TRACE Component Introduction – Part 2

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Objective

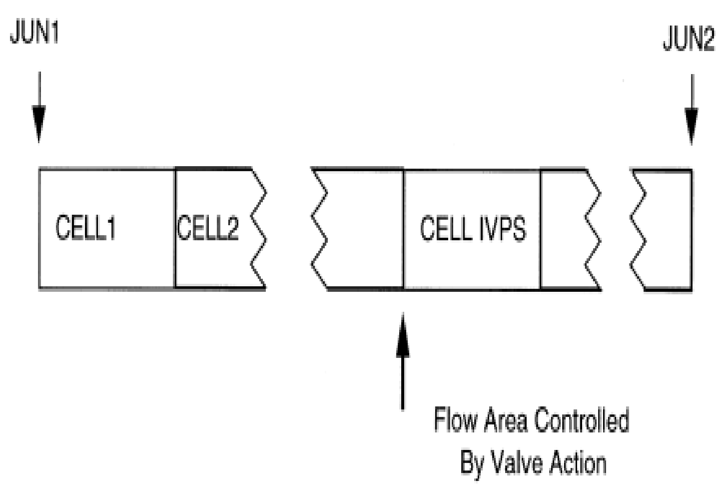
In preparation for the exercise that follows, provide the second set of basic information about the TRACE components used for building system models ………

Outline

- VALVE Component
- PUMP Component
- BREAK Component
- TEE Component
- SEPD Component
- JETP Component
- Control System Input: Trips

VALVE Component

- VALVE components include fluid cells and internal flow faces, variable control over one internal cell face (the valve location), specification of junction numbers for connections to other TRACE components, and piping wall heat structures
- Flexibility for modeling a wide variety of valve-face control schemes
- The VALVE component is similar to a PIPE component with two or more cells (or a zero-cell, single-junction type component), in which the flow area at one of the cell faces may be controlled



VALVE Component

- The cell face at which the control is implemented is indicated by input variable IVPS
- IVPS cannot be specified at the JUN1 or JUN2 faces unless (1) the junction connects to a BREAK component or (2) the VALVE is a zero-cell, single junction type component
- TRACE offers a variety of methods for controlling the valve flow area, as selected using the Valve Type (IVTY) input parameter

VALVE Component

Some of the more commonly used Valve Types are:

IVTY	Valve Face Control
-1	Area fraction calculated using a control system
1	Area fraction from a table as function of an independent variable
2	Valve stem position from a table as function of an independent variable (with area fraction versus stem position specified in another table)
3	Constant flow area until trip (input parameter IVTR) is set to on, then afterward the same as IVTY=1
8	TRAC-B style motor valve (control is a function of pressure calculated in one of the VALVE cells)
9	Check valve
11	RELAP5-style motor valve (open and close commands specified using trips, open and close change rates specified)

VALVE Component

Example of VALVE component modeling:

PORV that opens when the steam line pressure exceeds a certain setpoint value and reseats when the steam line pressure falls below a lower setpoint value

One-cell VALVE connected to a BREAK with the flow area controlled at Face 2 (IVPS=2)

Valve flow area fraction calculated as Control Block 1162

IVTY = 1 method used (Area fraction from a table as a function of independent variable IVSV = -1162. With parameter NVTB1 set to zero, Control Block 1162 is used directly as the area fraction)

Could also have used IVTY = -1 method (Area Fraction = Control Variable)

VALVE Component

```
*      numtcr       ieos       inopt       nmat
*       type        num          id      ctitle
valve               116         116     $116$ msl 1 porv
*      ncells      nodes       jun1        jun2       epsw
            1          1        116         118   0.0000e+00
*      nsides
            0
*        ichf       iconc      ivty        ivps      nvtb2
            1          1          1           2          0
*        ivtr       ivsv       nvtb1       nvsv      nvrf
            0       -1162         0           0          0
*      iqp3tr     iqp3sv     nqp3tb     nqp3sv     nqp3rf
            0          0          0           0          0
*      ivtrov     ivtyov
            0          0
*        rvmx       rvov       fminov       fmaxov
   5.0000e+00  0.0000e+00  0.0000e+00  1.0000e+00
*       radin         th        houtl        houtv        toutl
   3.0493e-01  2.5270e-02  0.0000e+00  0.0000e+00  3.0000e+02
*       toutv      avlve        hvlve       favlve         xpos
   3.0000e+02  4.1484e-03  1.5240e-01  0.0000e+00  0.0000e+00
*       qp3in      qp3off      rqp3mx      qp3scl
   0.0000e+00  0.0000e+00  0.0000e+00  1.0000e+00
*
```

RVMX is the maximum rate of change of the valve flow area fraction (1/s). Regardless of how fast CB 1162 changes, 0.2 s is required for valve to go from fully closed to fully open

The flow area and hydraulic diameter associated with the fully-open valve

The initial valve flow area fraction, 0.0 = fully closed

VALVE Component

```
* dx    *     1.0000e+00e
* vol   *     2.9210e-01e
* fa    * f   2.9210e-01e
* fric  * f   0.0000e+00e
* rv fri* f   0.0000e+00e
* grav  * f   0.0000e+00e
* hd    * f   6.0985e-01e
* icflg *         0         1e
* nff   * f             1e
* alp   *     1.0000e+00e
* vl    * f   0.0000e+00e
* vv    * f   0.0000e+00e
* tl    *     5.4211e+02e
* tv    *     5.4212e+02e
* p     *     5.4158e+06e
* pa    *     0.0000e+00e
* qppp  *     0.0000e+00e
* matid *               9e
* tw    *     5.4211e+02e
* conc  *     0.0000e+00e
```

The VALVE component cell and cell-face flow area is greater than the valve full-open flow area (AVLVE)

The default choked flow model is activated at the cell face where the flow area fraction is controlled

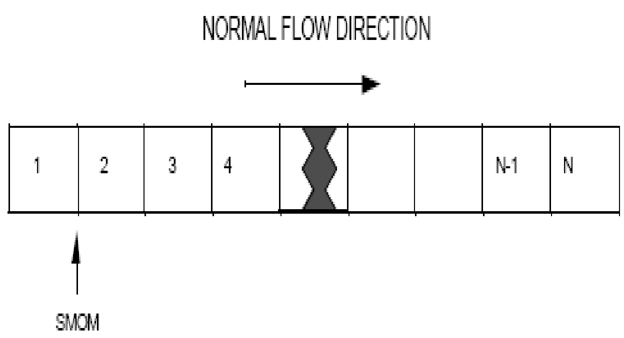
PUMP Component

Except for the momentum source, the features of the TRACE PUMP component are similar to those of the TRACE PIPE component:

- Multiple fluid cells
- A PUMP must contain at least two cells
- Connections between the internal cells of the component
- Junctions specified at the two ends of the PUMP
- Exceptions for the special case of a zero-cell single-junction type PUMP
- Capabilities for modeling a wall heat structure

PUMP Component

The pump momentum is calculated by TRACE and (except for the special case single-junction type PUMP) is added or subtracted at Face 2 of the PUMP as illustrated here:



The basic TRACE PUMP models for calculating the momentum are the same as used in the TRAC, RELAP5 and RETRAN code pump models

PUMP Component

The momentum interaction between the rotor and the coolant of a centrifugal pump is described using a set of non-dimensional homologous curves for the relationships between:

- Pump developed head, speed and flow
- Pump delivered torque, speed and flow

The user may input homologous curve data for a specific pump application or use TRACE "built-in" homologous curve data for:

- Semiscale Mod-1 pump
- LOFT pump
- PWR Bingham-Willamette pump
- PWR Westinghouse pump

Acceptability of using built-in data is typically judged based on hydraulic-similarity comparisons (specific speed and other pump performance non-dimensional parameters)

PUMP Component

Calculation of the PUMP Momentum Source

Homologous curves represent the performance of the centrifugal pump using data for the pump head, volumetric flow rate and speed for single-phase liquid

H = the pump head, $(\Delta P)/\rho_m$ (Pa-m^3/kg, m^2/s^2, or N-m/kg),

Q = the impeller-interface volumetric flow rate, $A_{j+1/2} \cdot V_{j+1/2}$ (m^3/s), and

Ω = the pump-impeller angular velocity (rad/s),

A similar set of homologous curves represent the performance of the centrifugal pump using data for the pump torque, volumetric flow rate and speed for single-phase liquid

Pump heat addition due to work performed on the fluid is included in the model (except currently for the single junction component PUMP type)

PUMP Component

Four-quadrant homologous curve functions

Dimensionless head, volumetric flow, and pump speed are used (with normalization based on the user inputs for the rated head, rated flow and rated speed)

$$h = H / H_R$$

$$q = Q / Q_R$$

$$\omega = \Omega / \Omega_R$$

Curve Segment	$\left\|\frac{q}{\omega}\right\|$	ω	q	Correlation
1	≤ 1	> 0	$\pm$	$\frac{h}{\omega^2} = f\left(\frac{q}{\omega}\right)$
4	≤ 1	< 0	$\pm$	
2	> 1	$\pm$	> 0	$\frac{h}{q^2} = f\left(\frac{\omega}{q}\right)$
3	> 1	$\pm$	< 0	

a. For the special case of both $\omega = 0.0$ and $q = 0.0$, the code sets $h = 0.0$

PUMP Component

Example of single-phase liquid head data

(Semiscale pump)

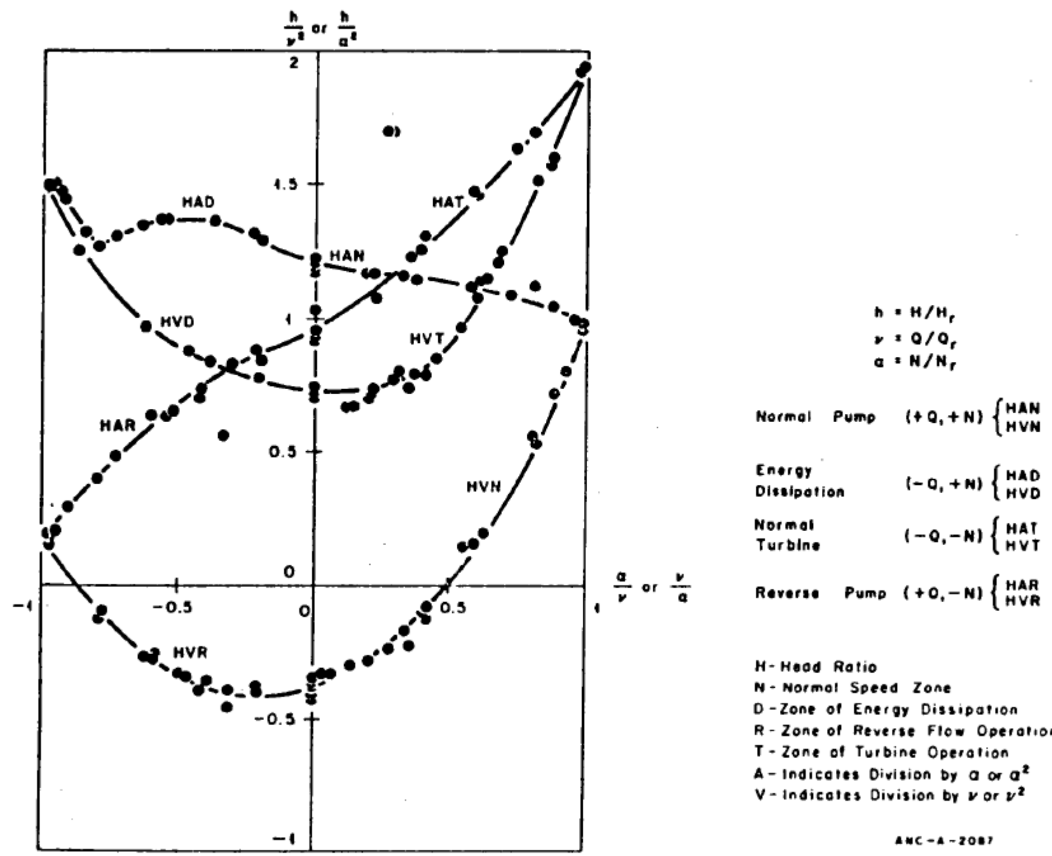


Figure 186. Single-phase homologous head curve for the Mod-1 Semiscale pump.

PUMP Component

Two-phase head degradation due to void present within the fluid

$$H = H_{1\phi} - M(\alpha) \cdot [H_{1\phi} - H_{2\phi}]$$

where

H = the total pump head,

$H_{1\phi} = h_{1\phi} H_R$ = the single-phase pump head ($h_{1\phi}$ is the non-dimensional head from the single-phase homologous head curves),

$H_{2\phi} = h_{2\phi} H_R$ = the two-phase fully degraded pump head ($h_{2\phi}$ is the non-dimensional head from the fully degraded homologous head curves),

$M(\alpha)$ = the head degradation multiplier, and

α = the upstream void fraction.

Two-phase torque degradation is treated in a similar manner

PUMP Component

Example of pump two-phase degradation data and pump behavior during a Semiscale large break LOCA experiment

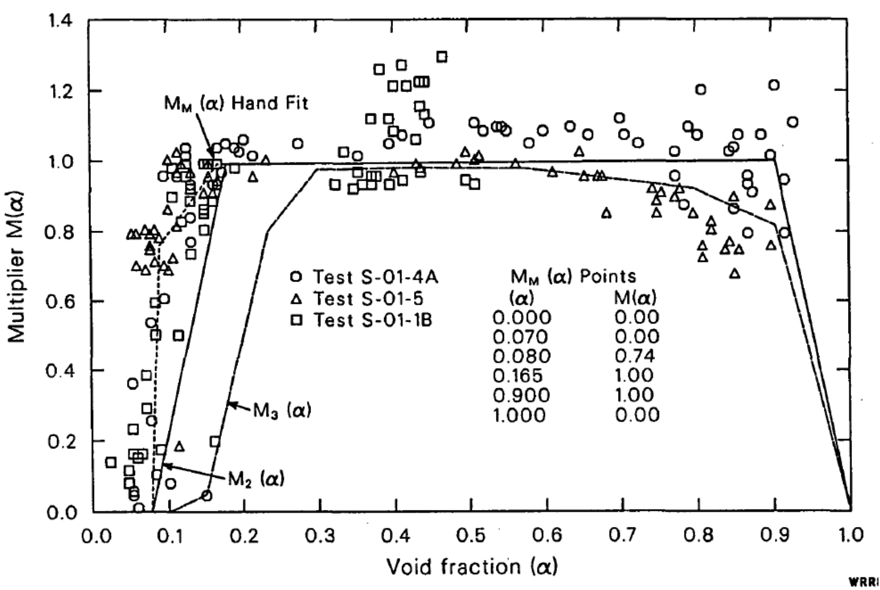


Figure 191. Three two-phase multipliers for the Semiscale Mod-1 pump.

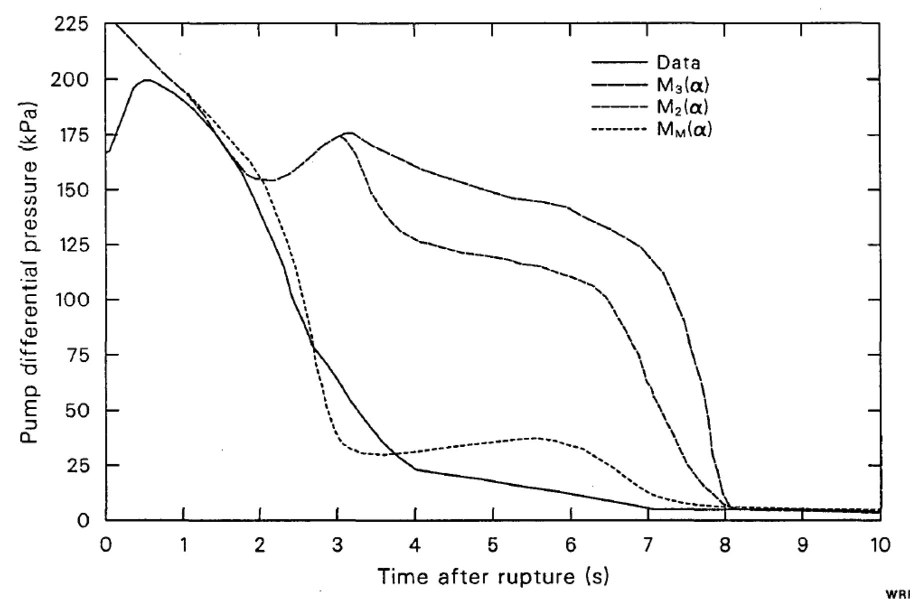


Figure 192. Pump differential pressure calculated using various multipliers.

PUMP Component

PUMP Speed Control

- Pump speed control for representing steady plant operation is available using Constrained Steady State Controllers or a number of other options (see descriptions for parameter IPMPTY in the TRACE Manual)
- Prior to a pump trip (parameter IPMPTR) during transient calculations, TRACE can hold a constant pump speed (or vary it as desired) representing an energized pump motor
- After a pump trip the speed behavior may be represented using either an inertial coast-down model or a speed table
  - Inertial coast-down is based on a pump shaft angular momentum calculation which considers the speed at the time of pump trip, the total moment of inertia of the pump shaft, rotor and flywheel and the hydraulic frictional torque between the pump impeller and the fluid.
  - If pump speed behavior following trip is known, then a table may be used to specify pump speed as a function of time or (using signal variables) some other calculated parameter

PUMP Component

Example #1 of TRACE PUMP Constrained Steady State Speed Control

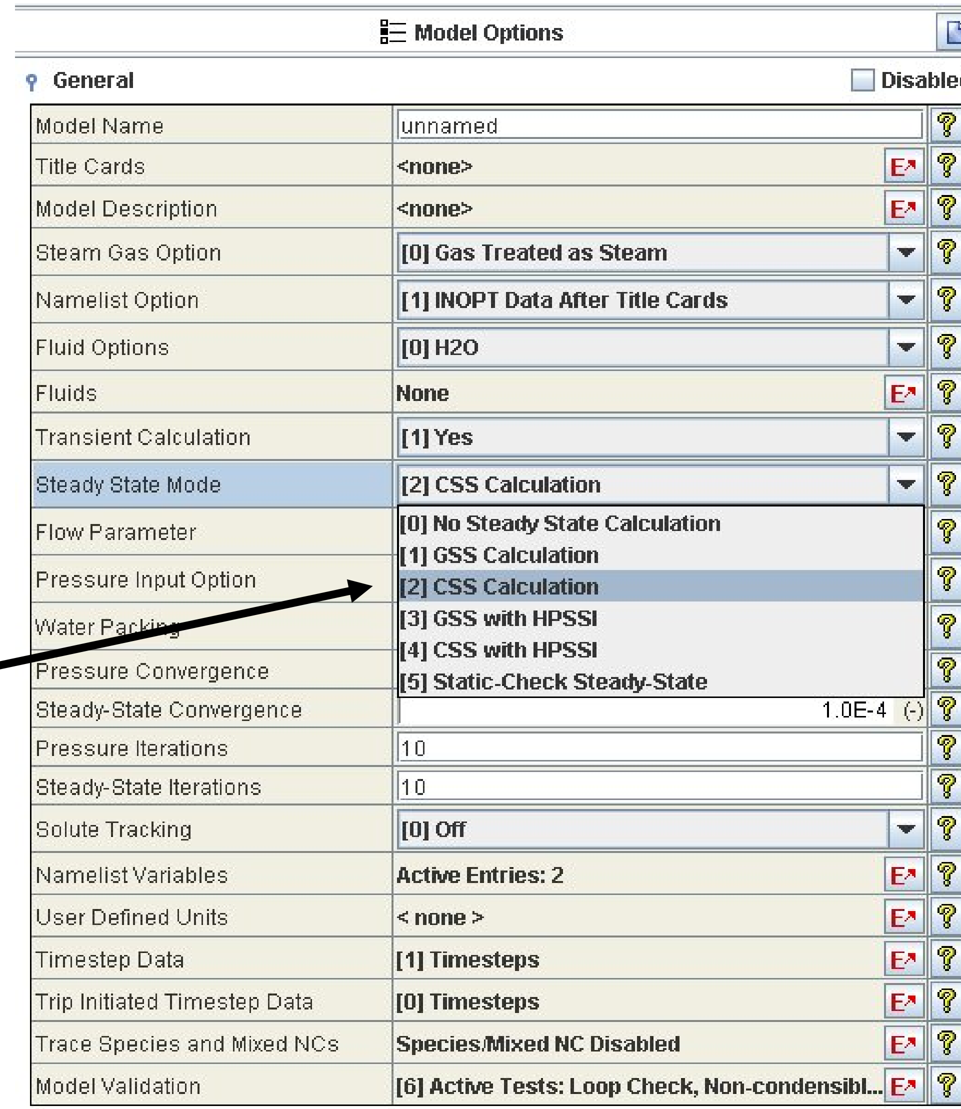
The speed of PUMP 130 is controlled between a minimum of 0.0 and a maximum of 200 rad/sec to attain a desired liquid mass flow rate of 2463.3 kg/sec. For NMPCSS = -1, the desired mass flow through the pump is specified as the sum of the liquid and mass flow rates that are input for the PUMP momentum source face (Face 2):

```
* constrained steady-state data (entered just before Signal Variable data)
* numcss     amncss      maxcss      nmpcss      napcss
  130        0.0         200.0       -1          0
************************************************************************
* type       num         id          ctitle


pump         130         130 $130$ loop 1a pump
*
*   ncells    nodes     jun1      jun2      epsw
    5         1         125        131        1.0e-05
* alp   *   f 0.0 e
* vl/ml*  0.0  2463.3  f 0.0 e
* vv/mv*  f 0.0 e
* tl    *  f 549.1 e
```

PUMP Component

With SNAP, the Constrained Steady State Data is Entered Using the “Model Options” Input Menu



PUMP Component

Example #2 of TRACE PUMP Speed Control - Constant Speed Until Trip, Then Inertial Coast-Down Afterward

The speed of PUMP 4 is held constant at its initial speed, OMEGAN = 176.68 rad/sec until the pump motor power is cut off by Trip 10 ...

```
*******   type          num          id       ctitle
pump           4        4 $4$ pump no. 2
*       ncells        nodes        jun1         jun2         epsw
             2            4           4            6   0.0000e+00
*         ichf        iconc      ipmpty          irp          ipm
             1            0           2            1            1
*       ipmptr       ipmpsv      npmptb       npmpsv       npmprf
            10            0           0            0            0
*        rhead        rtork       rflow         rrho       romega
    9.4154e+02   5.0000e+02  3.1500e-01   6.1400e+02   3.6966e+02
*       omegan       omgoff      romgmx       omgscl       npmpsd
    1.7668e+02   0.0000e+00  1.0000e+20   1.0000e+00            0
```

PUMP Component

Example #2 of TRACE PUMP Speed Control - Constant Speed Until Trip, Then Inertial Coast-down (continued)

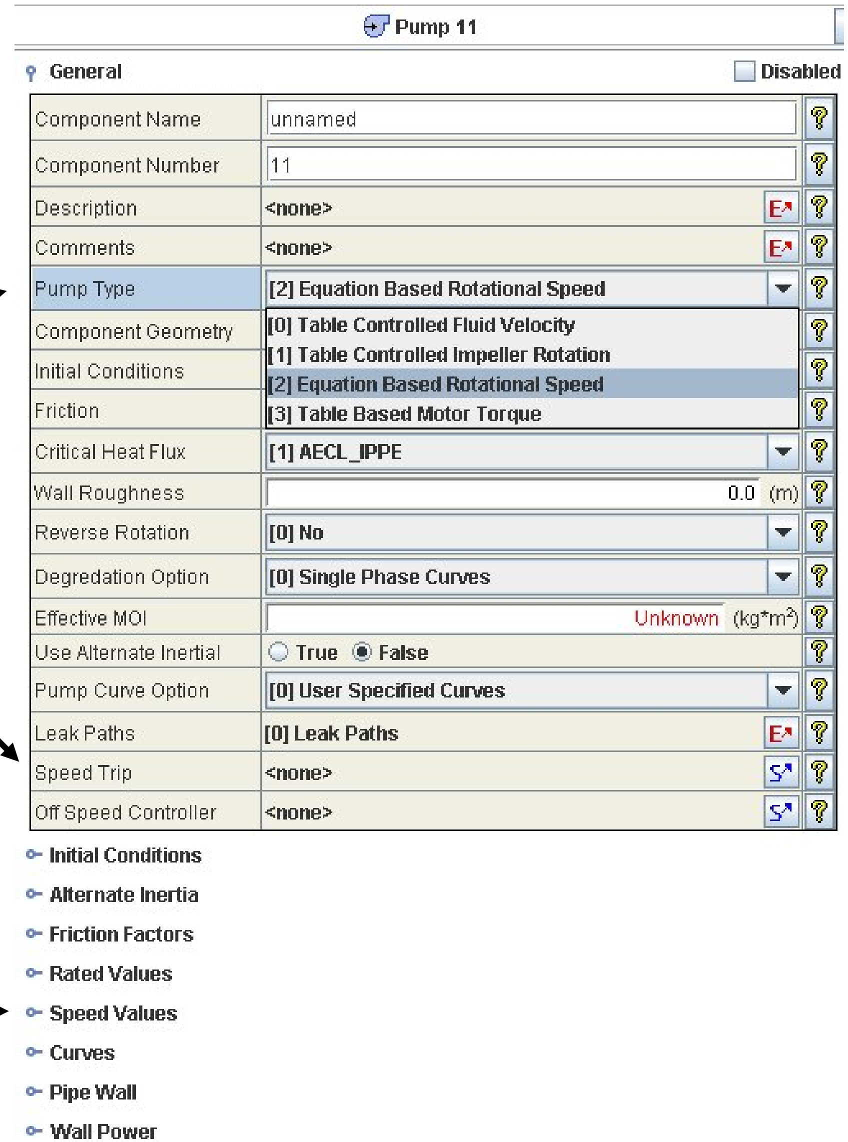
… and Trip 10 is set true when the value of Signal Variable 1 (problem time) exceeds 0.80 seconds:

```
* signal variables
* SV   Parameter   Component/Trip   Location       Referenced by
*  1   t                                           lots
*           idsv          isvn          ilcn          icn1          icn2
               1             0             0             0             0
* trips
*           idtp          isrt          iset          itst          idsg
              10             2             0             1             1
*        setp(1)       setp(2)
      0.0000e+00    8.0000e-01
*        dtsp(1)       dtsp(2)
      0.0000e+00    0.0000e+00
*        ifsp(1)       ifsp(2)
               0             0
*
```

PUMP Component

With SNAP, the Pump Type (IPMPTY) and Pump Trip (IPMPTR) are Entered in the PUMP "General" Input Menu

And, the initial pump speed (OMEGAN) is entered in the PUMP "Speed Values" input menu



PUMP Component

Frictional Torque Considerations

- The pump shaft frictional torque is entered on TRACE PUMP Cards 16 and 17 with parameters TFR and TFRL (Using SNAP, these are entered in the “friction factors” input menu)

- The frictional torque data input are two sets of coefficients used in cubic equations for high and low speed ranges

  High Speed: $T_f = TFR0 + TFR1\ \Omega + TFR2\ \Omega^2 + TFR3\ \Omega^3$

  Low Speed: $T_f = TFRL0 + TFRL1\ \Omega + TFRL2\ \Omega^2 + TFRL3\ \Omega^3$

  Input parameter TFRB defines the speed where the high and low speed ranges intersect

- To prevent unphysical “pin-wheeling” of the pump rotor during periods of coolant loop natural circulation flow it is recommended that non-zero entries be used for parameters TFR0 and TFRL0

BREAK Component

The features of the BREAK component include:

- A single hydrodynamic cell with user-specified or controlled fluid conditions
- A junction specifying another TRACE component that is connected to the BREAK

Example applications for the BREAK:

- Modeling inflow/outflow between a piping system and a large volume (such as a containment), for which the pressure is known or can be assumed
- Modeling a location in a test section where the pressure distribution is known as a function of time
- Establishing a pressure difference across a test section or piping network as a means of driving flow through it

BREAK Component

- BREAK modeling options
  - Constant boundary conditions
  - Table driven boundary conditions
  - Control system driven boundary conditions
  - Active BREAK option (fluid conditions set to agree with those in another cell of the TRACE model)
  - Containment-coupled BREAK (used with the CONTAN component as discussed later in this presentation)
- Calculating choked flow
  - Setting Namelist Variable ICFLOW to 1 will activate the choked flow model at all BREAK junctions
  - Default subcooled and saturated discharge coefficients used (1.0, 1.0)

SBLOCA Break Modeling Recommendation

Previous recommendation for SBLOCAs (going back to TRAC-P experience) included using a short cell (with a length equal to the pipe wall thickness) between the ruptured pipe and the pressure boundary condition

- Needed in order to provide the critical flow model with correct fluid conditions immediately upstream of the break
- Led to difficulties because of high velocities in the short cell

With recent improvements to the TRACE momentum solution, recommendation for SBLOCAs is now to use a simpler break modeling approach:

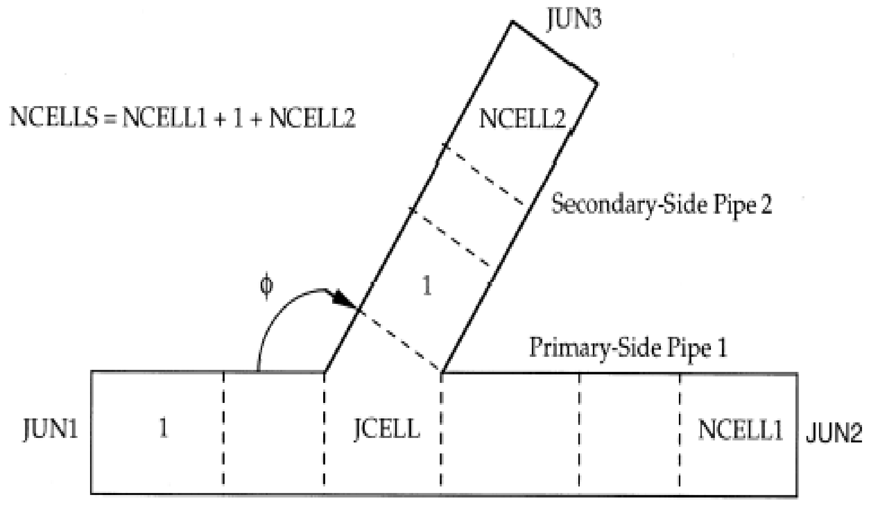
- Use a single junction PIPE or VALVE component to connect the BREAK to the TRACE component representing the ruptured pipe
- Note that BREAKs cannot be directly connected to VESSEL, FILL or PLENUM components

TEE Component

Main branching component in TRACE

Features included: fluid cells and interconnecting internal flow interfaces for a main flow path and a connecting side flow path, piping wall heat structures for both the main and side flow paths.

The TEE is basically two PIPE components joined together at a cell (JCELL) in the main flow path



TEE Component

Junctions connecting a TEE to other TRACE components are specified at the two end faces of the main path and at the free end of the side path

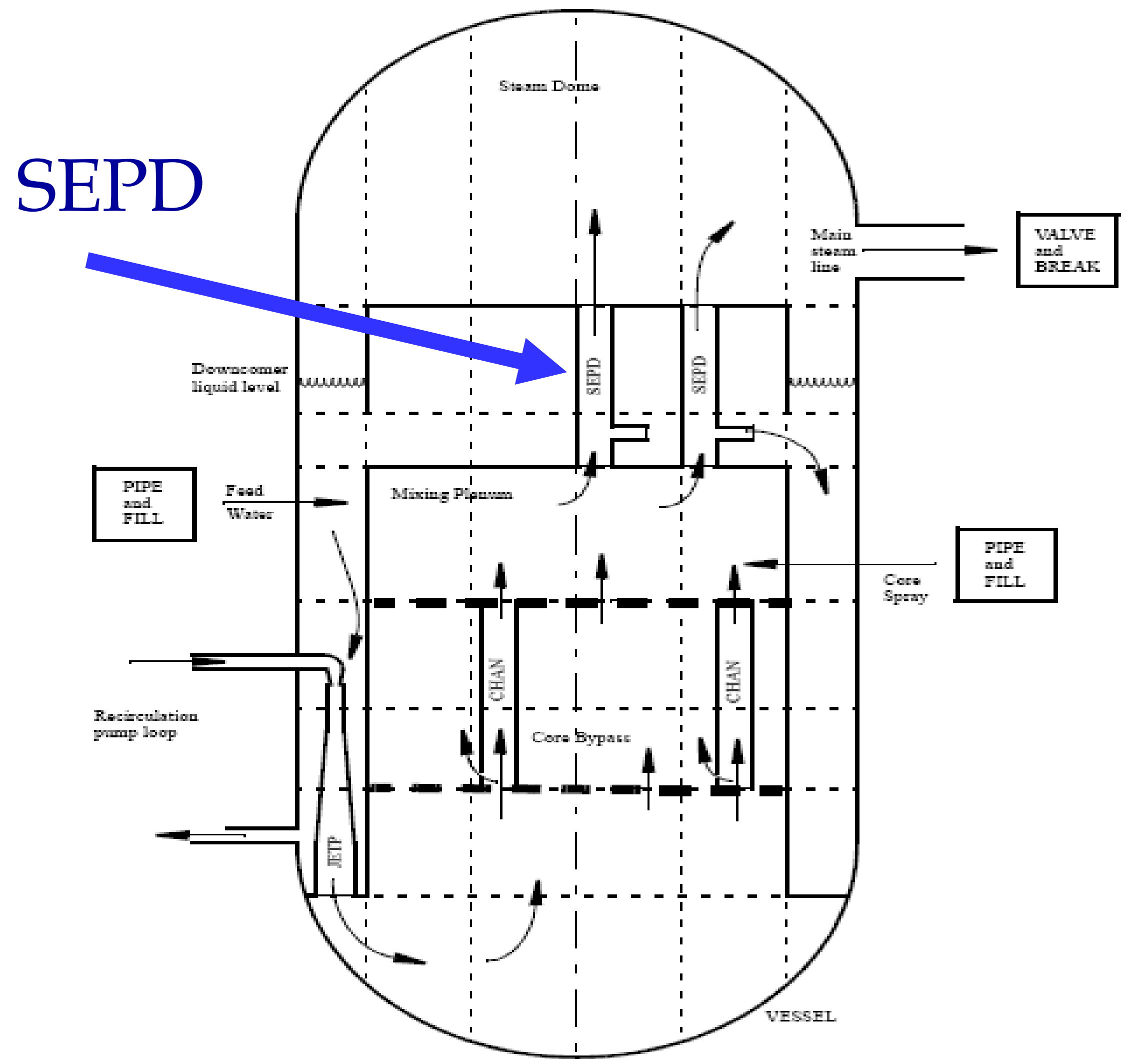
The angle between the main and side paths is specified and the momentum solution at the TEE is dependent upon the angle

The side tube of the TEE may have zero cells

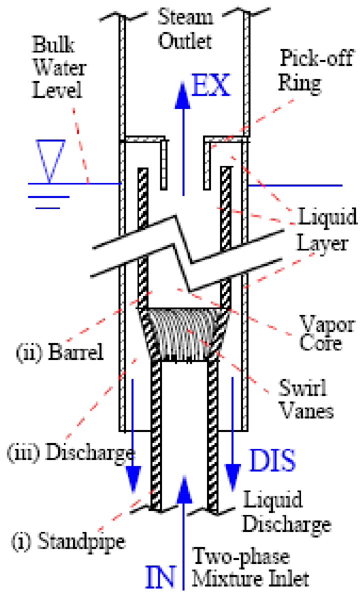
The TEE component has an off-take model option available for top, bottom and side connections to horizontal regions of the main flow path

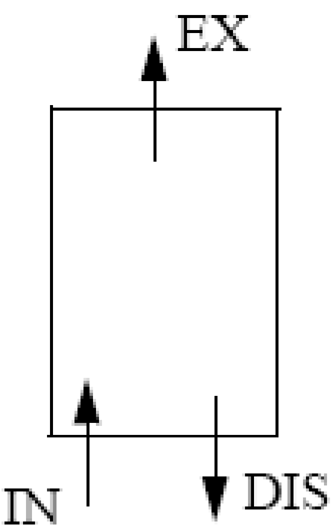
SEPD Component

The SEPD component is a specialized TEE that is used for representing the steam separator and dryer regions in PWR U-tube type steam generators and in BWRs (located as shown here)



SEPD Component





Separation is modeled at a specified cell in the SEPD component. Flow enters the cell through the inlet junction (IN), a steam-rich outlet flow exits through the exhaust junction (EX) and a liquid-rich return flow exits through the discharge junction (DIS)

SEPD Component

Separator performance is characterized by the carry-over of liquid (x_{CO}) through the exhaust junction and the carry-under of vapor (x_{CU}) through the liquid return junction

Carry-over and carry-under are modeled as functions of the separator inlet flow quality, x_{IN}.

The user specifies the function type for the separation process

The *separator inlet quality* is defined as the ratio:

$$x_{IN} = \frac{\dot{m}_{g,IN}}{\dot{m}_{g,IN} + \dot{m}_{l,IN}}$$

The *liquid carry-over quality* is defined as the ratio:

$$x_{CO} = \frac{\dot{m}_{l,EX}}{\dot{m}_{l,EX} + \dot{m}_{g,EX}}$$

The *vapor carry-under quality* is defined as the ratio:

$$x_{CU} = \frac{\dot{m}_{g,DIS}}{\dot{m}_{g,DIS} + \dot{m}_{l,DIS}}$$

SEPD Component

Separation Function Types Available

Perfect separation: $x_{CO} = 0.0$ and $x_{CU} = 0.0$

Simple separation: x_{CO} and x_{CU} are expressed as functions of the inlet flow quality, x_{IN}

Variable separation performance: x_{CO} and x_{CU} are expressed as functions of other TRACE calculated parameters using the control system

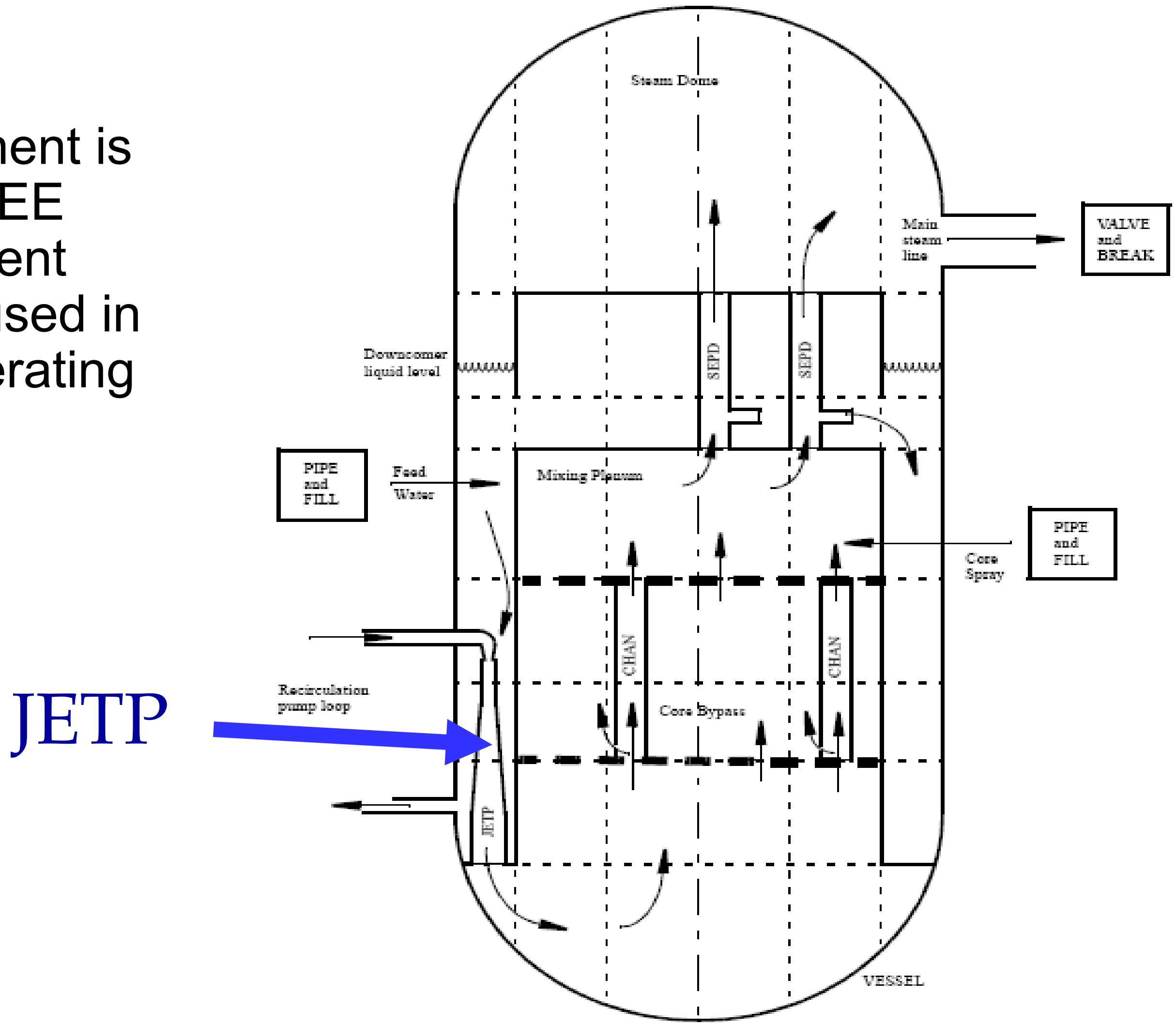
GE Mechanistic Separator performance: TRACE can calculate x_{CO} and x_{CU} to represent behavior of General Electric BWR two-stage or three-stage separators (requires detailed geometrical input and is applicable only for these specific separators)

SEPD Component

- In practice, separator performance data and specific separator geometry are often not available
- Therefore, simple separation (x_{CO} and x_{CU} functions of x_{IN}) is often used
  - Perfect separation for intermediate values of x_{IN}
  - Liquid carry-over increases as the separation cell fills
  - Vapor carry-under increases as the separation cell empties
- The SEPD component also includes a dryer option
  - If activated, a second stage of separation based on a user-input dryer efficiency is applied to x_{CO}

JETP Component

The JETP component is a specialized TEE that can represent the jet pumps used in most of the operating BWRs

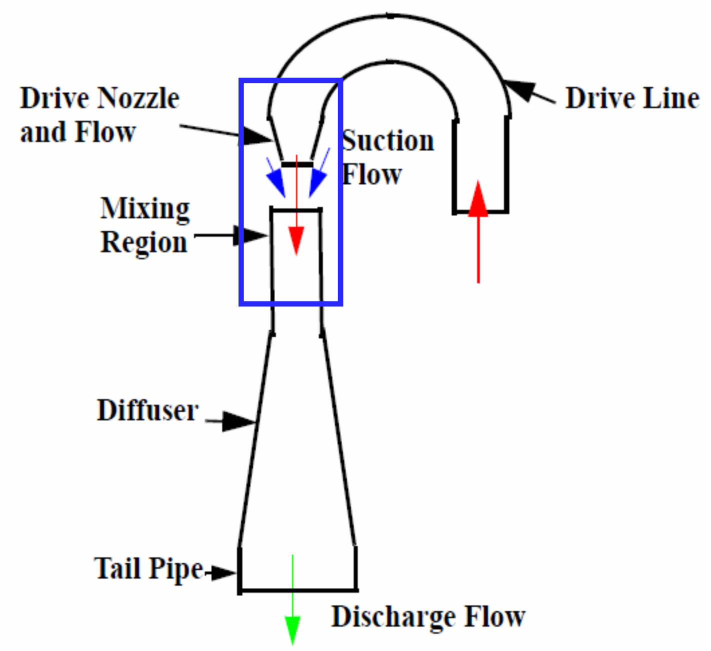


JETP Component

In normal operation, the BWR core is cooled by a recirculating water flow in the reactor pressure vessel (upward through the reactor core, into the separators, and downward through the downcomer)

The downcomer flow must pass through the jet pumps

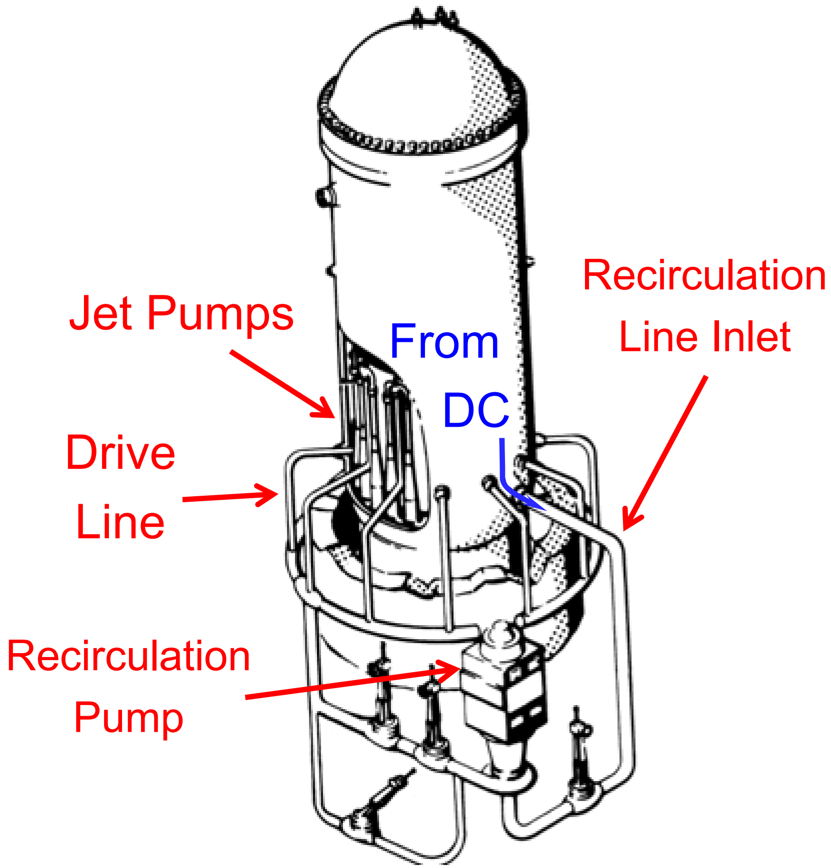
The jet pumps drive the reactor pressure vessel recirculation by transferring momentum from a driver flow into the downcomer flow



JETP Component

A typical operating BWR has 20 jet pumps with the driving flow coming from two pumped recirculation loops located external to the reactor pressure vessel

Flow through the jet pump drive lines is maintained by the recirculation pumps

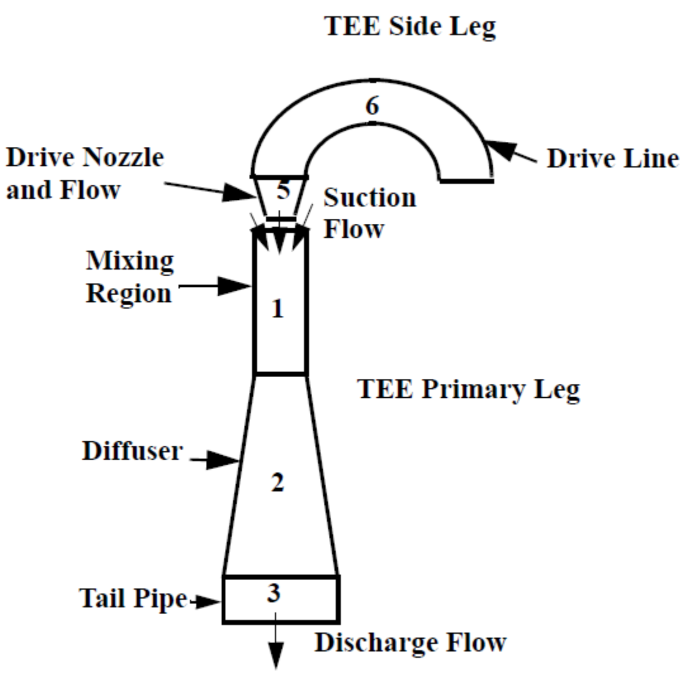


JETP Component

The JETP component includes:

- Fluid cells and piping heat structures for the primary (main downcomer) and side arm (driver) flow paths
- Internal models for simulating nozzle, diffuser and other flow losses, mixing losses, and pressure recovery
- Capabilities for representing jet pump behavior for all combinations of positive and negative main and drive line flows

Presentation of detailed information on JETP input and modeling is beyond the scope of this workshop (see TRACE User's Manual and May 14-17, 2011 Advanced Trace Users Workshop notebook)

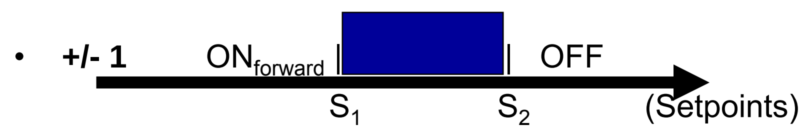


Control System Input: Trips

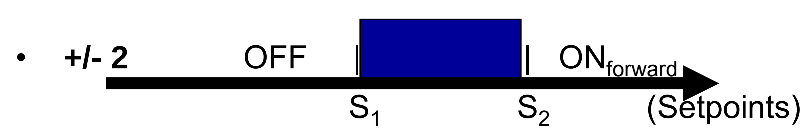
A Trip is a logical operator with an output status that is specified as $ON_{forward}$, OFF or $ON_{reverse}$, with numerical values of 1.0, 0.0 and -1.0, respectively.

Trips test the current value of an independent variable against a set of criteria (involving user-input setpoints and time delays) to determine a current value for the trip status. Changing the trip type from positive to negative (e.g., from 3 to -3) changes $ON_{forward}$ to $ON_{reverse}$ and changes $ON_{reverse}$ to $ON_{forward}$.

The test criteria is specified according to trip type (11 trip types are available). The two most commonly-used trips are Types 1 and 2, which have a status of $ON_{forward}$ (1.0) or OFF (0.0).



Example use - Pressurizer Heater Rod Power Control: If the pressure declines below 15.2 MPa (S_1) then turn on the power. When the pressure increases above 15.5 MPa (S_2) then turn the power off.

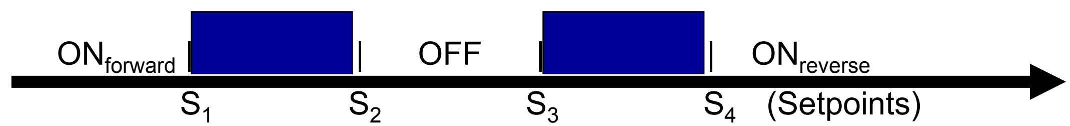


Example use – Relief Valve Action: open a relief valve if the pressure exceeds 16 MPa (S_2) and close the valve if the pressure is less than 15 MPa (S_1).

Control System Input: Trips

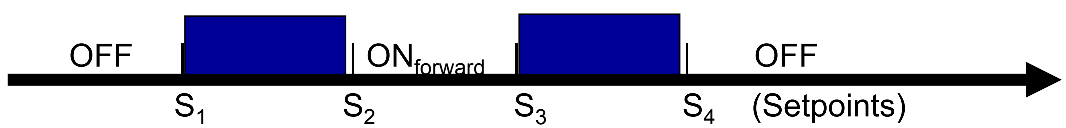
Trip Types 3, 4 and 5 increase the number of setpoints.

- **+/- 3**



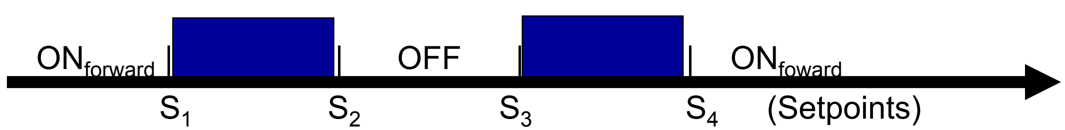
Example use - Pressurizer PORV: Type is -3. If the pressure is equal to or less than 16.4 MPa (S1) then no action is taken. Further, no action is taken if the pressure is greater than or equal to 16.45 MPA (S2) and less than 16.994 MPa (S4). When the pressure is equal to or greater than 16.994 MPa (S4) then the PORV opens. When the pressure declines to 16.511 MPa (S3) or less then the PORV closes.

- **+/- 4**



Example use – EFW for SBLOCA: SBLOCA signal and core exit subcooling alarm are summed (0.0, 1.0, or 2.0). If the signal is less than or equal to 0.8 (S_1) or equal to or greater than 1.9 (S_4) then no action is taken. If the signal is equal to or greater than 0.9 (S_2) and less than or equal to 1.8 (S_3) then action is taken to activate the EFW.

- **+/- 5**



Example use – Reactor Trip on Low or High Pressurizer Pressure: If the pressure is less than or equal to 12.8 MPa (S1) or equal to or greater than 16.485 MPa (S4) then trip the reactor power. If the pressure is greater than or equal to 12.817 MPa (S2) or less than or equal to 16.4 MPa (S3) then no action is taken.

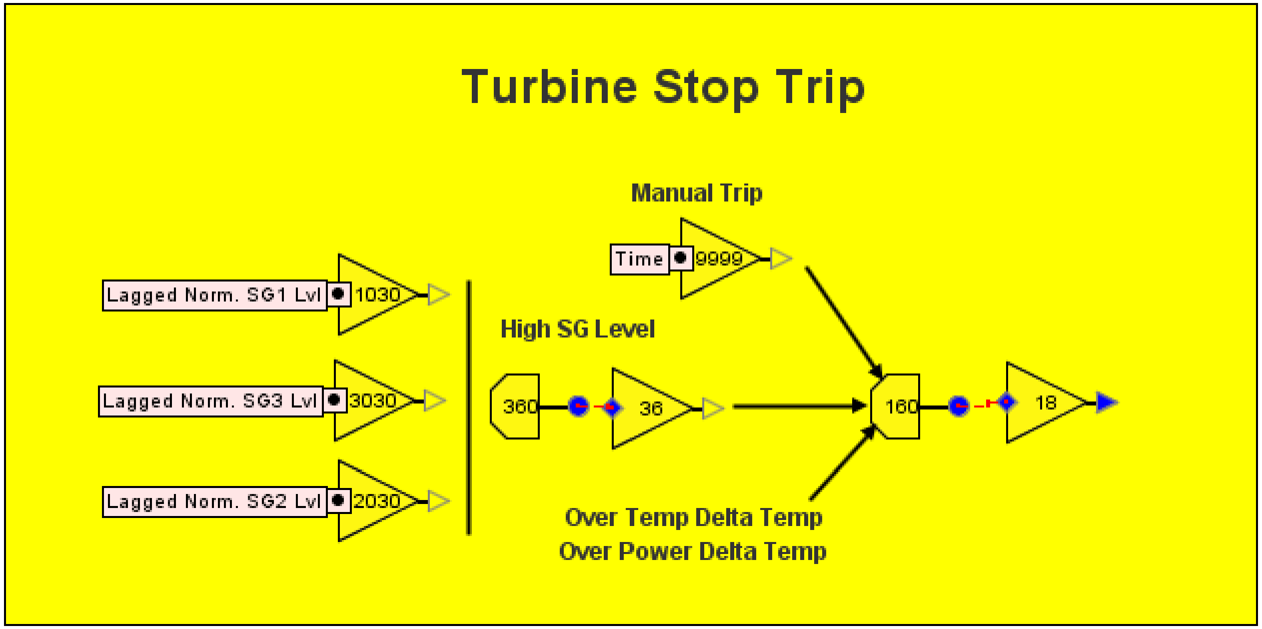
Control System Input: Trips

Trip Types 6 through 11 are simple trips that were developed for the purpose of converting RELAP5 input files into TRACE input files. Making the trip type negative for Types 6 through 11 has no impact.

- **+/- 6 Signal .EQ. Setpoint**
- **+/- 7 Signal .NE. Setpoint**
- **+/- 8 Signal .LT. Setpoint**
- **+/- 9 Signal .GT. Setpoint**
- **+/- 10 Signal .LE. Setpoint**
- **+/- 11 Signal .GE. Setpoint**

Control System Input: Trips

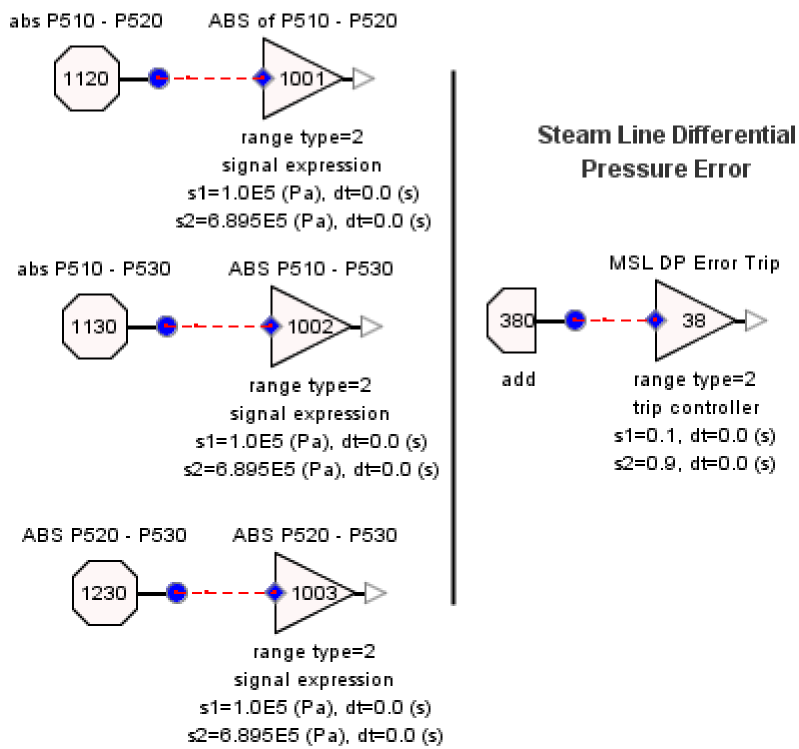
Trip-Controlled-Trip Signal Cards are used to add or multiply the output of two or more (maximum of 10) trips.



Trip-Controlled-Trip 360 sums the output of Trips 1030, 2030 and 3030. The output of Trip-Controlled-Trip 360 is input to Trip 36. If the output of Trip 360 is greater than or equal to 2 then Trip 36 is true.

Control System Input: Trips

Trip-Signal-Expression Signal Cards are used to perform arithmetic operations on two arguments. The arguments can be signal-variable values, control block values, subexpressions, and trip outputs. Some of the arithmetic expressions are addition, subtraction, multiplication, division, exponentiation, minimum/maximum values, absolute value, logical AND.



Trip-Signal-Expression 1120 is the absolute value of the pressure difference between steam line 1 and steam line 2. Trip-Signal-Expression 1130 is the absolute value of the pressure difference between steam line 1 and 3. Trip-Signal-Expression 1230 is the absolute value of the pressure difference between steam line 2 and 3. Trips 1001, 1002 and 1003 evaluate signals from the Trip-Signal-Expressions and turn true if the pressure difference is greater than or equal to 6.895e5 Pa. Trip-Controlled-Trip 380 sums the output from the three trips. If the output of Trip-Controlled-Trip 380 is greater than or equal to 1.0 then Trip 38 turns true.

Questions?

Any questions before moving on to the workshop exercise?