxgain       luxmin       luxmax       lucon1       lucon2
              lunounit       ludtdt       ludtdt     lunounit     lunounit
*               cbgain       cbxmin       cbxmax       cbcon1       cbcon2
            1.0000e+00  -1.0000e+00   1.0000e+00   0.0000e+00   0.0000e+00
*
* allowable deviation in the cooldown rate
*                 idcb         icbn         icb1         icb2         icb3
                   -18            9            0            0            0
*              luxgain       luxmin       luxmax       lucon1       lucon2
              lunounit       ludtdt       ludtdt       ludtdt     lunounit
*               cbgain       cbxmin       cbxmax       cbcon1       cbcon2
            1.0000e+00   1.0000e-03   1.0000e-03   1.0000e-03   0.0000e+00
*
* fractional error e with constraint limits applied
*                 idcb         icbn         icb1         icb2         icb3
                   -19           14          -17          -18            0
*              luxgain       luxmin       luxmax       lucon1       lucon2
              lunounit     lunounit     lunounit     lunounit     lunounit
*               cbgain       cbxmin       cbxmax       cbcon1       cbcon2
            1.0000e+00  -1.0000e+00   1.0000e+00   0.0000e+00   0.0000e+00
*
* valve flow-area fraction fa
*                 idcb         icbn         icb1         icb2         icb3
                   -20           56          -19            0            0
*              luxgain       luxmin       luxmax       lucon1       lucon2
              lunounit     lunounit     lunounit     lunounit     lunounit
*               cbgain       cbxmin       cbxmax       cbcon1       cbcon2
           -5.0000e-01   0.0000e+00   1.0000e+00  -1.0000e+00   0.0000e+00
*
*************
* trip data *
*************
*
* trip 105 activates adv cooldown-rate controller at 660.0 s
*                 idtp         irst         iset         itst         idsg
                   105            2            0            1            1
*              setp(1)      setp(2)
            0.0000e+00   6.6000e+02
*              dtsp(1)      dtsp(2)
            0.0000e+00   0.0000e+00
*              ifsp(1)      ifsp(2)
                     0            0
*
```

TABLE 7-6
COMPONENT INPUT DATA FOR CONTROLLER-ACTIVATED ADV

```
*
*********************************************************************
*******            type            num            id          ctitle
valve                               53            53 $53$ atm. dump valve in loop
*                ncells          nodes          jun1           jun2          eps
                      1              1            53             54    0.0000e+C
*                  ichf          iconc          ivty           ivps         nvtk
                      0              1             3              2
*                  ivtr           ivsv          nvtbl          nvsv          nvr
                    105            -20             0              0
*                iqp3tr         iqp3sv        nqp3tb         nqp3sv        nqp3r
                      0              0             0              0
*                ivtrov         ivtyov
                      0              0
*                  rvmx           rvov        fminov         fmaxov
             1.0000e+01     0.0000e+00    0.0000e+00     1.0000e+00
*                 radin             th         houtl          houtv         tout
             4.0767e-01     2.4130e-02    0.0000e+00     0.0000e+00    2.9500e+C
*                 toutv          avlve         hvlve         favlve          xpc
             2.9500e+02     8.2130e-03    1.0226e-01     0.0000e+00    0.0000e+C
*                 qp3in         qp3off        rqp3mx         qp3scl
             0.0000e+00     0.0000e+00    0.0000e+00     0.0000e+00
*
* dx        *                1.6714e+00e
* vol       *                8.7269e-01e
* fa        * f              5.2212e-01e
* kfac      *                0.0000e+00    1.1000e-01e
* rkfac     *                0.0000e+00    5.5000e-02e
* grav      * f              0.0000e+00e
* hd        * f              8.1534e-01e
* icflg     * f                       0e
* nff       *                         1           -1e
* alp       *                1.0000e+00e
* vl        * f              0.0000e+00e
* vv        * f              0.0000e+00e
* tl        *                5.5120e+02e
* tv        *                5.5150e+02e
```

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 ADV controlling trip IVTR = 105 whose trip signal is problem time. We define trip ID 105 to have a trip-signal-range type ISRT = 2 and setpoint S_2 = 660.0 s. In the VALVE component data of Table 7-6, we set IVTR = 105 for the controlling trip ID number, and set FAVLVE = 0.0000E+00 to indicate that the initial state of the VALVE is closed until its controlling trip 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 its controlling trip IVTR = 105 is set to $ON_{forward}$ at problem time 660.0 s. Thereafter, the VALVE component-action flow-area fraction FA of control block IVSV = –20 is defined to FAVLVE at the beginning of each timestep by a component-action table with NVTB1 = 0 entry data pairs (indicating that the table's independent variable defines the table's dependent variable directly).

7.3.5. Example 5: Use of a Rate-Factor Table to Reduce Overadjustment 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 Fig. 7-15. 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 Fig. 7-15, 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 Fig. 7-15 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 Fig. 7-15 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 7-7 shows the steam-flow control valve's VALVE component 44 input data with the VALVE component-action and rate-factor tables shown in Fig. 7-15. Figure 7-16 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.

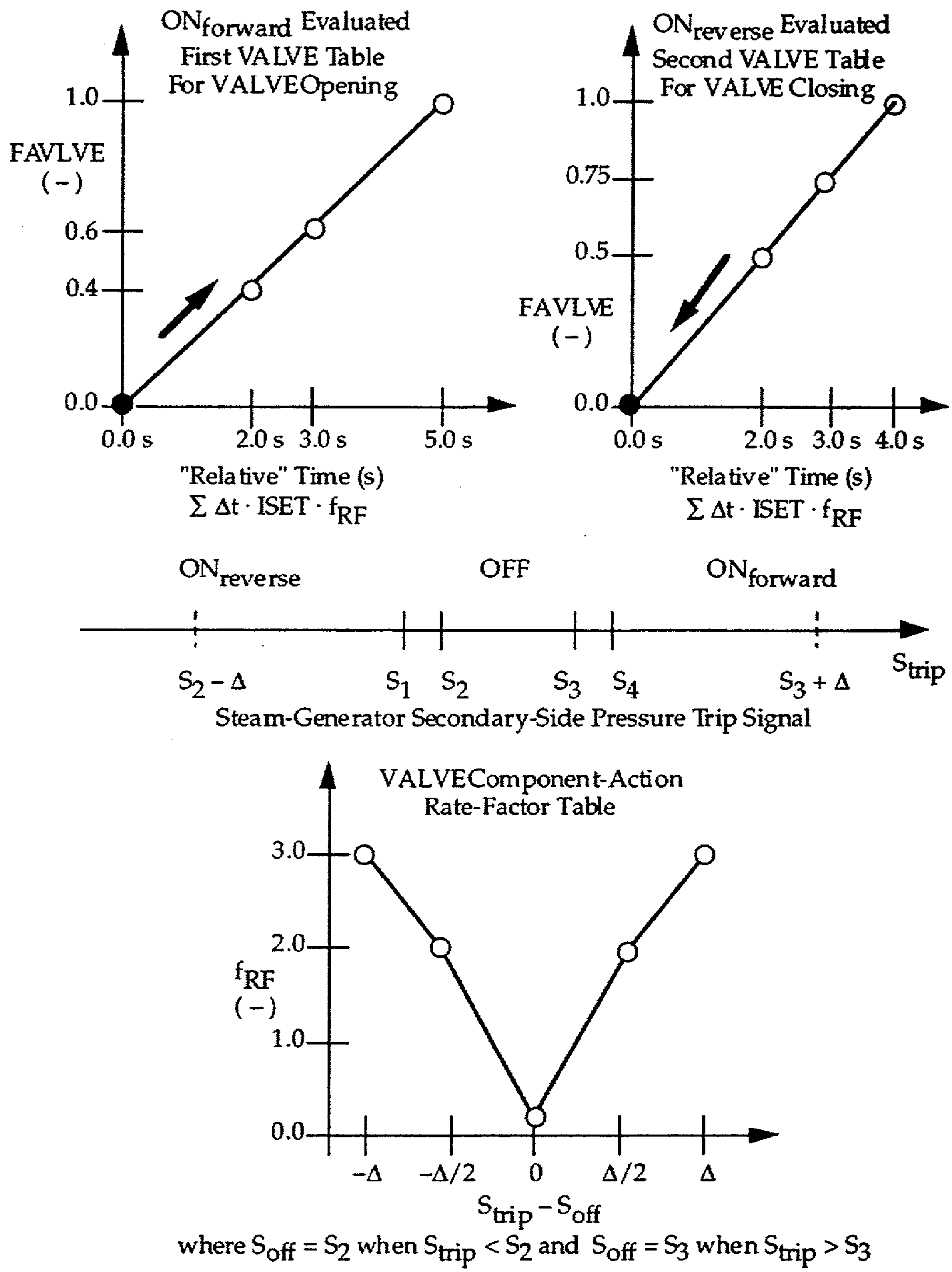


Fig. 7-15. ON/OFF switch trip controller with a rate-factor table.

TABLE 7-7
VALVE COMPONENT INPUT DATA WITH A RATE-FACTOR TABLE

```
*
*******************************************************************
*******          type          num          id        ctitle
valve                           44          44 $44$ steam-flow control valve
*              ncells        nodes        jun1          jun2          epsw
                    1            1          54           182    0.0000e+00
*                ichf        iconc        ivty          ivps         nvtb2
                    1            0           3             2            -4
*                ivtr         ivsv       nvtb1          nvsv          nvrf
                  113            1          -4             0             5
*             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    1.0000e+00
*               radin           th       houtl         houtv         toutl
           3.0960e-01   3.9600e-02  0.0000e+00    0.0000e+00    2.9500e+02
*               toutv        avlve       hvlve        favlve          xpos
           2.9500e+02   5.8600e-01  6.0960e-01    1.0000e+00    1.0000e+00
*               qp3in       qp3off      rqp3mx        qp3scl
           0.0000e+00   0.0000e+00  0.0000e+00    0.0000e+00
*
* dx        *           1.0000e+00e
* vol       *           5.8600e-01e
* fa        * f         5.8600e-01e
* fric      * f         0.0000e+00e
* grav      * f         0.0000e+00e
* hd        * f         6.0960e-01e
* icflg     * f                  0e
* nff       * f                  1e
* alp       *           1.0000e+00e
* vl        * f         0.0000e+00e
* vv        * f         0.0000e+00e
* tl        *           6.1000e+02e
* tv        *           6.1000e+02e
* p         *           6.3740e+06e
* pa        *           0.0000e+00e
* qppp      *           0.0000e+00e
* matid     *                    9e
* tw        *           6.1000e+02e
*
* opening valve table
* vtbl      *           0.0000e+00  0.0000e+00   2.0000e+00   4.0000e-01s
* vtbl      *           3.0000e+00  6.0000e-01   5.0000e+00   1.0000e+00e
*
* closing valve table
* vtb2      *           0.0000e+00  0.0000e+00   2.0000e+00   5.0000e-01s
* vtb2      *           3.0000e+00  7.5000e-01   4.0000e+00   1.0000e+00e
*
* rate-factor table
* rftb      *          -1.3000e+06  3.0000e+00  -6.5000e+05   2.0000e+00s
* rftb      *           0.0000e+00  2.0000e-01   6.5000e+05   2.0000e+00s
* rftb      *           1.3000e+06  3.0000e+00e
*
```

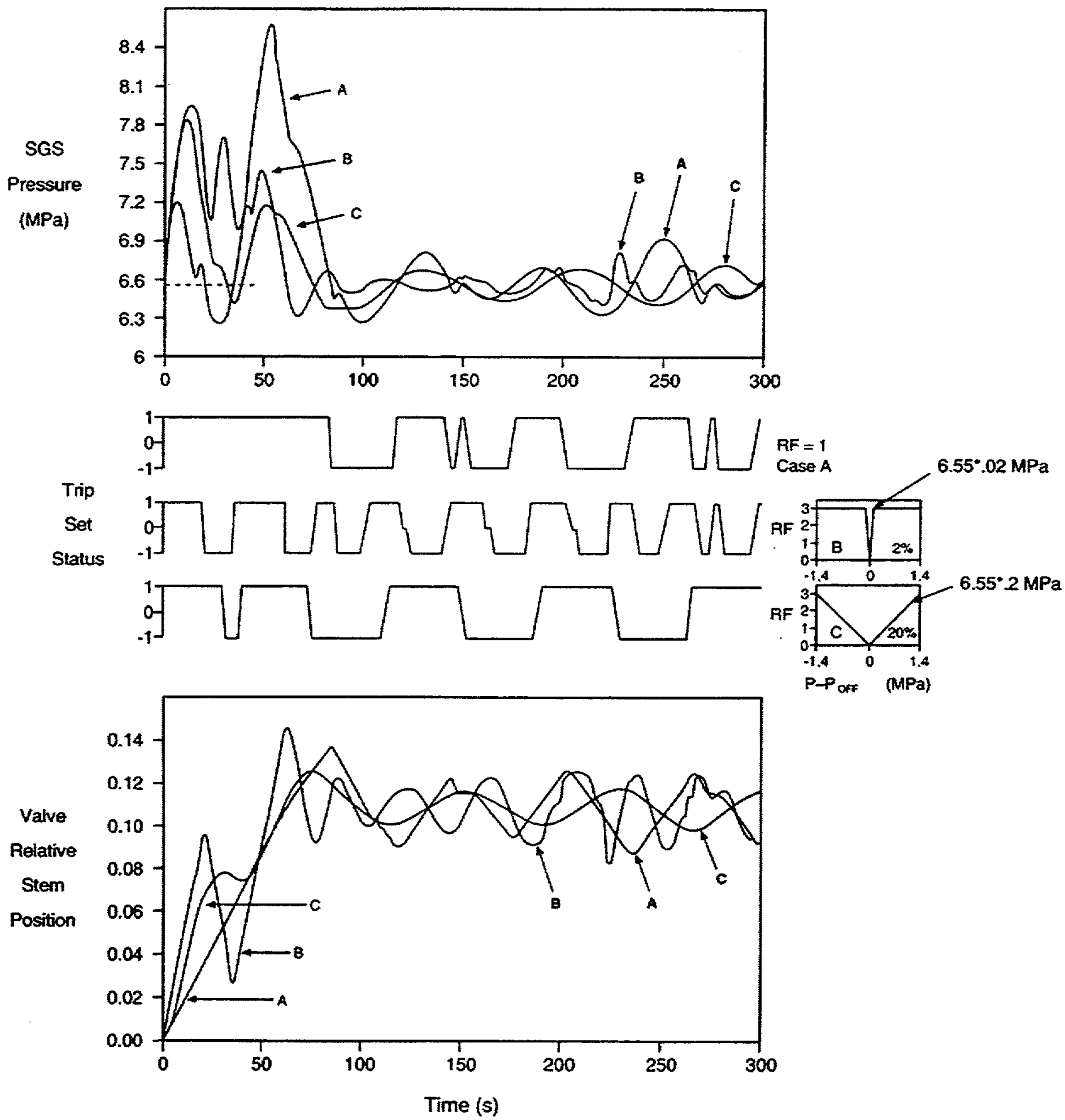


Fig. 7-16. ON/OFF switch trip controller adjustment of the steam flow control valve.

7.3.6. Example 6: SG Level Controller

The steady-state input-data TRACIN file in Appendix E simulates a three-loop plant. One portion of the control system maintains the proper secondary-side liquid level in each SG by adjusting the main-feedwater valve (see VALVE components 154, 254, and 354 in Appendix E). Two parameters are monitored for each SG by the control system to determine the required feedwater-valve adjustment. The first parameter is the error in the steam-generator liquid level (desired level minus monitored level); the second parameter is the mismatch between the steam mass flow and feedwater mass flow (steam mass flow minus feedwater mass flow). If both errors are positive (low liquid level and low feedwater mass flow), we clearly want to increase the flow area of the VALVE to increase the feedwater mass flow. Similarly, if both errors are negative (high liquid level and high feedwater mass flow), we want to decrease the flow area of the VALVE to decrease the feedwater mass flow. If the errors are of opposite numerical sign, the larger error determines in which direction the valve is adjusted. This is accomplished by summing the two errors in control blocks –1011, –2011, and –3011.

Figure E-2 of Appendix E is a logic diagram of the steam-generator level controller. It shows the control-block function operations and how the control blocks are linked together by their input and output signals. The more important control-block output-signal results are identified. We strongly urge the user to construct diagrams similar to Fig. E-2 during the process of developing their control system. With such a diagram, it is a relatively straightforward process to generate the input data for the control blocks because the required data are already identified on the diagram. In addition, it identifies the required signal variables as well. Such a diagram allows another user to understand more easily the defined control procedure.

The input data corresponding to the control blocks shown in Fig. E-2 are given in the control procedure data section of the annotated input data in Section E.2. The input data for each control block should be carefully reviewed. Note the function operator chosen; the values assigned to the ICB1, ICB2, and ICB3 input-signal identifiers; the gain, constraint, and constant values and units-name labels of CBGAIN, CBXMIN, CBXMAX, CBCON1, and CBCON2; and how tabular data are entered (function operation 101 of control blocks –0015, –4242, and –4243). This is all defined in the input-data format description for control blocks in Section 6.3.5.4.

In the flow-control portion of the controller, we note that the steam-line mass flow and main-feedwater mass flow are calculated based on a pressure drop; i.e., $\dot{m} \sim (\Delta P)^{1/2}$ (control blocks –3106 and –3706). Because TRAC-M calculates the steam-line and main-feedwater mass flows, a question naturally arises: why not define these parameters as signal variables and use them directly as input to control block –3009? The controller could be defined this way, but our experience in this area indicates that the method shown in Fig. E-2 results in quicker convergence to the steady-state condition. Also, computing mass flow from a pressure drop more closely simulates what is done by the actual control hardware of the SG.

Note that use is made of a proportional integral (PI) type controller to adjust the feedwater control valve (control blocks –3012, –3013, and –3014). A PI controller dampens overshoot by its integral feature and removes steady-state error by its proportional feature. Note also that the output signal of control block –3013, the calculated change in the flow-area fraction of the VALVE, is limited to ±0.10 s^{-1} to avoid introducing a severe perturbation to the hydraulic system. The output signal of control block –3014, the applied flow-area fraction, is limited to the physical range 0.0 to 1.0. In the VALVE component data, NVTB1 and NVTB2 are 0 (no VALVE component-action table data is specified). This makes the output signal of control block IVSV = –3014 the defined flow-area fraction of the VALVE.

7.3.7. Example 7: Pressurizer Control System

The pressurizer control system for the Appendix E full-plant model is shown in Fig. E-1. Simply stated, the purpose of the pressurizer control system is to maintain, with certain allowable tolerances, the liquid level and pressure at specified values. If the liquid level is too high, letdown flow is increased to lower the liquid level in the pressurizer. If the liquid level is too low, makeup flow is used to add liquid to the primary system. If the pressure is too high, the sprayers are used to condense steam in the pressurizer and lower the pressure. If the pressure is too low, the heaters are turned on to generate steam and raise the pressure. Care must be taken before turning on the heaters and the liquid level must be high enough to cover the heaters, otherwise they could burn out. The controller, therefore, must monitor not only the pressure but also the liquid level in determining whether to turn on the heaters.

The pressurizer control system consists of the following three parts. The first monitors liquid level and controls makeup and letdown flows. The second monitors pressure to determine if the sprayers should be activated. The third uses input from the level and pressure control portions to determine whether to activate the heaters. The first two systems are relatively straightforward. The types of control blocks used in these controllers were covered in Example 6. The heater control portion, however, utilizes control-block function operations that we have not covered. You should review the control blocks used in this controller as well as the corresponding data in the input deck to be sure you understand this control system. We will examine the three parts of the pressurizer control system in the following sections.

7.3.7.1. Level Controller. This system determines the relative liquid level in the pressurizer by converting a ΔP measurement to a level and dividing by a reference level (the reciprocal gain value) in control block –406. It compares this value with a desired relative liquid level from control block –408 by computing an error in the relative liquid level in control block –410. Control block –412 integrates the error, and control block –414 combines the error and its integrated error with 0.8 and 0.2 weighting factors, respectively. Note that control blocks –406, –408, –410, –412, and –414 constitute a PI controller. The output of control block –414 is the level error and is the IFSV parameter in FILL components 91 (for letdown flow) and 92 (for makeup flow) of the input data. Note the tabular-data entries for VMTB in both FILL components. When the output signal of control block IFSV = –414 is > 0.0 (liquid level too high), only letdown flow is activated. When the output signal of control block IFSV = –414 is < 0.0 (liquid level too low), only makeup flow is activated. A negative value for letdown flow indicates that fluid is being removed from the primary system; a positive value for makeup flow indicates that fluid is being added to the primary system. The level controller controls the letdown- and makeup-flow FILL components to maintain a desired liquid level in the pressurizer.

7.3.7.2. Pressure Controller. The pressure controller compares the measured pressure with the desired pressure by computing an error signal (measured pressure minus desired pressure) in control block –0430. Control block –432 integrates the error, and control block –434 combines the error and its integrated error with 1.0 and 0.0833 weighting factors, respectively. This is a PI controller that determines the pressure-error output signal of control block –0434 that is used as parameter IFSV in FILL component 43 (for the pressurizer sprayer) of the input data. In the FILL mass-flow table, when the pressure error is 1.7237E+05 Pa (2.5000E+01 psid) or less, only a trickle mass flow of 5.0000E-02 kg s^{-1} (1.0000E+00 gpm) is sprayed into the pressurizer. The mass flow increases linearly from the pressure error of 1.7237E+05 Pa (2.5000E+01 psid) to the pressure error of 5.1711E+05 Pa (7.5000E+01 psid) where the sprayer's full mass flow of 3.7690E-02 kg s^{-1} (6.0000E+02 gpm) is reached.

7.3.7.3. Heater Controller. This part of the control system utilizes the error signals from both the pressure and level controllers, because the heaters only can be turned on to increase pressure if the liquid level in the pressurizer is high enough to cover the heaters. This control section uses control-block function operations 19, 21, and 22, which have not been applied yet (see Table 6-3).

Control block –436 determined the power of the proportional heater from a tabular function of power vs the pressure error signal (measured pressure minus desired pressure) from the pressure controller. Control block –438 compares that pressure error signal with the backup heater pressure-difference setpoint –1.3790E+05 Pa (-2.0000E+01 psid). If the pressure error exceeds the setpoint value, the pressure is within acceptable limits and the output from control block –438 is 1.0, otherwise the output is 0.0. Control block –440 compares the relative liquid-level error from the level controller with the backup heater setpoint 0.05. If the setpoint value is greater than the relative liquid-level error (the liquid level is low), the output of control block –440 is 1.0, otherwise the output is 0.0.

At this point, we have tested the level and pressure setpoints for the backup heaters. The outputs of control blocks –438 and –440 (outputs are 0.0 or 1.0 only) are input to control block –442, which uses the logical "inclusive or" function operation 25. If the inputs sum to 0.0 (pressure low, liquid level acceptable), the output signal is 0.0. For all other cases, the output signal is the gain value of 1.0 (pressure low and liquid level low, pressure high and liquid level low, pressure high and liquid level acceptable).

The output signal of control block –442 is the logical input signal to control block –444 along with input signals from control block –1, the constant 0.0 W (0.0 Btu h^{-1}), and control block –10, the constant backup-heater power 4.0870E+05 W (1.3945E+06 Btu h^{-1}). If the output signal of control block –442 is 0.0 (pressure low and liquid level acceptable), the output signal of control block –444 is the activated backup-heater power of 4.0870E+05 W (1.3945E+06 Btu h^{-1}). Otherwise, its power is 0.0 W (0.0 Btu h^{-1}) because either the pressure is high or the liquid level is low. Control block –446 adds the total power from control blocks –436 and –444 for the proportional and backup heaters.

Control block –448 tests the fractional liquid level from the level controller against the control block –3 low-level heater setpoint 0.144 and outputs a 1.0 if the fractional liquid level is acceptable (> 0.144) or otherwise outputs a 0.0. Control block –450 outputs the control block –446 total heater power to PIPE component 40 (pressurizer heater section) if the output of control block –448 is 1.0 (liquid level is acceptable). If the output of control block –448 is 0.0 (the liquid level is not acceptable), a 0.0 W (0.0 Btu h^{-1}) heater power is output to PIPE component 40. In the PIPE component 40 input data, parameter IPOWSV = –450 defines the power-to-the-fluid component-action table independent variable. Because the number of table entry pairs NPOWTB = 0, the value of control block IPOWSV = –450 defines the total power to the fluid directly.

7.3.8. Example 8: Steam-Dump Control System

During the operation of a PWR plant, conditions may occur that result in a turbine trip or partial load rejection. In these cases, excess steam must be dumped to the condensers or atmosphere. For the full-plant model in Appendix E, there are three banks of valves used to dump steam. There are two banks of condenser dump valves (CDVs); one bank having three CDVs and the other bank having two CDVs. The third bank of steam dump valves is a set of three PORVs, one for each SG, that dumps steam to the atmosphere. The steam-dump valves can be modulated open or tripped open, depending upon the severity of the accident. The control system for the steam-dump valves is diagrammed in Fig. E-3.

The controller determines the TAV maximum value of the measured average temperature, $TAV_{loop} = (T_{hot,\ loop} + T_{cold,\ loop})/2$, in each of the three coolant loops. It compares that value with the value of TAV for the no-load condition and with a reference TAV based upon the turbine impulse pressure. It uses these comparisons to set the required flow-area fractions of the CDVs and PORVs for turbine trip and load rejection. Based upon the turbine-trip or load-rejection status, these flow-area fractions are communicated to the VALVE components for the CDV and secondary-side PORV.

Control blocks –4310 and –4312 determine the maximum TAV for the three-loop plant by using function operation 35 (maximum of two signals). This is compared with the no-load TAV to generate the required CDV flow-area fraction for a turbine trip. Control block –4304 generates a reference TAV based upon the turbine impulse pressure. This is compared with the maximum TAV in control block –4332. The difference (maximum TAV minus reference TAV) is input to control blocks –4334, –4336, and –4338 to generate the required CDV and PORV flow-area fractions for the case of load rejection. Control block –3160 uses as input signal variable 3121 (loop 3 steamline SRV pressure) to generate the required PORV flow-area fraction for a turbine trip. Control blocks –3162, –4340, and –4342 use the input switch function operation and the turbine trip status defined by signal variable 4240 to input the required flow-area fractions to VALVE components 316, 436, and 432, respectively. The IVSV parameter in the input data for these VALVE components equals the IDCB parameters of these control blocks, which set the required flow-area fractions.

Signal variable 4240 is an example of a signal-variable parameter we have not yet discussed. It defines the set-status value of trip ID 16. The concept of a trip-controlled trip also is encountered in examining the input for trip ID 16. These concepts will be discussed in the next example.

7.3.9. Example 9: Trip-Controlled Trip

In the previous example, we saw the set status of the turbine trip ID 16 used as a control block input signal by defining it with a signal variable. This is done by setting the signal-variable input parameter ISVN = 56 and using the signal-variable input parameter ILCN to define the trip ID number. In the signal-variable definition section of the Appendix E full-plant input data, we see that signal variable 4240 defines the set-status value of trip ID 16 (ILCN = 16), the turbine trip. In the trip definition section of the Appendix E full-plant input data for trip ID 16, input parameters ITST = 3 and IDSG = 160. The value of ITST indicates that trip ID 16 is a trip-controlled trip whose set status is determined by the trip-controlled-trip signal definition of IDSG = 160. A simple example will help to clarify this concept.

Assume that we wish to open a VALVE if the hot-leg temperature exceeds 5.6100E+02 K (5.5013E+02°F) or the steamline pressure exceeds 7.0670E+06 Pa (1.0250E+03 psia). We will assume the hot-leg temperature has been defined as signal variable ID 36 and the steamline pressure as signal variable ID 5. We define the trip ID 132 trip signal to be the hot-leg temperature (ITST = 1 and IDSG = 36) and the trip ID 130 trip signal to be the steamline pressure (ITST = 1 and IDSG = 5). The input data for these trips are shown in Table 7-8. We also define trip ID 135 to control the VALVE. We wish to have the set status of trip ID 135 be 1.0 ($ON_{forward}$) if either trip ID 130 or trip ID 132 has a trip set status of 1.0. We do this by adding the trip set-status values of trips ID 130 and trip ID 132, using the result as the trip signal for trip ID 135, and using setpoint values of 0.2 and 0.8 for trip ID 135. If both trip ID 130 and trip ID 132 have a trip set-status value of 0.0, the sum of their set-status values is 0.0, the trip signal for trip ID 135 is 0.0, its set status is OFF, and its trip-controlled action is not evaluated. If either or both trip ID 130 and trip ID 135 have a set-status value of 1.0, the trip signal for trip ID 135 is 1.0 or 2.0, the set status of trip ID 135 is $ON_{forward}$, and the VALVE component-action that trip ID 135 controls is evaluated to open.

Had we desired that both trip ID 130 and trip ID 132 have a set-status value of 1.0 for the VALVE to open, we could either change the trip ID 135 setpoints to 1.2 and 1.8 or multiply their set-status values to define the trip signal for trip ID 135. Defining trip ID 135 with IDSG > 0 adds while IDSG < 0 multiplies the set status values. Multiplying results in the trip signal for trip ID 135 being 0.0 unless the set-status values of both trip ID 130 and trip ID 132 are 1.0. The user should refer to Section on trip-controlled trips and also the trip input data in the full-plant input deck of Appendix E for further information.

TABLE 7-8
INPUT DATA FOR A TRIP-CONTROLLED TRIP

```
* trip data
*
* trip 130 steamline pressure trip
*              idtp          isrt           iset           itst           idsg
                130             2              0              1              5
*           setp(1)       setp(2)
         7.0500e+06    7.0670e+06
*           dtsp(1)       dtsp(2)
         0.0000e+00    0.0000e+00
*           ifsp(1)       ifsp(2)
                  0             0
*
* trip 132 hot-leg temperature trip
*              idtp          isrt           iset           itst           idsg
                132             2              0              1             36
*           setp(1)       setp(2)
         5.6050E+02    5.6100E+02
*           dtsp(1)       dtsp(2)
         0.0000e+00    0.0000e+00
*           ifsp(1)       ifsp(2)
                  0             0
*
* trip 135 turbine bypass valve trip
*              idtp          isrt           iset           itst           idsg
                135             2              0              3            133
*           setp(1)       setp(2)
         2.0000e-01    8.0000e-01
*           dtsp(1)       dtsp(2)
         0.0000e+00    0.0000e+00
*           ifsp(1)       ifsp(2)
                  0             0
*
* trip-controlled-trip signal data
*
* trip-controlled-trip signal 133 is 0.0 if trip 130 and trip 132 are off
* trip-controlled-trip signal 133 is 1.0 if trip 130 or trip 132 is on
* trip-controlled-trip signal 133 is 2.0 if trip 130 and trip 132 are on
*              idtn          intr
                133             2
*            itn(1)        itn(2)
                130           132
```

7.4. 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.

7.4.1. Initial Conditions

You have several approaches and options for developing the initial conditions for a transient calculation. First, you can directly input 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) TRAC-M cannot readily calculate the numerical solution without reasonable initial conditions, or (3) the initial condition is not at steady state.

The second approach is for you to provide a complete but approximate specification of the initial conditions and let TRAC-M calculate an accurate set of steady-state initial conditions. The TRAC-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 Sections 3.6. and 8.2. for additional information regarding the TRAC-M steady-state calculation.

Two improvements can be made to the second approach. Constrained steady-state controllers (conveniently defined through input, as described in Section) 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 TRAC-M internally initialize the phasic cell temperature and interface velocity distributions throughout the modeled system by its hydraulic-path steady-state initialization procedure in Section 6.3.4. 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 TRCOUT 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 the user 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).

7.4.2. Boundary Conditions

Boundary conditions that determine the course of a transient can be input-specified to TRAC-M either explicitly, implicitly, or (usually) in combination. Examples of explicit specification of boundary conditions are the apriori 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 Section 7.1.2.5. and presented in Table 7-1 is based solely on the explicit statement of its closure state boundary condition.

A user-specified control procedure can be used in TRAC-M to define implicit boundary conditions. The user defines the boundary conditions but does not know in advance whether or not and when 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 TRAC-M control procedures is the manner in which boundary conditions are implicitly defined in a TRAC-M model. We refer you to Section 7.3. for a discussion on control procedure examples. The full-plant model presented in Appendix E contains many examples of the application of such control procedures to define boundary conditions based on implicit feedback from the thermal-hydraulic solution.

As previously mentioned, a combination of explicit and implicit specifications usually is found in a plant or facility system model. TRAC-M is sufficiently general in its formulation and capabilities to permit a wide range of realistic boundary conditions to be modeled.

7.5. Model-Selection Parameters

For the most part, you need not have a detailed knowledge of the various constitutive models in TRAC-M to use the code. Please note that this is not a recommendation that you apply TRAC-M without understanding its models. It is a recognition that a full understanding of its models is not required to use TRAC-M. However, there are several parameters that must be input-specified by the user. Here, we briefly describe some of these model-selection parameters and recommend input values.

7.5.1. ICHF

ICHF is the critical-heat-flux option flag. If ICHF = 1, the entire boiling curve is used by TRAC-M 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.

7.5.2. 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.

7.6. Reactor Geometry

The VESSEL component in TRAC-M models a PWR vessel, its internal structures, and the reactor core. The VESSEL is the only TRAC-M 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 input specifying the VESSEL-component geometry. In the next section, we present guidelines for HTSTR modeling including heat transfer, core reflood, and neutronics.

You are referred to the VESSEL model in Appendix E for an example of a complete input-data model. We have prepared annotation notes to assist you in understanding the options and values selected for its many modeling features. We also refer you to Section 6.3.7.11. for the VESSEL-component input-data description; to Section 4.11. for a description of the VESSEL component; and the TRAC-M/F90 Theory Manual for a detailed discussion on the fluid-dynamics, heat-transfer, and point-kinetics equations and solution methods for the multidimensional VESSEL component.

As discussed in Section 5.0., 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 in Appendix E and shown in Fig. 5-6 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 sweepout is important.
2. We reemphasize 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.
4. A loop's 1D hydraulic-component connections to the mesh-cell faces of a VESSEL should be to the same directional face (azimuthal, radial, or axial) if the SETS3D solution algorithm is used [NAMELIST variable NOSETS = 0 or 2 (default)]. This is required to provide implicit coupling for a numerically stable solution. If a coolant loop's connections are to different directional faces (for example, one end is to a VESSEL cell's radial face and the other end is to another VESSEL cell's axial face), define NAMELIST variable NOSETS = 1 so it does not evaluate the SETS3D equations. This will limit the calculation's timestep size to the material Courant limit in the VESSEL.

As shown in Fig. 5-6, 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 Fig. 5-6, 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). Inputting 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 Fig. 7-17. This cell and face numbering convention is used to define where external 1D hydraulic connections are made to VESSEL cell faces. This defining convection is discussed with examples in the VESSEL component annotation notes in Appendix E. You may find it useful to review those notes and the input-data listing.

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 Fig. 5-6. 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 Fig. 7-17. 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 Fig. 7-17) 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 TRAC-M on the basis of the geometric and directional mesh-cell spacings and the fluid volume and flow-area fractions input 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 input specified with nonzero values. NAMELIST variable

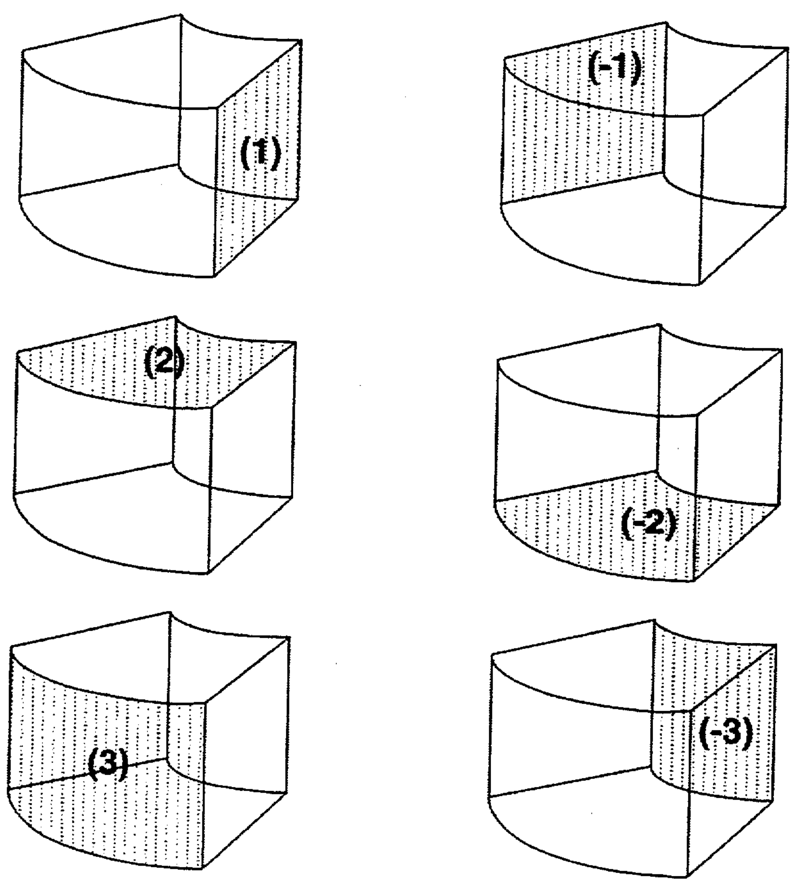


Fig. 7-17. Numbering convention for VESSEL-cell faces.

IGEOM3 can be used to allow nonzero flow-area fractions to be input specified in the downcomer wall to model leakage flow paths.

There are restrictions on interface flow areas in TRAC-M. This was required when cell-to-cell flow-area ratios where applied to the momentum-convection term in TRAC-PF1/MOD2 to model Bernoulli-equation reversible flow losses correctly. Now the interface flow area specified cannot be > 1.1 times the maximum VOL/DX (where $DX = \Delta Z$, ΔY or $R\ \theta\Delta$, and ΔX or ΔR 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. TRAC-M 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 ROD or SLAB (geometry) element thermal calculation couples directly to the fluid thermal-dynamics of the VESSEL's axial stack of cells. One average ROD or SLAB element models the average power of the ensemble of fuel rods in each axial stack of mesh cells. One or more supplemental ROD or SLAB elements model the average power times a RPKF peaking factor. The thermal analysis of supplemental ROD or SLAB 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 ROD or SLAB 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. 7-9). 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

$$CFZLXR_{i+1/2} = CFZVXR_{i+1/2} = 4Nf_{dt}/(\Delta X_i + \Delta X_{i+1}), \quad \text{or} \quad 4Nf_{dt}/(\Delta R_i + \Delta R_{i+1}) \tag{7-15}$$

where N is the number of transverse rows of rods from the center of cell i to the center of cell i+1, ΔX_i and ΔX_{i+1} or ΔR_1 and ΔR_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 Fig. 7-18. The y- or θ-direction additive-friction-loss coefficients for liquid and vapor at interface j+1/2 are defined by

$$CFZLYT_{j+1/2} = CFZVYT_{j+1/2} = (4Nf_{dt}/\Delta Y_j + \Delta Y_{j+1}), \quad \text{or} \quad (4Nf_{dt})/(R_i\Delta\theta_j + R_i\Delta\theta_{j+1}) \tag{7-16}$$

where ΔY_j and ΔY_{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

$$CFZLZ_{k+1/2} = CFZVZ_{k+1/2} = K_{k+1/2}D_{k+1/2}/(\Delta Z_k + \Delta Z_{k+1}) \,, \tag{7-17}$$

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.

TRAC-M requires that positive additive-friction-loss coefficients be input for interfaces between cells where the change in the VOL/DX average flow area (where $DX = \Delta Z$, ΔY or $R\Delta\theta$, and ΔX or ΔR 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 TRAC-M to internally evaluate an abrupt flow-area-change irreversible form loss (like that done by NFF for 1D hydraulic components) or/and by input specifying an additive-friction-loss coefficient, |CFZL#| > 0.0 and CFZV# > 0.0. This is defined in Section 6.3.7.11. by the additive-friction-loss coefficient input data for the VESSEL component and discussed in the TRAC-M/F90 Theory Manual.

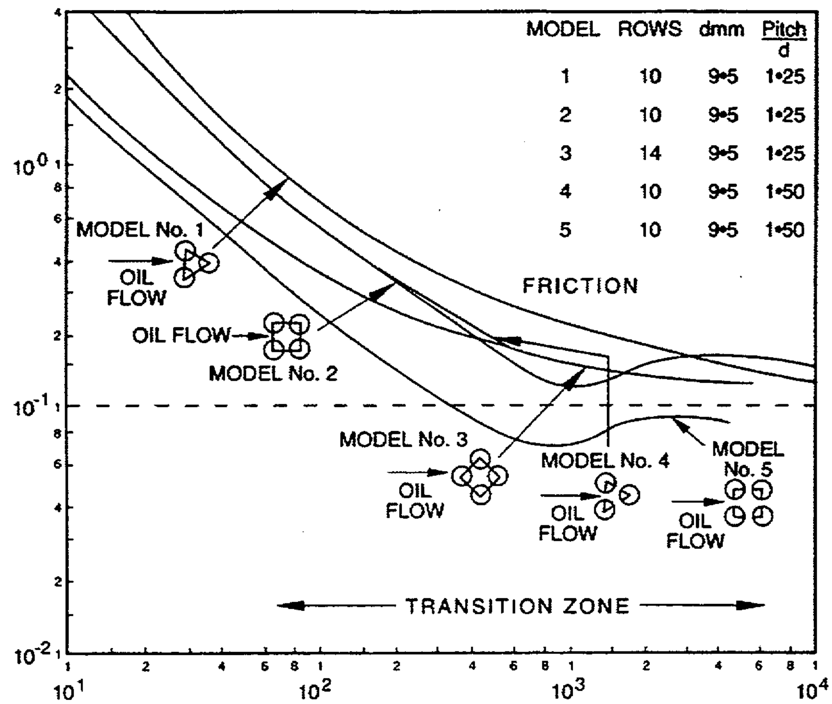


Fig. 7-18. Special friction factor f_{dt} for cross flow in rod bundles (Ref. 7-7).

7.7. Heat-Structure Components

Heat transfer in fuel rods and structural hardware, thermally coupled to the fluid in PIPE, PRIZER, PUMP, SEPD, TEE, TURB, VALVE, and VESSEL hydraulic components, can be modeled using the HTSTR (heat-structure) component. This component allows greater modeling flexibility than was possible using the fuel-rod heat-transfer model in the TRAC-PF1/MOD1 VESSEL, the STGEN-component heat-transfer paths, or what is currently provided using the wall heat-transfer model in the 1D hydraulic components. Reactor core to downcomer heat transfer can now 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. The STGEN (steam-generator) component was eliminated from TRAC-M's predecessor TRAC–P because HTSTR, PIPE, and TEE components can provide an equivalent model (see Appendix J). Thermal analysis of the cylindrical wall of 1D hydraulic PIPE, PRIZER, PUMP, SEPD, TEE, TURB, and VALVE 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. If wall or structure heat transfer to the fluid of a PLENUM is considered important, the PLENUM fluid and hardware should be modeled by a PIPE, TEE, or VESSEL.

The HTSTR component is discussed in Section 4.3. In this section, we present some guidelines for geometric modeling, use of the core-reflood option, and specification of neutronics.

7.7.1. Geometry

Heat structures in TRAC-M are modeled by the geometry of a ROD or SLAB element. A cylindrical ROD 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 SLABs 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 TRAC-M 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 the SLAB 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 SLAB element.

7.7.1.1. 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:

$$V = A \cdot L , \tag{7-18}$$

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 TRAC-M 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 new flexibility in the HTSTR component allows a more straightforward approach than was possible before. For the wall of a vessel, for example, the user simply inputs the correct geometry (WIDTH, HDRI, and HDRO) and specifies 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 (6.6279E+00 ft^3) and has a surface area of 1.5488E+01 m^2 (1.6672E+02 ft^2). The thickness of the baffle wall is 3.1750E-02 m (1.0417E-01 ft) and has 981 holes of 7.3025E-02 m (2.3958E-01 ft) 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

$$L = 1.8768\text{E-01 m}^3/1.5488\text{E+01 m}^2 = 1.2118\text{E-02 m}(3.9756\text{E-02 ft}) \qquad (7\text{-}19)$$

and, for six symmetric azimuthal cells, the corresponding surface area per cell would be

$$A = 1.5488\text{E+01 m}^2/6 = 2.5813\text{E+00 m}^2(2.7785\text{E+01 ft}^2) \qquad (7\text{-}20)$$

7.7.1.2. 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:

$$V = \frac{1}{\rho \cdot C_p} \sum_i \rho_i \cdot C_{p,i} \cdot V_i \; , \qquad (7\text{-}21)$$

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

$$\rho c_p V\left(1 - \sum_n^N D_n e^{-\gamma_n^2 Fo}\right) = \sum_i \rho_i c_{pi} V_i \left[\sum_n^N D_{ni} e^{-\gamma_{ni}^2 Fo_i}\right] \; . \qquad (7\text{-}22)$$

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,

$$Fo = (\alpha t)/L^2, \tag{7-23}$$

where $\alpha = k / (\rho C_p)$. The γ_n is a constant obtained from the transcendental equation,

$$\gamma_n = \gamma_n \tan(\gamma_n) = Bi, \tag{7-24}$$

where $Bi = h L / k$ is the Biot number, and

$$D_n = \frac{2\sin^2\gamma_n}{(\gamma_n^2 + \gamma_n \sin\gamma_n \cos\gamma_n)}, \tag{7-25}$$

where α, 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 RODs or SLABs 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 SLAB 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 SLAB.

7.7.2. Reactor-Core Reflood

Note: **TRAC-M/F90 and TRAC-M/F77 Reflood Models.** As discussed in Sections 2 and 6, TRAC-M/F90 contains a core-reflood model that was brought over from TRAC-PF1/MOD2; TRAC-M/F77 also contains, in addition to this model, a more recent reflood model that was developed for analysis of simultaneous top-down/bottom-up quenching. The following discussion refers only to the MOD2 reflood model. The changes to input file TRACIN for the additional model in TRAC-M/F77 are described in Appendix M. See the references in Sections 2 and 6 for a detailed discussion of the additional TRAC-M/F77 model.

The reactor-core reflood phase of a postulated LBLOCA is characterized by a sequence of heat-transfer and two-phase flow regimes advancing through the reactor core. The TRAC-M core-reflood model is built around the determination of flow regimes downstream of the quench front. The regimes were determined from a position-dependent, flow-regime map suggested for up-flow conditions. The inverted annular flow (IAF) regimes considered were smooth IAF, rough-wavy IAF, agitated IAF, dispersed flow with large droplet sizes (post-agitated IAF), and highly dispersed flow. The core-reflood model also incorporates a position-dependent transition-boiling model. The length of the transition-boiling regime mainly controls the propagation rate of the quench front and was formulated as a function of the capillary number (defined based upon the liquid velocity) and the gas volume fraction at the quench front. The wall and interfacial heat transfer and the interfacial momentum transfer were formulated separately for each of the IAF regimes.

To turn the core-reflood model on, the user must input several quantities. First, the NAMELIST variable NEWRFD must be set to 1 from its 0 default value. Second, the HTSTR's fine-mesh rezoning option must be turned on by specifying the controlling trip ID number IRFTR (Word 3 on Card 9 of HTSTR input data) and setting the set status of trip ID IRFTR ON. Third, the HTSTR's core-reflood model option must be turned on by specifying the controlling trip ID number IRFTR2 (Word 5 on Card 9) and setting the set status of trip ID IRFTR2 ON. All three of these conditions must be met before the new core-reflood model will be invoked by TRAC-M in specific HTSTR components. The NAMELIST option gives the user the capability of making global changes in the use of the model without significant changes to an existing input-data file, i.e., the core-reflood model can be turned OFF without having to make changes to every HTSTR component where IRFTR2 has been set to a nonzero trip ID number. The two trip IDs allow the user to (1) use the core-reflood model in selected HTSTRs while not in others and (2) turn its evaluation ON later after the fine-mesh rezoning evaluation has been turned ON. This latter capability is needed, for example, when modeling a large-break blowdown where the fine-mesh rezoning option might be tripped ON early in the blowdown to evaluate a blowdown rewet before core reflood begins much later. On the other hand, the user may make the trip IDs for IRFTR and IRFTR2 the same if modeling a separate-effects experiment where implementation of the fine-mesh rezoning option and core-reflood model are evaluated together.

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 controlling trip ID number IRFTR 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 user-specified value. 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; DTXHT(1) and DTXHT(2), the maximum temperature difference specifications; 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:

$$\begin{aligned} DTXHT(1) &= 2.0000E+00K(3.6000E+00°F) , \\ DTXHT(2) &= 1.0000E+01K(1.8000E+01°F) , \\ \text{DZNHT} &= \text{1.0000E-03 m (3.2808E-03 ft), and} \\ \text{NZMAX} &= \text{100 to 250} . \end{aligned} \tag{7-26}$$

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. You are referred to the input-data listing in Appendix E for an example of implementing the fine-mesh noding option in a full-plant model. NRSLV = 1 is recommended.

Because the IAF-regime map and the transition-boiling model are formulated for up-flow conditions, the application of the core-reflood model is limited to up-flow conditions in the reactor-core region. The wall-to-fluid and interfacial heat-transfer correlations used in the model were developed from data bases including a large range of operating parameters. The assessment of the model with some of the available steady-state and transient post-CHF data indicated that both the prediction of wall and interfacial heat transfer and interfacial momentum transfer (correspondingly the wall and vapor temperatures and the pressure drops) were reasonable. The model is expected to predict reasonable results for a large range of operating parameters; however, the user should be aware of the fact that for extremely large or small mass fluxes > 1.0000E+03 kg m^{-2} s^{-1} (7.3734E+05 lb_m ft^{-2} h^{-1}) or < 5.0000E+00 kg m^{-2} s^{-1} (3.6867E+03 lb_m ft^{-2} h^{-1}), and heat fluxes > 3.0000E+05 W m^{-2} (9.5099E+04 Btu h^{-1} ft^{-2}) or < 5.0000E+03 W m^{-2} (1.5850E+03 Btu h^{-1} ft^{-2}), the prediction of gas (vapor) and wall temperatures could show relatively higher discrepancies between measured and predicted values.

The most important improvement in the model is the use of an axial-history dependent transition-boiling model. This ensures the elimination of difficulties associated with nodalization sensitivity. The assessment of the model with the CCTF Run 54 test using several different nodalization schemes indicated that the model was not sensitive to the nodalization differences. The selection of hydraulic node sizes in the range of 1.0000E-01 m (3.2808E-01 ft) to 5.0000E-01 m (1.6404E+00 ft) is expected to give similar results and is recommended. The use of smaller nodes at the beginning of calculation was found useful in predicting the correct thermal-hydraulic behavior during the earlier stage of the transient.

The modeling of the power distribution is important in the core-reflood model. When there is a large step change in the power level within a hydraulic cell, the predicted thermal-hydraulic parameters can experience some variations. To eliminate this type of difficulty, the use of similar node sizes for both the hydraulic and conduction cells is recommended. The use of the histogram power-distribution option with the fine-mesh noding option turned ON is not advisable. If the histogram option is used, the user is advised to select a sufficiently large number of histogram steps (for example, for CCTF Run 54, 1200 steps are used in the representation of the power distribution by a histogram).

The heat-transfer correlations used in the core-reflood model were developed using single-tube data. Therefore, 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.

7.7.3. Reactor-Core Fuel Rods

The total power level in the HTSTR-component ROD or SLAB elements in the reactor core may be specified by one of two methods. In the first method, the user input 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, TRAC-M 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 input specifies programmed reactivity to account for reactivity effects not accounted for by feedback reactivity such as control-rod movement. TRAC-M 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, TRAC-M internally defines the 6-group delayed-neutron constants presented in the TRAC-M/F90 Theory Manual. If NDHX ≤ 0 is input, TRAC-M internally defines the 69-group decay-heat constants presented in the TRAC-M/F90 Theory Manual. If both NDGX ≤ 0 and NDHX ≤ 0 and no prompt-fission power history is input with NHIST = 0, TRAC-M assumes that initially steady-state conditions exist to initialize the CDGN and CDHN precursor power concentrations internally in TRAC-M based on the initial power, RPOWRI. The above internally defined data used in TRAC-M closely approximate the standard American Nuclear Society decay-heat curve (Ref. 7-10).

The Westinghouse three-loop full-plant model in Appendix E 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 TRAC-M 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 TRAC-M 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 input specifies a reactivity coefficient for each of these reactivity-feedback parameters by choosing one of the reactivity-coefficient forms in the TRAC-M/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 TRAC-M/F90 Theory Manual for additional information about this analytical model and its many options. An example of modifying the Westinghouse three-loop, full-plant, input-data model in Appendix E to model reactivity feedback in the HTSTR component for the reactor-core fuel rods is given in Appendix I.

There are two types of user-specified fuel rods in TRAC-M: 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 input 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,

$$P(i,j,k) = S \cdot POWAVG \cdot RDPWR(i) \cdot CPOWR(j) \cdot ZPWTB(k) \ , \qquad (7\text{-}27)$$

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 TRAC-M 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:

$$S = 1/\sum_{i,j,k} RDPWR(i) \cdot CPOWR(j) \cdot ZPWTB(k) \cdot Volume(i,j,k) \ . \qquad (7\text{-}28)$$

All three user-specified power-density shapes are normalized after input to have a spatially average value of unity.

$$1.0 = \sum_i RDPWR(i) \cdot Volume(i) / \sum_i Volume(i),$$

$$1.0 = \sum_j CPOWR(j) \cdot Volume(j) / \sum_j Volume(j) \ \text{, and}$$

$$1.0 = \sum_k ZPWTB(k) \cdot Volume(k) / \sum_k Volume(k) \ . \qquad (7\text{-}29)$$

For the analysis of supplemental fuel rods, the average fuel rod power density $P(i,j,k)$ is multiplied by an input 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. 7-10). According to Ref. 7-11, 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

$$\bar{\Phi}_T(t) \rightarrow \frac{\beta}{\beta - \rho_s} \cdot \Phi_T(0) \tag{7-30}$$

where

$\Phi_T(0)$ = steady-state reactor-core-averaged thermal-neutron flux,

$\Phi_T(t)$ = reactor-core-averaged thermal-neutron flux after scram,

β = delayed-neutron fraction, and

ρ_s = scram reactivity, where $\rho_s < -\beta < 0$,

followed by an ~80.0 s thermal-neutron flux decay. For a large scram reactivity where $\rho_s \rightarrow -1.0 + \beta$, $\Phi_T(t)$ can be approximated by $\beta \cdot \Phi_T(0)$. The delayed-neutron fraction for a typical US PWR is β = ~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.

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 Ref. 7-12. 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 Refs. 7-13 and 7-14, are listed in Table 7-9.

The transient reactor-core total power for both calculations is given in Fig. 7-19. 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

TABLE 7-9
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, Λ_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 ρ_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

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 Fig. 7-20 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 Fig. 7-21 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.

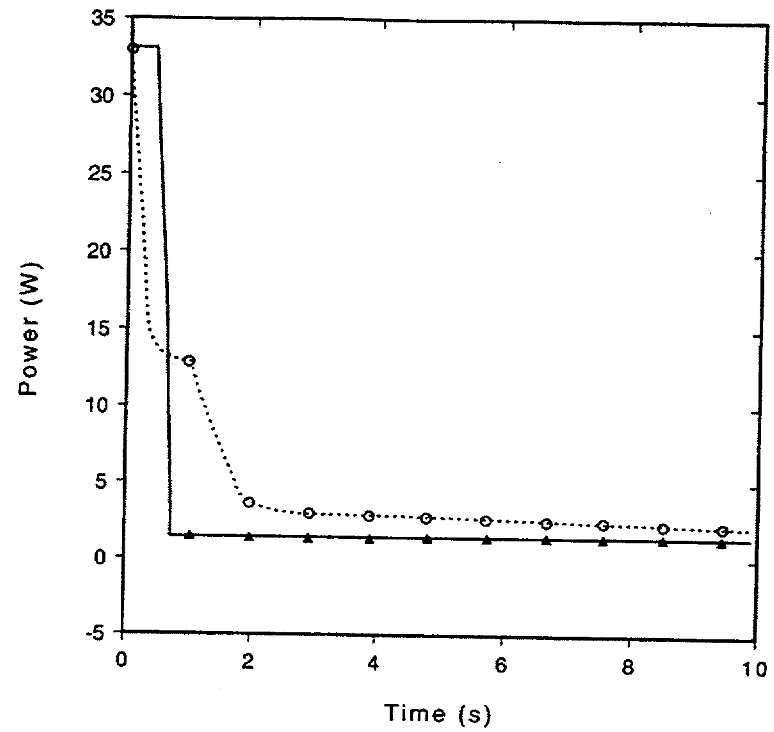


Fig. 7-19. Transient reactor power for the power-vs-time calculation (solid line) and the point-reactor kinetics calculation (dashed line).

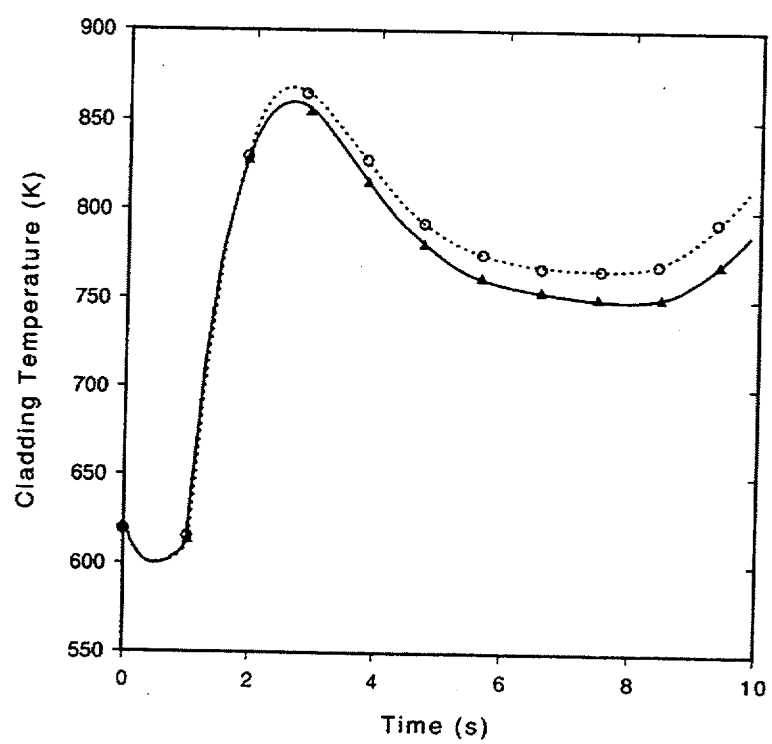


Fig. 7-20. Cladding temperature at the reactor-core midplane for the power-vs-time calculation (solid line) and the point-reactor kinetics calculation (dashed line).

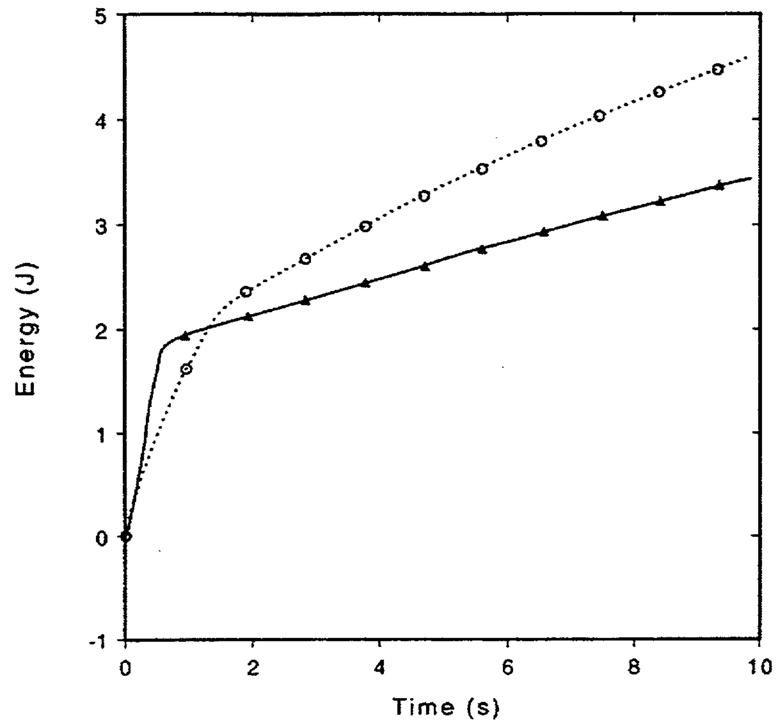


Fig. 7-21. Integrated reactor power for the power-vs-time calculation (solid line) and the point-reactor kinetics calculation (dashed line).

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 TRAC-M). This was accomplished by using the 23 decay-heat groups for ^{235}U fissions given in Ref. 7-10. The 23 decay-heat groups in TRAC-consistent units are given in Table 7-10. 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 7-11, 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.

Also, the TRAC-P (and TRAC-M) 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 7-12. In Table 7-13, 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.

TABLE 7-10
EXPANDED SET OF DECAY-HEAT CONSTANTS

Group j	Decay Constant λ_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
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 7-11
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 7-12
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 7-13
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

$$G(t,T) = 1.0 + (3.24\times10^{-6} + 5.23\times10^{-10}t)T^{0.4}Y\,, \qquad (7\text{-}31)$$

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 TRAC-M through input; however, a conservative approximation can be obtained by using Table 7-14, which was obtained from Ref. 7-10. Given the length of the transient to be evaluated after shutdown, the G(t) factor can be estimated from Table 7-14 and applied uniformly to the E_js for the 23 decay-heat groups in Table 7-10.

Heavy-element decay heating also can be included in a TRAC-M point-reactor kinetics model. According to ANS 5.1, heavy-element decay heating is

$$\frac{P_{HE}(t,T)}{P(0)} = \frac{R}{Q}\left\{E_{24}[1-e^{-\lambda_{24}T}]e^{-\lambda_{24}T} + E_{25}\left[\frac{\lambda_{24}}{\lambda_{24}-\lambda_{25}}(1-e^{-\lambda_{25}T})e^{-\lambda_{25}T} - \frac{\lambda_{25}}{\lambda_{24}-\lambda_{25}}(1-e^{-\lambda_{24}T})e^{-\lambda_{24}T}\right]\right\} \quad (7\text{-}32)$$

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),
λ_{24}	=	decay constant for ^{239}U (4.91×10^{-4} s^{-1}), and
λ_{25}	=	decay constant for ^{239}Np (3.41×10^{-6} s^{-1}).

The previous equation can be rewritten in a form consistent with the TRAC-M decay-heat model,

$$\frac{P_{HE}(t,T)}{P(0)} = \frac{R}{Q}\left[E_{24} - E_{25}\frac{\lambda_{24}}{\lambda_{24}-\lambda_{25}}\right][1-e^{-\lambda_{24}T}]e^{-\lambda_{24}t} + \frac{R}{Q}\left[E_{25}\frac{\lambda_{24}}{\lambda_{24}-\lambda_{25}}\right][1-e^{-\lambda_{25}T}]e^{-\lambda_{25}t} . \quad (7\text{-}33)$$

Evaluation of this equation yields two additional decay-heat groups that are listed in Table 7-15. From Table 7-15, it is apparent that the E_js for these two groups still are dependent upon R. The parameter R is a function of initial fuel enrichment and fuel

TABLE 7-14
RATIO OF DECAY HEAT WITH NEUTRON ABSORPTION TO VALUES WITHOUT 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_js given in Tables 7-10 and 7-15 should be multiplied by 1.20 and input to TRAC-M. 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 7-10 and the 2 groups in Table 7-15 is given in Fig. 7-22. The results from using 1.2 times the E_js for the 23+2 decay-heat groups is plotted in Fig. 7-23. The transient fission-product decay-heat power after scram at time zero is divided by the initial reactor-core power plotted in both Figs. 7-22 and 7-23. The results using 1.2 times the E_js were divided by the results using the E_js and plotted in Fig. 7-24. From Fig. 7-24, 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 7-15
TRAP-P (and TRAC-M) INPUT FOR THE HEAVY-ELEMENT DECAY-HEAT GROUPS

j	Energy Fraction E_j	Decay Constant λ_j^H (s^{-1})
24	2.3553E-03	4.91E-04
25	2.1097E-03	3.41E-06

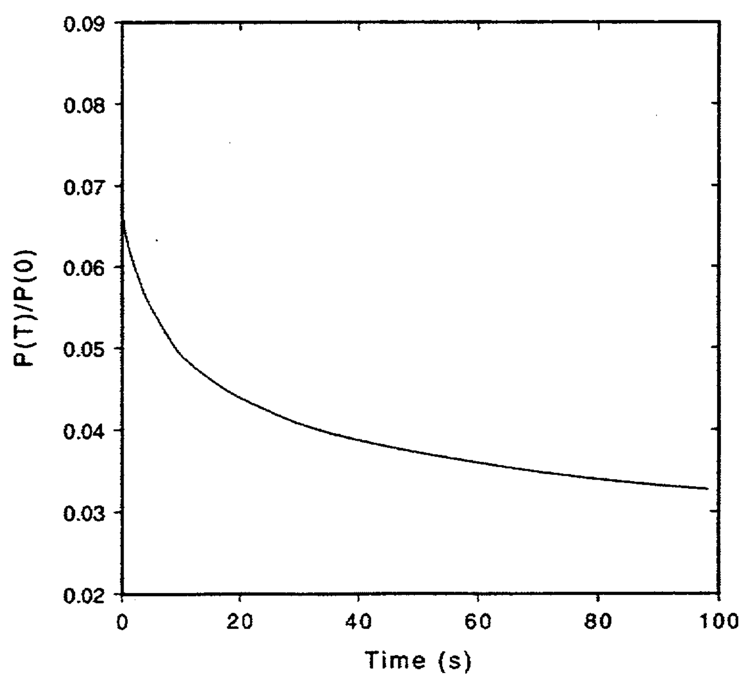


Fig. 7-22. TRAC–P calculated ANS power curve.

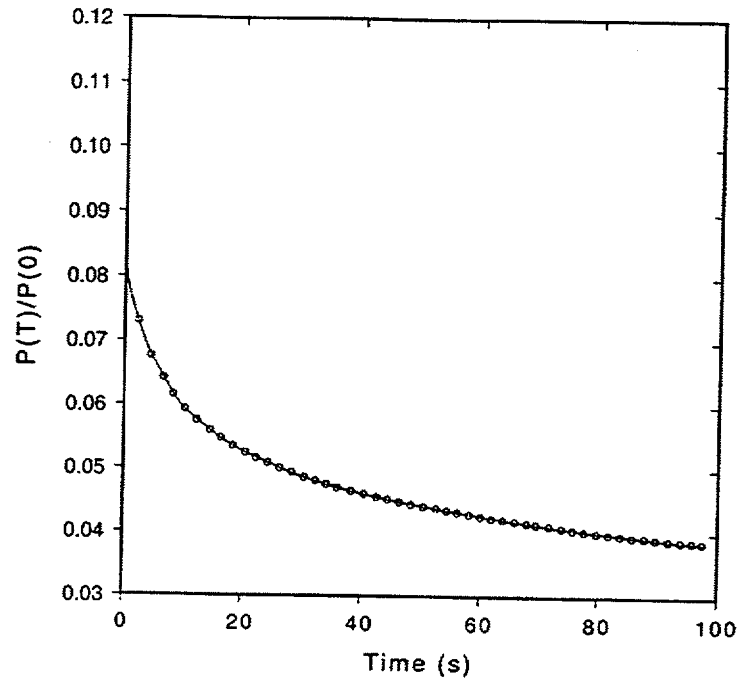


Fig. 7-23. TRAC–P calculated 1.2 times ANS power curve.

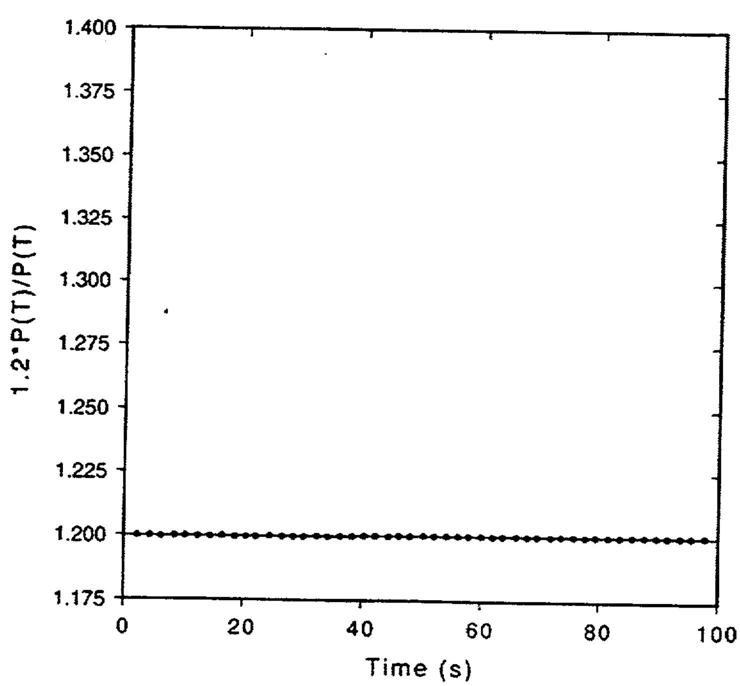


Fig. 7-24. Ratio of the TRAC–P 1.2 times ANS divided by ANS power curve.

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8.0. EXECUTION OF TRAC-M

The creation of an input-data TRACIN file required for a TRAC-M simulation is discussed in Section 8-1. In this section , we present some additional guidelines for input-data preparation and checkout, instructions for executing TRAC-M, and suggestions for processing and interpreting the output and validating the results. Once you execute TRAC-M on your input-data model, you will be faced with the realities associated with running a large, complex computer code upon a highly detailed and complex input-data model. In short, you probably will encounter difficulties. The objective of this section is to help you execute your system model on the TRAC-M code. If you follow the steps outlined, you will be drawing on the experience of many TRAC users, which should reduce the effort required to complete your analysis. We emphasize that you can solve many of the difficulties you will encounter if you take the time to work through the steps that we discuss in the remainder of this section.

8.1. Assembling the Input-Data File

The input-data TRACIN file is divided into eight major sections as shown in Fig. 6.1.: (1) main data, (2) countercurrent flow-limitation data, (3) material-properties data, (4) hydraulic-path steady-state initialization data, (5) control-parameter data, (6) radiation enclosure data, (7) component data, and (8) timestep data. These data blocks are assembled into a file named TRACIN (a naming convention that is required by TRAC-M). We use upper case letters for all of TRAC-M's input and output files only for clarity. If your system is case-sensitive, lower case file names are read from and written to. A detailed description of the input-data cards for each of the eight major sections is presented in Section 6.0. The information that we provide in this section is not intended to replace those detailed input-data preparation instructions. Rather, we will provide guidelines for each of the major input-data sections that will help you to focus on the specific information that normally will be required by the first-time or inexperienced user of TRAC-M. Once again we emphasize the value of annotating the input-data cards with comments as they are prepared; the data then can be easily identified when you need to locate a specific card for either updating or correction. Refer to Appendix E for an illustration of a TRACIN file that has been annotated with FORTRAN variable names and comments.

8.1.1. Main Data

Main-Data cards 1 through 7 are required. We recommend that the user provide "title cards" to identify briefly the plant or facility, the data base used to prepare the input-data model, the storage location of the input-data TRACIN file, and what changes have been made to this input-data TRACIN file or its restart calculation TRACIN files to do follow-on analyses. NAMELIST-data cards generally appear in most TRACIN files where a few of the NAMELIST variables are defined with values that differ from their default values (for example, the choked-flow model option variable ICFLOW could be input with the value 2 to change its default value of 1).

8.1.2. Countercurrent Flow-Limitation Data

Generally, this data block is not input unless the TRAC-M user expects countercurrent liquid flow down and gas flow up in a vertical flow channel and has a data correlation that defines that flow relationship. This correlation model constrains the phasic flow relationship accordingly at user-selected mesh-cell interfaces rather than having TRAC-M evaluate this flow condition directly based on a detail flow-geometry model. This input-data block is specified when NCCFL > 0 (Word 5 on Main-Data Card 6).

8.1.3. Material-Properties Data

The TRAC-M internally defined materials, listed in Sec. 6.3.7.2. for the HTSTR-component MATRD array with ID numbers 1 through 12, are appropriate for most applications. You will not need to provide these cards unless you have a plant or facility constructed of different materials that you have property data for. The new material ID numbers must be > 50. This input-data block is specified when NMAT > 0 (Word 4 on Main-Data Card 2).

8.1.4. Hydraulic-Path, Steady-State Initialization Data

This data block is input for steady-state calculations when the TRAC-M user desires a better initial solution estimate for the phasic temperatures and velocities throughout the modeled system than are defined by the component data. This better initial solution estimate generally halves the calculative effort to converge to the steady-state solution. This input-data block is specified when STDYST = 3 or 4 (Word 1 on Main-Data Card 4).

8.1.5. Control-Parameter Data

This data block specifies modeled-system parameters and logic procedures used to control the simulated operation of the system model. The control procedure is modeled by signal variables (NTSV > 0, Word 1), control blocks (NTCB > 0, Word 2), and/or trips (NTRP > 0, Word 4 on Main-Data Card 7). Almost all TRAC-M input-data models use one or more of these control parameters. To simulate a control procedure effectively, you will need to know how to use signal variables, control blocks, and trips. Once again, as in Section 5.0., we emphasize that you will need a detailed knowledge of how the plant operates to model its control procedure. You also will need to understand how to translate this operational behavior into a control model defined by signal variables, control blocks, and trips that may require a multipass control-parameter evaluation procedure.

8.1.5.1. Multipass Control-Parameter Data. Control parameters are evaluated at the beginning of each timestep in the following order: signal variables, control blocks, and trips. This means that the current beginning-of-timestep information will not be available in some circumstances to evaluate some signal variables, control blocks, and trips unless the user specifies a multipass evaluation procedure so that each parameter eventually is evaluated based on current timestep information (if such is desired). The following four circumstances do not evaluate beginning of timestep conditions on the first evaluation pass: when a signal variable is defined by a trip, when a control block has an input signal that is defined by a trip-defining signal variable or another control block that hasn't yet been evaluated, when a trip signal or its setpoints are defined by the above signal variables and control blocks, and when the control procedure has an implicitly coupled, control-block evaluation loop. If an input signal varies rapidly or has strong coupling to the parameter being evaluated, the lag of the parameter evaluation being one timestep delayed may yield an unacceptable error in the affected control parameter. In the first three circumstances, this can be avoided by multiple-evaluation passes so that eventually each parameter is evaluated based on only beginning-of-timestep information. The fourth and last circumstance cannot achieve this with an explicitly-coupled evaluation, but it can converge approximately to the beginning-of-timestep value after a finite number of such evaluation passes. The TRAC-M user needs to define an appropriate number of control-parameter evaluation passes and what parameters are evaluated on each pass so that the control procedure is simulated accurately.

8.1.5.2. Signal-Variable Data. Signal variables, which access the values of parameters in the modeled system, are needed by most TRAC-M control procedures. They are the input signals to the control procedure's control blocks, trips, and component actions that provide feedback from the thermal-hydraulic system model to the control procedure. Further information about the definition and usage of signal variables is provided in Sections 3.0., 4.0., and 6.0. and Appendix E.

8.1.5.3. Control-Block Data. Control blocks, which evaluate functions operating on input signals to determine an output signal (for example, the ADD function adds two input signals to define the sum output signal), are used in many but not all TRAC-M calculations. This is a very useful control parameter because the user can model through input data a network on coupled control blocks that simulate the logic of a control procedure of any complexity. Because of this capability, TRAC-M can be used solely to evaluate a network of coupled control blocks that simulate a control system with no interest in a simple hydraulic-component system model that must be input. Further information about the definition and usage of control blocks is provided in Sections 3.0., 6.0., and 7.0. and Appendix E.

8.1.5.4. Trip Data. Trips, which are ON/OFF switch controllers for the signal logic of control blocks and for when component actions are evaluated, are used in many but not all TRAC-M calculations. Trips are generally the most direct way of initiating component, operator, and abnormal actions. The trip's ON/OFF set status is defined based on the value of the trip signal lying within a subrange labeled with a set status. Setpoint values define the boundary limits of those subranges so that when the trip signal crosses a setpoint value, the trip's set status, after a user-specified delay time, changes to the set status of the new subrange where in the trip signal now lies. There are three types of trips based on how their trip signal is defined: by a signal variable or control block, by a trip-signal-expression, or by a trip-controlled-trip. The most common is a trip signal defined by a signal variable or control block. A trip-signal-expression trip signal is a simple arithmetic expression based on one or more signal-variable or control-block input signals (the equivalent of a simple control-block network). A trip-controlled-trip trip signal is the combined set status values of two or more trips (where OFF has a 0.0 value and ON has a –1.0 value for $ON_{reverse}$ and +1.0 value for $ON_{forward}$). The combining operator is addition for a coincidence trip (where the trip is set ON or OFF when the set status of M of N trips are ON) and is multiplication for a blocking trip (where the trip is set ON or OFF when all N trips are ON or any one trip is OFF). Trip setpoints are constant or vary if set-point-factor-table cards are input. Generally, setpoints are constant in value. Trip-initiated restart-dump and problem-termination cards can be used to generate data dumps when any one of a number of trips is set ON and, if desired, can terminate the calculation as well. Trip-initiated timestep data cards let the user apply a set of special timestep data for a problem time interval after one of the controlling trips is set ON. Guidelines and examples of trip-modeling techniques are provided in Section 7.3.

8.1.6. Radiation-Enclosure Data

This data block for the optional thermal-radiation heat transfer model is only input if NAMELIST variable NENCL is not 0.

Note: **TRAC-M/F90.** The thermal-radiation heat transfer model currently is not available in TRAC-M/F90; it is available in TRAC-M/F77.

8.1.7. Component Data

This data block is required. The input data for each component may include several types of data. As discussed in Section 6.0. these include data about the thermal-hydraulic geometry, wall heat-transfer structures, component actions and their controlling trips, boundary and initial conditions, and feature- or option-selection parameters. If you followed the general guidelines in Section 5.0. and the detailed guidelines in Section 7.0. you will have assembled the data for each component. The components are then assembled one following another in this component-data section of the TRACIN file. You will probably find it convenient to order your input-data blocks for each component in some logical fashion (usually in the order of increasing component numbers so that a component can be found easily). All HTSTR components must follow the hydraulic components. TRAC-M will arrange the components in another order for computational and output purposes. That order will depend on the order in which thermal-hydraulic loops are processed by TRAC-M. The component order you choose is for your convenience in finding component data in the TRACIN file.

8.1.8. Timestep Data

This final data block is required. Its two cards define timestep-size and output-frequency control parameters for use during a problem-time interval of the calculation. One or more sets of these two cards are needed to span the entire problem time range. These control parameters for a predetermined problem time interval are used unless trip-controlled special timestep data override this timestep data for a specified problem time interval after one of its controlling trips is set ON.

8.2. Steady-State Calculation

Once you have assembled these eight data blocks into an input-data file named TRACIN, you are ready to execute TRAC-M to evaluate a steady-state solution. You will have specified a steady-state convergence criterion, EPSS (Word 2 on Main-Data card 5). The suggested value for EPSS is 1.0000E-04 for the maximum fractional change per second. For single-phase and consistently defined models, TRAC-M generally converges to the steady-state solution and terminates the calculation before the user-specified full problem time has been evaluated. This occurs for most two-phase models as well.

TRAC-M determines whether or not an acceptable steady-state solution has been evaluated in a two-step process. First, TRAC-M determines every NETth = 5th timestep the maximum fractional change per second of seven key parameters (total pressure, liquid and gas velocities, gas volume fraction, liquid and gas temperatures, and noncondensable-gas pressure) over the entire hydraulic-system model. Then TRAC-M requires that all seven maximum rate-of-change values be less than or equal to EPSS for steady-state convergence to be satisfied. This test feature also is provided in transient calculations that evaluate an asymptotic steady-state solution by the NAMELIST-variable ISSCVT option.

Steady-state convergence is not satisfied in some steady-state calculations because of undampened oscillatory behavior (by driven manometer-flow oscillations, switching between two-phase multiple-solution states, switching between two correlation states, etc.) or inconsistently defined constraints on the steady-state solution (user-defined by the nature of the system model or by constrained steady-state controllers that mutually can't be satisfied). To determine the source of such localized oscillations that prevent steady-state convergence, we generally prepare plots of the primary pressure, hot- and cold-leg temperatures, primary mass flows, steam-generator mass inventories, and the secondary-side feedwater and steam-line mass flows. This is a generalized list of parameters; additional parameters may be appropriate for your specific problem. The location of such oscillations usually can be seen on such plots. The driving mechanism usually has the strongest coupling where the largest amplitude of the oscillation occurs. Generally, when the oscillatory amplitude is small and local and the maximum fractional change per second values are less than 0.01 or 0.001 but greater than the EPSS value, the steady-state solution can be approximated as being converged.

Many plants have local oscillations that never reach a static steady-state condition. This is common behavior on the secondary-side of many steam generators. The source of that behavior is inherent in their design. TRAC-M's simulation of such oscillatory behavior should be expected from its steady-state calculation. Thus, be aware that oscillatory behavior during a steady-state calculation may not be due to a defect in the plant model or its control procedure for converging the steady-state solution.

8.2.1. Matching Known Performance

We recommend that you compile a table of the key parameters to match their operating condition in the steady-state solution. A compilation of the key steady-state parameters for a Westinghouse three-loop PWR is presented in Table 8-1. If your calculation converges to steady state, but does not match the known steady-state performance of the plant, you will need to correct your input-data model. Typically, such deviations from known steady-state performance are of several types: incorrect primary-side mass flows, pressure, and temperatures and secondary-side pressure, gas volume fraction, and liquid inventories. The correction of these deviations usually is straightforward.

We recommend that CSS controllers be used during steady-state calculations to adjust uncertain parameters so that known parameter conditions are determined. TRAC-M provides four different CSS controller types that can be multiply applied throughout the modeled system. Using CSS controllers assumes that you start with an accurate plant model based on correct data. Applying incorrect CSS-controller adjustments to compensate for error/s in the plant model compounds the effect of modeling errors. Correct geometrical modeling will minimize the need for model adjustments of this type. Flow losses need to be modeled appropriately at the locations where they occur for the pressure distribution and mass flows to be accurate. Power sources and sinks at their appropriate locations affect the phasic temperature and gas volume fraction distributions.

Error in the primary-side temperature level can be corrected by adjusting secondary-side parameters. Specifically, the primary-side temperature level is adjusted up or down by increasing or decreasing the secondary-side steam-line pressure, respectively. A small change in the steam-line pressure is the simplest way to correct for a small error in the primary-to-secondary heat-transfer specification (usually the steam-generator heat-transfer coefficients and areas). If the steady-state, steam-generator, secondary-side, mass inventory is in error, adjust the input-specified gas volume fractions accordingly and rerun the calculation until an acceptable mass inventory value is obtained. Usually this requires a secondary side with down-comer recirculating flow rather than a PIPE with once-through flow.

8.2.2. Debugging Techniques

In the previous section we discussed how to modify your input-data model if TRAC-M calculates a steady-state solution that does not match the known steady-state condition. In a real sense, this is part of the debugging process for your input-data model. Here, however, we intend a more restricted usage of the term debugging where we describe what to do if TRAC-M exits the calculation through an execution error abort. We begin by re-emphasizing the first step. Check your input-data TRACIN file to ensure that the values TRAC-M uses are the values you intended. There is a straightforward way to accomplish this. You can provide TRAC-M with a calculation end time of TEND = 0.0 s temporarily (see the timestep data description). TRAC-M will read and process your input-data file and provide an output echo of the input data to the TRCOUT file before ending the calculation. Carefully checking the echoed output against your input data will eliminate TRAC-M reading different values from what you intended and reduce the time and effort required to obtain a successful steady-state solution. Making the comparison with values from your working notes as well as TRACIN file also will catch errors in going from your working notes to the typed input data in your TRACIN file.

8.2.2.1. TRAC-M Diagnostic Outputs. You may need to make several execution passes (with partial input-data correction each time) before TRAC-M is able to read your entire input-data TRACIN file that contains errors. TRAC-M checks the input data as they are being read in and catches many input-data errors. Descriptive error messages are output to the terminal and the TRCMSG and TRCOUT files that will direct you to the difficulty area in your input data. If the error is detected while the input-data file is being read, TRAC-M will identify the offending card's record line number for scalar data.

TABLE 8-1
TRAC–P PLANT MODEL STEADY-STATE CONDITIONS

	TRAC–P	PLANT
Reactor-core thermal power (100% power)	2.300×10^9 W (7.848×10^9 Btu h^{-1})	2.308×10^9 W (7.875×10^9 Btu h^{-1})
Primary-side hot-leg temperature	591.8 K (605.5 °F)	591.1 K (604.2 °F)
Primary-side cold-leg temperature	559.4 K (547.2 °F)	559.1 K (546.6 °F)
Primary-side mass flow (each loop)	4253.0 kg s^{-1} (3.375×10^7 lb_m h^{-1})	4259.0 kg s^{-1} (3.380×10^7 lb_m h^{-1})
Vessel bypass flows (% of loop flow):		
Downcomer to upper head	0.174%	0.18%
Outlet-nozzle bypass	0.89%	0.81%
Primary-side pressure drop	5.890×10^5 Pa (85.4 psia)	5.770×10^5 Pa (83.7 psia)
Pressurizer pressure	1.5513×10^7 Pa (2249.9 psia)	1.5513×10^7 Pa (2249.9 psia)
Steam generator (each loop):		
Steam pressure	5.56×10^6 Pa (806.4 psia)	5.52×10^6 Pa (800.6 psia)
Steam outlet temperature	543.8 K (519.1 °F)	542.1 K (516.1 °F)
Main feedwater flow (also steam flow)	413.0 kg s^{-1} (3.278×10^6 lb_m h^{-1})	402.7 kg s^{-1} (3.196×10^6 lb_m h^{-1})
Feedwater temperature	488.7 K (420.0 °F)	488.7 K (420.0 °F)
Secondary-side water mass inventory	4229.0 kg (9323.3 lb_m)	4230.0 kg (9325.6 lb_m)
Recirculation flow ratio (ratio of tube-bundle flow to feedwater flow)	4.10	3.95 – 4.15

Array data read by subroutine LOAD identifies the card number (1, 2, etc.) of the array that is read rather than the TRACIN-file record line number. Determining the array and its component requires searching the TRCOUT file for the word "warning".

Each warning will be followed by an appropriate message describing the error and an output echo of the array data that is suspect. If all the input data have been read by TRAC-M and a data inconsistency is found, TRAC-M will output an appropriate message identifying the inconsistency. For example, providing different flow areas at the same interface junction between two hydraulic components will lead to an error message of the type just described. An example list of common input errors with their corresponding TRAC-M message and an explanation is presented in Table 8-2. A complete list of TRAC-M/F90 error messages and explanations is presented in Appendix L. Before subroutine ERROR is called to output one of these abbreviated-description TRAC-M messages, TRAC-M generally outputs more detailed information with values of the variables that were tested and found at fault. Generally, this information along with the explanation of the abbreviated-description message is very useful in determining the cause of the error.

8.2.2.2. Timestep Control. TRAC-M code developers have attempted to provide a sophisticated internally evaluated timestep-size control algorithm. However, we have occasionally experienced numerical-solution difficulties when the minimum or maximum timestep size specified by the user is too large, a rapid-transient event occurs at such a timestep size, the numerical solution fails to converge, and TRAC-M fails to recover by reducing the timestep size before the maximum user-specified iteration-limit number is reached. This difficulty usually is experienced during transient calculations when a rapid-transient event (component action, phenomena, etc.) is initiated, but it can also occur at the start of a steady-state calculation when the timestep size is too large for a poor initial solution estimate. If you specify a large minimum or maximum timestep size and an error abort occurs on a maximum-number-of-iterations failure, make the DTMIN minimum or DTMAX maximum timestep size smaller (by a factor of 0.1 to 0.01) and repeat the calculation (using a recent data-dump restart if a significant calculative effort has already been spent). More descriptive information on the TRAC-M code timestep-size control procedure is provided in Sec. 8.3.2.2.

8.2.2.3. On-Line Debugging Tools. We briefly discuss interactive debuggers here because they yield insights into debugging procedures for more complex code-related difficulties. One such tool is DBX, a source level symbolic debugging tool under UNIX, that can be used either during TRAC-M execution or after a TRAC-M error abort (Ref. 8-1). Because the need for such a tool arises most frequently during a transient calculation, we discuss it in Sec. 8.3.2.3.

8.2.3. Sample Input-Data Files

Our objective in providing you with sample input-data files is to enhance your understanding of how TRAC-M input-data models are prepared. We provide two such steady-state input-data files. A standalone model to be used in sizing valves is shown in Table 7-1. Although the model is small, it is a complete TRAC-M steady-state input-data TRACIN file. We also provide a full-plant steady-state input-data model in Appendix E.

This plant model consists of the thermal-hydraulics on both the primary and secondary sides and a variety of signal variables, control blocks, and trips in an extensive control procedure. Its input-data TRACIN file has good internal annotation and additional notes are provided in Appendix E to assist you in understanding the input-data features of the model. Noding diagrams for the full-plant input-data model in Appendix E are provided in Section 5.3. Both of these steady-state input-data files are in metric SI units as specified by NAMELIST variable IOINP = 0 (default). They could have been defined in English units, which would have required inputting IOINP = 1.

8.2.4. TRAC-M Output Files

Each TRAC-M calculation generates five output files of interest to the user, as shown in Fig. 5-2. They are the TRCMSG, TRCOUT, TRCXTV, TRCDMP, and INLAB files. We will briefly discuss each of these files.

8.2.4.1. TRCMSG. The primary function of the TRCMSG file is to provide condensed output on the behavior of the numerical calculation and of warning messages produced by various computational subroutines within TRAC-M. This documents the progress of the calculation and any numerical difficulties that were encountered. If TRAC-M terminates because of some numerical difficulty, the TRCMSG file will have output information that describes that difficulty. Although the TRCMSG file only contains numerical-status information and warning messages, it can contain many lines of text if TRAC-M encountered numerical-solution difficulty over an extended period of time. This may be the case, so the size of the TRCMSG file should be checked before requesting a hard copy. Looking at more than 1000 lines of warning messages generally is of no use to anyone. Usually only the first few hundred lines of warning messages provide useful information as to the cause of any numerical difficulty. We present, annotate, and discuss the TRCMSG files from the steady-state and transient calculations of the Westinghouse three-loop plant, single-tube, double-ended-guillotine break simulation in Appendix G. Solution results output to the TRCMSG file are in SI units.

8.2.4.2. TRCOUT. The primary purpose of the TRCOUT file is to provide an output record of the calculational results. Via timestep data, the user selects the SEDINT and EDINT time-interval frequencies at which short and large edits are generated, respectively. Before outputting the short and large edits, TRAC-M outputs an echo of the input data (including the problem title cards) from the TRACIN file and TRCRST file (for restart calculations) and a start-time short and large edit of the initial-condition state of the problem. For the initial calculation, the initial condition of the thermal-hydraulic system model is that specified in the input-data TRACIN file. For subsequent restart calculations, the initial condition is that obtained from the TRCRST file (the TRCDMP file of the previous calculation) with an overlaid modification of selected control parameters and components from the TRACIN file.

TABLE 8-2
TRAC-M INPUT-DATA PROCESSING WARNING MESSAGES

MESSAGE	EXPLANATION
ARRAY FILLED BUT OPERATION END NOT FOUND	Most components (BREAK, FILL, and PLENUM are exceptions) require "array data" to specify cell lengths, volumes, areas, etc. An "E" to denote the end of the array data was not found where expected by TRAC-M.
BOUNDARY ERROR DETECTED	Adjacent components have mismatched geometry and hydraulic input-data at their junction interface. TRAC-M identifies the component, the mismatched parameter (area, hydraulic diameter, gravity parameter, etc.), and the unequal values.
CANNOT REDUCE TIMESTEP FURTHER	The timestep was reduced to the DTMIN minimum specified by the user, and the solution (outer iteration) failed to converge. This is one of the more difficult messages to handle because when it occurs at the start of a calculation, there probably is a difficulty with the input-data model. See Section 8.2.2. and 8.3.2. for guidance.
CNTL. BLOCK NOT FOUND	A control-block output signal's ID number was specified to define the independent variable for a component-action table in component data, but the ID number could not be found in the list of defined control blocks.
DUMP NOT FOUND ON RESTART FILE	On Main-Data card 3, the DSTEP timestep number of the data dump to be used for restart was specified. The restart file (TRCRST, which is TRCDMP from the previous calculation) was searched and this timestep number (an integer) could not be found. Refer to the TRCOUT or TRCMSG file from the calculation that generated the TRCDMP file (renamed TRCRST for the current restart calculation), and check the timestep number for the data dump that is desired. Searching the TRCMSG or TRCOUT files for the word "restart" with a text editor will reveal the timestep numbers of all data dumps generated.
DUPLICATE COMP NUMBERS IN ORDER	Two components with the same number were found in the TRACIN file IORDER array.

TABLE 8-2 (cont)
TRAC-M INPUT-DATA PROCESSING WARNING MESSAGES

MESSAGE	EXPLANATION
FATAL INPUT ERRORS	TRAC-M will attempt to read the entire input-data file even if fatal errors are encountered. This message occurs after input-data processing is complete and indicates that you will need to correct all fatal errors encountered while TRAC-M was reading the input data (all of which have been flagged by warning messages).
FILE TRCRST DOES NOT EXIST	This message occurs in two ways. First a restart calculation has been specified (DSTEP ≠ 0, Main-Data card 3) but file TRCRST is not provided in the local file space. Second, you are making an initial (not a restart) calculation and you have provided fewer control parameters and/or component-data blocks than the NTSV, NTCB, and NTRP number of control para-meters on Main-Data Card 7 and/or NCOMP specified number of components on Main-Data Card 4. TRAC-M is trying to find the TRCRST file to provide the data for the missing control parameters and/or components. Because this is an initial calculation, no TRCRST file is defined.
HYDRO CMP NUM. GE. HT-ST CMP NUM	The component numbers for all HTSTR components must be larger than the largest hydrau-lic component number.
ILLEGAL MATERIAL ID NUMBER	The material ID number is not a valid number between 1 and 12 for internal TRAC-M materials or >50 for user-defined materials.
INOPTS NAMELIST DATA	The NAMELIST-data input option INOPT = 1 (word 3 on Main-Data card 2) was specified but no NAMELIST data were defined on the TRACIN file.
INPUT ERROR DETECTED IN TRACIN. CARD NUMBER XXXX	The free-format input-option preprocessor subroutine PREINP found an input-data error. Possible causes include an invalid character (for example, the = character in 1.0000E=07), the omission of Main-Data card number 1, or a simple typographical error. An immediate fatal error occurs if Main-Data card 1 is incorrect. In all other cases, a flag is set that stops execution after the entire input-data TRACIN file has been processed.

TABLE 8-2 (cont)
TRAC-M INPUT-DATA PROCESSING WARNING MESSAGES

MESSAGE	EXPLANATION
INPUT ERROR ENCOUNTERED ON CARD NO. XXXX, REST ON CARD NO. XXXX, REST	Array-reading subroutine LOAD found an error on a free-format defined card set. The rest of the component data are skipped. Execution of TRAC-M stops after the entire input-data TRACIN file is processed.
INPUT ERROR — NEW COMPONENT WAS ENCOUNTERED UNEXPECTEDLY	Data for a new component were found before reading the data for the current component was finished. For example, you may have omitted a data card expected by TRAC-M. The card might be required by an INOPTS option or a component feature; due to a simple oversight this was not provided.
INPUT ERROR – UNEXPECTED LOAD DATA ENCOUNTERED	TRAC-M encountered array data but was expecting nonarray data. You have either too many or too few input-data cards because the card read is out of sequence.
JUNCTION COUNT ERROR	The number of junctions specified by NJUN (word 4 on Main-Data card 4) is inconsistent with the number of junctions defined by the component data. TRAC-M will output the required number of junctions based on the component data. Change the value of NJUN to use this TRAC-M number.
NOT ENOUGH DATA TO FILL ARRAY	Insufficient data were input to define an array. Remember that one more value is required for cell-edge parameters such as flow area, hydraulic diameter, and the gravity parameter than for cell-centered parameters such as cell length and volume.
NUMBER TRIPS EXCEED DIMENSION	The number of trips defined by the TRACIN file and TRCRST file exceeds its NTRP storage-allocation number on Main-Data card 7.
REAL DATA ENCOUNTERED IN INTEGER ARRAY	Real array data were found where integer array data were expected. You have either too many or too few input-data cards because the card read is out of sequence.

TABLE 8-2 (cont)
TRAC-M INPUT-DATA PROCESSING WARNING MESSAGES

MESSAGE	EXPLANATION
SIGNAL VAR. NOT FOUND	A signal variable's ID number was specified to define the independent variable for a component-action table in component data, but the ID number could not be found in the list of defined signal variables.
SIG. VARIABLES EXCEED DIMENSION	The number of signal variables defined by the TRACIN file and TRCRST file exceeds its NTSV storage-allocation number on Main-Data card 7.
STEADY STATE NOT CONVERGED	The steady-state calculation did not reach a converged steady-state solution within the user-specified problem time for the calculation. See Sec. 8.2. for additional discussion.

A short edit is a half-page display. The initial line outputs the current problem time, timestep size, and timestep number and the number of iterations required to converge the last outer iteration. This is followed by the maximum convective power difference, the component and its location limiting the current timestep size, the minimum, average, and maximum number of outer iterations since the last short edit, the number of timesteps that each component was the last to converge its outer-iteration solution, and the current-calculation and accumulated-calculations CPU execution times. This information conveys how well the numerical solution is doing and where in the model the solution convergence is most limited and the timestep size controlled.

Each large edit provides a "snapshot" of the modeled system's thermal-hydraulic solution at a given point in time. For even modestly sized systems with less than a dozen large edits, the TRCOUT file can be large. You are cautioned to be judicious in your selection of the large-edit EDINT time-interval frequency. The TRCOUT-file output is useful because each snapshot can be analyzed for the detailed spatial behavior of the solution and for diagnostic purposes. However, we have found that transient phenomena are best captured and understood by plotting the solution data vs. problem time obtained from the TRCXTV file.

To assist you in interpreting the output solution results from a TRCOUT file, we have provided segments of two TRCOUT files in Appendix H. Only selected portions are shown because the full TRCOUT files are so large. Appendix H shows the TRCOUT-file solution results from a steady-state calculation based on the input-data TRACIN file shown in Appendix E and from its restart transient calculation based on the data-dump TRCDMP file from the steady-state calculation and the input-data TRACIN file shown in Appendix F. We have annotated the TRCOUT files in serial fashion and provided annotation notes to guide your review of the output solution results from these TRCOUT files. The solution results output to the TRCOUT file are in metric SI or English units depending upon NAMELIST variable IOOUT being user specified as 0 (default) or 1, respectively.

8.2.4.3. TRCDMP. TRAC-M generates a data-dump TRCDMP file that contains snapshots of the solution state of the modeled system that are output at user-specified DMPINT time intervals during the course of a calculation. The file contains unformatted binary data that are not intended for visual examination. Any one of these snapshots, called a restart data dump, may be used to initialize all or part of the system model for subsequent restart calculations from its data-dump edit time. The TRCDMP file is renamed TRCRST for recognition by TRAC-M as the restart-data file. Besides generating data dumps at a DMPINT time interval, the TRAC-M user can specify trip-controlled data dumps that are generated whenever any one of its controlling trips is set ON. TRAC-M also generates data dumps automatically at TDUMPINT time intervals of CPU execution time (currently, CPUDMP = 10^{10} s in subroutine TIMCHK results in no such data dumps being generated by TRAC-M). The TRCMSG and TRCOUT files can be searched for the word "restart" to show all output messages of the problem times and timestep numbers when data dumps were generated during the calculation. For selection of any but the final data dump, you must identify the timestep number of the data dump to define DSTEP (Word 1 on Main-Data card 2) in the TRACIN file for the restart calculation. The solution results output to the TRCDMP file are always in metric SI units.

8.2.4.4. TRCXTV. Most users find the TRCXTV file to be the most useful output vehicle because it is used to graphically display the solution results of a calculation. The file contains unformatted binary data that cannot be read without a postprocessor. The user specifies through timestep data the GFINT time-interval frequency with which graphics data are output to the TRCXTV file. The solution results output to the TRCXTV file are in metric SI or English units depending upon NAMELIST variable IOGRF being user specified as 0 (default) or 1, respectively. Two postprocessors of TRCXTV data are XTV (TRAC-M/F77 and F90) and XMGR5 (TRAC-M/F90 only) (See Section 8.4.).

8.2.4.5. INLAB. The NAMELIST-variable INLAB option allows the user to output an echo of all input data from the TRACIN file to a file named INLAB. All values are columnized like TRAC-format data but the INLAB file is in FREE-format because "*" comments show the FORTRAN variable names associated with all data values as defined in Section 6.0. Existing user-defined comments in the TRACIN file are not transferred to the INLAB file. You will need to transfer them from file TRACIN to file INLAB by manual copy commands to keep them in the INLAB file. File INLAB becomes a new "cleaned up" version of the TRACIN file when it is renamed TRACIN. The INLAB option is a convenient way for the user to "clean up" the appearance of a TRACIN file (that has few existing comments) for better readability of the input data. The input-data files in Appendicies E and F were originally generated as INLAB files to improve their readability back in 1990 when a Los Alamos code called GOCNVT translated their input data from MOD1 to MOD2. Before then, their TRACIN files had record upon record of random space-delimited data values with one or two comment lines on each page of data. The nature of such input data is prone to being incomprehensible and prone to causing user errors. The INLAB option also allows the units of the input data to be changed conveniently from metric SI to English or from English to metric SI. The TRACIN-file units are metric SI or English depending upon NAMELIST variable IOINP being 0 (default) or 1; the LABIN-file units are metric SI or English depending upon NAMELIST variable IOLAB being 0 (default) or 1, respectively.

8.3. Transient Calculation

As discussed in Sec. 7.4, the thermal-hydraulic state initial condition for a TRAC-M transient calculation usually is obtained from a TRAC-M steady-state calculation. In contrast to the usual large size of a steady-state input-data TRACIN file, the transient input-data TRACIN file generally is small. A restart transient calculation annotated input-data TRACIN-file listing is provided in Appendix F.

You are more likely to encounter numerical-solution difficulties during the course of a transient calculation than during a steady-state calculation. The reason is straightforward: generally you will be analyzing accident conditions that produce rapid changes in the thermal-hydraulic state either locally or throughout the system. These rapid changes challenge the ability of TRAC-M to adjust the timestep size automatically to maintain both accuracy and numerical stability with a small enough timestep size while minimizing computational effort and hence cost with a large enough timestep size. When TRAC-M has difficulty in dealing with such changes, the numerical calculation may fail. Although this occurs infrequently, you will need to be prepared to deal with such a difficulty. We discuss debugging techniques for transient calculations in Section 8.3.2.

8.3.1. Matching Known Performance

If you have data describing the transient performance of your system, it is important that you use it to compare with the calculative results to validate your input-data model. Such data frequently are available for experimental facilities. Usually, data obtained from relatively benign tests and operational transients exist for operating PWRs. An extensive program of independent developmental assessment was conducted at Los Alamos for each major-release TRAC–P version. Appendix A has a listing of the developmental-assessment documentation. The TRAC–P assessment program has used both single-effect and integral-facility data to verify and validate its programmed form. TRAC-M/F77 (Version 5.5 and earlier) has also been extensively assessed (Refs. through 8-5), and there are plans for developmental assessment of TRAC-M/F90.

If your calculational results do not match the data, you should make an effort to understand the cause(s). Care must be taken to review the entire system model and its calculative results in an attempt to identify the key factors affecting a result. This is made difficult by the strong coupling of phenomena in a full-plant or experimental facility. You may need to make several parametric investigations, including input-model modifications, to confirm that your assessment is correct. Again, we refer you to the documents cited in Appendix A and in Refs. 8-2 through 8-5 for further insight into the assessment process.

8.3.2. Debugging Techniques

As stated in Sec. 8.2.2., we use the term debugging to describe our follow-up activities after TRAC-M aborts its execution because of an numerical-solution error. Again, we recommend that you check your input data. If you do not have an input-data error, you should begin an orderly effort to identify the difficulty. We have provided a diagnostic check list in Appendix B. In that check list, you are directed to the following activities: review of the messages from subroutine ERROR, review of the TRCMSG file, review of the TRCOUT file, and follow-on diagnostic activities. These and other important debugging activities are covered in the following sections.

8.3.2.1. TRAC-M diagnostic outputs. As discussed above, TRAC-M does a good job of providing diagnostic messages when reading input data from the TRACIN file. Because the steady-state input-data TRACIN file contains the majority of the system-model description, these TRAC-M diagnostic messages are helpful while the steady-state input-data TRACIN file is being debugged. These messages also are helpful for the transient input-data TRACIN file, but this file usually is much smaller so there are fewer such input-data errors. During the evaluation of a transient, numerical-solution difficulties produce diagnostic warning and error messages that are very important in diagnosing the difficulty. The type of message and the output values of affected parameters define the condition. The location of the difficulty may tell you something about the model at that location that causes the numerical solution to have such difficulty. An appropriate change in the model may eliminate the numerical difficulty in a repeat calculation. For example, closing an adjustable VALVE interface in 0.2 s, rather than a more realistic 2.0 s, can cause numerical solution difficulties that a slower closing adjustable VALVE interface does not. These messages are output to the TRCMSG file and to the terminal.

8.3.2.1.1. Review of messages from subroutine ERROR. If error messages are generated by TRAC-M and you are still in the input-data processing stage, you should be able to correct the input-data file to proceed. TRAC-M has good diagnostic messages that describe the commonly made input-data errors. Examples of such messages are shown in Table 8-2. If the transient timestep calculation has begun and error messages are being generated, you will need to read them and try to understand their cause. Even if they don't abort the calculation, they may indicate the need for a modeling change or for more restrictive timestep data. If they abort the transient calculation, you will have no choice but to resolve the error causing the abort. We are aware that the error messages are brief, but TRAC-M usually outputs more information with affected parameter values to file TRCMSG before calling subroutine ERROR to issue its brief error message.

8.3.2.1.2. Review of the TRCMSG file. We cannot overemphasize the importance of carefully reviewing the TRCMSG file. This file contains a brief summary of the behavior of the numerical solution and diagnostic information generated when TRAC-M encounters calculational difficulties. In some cases, a review of the TRCMSG file will provide all the information needed to identify the difficulty. In other cases, you may need to review the thermal-hydraulic solution details in the TRCOUT file and use your understanding of the TRAC-calculated physical phenomena to provide the information you'll need for the debugging process.

The output information in file TRCMSG can be difficult to interpret without explanation; therefore, we have provided steady-state and transient calculation TRCMSG files with annotated notes in Appendix G. In each case, we have tried to provide an overview for the noted error messages to lend perspective to the diagnostic process. The nature of the discussion about each error message emphasizes that you must not only review the TRCMSG file but must also be aware of the specific features of your plant or facility model and the phenomena that TRAC-M is calculating. Understanding a calculation and diagnosing its warning error messages requires both a macro and micro examination process. The diagnostic messages that appear in the TRCMSG file were originally developed to provide guidance to advanced TRAC-M users. Although effort has been expended to make the diagnostic messages more easily understood by the beginning or intermediate user, further improvements should be made by outputting more information about the difficulty that TRAC-M is aware of when generating the error message.

If you are to understand the diagnostic messages appearing in the TRCMSG file, you must be aware of the concept of "phantom cells" in SEPD and TEE components. As we already have discussed, TRAC-M evaluates and stores both cell-centered and cell-edge array variables. There will always be one more cell-edge value than cell-centered values in such arrays. Data storage within TRAC-M reflects this difference. SEPD and TEE components provide an exception to array internal storage of cell-center and cell-edge data. Diagnostic messages that refer to a specific cell or interface in a SEPD or TEE component are based on the TRAC-M internal data storage system for SEPD and TEE components that includes an extra phantom cell between the main-tube and side-tube cells. A cell-centered array stores the main-tube cell values first, then a phantom cell value, and finally the side-tube cell values. A cell-edge array uses the phantom cell edge to store the extra cell-edge value on the main-tube side. Consider a TEE with five cells in the main tube and four cells in the side tube. A diagnostic error message referring to cell 7 of a cell-centered array variable is referring to the first cell in the side tube (cell 7 – 5 main-tube cells – 1 phantom cell = side-tube cell 1). A diagnostic error message referring to cell-edge 7 of a cell-edge array variable is referring to the first side-tube cell-edge (cell-edge 7 – 6 main-tube cell edges = side-tube cell-edge 1) that joins the side tube to the main-tube JCELL.

8.3.2.1.3. Diagnostic check-list assistance. As noted in the diagnostic check list of Appendix B, you may encounter several types of difficulties while using TRAC-M. These include: (1) model input-data errors, (2) modeling decisions that result in a TRAC-M failure, and (3) a programming error in TRAC-M.

We believe that after carefully reviewing the terminal output and the TRCMSG and TRCOUT files, you should be able to identify and correct all type-1 difficulties and most type-2 difficulties. However, if you encounter an unsolvable type-2 difficulty or a type-3 difficulty, the diagnostic check list will assist you in collecting the information necessary for personnel at the United States Nuclear Regulatory Commission (USNRC) to assist you in resolving your difficulty.

As a final follow-on diagnostic activity, you are requested in the diagnostic check list of Appendix B to obtain "detailed diagnostic printout" and are referred to this section. Diagnostic printout can be obtained by resetting selected NAMELIST variable parameters in the input data. The parameters are listed below with a brief description of their reset values.

IDIAG = 2, 3, or 4 requests that detailed diagnostic output be provided (2 gives flow-reversal diagnostics; 3 gives flow-reversal and gas volume-fraction temporal-change diagnostics; 4 gives flow-reversal, gas volume-fraction temporal-change, and out-of-bounds gas volume-fract-ÿn reiteration diagnostics). If the error messages relate to two-phase conditions, use options 3 or 4; otherwise, use option 2.

NSPL = beginning timestep number at which a large edit is output to the TRCOUT file every timestep.

NSPU = ending timestep number at which a large edit is output to the TRCOUT file every timestep.

NSDL = beginning timestep number at which short edit and pressure change to total pressure and the difference between basic and stabilizer macroscopic densities diagnostics are output to the TRCOUT file and gas volume-fraction temporal-change diagnostic (when IDIAG = 3 or 4) are output to the TRCMSG file each timestep.

NSDU = ending timestep number at which short edit and pressure change to total pressure and the difference between basic and stabilizer macroscopic densities diagnostic are output to the TRCOUT file and gas volume-fraction temporal-change diagnostic (when IDIAG = 3 or 4) are output to the TRCMSG file each timestep.

NSEND = timestep number at which the TRAC-M calculation ends.

Note that the timestep numbers referred to above correspond to the timestep numbers in the error messages output to the TRCMSG file. The timestep counter NSTEP is incremented at the completion of each timestep calculation just before the end-of-timestep solution state may be output to the TRCOUT file. You are urged to use the additional IDIAG Š 2 diagnostic printout only as a last resort. You are given control over the beginning and ending timesteps because the output generated can be extremely large. You determine the timesteps to specify by reviewing the TRCMSG file from the previous run to determine the timestep number at which the difficulty first occurred. Usually only a few timesteps of diagnostic information is useful for debugging. This output is cryptic and may be hard to understand. Your contact representative at the USNRC (see Appendix B) may require this information if all other things investigated fail. The USNRC would appreciate any corrections or suggestions for improvement that you may have concerning this manual and support provided. Please use the form in Appendix C to convey this information to the USNRC.

8.3.2.2. Timestep control. TRAC-M calculates a timestep size limit based on several different phenomenal rate tests. Each test corresponds to a different variable or set of variables. In general, the limiting timestep size for a particular variable is calculated by multiplying the previous timestep size by the ratio of a fixed maximum-allowed change in that variable to the change in that variable during the previous timestep.

The phenomena-limiting timestep sizes evaluated in TRAC-M are DELAMX, DELCMX, DELDMX, DELEMX, DELPMX, DELRMX, DELVMX, and DELXMX. DELAMX monitors the relative change in the gas volume fraction in VESSEL cells from one timestep to the next. DELCMX limits the change in liquid, gas, ROD-element, and SLAB-element temperatures and the fractional pressure change from one timestep to the next by its timestep size. It defines the most restrictive value from its five different tests. DELDMX limits the timestep size to the diffusion number for explicit axial conduction in HTSTR-component ROD or SLAB elements. DELDMX is not evaluated if implicit axial conduction is evaluated. DELEMX limits the VESSEL mass-conservation error from one timestep to the next. Its mass-conservation error has not been appreciable in recent TRAC-M version calculations, so this test is no longer limiting. DELPMX limits the timestep size to a maximum 10% change in power generated in powered HTSTR components. DELRMX limits the maximum relative pressure change over the last timestep to ≤10%. DELVMX is the material-Courant timestep-size limit for the VESSEL component and 1D hydraulic components (the minimum cell length to interface velocity ratio). If the SETS3D method is not activated when NAMELIST variable NOSETS = 1 or is activated when NOSETS = 0 or 2, the timestep size is not allowed to exceed 1.0 or 1000.0 times the material Courant limit, respectively. For 1D hydraulic components based on the SETS1D method, the timestep size is not allowed to exceed 1000.0 times the material Courant limit. DELXMX limits the change in the adjustable-interface flow area of all VALVE components. That maximum change gets smaller as the interface flow area goes to zero. A minimum of 12 timesteps are required to fully open or close an adjustable VALVE interface by this criterion.

These DELAMX, DELCMX, DELDMX, DELEMX, DELPMX, DELRMX, DELVMX and DELXMX timestep-limiting values are output by the short edit. A value of 1.0E+08 indicates that the test value would not have restricted the timestep size. The number underneath each timestep-limiting value is the number of times that test limited the timestep size since the last short edit. This information is helpful in recognizing the phenomena that limited the timestep size during the calculation.

TRAC-M also has an option to provide additional diagnostic information on the timestep-size control, which is written to file TRCMSG. For a range of timesteps or problem time (or both) specified by the user, a description of the reason for the timestep-size selection is written, for each step. This option is under control of NAMELIST variables TSDLS, TSDLT, TSDUS, and TSDUT.

Note: **Detailed Timestep-Size Diagnostics.** Currently, in TRAC-M/F90 (Version 3.0), the option to obtain detailed diagnostic information on the timestep-size control for a calculation, via NAMELIST variables TSDLS, TSDLT, TSDUS, and TSDUT, is not available. The option is available in TRAC-M/F77.

8.3.2.3. On-line debugging tools. On-line debugging tools, such as DBX (Ref. 8-1), assist the user in debugging coding interactively. When using DBX to execute TRAC-M, you may stop TRAC-M at any location during its execution, examine the contents of computer memory and the values of parameters, and change the coding or parameter values. Programs like DBX are specific to the computer being used, and we mention it here so that users are aware that such debugging tools exist. For large complex computer programs like TRAC-M, detailed debugging can be done efficiently with a tool like DBX.

8.3.3. Sample Input-Data Files

Our objective in providing you with sample input-data files is to enhance your understanding of how TRAC-M input-data models and files are created. We have provided a steady-state input-data TRACIN file in Appendix E and a restart transient input-data TRACIN file in Appendix F for tutorial instruction.

8.3.4. TRAC-M Output Files

As shown in Fig. 5-2, each TRAC-M calculation generates five output files of interest to the user. These are the TRCMSG, TRCOUT, TRCXTV, TRCDMP, and INLAB files. We have briefly discussed each of these files:

TRCMSG	See Section 8.2.4.1. and Appendix G.
TRCOUT	See Section 8.2.4.2. and Appendix H.
TRCDMP	See Section 8.2.4.3..
TRCXTV	See Section 8.2.4.4..
INLAB	See Section 8.2.4.5..

8.4. Output Processors

The amount of data (output results) produced by even a moderately sized TRAC-M model of a PWR or experimental facility is huge. In Appendix H, we present annotated portions of a TRCOUT file from a TRAC-M steady-state calculation based on the full-plant model input-data TRACIN file in Appendix E and annotated portions of a TRCOUT file from the TRAC-M restart transient calculation based on the TRCDMP (renamed TRCRST) restart-data file and the input-data TRACIN file in Appendix F. Although we limited the number to two steady-state and seven transient large edits, 145 double-sided pages (37 217 lines) of steady-state output and 338 double-side pages (86 447 lines) of transient output were produced. This printed information is useful for diagnostic activities and for providing time-point snapshots of the thermal-hydraulic solution for a specific component or the entire system model. However, we find that other approaches to studying the calculated results are necessary for a better and faster way to understand transient phenomena and coupling processes throughout the system.

At present, two postprocessors are available for graphical analysis of TRAC-M results, XTV (TRAC-M/F77 and F90) (Ref. 8-6) and XMGR5 (TRAC-M/F90 only). Both of these tools read data from file TRCXTV; both are based on a graphical user interface.

Note: **XMGR5; TRAC-M/F90, Version 3.0.** In Version 3.0 of TRAC-M/F90 XMGR5 graphics postprocessing is only available by selecting NAMELIST-input variable IOGRF = 2, which creates file TRCXTV in XDR format. In this case file TRCXTV is in SI units. Future versions of TRAC-M/F90 will only support the XDR format, and will support both SI and English units. This format will be readable by both XMGR5 and a future version of XTV.

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APPENDIX A

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APPENDIX B

DIAGNOSTIC CHECK LIST AND CONTACT INFORMATION

Users may encounter several types of difficulties while executing TRAC-M. These include: (1) model input-data errors, (2) modeling decisions (but not input-data errors) that result in a TRAC–M failure, and (3) an error in TRAC-M.

You should be able to resolve all difficulties in category 1. TRAC–M input-data checking diagnostic messages will help you identify, locate, and correct input-data errors. Difficulties in category 2 often are more difficult to resolve. Nevertheless, a review of the TRAC–M message file, TRCMSG, and TRAC–M output file, TRCOUT, will frequently lead you to the modeling feature that is creating the TRAC–M failure. Category 3 is the most difficult to resolve and requires an understanding of the theory, organization, and programming of TRAC-M. When you become convinced that you do not have a category 1 input-data error and you have done all you can to find a category 2 error, you can contact the United States Regulatory Commission (USNRC). The telephone number is given at the end of this check list. We ask that you to complete the following check list of information before calling.

1. PRELIMINARY INFORMATION

____ TRAC–M code version
____ list of official pending updates added to the code version
____ list of other updates added to the code version
____ component network and noding diagram for the system model

2. TRAC–M CALCULATION TYPE

____ steady state
____ transient
____ static check

3. STAGE AT WHICH TRAC–M FAILURE OCCURRED

____ initial input
____ restart input
____ initialization
____ prep
____ outer
____ post
____ after a backup

4. OUTPUT REVIEW

4.1. Messages from subroutine ERROR
____ no error messages
____ error messages (list below or have readily available)
1.
2.

3.

____ unable to resolve all error messages (list those not resolved)

____ nonphysical results but no error messages

4.2. TRCMSG file review

____ TRCMSG reviewed

____ warning and abort message types identified (including ERROR messages)

____ water-packer messages [components(s)]

____ outer-iteration failures [component(s), bad parameter values]

____ other significant information

4.3. TRCOUT file review (this review can be particularly helpful for errors during input because you can check what values are read against their intended input values)

____ checked physical-phenomena parameters in the component having the solution difficulty (usually flagged in the TRCMSG file). Does it make physical sense?

____ checked recent code updates to see if they deal with the type of difficulty being experienced

____ checked for timestep-size control difficulties

5. FOLLOW-ON DIAGNOSTIC ACTIVITIES

____ Reduced DTMAX maximum timestep size and tried to rerun through the time frame of solution difficulty. We recommend that you set the timestep data-dump interval to obtain a TRAC–M data dump shortly before the time of the previous failure (within about 20 timesteps) so that repeated restart calculations may be done.

____ Adjust or modify the model in the area of apparent difficulty.

____ If you still do not know what to do, turn on the detailed diagnostic printout (using NAMELIST variable IDIAG = 2, 3, or 4 discussed in Section 8.3.2.1.3.) just before the failure, execute TRAC–M to the failure, and make a telephone call for diagnostic help. Have the diagnostic check list and printouts available.

6. CONTACT

Dr. Frank Odar
Reactor and Plant Systems Branch
US Nuclear Regulatory Commission
Mail Stop T 10 E46
11545 Rockville Pike
North Bethesda, MD 20852

Telephone: (301) 415-6500

APPENDIX C

SUGGESTED IMPROVEMENTS TO THE TRAC-M USER'S MANUAL

We encourage comments and suggestions for improving the TRAC-M User's Manual. The User's Manual is in notebook format to permit updating of selective pages when they have changed.

MAIL TO: Dr. Frank Odar
Reactor and Plant Systems Branch
US Nuclear Regulatory Commission
MS T 10 E46
11545 Rockville Pike
North Bethesda, MD 20852

email: fxo@nrc.gov

SUGGESTION TYPE

Needed improvement to an existing section
Section
Appropriate documentation that is missing
Section
New TRAC-M feature that needs to be documented
Section
New guideline suggestion
Section

SUGGESTION DESCRIPTION

If documentation supporting the suggestion is available, please attach a copy.
If a citation reference is available, please provide it.

APPENDIX D

CODE INSTALLATION

Contact the United States Nuclear Regulatory Commission (USNRC) at the address and telephone number provided in Appendix B, for instructions on obtaining and installing TRAC–M.