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STANDARD NOMENCLATURE

Independent Variables

r	Radial coordinate in cylindrical geometry.
t	Time.
θ	Azimuthal coordinate in cylindrical geometry.
x	Coordinate for one-dimensional geometry.
z	Axial coordinate in cylindrical geometry.

Other Variables

A	Area.
c	Shear or friction coefficient in two-fluid equations.
c_p	Specific heat at constant pressure.
c_v	Specific heat at constant volume.
D	Diameter.
e	Specific internal energy.
FA	Flow area.
g	Acceleration caused by gravity.
G	Mass flux ($\rho_m V_m$).
h	Specific enthalpy or heat-transfer coefficient.
h_{lg}	Latent heat of vaporization.
H	Pump head ($\Delta p / \rho$).
k	Thermal conductivity, form-loss coefficient, pipe roughness, or reactor multiplication constant.
m	Mass.
Nu	Nusselt number.
p	Pressure or power.
q	Heat generation rate.
q''	Heat flux.
q'''	Volumetric heat-generation rate.
Q	Pump volumetric flow.
R	Radius or neutronic reactivity.
Re	Reynolds number.
T	Temperature.
V	Velocity.

STANDARD NOMENCLATURE (cont.)

Other Variables

vol	Hydrodynamic cell volume.
We	Weber number.
x	Quality.
α	Vapor volume fraction or absorptivity.
Γ	Net volumetric vapor-production rate caused by phase change.
δ	Mean fuel-surface roughness.
Δ	Increment.
ϵ	Emissivity.
μ	Viscosity.
ρ	Microscopic density.
σ	Surface tension or Stefan-Boltzmann constant.
τ	Shear stress.
ϕ^2	Two-phase friction-factor multiplier.
ω	Angular velocity.
Ω	Pump-impeller angular velocity.

Subscripts

a	Noncondensable gas component.
b	Bubble.
c	Cladding.
d	Droplet.
f	Fuel or friction.
g	Gas field or vapor.
h	Hydraulic.
i	Interface (liquid-vapor) quantity or one-dimensional cell index in heat-transfer equations.
j	One-dimensional cell index in hydrodynamics equations.
l	Liquid field.
lg	Liquid to vapor.
m	Mixture quantities.

TRAC-PF1/MOD1:
AN ADVANCED BEST-ESTIMATE COMPUTER PROGRAM
FOR PRESSURIZED WATER REACTOR THERMAL-HYDRAULIC ANALYSIS

by

Safety Code Development Group
Energy Division

ABSTRACT

The Los Alamos National Laboratory is developing the Transient Reactor Analysis Code (TRAC) to provide advanced best-estimate predictions of postulated accidents in light-water reactors. The TRAC-PF1/MOD1 program provides this capability for pressurized water reactors and for many thermal-hydraulic test facilities. The code features either a one- or a three-dimensional treatment of the pressure vessel and its associated internals, a two-fluid nonequilibrium hydrodynamics model with a noncondensable gas field and solute tracking, flow-regime-dependent constitutive equation treatment, optional reflood tracking capability for bottom-flood and falling-film quench fronts, and consistent treatment of entire accident sequences including the generation of consistent initial conditions. The stability-enhancing two-step (SETS) numerical algorithm is used in the one-dimensional hydrodynamics and permits this portion of the fluid dynamics to violate the material Courant condition. This technique permits large time steps and, hence, reduced running time for slow transients.

In addition to the components contained in previous TRAC versions, TRAC-PF1/MOD1 includes an improved steam-generator model, a turbine component, and a control system together with modified constitutive relations to model the balance of plant on the secondary side and to extend the applications to transients without loss of coolant. This report describes the thermal-hydraulic models and the numerical solution methods used in the code. Detailed programming and user information are provided.

I. COMPUTER PROGRAM OUTLINE

A. Program Name

The program name is TRAC-PF1/MOD1, version 12.1

B. Computers

The code is designed for the Control Data Corporation CDC 7600 and for the Cray Research, Inc., Cray-1 computers. Efforts have been made to make the programming as machine independent as possible.

C. Problem or Function Description

TRAC-PF1/MOD1 performs best-estimate analyses of loss-of-coolant accidents (LOCAs) and other transients in pressurized light-water reactors (LWRs). The code also models a wide range of thermal-hydraulic experiments in reduced-scale facilities. Models used include reflood, multidimensional two-phase flow, nonequilibrium thermodynamics, generalized heat transfer, and reactor kinetics. Automatic steady-state and dump/restart capabilities also are provided.

D. Solution Method

The partial differential equations that describe the two-phase flow and the heat transfer are solved by finite differences. The heat-transfer equations are treated using a semi-implicit differencing technique. The fluid-dynamics equations in the one-dimensional components use a multistep procedure that allows the material Courant condition to be violated. The three-dimensional vessel option uses semi-implicit differencing. The finite-difference equations for hydrodynamic phenomena form a system of coupled, nonlinear equations that are solved by a Newton iteration procedure.

E. Problem Complexity Restrictions

All storage arrays in the code are allocated dynamically so the only limit on the problem size is the amount of core memory. The number of reactor components in the problem and the manner in which they are coupled are arbitrary. Reactor components in TRAC-PF1/MOD1 are accumulators, breaks and fills, cores, pipes, pressurizers, pumps, steam generators, tees, turbines, valves, and vessels with associated internals.

F. Typical Running Time

Running time is highly problem dependent and is a function of the total number of mesh cells, the maximum allowable time-step size, and the selection of a one- or three-dimensional vessel. For a one-dimensional model, very

large time steps can be used for slow transients. For a three-dimensional model, a material Courant limit in the vessel may reduce the maximum time-step size allowed and may increase the running time. Typical times for a CDC 7600 computer average 2-3 ms per time step per mesh cell.

G. Unusual Program Features

The highly versatile TRAC-PF1/MOD1 describes most thermal-hydraulic experiments in addition to a wide variety of LWR system designs. The code's modularity allows better geometric problem descriptions, more detailed models of physical processes, and reduced maintenance costs.

H. Related and Auxiliary Programs

One output file, TRCGRF, contains graphics information that can be used to produce plots and movies. Two auxiliary programs, TRAP and EXCON, also are available for this purpose and are documented separately. These programs may require changes to be compatible with graphics software and hardware at various installations.

I. Status

The code is used at the Los Alamos National Laboratory and at many other installations.

J. References

References are provided in the manual.

K. Machine Requirements

For most applications, a CDC 7600 computer with 60000 words of small-core memory (SCM) and 220000 words of large-core memory (LCM) is required. For very large system simulations, a Cray-1 or a similar computer is recommended.

L. Programming Languages

The programming language is FORTRAN-IV. (Although COMPASS matrix inversion subroutines are available, they are not mandatory.)

M. Operating Systems or Monitors

The code compiles on a standard Fortran Extended (FTN) compiler. The Cray-1 version compiles on a Cray Fortran (CFT) compiler. Los Alamos operates its CDC 7600 computers on the Livermore Time-Sharing System (LTSS) and Cray-1 computers on a similar Cray Time-Sharing System (CTSS). Compatibility with the CDC SCOPE operating system has been maximized.

N. Other Programming, Operating Information, or Restrictions

The code is modified through CDC Update files.

O. Available Materials

A source listing, a TRAC-PF1/MOD1 manual, and sample problems are available.

II. INTRODUCTION

The Transient Reactor Analysis Code (TRAC), an advanced best-estimate systems code for analyzing LWR accidents, is being developed at the Los Alamos National Laboratory under the sponsorship of the Reactor Safety Research Division of the US Nuclear Regulatory Commission (NRC). A preliminary TRAC version consisting of only one-dimensional components was completed in December 1976. Although this version was not released publicly nor documented formally, it was used in TRAC-P1 development and formed the basis for the one-dimensional loop-component modules. The first publicly released version, TRAC-P1, was completed in December 1977. It is described in Los Alamos report LA-7279-MS (June 1978).

The TRAC-P1 program was designed primarily for the analysis of large-break LOCAs in pressurized water reactors (PWRs). However, because of its versatility, it could be applied directly to many analyses ranging from blowdowns in simple pipes to integral LOCA tests in multiloop facilities. A refined version, TRAC-P1A, was released to the National Energy Software Center (NESC) in March 1979. It is described in Los Alamos report LA-7777-MS (May 1979). Although it still treats the same class of problems, TRAC-P1A is more efficient than TRAC-P1 and incorporates improved hydrodynamic and heat-transfer models. It also is easier to implement on various computers. TRAC-PD2 contains improvements in reflood, heat-transfer models, and numerical solution methods. Although a large-break LOCA code, it has been applied successfully to small-break problems and to the Three Mile Island incident.

TRAC-PF1 was designed to improve the ability of TRAC-PD2 to handle small-break LOCAs and other transients. TRAC-PF1 has all of the major improvements of TRAC-PD2; in addition, it uses a full two-fluid model with two-step numerics in the one-dimensional components. The two-fluid model, in conjunction with a stratified-flow regime, handles countercurrent flow better than the drift-flux model used previously. The two-step numerics allow large time steps for slow transients. A one-dimensional core component permits calculations with reduced dimensionality although the three-dimensional vessel option has been retained. A noncondensable gas field has been added to the one- and the three-dimensional hydrodynamics. Significant improvements also have been made to the trip logic and the input. TRAC-PF1 was released publicly in July 1981.

TRAC-PF1/MOD1 provides full balance-of-plant modeling through the addition of a general capability to model plant control systems. The steam-generator model was replaced to allow a wider variety of feedwater connections and better modeling of steam-tube ruptures. New components were not required to model condensers, heaters, and pumps in the secondary system; however, a special turbine component was added. The TRAC-PF1/MOD1 physical models also have been modified; the condensation model contains the most significant changes. During condensation the liquid-side interfacial heat-transfer coefficient (HTC), which is sensitive to the flow regime, includes a special model for thermally stratified configurations. Wall heat transfer in the condensation and film-boiling regimes has been improved. The motion equations include momentum transport caused by phase change, and their momentum flux terms in the three-dimensional flow equations have been modified. This last modification can change substantially the computed pressure drop across a vessel from that calculated by previous codes. These model changes make TRAC-PF1/MOD1 a superior code not only for small-break and operational transients but also for large-break analyses.

A. TRAC Characteristics

Some distinguishing characteristics of TRAC-PF1/MOD1 are summarized below. Within restrictions imposed by computer running times, we are incorporating state-of-the-art technology in two-phase thermal hydraulics into the code.

1. Variable-Dimensional Fluid Dynamics. A three-dimensional (r, θ, z) flow calculation can be used within the reactor vessel; the flow within the loop components is treated one dimensionally to allow an accurate calculation of the complex multidimensional flow patterns inside the reactor vessel that are important in determining accident behavior. For example, phenomena such as emergency core-coolant (ECC) downcomer penetration during blowdown, multidimensional plenum and core flow effects, and upper-plenum pool formation and core penetration during reflood can be treated directly. However, a one-dimensional vessel model may be constructed that allows fast transient calculations because the usual time-step restrictions are removed by the special stabilizing numerical treatment.

2. Nonhomogeneous, Nonequilibrium Modeling. A full two-fluid (six-equation) hydrodynamics model describes the steam-water flow, thereby allowing important phenomena such as countercurrent flow to be treated explicitly. A stratified-flow regime has been added to the one-dimensional hydrodynamics; a seventh field equation (mass balance) describes a noncondensable gas field; and an eighth field equation tracks the solutes in the liquid.

3. Flow-Regime-Dependent Constitutive Equation Package. The thermal-hydraulic equations describe the transfer of mass, energy, and momentum between the steam-water phases and the interaction of these phases with the heat flow from the system structures. Because these interactions are dependent on the flow topology, a flow-regime-dependent constitutive equation package has been incorporated into the code. Although this package undoubtedly will be improved in future code versions, assessment calculations performed to date indicate that many flow conditions can be handled adequately with the current package.

4. Comprehensive Heat-Transfer Capability. TRAC-PF1/MOD1 incorporates detailed heat-transfer analyses of the vessel and the loop components. Included is a two-dimensional (r,z) treatment of fuel-rod heat conduction with dynamic fine-mesh rezoning to resolve both bottom-flood and falling-film quench fronts. The heat transfer from the fuel rods and other system structures is calculated using flow-regime-dependent HTC's obtained from a generalized boiling curve based on local conditions.

5. Consistent Analysis of Entire Accident Sequences. An important TRAC feature is its ability to address entire accident sequences, including computation of initial conditions, with a consistent and continuous calculation. For example, the code models the blowdown, refill, and reflood phases of a LOCA. This modeling eliminates the need to perform calculations using different codes to analyze a given accident. In addition, a steady-state solution capability provides self-consistent initial conditions for subsequent transient calculations. Both a steady-state and a transient calculation can be performed in the same run, if desired.

6. Component and Functional Modularity. The TRAC program is completely modular by component. The components in a calculation are specified through input data; available components allow the user to model virtually any PWR design or experimental configuration. Thus, TRAC has great

versatility in its range of applications. This feature also allows component modules to be improved, modified, or added without disturbing the remainder of the code. TRAC component modules currently include accumulators, breaks and fills, cores, pipes, pressurizers, pumps, steam generators, tees, turbines, valves, and vessels with associated internals (downcomer, lower plenum, core, upper plenum, etc.).

The TRAC program also is modular by function; that is, the major aspects of the calculations are performed in separate modules. For example, the basic one-dimensional hydrodynamics solution algorithm, the wall-temperature field solution algorithm, HTC selection, and other functions are performed in separate sets of routines that are accessed by all component modules. This modularity allows the code to be upgraded readily as improved correlations and test information become available.

B. Physical Phenomena Treated

Because of the detailed modeling in TRAC, the code can simulate physical phenomena important in large- and small-break LOCA analysis, such as

1. ECC downcomer penetration and bypass, including the effects of countercurrent flow and hot walls;
2. lower-plenum refill with entrainment and phase separation effects;
3. bottom-flood and falling-film reflood quench fronts;
4. multidimensional flow patterns in the core and plenum regions;
5. pool formation and countercurrent flow at the upper-core support-plate (UCSP) region;
6. pool formation in the upper plenum;
7. steam binding;
8. average-rod and hot-rod cladding-temperature histories;
9. alternate ECC injection systems, including hot-leg and upper-head injection;
10. direct injection of subcooled ECC water, without artificial mixing zones;
11. critical flow (choking);

12. liquid carryover during reflood;
13. metal-water reaction;
14. water-hammer effects;
15. wall friction losses; and
16. horizontally stratified flow, including reflux cooling.

C. Significant Changes from Previous TRAC Versions

Because our funding has been insufficient to provide the automatic input-deck conversions that were released in the past, we wish to alert the user to the many significant changes that have been made to the TRAC-PF1/MOD1 input. Substantial changes have been made to all input sections that cover the use of trips and signal variables to provide a more general control capability. The initial definition cards for almost all components were modified. The user is cautioned to be especially careful when setting the parameter that regulates the maximum rate of change for quantities controlled by tables. The definitions of the wall heat sources and the direct power to the fluid were changed. The capabilities of the input loss coefficients and hydraulic diameters were expanded.

Four significant model changes should be considered when the TRAC-PF1/MOD1 results are compared with those from previous TRAC versions. Many details that affect the core reflood were changed; thus, the TRAC-PF1/MOD1 reflood calculations are significantly better than those from TRAC-PF1. The condensation model improvements include a more detailed flow-regime dependence and a special model for condensation on a stagnant interface in a vertical one-dimensional component. Also, the choked-flow model was improved. Finally, the axial-momentum transport terms in the vessel were modified so that internally generated losses at orifices were eliminated. Loss coefficients probably will be required at core support plates to match results from previous TRAC versions.

D. Planned Improvements

TRAC-PF1/MOD1 combines all of the PWR accident analysis capabilities thus far requested by the NRC into a single code. This code represents such an important milestone in the TRAC series that future versions will be designed to accept any TRAC-PF1/MOD1 input deck.

Most of our short-term plans involve increasing the speed of the code and making it more flexible and convenient for the user. Recent studies indicate that a change in the data base combined with recoding some key subroutines will cut run times by at least 30%. Most user-convenience features are being developed under the Nuclear Plant Analyzer (NPA) project. However, we expect to simplify the standard TRAC input by adding an option that allows input of the trips and controllers in Fortran-like code.

E. Scope of TRAC Manual

We wrote this manual to describe TRAC-PF1/MOD1, version 12.1 (the frozen version). Relative to the initial release of TRAC-PF1/MOD1, the frozen code includes error corrections and new features such as a PLENUM component and super-critical water properties. Earlier versions of TRAC-PF1/MOD1 do not necessarily provide all features and capabilities described in this manual.

This manual describes TRAC basic methods and models and provides user information and programming details. Section III describes the basic hydrodynamics and heat-transfer methods and discusses the overall strategies for transient and steady-state solutions. Section III is supplemented by Apps. A and B that supply, respectively, the fluid and material properties for the thermal-hydraulic analyses. Appendix C describes the stability-enhancing two-step (SETS) method. Appendix D describes the TRAC-PF1/MOD1 choking model.

A standard nomenclature guide is included. Quantities that are not included in the standard nomenclature list are defined in the text. All units are metric as given in National Bureau of Standards Special Publication 330, "The International System of Units (SI)," unless otherwise specified.

Section IV describes the component models. The user should study these descriptions if questions arise when preparing detailed input specifications for a TRAC problem.

Section V provides input specifications and other user information. Appendix E provides three sample input decks for LOFT experiments to provide additional guidance for input preparation. Appendix F explains the error messages that might occur during a calculation.

Section VI discusses the overall code organization, input and output processing, storage requirements, and other programming details associated with both transient and steady-state solutions. Appendix G provides a list of TRAC

subprograms; App. H, a compilation of COMMON arrays; and App. I, component data tables.

An important aspect of the TRAC program involves the developmental assessment of the code through comparisons with measurements obtained from test facilities. Developmental assessment calculations already have been performed with TRAC-PF1/MOD1. A Los Alamos report entitled "TRAC-PF1/MOD1 Developmental Assessment," which summarizes the key developmental assessment results, will be published.

III. BASIC METHODS

A. Hydrodynamics

1. Field Equations. Unlike previous TRAC versions, TRAC-PF1/MOD1 uses the same two-phase two-fluid model for fluid flow in both the one- and the three-dimensional components. We added a noncondensable gas component in the vapor field and a solute field for boron tracking that require two extra mass-continuity equations. We assumed that homogeneity and thermal equilibrium exist in the combined gas field.

Eight differential equations describe the four-component, two-fluid model.^{1,2}

Liquid Mass Equation

$$\frac{\partial (1 - \alpha)\rho_\ell}{\partial t} + \nabla \cdot [(1 - \alpha)\rho_\ell \vec{V}_\ell] = -\Gamma \quad (1)$$

Combined Vapor Mass Equation

$$\frac{\partial (\alpha\rho_g)}{\partial t} + \nabla \cdot (\alpha\rho_g \vec{V}_g) = \Gamma \quad (2)$$

Noncondensable Gas Mass Equation

$$\frac{\partial (\alpha\rho_a)}{\partial t} + \nabla \cdot (\alpha\rho_a \vec{V}_g) = 0 \quad (3)$$

Solute Concentration Equation

$$\frac{\partial (1 - \alpha)m\rho_\ell}{\partial t} + \nabla \cdot [(1 - \alpha)m\rho_\ell \vec{V}_\ell] = S_c \quad (4)$$

Combined Vapor Equation of Motion

$$\begin{aligned} \frac{\partial \vec{v}_g}{\partial t} + \vec{v}_g \cdot \nabla \vec{v}_g = & - \frac{1}{\rho_g} \nabla p - \frac{c_i}{\alpha \rho_g} (\vec{v}_g - \vec{v}_l) |\vec{v}_g - \vec{v}_l| \\ & - \frac{\Gamma^+}{\alpha \rho_g} (\vec{v}_g - \vec{v}_l) - \frac{c_{wg}}{\alpha \rho_g} \vec{v}_g |\vec{v}_g| + \vec{g} \quad . \end{aligned} \quad (5)$$

Liquid Equation of Motion

$$\begin{aligned} \frac{\partial \vec{v}_l}{\partial t} + \vec{v}_l \cdot \nabla \vec{v}_l = & - \frac{1}{\rho_l} \nabla p + \frac{c_i}{(1 - \alpha) \rho_l} (\vec{v}_g - \vec{v}_l) |\vec{v}_g - \vec{v}_l| \\ & - \frac{\Gamma^-}{(1 - \alpha) \rho_l} (\vec{v}_g - \vec{v}_l) - \frac{c_{wl}}{(1 - \alpha) \rho_l} \vec{v}_l |\vec{v}_l| + \vec{g} \quad . \end{aligned} \quad (6)$$

Combined Vapor Energy Equation

$$\begin{aligned} \frac{\partial}{\partial t} (\alpha \rho_g e_g) + \nabla \cdot (\alpha \rho_g e_g \vec{v}_g) = & - p \frac{\partial \alpha}{\partial t} - p \nabla \cdot (\alpha \vec{v}_g) \\ & + q_{wg} + q_{lg} + \Gamma h_{sg} \quad . \end{aligned} \quad (7)$$

Total Energy Equation

$$\begin{aligned} \frac{\partial [(1 - \alpha) \rho_l e_l + \alpha \rho_g e_g]}{\partial t} + \nabla \cdot [(1 - \alpha) \rho_l e_l \vec{v}_l + \alpha \rho_g e_g \vec{v}_g] \\ = & - p \nabla \cdot [(1 - \alpha) \vec{v}_l + \alpha \vec{v}_g] + q_{wl} + q_{wg} \quad . \end{aligned} \quad (8)$$

In these equations the vapor densities and energies are sums of the steam and the noncondensable components,

$$\rho_g = \rho_s + \rho_a \quad (9)$$

and

$$\rho_g e_g = \rho_s e_s + \rho_a e_a \quad (10)$$

We assume Dalton's law applies; therefore,

$$p = p_s + p_a \quad (11)$$

A subscript, a, is used for the noncondensable gas because the internal thermodynamic properties model air. It would be easy to replace these properties with others describing different noncondensable gases.

In addition to the thermodynamic relations that are required for closure [Eqs. (28)-(29)], specifications for the interfacial-drag coefficients (c_i), the interfacial heat transfer (q_{ig}), the phase-change rate (Γ), the solute source term (S_c), the wall-shear coefficients (c_{wg} and c_{wl}), and the wall heat transfers (q_{wg} and q_{wl}) are required. Gamma is evaluated from a simple thermal-energy jump relation,

$$\Gamma = \frac{-(q_{ig} + q_{il})}{h_g - h_l} \quad (12)$$

where

$$q_{ig} = h_{ig} A_i \frac{(T_{ss} - T_g)}{vol} \quad (13)$$

and

$$q_{il} = h_{il} A_i \frac{(T_{ss} - T_l)}{vol} \quad (14)$$

Here A_i and the h_i terms are the interfacial area and HTC's, and T_{ss} is the saturation temperature corresponding to the partial steam pressure. The term Γ^+ is equal to Γ for positive Γ and zero for negative Γ ; Γ^- is equal to Γ for negative Γ and zero for all other values of Γ . The quantities h_g and h_l are the appropriate enthalpies of the vapor and liquid, respectively. These enthalpies are the bulk fluid enthalpy for the phase moving to the interface and the saturation enthalpy for the product of the phase change.

Wall heat-transfer terms assume the form

$$q_{wg} = h_{wg} A_{wg} \frac{(T_w - T_g)}{vol} \quad (15)$$

and

$$q_{wl} = h_{wl} A_{wl} \frac{(T_w - T_l)}{vol} \quad (16)$$

where A_{wg} and A_{wl} are the actual heated surface areas of the cell, except during reflood when the average HTC values reflect the fraction of the heated surface area that is quenched.

TRAC-PF1/MOD1 includes a mass-continuity equation for a solute moving with the liquid field instead of a physical diffusion model. The solute does not affect the hydrodynamics directly. If we assume that the solute represents boron, the amount of the dissolved and the plated-out boron in the core may affect the hydrodynamics indirectly through reactivity feedback corresponding to user-specified input values obtained from a boron-mass reactivity-coefficient table (Sec. III.C). If the solute concentration exceeds the orthoboric-acid solubility at the fluid temperature in a specific hydrodynamic cell, we assume that the solute in that cell plates out. Plating also occurs if the cell fluid flashes or boils. We also assume that any

plated-out solute instantaneously redissolves to the maximum allowable concentration if more liquid enters the cell. Because the solute does not affect the hydrodynamics directly, the solute variable may be used as a tag to track the movement of fluid from a specific source through the system.

2. Three-Dimensional Finite-Difference Equations. The momentum equations are separated into three coordinate components. Only the vapor equation is discussed with the understanding that the liquid-momentum equation is treated analogously. The vapor-momentum differential equation has three components.

Axial (z) Component

$$\begin{aligned} \frac{\partial v_{gz}}{\partial t} = & - \left(v_{gr} \frac{\partial v_{gz}}{\partial r} + \frac{v_{g\theta}}{r} \frac{\partial v_{gz}}{\partial \theta} + v_{gz} \frac{\partial v_{gz}}{\partial z} \right) - \frac{1}{\rho_g} \frac{\partial p}{\partial z} - \frac{\Gamma^+}{\alpha \rho_g} (v_{gz} - v_{lz}) \\ & - \frac{c_{iz}}{\alpha \rho_g} (v_{gz} - v_{lz}) |\vec{v}_g - \vec{v}_l| - \frac{\Gamma}{\alpha \rho_g} (v_{gz} - v_{igr}) - \frac{c_{wgz}}{\alpha \rho_g} v_{gz} |\vec{v}_g| + g. \quad (17) \end{aligned}$$

Radial (r) Component

$$\begin{aligned} \frac{\partial v_{gr}}{\partial t} = & - \left(v_{gr} \frac{\partial v_{gr}}{\partial r} + \frac{v_{g\theta}}{r} \frac{\partial v_{gr}}{\partial \theta} - \frac{v_{g\theta}^2}{r} + v_{gz} \frac{\partial v_{gr}}{\partial z} \right) - \frac{1}{\rho_g} \frac{\partial p}{\partial r} - \frac{\Gamma^+}{\alpha \rho_g} (v_{gr} - v_{lr}) \\ & - \frac{c_{ir}}{\alpha \rho_g} (v_{gr} - v_{lr}) |\vec{v}_g - \vec{v}_l| - \frac{\Gamma}{\alpha \rho_g} (v_{gr} - v_{igr}) - \frac{c_{wgr}}{\alpha \rho_g} v_{gr} |\vec{v}_g|. \quad (18) \end{aligned}$$

Azimuthal (θ) Component

$$\begin{aligned} \frac{\partial v_{g\theta}}{\partial t} = & - \left(v_{gr} \frac{\partial v_{g\theta}}{\partial r} + \frac{v_{g\theta}}{r} \frac{\partial v_{g\theta}}{\partial \theta} + \frac{v_{gr} v_{g\theta}}{r} + v_{gz} \frac{\partial v_{g\theta}}{\partial z} \right) - \frac{1}{\rho_g r} \frac{\partial p}{\partial \theta} - \frac{r^+}{\alpha \rho_g} (v_{g\theta} - v_{l\theta}) \\ & - \frac{c_{i\theta}}{\alpha \rho_g} (v_{g\theta} - v_{l\theta}) |\vec{v}_g - \vec{v}_l| - \frac{\Gamma}{\alpha \rho_g} (v_{g\theta} - v_{ig\theta}) - \frac{c_{wg\theta}}{\alpha \rho_g} v_{g\theta} |\vec{v}_g| \quad . \quad (19) \end{aligned}$$

In the TRAC-staggered scheme^{3,4} the velocities are defined on the mesh-cell surfaces at the locations shown in Fig. 1, where the subscript a stands for either l or g. However, the volume properties p , α , T , e , and ρ are located at the mesh-cell centers. The scalar field equations are written over a given mesh cell, whereas the momentum equations are staggered between mesh cells in the three component directions.

Fig. 1.
Three-dimensional mesh-cell velocities.

The written difference scheme for each of the momentum equations is lengthy because of the cross-derivative terms. Therefore, only the vapor z-direction finite-difference equations for a typical mesh cell are given to illustrate the procedure used. The time levels are indicated by the superscript n (old time) or n+1 (new time). The subscript g (for vapor) is dropped unless it is needed for clarity.

Using these conventions, the finite-difference vapor-momentum equation in the z-direction is

$$\begin{aligned}
v_z^{n+1}(r, \theta, z+1/2) = & v_z^n(r, \theta, z+1/2) \\
& - \Delta t \left\{ \frac{v_r^n(r, \theta, z+1/2)}{\Delta r} [v_z(r+1/2, \theta, z+1/2) - v_z(r-1/2, \theta, z+1/2)]^n \right. \\
& + \frac{v_\theta^n(r, \theta, z+1/2)}{r \Delta \theta} [v_z(r, \theta+1/2, z+1/2) - v_z(r, \theta-1/2, z+1/2)]^n \\
& + \frac{v_z^n(r, \theta, z+1/2)}{\Delta z} [v_z(r, \theta, z+1) - v_z(r, \theta, z)]^n \\
& - \frac{[p(r, \theta, z+1) - p(r, \theta, z)]^{n+1}}{\rho^n(r, \theta, z+1/2) \Delta z} \\
& - \frac{c_{1z}^n(r, \theta, z+1/2) [v_{zg}(r, \theta, z+1/2) - v_{zl}(r, \theta, z+1/2)]^{n+1}}{\alpha^n(r, \theta, z+1/2) \rho^n(r, \theta, z+1/2)} \\
& \times |v_g(r, \theta, z+1/2) - v_l(r, \theta, z+1/2)|^n \\
& - \frac{r^{+n}(r, \theta, z+1/2) [v_{gz}(r, \theta, z+1/2) - v_{lz}(r, \theta, z+1/2)]^{n+1}}{\alpha^n(r, \theta, z+1/2) \rho^n(r, \theta, z+1/2)} \\
& \left. - \frac{c_{wz}^n(r, \theta, z+1/2) v_z^{n+1}(r, \theta, z+1/2) |v^n(r, \theta, z+1/2)|}{\alpha^n(r, \theta, z+1/2) \rho^n(r, \theta, z+1/2)} \right\}, \tag{20}
\end{aligned}$$

where Δt is the time-step size.

In any finite-difference scheme, certain quantities are required at locations where they are not defined formally; therefore, additional relations are needed. The volume properties Γ , α , and ρ_g are donor-celled depending on the direction of $V_z(r, \theta, z+1/2)$.

For example,

$$\begin{aligned} \alpha(r, \theta, z+1/2) &= \alpha(r, \theta, z) , & \text{if } V_z(r, \theta, z+1/2) \geq 0 & ; \\ &= \alpha(r, \theta, z+1) , & \text{if } V_z(r, \theta, z+1/2) < 0 & . \end{aligned} \quad (21)$$

The radial component of the velocity at the axial location $(z+1/2)$ is obtained from

$$\begin{aligned} V_r(r, \theta, z+1/2) &= \frac{1}{4} [V_r(r+1/2, \theta, z) + V_r(r-1/2, \theta, z) + V_r(r+1/2, \theta, z+1) \\ &\quad + V_r(r-1/2, \theta, z+1)] ; \end{aligned} \quad (22)$$

a similar expression applies to $V_\theta(r, \theta, z+1/2)$. The spatial differences for V_z are, in the r -direction,

$$\begin{aligned} V_z(r+1/2, \theta, z+1/2) - V_z(r-1/2, \theta, z+1/2) &= V_z(r, \theta, z+1/2) - V_z(r-1, \theta, z+1/2) , \\ &\text{if } V_r(r, \theta, z+1/2) \geq 0 , \text{ or} \\ x_z(r+1/2, \theta, z+1/2) - V_z(r-1/2, \theta, z+1/2) &= V_z(r+1, \theta, z+1/2) - V_z(r, \theta, z+1/2) , \\ &\text{if } V_r(r, \theta, z+1/2) < 0 . \end{aligned} \quad (23)$$

In the θ -direction,

$$V_{\theta}(r, \theta+1/2, z+1/2) - V_{\theta}(r, \theta-1/2, z+1/2) = V_z(r, \theta, z+1/2) - V_z(r, \theta-1, z+1/2) ,$$

if $V_{\theta}(r, \theta, z+1/2) \geq 0$, or

$$V_z(r, \theta+1/2, z+1/2) - V_z(r, \theta-1/2, z+1/2) = V_{\theta}(r, \theta+1, z+1/2) - V_{\theta}(r, \theta, z+1/2) ,$$

if $V_{\theta}(r, \theta, z+1/2) < 0$.

(24)

In the z -direction,

$$V_z(r, \theta, z+1) - V_z(r, \theta, z) = \frac{V_z(r, \theta, z+1/2) \cdot FA_{z+1/2}}{FA_{z+1}} - \frac{V_z(r, \theta, z-1/2) \cdot FA_{z-1/2}}{FA_z} ,$$

if $V_z(r, \theta, z+1/2) \geq 0$, or

$$V_z(r, \theta, z+1) - V_z(r, \theta, z) = \frac{V_z(r, \theta, z+3/2) \cdot FA_{z+3/2}}{FA_{z+1}} - \frac{V_z(r, \theta, z+1/2) \cdot FA_{z+1/2}}{FA_z} ,$$

if $V_z(r, \theta, z+1/2) < 0$.

(25)

The convective terms in the finite-difference relations for the scalar field equations are written in conservative form. The finite-difference form of the overall mixture mass equation is

$$\begin{aligned} \rho_m^{n+1} = \rho_m^n + \left[\frac{\Delta t}{vol} \right] & \{ FA_{z-1/2} \{ [(1-\alpha)\rho_\ell] n_{V_\ell}^{n+1} + (\alpha\rho_g) n_{V_g}^{n+1} \}_{z-1/2} \\ & - FA_{z+1/2} \{ [(1-\alpha)\rho_\ell] n_{V_\ell}^{n+1} + (\alpha\rho_g) n_{V_g}^{n+1} \}_{z+1/2} \\ & + FA_{r-1/2} \{ [(1-\alpha)\rho_\ell] n_{V_\ell}^{n+1} + (\alpha\rho_g) n_{V_g}^{n+1} \}_{r-1/2} \\ & - FA_{r+1/2} \{ [(1-\alpha)\rho_\ell] n_{V_\ell}^{n+1} + (\alpha\rho_g) n_{V_g}^{n+1} \}_{r+1/2} \\ & + FA_{\theta-1/2} \{ [(1-\alpha)\rho_\ell] n_{V_\ell}^{n+1} + (\alpha\rho_g) n_{V_g}^{n+1} \}_{\theta-1/2} \\ & - FA_{\theta+1/2} \{ [(1-\alpha)\rho_\ell] n_{V_\ell}^{n+1} + (\alpha\rho_g) n_{V_g}^{n+1} \}_{\theta+1/2} \} , \end{aligned} \quad (26)$$

where vol is the hydrodynamic cell volume and FA is the flow area at the mesh-cell edge. The other scalar equations are differenced similarly.

All of the field equations [Eqs. (1)-(8)] have additional source terms to allow piping to be connected anywhere in the mesh. The source terms in the mass and energy equations are given below. The subscripts p and v refer to pipe and vessel quantities, respectively.

Overall Mass-Continuity Source Term

$$[\alpha \rho_g v_g^{n+1} FA + ((1 - \alpha) \rho_l)^n v_l^{n+1} FA]_p .$$

Vapor Mass-Continuity Source Term

$$[(\alpha \rho_g)^n FA v_g^{n+1}]_p .$$

Overall Energy Source Term

$$[(1 - \alpha) \rho_l e_l]^n FA v_l^{n+1}]_p + [(\alpha \rho_g e_g)^n FA v_g^{n+1}]_p \\ + p_v [\alpha^n FA v_g^{n+1} + (1 - \alpha)^n FA v_l^{n+1}]_p .$$

Vapor Energy Source Term

$$[(\alpha \rho_g e_g)^n FA v_g^{n+1}]_p + p_v (\alpha^n FA v_g^{n+1})_p .$$

The momentum source terms are complicated because of the staggered differencing and the fact that pipes may enter at an arbitrary angle. For TRAC-PF1/MOD1, we have assumed that the pipe enters normal to the vessel mesh-cell face. The basic forms for the liquid- and vapor-momentum source terms follow.

Liquid-Momentum Source Term

$$\left(\frac{v_{lp} v_{lv}}{\Delta x_v} \right)^n .$$

Vapor-Momentum Source Term

$$\left(\frac{V_{g_p} V_{g_v}}{\Delta x_v} \right)^n .$$

The existence of the momentum source terms is dependent on the sign of the velocities in the vessel to keep the vessel donor-cell momentum equations consistent. For example, if the nearest vessel liquid velocity indicates that the flow is into the pipe from the vessel, then the source term is set equal to zero.

If structure exists in the mesh cell, the hydrodynamic FA and vol are reduced from their geometric mesh-cell values. Thus, FA may be less than or equal to the geometric mesh-cell area and vol may be less than or equal to the geometric mesh-cell volume. When the FA is zero, all fluxes across that plane, as well as the individual velocities of each phase, are suppressed. This procedure allows large obstacles such as the downcomer walls to be modeled properly. The user specifies the flow and volume restrictions.

The finite-difference equations thus formed are semi-implicit, because the pressure gradient terms in the vapor- and liquid-momentum equations are treated at the new time. A Courant stability criterion,

$$\Delta t < \frac{L}{|V|} = \min \left(\frac{\Delta x}{V_{gz}}, \frac{r\Delta\theta}{V_{g\theta}}, \frac{\Delta r}{V_{gr}}, \frac{\Delta z}{V_{lz}}, \frac{r\Delta\theta}{V_{l\theta}}, \frac{\Delta r}{V_{lr}} \right) , \quad (27)$$

is necessary.

a. Solution of Difference Equations. A linearization procedure is needed to solve the finite-difference equations. All the scalar equations are reduced to a linear system in V_l , V_g , T_l , T_g , α , and p by using the thermal equations of state,

$$\rho_l = \rho_l(p, T_l) \quad (28)$$

and

$$\rho_g = \rho_g(p, T_g) \quad ; \quad (29)$$

the caloric equations of state,

$$e_l = e_l(p, T_l) \quad (30)$$

and

$$e_g = e_g(p, T_g) \quad ; \quad (31)$$

and the definitions for ρ_m and e_m .

A further system reduction is accomplished by observing that the finite-difference vapor- and liquid-momentum equations yield equations of the form

$$v^{n+1} = v^n + \left[\text{conv}^n + \frac{1}{\rho_l} \nabla p^{n+1} + \text{FRIC} \right] \Delta t \quad , \quad (32)$$

where conv designates the explicit convection terms and FRIC includes both the wall and the interfacial shears. Equation (32) indicates that changes in V are linearly dependent (after an explicit pass on the explicit parts of the momentum equations) on changes in pressure. Therefore, the system of variables may be reduced further to T_l , T_g , p , and α and solved by a block Gauss-Seidel method. Reference 5 provides a much more detailed description of the basic block Gauss-Seidel numerical technique.

An improvement to the method proposed in Ref. 5 has been implemented to reduce the computing cost. The linear system that results from this method is a seven-stripe block matrix. In performing the Gauss-Seidel operation, if the nonlinear terms are not updated, the matrix coefficients remain constant for the time step. In this case a Gauss elimination technique can be applied once

at each time step to the seven-stripe block array that allows its reduction to a seven-stripe single-element array. This results in a much faster iteration (after the first iteration) for the pressure. The actual iteration is performed in subroutine ITR1. When the vessel pressures are obtained for a specified convergence criterion, a backward substitution in subroutine FF3D is performed to unfold T_l , T_g , α , and the velocities for each phase. A call to THERMO in FF3D then updates all of the thermodynamic properties and their derivatives in preparation for the next time step.

b. Pressure Matrix Solution.

Two options are available for solving the vessel pressure matrix. The first is a direct inversion of the pressure solution matrix when the number of vessel cells is sufficiently small (≤ 80). The second feature is a coarse-mesh rebalance method for other cases where Gauss-Seidel iteration is required. During the iteration the pressure solution is scaled nonuniformly to reduce the overall iteration error. Such scaling can be represented by

$$P^{(i)} = S^{(i)} P^{(i)} ,$$

where $P^{(i)}$ is the pressure solution vector after i iterations and $S^{(i)}$ is its scaling matrix that is diagonal with scalar elements s_j . We define coarse-mesh regions as those vessel regions having the same scale factor. The scaled pressure solution vector is then

$$P' = s_1 P_1 + s_2 P_2 + \dots ,$$

where P_i is a vector of pressures belonging to coarse-mesh region i . With this equation in the vessel pressure equation,

$$A \cdot P = B ,$$

and with the requirement that the least-squares error in P' be a minimum yield an equation for the scale factors,

$$U \cdot S = V \quad ,$$

where $U_{ij} = (P_i, AP_j)$, $V_i = (P_i, B)$, and the notation (X, Y) means the inner product of the vectors X and Y . The matrix size of U is equal to the number of coarse-mesh regions and normally is small enough to be solved by direct inversion.

The choice of coarse-mesh regions is extremely important. We have selected a scheme that follows the flow path in the vessel so that coarse-mesh regions are coupled in the flow direction. We use the facts that the vessel matrix A is a seven-stripe matrix for a three-dimensional vessel and that coupling occurs only between nearest neighbors (there is no coupling if neighbors are separated by a wall such as a downcomer boundary). Based on these facts we select coarse-mesh regions as follows. All mesh cells on a level in the downcomer form a single coarse-mesh region, and all other mesh cells on a level form another coarse-mesh region. Hence, the total number of coarse-mesh regions is equal to the number of downcomer levels plus the total number of vessel levels. Although this choice of coarse-mesh regions is not unique, we have found it to be very effective in reducing the number of vessel iterations (typically a factor of 10).

c. Water Packing. The three-dimensional hydrodynamics package has a water-packing algorithm that is similar in function to the one-dimensional algorithm but somewhat different in construction. In subroutine TF3DI, after the initial block matrix inversion, the center diagonal δP is calculated. If the resulting predicted pressure is either very low or very high and the mesh cell has a large liquid fraction, then the surrounding region is scanned for additional information. If an adjoining cell has a liquid fraction less than 0.9, the momentum derivative $\delta V_L / \delta P_i$ (derived from the momentum equation) is multiplied by a large constant wherever it appears in terms within the offending mesh cell. This step reduces the liquid inertia and consequently allows the resultant velocity to adjust during the time step to ameliorate the

effects of the sudden pressure change. The matrix is then re-evaluated and the calculation continues.

3. One-Dimensional Finite-Difference Methods. The stability-enhancing two-step (SETS) method^{6,7} used for one-dimensional flow eliminates the material Courant stability limit from all one-dimensional components. As a result, this upper time-step bound applies only in vessel cells and at junctions to the vessel. We recommend that users unfamiliar with the SETS method read the simplified description provided in App. C before completing this section.

The SETS method consists of a basic step (which is almost identical to the standard semi-implicit method used in the vessel) and a stabilizing step. For homogeneous flow, the order of these steps does not matter; however, for two-fluid flow with noticeable relative velocity, the stabilizing step for the equations of motion must be performed before the basic step. When this stabilizing step precedes the basic step, an initial explicit prediction of velocities gives strong coupling through the interfacial-drag terms without requiring direct communication between the stabilizing equations for liquid and vapor motion. To provide improved conservation and to minimize machine storage required by TRAC, the stabilizing steps for mass and energy equations are done as the final portion of the calculation.

The spatial mesh used for the finite-difference equations is staggered with thermodynamic properties evaluated at the cell centers and velocities evaluated at the cell edges. For stability, flux terms at cell edges require donor-cell averages of the form,

$$\begin{aligned} \langle YV \rangle_{j+1/2} &= Y_j V_{j+1/2}, & \text{if } V_{j+1/2} \geq 0 &; \\ &= Y_{j+1} V_{j+1/2}, & \text{if } V_{j+1/2} < 0 &, \end{aligned} \quad (33)$$

where Y can be any cell-center state variable or a combination of such variables and V may be either liquid or vapor velocity. With this notation the finite-difference divergence operator for one-dimensional calculations is

$$\nabla_j \cdot (YV) = \frac{(A_{j+1/2} \langle YV \rangle_{j+1/2} - A_{j-1/2} \langle YV \rangle_{j-1/2})}{\text{vol}_j}, \quad (34)$$

where A is the local cross-sectional area and vol_j is the volume of the jth cell. For the equations of motion, the donor-cell form of any $V \cdot \nabla V$ term is

$$\begin{aligned} v_{j+1/2} \nabla_{j+1/2} v &= \frac{v_{j+1/2} (v_{j+1/2} - v_{j-1/2})}{\Delta x_{j+1/2}}, \text{ if } v_{j+1/2} \geq 0 ; \\ &= \frac{v_{j+1/2} (v_{j+3/2} - v_{j+1/2})}{\Delta x_{j+1/2}}, \text{ if } v_{j+1/2} < 0 ; \end{aligned} \quad (35)$$

where $\Delta x_{j+1/2}$ is half the sum of Δx_j and Δx_{j+1} .

The following finite-difference equations (roughly in order of their calculation) currently are used.

Predictors for Equations of Motion

Vapor

$$\begin{aligned} \frac{(\hat{v}_g^{n+1} - v_g^n)}{\Delta t} + v_g^n \nabla_{j+1/2} \tilde{v}_g^n + \beta (\hat{v}_g^{n+1} - v_g^n) \nabla_{j+1/2} \tilde{v}_g^n \\ + \frac{(c_f^n |v_g^n - v_\ell^n| + \Gamma_{j+1/2}^{+n})}{(\overline{\alpha \rho}_g)_n^{j+1/2}} [2(\hat{v}_g^{n+1} - \hat{v}_\ell^{n+1}) - (v_g^n - v_\ell^n)] \end{aligned}$$

$$\begin{aligned}
& + \frac{1}{(\overline{\rho_g})_{j+1/2}^n} \frac{(p_{j+1}^n - p_j^n)}{\Delta X_{j+1/2}} \\
& + \frac{c_{wg}}{(\overline{\alpha\rho_g})_{j+1/2}^n} (2\hat{v}_g^{n+1} - v_g^n) |v_g^n| + g \cos \theta = 0 \quad , \quad (36)
\end{aligned}$$

where

$$\begin{aligned}
\beta &= 0 \quad , \quad \text{if } v_{j+1/2}^n \leq 0 \quad ; \\
&= 1 \quad , \quad \text{if } v_{j+1/2}^n > 0 \quad .
\end{aligned}$$

Liquid

$$\begin{aligned}
& \frac{(\hat{v}_\ell^{n+1} - v_\ell^n)}{\Delta t} + v_\ell^n v_{j+1/2} \tilde{v}_\ell^n + \beta (\hat{v}_\ell^{n+1} - v_\ell^n) v_{j+1/2} \tilde{v}_\ell^n \\
& + \frac{(c_I^n |v_g^n - v_\ell^n| - \Gamma_{j+1/2}^n)}{[(1 - \alpha)\rho_\ell]_{j+1/2}^n} [2(\hat{v}_\ell^{n+1} - \hat{v}_g^{n+1}) - (v_\ell^n - v_g^n)] \\
& + \frac{1}{(\overline{\rho_\ell})_{j+1/2}^n} \frac{(p_{j+1}^n - p_j^n)}{\Delta X_{j+1/2}} \\
& + \frac{c_{w\ell}}{[(1 - \alpha)\rho_\ell]_{j+1/2}^n} (2\hat{v}_\ell^{n+1} - v_\ell^n) |v_\ell^n| + g \cos \theta = 0 \quad . \quad (37)
\end{aligned}$$

Stabilizer Equations of Motion

Vapor

$$\begin{aligned}
 & \frac{(\tilde{v}_g^{n+1} - v_g^n)}{\Delta t} + v_g^n \nabla_{j+1/2} \tilde{v}_g^{n+1} + \beta (\tilde{v}_g^{n+1} - v_g^n) \nabla_{j+1/2} \tilde{v}_g^n \\
 & + \frac{(c_1^n |v_g^n - v_\ell^n| + \Gamma_{j+1/2}^{+n})}{(\overline{\alpha \rho_g})_{j+1/2}^n} [2(\hat{v}_g^{n+1} - \hat{v}_\ell^{n+1}) - (v_g^n - v_\ell^n)] \\
 & + \frac{1}{(\overline{\rho_g})_{j+1/2}^n} \frac{(p_{j+1}^n - p_j^n)}{\Delta X_{j+1/2}} \\
 & + \frac{c_{wg}}{(\overline{\alpha \rho_g})_{j+1/2}^n} (2\tilde{v}_g^{n+1} - v_g^n) |v_g^n| + g \cos \theta = 0 \quad . \quad (38)
 \end{aligned}$$

Liquid

$$\begin{aligned}
 & \frac{(\tilde{v}_\ell^{n+1} - v_\ell^n)}{\Delta t} + v_\ell^n \nabla_{j+1/2} \tilde{v}_\ell^{n+1} + \beta (\tilde{v}_\ell^{n+1} - v_\ell^n) \nabla_{j+1/2} \tilde{v}_\ell^n \\
 & + \frac{c_1^n |v_g^n - v_\ell^n| - \Gamma_{j+1/2}^{-n}}{[(1 - \alpha)\rho_\ell]_{j+1/2}^n} [2(\hat{v}_\ell^{n+1} - \hat{v}_g^{n+1}) - (v_\ell^n - v_g^n)] \\
 & + \frac{1}{(\overline{\rho_\ell})_{j+1/2}^n} \frac{(p_{j+1}^n - p_j^n)}{\Delta X_{j+1/2}} \\
 & + \frac{c_{w\ell}}{[(1 - \alpha)\rho_\ell]_{j+1/2}^n} (2\tilde{v}_\ell^{n+1} - v_\ell^n) |v_\ell^n| + g \cos \theta = 0 \quad . \quad (39)
 \end{aligned}$$

Basic Equations of Motion

Vapor

$$\begin{aligned}
 & \frac{(v_g^{n+1} - v_g^n)}{\Delta t} + v_g^n \nabla_{j+1/2} \tilde{v}_g^{n+1} + \beta (v_g^{n+1} - v_g^n) \nabla_{j+1/2} \tilde{v}_g^n \\
 & + \frac{(c_i^n |v_g^n - v_\ell^n| + r_{j+1/2}^n)}{(\overline{\alpha \rho_g})_{j+1/2}^n} [2(v_g^{n+1} - v_\ell^{n+1}) - (v_g^n - v_\ell^n)] \\
 & + \frac{1}{(\overline{\rho_g})_{j+1/2}^n} \frac{(\tilde{p}_{j+1}^{n+1} - \tilde{p}_j^{n+1})}{\Delta X_{j+1/2}} \\
 & + \frac{c_{wg}}{(\overline{\alpha \rho_g})_{j+1/2}^n} (2v_g^{n+1} - v_g^n) |v_g^n| + g \cos \theta = 0 \quad . \quad (40)
 \end{aligned}$$

Liquid

$$\begin{aligned}
 & \frac{(v_\ell^{n+1} - v_\ell^n)}{\Delta t} + v_\ell^n \nabla_{j+1/2} \tilde{v}_\ell^{n+1} + \beta (v_\ell^{n+1} - v_\ell^n) \nabla_{j+1/2} \tilde{v}_\ell^n \\
 & + \frac{(c_i^n |v_\ell^n - v_g^n| - r_{j+1/2}^n)}{[(1 - \alpha)\rho_\ell]_{j+1/2}^n} [2(v_\ell^{n+1} - v_g^{n+1}) - (v_\ell^n - v_g^n)] \\
 & + \frac{1}{(\overline{\rho_\ell})_{j+1/2}^n} \frac{(\tilde{p}_{j+1}^{n+1} - \tilde{p}_j^{n+1})}{\Delta X_{j+1/2}} \\
 & + \frac{c_{wl}}{[(1 - \alpha)\rho_\ell]_{j+1/2}^n} (2v_\ell^{n+1} - v_\ell^n) |v_\ell^n| + g \cos \theta = 0 \quad . \quad (41)
 \end{aligned}$$

Basic Mass Equations

Vapor

$$\frac{[(\tilde{\alpha}\tilde{\rho}_g)^{n+1} - (\alpha\rho_g)^n]}{\Delta t} + \nabla_j \cdot (\alpha\rho_g v_g^{n+1}) = \tilde{\Gamma}^{n+1} \quad . \quad (42)$$

Noncondensable Gas

$$\frac{[(\tilde{\alpha}\tilde{\rho}_a)^{n+1} - (\alpha\rho_a)^n]}{\Delta t} + \nabla_j \cdot (\alpha\rho_a v_g^{n+1}) = 0 \quad . \quad (43)$$

Liquid

$$\begin{aligned} & \frac{[(1 - \tilde{\alpha})^{n+1} \tilde{\rho}_\ell^{n+1} - (1 - \alpha)^n \rho_\ell^n]}{\Delta t} + \nabla_j \cdot [(1 - \alpha) \rho_\ell v_\ell^{n+1}] \\ & = - \tilde{\Gamma}^{n+1} \quad . \end{aligned} \quad (44)$$

Basic Energy Equations

Vapor

$$\begin{aligned} & \frac{[(\tilde{\alpha}\tilde{\rho}_g\tilde{e}_g)^{n+1} - (\alpha\rho_g e_g)^n]}{\Delta t} + \nabla_j \cdot (\alpha\rho_g e_g v_g^{n+1}) \\ & + \tilde{p}^{n+1} \left[\frac{(\tilde{\alpha}^{n+1} - \alpha^n)}{\Delta t} + \nabla_j \cdot (\alpha^n v_g^{n+1}) \right] \\ & = \tilde{q}_{wg}^{n+1} + \tilde{q}_{ig}^{n+1} + \tilde{\Gamma}^{n+1} \tilde{h}_{sg}^{n+1} \quad . \end{aligned} \quad (45)$$

Mean

$$\begin{aligned} & \frac{\{[\tilde{\alpha}\tilde{\rho}_g\tilde{e}_g + (1 - \tilde{\alpha})\tilde{\rho}_l\tilde{e}_l]^{n+1} - [\alpha\rho_g e_g + (1 - \alpha)\rho_l e_l]^n\}}{\Delta t} \\ & + \nabla_j \cdot [(\alpha\rho_g e_g) v_g^{n+1} + (1 - \alpha)\rho_l e_l v_l^{n+1}] \\ & + \tilde{p}^{n+1} \nabla_j \cdot [(1 - \alpha)^n v_l^{n+1} + \alpha^n v_v^{n+1}] = \tilde{q}_{wg}^{n+1} + \tilde{q}_{wl}^{n+1} . \end{aligned} \quad (46)$$

Stabilizing Mass Equations

Vapor

$$\frac{[(\alpha\rho_g)^{n+1} - (\alpha\rho_g)^n]}{\Delta t} + \nabla_j \cdot [(\alpha\rho_g)^{n+1} v_g^{n+1}] = \tilde{\Gamma}^{n+1} . \quad (47)$$

Noncondensable Gas

$$\frac{[(\alpha\rho_a)^{n+1} - (\alpha\rho_a)^n]}{\Delta t} + \nabla_j \cdot [(\alpha\rho_a)^{n+1} v_g^{n+1}] = 0 . \quad (48)$$

Liquid

$$\begin{aligned} & \frac{[(1 - \alpha)^{n+1} \rho_l^{n+1} - (1 - \alpha)^n \rho_l^n]}{\Delta t} + \nabla_j \cdot [(1 - \alpha)^{n+1} \rho_l^{n+1} v_l^{n+1}] \\ & = -\tilde{\Gamma}^{n+1} . \end{aligned} \quad (49)$$

Solute

$$\frac{[(1 - \alpha)^{n+1} \tilde{m}^{n+1} \rho_\ell^{n+1} - (1 - \alpha)^n m^n \rho_\ell^n]}{\Delta t}$$

$$+ \nabla_j \cdot [(1 - \alpha)^{n+1} \tilde{m}^{n+1} \rho_\ell^{n+1} v_\ell^{n+1}] = 0 ; \quad (50)$$

$$m^{n+1} = \min (\tilde{m}^{n+1} + S_c^N, m_{\max}) ; \text{ and} \quad (51)$$

$$s^{n+1} = \tilde{m}^{n+1} + s^n - c^{n+1} . \quad (52)$$

Stabilizing Energy Equations

Vapor

$$\frac{[(\alpha \rho_g e_g)^{n+1} - (\alpha \rho_g e_g)^n]}{\Delta t} + \nabla_j \cdot [(\alpha \rho_g e_g)^{n+1} v_g^{n+1}]$$

$$+ \tilde{p}^{n+1} \left[\frac{(\tilde{\alpha}^{n+1} - \alpha^n)}{\Delta t} + \nabla_j \cdot (\alpha^n v_g^{n+1}) \right]$$

$$= \tilde{q}_{ig}^{n+1} + \tilde{q}_{wg}^{n+1} + \tilde{\Gamma}^{n+1} \tilde{h}_{sg}^{n+1} . \quad (53)$$

Liquid

$$\frac{\{[(1 - \alpha) \rho_\ell e_\ell]^{n+1} - [(1 - \alpha) \rho_\ell e_\ell]^n\}}{\Delta t} + \nabla_j \cdot \{[(1 - \alpha) \rho_\ell e_\ell]^{n+1} v_\ell^{n+1}\}$$

$$+ \tilde{p}^{n+1} \left\{ \frac{(\alpha^n - \tilde{\alpha}^{n+1})}{\Delta t} + \nabla_j \cdot [(1 - \alpha)^n v_\ell^{n+1}] \right\}$$

$$= \tilde{q}_{wl}^{n+1} - \tilde{q}_{lg}^{n+1} - \tilde{\Gamma}^{n+1} \tilde{h}_{sg}^{n+1} . \quad (54)$$

A caret above velocities denotes explicit predictor values. A tilde above a variable indicates that it is the result of an intermediate step and not a final value for the end of the time step. A horizontal line above a quantity indicates that it is obtained with a 50% average between values at adjacent cells. If there are no subscripts denoting cell location, we assume subscript j for mass and energy equations and subscript $j+1/2$ for equations of motion. Finally, θ is the angle between a vector from the center of cell j to the center of cell $j+1$ and a vector directed against gravity.

Time levels were omitted from some flux terms in Eqs. (42)-(46) because these terms contain both old and new time quantities. If X is a combination of state variables without a time superscript, then the correct definition for the divergence term in which it appears is

$$\begin{aligned} \nabla_j(XV_j^{n+1}) = & \{A_{j+1/2} v_{j+1/2}^{n+1} [f_{j+1/2} x_j^m + (1 - f_{j+1/2}) x_{j+1}^n] \\ & - A_{j-1/2} v_{j-1/2}^{n+1} [f_{j-1/2} x_{j-1}^n + (1 - f_{j-1/2}) x_j^m]\} / \text{vol}_j, \end{aligned} \quad (55)$$

where

$$x_j^m = g' x_j^n + (1 - g') x_j^{n+1}. \quad (56)$$

The weighting function used to obtain donor-cell averaging [Eq. (33)] is f , and g' is a weighting factor that depends on the rate of phase change, which goes to unity as the phase change disappears and to zero as the phase change approaches the total outflow of the phase created in the cell. For nonzero g' , this form of the divergence operator is nonconservative, but total conservation is maintained by the stabilizer step.

Equations (36) and (37) do not involve any implicit coupling between cells and can be solved rapidly for each cell. Because Eqs. (38) and (39) do not couple, each one requires only the solution of a tridiagonal linear system. Equations (40)-(46), combined with the necessary thermodynamic and constitutive equations, form a coupled system of nonlinear equations. Equations (40) and (41) are solved directly to obtain v_g^{n+1} and v_k^{n+1} as dependent variables. After substituting these equations for velocity into

Eqs. (42)-(46), the resulting system is solved for the independent variables $\tilde{p}^{n+1}$, $\tilde{p}_a^{n+1}$, $\tilde{T}_g^{n+1}$, $\tilde{T}_l^{n+1}$, and $\tilde{\alpha}^{n+1}$ with a standard Newton iteration, including all coupling between cells. In practice, the linearized equations solved during this iteration can be reduced easily to a tridiagonal system involving only total pressures. The final eight stabilizing equations [Eqs. (47)-(54)] also are simple tridiagonal linear systems because v_g^{n+1} and v_l^{n+1} are known after solving Eqs. (40)-(46). Because the pressure and fluid temperatures are used mainly as the starting point for the next iteration, the start of time-step values for these quantities are the tilde values from the end of the previous basic step. This approximation prevents an extra evaluation of the thermodynamic and transport properties. A void fraction consistent with the stabilizer mass and energy quantities is calculated by a simple linearization.

4. Constitutive Equations. The field equations [Eqs. (1)-(8)] require certain auxiliary or constitutive equations to effect closure. Thermal and caloric equations of state for each phase are required, and these are discussed in App. A. In addition, the liquid and vapor wall shear, interfacial drag, wall heat transfer, interfacial heat transfer, and the net vaporization rate are necessary.

The wall heat transfers, q_{wg} and q_{wl} , are accounted for in the standard way [see Eqs. (15) and (16)]. The surface areas represent an actual estimate of the total wall surface area wetted by each phase, whereas h_{wl} and h_{wg} are based on heat-transfer correlations from the literature. In many two-phase flow situations the walls are wetted totally by the liquid phase, in which case wall heat transfer to the vapor is zero.

a. One-Dimensional Wall Shear and Form Losses. The total pressure gradient calculated in the momentum equations is expressed as the sum of the frictional dissipation, acceleration head, and potential head terms. Subroutine FWALL calculates coefficients for the frictional dissipation terms and for losses associated with abrupt area changes. Under single-phase flow conditions, pressure drops associated with frictional losses are correlated as functions of fluid velocity, fluid density, fluid viscosity, channel hydraulic diameter, and surface roughness of the channel wall. When a two-phase mixture is flowing in a channel, a correction to the single-phase frictional loss is necessary to account for added dissipation between phases and interactions

with the channel walls. This correction factor is the two-phase flow multiplier.

The wall shear coefficients, c_{wg} and c_{wl} , are defined as

$$c_{wg} = \alpha \rho_g \frac{c_{fg}}{D_h}$$

and

$$c_{wl} = (1 - \alpha) \rho_l \frac{c_{fl}}{D_h} ,$$

where c_{fg} and c_{fl} are the vapor and liquid friction factors. The options available to calculate the wall friction are

NFF = 0, constant value (user input);

NFF = 1, homogeneous model; and

NFF = 2, annular model;

where NFF is the user-specified index. Use of a negative index value results in an automatic calculation of an appropriate form-loss coefficient in addition to the selected two-phase flow friction factor if there are abrupt area changes. This option is not available for the accumulator component where a constant value for the friction factor is used.

i. Homogeneous Model. The homogeneous friction-factor model alters the single-phase value by using a two-phase viscosity ($\bar{\mu}$) defined in terms of the flow quality (x),⁸

$$\frac{1}{\bar{\mu}} = \frac{x}{\mu_g} + \frac{(1 - x)}{\mu_l} . \quad (57)$$

The homogeneous friction factor⁹ then is given by

$$f = 0.046 (\text{Re})^{-0.2} , \quad \text{if } \text{Re} \geq 5000 ; \quad (58)$$

$$f = 0.032 , \quad \text{if } \text{Re} \leq 500 ; \quad (59)$$

$$f = 0.032 - 5.25 \times 10^{-6}(\text{Re} - 500) , \quad \text{if } 500 < \text{Re} < 5000 ; \quad (60)$$

where $\text{Re} = \text{GD}_h/\bar{\mu}$ and $G = \rho_m V_m$. The development of Eq. (58) assumes smooth pipe walls.

Equations (58)-(60) represent a constant friction factor for $\text{Re} \leq 500$ and a linear interpolation between $500 < \text{Re} < 5000$, where the friction factor is given by Eq. (58). The coefficient of friction for the liquid is

$$c_{f_l} = 2.0 f , \quad (61)$$

and, if the void fraction is greater than 0.90, the vapor coefficient of friction is

$$c_{f_g} = (10.0\alpha - 9.0)^2 (21.0 - 20.0\alpha) c_{f_l} . \quad (62)$$

The purpose of this function is to ensure a smooth transition from zero-vapor wall friction at $\alpha = 0.9$ to the single-phase vapor value at $\alpha = 1.0$.

ii. Annular-Flow Model. The annular-flow friction-factor method from Ref. 10 is adopted with a modification at high vapor fractions. The single-phase friction factor (f_{sp}) from Ref. 11 is

$$f_{sp} = a + b\text{Re}^{-c} , \quad (63)$$

where

$$a = 0.026 \left(\frac{k}{D} \right)^{0.225} + 0.133 \left(\frac{k}{D} \right) , \quad (64)$$

$$b = 22.0 \left(\frac{k}{D} \right)^{0.44} , \quad (65)$$

$$c = 1.62 \left(\frac{k}{D} \right)^{0.134} , \quad (66)$$

and k/D is the relative pipe wall roughness. A value of $k = 5.0 \times 10^{-6}$ m, which is ~23.3 times the roughness of drawn tubing and ~20.11 times the roughness of commercial steel pipe, is used for the absolute pipe roughness. The annular-flow friction factor is then

$$f = f_{sp} \Phi^2 , \quad (67)$$

where

$$\Phi^2 = \frac{\rho_l}{\rho_m} . \quad (68)$$

At vapor fractions above 0.90, the annular-flow friction factor is merged linearly into the homogeneous model with full transition occurring at $\alpha = 0.9995$. As discussed in Sec. III.A.1, the wall friction is partitioned between the liquid and vapor phases for a void fraction greater than 0.90.

iii. Form Losses. The finite-difference equations yield the correct pressure loss for an abrupt expansion. However, this is not true for an abrupt contraction or for an orifice. Form-loss corrections can be included in a TRAC calculation in two ways. For one-dimensional components, the simplest method is to specify a negative value for the input friction-option variable NFF (see any one-dimensional component in Sec. V.C.5) at the location of any abrupt area change. This triggers logic in the code that examines the local pipe geometry, the flow direction, and the implicitness level of the

difference equations to determine an appropriate loss correction. An extra term in the Bernoulli equation of the form,

$$\Delta p = \frac{k \rho V^2}{2} , \quad (69)$$

where k is a form-loss coefficient, accounts for these corrections. The values used for k are

$$k = \left(1 - \frac{A_1}{A_2}\right)^2 \quad (70)$$

for an abrupt expansion or zero-length orifice, and

$$k = 0.5 - 0.7\left(\frac{A_1}{A_2}\right) + 0.2\left(\frac{A_1}{A_2}\right)^2 \quad (71)$$

for an abrupt contraction where A_1 and A_2 are the smaller and the larger FAs, respectively. Equation (71) is a curve that was fitted to the values reported in Ref. 12. Experience has shown that these classic form losses often do not match pressure drops in real systems. This option should be used with caution.

The other way to account for form losses is through the use of the FRIC input array. Losses computed using this array are added to those specified with the NFF option. The pressure loss that results from FRIC is

$$\Delta p_j = \frac{(\Delta x_j + \Delta x_{j-1})}{2D_{h,j}} \text{FRIC}_j \rho_m V_m |V_m| , \quad (72)$$

where j is the mesh-cell index.

An input option allows standard k factors^{13,14} to be input.

b. Three-Dimensional Wall Shear Coefficients. The wall shear coefficients, c_{wg} and c_{wl} , are defined similarly to the one-dimensional wall friction. The standard homogeneous correlation is used to provide the wall friction factors for two-phase flow. These factors approach the appropriate single-phase values for $\alpha = 0$ and $\alpha = 1$.

The velocity used by the correlations in the z direction is determined from the average mesh-cell porosity; therefore, at locations where orifice plates exist and velocities are high, the wall friction is calculated using V_{avg} determined by continuity considerations. This prevents excessive losses at major flow restrictions. A total friction factor is calculated from the information above and is ascribed completely to the liquid-momentum equation until a vapor fraction of 0.75 is reached. If $0.75 < \alpha < 0.95$, the shear is assigned with linear weighting (in α) to both the liquid and vapor. If $\alpha > 0.95$, the entire skin friction is assigned to the vapor.

A single friction coefficient is generated from this procedure for both the outer radial and upper axial cell face. However, the hydraulic diameter used in the radial and axial directions, in general, will vary depending on the geometry. If nonzero hydraulic diameters are specified in the problem input, these are used. If the hydraulic diameters are zero in the input, then TF3DE calculates where $i = (\theta, z, r)$ and the wetted perimeter (P_i) normal to direction i includes the surface area of any rods, wall heat slabs, or flow boundaries. If there is no solid material in a mesh cell, the wall shear is zero. A similar procedure is used to calculate a wall shear in the theta direction. However, in this case vector velocities and properties on the appropriate theta face (rather than the cell-centered averages) are used to achieve theta symmetry where such symmetry should exist.

The basic finite-difference scheme properly calculates classical Bourda form losses at an expansion but overpredicts the losses at a contraction (see discussion in Sec. III.A.4.a.iii). The user can specify an additional constant hydraulic loss factor in any of the coordinate directions to account for geometric details whose scale is smaller than the mesh-cell size. The relation between this input friction term and the pressure drop that it

produces is the same as the one in eq. (72) except that the hydraulic diameter (D_h) is omitted from the expression.

c. Interfacial Heat Transfer and Shear. The interfacial constitutive equations basically are identical for the one- and the three-dimensional portions of TRAC-PF1/MOD1. A generic description of these relations will be given and any differences between the one- and the three-dimensional sections will be noted. The interfacial heat transfer during boiling and the interfacial shear are calculated in conjunction with a simple flow-regime map.¹⁵ This flow-regime map, although originally developed for vertical pipe flow, is the simplest prescription that provides a rational means for defining the constitutive equations. Figure 2 illustrates how the flow map is implemented in the code.

If the void fraction is less than or equal to 0.3 (or $\alpha \leq 0.5$ if $G \geq 2700 \text{ kg/m}^2\text{s}$), a bubbly flow is assumed. The interfacial surface area in this regime is calculated in conjunction with a critical bubble Weber number, We_b . A value of $We_b = 7.5$ is used in TRAC-PF1/MOD1. This choice was based on comparisons between the TRAC predictions and the experimental results for low

Fig. 2.
Flow-regime map for three-dimensional hydrodynamics.
(Cross-hatched regions are transition zones.)

subcooling (that is, shear-dominated) downcomer tests performed by Creare, Inc.¹⁶ The expression relating interfacial surface area to We_b is

$$\frac{\rho_l v_r^2 D_b}{\sigma} = We_b$$

or

$$D_b = \frac{We_b \sigma}{\rho_l v_r^2} , \quad (73)$$

where D_b is the bubble diameter. The bubble diameter must lie between the mesh-cell hydraulic diameter and 10^{-4} m. For this diameter, with the assumption of a uniform bubble distribution within the mesh-cell vol, the number of bubbles is

$$CNB = \frac{6\alpha \text{ vol}}{\pi D_b^3} , \quad (74)$$

and the interfacial area is

$$A_i = 6\alpha \text{ vol } \rho_l \frac{v_r^2}{We_b \sigma} . \quad (75)$$

If the relative velocity is very small, this area can become small enough to allow significant nonequilibrium. Another surface area,

$$A = 4.83\alpha^{2/3} (N_B)^{1/3} \text{ vol} , \quad (76)$$

based on a minimum number density ($N_B = 10^{10}$ bubbles/m³), is computed, and the actual surface area used is the larger of the two.

For boiling, the liquid-side interfacial HTC is the larger of an approximate formulation of the Plesset-Zwick bubble growth model,¹⁷

$$Nu = \frac{12}{\pi} (T_\ell - T_s) \rho_\ell \frac{\frac{\partial e_\ell}{\partial T_\ell}}{[\rho_g (h_{sg} - h_{sl})]} , \quad (77)$$

and a sphere convection coefficient,¹⁸

$$Nu = 2.0 + 0.74 Re_b^{0.5} , \quad (78)$$

where

$$Re_b = \rho_\ell V_r \frac{D_b}{\mu_\ell} .$$

For subcooled liquid in a dispersed bubbly regime, the liquid side interfacial HTC, obtained from turbulent convection, is

$$h_{il} = 0.02 \rho_\ell c_{p\ell} V_r . \quad (79)$$

In the bubbly regime, the vapor-to-interface HTC is one of two constants. If the vapor is superheated, h_{ig} is 1 000; if it is subcooled, h_{ig} is 10 000. The interfacial shear coefficient is provided by a standard set of formulas for a sphere,¹¹

$$c_i = \frac{3c_b \alpha \rho_\ell}{4D_b} , \quad (80)$$

where

$$c_b = 180 \quad , \quad \text{if } Re_b < 0.1 \quad ;$$

$$= \frac{18}{Re_b} (1 + 15 Re_b^{0.687}) \quad , \quad \text{if } 0.1 \leq Re_b \leq 989 \quad ;$$

or

$$= 0.33 \quad , \quad \text{if } Re_b > 989 \quad .$$

If the cell-average mass flux is less than $2000 \text{ kg/m}^2\text{s}$ and the vapor fraction is between 0.3 and 0.5, the flow enters the slug regime. At the maximum α of 0.5, 40% of the vapor is assumed to exist in the form of trailing bubbles with the remainder contained in the slug. These bubbles probably contribute to the majority of the interfacial heat transfer and the liquid-side coefficient is calculated from the heat-transfer relations for the entrained bubbles. If the mass flux is greater than $2700 \text{ kg/m}^2\text{s}$, all of the vapor is assumed to exist in bubbly form. Linear interpolation in mass flux is used in the range of 2000 to $2700 \text{ kg/m}^2\text{s}$. In the slug regime the bubble diameter is determined by a linear weighting in α between the Weber number criterion and the channel hydraulic diameter ~~criteria~~ such that the value is the hydraulic diameter at a void fraction of 0.5 and the value determined by the Weber number size at an α of 0.3.

In the vapor-fraction range of 0.75 to 1.0, an annular or annular-mist regime is assumed. The liquid fraction that exists as mist is obtained from an entrainment correlation, which combines a simple s-shaped entrainment correlation based on the critical Weber number and a correlation by Kataoka and Ishii.¹⁹ Thus,

$$E = \max \left\{ 1 - \exp \left[-\frac{(V_E - V_g)}{V_E} \right] 0.5 \quad , \quad 7.75 \times 10^{-7} We_e (Re_l We_e)^{1/4} \right\} \quad , \quad (81)$$

where

$$v_E = 2.33 \left[\frac{(\rho_l - \rho_g) \sigma We_d}{\rho_g^2} \right]^{1/4}$$

and

$$We_e = \frac{\rho_g^{2/3} (\alpha V_g)^2 D_h (\rho_l - \rho_g)^{1/3}}{\sigma}$$

This method appears to provide reasonable results for the Dartmouth flooding tests.

The remainder of the liquid is in a film or sheet. The interfacial shear and heat transfer are volume averages of the film and droplet relations in the annular-mist regime. The wetted surface area of the mesh cell is determined from the rod or slab heat-transfer area in the cell and the portion of the geometric FA that is blocked. If the cell is in a region devoid of any structure, the geometric surface area is used as a scaling factor. This, of course, is artificial but in a realistic PWR simulation very few, if any, of the mesh cells are completely free of metal structure. The total interfacial surface area is determined by the sum of the areas contained in the wetted film and the droplets. A critical Weber number equal to four for the drops is used with a calculation procedure similar to that for bubbly flow. This value of the Weber number is appropriate for accelerating drops. For those cases where sensitivity to We_d was tested, the results were not influenced strongly by We_d in the range of $2 \leq We_d \leq 12$.

For superheated drops, the liquid-side HTC is simply

$$h_{il} = \frac{ak_l}{D_d}, \quad (82)$$

where a , a constant, has been adjusted to drive the drops to equilibrium under a variety of flow conditions. In TRAC-PF1/MOD1, $a = 15\,000$, which implies a

droplet thermal boundary layer that is approximately one ten-thousandth of the drop diameter.

For subcooled drops, h_{il} is obtained by assuming circulation in the drop giving

$$h_{il} = 0.02 \rho_l c_{pl} V_{circ} \quad , \quad (83)$$

where

$$V_{circ} = 0.5 \left(\frac{\mu_g}{\mu_g + \mu_l} \right) V_r \quad . \quad (84)$$

At some point, this expression for V_{circ} produces centripetal source terms large enough compared to the surface tension to produce distortion and eventually to break up the drop. Hence, V_{circ} can not exceed $1.4 \sqrt{\sigma / (D_{drop} \rho_l)}$. The heat transfer between the vapor and the droplet interface is obtained from

$$Nu = 2.0 + 0.74 Re_g^{1/2} Pr_g^{1/3} \quad . \quad (85)$$

For any wall film that may exist along with the drops, the liquid-side interfacial HTC is

$$h_{il} = 0.02 \rho_l c_{pl} V_l \quad ; \quad (86)$$

for the vapor side,

$$h_{ig} = 0.02 \rho_g c_{pg} V_g \quad . \quad (87)$$

The interfacial-drag coefficient for the annular-drop regime combines the droplet drag [analogous to Eq. (80)] and Wallis' correlation for annular flow,²⁰

$$c_i = \frac{0.01\rho_g}{D_h} (1.0 + 75.0 (1 - \alpha)(1 - E)) \quad , \quad (88)$$

where E is given by Eq. (88). To avoid a singularity in the liquid acceleration, a void fraction, α_{cut} , is calculated that corresponds to the minimum allowed film thickness. Above this void-fraction value, Eq. (88) is multiplied by $(1 - \alpha)/(1 - \alpha_{cut})$. To obtain the total interfacial-drag coefficient, droplet drag is weighted by the liquid fraction that is entrained, and Wallis' annular flow is weighted by the fraction remaining as film.

For the regime between the droplet and the bubbly slug flow, a cubic spline interpolation in the vapor fraction is made between the conditions that would exist if the vapor fraction were 0.75 in the annular or annular-mist topology and the conditions that would exist if the void fraction were 0.5 in the bubbly slug regime. This interpolation assures that the correlation for the interfacial shear, interfacial heat transfer, and surface area is a continuous function of the vapor fraction, the relative velocity, the mass flux, and the various fluid thermodynamic and transport properties.

If the liquid is subcooled, several other considerations are used to determine the liquid-side interfacial heat transfer. Local conditions are tested for horizontally stratified flow (Sec. III.A.4.e). If it occurs, Eq. (86) is used for h_{il} , and the interfacial area is taken as the area of the stratified interface. If flow is not stratified, adjacent void fractions are tested for a plug interface. If this is detected, Eq. (86) again is used, and the surface area is obtained from an estimate of the flow cross section. If a pipe enters a given three-dimensional mesh cell and the liquid flows into that cell, then a jet is assumed with an α -weighted diameter, a surface area for condensation based on a right circular cylinder is provided, and h_{il} is given by Eq. (86) multiplied by $(\Delta X/D_{jet})^2$. Local conditions also are tested for vertically stratified flow (sharp mixture-density discontinuity with low

cell-average vapor velocity). If the flow is stratified, h_{il} is reduced by a factor of 10^3 , and the interfacial area is the sum of the stratified interface area and the wall area exposed to the gas phase. However, if the liquid velocity into the cell from the top cell edge exceeds a threshold value (for example, a criterion that would be satisfied by a pressurizer spray), h_{il} instead is increased by a factor of 10^4 .

If a noncondensable gas is present, the condensation rate is reduced according to the formula,

$$\frac{h_{nc}}{h_{il}} = 0.168 \left(\frac{\alpha \rho_s^2}{\rho_a (1 - \alpha) \rho_l} \right)^{0.1}, \quad (89)$$

where h_{nc} is the liquid interfacial HTC when a noncondensable gas is present. Small cutoffs on $(1 - \alpha)$ and ρ_a prevent the denominator from ever coming so close to zero as to cause difficulties. This model is based on Russian jet data²¹ and can reduce dramatically condensation when a vapor other than steam is in a region.

d. Interface Sharpener. An interface sharpener is used in the lower plenum and core of the three-dimensional vessel to improve the liquid distribution during reflood. Simple void-fraction tests are used to detect any sharp mixture-density discontinuity. The entrainment model then is used to predict the void fraction for convection from the positive face of the mesh cell. This void fraction always will be greater than or equal to the actual void fraction in the cell. The interfacial shear constitutive relations are calculated based on this void fraction, and the scalar field equations use this new value in the z-direction convective terms. A cubic spline is used to merge the sharpened alpha as the mesh cell fills.

e. Horizontal Stratified Flow. In TRAC-PF1/MOD1 the one-dimensional components have an additional flow regime if the angle from the horizontal is less than 30° . A stratification criterion based on the modified Froude number analysis developed by Y. Taitel and A. E. Dukler²² is used to determine if the flow is stratified.

The critical velocity U_{crit} is calculated by

$$U_{crit} = C_2 \left[\frac{(\rho_l - \rho_g)g \cos \beta A_g}{\rho_g \frac{dA_l}{dh_l}} \right]^{1/2}, \quad (90)$$

where

$$C_2 = 1 - \frac{h_l}{D},$$

$$\frac{dA_l}{dh_l} = [D^2 - (2h_l - D)^2]^{1/2},$$

h_l is the collapsed liquid height (determined by a standard mensuration formula), and D is the pipe inside diameter. If the absolute value of the vapor velocity is more than double the U_{crit} value, the standard flow map is used. Below the U_{crit} value, the wall shear coefficients are calculated by the Blasius relation (but are based on a minimum turbulent Reynolds number); the interfacial shear coefficient is assumed to be a constant (0.01) times the vapor density. A cubic spline employing the independent variable $ABS(V_g)$ connects the two end points. This form of interpolation is necessary to prevent oscillations in the flow pattern with the large time steps often used by the code.

In addition, the hydraulic approximation for the difference in gravitational head caused by collapsed liquid height variations is added explicitly into the liquid equation of motion. Because this calculation is explicit, horizontal manometer oscillations can occur at larger time-step sizes. To prevent this difficulty, the magnitude of this added term is reduced as the time-step size is increased beyond the basic stability limit. This reduction eliminates the undesired oscillations.

f. Subcooled Boiling Model. If hot metal surfaces are present in a region, then the flashing rate $\dot{V}$ is modified to include the effects of subcooled boiling. If rods or slabs exist and $T_w > T_s$, the h_{wx} is compared to the Dittus-Boelter liquid convective coefficient. If h_{wx} is larger, the difference in wall flux (q_{sb}) is attributed to subcooled boiling and

$$\dot{V}' = \frac{q_{il} + q_{ig} + q_{sb}}{h_{lg}} .$$

Both in the vapor-continuity equation and in the vapor thermal-energy equation, the potentials, $(T_s - T_g)$ and $(T_s - T_l)$, are evaluated at the new time level, whereas $h_{ig}A_i$ and $h_{il}A_i$ are evaluated at the old time.

B. Structural Heat Transfer

The TRAC code models three fundamental heat-transfer mechanisms that include the interfacial heat transfer between the vapor and liquid phases, conduction within the reactor structural components, and the heat transfer between the structures and the fluid. Interfacial heat transfer was discussed in Sec. III.A.4.c. The remaining two mechanisms are discussed here.

The thermal history of the structural reactor materials is obtained from a solution of the heat-conduction equation. The energy exchange between the structures and the fluid is modeled using Newton's law. The coupling algorithm (Fig. 3) is semi-implicit. For each new time step, the fluid-dynamics equations are solved based on previous values for the wall HTC's (h) and surface wall temperatures (T_w); that is,

$$q_w^{n+1} = h^n (T_w^n - T_f^{n+1}) . \quad (91)$$

After the fluid-dynamics equations are solved, the wall temperature distributions are deduced from the conduction equation.

1. Heat-Conduction Models. For simplicity, as well as computing efficiency, the conduction models are separated according to their geometric function. They include conduction within cylindrical walls, slabs, and core rods. The first model analyzes heat conduction within the walls of the

Fig. 3.

Semi-implicit coupling between hydrodynamics and structural heat transfer.

one-dimensional loop components, such as the pipe walls. The latter two are associated with heat transfer within structural components of the vessel. Each of these models will be discussed in detail.

a. Cylindrical Wall Heat Conduction. The temperature distribution within the walls of the one-dimensional components is determined by subroutine CYLHT. A solution is obtained from a finite-difference approximation to the one-dimensional conduction equation,

$$\rho c_p \frac{\partial T}{\partial t} = \frac{1}{r} \left[\frac{\partial}{\partial r} \left(rk \frac{\partial T}{\partial r} \right) \right] + \dot{q}'''. \quad (92)$$

The finite-difference equations are derived by applying an integral method²³ to the elemental volumes shown in Fig. 4. The general form for the i th volume ($1 < i < N$) is

$$\begin{aligned}
& \frac{r_{i-1/2} k_{i-1/2}}{\Delta r_{i-1}} T_{i-1}^{n+1} - \left\{ \frac{r_{i-1/2} k_{i-1/2}}{\Delta r_{i-1}} + \frac{r_{i+1/2} k_{i+1/2}}{\Delta r_i} \right. \\
& + \frac{1}{2\Delta t} \left[\left(r_i \Delta r_{i-1} - \frac{\Delta r_{i-1}^2}{4} \right) (\rho c_p)_{i-1/2} + \left(r_i \Delta r_i + \frac{\Delta r_i^2}{4} \right) (\rho c_p)_{i+1/2} \right] T_i^{n+1} \\
& + \frac{r_{i+1/2} k_{i+1/2}}{\Delta r_i} T_{i+1}^{n+1} = - \frac{1}{2} \left\{ \left(r_i \Delta r_{i-1} - \frac{\Delta r_{i-1}^2}{4} \right) \left[\frac{(\rho c_p)_{i-1/2}}{\Delta t} T_i^n + \dot{q}_{i-1/2} \right] \right. \\
& + \left. \left(r_i \Delta r_i + \frac{\Delta r_i^2}{4} \right) \left[\frac{(\rho c_p)_{i+1/2}}{\Delta t} T_i^n + \dot{q}_{i+1/2} \right] \right\} , \tag{93}
\end{aligned}$$

where

$$f_i^n \equiv f(t^n, r_i).$$

The boundary conditions applied to the inner ($i=1$) and outer ($i=N$) surfaces are

$$-k \left. \frac{\partial T}{\partial r} \right|_{i=1, N} = \pm [h_\ell (T_\ell - T_i) + h_g (T_g - T_i)] . \tag{94}$$

Fig. 4.
Cylindrical wall geometry.

For example, application of this boundary condition to the inner surface (\$i=1\$) yields

$$\begin{aligned}
 & -\left\{ \frac{r_3/2 k_{3/2}}{\Delta r_1} + \frac{1}{2} \left[r_1 \Delta r_1 + \frac{\Delta r_1^2}{4} \right] \frac{(\rho c_p)_{3/2}}{\Delta t} + f_{ss} r_1 (h_\ell + h_g) \right\} T_1^{n+1} + \frac{r_3/2 k_{3/2}}{\Delta r_1} T_2^{n+1} \\
 & = -\frac{1}{2} \left(r_1 \Delta r_1 + \frac{\Delta r_1^2}{4} \right) \left[\frac{(\rho c_p)_{3/2}}{\Delta t} T_1^n + \dots \right] \\
 & + r_1 [h_\ell (f_t T_1^n - T_\ell^{n+1}) + h_g (f_t T_1^n - T_g^{n+1})] \quad . \quad (95)
 \end{aligned}$$

The parameters \$f_t\$ and \$f_{ss}\$ are 0 and 1, respectively, to provide maximal stability.

Note that the above formulation conveniently positions nodal points on material interfaces. Material properties are evaluated between nodes.

The resulting linear equations are solved in a sequential fashion in the axial (z) direction. For each axial position a solution is achieved using Gaussian elimination.

A lumped-parameter solution is available to the user if the number of nodes equals one. For this option the wall temperature is obtained from the equation,

$$T^{n+1} = \left\{ \frac{1}{2} \left(2\Delta r + \frac{\Delta r^2}{R_i} \right) \left(\frac{\rho c_p}{\Delta t} T^n + \dot{q}'' \right) + h_{\ell_i} (T_{\ell_i}^{n+1} - f_t T^n) \right. \\ \left. + h_{g_i} (T_{g_i}^{n+1} - f_t T^n) - \left(1 + \frac{\Delta r}{R_i} \right) [h_{\ell_o} (f_t T^n - T_{\ell_o}^{n+1}) + h_{g_o} (f_t T^n - T_{g_o}^{n+1})] \right\} \\ / \left\{ \frac{1}{2} \left(2\Delta r + \frac{\Delta r^2}{R_i} \right) \left(\frac{\rho c_p}{\Delta t} \right) + f_{ss} [h_{\ell_i} + h_{g_i} + \left(1 + \frac{\Delta r}{R_i} \right) (h_{\ell_o} + h_{g_o})] \right\} \quad (96)$$

The subscripts i and o refer to the inner and outer radii, respectively.

b. Slab Heat Conduction. Heat conduction within vessel structures (such as downcomer walls and support plates) is modeled in subroutine SLABHT. Only one slab is allowed in each fluid-dynamic cell. The number of nodes used to determine the temperature distributions is identical for all slabs within the vessel. The model includes the ability to account for the temperature effects in the slab properties (ρ , c_p , k , etc.). The temperature distribution is obtained from the one-dimensional conduction equation,

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) \quad (97)$$

The appropriate finite-difference equation is derived by applying an integral method to an elemental volume in a manner similar to that used for the cylindrical wall heat-conduction solution technique (Sec. III.B.1.a). The provision for a variable node spacing allows the location of nodes in regions where large or rapid temperature variations are anticipated.

The slab conduction model includes a symmetry (adiabatic) condition ($\partial T / \partial x|_{i=1} = 0$) at the first node. Newton's law

$$-k \frac{\partial T}{\partial x} \bigg|_{i=N} = [h_l(T_l - T_i)) + h_g(T_g - T_i)] \quad . \quad (98)$$

is applied to the outer ($i=N$) surface.

The ability to model an arbitrary number of interfaces between dissimilar materials also has been included in the slab conduction model. The solution technique is identical to the method used in the rod conduction model (Sec. III.B.1.c.i).

Heat slabs of arbitrary thickness and surface areas can be defined in any mesh cell (including core regions) to model the heat capacity of structures within the vessel. One HTC is computed for each slab using the local fluid conditions.

Although the slab conduction model is simplistic, it effectively analyzes the energy exchange between the fluid and the structures in a computational cell. However, the heat capacity and the effective time constant of the structural materials within a cell²⁴ must be modeled carefully. If there is only one structural component associated with a cell, the user must conserve the volume of that structure. If the characteristic thickness (distance to an adiabatic surface) or the surface area is well defined, the remaining geometric component (HSA or HSX in the TRAC input) may be calculated.

If several structural components are associated with one computational cell, an accurate slab model becomes more difficult to define. A useful technique²⁴ first defines an effective volume,

$$V = \frac{1}{\rho c_p} \sum_i (\rho_i c_{pi} V_i) \quad , \quad (99)$$

where the sum includes all material structures within the computational cell, and ρ and c_p are the user-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,

$$\rho c_p V (1 - \sum_n^N D_n e^{-\gamma_n^2 Fo}) = \sum_i \rho_i c_{pi} V_i [1 - \sum_n^N D_{ni} e^{-\gamma_{ni}^2 Fo_i}] \quad (100)$$

Equation (100) represents a series solution (composed of N terms) to the transient one-dimensional conduction equation. In Eq. (100),

$$Fo \equiv \frac{\alpha t}{L^2} \text{ (Fourier Number)} \quad ;$$

$$\alpha \equiv \frac{k}{\rho c_p} \quad ;$$

γ_n is a constant obtained from the transcendental equation, $\gamma_n \tan \gamma_n = Bi$;

$$Bi \equiv \frac{hL}{k} \text{ (Biot Number)} \quad ;$$

and

$$D_n = \frac{(2 \sin^2 \gamma_n)}{(\gamma_n^2 + \gamma_n \sin \gamma_n \cos \gamma_n)} \quad .$$

The right side of Eq. (100) is the total energy exchange for the time interval $0 \leq t' \leq t$ for each structure (i). The left side is the energy exchange for the effective slab. As in Eq. (99), the properties (ρ , c_p , k , h , ...) for the effective slab are specified by the user. With the effective length ($L = HSX$) determined from Eq. (100), the volume (V) from Eq. (99), and the user-specified properties, the remaining variable, which is the surface area per

cell ($HSA = V/L$), may be computed. The above formulation effectively can model the energy exchange between the vessel structures and the fluid.

c. Rod Heat Conduction. Subroutine RODHT analyzes the conduction of the reactor rods on a rod-by-rod basis. The formulation can model diverse rod geometries. Both nuclear and electrically heated rods can be analyzed. The effects of internal heat generation, gap conduction, metal-water reaction, and variable rod properties are included.

The numerical procedures can model the entire LOCA in a consistent and mechanistic fashion. The model also can resolve large axial (z) gradients characteristic of the reflood phase.

One computational rod is associated with each segment [that is, for each (r, θ) region] within the core. This "average" rod is coupled to the fluid by Newton's law of cooling. Any number of additional user-specified rods may be included in each segment. The rod power factors (that is, relative to the average rod located within each segment) also are specified by the user. The supplemental rods allow the user to include hot rods in the reactor vessel. Such rods do not affect the fluid-dynamics calculations.

i. Numerical Model. The thermal response of the vessel rods is modeled using the two-dimensional (r, z) cylindrical conduction equation. Azimuthal symmetry has been assumed.

$$\rho c_p \frac{\partial T}{\partial t} = \dot{q}''' + \frac{1}{r} \frac{\partial}{\partial r} \left(rk \frac{\partial T}{\partial r} \right) + \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) \quad (101)$$

The effects of internal heat generation resulting from nuclear fission, electrical current, or the metal-water reaction may be included.

Appropriate finite-difference equations are obtained by applying an integral method²³ to appropriate differential volumes. The noding within the rods (Fig. 5) is staggered with respect to the nodes used in the fluid-dynamics calculations. This noding scheme is necessary to simplify the algorithm that generates the fine mesh required by the reflood calculations. The staggered mesh gives the further advantage of providing axial numerical smoothing.

Fig. 5.
Rod geometry.

Differencing in the radial (r) direction is implicit. Therefore, large radial power variations do not create any numerical difficulties. Differencing in the axial (z) direction is explicit to simplify the computations and to reduce computer costs. The explicit differencing does limit the minimum axial spacing between nodes for a given time increment. However, this spacing is normally orders of magnitude less than that used by the fluid-dynamics calculations. The resulting finite-difference equations form a tridiagonal matrix for each row (z fixed) within the rod. The temperature distribution is obtained by using Gaussian elimination on each row in a sequential manner.

Consider a general differential volume (that is, the volume labeled 1 in Fig. 5). The finite-difference equation for this volume is

$$\begin{aligned}
 & \{(\rho c_p)_{ij} \frac{T_{ij}^{n+1} - T_{ij}^n}{\Delta t} - \dot{q}_{ij}\} \frac{1}{2} \left[\left(r_i \Delta r_i + \frac{\Delta r_i^2}{4} \right) + \left(r_i \Delta r_{i-1} - \frac{\Delta r_{i-1}^2}{4} \right) \right] \left[\frac{\Delta z_j + \Delta z_{j-1}}{2} \right] \\
 &= \left\{ r_{i+1/2} k_{i+1/2, j} \left(\frac{T_{i+1, j}^{n+1} - T_{ij}^{n+1}}{\Delta r_i} \right) + r_{i-1/2} k_{i-1/2, j} \left(\frac{T_{i-1, j}^{n+1} - T_{ij}^{n+1}}{\Delta r_{i-1}} \right) \right\} \\
 &\times \left[\frac{\Delta z_j + \Delta z_{j-1}}{2} \right] + \left\{ k_{i, j+1/2} \left(\frac{T_{i, j+1}^n - T_{ij}^n}{\Delta z_j} \right) + k_{i, j-1/2} \left(\frac{T_{i, j-1}^n - T_{ij}^n}{\Delta z_{j-1}} \right) \right\} \\
 &\times \frac{1}{2} \left[\left(r_i \Delta r_i + \frac{\Delta r_i^2}{4} \right) + \left(r_i \Delta r_{i-1} - \frac{\Delta r_{i-1}^2}{4} \right) \right] , \tag{102}
 \end{aligned}$$

where $f_{ij}^n \equiv f(t^n, r_i, z_j)$. In Fig. 5, the locations of nodes within the volumes located at the boundaries differ. This difference should be considered when values are assigned for the relative power densities at each node.

The boundary conditions applied to the vessel rods are

- the top ($z = z_u$) and bottom ($z = z_l$) of the rods are assumed to be insulated,

$$k \frac{\partial T}{\partial z} \bigg|_{z = z_l, z_u} = 0 ;$$

- the rod centerline ($r = 0$) is a line of symmetry,

$$\frac{\partial T}{\partial r} \bigg|_{r = 0} = 0 ; \text{ and}$$

- heat transfer at the inner and outer gap surfaces ($r = r_{\text{gap}}^-, r_{\text{gap}}^+$) and at the cladding surface ($r = r_o$) is specified using Newton's law,

$$k \frac{\partial T}{\partial r} \Big|_{r = r_{\text{gap}}^{\pm}} = - h_{\text{gap}}^{\pm} (T_{r_{\text{gap}}^-} - T_{r_{\text{gap}}^+}) \quad \text{and}$$

$$k \frac{\partial T}{\partial r} \Big|_{r = r_o} = - h_{\text{fluid}} (T_{r_o} - T_{\text{fluid}}) ,$$

where $h_{\text{gap}}^+ = h_{\text{gap}}^- (r_{\text{gap}}^- / r_{\text{gap}}^+)$ to conserve energy.

All properties (that is, ρ , c_p , and k) required by the difference equations are stored at the node locations. Linear interpolation is used to obtain properties between nodes (that is, at cell surfaces). A node located at the interface between two dissimilar materials requires two sets of properties. Consider the differential volume provided in Fig. 6. Application of an integral technique to this volume results in the differential equation (after dividing through by the volume),

$$\begin{aligned} \overline{(\rho c_p)}_{ij} \left(\frac{T_{ij}^{n+1} - T_{ij}^n}{\Delta t} \right) - \dot{q}_{ij} = & \{ r_{i+1/2} k_{i+1/2, j} \left(\frac{T_{i+1, j}^{n+1} - T_{ij}^{n+1}}{\Delta r_i} \right) \\ & + r_{i-1/2} k_{i-1/2, j} \left(\frac{T_{i-1, j}^{n+1} - T_{ij}^{n+1}}{\Delta r_{i-1}} \right) \} \left[\frac{(r_i \Delta r_i + \frac{\Delta r_i^2}{4}) + (r_i \Delta r_{i-1} + \frac{\Delta r_i^2}{4})}{2} \right]^{-1} \\ & + \{ \bar{k}_{i, j+1/2} \left(\frac{T_{i, j+1}^n - T_{ij}^n}{\Delta z_j} \right) + \bar{k}_{i, j-1/2} \left(\frac{T_{i, j-1}^n - T_{ij}^n}{\Delta z_{j-1}} \right) \} \left[\frac{\Delta z_j + \Delta z_{j-1}}{2} \right]^{-1} , \quad (103) \end{aligned}$$

where

$$\overline{(\rho c_p)}_{ij} \equiv \frac{[(\rho c_p)_{i^+, j}^{R^+} + (\rho c_p)_{i^-, j}^{R^-}]}{R^+ + R^-}$$

Fig. 6.

Node located at the interface between two dissimilar materials.

and

$$\bar{k}_{i,j+1/2} \equiv \frac{[k_{i+,j+1/2} R^+ + k_{i-,j+1/2} R^-]}{[R^+ + R^-]} .$$

In the above equations,

$$R^+ \equiv \left(r_i + \frac{\Delta r_i}{4} \right) \frac{\Delta r_i}{2} \quad (104)$$

and

$$R^- \equiv \left(r_i - \frac{\Delta r_{i-1}}{4} \right) \frac{\Delta r_{i-1}}{2} . \quad (105)$$

The superscript + (-) refers to the material to the right (left) of the interface.

ii. Reflood Algorithm. The reflood phase of a postulated LOCA is characterized by a sequence of heat-transfer and two-phase flow regimes advancing rapidly through the vessel core. A correctly predicted thermal response from the rods during 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 ($\Delta z \sim 1 \text{ mm}$).²⁵ The front advancement is controlled by two heat-removal mechanisms, the first being axial conduction from the dry region ahead of the quenched region to the wetted region behind the advancing film. The second is the precursory rod cooling associated with heat transfer to the droplets entrained in the advancing vapor field. The rod conduction model contains the necessary physics to analyze such phenomena. The need remains to define an algorithm capable of resolving the large gradients.

When reflood begins, supplemental rows of conduction nodes (Fig. 7) are inserted in the rod. The number of rows inserted within each fluid level is specified by the user. The rows are uniformly spaced (that is, Δz is constant) within each fluid level. The temperature values at the supplemental nodes are determined from a three-point Lagrangian interpolation technique. The interpolation is normalized to conserve the total rod energy. The nodes added in this fashion remain during the entire reflood phase.

To model the inherently nonstationary, Lagrangian quench-front motion and to resolve the related thermal gradients, a fine-mesh rezoning technique²⁶ is used during the reflood conduction calculations. The axial gradients encountered within the rewetting region are resolved by the insertion of rows of transitory nodes (Fig. 7). These nodes are added whenever the temperature difference between adjacent rod surface nodes exceeds a user-specified value ($T_{\max}$). The temperatures assigned to the nodes are required to conserve energy (Fig. 8),

$$\sum_{j=j_0}^{j_0+2} \rho'_{ij} c'_{p_{ij}} T'_{ij} V'_{ij} = \sum_{j=j_0}^{j_0+1} \rho_{ij} c_{p_{ij}} T_{ij} V_{ij}; \quad i = 1, \dots, \text{nodes} \quad (106)$$

The primed quantities denote rod properties after the nodes have been added. The values of ρ' , c'_p , and T' at the original node locations are set equal to

Fig. 7.
Fine-mesh rezoning.

Fig. 8.
Insertion of conduction nodes during reflood.

their original values. After the quench front has progressed beyond the location of the inserted rows and the surface temperature difference falls below a prescribed value ($\Delta T_{\min}$), the transitory nodes are eliminated. Temperatures at nodes axially adjacent to those deleted retain their original values. For small $\Delta T_{\min}$, this results in a negligible effect on the total rod energy.

Two values for $\Delta T_{\max}$ are specified by the user. The first and smaller value is applied to the part of the rewetting region that is in a nucleate- or transitional-boiling regime. The largest wall heat fluxes occur in these heat-transfer regimes. The second $\Delta T_{\max}$ value is applied to all other heat-transfer regimes. The specified values for the $\Delta T_{\max}$ are the bases of the $\Delta T_{\min}$ values, which are computed internally.

The above algorithm can analyze multiple quench fronts simultaneously. Both quenching and dryout are modeled automatically.

During the reflood phase, a number of surface conduction nodes are located within each fluid-dynamics cell. Therefore, it is necessary to calculate an effective wall temperature and HTC for the fluid-dynamics computations. These values are obtained by ensuring the conservation of the total energy transferred to the fluid within each cell. Values applied to the liquid phase that satisfy this criterion are

$$\bar{h}_l \equiv \frac{\sum_j h_{l,j} A_j}{\sum_j A_j}$$

and

$$\bar{T}_{w_l} \equiv \frac{\sum_j h_{l,j} A_j T_j}{\sum_j h_{l,j} A_j},$$

where the sum is taken over all surface nodes in each fluid cell. Similar values are used in the vapor phase.

It already has been noted that, for a given time step (Δt), a minimum spacing (Δz) between rows of conduction nodes exists because of the explicit axial differencing. For reflood calculations, this axial spacing can be violated, resulting in stability problems. To avoid such problems, the time step is limited internally by a diffusion number. The user also can specify minimum spacing ($\Delta z_{\min}$) beyond which supplemental rows of conduction nodes will not be added. This additional advantage can prevent excessively large computer costs.

Computing costs are reduced further by calculating material properties only at those nodes located at the edges of the fluid cells. Linear interpolation is used to obtain the properties at any additional locations required by the reflood calculations. However, the HTC's are obtained directly from the boiling curve for all rod surface nodes.

iii. Fuel-Cladding Gap Conductance. Two options are available in TRAC-PF1/MOD1 for the fuel-cladding gap conductance. If the input variable $NFCI = 0$, a constant input value for the gap conductance is used throughout the entire calculation. If the input variable $NFCI = 1$, the input value for the gap conductance becomes the initial value, and a thermal-expansion model is used to calculate the transient gap conductance.

Subroutine GAPHT calculates the gap HTC (h_{gap}) as a function of three components: gap gas conductance, fuel-cladding interfacial contact, and fuel-cladding thermal radiation;

$$h_{\text{gap}} = h_{\text{gas}} + h_{\text{contact}} + h_{\text{radiation}} \quad , \quad (107)$$

where

$$h_{\text{gas}} = \frac{k_{\text{gas}}}{\Delta r_{\text{gap}} + \delta} \quad , \quad (108)$$

$$h_{\text{radiation}} = \frac{\sigma F(T_f^4 - T_c^4)}{(T_f - T_c)} \quad , \quad (109)$$

and

$$F = \frac{1}{\frac{1}{\epsilon_f} + \frac{R_f}{R_c} \left(\frac{1}{\epsilon_c} - 1 \right)} \quad (110)$$

Subscripts f and c refer to fuel and cladding, respectively, and σ is the Stefan-Boltzmann constant. A value of 4.4×10^{-6} m is used for δ , which includes the mean surface roughness of the fuel and the cladding plus the temperature jump distances.^{27,28} The contact conductance, h_{contact} , is zero in the present code.

The fuel-cladding radial gas gap, Δr_{gap} , is found by using the uncoupled, quasi-static approximation.²⁹ In this approximation the mechanical coupling term in the energy equation and the inertial term in the mechanical force balance are omitted. By neglecting these terms we assume that the fuel-cladding strains minimally affect the temperature distribution and that displacements are instantaneous. Figure 9 shows the fuel-cladding gap system modeled in three regions: solid fuel, cracked fuel, and cladding. Gap changes

Fig. 9.
Fuel-rod geometry.

are found by calculating the radial displacement of each region caused by thermal expansion.

The calculations for the deformation of a hollow or solid circular cylindrical body of outer radius b and of height h are given in Ref. 29 for the case of plane strain where the ratio h/b is large compared to unity. Other assumptions are made that the cylindrical surfaces are free of forces and that axial displacement is allowed. Because the uncoupled, quasi-static approximation is used, the temperature distributions are assumed to be known from the energy balance. The radial displacement u is given by

$$u(r) = \frac{\alpha}{r(1-\nu)} \left[(1+\nu) \int_a^r T r \, dr + \frac{(1-3\nu)r^2 + a^2(1+\nu)}{b^2 - a^2} \int_a^b T r \, dr \right] , \quad (111)$$

where a is the inner radius of a cylindrical shell, ν is Poisson's ratio, and α is the linear thermal-expansion coefficient. Equation (111) is used to calculate the radial displacement of the cladding inner radius and the solid-fuel radius, $r = a$ and $r = r'$, respectively. The results are

$$u(a) = \frac{2\alpha_c a}{b^2 - a^2} \int_a^b T_c r \, dr \quad (112)$$

and

$$u(r') = \frac{2\alpha_f}{r'} \int_0^{r'} T_f r \, dr . \quad (113)$$

The cladding inner radius and the solid-fuel radius after thermal expansion are

$$a_{\text{new}} = a + u(a) \quad (114)$$

and

$$r'_{\text{new}} = r' + u(r') \quad . \quad (115)$$

A parabolic radial temperature distribution is assumed across the fuel pellet,

$$T_f = T_{cl} + \frac{(T_{\text{surf}} - T_{cl})r^2}{R^2} \quad , \quad (116)$$

where T_{cl} is the fuel centerline temperature and T_{surf} is the fuel surface temperature. A linear temperature profile is assumed across the cladding,

$$T = \frac{(T_{co} - T_{ci})(r - a)}{b - a} + T_{ci} \quad , \quad (117)$$

where T_{co} and T_{ci} are the cladding outside and inside temperatures, respectively; and a and b are the cladding inside and outside radii.

The following equation is used for the cracked-fuel thickness,

$$t = t_0 \left[1 + \frac{\alpha_f}{R - r'} \int_{r'}^R T_f dr \right] \quad , \quad (118)$$

where t_0 is the initial undeformed radial thickness of the cracked fuel,

$$t_0 = R - r' \quad . \quad (119)$$

The radial gap width after thermal expansion is

$$\text{gap width} = a_{\text{new}} - (r'_{\text{new}} + t) \quad (120)$$

or

$$\begin{aligned} \text{gap width} = & (a - r') + \frac{2\alpha_c a}{b^2 - a^2} \int_a^b T_c r \, dr - \frac{2\alpha_f}{r'} \int_0^{r'} T_f r \, dr \\ & - t_0 x^1 - \frac{\alpha_f}{R - r'} \int_{r'}^R T_f \, dr \quad (121) \end{aligned}$$

Subroutine DELTAR evaluates the fuel-cladding radial spacing.

iv. Metal-Water Reaction. When Zircaloy reaches a sufficiently high temperature in a steam environment, an exothermic reaction may occur that influences the peak cladding temperatures. The zirconium-steam reaction equation is

Given sufficient steam, the reaction rate equation^{30,31} is assumed valid,

$$\tau \frac{d\tau}{dt} = A \exp \left(-\frac{B}{T} \right) \quad (123)$$

where τ = total oxygen consumed (kg/m^2), $A = 16.8 \text{ kg}^2/\text{m}^4\text{s}$, and $B = 2.007 \times 10^4 \text{ K}$.

The kinetic parameter τ is converted to an effective zirconium-oxide layer thickness according to

$$1.5(R_0 - r) = \frac{\tau}{0.26\rho_{\text{ZrO}_2}}, \quad (124)$$

where

r = reacting surface radius (m),

R_0 = cladding outer radius (m), and

ρ_{ZrO_2} = density of zirconium oxide (kg/m^3).

Equation (124) is based on a reacted-material volume expansion of 50% in the radial direction. This assumption leads to $\rho_{\text{ZrO}_2} = 0.90 \rho_{\text{Zr}}$. Equation (124) allows Eq. (123) to be rewritten as

$$\tau \frac{d\tau}{dt} = -C(R_0 - r) \frac{dr}{dt},$$

where $C = (0.351 \rho_{\text{Zr}})^2$.

The method outlined in Ref. 30 is used to calculate the zirconium-oxide penetration depth and associated heat source. The mass per unit length of zirconium (m_{Zr}^{c}) consumed by the reaction in one time step is

$$m_{\text{Zr}}^{\text{c}} = \pi \rho_{\text{Zr}} [(r^n)^2 - (r^{n+1})^2]. \quad (125)$$

Equation (123) is used to calculate r^{n+1} , yielding

$$r^{n+1} = R_0 - [(R_0 - r^n)^2 + 2 \frac{A}{C} \Delta t \exp(-\frac{B}{T})]^{1/2}. \quad (126)$$

If a one-region cladding is assumed, the heat source ($\dot{q}_{mw}''$) added to the conduction equations is

$$\dot{q}_{mw}'' = 6.45 \times 10^6 \dot{m}_{Zr} [\Delta t (R_0^2 - R_i^2)\pi]^{-1}, \quad (127)$$

where R_i is the inner cladding radius and 6.45×10^6 J/kg corresponds to the energy released per kilogram of oxidized zirconium.

2. Wall-to-Fluid Heat Transfer. The wall-to-fluid HTC's are obtained from a generalized boiling curve constructed within subroutine HTCOR. The HTC correlations in HTCOR are used by all TRAC components under all conditions. Figure 10 shows a portion of the boiling curve, which is not dependent on the flow regime. The single-phase vapor and condensation regimes are not shown in this figure.

Fig. 10.
TRAC-PF1/MOD1 boiling curve.

The individual correlations used for each heat-transfer regime and the method of partitioning the energy between the two phases are discussed in this section. We have tried to make the boiling curve continuous between regimes; thus, we also discuss our methods to smooth the boiling curve.

a. Wall-to-Fluid HTC Selection Logic. Figure 11 outlines the HTC selection logic. The following sequence, corresponding to the numbers on the left side of Fig. 11, is used. If one step is not satisfied, then the next step is examined.

Step 1. Initialize subroutine HTCOR by calculating absolute values, the slip, and the flow and equilibrium qualities. If the slip is less than or equal to zero in HTCOR, it is set equal to 1.0.

Step 2. If $T_w < T_s$, $\alpha > 0.05$ and $T_w < T_g$; $T_w < T_s$, $\alpha > 0.05$, $T_w \geq T_g$, and $T_w < T_g$; or the liquid-vapor interface is present in the cell, the heat transfer is in the condensation regime. The Nusselt⁸ and Chen³² correlations, discussed in Sec. III.B.2.b.ii, are used in this regime to calculate the vapor and liquid HTCs, respectively. If the equilibrium quality, x_l , is less than or equal to 0.71, $h_g = 0$. For $x > 0.71$, h_g is found by linear interpolation between zero and the value obtained from the Nusselt analysis. The suppression factor, S , for the Chen correlation is set to zero. If $x_l > 0.71$, the limit of Chen's data base, then the Chen correlation is evaluated at $x = 0.71$, which gives h_l . Linear interpolation is used between h_l calculated corresponding to $x_l = 0.71$ and the single-phase vapor h_g of zero, for an equilibrium quality exceeding 0.71.

Step 3. If $0.96 < \alpha < 1.0$, a single-phase vapor HTC is calculated. When $\alpha > 0.98$, linear interpolation is used between the HTCs from the appropriate heat-transfer regime and the single-phase vapor values. The h_l is interpolated between $0.98 \leq \alpha \leq 0.999$; the h_g is interpolated between $0.98 \leq \alpha \leq 1.0$.

Step 4. When the input variable $ICHF = 0$, the boiling curve is not used to determine the liquid and vapor HTCs. These values are obtained from the two-phase mixture equations only (heat-transfer regime 7), described in Sec. III.B.2.b.vii.

Step 5. The forced-convection and nucleate-boiling HTCs are calculated by using the Chen correlation. At this point the heat-transfer regime has not been determined.

Fig. 11.
HTC correlation selection logic.

Step 6. If $T_w < T_l$ or $T_w < T_s$, the heat-transfer regime is single-phase liquid.

Step 7. The critical heat flux (CHF) and the corresponding temperature, T_{CHF} , are calculated next.

Step 8. If $T_w < T_{CHF}$, nucleate boiling exists.

Step 9. The minimum stable film-boiling temperature, T_{min} , is calculated by using the homogeneous-nucleation model. This correlation is discussed in Sec. III.B.2.d.

Step 10. If $T_w < T_{min}$, transition boiling exists. It previously has been determined that T_w is greater than the temperature at CHF conditions (step 8).

Step 11. If $T_w > T_{min}$, film boiling is occurring.

Step 12. The HTC's are restricted to zero or positive values. (For $\alpha > 0.999$, extrapolation occurs and a negative h_l could result. See step 3.) For $\alpha < 0.15$, the vapor heat flux is interpolated linearly from its value at $\alpha = 0.15$ to a value of 0.0 at $\alpha = 0.01$. The liquid heat flux is adjusted so that the total heat flux remains unchanged. Then, h_l and h_g are recalculated from the adjusted heat fluxes and the known temperature differences to prevent an extremely small mass of vapor from becoming superheated to an unrealistic value.

Step 13. The HTC's are averaged between the previous and the current time steps.

b. HTC Correlations. In this section we discuss the HTC correlations used in the construction of the boiling curve. In addition, the correlation for $ICHF = 0$ is discussed. Because TRAC-PF1/MOD1 is a nonequilibrium code, HTC's are needed for the liquid and the vapor phases; this partitioning of energy between the phases also is discussed. Table I, lists the TRAC-PF1/MOD1 heat-transfer regimes.

i. Single-Phase Liquid (Heat-Transfer Regimes 1 and 12). Either forced convection (regime 1) or natural convection (regime 12) can occur when single-phase liquid is present. Forced-convection correlations are used when the ratio of the Grashof number to the Reynolds number squared is less than or equal to 1.0. Laminar or turbulent forced-convection correlations are

TABLE I
TRAC-PF1/MOD1 HEAT-TRANSFER REGIMES

<u>IDREG</u> <u>(IHTF)</u>	<u>Wall-to-Fluid Heat-Transfer Regime</u>
1	Forced convection to single-phase liquid
2	Nucleate boiling
3	Transition boiling
4	Film boiling
6	Convection to single-phase vapor
7	Convection to two-phase mixture
11	Condensation
12	Liquid natural convection

available. These equations are contained in subroutine CHEN because they constitute one part of the Chen correlation. The laminar equation⁹ is

$$h_l = 4.0 \frac{k_l}{D_h} \quad (128)$$

The turbulent HTC is found from the Dittus-Boelter equation,²⁷

$$h_l = 0.023 \frac{k_l}{D_h} Re_l^{0.8} Pr_l^{0.4} \quad (129)$$

where the liquid Reynolds number is

$$Re = \frac{\rho_l V_l D_h}{\mu_l} \quad (130)$$

and the liquid Prandtl number is

$$Pr_l = \left(\frac{\mu c_p}{k} \right)_l . \quad (131)$$

All the properties are evaluated at T_l . The maximum of Eqs. (118) and (129) is set equal to the single-phase liquid forced-convection HTC, HFORC. In heat-transfer regime 1, the Chen F factor is set equal to 1.0.

In heat-transfer regime 12, natural convection to single-phase liquid, the maximum of the laminar and turbulent correlations for vertical flat plates and cylinders is used.³³ For laminar flow, the equation is

$$Nu = 0.59 (GrPr)^{0.25} ; \quad (132)$$

for turbulent flow,

$$Nu = 0.10 (GrPr)^{0.3333} ; \quad (133)$$

where the Grashof number is

$$Gr = \frac{g\beta |T_w - T_l| \rho_f^2 D_h^3}{\mu^2} , \quad (134)$$

the Prandtl number is

$$Pr = \left(\frac{\mu c_p}{k} \right)_l , \quad (135)$$

and the Nusselt number is

$$Nu = \frac{h_\ell D_h}{k_\ell} . \quad (136)$$

The maximum of the laminar and turbulent Nusselt numbers is used. To avoid extra calls to the thermodynamic property subroutine THERMO, all the properties are evaluated at T_ℓ except the density, ρ_f , and the volume coefficient of expansion, β ; these are evaluated by using a Taylor-series expansion about T_ℓ ,

$$\rho_f = \rho_\ell + \frac{\partial \rho_\ell}{\partial T} (T_f - T_\ell) , \quad (137)$$

$$\beta = - \frac{\partial \rho_\ell}{\partial T} \frac{1}{\rho_f} , \quad (138)$$

and

$$T_f = \frac{1}{2} (T_w + T_\ell) . \quad (139)$$

Two points should be noted about heat-transfer regimes 1 and 12. First, because only single-phase liquid is assumed to be present, the vapor HTC, h_g , is set equal to zero. Second, in Eq. (132) the hydraulic diameter, D_h , is used for the characteristic length even though the axial distance would be more appropriate, because the axial length would approach zero near the bottom of a channel. The characteristic-length term drops out of Eq. (133) and appears only to the -0.25 power in Eq. (132). Thus, the choice of the characteristic length has a small effect on the HTC.

ii. Nucleate-Boiling HTCs (Heat-Transfer Regime 2). The Chen correlation³² is used in heat-transfer regime 2, nucleate boiling.

In addition, the nucleate-boiling HTC correlation affects the transition-boiling regime through the interpolation between the CHF and the minimum stable film-boiling points. The Chen correlation has two parts, a forced-convection term multiplied by the Reynolds F factor and a nucleate-boiling term that contains the S factor,

$$h_l = h_{\text{forc}} + \min \left(1, \frac{T_w - T_s}{T_w - T_l} \right) h_{\text{nucb}} \quad , \quad (140)$$

where h_{forc} (HFORC in the code), with the F factor equal to 1.0, was discussed in the previous section, and the nucleate-boiling term is given by

$$h_{\text{nucb}} = 0.00122 \frac{k_l^{0.79} c_{pl}^{0.45} \rho_l^{0.49}}{\sigma^{0.5} \mu^{0.29} h_{lg}^{0.24} \rho_g^{0.24}} (T_w - T_s)^{0.24} (p_w - p)^{0.75} S \quad , \quad (141)$$

where p_w is the saturation pressure corresponding to the wall temperature, and F and S are functions that are given in graphical form by Chen. The Reynolds number factor, F,³⁴ can be expressed as

$$F = 1.0 \quad , \quad \text{for } \chi_{TT}^{-1} \leq 0.10 \quad ; \quad (142)$$

and

$$F = 2.35 (\chi_{TT}^{-1} + 0.213)^{0.736} \quad , \quad \text{for } \chi_{TT}^{-1} > 0.10 \quad ; \quad (143)$$

where χ_{TT}^{-1} , the Lockhart-Martinelli factor, is

$$\chi_{TT}^{-1} = \left(\frac{x}{1-x} \right)^{0.9} \left(\frac{\rho_l}{\rho_g} \right)^{0.5} \left(\frac{\mu_g}{\mu_l} \right)^{0.1} \quad . \quad (144)$$

The value of χ_{TT}^{-1} is restricted to a value less than 100.0.

The S factor³⁴ can be expressed as

$$S = [1 + 0.12(\text{Re}_{tp})^{1.14}]^{-1}, \quad \text{for } \text{Re}_{tp} < 32.5, \quad (145)$$

or

$$S = [1 + 0.42(\text{Re}_{tp})^{0.78}]^{-1}, \quad \text{for } 32.5 \leq \text{Re}_{tp} \leq 70.0, \quad (146)$$

where

$$\text{Re}_{tp} = \frac{10^{-4} |v_\ell| \rho_\ell (1 - \alpha)}{\mu_\ell} D_h F^{1.25}. \quad (147)$$

The value of Re_{tp} is restricted to a value less than 70.0.

The above correlations for the suppression factor do not approach the correct limit (zero) as the void fraction approaches one. In the above equations, $S \rightarrow 1.0$ as $\alpha \rightarrow 1.0$. The following procedure is used to ensure that S approaches the correct limit. For $\alpha > 0.70$, S is calculated at $\alpha_s = 0.70$, and at the current value of α and the minimum value of the two suppression factors, $S_{\min}$, is saved. Linear interpolation is then used between $S_{\min}$ and $S = 0$ at $\alpha = \alpha_c$,

$$S = \frac{S_{\min}(\alpha_c - \alpha)}{\alpha_c - \alpha_s}.$$

In TRAC-PF1/MOD1, $\alpha_c = 0.98$ and $\alpha_s = 0.70$. For $\alpha > \alpha_c$, $S = 0.0$.

The properties are evaluated at the liquid and vapor temperatures; x is the equilibrium quality, and V_ℓ is the liquid velocity parallel to the surface. Because the nucleate-boiling contribution to the Chen correlation was developed for saturated conditions,³² h_{nucb} is multiplied by a temperature ratio to adjust the HTC to the actual T_ℓ , Eq. (140). Because TRAC-PF1/MOD1

can calculate superheated liquids, the adjustment factor is restricted to a maximum of 1.0 so that the adjustment is made for subcooled liquid only.

The vapor HTC goes from zero at $T_w = T_s$ to the transition-boiling value at $T_w = T_{CHF}$ (Sec. III.B.2.b.iii); thus,

$$h_g = \left(\frac{T_w - T_s}{T_{CHF} - T_s} \right)^2 \max(h_{nc}, h_{dr}) ,$$

where h_{nc} and h_{dr} are the natural-convection and Dougall-Rohsenow HTCs, respectively. The vapor HTC is calculated in subroutine HVFILM. For a void fraction greater than a cutoff value, α_c , linear interpolation is used between the current values of h_l and h_g and the values that are calculated for single-phase vapor; that is, $h_l = 0$ and h_g , calculated as discussed in Sec. III.B.2.b.v. This linear interpolation ensures that the boiling curve is smooth between heat-transfer regimes.

iii. Transition-Boiling HTCs. (Heat-Transfer Regime 3). Transition boiling may be considered as a combination of nucleate and film boiling. A given spot on the wall surface is wet part of the time and dry during the remainder of the time. Therefore, contributions to the liquid and vapor HTCs exist for all conditions.

The total wall-to-fluid heat flux is obtained from a quadratic interpolation between the CHF and the minimum stable film-boiling points,³⁴

$$q_{trans} = \delta q_{CHF}'' + (1.0 - \delta) q_{min}'' , \quad (148)$$

where q_{CHF}'' is the heat flux at CHF conditions, found from the Biasi correlation (Sec. III.B.2.c), and q_{min}'' is the heat flux at the minimum stable film-boiling point, that is, the intersection of the transition- and the film-boiling points. This point is found from the homogeneous-nucleation

correlation, as discussed in Sec. III.B.2.d. Delta is a function of the wall temperature and the temperatures corresponding to q_{CHF} and q_{min} ,

$$\delta = \left(\frac{T_w - T_{min}}{T_{CHF} - T_{min}} \right)^2 . \quad (149)$$

The vapor HTC is

$$h_g = \max (h_{nc}, h_{DR}) ,$$

where h_{nc} and h_{DR} are the natural-convection and Dougall-Rohsenow HTCs, respectively. These correlations are discussed in the next section.

As in the nucleate-boiling heat-transfer regime, linear interpolation is used for $\alpha > \alpha_c$. The liquid HTC is

$$h_l = \frac{q_{trans} - h_g(T_w - T_g)}{T_w - T_l} .$$

iv. Film-Boiling HTCs (Heat-Transfer Regime 4). In the film-boiling heat-transfer regime, radiative and dispersed-flow heat transfers occur between the surface and the liquid; convective heat transfer occurs between the wall and the adjacent vapor. The liquid HTC is given by

$$h_l = (h_r + h_{fbb}) \left[\frac{T_w - T_s}{T_w - T_l} \right] + h_{df} ,$$

where h_{df} is the dispersed-flow HTC.

The radiative contribution is

$$h_r = (1 - \alpha)\sigma\epsilon\left(\frac{T_w^4 - T_s^4}{T_w - T_s}\right) , \quad (150)$$

where σ is the Stefan-Boltzmann constant and ϵ is the wall emissivity. In Eq. (150) the liquid absorptivity is 1.0.

The Bromley film-boiling HTC is h_{fbb} ,³⁵

$$h_{fbb} = 0.62 \left[\frac{\rho_g k_g^3 (\rho_l - \rho_g) g h'_{lg}}{\mu_g (T_w - T_s) \lambda} \right]^{1/4} , \quad (151)$$

where the characteristic length, λ , is

$$\lambda = 2\pi \left[\frac{\sigma}{g(\rho_l - \rho_g)} \right]^{1/2} .$$

The latent heat of vaporization is modified as suggested in Ref. 36,

$$h'_{lg} = h_{lg} + 0.5(c_p)_g(T_g - T_s) .$$

The dispersed-flow HTC, h_{df} , uses the Forslund and Rohsenow equation,³⁷ modified by multiplying $(1 - \alpha)$ by the entrained liquid fraction, E ; thus,

$$h_{df} = 0.2c_{l1}[(1 - \alpha)E]^{0.6667} \text{BRAC}^{0.25} \left(\frac{T_w - T_s}{T_w - T_l} \right) , \quad (152)$$

where c_1 is a constant equal to 1.2760 and

$$\text{BRAC} = \frac{g \rho_l \rho_g h_l k^3}{|T_w - T_s| \mu_g d_{\text{drop}}} .$$

The dispersed-flow HTC is set equal to zero if $(1 - \alpha)E > 0.05$.

Equation (152) is multiplied by the temperature ratio to change the base of the HTC from T_s to T_l . The droplet diameter, d_{drop} , is found from a Weber number criterion of 4.0,

$$d_{\text{drop}} = \frac{\text{We} \sigma}{\rho_g (V_g - V_l)^2} .$$

The droplet diameter is restricted to the range,

$$1.0 \times 10^{-4} \leq d_{\text{drop}} \leq 3.0 \times 10^{-3} .$$

The entrained liquid fraction is found in the following manner,

$$E = 0 , \quad \text{if } |V_g| \leq V_E ,$$

or

$$E = 1.0 - \exp 0.23[-(|V_g| - V_E)] , \quad \text{if } |V_g| > V_E ,$$

where the entrainment velocity is

$$V_E = 3.65 \left[\frac{(\rho_l - \rho_g) \sigma}{\rho_g^2} \right]^{1/4}$$

and E is restricted to values between 0.07 and 1.0.

The vapor HTC is the maximum of the Bromley, natural-convection, and Dougall-Rohsenow values,

$$h_g = \max(h_{nc}, h_{DR}) \quad (153)$$

The turbulent natural-convection equation³⁸ used in this heat-transfer regime is

$$h_{nc} = 0.13 k_g \left(\frac{\rho_g^2 |T_w - T_g|}{\mu^2 T_g} \right)^{0.333} Pr_g^{0.333} \quad (154)$$

The forced-convection equation is based on Dougall and Rohsenow's modification³⁹ to the Dittus-Boelter equation,³⁸

$$h_{fc} = 0.023 \frac{k_g}{D_h} \left\{ \frac{\rho_g [\alpha |V_g| + (1 - \alpha) |V_l|] D_h}{\mu_g} \right\}^{0.8} \left[\frac{\mu_g (c_p)_g}{k_g} \right]^{0.4},$$

where the Reynolds number is modified to reflect the volumetric flow rate of the two-phase mixture.

As in the previous heat-transfer regimes, linear interpolation is used for $\alpha > \alpha_c$.

v. Single-Phase Vapor HTCs (Heat-Transfer Regime 6). For the single-phase vapor heat-transfer regime, $h_l = 0$ and h_g is the maximum of Eq. (154), of turbulent natural convection, and of the Dittus-Boelter Eq. (129) evaluated with the use of vapor properties and flow conditions.

vi. Condensation HTCs (Heat-Transfer Regime 11). Nusselt's analysis⁸ is used to calculate the vapor HTC when condensation occurs. For an equilibrium quality $x \leq 0.71$, h_g is set to zero. For $x > 0.71$, h_g is found by linear interpolation between zero and the value of h_g found from Nusselt's analysis. The liquid HTC is calculated using the Chen correlation.³² The S factor is set equal to zero. The Chen correlation is based upon data taken

up to $x = 0.71$. For $x > 0.71$, the Chen correlation is evaluated at $x = 0.71$, and h_l is found by linear interpolation between the value of h_l at $x = 0.71$ and the single-phase vapor h_l of zero.

vii. Two-Phase Mixture HTC's (Heat-Transfer Regime 7). This heat-transfer regime is unique because it is not part of the boiling curve discussed previously. Regime 7 is used only when the input flag $ICHF = 0$. When $ICHF = 0$, h_l and h_g are calculated from regime 7 only. Critical heat flux cannot occur in this case.

If the void fraction is less than or equal to the cutoff void fraction, $h_g = 0$, and h_l is the maximum of the laminar and turbulent values,

$$h_l = \max (h_{l\text{lam}}, h_{l\text{turb}}) , \quad (155)$$

where

$$h_{l\text{lam}} = \frac{4k_l}{D_h} , \quad (156)$$

$$h_{l\text{turb}} = \frac{(0.023k_l Re_m^{0.8} Pr_l^{0.4})}{D_h} , \quad (157)$$

and

$$Re_m = \frac{GD_h}{\mu_m} . \quad (158)$$

The two-phase viscosity is calculated by using McAdam's equation,³⁸

$$\mu_m = \frac{1}{\frac{x_f}{\mu_g} + \frac{1-x_f}{\mu_l}}, \quad (159)$$

where x_f is the flow quality.

If the void fraction is greater than the cutoff void fraction, h_g is the maximum of the Dittus-Boelter value for vapor and the turbulent natural-convection value,

$$h_g = \max(h_{vnc}, h_{vturb}) \quad (160)$$

where the natural-convection value³⁸ is

$$h_{vnc} = 0.13k_g \left(\frac{\rho_g^2 |T_w - T_g|}{\mu_g^2 T_g} \right)^{0.333} Pr_g^{0.333} \quad (161)$$

and the forced-convection HTC is given by the Dittus-Boelter equation,

$$h_{vturb} = \frac{0.023k_g Re_g^{0.8} Pr_g^{0.333}}{D_h} \quad (162)$$

The Reynolds and Prandtl numbers in Eq. (162) are calculated by using vapor properties evaluated at the vapor temperature.

For $\alpha > \alpha_c$, linear interpolation is used between the current values of h_l and h_g and the single-phase values.

c. Critical Heat Flux (CHF). The CHF point has two purposes in relation to the TRAC-PF1/MOD1 boiling curve. First, the CHF point indicates the change from nucleate boiling (heat-transfer regime 2) to transition boiling (regime 3). Second, the CHF point is used in the quadratic interpolation that gives the transition-boiling liquid HTC. If the input variable ICHF = 1, the Biasi forced-flow CHF correlation⁴⁰ is used. For ICHF = 0 and for steady-state calculations (ISTDY = 1), no CHF calculation is performed. In the vessel ICHF = 1 is used always, and it also is recommended for other components.

The Biasi correlation has a data base that covers the mass-flux range, G , between 100 kg/m²s and 6000 kg/m²s. For mass-flux values between 0 and 200 kg/m²s, the Biasi correlation is evaluated at 200 kg/m²s. For negative values of G , the absolute value of G is used. The Biasi CHF correlation consists of two equations for q_{CHF}'' , and the maximum CHF value calculated by the two equations is used,

$$q_{CHF}'' = \frac{1.883 \times 10^7}{D_h^n G^{1/6}} \left[\frac{f_p}{G^{1/6}} - x \right] \quad (163)$$

and

$$q_{CHF}'' = \frac{3.78 \times 10^7}{D_h^n G^{0.6}} h_p (1 - x) \quad , \quad (164)$$

where

$$n = 0.4, \quad \text{for } D_h \geq 1 \text{ cm};$$

$$n = 0.6, \quad \text{for } D_h < 1 \text{ cm};$$

$$f_p = 0.7249 + 0.099p \exp(-0.032p);$$

$$h_p = -1.159 + 0.149p \exp(-0.019p) + \frac{8.99p}{10 + p^2};$$

D_h = hydraulic diameter (cm);

G = mass flux ($\frac{g}{cm^2 s}$);

p = pressure (bar); and

x = equilibrium quality.

Note that the Biasi correlation uses cgs units, but the constants in Eqs. (163) and (164) have been changed so that q_{CHF}' is in W/m^2 .

Predictions made with earlier versions of TRAC show that the Biasi correlation sometimes fails to predict CHF at high void fraction, even though the data indicate that CHF has occurred. To correct this problem, the Biasi correlation is used for a void fraction less than 0.97, and linear interpolation is used between the HTC at this void fraction and the one at 0.98, with the assumption that the T_{CHF} is one-half degree above T_s . For a void fraction greater than 0.98, the T_{CHF} is fixed at one-half degree above T_s .

Once q_{CHF}' is obtained, the temperature corresponding to the CHF point, T_{CHF} , is calculated by using a Newton-Raphson iteration⁴¹ to determine the intersection of the heat flux found by using the nucleate-boiling HTC and the CHF. An iteration is required because $T_w = T_{CHF}$ must be known to evaluate the Chen correlation; and, in turn, the Chen HTC must be known to calculate the wall temperature,

$$q_{CHF}' = h(T_w - T_s) \quad (165)$$

The equation for T_{CHF} is

$$T_{CHF}^{n+1} = T_{CHF}^n - \frac{(T_{CHF}^n - T_s - \frac{q_{CHF}^n}{h})}{[1 + (\frac{q_{CHF}^n}{h^2} \frac{dh}{dT_w})]}, \quad (166)$$

where T_{CHF}^n is the CHF temperature for the n th iteration, h is the HTC evaluated by using the Chen correlation, and dh/dT_w is the derivative of the HTC with respect to the wall temperature.

Convergence occurs if $|T_{CHF}^{n+1} - T_{CHF}^n| < 1.0$. A maximum of ten iterations is allowed; if convergence does not occur, a message is printed and a fatal error occurs.

The CHF temperature is restricted to the range, $T_s + 0.5 \leq T_{CHF} \leq T_s + 100$. The CHF calculations are done in subroutines CHF and CHF1.

d. Minimum Stable Film-Boiling Temperature, T_{min} . The minimum stable film-boiling point is the intersection point between the transition- and film-boiling heat-transfer regimes (Fig. 10). In addition, this point is one of the points used in the interpolation scheme for the calculation of the transition-boiling heat flux.

The homogeneous-nucleation minimum stable film-boiling temperature correlation⁴² is

$$T_{min} = T_{nh} + (T_{nh} - T_l)R^{0.5}, \quad (167)$$

where

$$R = \frac{(k\rho c)_l}{(k\rho c)_w} \quad (168)$$

and T_{nh} is the homogeneous-nucleation temperature. In Eq. (168) the subscript l indicates liquid properties and the subscript w indicates wall properties. The homogeneous-nucleation temperature is given by Fauske, and a curve fit to these results, from the COBRA-TF code,* is used in TRAC-PF1/MOD1.

$$T_{nh} = 705.44 - (4.722 \times 10^{-2})DP \\ + (2.3907 \times 10^{-5})DP^2 \\ - (5.8193 \times 10^{-9})DP^3 ,$$

where $DP = 3203.6 - P$. The pressure P is in psia units, and T_{nh} is in degrees Fahrenheit. In TRAC-PF1/MOD1, P is converted to a temporary variable in British units, and T_{nh} is converted to Kelvin after the equation is evaluated.

After T_{min} is evaluated, the corresponding heat flux, q'_{min} , in the transition-boiling HTC interpolation can be calculated,

$$q'_{min} = h_{lmin}(T_{min} - T_l) + h_{gmin}(T_{min} - T_g) + h_{fbb}(T_{min} - T_{sat}) ,$$

where h_{lmin} and h_{gmin} are the liquid and vapor HTCs, respectively, evaluated at the minimum stable film-boiling temperature. Thus,

$$h_{lmin} = h_r \left(\frac{T_{min} - T_s}{T_{min} - T_l} \right) + h_{df}$$

and

$$h_{gmin} = \max (h_{nc}, h_{DR}) .$$

*This information was provided by M. J. Thurgood and J. M. Kelley, Battelle Pacific Northwest Laboratories (December 1979).

If $\alpha > \alpha_c$, linear interpolation again is used between the values of the HTC's at α_c and the single-phase vapor values.

e. Steady-State Calculations. The steady-state (ISTDY = 1) and transient (ISTDY = 0) wall-to-fluid HTC code logics differ. The entire boiling curve is not available to rods during steady state; only that part of the heat transfer before CHF is calculated (Sec. III.B.2.a).

C. Reactor Kinetics

Subroutine RKIN evaluates power generation in the reactor core by one of two methods. In the first method the user specifies power to be a constant or defined by a power table supplied through input. The table is a function of a system signal-variable parameter or a control-block output parameter. Values between entries in the table are determined by linear interpolation. Power determination can be trip controlled by evaluating the power table when the controlling trip is ON and by holding the power constant when the trip is OFF. In the second method, the user determines power from the solution of the point-reactor kinetics equations. These equations specify the time behavior of the core power level with neutronic reactivity (R) [the sum of programmed reactivity (R_{prog}) and feedback reactivity (R_{fdbk})] as the driving function. The user inputs programmed reactivity (defining reactivity effects not accounted for by feedback reactivity, such as fuel reactivity and control-rod movement) with the same forms that define power in the first method. Subroutine RFDBK evaluates feedback reactivity based on changes in the core-averaged fuel temperature, coolant temperature, coolant vapor fraction, and boron concentration.

The point-reactor kinetics equations are a coupled set of (I+1) first-order differential equations defining the total thermal power P and the delayed-neutron precursor concentrations C_i as a function of time.

$$\frac{dP}{dt} = \frac{R - \beta}{\Lambda} P + \sum_{i=1}^I \lambda_i C_i \quad (169)$$

and .

$$\frac{dC_i}{dt} = -\lambda_i C_i + \frac{\beta_i P}{\Lambda} \quad , \text{ for } i = 1, 2, \dots, I \quad , \quad (170)$$

where

P = total thermal power (W) that results from fissions occurring at time t ,

t = problem time (s),

R = neutronic reactivity = $(k - 1)/k = R_{\text{prog}} + R_{\text{fdbk}}$,

k = reactor multiplication constant = $k_{\text{prog}} + \Delta k_{\text{fdbk}}$,

R_{prog} = programmed reactivity = $(k_{\text{prog}} - 1)/k_{\text{prog}}$,

R_{fdbk} = feedback reactivity = $(\Delta k_{\text{fdbk}}/k_{\text{prog}})/k$,

β = total fraction of delayed neutrons = $\sum_i^I \beta_i$,

β_i = fraction of delayed neutrons in group i ,

Λ = effective prompt-neutron lifetime (s),

λ_i = decay constant for the delayed-neutron precursors in group i (s^{-1}),

C_i = concentration of the delayed-neutron precursors in groups i (W), and

I = number of delayed-neutron groups.

The TRAC-PF1/MOD1 program uses the Kaganove method⁴³ to solve these equations.

The prompt-fission power solution is applied to the decay-heat equations

$$\frac{dH_j}{dt} = -\lambda_j^H H_j + E_j P \quad , \text{ for } j = 1, 2, \dots, J, \quad (171)$$

where

H_j = concentration of decay-heat group j (W · s),

λ_j^H = decay constant for decay-heat group j (s^{-1}),

E_j = effective energy fraction of decay-heat group j , and

J = number of decay-heat groups.

Then, each j th equation is solved for H_j . After this is done, the total thermal power generated in the reactor fuel at time t from prompt fission, precursor decay, and delayed fission is

$$P_{\text{eff}} = \left(1 - \sum_j E_j\right)P + \sum_j \lambda_j^H H_j \quad (172)$$

The user inputs the number of delayed-neutron groups, I ; the delayed-neutron parameters, λ_i and β_i ; the number of decay-heat groups, J ; the decay-heat parameters, λ_j^H and E_j ; and either the prompt-fission power history $P(-t)$ for $-t \leq 0$ or the initial delayed-neutron precursor concentrations $C_i(0)$ and decay-heat concentrations, $H_j(0)$. If $I \leq 0$ is input, TRAC internally sets I to 6 and defines λ_i and β_i with the values in Table II. If $J \leq 0$ is input, TRAC internally sets J to 11 and defines λ_j^H and E_j with the values in Table III. The power decay that these parameters evaluate closely approximates the standard American Nuclear Society (ANS) decay-heat curve.⁴⁴

If $I \leq 0$ and/or $J \leq 0$ and no prompt-fission power history is input, we assume that an initial steady-state condition exists to initialize $C_i(0)$ and/or $H_j(0)$ internally in TRAC. This requires use of the initial power $P(0)$ that is input. If dC_i/dt and dH_j/dt are set to zero at the initial time ($t = 0$) in Eqs. (170) and (171), then

$$C_i(0) = \frac{\beta_i}{\lambda_i \Lambda} P(0) \quad , \text{ for } i = 1, 2, \dots, I, \quad (173)$$

and

$$H_j(0) = \frac{E_j}{\lambda_j^H} P(0) \quad , \text{ for } j = 1, 2, \dots, J \quad (174)$$

TABLE II
DELAYED-NEUTRON CONSTANTS

<u>Group i</u>	<u>Decay Constant $\lambda_i(s^{-1})$</u>	<u>Neutron Fraction β_i</u>
1	3.87	0.000 169
2	1.40	0.000 832
3	0.311	0.002 64
4	0.115	0.001 22
5	0.031 7	0.001 38
6	0.012 7	0.000 247

))

TABLE III
DECAY-HEAT CONSTANTS

<u>Group j</u>	<u>Decay Constant $\lambda_j^H(s^{-1})$</u>	<u>Energy Fraction E_j</u>
1	1.772	0.002 99
2	0.577 4	0.008 25
3	0.067 43	0.015 50
4	0.006 214	0.019 35
5	4.739×10^{-4}	0.011 65
6	4.810×10^{-5}	0.006 45
7	5.344×10^{-6}	0.002 31
8	5.726×10^{-7}	0.001 64
9	1.036×10^{-7}	0.000 85
10	2.959×10^{-8}	0.000 43
11	7.585×10^{-10}	0.000 57

TRAC evaluates $C_i(0)$ and $H_j(0)$ from Eqs. (170) and (171) if the prompt-fission power history $P(-t)$ is entered with tabular data (t_ℓ, P_ℓ) pairs for $\ell = 1, 2, \dots, L$ where $-t_{\ell+1} < -t_\ell \leq 0$. The prompt-fission power is assumed to vary linearly between data pairs in the power-history table, that is,

$$P(t) = a_\ell + b_\ell t \quad , \text{ over the time interval, } -t_{\ell+1} \leq t \leq -t_\ell \quad . \quad (175)$$

Substituting Eq. (175) into Eq. (170) and integrating the resulting equation analytically from $t = -t_L$ [where $C_i(-t_L) = 0$ is assumed] to $t = 0$ gives

$$C_i(0) = \frac{\beta_i}{\lambda_i \Lambda} \sum_{\ell=1}^{L-1} \left\{ \left(\frac{a_\ell - b_\ell}{\lambda_i} \right) (1 - \exp [-\lambda_i(t_{\ell+1} - t_\ell)]) \right. \\ \left. + b_\ell(t_{\ell+1} \exp [-\lambda_i(t_{\ell+1} - t_\ell)] - t_\ell) \right\} \exp [-\lambda_i t_\ell] \quad . \quad (176)$$

A similar expression for $H_j(0)$ is obtained by doing the same for Eq. (171). The expression for $H_j(0)$ is Eq. (176) with replacement of C_i by H_j , λ_i by λ_j^H , β_i by E_j , and Λ by 1. TRAC-PF1/MOD1 evaluates these two expressions for $C_i(0)$ and $H_j(0)$ when a prompt-fission power-history table is input.

Subroutine RFDBK evaluates reactivity feedback. The reactivity-feedback model is based on the assumption that only changes in the core-averaged fuel temperature (T_f), coolant temperature (T_c), coolant vapor fraction (α), and boron concentration (B_m or B_r) affect the neutron-multiplication reactivity of the reactor core. The code determines core-averaged values by applying fuel- or coolant-mass times power-weighting factors to the temperatures and a power-weighting factor to the coolant vapor fraction and boron concentration. These factors approximate the product of the local adjoint flux, neutron flux, and volume. This weighting-factor product is taken from perturbation theory where it is used to weight spatially the change in reaction-rate cross sections to estimate their reactivity change. It is approximated in TRAC by the product of the coolant-channel volume and the fission-power density distribution raised to a user-specified power POWEXP. For POWEXP = 1.0, the adjoint-flux distribution is being approximated by the fission reaction-rate cross-section distribution. For POWEXP = 2.0, when the fission reaction-rate cross section is spatially constant, the adjoint flux is being approximated by the neutron flux (Galerkin approximation). The appropriate value to use for POWEXP will depend on the fuel-loading distribution in the reactor core. However, keep in mind that two levels of approximation are being made: first, that the coolant-channel volume times the fission-power density distribution raised to the POWEXP power is a good approximation for the perturbation-theory product of the adjoint flux, neutron flux, and volume and, second, that the

theoretical basis for the use of that weighting factor for reaction-rate cross sections can be applied to the reactivity-feedback parameters we wish to average over the reactor core. The user has the option of replacing any of the three spatial shapes (fuel-rod radial, core horizontal plane, and core axial) in the fission-power density distribution with a different shape to weight the spatial averaging of reactivity-feedback parameters over the core. These spatial-shape replacements are specified through input.

The user defines a reactivity coefficient for each of the reactivity-feedback independent variable parameters, $x = T_f, T_c, \alpha$, and B_m or B_r , by choosing one of the reactivity-coefficient forms in Table IV. Each reactivity coefficient is defined through input by a table of reactivity-coefficient values that are dependent on all four reactivity-feedback parameters. Each parameter has one or more values specified in defining the table. Defining one value for a parameter corresponds to the reactivity coefficient having no dependence on that reactivity-feedback parameter. Defining two or more values for a parameter gives the reactivity-coefficient dependence on it. Linear interpolation is used to evaluate the reactivity coefficient for values of each parameter between its table values. Multidimensional linear-surface interpolation is performed when the reactivity coefficient is dependent on two or more of the reactivity-feedback parameters.

TABLE IV
REACTIVITY-COEFFICIENT FORMS

<u>Form Number</u>	<u>Reactivity-Coefficient Form</u>
0	$\frac{\partial k}{\partial x}$
1	$\frac{1}{k} \frac{\partial k}{\partial x} \approx \frac{\partial R}{\partial x}$
2	$x \frac{\partial k}{\partial x}$
3	$\frac{x}{k} \frac{\partial k}{\partial x} \approx x \frac{\partial R}{\partial x}$

Boron in the derivative and dependence of a reactivity coefficient are defined in terms of the boron concentration in the coolant channel B_m in units of kg/m^3 or the boron mass to liquid-coolant mass ratio B_r in units of boron mass/liquid-coolant mass parts per million (ppm). The boron reactivity coefficient is based on the change in the amount of boron without changing T_c and α when the coefficient is defined as a derivative of B_r . The boron dependence of a reactivity coefficient is important when the reactivity-coefficient value is sensitive to a shift in the neutron-energy spectrum. Through the proportionality to the amount of neutron capture in boron, B_m or B_r dependence characterizes this shift.

All forms of boron in the reactor core are included in the evaluation of B_m or B_r for boron dependence: dissolved boric acid in the liquid coolant, boric acid plated on core structure, borosilicate glass in burnable-poison pins, and boron oxide in control-rod-cluster pins. The first two forms are based on boron convection into the reactor core from throughout the modeled system and on plateout of boric acid in the core as a result of coolant dryout. The burnable-poison pin and control-rod-cluster pin forms are to be defined by the user through input with what would be their equivalent boron concentrations in the coolant channel. The equivalent burnable-poison pin boron concentration is input as a first-order polynomial function of the core-averaged coolant temperature T_c ,

$$BPP = BPPO + BPP1 \cdot T_c \quad (\text{kg/m}^3, \text{ boron mass in the coolant-channel volume}).$$

(177)

Whereas the physical amount of boron in the burnable-poison pins is constant during the transient, its equivalent concentration for neutron capture increases with coolant temperature because of reduced spatial self-shielding of boron to neutrons in the burnable-poison pins. The amount of control-rod-cluster pin boron in the reactor core depends on the amount of control-rod

insertion into the core. Its equivalent concentration is input as a first-order polynomial function of programmed reactivity R_{prog} ,

$$\text{BCR} = \text{BCRO} + \text{BCR1} \cdot R_{\text{prog}} \text{ (kg/m}^3\text{, boron mass in the coolant-channel volume) } . \quad (178)$$

Programmed reactivity is assumed to be proportional to the amount of effective boron-mass change caused by control-rod movement in the core. Initially, $\text{BCR} = \text{BCRO}$ when the reactor core was at steady-state conditions.

Only the first two forms of boron in the reactor core are included in the evaluation of B_m or B_r for the boron reactivity-coefficient derivative parameter because the amount of boron in burnable-poison pins is constant during the transient that is being evaluated. Control-rod movement changes the amount of boron, but the reactivity change associated with this change is accounted for in the user-defined programmed reactivity R_{prog} .

After all four reactivity coefficients are evaluated by linear interpolation in their four dimensionally dependent tables, feedback reactivity is evaluated in terms of its change in the neutron multiplication constant over the last time step Δt^{n-1}

$$k(t^n - \Delta t^{n-1})k(t^n)R_{\text{fdbk}}(t^n) = \Delta k_{\text{fdbk}}(t^n) = \sum_{i=1}^4 \frac{1}{2} \left[\frac{\partial k(t^n)}{\partial x_i} + \frac{\partial k(t^n - \Delta t^{n-1})}{\partial x_i} \right] \times [x_i(t^n) - x_i(t^n - \Delta t^{n-1})] , \quad (179)$$

where $x_1 = T_f$, $x_2 = T_c$, $x_3 = \alpha$, and $x_4 = B_m$ or B_r . The value of $\partial k(t^n)/\partial x_i$ in Eq. (179) for reactivity-coefficient forms 1, 2, and 3 (Table IV) is obtained by multiplying these reactivity coefficients by $k(t^n - \Delta t^{n-1})$, $1/x_i(t^n)$, and $k(t^n - t^{n-1})/x_i(t^n)$, respectively. Using $k(t^n - t^{n-1})$ rather than $k(t^n)$ (which is not known yet) to convert reactivity-coefficient forms 1 and 3 to k/x_i is an approximation. The values of k/x_i and x_i at time t^n (the start of the present time step) are evaluated as described above; their values at

time $t^n - \Delta t^{n-1}$ are those saved from their evaluation at the start of the previous time step.

The change in x_i over the last time step (with the other x_i parameters held constant) is defined in the last factor of Eq. (179). B_m or B_r includes only dissolved boric acid in the liquid coolant and boric acid plated on the core structure. There is no change in the B_r equivalent boron concentration in burnable-poison pins when T_f , T_c , and α do not vary.

To determine reactivity feedback during the current time step $\Delta t^n = t^{n+1} - t^n$, TRAC would need to know the end-of-time-step values of T_f , T_c , α , B_m , and B_r . To evaluate that reactor-core state requires knowing the current core state and the total energy-generation rate, $P_{eff}(t)$, over the time step $t^n \leq t \leq t^{n+1}$. The neutronic reactivity $R(t)$ defined by the reactivity-feedback contribution, $R_{fdbk}(t)$, must be known to determine the value of $P_{eff}(t)$ from the solution of the reactor-kinetics equations. Thus, the evaluation of reactivity feedback during the current time step requires first knowing what it is.

This difficulty of needing to know the reactivity feedback to evaluate it is handled in TRAC by assuming its Δk feedback-reactivity rate is zero. The Δk programmed-reactivity rate is assumed to be the same as in the previous time step, Δt^{n-1} ,

$$(\Delta k_{prog}^{est})^n = \Delta t^n \left\{ \frac{k_{prog}(t^n) - k_{prog}(t^n - \Delta t^{n-1})}{\Delta t^{n-1}} \right\} \quad (180)$$

We estimate $(\Delta k_{prog})^n$ because the independent variable needed to evaluate its tabular definition generally is a function of the reactor-core state. A similar approximation for $(\Delta k_{fdbk}^{est})^n$ was tested in TRAC, but near steady state it caused the value sign of $(\Delta k_{fdbk}^{est})^n$ to change each time step. It is better to assume that $(\Delta k_{fdbk}^{est})^n = 0$ than to estimate its value based on its value in the

previous time step. Thus, the reactor multiplication constant and neutronic reactivity are estimated for the end of the present time-step reactor state by

$$(k^{est})^n = k(t^n) + (\Delta k_{prog}^{est})^n \quad (181)$$

and

$$(R^{est})^n = \frac{[(k^{est})^n - 1]}{(k^{est})^n} \quad (182)$$

After each time-step solution, TRAC compares the actual programmed reactivity with its estimated value. Any discrepancy is corrected by applying

$$(\Delta k^{cor})^{n+1} = [(\Delta k_{prog})^n - (\Delta k_{prog}^{est})^n] \cdot \min\left(\frac{\Delta t^n}{\Delta t^{n+1}}, 2\right) \quad (183)$$

during the next time step, Δt^{n+1} . To prevent a time-step reactivity correction from becoming very large by applying it over a much smaller time step $\Delta t^{n+1} \ll \Delta t^n$, $(\Delta k^{cor})^{n+1}$ in Eq. (183) is constrained to be no more than twice the Δt^n time-step value. Including this correction and the actual reactivity-feedback change in Δk during the previous time step in the reactor multiplication constant end-of-time-step estimate gives Eq. (181) a modified form,

$$(k^{est})^n = k(t^n) + (\Delta k_{prog}^{est})^n + (\Delta k^{cor})^n + (\Delta k_{fdbk})^{n-1} \quad (184)$$

In this procedure, we assume $(\Delta k^{cor})^n$ and $(\Delta k_{fdbk})^{n-1}$ are small enough not to require an iterative evaluation of the present time-step solution but that $(\Delta k^{cor})^n$ is large enough to be included in the next time-step solution rather

than be neglected. A similar estimate and correction procedure is applied to the end-of-time-step power in the first method for specifying the total power.

The point-reactor kinetics equations [Eqs. (169)-(171)] are solved by the Kaganove method.⁴³ Its derivation in Ref. 43 approximates the time dependence of P and $k_{ex} = k - 1 = R/(1 - R)$ over each integration time step by second-order polynomials and assumes $\Lambda(t) = \ell/[1 + k_{ex}(t)]$ where ℓ is a constant. For TRAC, it is more appropriate to approximate the time dependence of P by a second-order polynomial, R by a first-order polynomial, and Λ by a constant because TRAC extrapolates its estimate of $R(t)$ over the fluid-dynamics time step to be evaluated and because the weak time dependence of Λ generally is unknown. These modified assumptions, when applied to the point-reactor kinetics equations, simplify the form that these equations take when analytically integrated over the integration time step Δt . The derivation of those analytically integrated equations follows. TRAC then evaluates them for $\Delta t^n/\Delta t$ integration time steps during the Δt^n fluid-dynamics time step.

We assume that

$$P(t) = P(0) + P_1 t + P_2 t^2, \quad (185)$$

$$R(t) = R(0) + R_1 t, \quad (186)$$

and Λ , λ_i , β_i , λ_j^H , and E_j are constant for $0 \leq t \leq \Delta t$, where $P(0)$, $R(0)$, and $R_1 = [(R^{est})^n - R(0)]/\Delta t^n$ are known values. Solving Eq. (170) for $C_i(t)$ in terms of a functional of the prompt-fission power $P(t)$ gives

$$C_i(t) = C_i(0) \exp[-\lambda_i t] + \frac{\beta_i}{\Lambda} \int_0^t \exp[-\lambda_i(t - \tau)] P(\tau) d\tau. \quad (187)$$

Substituting Eq. (187) into Eq. (169) and integrating the resulting equation term-by-term gives

$$P(t) = P(0) + \int_0^t \frac{R(\tau)P(\tau)}{\Lambda} d\tau - \sum_i \frac{\beta_i}{\Lambda} \int_0^t \exp[-\lambda_i(t-\tau)] P(\tau) d\tau + \sum_i c_i(0) [1 - \exp[-\lambda_i t]] \quad (188)$$

Substituting Eq. (185) for $P(\tau)$ and Eq. (186) for $R(\tau)$ in Eq. (188), evaluating the integrals, and rearranging the resulting equation in terms of the P_1 and P_2 unknowns gives

$$a_1(t)P_1 + a_2(t)P_2 = q(t) \quad , \quad (189)$$

where

$$\begin{aligned} a_1(t) &= t\Lambda - t^2 \left[\frac{1}{2} R(0) + \frac{1}{3} R_1 t \right] + \sum_i \beta_i t^2 I_{i1}(t) \quad , \\ a_2(t) &= t^2 \Lambda - t^3 \left[\frac{1}{3} R(0) + \frac{1}{4} R_1 t \right] + \sum_i \beta_i t^3 I_{i2}(t) \quad , \\ q(t) &= t \left[R(0) + \frac{1}{2} R_1 t \right] P(0) + \sum_i [\Lambda \lambda_i c_i(0) - \beta_i P(0)] t I_{i0}(t) \quad , \end{aligned}$$

and

$$t^{m+1} I_{im}(t) = \int_0^t \exp[-\lambda_i(t-\tau)] \tau^m d\tau \quad , \text{ for } m = 0, 1, 2 \quad .$$

The P_1 and P_2 polynomial coefficients are evaluated by requiring Eq. (189) to be satisfied for $t = \Delta t$ (at the end of the integration time step) and $t = \Delta t/2$ (at the midpoint of the integration time step). Solving the two equations

$$a_1(\Delta t)P_1 + a_2(\Delta t)P_2 = q(\Delta t) \quad (190)$$

and

$$a_1\left(\frac{\Delta t}{2}\right)P_1 + a_2\left(\frac{\Delta t}{2}\right)P_2 = q\left(\frac{\Delta t}{2}\right) \quad (191)$$

for P_1 and P_2 gives

$$P_1 = \frac{[q(\Delta t)a_2(\frac{\Delta t}{2}) - q(\frac{\Delta t}{2})a_2(\Delta t)]}{D} \quad (192)$$

and

$$P_2 = \frac{[q(\frac{\Delta t}{2})a_1(\Delta t) - q(\Delta t)a_1(\frac{\Delta t}{2})]}{D}, \quad (193)$$

where $D = a_1(\Delta t)a_2(\Delta t/2) - a_1(\Delta t/2)a_2(\Delta t)$. The prompt-fission power at the end of the integration time step $t = \Delta t$ from Eq. (185) is

$$P(\Delta t) = P(0) + P_1\Delta t + P_2\Delta t^2 \quad (194)$$

If we know $P(t)$ for $0 \leq t \leq \Delta t$, we evaluate $C_i(\Delta t)$ by substituting Eq. (185) into Eq. (187) and using $\Delta t I_{i0}(\Delta t) = [1 - \exp[-\lambda_i \Delta t]]/\lambda_i$ from analytically integrating its definition in Eq. (189).

$$C_i(\Delta t) = C_i(0)[1 - \lambda_i \Delta t I_{i0}(\Delta t)] + \frac{\beta_i}{\lambda_i} [P(0) \Delta t I_{i0}(\Delta t) + P_1 \Delta t^2 I_{i1}(\Delta t) + P_2 \Delta t^3 I_{i2}(\Delta t)] \quad , \text{ for } i = 1, 2, \dots, I \quad (195)$$

The decay-heat equations are evaluated in the same way to give

$$H_j(\Delta t) = H_j(0)[1 - \lambda_j^H \Delta t I_{j0}(\Delta t)] + E_j [P(0) \Delta t I_{j0}(\Delta t) + P_1 \Delta t^2 I_{j1}(\Delta t) + P_2 \Delta t^3 I_{j2}(\Delta t)] \quad , \text{ for } j = 1, 2, \dots, J \quad (196)$$

where $\Delta t^{m+1} I_{jm}(\Delta t) = \int_0^{\Delta t} \exp[-\lambda_j^H(\Delta t - \tau)] \tau^m d\tau$.

Evaluating $\Delta t^{m+1} I_{im}(\Delta t)$ is done with the following recursion relation,

$$\Delta t^{m+1} I_{im}(\Delta t) = \frac{[\Delta t^m - m \Delta t^m I_{im-1}(\Delta t)]}{\lambda_i} \quad , \text{ for } m = 1, 2, \quad (197)$$

once $\Delta t I_{i0}(\Delta t) = [1 - \exp[-\lambda_i \Delta t]]/\lambda_i$ is first evaluated. For $\lambda_i \Delta t \ll 1$, use of Eq. (197) results in the loss of several least-significant digits of accuracy with each application of the recursion formula. Thus, for $\lambda_i \Delta t < 1$, TRAC first evaluates $\Delta t^3 I_{i2}(\Delta t)$ using the Maclaurin expansion,

$$\Delta t^{m+1} I_{im}(\Delta t) = \Delta t^{m+1} m! \left[\frac{1}{(m+1)!} - \frac{\lambda_i \Delta t}{(m+2)!} + \frac{(\lambda_i \Delta t)^2}{(m+3)!} - \dots \right] \quad , \quad (198)$$

for $m = 2$ followed by evaluating the reciprocal of the Eq. (197)

$$\Delta t^m I_{im-1}(\Delta t) = \frac{[\Delta t^m - \lambda_i \Delta t^{m+1} I_{im}(\Delta t)]}{m}, \text{ for } m = 2, 1 \quad . \quad (199)$$

The accuracy of the second-order polynomial approximation for $P(t)$ can be increased by decreasing the integration time-step size Δt . We would like Δt to be as large as possible, however, while we maintain a desired level of accuracy in approximating $P(t)$. To achieve this, the following procedure for automatically adjusting the time step in TRAC is used. In the same manner that Eqs. (190) and (191) were defined, Eq. (189) must be satisfied at $t = \Delta t/4$,

$$a_1\left(\frac{\Delta t}{4}\right)P_1 + a_2\left(\frac{\Delta t}{4}\right)P_2 = q\left(\frac{\Delta t}{4}\right) \quad . \quad (200)$$

The $t = \Delta t/2$ second equation in Eqs. (190) and (191) and the above equation for $P_1 = P_1^*$ and $P_2 = P_2^*$ from Eq. (185) are solved over the time range $0 \leq t \leq \Delta t/2$ giving

$$P_1^* = \frac{[q(\frac{\Delta t}{2})a_2(\frac{\Delta t}{4}) - q(\frac{\Delta t}{4})a_2(\frac{\Delta t}{2})]}{D^*} \quad (201)$$

and

$$P_2^* = \frac{[q(\frac{\Delta t}{4})a_1(\frac{\Delta t}{2}) - q(\frac{\Delta t}{2})a_1(\frac{\Delta t}{4})]}{D^*}, \quad (202)$$

where $D^* = a_1(\Delta t/2)a_2(\Delta t/4) - a_1(\Delta t/4)a_2(\Delta t/2)$. This solution over half the integration time step provides a more accurate value for $P(t)$ at $t = \Delta t/2$,

$$P^*\left(\frac{\Delta t}{2}\right) = P(0) + P_1^*\left(\frac{\Delta t}{2}\right) + P_2^*\left(\frac{\Delta t}{2}\right)^2, \quad (203)$$

than the solution over the full integration time step at $t = \Delta t/2$,

$$P\left(\frac{\Delta t}{2}\right) = P(0) + P_1\left(\frac{\Delta t}{2}\right) + P_2\left(\frac{\Delta t}{2}\right)^2. \quad (204)$$

The difference between these two values is used as a measure of the error in the solution over the full integration time step Δt ,

$$\epsilon(\Delta t) = \left| \frac{P\left(\frac{\Delta t}{2}\right) - P^*\left(\frac{\Delta t}{2}\right)}{P^*\left(\frac{\Delta t}{2}\right)} \right|. \quad (205)$$

By defining two error bounds, ϵ_1 and ϵ_2 , Δt is doubled if $\epsilon(\Delta t)$ is too small or halved if $\epsilon(\Delta t)$ is too large, that is,

1. if $\epsilon_1 < \epsilon(\Delta t) < \epsilon_2$, maintain the present value of Δt ;
2. if $\epsilon_1 < \epsilon_2 \leq \epsilon(\Delta t)$, halve the value of Δt because the error in $P(\Delta t)$ is too large; and
3. if $\epsilon(\Delta t) \leq \epsilon_1 < \epsilon_2$, double the value of Δt because the error in $P(\Delta t)$ is too small.

When Δt is halved, the integration time step is reevaluated. When the third criterion is satisfied, the number of remaining integration time steps to be evaluated over the fluid-dynamics time step must be an even number for the integration time step to be doubled (and the number of remaining integration time steps to be halved). TRAC is programmed to use $\epsilon_1 = 10^{-6}$ and $\epsilon_2 = 10^{-4}$. A numerical study showed these values to yield a maximum fractional error less than 10^{-4} and an average fractional error less than 10^{-5} in the prompt-fission

power solution. The point-reactor kinetics solution required <1% of TRAC execution time.

D. Overall Solution Strategy

Overall solution strategies for both transient and steady-state calculations are described in this section. Each time step in the transient calculation consists of several sweeps through all the components in the system. The purpose of these sweeps is to converge to the solution of the nonlinear finite-difference equations.

1. Transient Solutions.

a. Outer Iteration Strategy. The solution of the thermal-hydraulic flow equations for all components is controlled by subroutines TRANS, PREP, OUTER, and POST. Subroutine TRANS controls the overall strategy whereas the others call each component in turn.

At least six passes are made through each one-dimensional component. Subroutine PREP makes two passes through all components. During the first pass, HTC's are evaluated by calls to subroutine HTCOR and the matrices for the stabilizer motion equations are obtained and reduced by subroutine FEMOM. The second pass in overlay PREP is for a backward substitution on the motion equation done in routine BKSMOM. The next two or more passes call the basic hydrodynamic routines until a solution is found within the convergence criterion or the maximum number of iterations is exceeded. This stage of the calculation is done by a call to subroutine OUTER, which performs both a forward elimination and a backward-substitution pass. The recommended convergence criterion (EPSO) is 10^{-4} , and the maximum outer iteration count (OUTMAX) generally should range between 6 and 10. The order in which subroutine OUTER calls the given components is determined by the IORDER array that is set after input by subroutine SRTLTP.

If the OUTER iteration process converges, a final pair of passes is made by subroutine POST. The first of these sets up and reduces the stabilizer equations for mass and energy using subroutine STBME. The second calls BKSSTB to compile the solution of these equations, updates the wall, slab, or rod heat conduction, and generates the information required to begin the next time step. If the OUTER iteration fails to converge, the time-step size is halved (subject to the constraint that Δt must be greater than or equal to the minimum time-step size indicated in the input); then, another attempt to

converge the OUTER iteration cycle begins. After six unsuccessful attempts, the code produces a dump and edit and shuts down.

Programming details of the iteration procedure for transient solutions are given in Sec. VI.D. A flow schematic for the TRANS routine is given in that section.

b. Details of the Solution Method. Solution of the fluid flow difference equations is broken into phases. First the stabilizing motion equations are solved, then the basic equation set is solved, and finally the stabilizing mass and energy equations are solved.

Solving the stabilizing motion equations is a relatively simple process because they are linear equations in $\tilde{V}_g$ and $\tilde{V}_l$, with no coupling between the $\tilde{V}_g$ and $\tilde{V}_l$ terms. First, the motion equations interior to all components are solved to obtain the interior velocities as linear functions of the junction velocities (done in subroutine FEMOM) in the form,

$$\tilde{V}_j = a_j + b_j \tilde{V}_L + c_j \tilde{V}_R + d_j \tilde{V}_T , \quad (206)$$

where the subscripts L, R, and T indicate the cell faces at the left, right, and tee (where applicable) component junctions. Next, the motion equations at component junctions are applied, and Eq. (206) is substituted into them where necessary to obtain a closed set of equations in the velocities at component junctions. This linear system is solved directly, using lower-upper (LU) decomposition. Finally, a backward substitution through all components is done using the known junction velocities and Eq. (206) to obtain values for the interior velocities (subroutine BKSMOM).

To solve the basic equation set (Secs. III.A.3 and III.A.4), a special junction variable and equation are defined,

$$\Delta P = \delta p_+ - \delta p_- , \quad (207)$$

where δp_+ is the linearized variation in pressure on one side of the junction and δp_- the variation on the other. When the basic equation set is linearized within each one-dimensional component, Eq. (207) is substituted into the

pressure gradient term of the motion equations at the component junctions. This linearized set of equations is solved in subroutine TFIDS to obtain the variations of independent variables (δp , δp_a , δT_e , δT_g , and $\delta \alpha$) as linear functions of the ΔP junction terms. For example,

$$\delta p_j = a'_j + b'_j \Delta P_L + C'_j \Delta P_R + d'_j \Delta P_T \quad . \quad (208)$$

After this has been done, Eq. (208) is substituted whenever applicable into the definition of Eq. (207) at all junctions, and the solution proceeds with the stabilizing velocities.

When one or more three-dimensional components are present, the situation is slightly more complicated. For the network in Fig. 12, a linear set of

Fig. 12.
Component network with one three-dimensional vessel.

equations in ΔP_i results after all possible substitutions are made. The equations have the form

$$\begin{bmatrix}
 X & X & 0 & 0 & 0 & 0 & \Delta P_1 \\
 X & X & X & 0 & X & 0 & \Delta P_2 \\
 0 & X & X & X & X & 0 & \Delta P_3 \\
 0 & 0 & X & X & 0 & 0 & \Delta P_4 \\
 0 & X & X & 0 & X & X & \Delta P_5 \\
 0 & 0 & 0 & 0 & X & X & \Delta P_6
 \end{bmatrix}
 =
 \begin{bmatrix}
 X \\
 X \\
 X \\
 X \\
 X \\
 X
 \end{bmatrix}
 +
 \begin{bmatrix}
 X \\
 0 \\
 0 \\
 0 \\
 0 \\
 0
 \end{bmatrix}
 \delta p_{v1}
 +
 \begin{bmatrix}
 0 \\
 0 \\
 0 \\
 X \\
 0 \\
 0
 \end{bmatrix}
 \delta p_{v4} , \quad (209)$$

where X indicates nonzero matrix and vector elements and p_{v1} and p_{v4} are the linear pressure variations in the vessel cells adjacent to junctions 1 and 4, respectively. This system is solved directly to obtain,

$$\Delta P_i = A_i + B_i \delta p_{v1} + C_i \delta p_{v4} . \quad (210)$$

The combination of these equations with the remaining linearized equations in the three-dimensional vessel region provides a closed linear-equation set that is solved in one of two ways. If the input variable IITMAX is set to zero, then the system is solved directly using calls to subroutines STDIR, SOLVE, and BACIT. If this variable is greater than zero, an iterative solution procedure is used. This iteration is a combination of a Gauss-Seidel and a coarse-mesh rebalance, as described in Sec. III.A.2. The recommended convergence criterion for this iteration (EPSI) is 10^{-5} , and the maximum allowed number of iterations (IITMAX) is 30-50. Backward substitution through the one-dimensional components again completes the solution of the full linear system.

A single, complete pass through this solution procedure provides the solution for the linearized finite-difference equations. Subsequent passes

through the procedure for the same time step produce a Newton iteration on the nonlinear difference equations, with quadratic convergence.

Solution of the stabilizing mass and energy equations is quite similar to that for the stabilizing motion equations. Because the unknown quantities are all cell centered, it is necessary to define the junction variables as those in a cell adjacent to the junction that occurs first in the calculational sequence. Special logic is provided to avoid conflicts when this criterion is applied to one cell components.

2. Steady-State Solutions. The TRAC steady-state capability provides time-independent solutions that may be of interest in their own right, or as initial conditions for transient calculations. The generalized steady-state finds the time-independent conditions of an arbitrary system. Desired steady-state parameters such as hot- and cold-leg temperatures may be obtained by using the control system (see Sec. III.E) to adjust pump speeds, steam-generator feed flows, and steam-flow control valves. Appendix C provides a specific example of this procedure.

Steady-state calculations use the transient fluid-dynamics and heat-transfer routines to search for time-independent conditions. The search is terminated when the normalized rates of change for the fluid and thermal variables are reduced below a user-specified criterion throughout the system.

Although the same subroutines are used in the transient and the steady-state calculations, there are important ways in which their behavior differs between the two calculations. The most crucial differences are

1. The time-step size used by the heat-transfer and fluid-flow calculations are not required to be equal during a steady-state calculation. The ratio of these time-step sizes is fixed through user-specified input. This permits compensation for the difference between the natural time scales of the two processes. (Caution should be taken not to exceed the diffusion limit in axial rod conduction by using too large a time-step ratio.)

2. Pressurizers are modeled as pressure boundary conditions during steady-state calculations. Therefore, the energy and mass inventory, as well as the pressure, of each pressurizer remain constant regardless of the flow rate between it and the remainder of the system.
3. Trips with positive identification numbers are not evaluated during steady-state calculations. Thus, even though conditions may exist that would cause the set status of a trip to change, the set status of the trip remains constant at its input value during the steady-state calculation.
4. The reactor power normally is set to zero for a period of time at the beginning of the steady-state calculation. It is increased to its nominal value once the fluid velocity has reached a certain value or its rate of change has fallen below a certain value. Power may be forced on by using the NAMELIST variables IPOWR and TPOWR. POWER may also be forced to stay off by using the variable IPOWR.
5. During the steady-state calculation the pump momentum source is averaged to prevent oscillations.
6. The reactor-kinetics calculation or input power option is not implemented during the steady-state calculation.
7. Control-procedure component actions are evaluated during the steady-state calculation only if they are controlled by the trips and their trip is ON.

Simple steady-state criteria are built into TRAC based on normalized numerical first derivatives of the void fraction, pressure, liquid and vapor temperatures, and velocities. The rate of change of variable x for time step $(n+1)$ at cell i is given by

$$\delta x_i^{n+1} = \frac{x_i^{n+1} - x_i^n}{|x_i^{n+1}|(t^{n+1} - t^n)} \quad . \quad (211)$$

Thus, δx_i^{n+1} is the fractional rate of change for the variable x_i^{n+1} in 1 s. This rate of change is checked every 100 time steps during the steady-state calculation. When the maximum absolute value of δx_i^n for all cells in the system is less than a user-specified convergence criterion for all variables, the steady-state calculation is ended. An edit, including the maximum rates of change and the component and cell number where it occurs for each variable, is printed every 100 time steps and at every long edit, dump, or time domain change. Logic is included to limit change rate checking to only those cells where the variable being checked is sufficiently important. For example, liquid temperature change rates are not calculated in cells where the void fraction is above 0.9999, because the liquid temperature in this cell is not a meaningful value. The variables considered in evaluating the approach to steady state are the two phasic velocities and temperatures, the void fraction, the total pressure, and the partial pressure of a noncondensable gas.

In addition to the normal steady state, a special static-check steady state is available. When this option is selected, all pumps and heat sources are deactivated. If the gravity vectors have been entered correctly, all motion should stop eventually in the system that is being tested. To achieve the best results from this option, we recommend that the user make the initial temperatures as uniform as possible in each group of cells that are coupled hydrodynamically.

More sophisticated steady-state tests can be constructed using the trips and controls to test long-term changes in selected variables or their averages. When these input criteria are met, a trip may be activated that forces a dump and termination of the calculation.

E. Control Procedure

Simulating PWR plant operation involves defining its mode of operation. This requires specifying a control procedure to adjust hardware according to the state of the system and its operating plan. In that procedure one needs to model manual control by operators, automatic control by regulating hardware, and abnormal hardware behavior. This involves specifying logic for initiating adjustable hardware action when certain conditions occur. For example, when the coolant pressure rises above or falls below a specified value, a valve is to be opened or closed, respectively. Abnormal hardware

behavior might be opening a valve to model a pipe break occurrence. The control procedure can consist of many such instructions that together direct and limit the mode of operation.

To be able to define a control procedure, one needs to understand how it fits into the TRAC model for the overall PWR plant system. The most basic part of that model is the component description of the physical hardware (pipes, pumps, reactor core, etc.) and the mass, momentum, and energy state of the system (density, velocity, pressure, temperature, etc.). This will be referred to as the PWR physical system model. To apply the control procedure to it, a selected list of system parameters have their values monitored. These values are input to the control procedure along with the control procedure specifications. Evaluating the control procedure results in controlled component hardware actions being adjusted within the PWR physical system model. This process, diagrammed in Fig. 13, is evaluated at the beginning of each time step on the basis of the beginning of the time-step system state. The control procedure determines what adjustments of hardware

Fig. 13.
TRAC simulation model of a PWR power plant.

are needed. The mode of operation of the system is thus directed as well as constrained by the control procedure.

Hardware actions that can be adjusted by the control procedure are listed in Table V. The TRAC components to which they are applied are shown along with the FORTRAN variable-name internal letters for defining the action. In addition, the control procedure also implements the use of special time-step data, editing of restart data dumps, and termination of the calculation. These are the adjustable features in the TRAC model over which the user can specify control.

All information for defining the control procedure is specified in the input data for application to the general control model. This fully defines the controlled mode of operation unless TRAC is executed in the interactive mode. In the interactive mode, the control-procedure data can be redefined at any time during the simulation. Preparing the input data involves first defining the PWR physical system model. Each of the hardware components is modeled by its corresponding TRAC component by specifying appropriate values for the component input parameters. For any of the components in Table V,

TABLE V
ADJUSTABLE COMPONENT HARDWARE ACTIONS BY THE CONTROL PROCEDURE

<u>Actions</u>	<u>Components</u>	<u>Variable-Name Letters</u>
Pressure boundary condition and fluid state	BREAK	B
Velocity or mass-flow boundary condition and fluid state	FILL	F
Reactor-core programmed reactivity or power	CORE, VESSEL	RPW
Reactor-core axial power shape	CORE, VESSEL	ZPW
Energy deposition in the coolant	PIPE, TEE, TURBINE	POW or PW
Energy generation in the wall	PIPE, PUMP, TEE, VALVE	QP3 or QP
Pump rotational speed	PUMP	PMP or OMG
Turbine power demand	TURBINE	TRB or POP
Valve flow-area fraction or relative stem position	VALVE	V

modeling one of its hardware actions is done as part of preparing the component input data. Implementing a hardware action involves specifying tabular data and associated control parameters for a component-action table. In the next section the detailed form of a general component-action table is discussed. This includes all of its associated control parameters, which together are part of the component input data.

1. Component-Action Table. Modeling a component adjustable hardware action is done by means of a component-action table, specified through the component input data. The table defines the component hardware action as a tabular function of an independent variable defined by physical system parameters. These parameters monitored from the PWR physical system model are called signal variables in TRAC. They can be applied as the component-action table's independent variable directly or after having been operated on by function operators called control blocks. In this section, the independent variable that is discussed is the independent variable of the component-action table.

Determining a hardware action by evaluating its component-action table is based on a component-action type option parameter. Its FORTRAN variable name has the general form IXXXTY where letters XXX are to be replaced by one to three letters characterizing the component action. Those letters for each of the actions in Table V are shown in the rightmost column. Through the option parameter the user specifies if the action is to be held constant, evaluated at all times from the component-action table, or evaluated from the component-action table only when an assigned controlling trip switch is ON but held constant when the trip is OFF. If the component-action table is to be evaluated under trip control, a trip ID number with general form variable name IXXXTR is specified as part of the component input data. The actual definition of the trip with the ID number label referenced here is specified in the trip input data section located elsewhere in the input data file. When IXXXTY defines no trip control for evaluating the component-action table, IXXXTR should be defined by zero or a blank field on input.

The independent variable is defined by physical system parameters in the form of a signal variable or a control-block output variable. The variable to be used is defined by its ID number with the general FORTRAN variable name IXXXSV. Positive ID numbers define signal variables; negative ID numbers

define control-block output variables. Signal variables and control blocks are described in Secs. III.E.3 and III.E.4.

The number of entry pairs (independent-variable value, component-action value) of tabular input data defining the component-action table is specified by the general FORTRAN variable name NXXXTB. Applied to its value is a plus or minus sign to define the form of the independent variable. When NXXXTB is positive, the independent variable is the IXXXSV variable. When NXXXTB is negative, the independent variable is the change in the value of the IXXXSV variable during the time the table is evaluated. For this latter form, the initial value of the component action corresponds to the component-action value in the table with an independent-variable value of zero. Internal to TRAC-PF1, the change in the IXXXSV variable value is incorporated into the table definition for each time step that is evaluated by translation of all the abscissa coordinate (independent variable) values in the table. As a result, the last interpolated component-action value from the table corresponds to the independent variable having a value of zero after translation. The user doesn't need to be concerned with this internal translation of the table's abscissa coordinate values by TRAC. The only time its effect can be seen is when the component-action table is edited on restart. Defining a NXXXTB < 0 table with the initial component-action value corresponding to an abscissa coordinate value of zero is all that need concern the user.

When a NXXXTB < 0 table is to be evaluated under trip control, the change in the IXXXSV variable value over each time step is further multiplied by the value of the controlling trip ON/OFF set status. FORTRAN variable ISET defines the trip set status. OFF has the value 0, and the two forms of ON, ON_{forward} and ON_{reverse}, have values +1 and -1, respectively. Because the component-action table under trip control is only evaluated when the trip is ON, ISET has the value +1 or -1 when the change in the IXXXSV variable value is multiplied by it to evaluate the independent variable. As a result, the trip set-status value affects the direction of interpolated movement in the table. The forward and reverse subscripts for ON correspond to the direction of the interpolated movement action.

The effect the values for IXXXTR, IXXXSV, and NXXXTB have on defining the independent variable is summarized in Table VI. Evaluation of the component-action table is trip controlled when IXXXTR $\neq$ 0. No component-action table is defined (the component action is held constant) when IXXXSV = 0 (or a blank data field) is input. When NXXXTB = 0 is input with IXXXSV $\neq$ 0, a table is defined, but it has no tabular data. This is a special case where the component action is defined directly by its independent-variable form, that is, a signal variable (IXXXSV $>$ 0) or a control-block output variable (IXXXSV $<$ 0).

In the above definition, the direction of interpolation in the component-action table can be trip controlled when IXXXTR $\neq$ 0 and NXXXTB $<$ 0. The trip set-status value (± 1) is applied to the magnitude of the movement defined by the change in the signal variable or control-block output variable. In most situations, this form is sufficient for modeling the quantity that the component action has dependence on. There are a few situations, however, where the user would like further control over the magnitude of the interpolated movement. He can do this with either a connected series of control-block operators defining the independent variable or by applying a rate factor to the independent-variable forms in Table VI. Operating on a parameter signal (signal variable value) with a connected series of control

TABLE VI

DEFINED FORMS OF THE COMPONENT-ACTION TABLE'S INDEPENDENT VARIABLE

<u>Component-Action Table's Defining Variables</u>			<u>Component-Action Table's Independent Variable Form^a</u>
<u>IXXXTR</u>	<u>IXXXSV</u>	<u>NXXXTB</u>	
All values	>0	≥ 0	A
0	>0	<0	ΔA
$\neq 0$	>0	<0	$\Delta A * ISET$
All values	<0	≥ 0	B
0	<0	<0	ΔB
$\neq 0$	<0	<0	$\Delta B * ISET$

^aA is a signal variable; B is a control-block output variable.

blocks and defining the independent-variable form with the last control-block output variable is an extended application of one of the last three forms in Table VI. Applying a rate factor to any one of the six forms is a direct adjustment to the rate of interpolated movement when evaluating the component-action table.

2. Rate-Factor Table. A rate factor can be defined by entering a rate-factor table of tabular data. Specifying a rate-factor table requires that its component-action table be defined ($IXXXSV \neq 0$) and that the user decide to apply a rate factor to the independent-variable form in Table VI. FORTRAN variables $NXXXSV$ and $NXXXRF$ define a rate-factor table in the same way that $IXXXSV$ and $NXXXTB$, respectively, define the component-action table. In addition to the six independent-variable forms in Table VI, entering $IXXXTR \neq 0$, $NXXXSV = 0$, and $NXXXRF \neq 0$ defines the independent-variable form to be the difference between the trip signal value and the trip set-point value that turns the trip OFF. This additional form provides a convenient means for adjusting the rate of interpolated movement in the component-action table. The further the trip signal departs from its desired value, specified by its set-point value that turns the trip OFF, the larger the rate factor and the faster the component action can be adjusted in order to return the trip signal to its desired value. Reading Sec. III.E.5 on how trips are defined will help to clarify the explanation for the above form.

When a rate-factor table is defined, the procedure for evaluating the component-action value is as follows. First, TRAC evaluates the independent-variable form (defined by $IXXXTR$, $NXXXSV$, and $NXXXRF$). This value is then used to linearly interpolate in the rate-factor table (when $NXXXRF \neq 0$) or define directly (when $NXXXRF = 0$) the rate-factor value. Next the independent-variable form (defined by $IXXXTR$, $IXXXSV$, and $NXXXTB$) is evaluated and multiplied by the rate factor. This product value is used to interpolate linearly in the component-action table (when $NXXXTB \neq 0$) or define directly (when $NXXXTB = 0$) the component-action value. The component hardware action in the modeled PWR system is then defined with this value. This procedure is evaluated at the beginning of each time step with the current state of the system parameters to evaluate the independent-variable forms for both tables. Not defining a rate-factor table [$NXXXSV = 0$ and $NXXXRF = 0$ (or blank data fields) are input] reduces the above procedure to evaluating the

independent-variable form and then using that value to interpolate linearly in the component-action table or define directly the component-action value.

The component-action table and rate-factor table defining variables IXXXTR, IXXXSV, NXXXTB, NXXXSV, and NXXXRF are specified in that order on one input data card. There is such a card for each type of component action in the component input data unless the IXXXTY option specifies that the component action is to be held constant. Then no component-action table and defining variables are input. There is also a second input data card defining the component action with the following real valued variables: XXXIN, XXXOFF, RXXXMX, and XXXSCL. Variable XXXIN defines the initial value for the component action. This value is used when the component action is to be held constant or when the user is evaluating the component action under trip control and the trip is initially OFF. For component actions that are trip controlled, variable XXXOFF defines the component-action value that is used when the trip is OFF after having been ON. Entering $\text{XXXOFF} = -1 \times 10^{19}$ defaults in TRAC to using the last component-action value evaluated when the trip was ON. Variable RXXXMX defines the maximum rate of change of the component-action value allowed by the user during the simulation. When the component action evaluated from the table varies faster than this maximum rate, the component action is redefined to vary at the maximum rate. Later when the rate of change of the table-evaluated component action falls below the maximum rate, the applied component-action value will be able to catch up to the value determined from the table. Variable XXXSCL is a scale factor to be applied during input to the component-action values in the input table.

The component-action table (with $|NXXXTB|*2$ values) and its rate-factor table (with $|NXXXRF|*2$ values) are input in the array data section of the component input using the LOAD format described in Sec. V.D. All component-action tables, with two exceptions, have one component-action value for each independent-variable value. Thus, there are two values for each of the $|NXXXTB|$ entry pairs in their tabular data. The two exceptions are the axial power shape and the energy generation in the wall component-action tables. Corresponding to each independent-variable value is an axial power shape with a relative power value at each axial interface in the reactor-core model or a QPPP factor shape with a QPPP factor value for each mesh cell in the component model. As an example, if the reactor core has five mesh cells axially, each

axial power shape would have six relative power values defined at the axial interfaces. The axial power shape table would have |NZPWTB| entry "pairs" with each "pair" having one independent-variable value and six axial power-shape values. There would be |NZPWTB|*(1+6) values of tabular data defining the table.

This section has discussed application of the component-action table in its general form. The XXX letters in all the FORTRAN variable names defined will need to be replaced by the component action one to three letters in Table VI to give their FORTRAN variable names. A main point to recognize from this section is that there is one form to the numerical model for applying adjustable control to a component action even though there are nine different component hardware actions that can be modeled. Understanding the general definition of control variables IXXXTY, IXXXTR, IXXXSV, NXXXTB, NXXXSV, NXXXRF, XXXIN, XXXOFF, RXXXMX, and XXXSCL gives the user the ability to model the dynamics of a myriad of possible control procedures encountered in PWR operation. The next four sections on signal variables, control blocks, trips, and ordered evaluation of control parameters go into the details of these modeling tools used to define the control procedure.

3. Signal Variables. Signal variables are PWR modeled-system parameters that the user defines for input to the control-procedure model used to adjust component hardware actions. They have their values determined by TRAC at the beginning of each time step on the basis of the state of the modeled system. Their values are used to determine the magnitudes of all adjustable component actions defined, which are then applied over the time step. This procedure approximates the magnitudes of the signal variables and component actions as being constant over the time step with step changes at the beginning of each time step. In reality, they vary continuously. Using small time steps can approximate this very well. With the hydrodynamics two-step solution method in TRAC-PF1, very large time steps are possible. When using large time steps, implementing control adjustment can be numerically delayed in time. Both the satisfied trip criteria for starting an action and the evaluated dependence that drives the action encounter fractional time-step lag. It is the accumulation of these small errors over many time steps that can contribute significant error when simulating a control procedure.

The 57 PWR-modeled system parameters, which are definable as signal variables, are listed in Table VII. Each parameter is defined by a parameter number assigned to FORTRAN variable name ISVN when defining a signal variable. Parameter number 0 is problem time defined by FORTRAN variable name STIME during steady-state calculations and TIMET during transient calculations. Parameter numbers 1 through 15 define control-panel vector (CPV) parameters that are only evaluated when TRAC is executed in the interactive mode. These parameters are those normally monitored by the plant operator on instrumentation in the control room. Parameter numbers 16 and 17 are dummy parameters, as yet undefined, that the user can define himself. System parameters not defined in Table VII can have their values assigned to either of these parameter numbers by hardwiring their value assignment in subroutine SVSET. The remaining system parameters in the Table VII list, except for the last two, are defined in a specific component. In addition, parameter numbers 20 through 40 require one or two mesh-cell numbers to further delimit the location in the component where the parameter is defined. Specific to the CORE and VESSEL components when fuel rods are present are the parameters with numbers 18, 19, 25, 26, and 44 through 54. The last two parameters in the list, numbers 55 and 56, are trip parameters that, when defined as signal variables, can be used for other control purposes.

The liquid water level, parameter number 20, is the geometric distance of collapsed liquid coolant from the bottom interface of mesh cell $|cell_1|$. It is defined by

$$\text{liquid water level} = \sum_{i=|cell_1|}^{I \pm 1} \Delta X_i + f \Delta X_I, \quad ,$$

where ΔX_i is the length of mesh cell i and the liquid-vapor interface is at a distance $f \Delta X_I$ above the lower interface of mesh cell I . The values of f and I are defined by requiring that the volume of liquid between mesh cells $|cell_1|$ and $|cell_2|$ be collapsed to fill the fluid volume of mesh cells $|cell_1|$ to $I \pm 1$ (+ when $|cell_1| > |cell_2|$ and - otherwise) and the fraction f of the volume of mesh cell I , that is,

TABLE VII
SIGNAL-VARIABLE PARAMETERS

Signal- Variable Parameter Number	Parameter Description	Additional Location Data
0	Problem time (s)	
1	Reactor power (W)	
2	Primary-pressure (Pa)	
3	Component pressure (Pa)	
4	Component temperature (K)	
5	Pressurizer water level (m)	
6	Refueling-storage-tank water level (m)	
7	Hot-leg temperature (K)	Coolant loop number
8	Cold-leg temperature (K)	Coolant loop number
9	Primary-coolant mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Coolant loop number
10	Emergency-core-coolant (ECC) mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Coolant loop number
11	Steam-generator-secondary pressure (Pa)	Coolant loop number
12	Steam-generator-secondary steam outflow ($\text{kg} \cdot \text{s}^{-1}$)	Coolant loop number
13	Steam-generator-secondary main feedwater flow ($\text{kg} \cdot \text{s}^{-1}$)	Coolant loop number
14	Steam-generator-secondary auxiliary feedwater flow ($\text{kg} \cdot \text{s}^{-1}$)	Coolant loop number
15	Steam-generator-secondary liquid level (m)	Coolant loop number
16	Dummy storage variable number 1	"
17	Dummy storage variable number 2	
18	Reactor power (W)	Component number
19	Reactor period (s)	Component number
20	Liquid water level (m)	Component, cell ₁ , and cell ₂ numbers
21	Cell pressure (Pa)	Component, cell ₁ , and cell ₂ numbers
22	Cell vapor temperature (K)	Component, cell ₁ , and cell ₂ numbers
23	Cell liquid temperature (K)	Component, cell ₁ , and cell ₂ numbers
24	Cell slab outer-surface temperature (K)	Component, cell ₁ , and cell ₂ numbers
25	Cell fuel-rod outer-surface temperature (K)	Component, cell ₁ , and cell ₂ numbers

TABLE VII (cont.)

Signal- Variable Parameter Number	Parameter Description	Additional Location Data
26	Cell fuel-rod centerline temperature (K)	Component, cell ₁ , and cell ₂ numbers
27	Cell vapor volume fraction	Component, cell ₁ , and cell ₂ numbers
28	θ -interface vapor mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
29	z-interface vapor mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
30	r-interface vapor mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
31	θ -interface liquid mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
32	z-interface liquid mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
33	r-interface liquid mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
34	θ -interface vapor velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
35	z-interface vapor velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
36	r-interface vapor velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
37	θ -interface liquid velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
38	z-interface liquid velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
39	r-interface liquid velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
40	Boron concentration ($\text{kg} \cdot \text{m}^{-3}$)	Component, cell ₁ , and cell ₂ numbers
41	Pump rotational speed ($\text{rad} \cdot \text{s}^{-1}$)	Component number
42	Valve flow-area fraction	Component number
43	Valve stem relative position	Component number
44	Reactor multiplication constant	Component number
45	Programmed reactivity	Component number
46	Total feedback reactivity	Component number
47	Fuel temperature feedback reactivity	Component number
48	Coolant temperature feedback reactivity	Component number

TABLE VII (cont.)

Signal- Variable Parameter Number	Parameter Description	Additional Location Data
49	Vapor coolant volume fraction feedback reactivity	Component number
50	Boron concentration feedback reactivity	Component number
51	Core averaged fuel temperature (K)	Component number
52	Core averaged coolant temperature (K)	Component number
53	Core averaged vapor coolant volume fraction	Component number
54	Core averaged boron concentration ($\text{kg} \cdot \text{m}^{-3}$)	Component number
55	Trip signal value	Trip ID number
56	Trip set-status value	Trip ID number
57	Prompt-fission power (W)	Component number
58	Decay-heat power (W)	Component number
59	Maximum average fuel-rod temperature (K)	Component number
60	Maximum supplemental fuel-rod temperature (K)	Component number
61	Pump head ($\text{m}^2 \cdot \text{s}^{-2}$)	Component number
62	Pump torque ($\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$)	Component number
63	Pump momentum source ($\text{m} \cdot \text{s}^{-1}$)	Component number
64	Valve hydraulic diam (m)	Component number
65	θ -interface hydraulic diam (m)	Component, cell ₁ , and cell ₂ numbers
66	z-interface hydraulic diam (m)	Component, cell ₁ , and cell ₂ numbers
67	r-interface hydraulic diam (m)	Component, cell ₁ , and cell ₂ numbers
68	θ -interface mixture mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
69	z-interface mixture mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
70	r-interface mixture mass flow ($\text{kg} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
71	θ -interface mixture average velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
72	z-interface mixture average velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
73	r-interface mixture average velocity ($\text{m} \cdot \text{s}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
74	Cell vapor density ($\text{kg} \cdot \text{m}^{-3}$)	Component, cell ₁ , and cell ₂ numbers
75	Cell liquid density ($\text{kg} \cdot \text{m}^{-3}$)	Component, cell ₁ , and cell ₂ numbers
76	Cell mixture density ($\text{kg} \cdot \text{m}^{-3}$)	Component, cell ₁ , and cell ₂ numbers

TABLE VII (cont.)

Signal- Variable Parameter Number	Parameter Description	Additional Location Data
77	Cell air density ($\text{kg} \cdot \text{m}^{-3}$)	Component, cell ₁ , and cell ₂ numbers
78	Cell air mass (kg)	Component, cell ₁ , and cell ₂ numbers
79	Cell air pressure (Pa)	Component, cell ₁ , and cell ₂ numbers
80	Cell air internal energy ($\text{W} \cdot \text{s} \cdot \text{kg}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
81	Cell vapor internal energy ($\text{W} \cdot \text{s} \cdot \text{kg}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
82	Cell liquid internal energy ($\text{W} \cdot \text{s} \cdot \text{kg}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
83	Cell saturation temperature (K) based on steam pressure	Component, cell ₁ , and cell ₂ numbers
84	Cell saturation temperature (K) based on total pressure	component, cell ₁ , and cell ₂ numbers
85	Cell vapor specific heat at constant pressure ($\text{W} \cdot \text{s} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
86	Cell liquid specific heat at constant pressure ($\text{W} \cdot \text{s} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
87	Cell latent heat of vaporization ($\text{W} \cdot \text{s} \cdot \text{kg}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
88	Cell average fuel-rod surface heat flux ($\text{W} \cdot \text{m}^{-2}$)	Component, cell ₁ , and cell ₂ numbers
89	Cell slab inside surface heat flux ($\text{W} \cdot \text{m}^{-2}$)	Component, cell ₁ , and cell ₂ numbers
90	Cell coolant interfacial heat flow (W)	Component, cell ₁ , and cell ₂ numbers
91	Cell vapor heat-transfer coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) at average rod surface	Component, cell ₁ , and cell ₂ numbers
92	Cell liquid heat-transfer coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) at average rod surface	Component, cell ₁ , and cell ₂ numbers
93	Cell vapor heat-transfer coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) at slab inside surface	Component, cell ₁ , and cell ₂ numbers
94	Cell liquid heat-transfer coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) at slab inside surface	Component, cell ₁ , and cell ₂ numbers
95	Cell coolant interfacial heat- transfer coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$)	Component, cell ₁ , and cell ₂ numbers
96	Cell coolant interfacial area (m^2)	Component, cell ₁ , and cell ₂ numbers

TABLE VII (cont.)

Signal- Variable Parameter Number	Parameter Description	Additional Location Data
97	θ -interface coolant inter- facial friction factor ($\text{kg} \cdot \text{m}^{-4}$)	Component, cell_1 , and cell_2 numbers
98	z -interface coolant inter- facial friction factor ($\text{kg} \cdot \text{m}^{-4}$)	Component, cell_1 , and cell_2 numbers
99	r -interface coolant inter- facial friction factor ($\text{kg} \cdot \text{m}^{-4}$)	Component, cell_1 , and cell_2 number
100	Cell solute plated on structure ($\text{kg} \cdot \text{m}^{-3}$)	Component, cell_1 , and cell_2 numbers
101	Cell vapor generation rate per unit volume ($\text{kg} \cdot \text{s}^{-1} \cdot \text{m}^{-3}$)	Component, cell_1 , and cell_2 numbers
102	Component wall heat loss to the inside (W)	One-dimensional component number
103	Component wall heat loss to the outside (W)	One-dimensional component number

(plus when $|\text{cell}_1| > |\text{cell}_2|$ and minus otherwise) and the fraction f of the volume of mesh cell I , that is,

$$\frac{|\text{cell}_2|}{\sum_{i=|\text{cell}_1|}^{|\text{cell}_2|} (1 - \alpha_i) V_i} \equiv \frac{\sum_{i=|\text{cell}_1|}^{I \pm 1} V_i}{\sum_{i=|\text{cell}_1|}^{I \pm 1} V_i} + f V_I \quad .$$

This collapsed liquid column can only be evaluated for mesh cells within a component and only for the primary or secondary side when the component is a TEE. To combine the liquid heights in several connected components requires defining a liquid water-level signal variable for each component (and side) and summing them with control blocks using appropriate weighting factors. The cosine of the angle the component mesh cells are inclined from vertical needs to be multiplied with the liquid water level to give the liquid's vertical height.

For mesh cells in components on the steam-generator secondary-side (SGS), $cell_1$ and $cell_2$ are defined with the SGS component ID number in the usual way. For mesh cells on the secondary side of a TEE component, $cell_1$ and $cell_2$ are defined as composites of the total number of mesh cells on the primary side, NCELL1, and the desired mesh-cell number on the secondary side, N2, that is,

$$\begin{aligned} cell_1 &= NCELL1 + N2 \\ cell_2 & \end{aligned} .$$

For the three-dimensional VESSEL component mesh cells, $cell_1$ and $cell_2$ are defined as composites of the relative cell number in the horizontal θ -r plane times 1000 plus the axial level number, that is,

$$\begin{aligned} cell_1 &= (\text{horizontal plane relative cell number}) * 1000 + (\text{axial level number}) \\ cell_2 & \end{aligned} .$$

When the signal-variable definition spans all cells from $cell_1$ to $cell_2$, a two-dimensional array of mesh cells between the minimum and maximum relative cell numbers and the minimum and maximum axial level numbers (defined by $cell_1$ and $cell_2$) are considered in the VESSEL. Using these composite definitions for TEE secondary and VESSEL mesh cells, enables the TRAC user to define them with the signal-variable definition form for one-dimensional components.

Signal-variable parameter numbers 28 through 39 define mass flow and velocity and have $cell_1$ and $cell_2$ numbers associated with mesh-cell interfaces. A one-dimensional component mesh cell i has boundary interfaces numbered i and $i+1$. In the three-dimensional VESSEL, the second azimuthal, the outer radial, and the upper axial interfaces are all associated with the mesh-cell number. If mass flow or velocity are specified on r or θ interfaces for one-dimensional components, their definitions default to the z -interface definition.

There are five different forms for defining signal-variable parameters when they are location dependent, that is, when they have ISVN parameter numbers 20 through 40. The signal variable is the

1. parameter value in mesh cell $|cell_1|$ or $|cell_2|$ when $cell_2 = 0$ or $cell_1 = 0$, respectively;
2. maximum value of the parameter in all mesh cells between mesh cells $|cell_1|$ and $|cell_2|$ when $cell_1$ and $cell_2$ are both positive;
3. minimum value of the parameter in all mesh cells between mesh cells $|cell_1|$ and $|cell_2|$ when $cell_1$ and $cell_2$ are both negative;
4. volume-averaged value of the parameter in all mesh cells between mesh cells $|cell_1|$ and $|cell_2|$ when $cell_1$ and $cell_2$ are of opposite signs; and
5. difference between the parameter values in mesh cells $|cell_1|$ and $|cell_2|$ when the ISVN parameter number is prefixed with a minus sign.

The fifth form can only have parameter numbers -40 through -21. Its signal variable is the parameter value in $|cell_1|$ minus the parameter value in $|cell_2|$. Mesh-cell numbers are defined above by the positive (absolute) values of $cell_1$ and $cell_2$. Forms 3 and 4 above are the only ones that define $cell_1$ and $cell_2$ with negative values. For all five forms, it is the absolute value of $cell_1$ and $cell_2$ that is used to define the mesh-cell number.

A unique, positive identification (ID) number is assigned by the user to each signal variable. This number serves as the signal-variable label for referencing the use of its value within the control procedure.

4. Control Blocks. Control blocks are function operators that operate on input parameter signals to produce an output parameter signal. The output signal can then be used as an input parameter to other control blocks. In this way, a control procedure for a component action can be constructed by coupling control-block operators in series and in parallel. PWR system parameters, defined by signal variables, provide the input data for the initial control block(s) and possible subsequent control blocks in a control procedure. The control procedure ends with a final control block whose output signal value is used to define a component-action table's independent variable or the action directly when the table has no tabular data.

Table VIII lists the 65 control-block function operations that are available in TRAC-PF1. The user selects the desired function operator for a control block and assigns its operation number (1 through 61, 100, 101, 200, and 201) in the leftmost column to FORTRAN input variable ICBN. The user also specifies for the control block zero to three input parameter signals and zero to two constants based on the required data for each block indicated in the five rightmost columns. Input parameter signals have their ID numbers defined as X# in the table where # = 1, 2, or 3; input parameters with logical values (0.0 or 1.0 only) have their ID numbers defined as L#. The values of X# or L# are input through FORTRAN variable name ICB#. When X# or L# in the table is enclosed in parentheses, that is, (X#) or (L#), it is not a required input parameter. The parentheses indicate that TRAC internally uses that input variable storage address to save intermediate results from the function evaluation for later use in evaluating the control block. The remaining information in the table is the control-block function name and its defined mathematical operation. XOUT is the control-block output value, which can be referenced with the control-block ID number by other control blocks for their input or by component-action tables for defining their independent variable. The control-block ID number is specified by the user through input with FORTRAN variable name IDCB and is required to be a negative integer greater than -10000. Thus, for a control block, defining ICB# with a positive ID number inputs a signal-variable value to the control block; a negative ID number inputs a control-block output signal value.

In addition to the five possible X#, L#, and C# control-block input parameters in Table VIII, all control blocks require from input a constant gain factor, G, and constant minimum and maximum limit values, XMIN and XMAX, which constrain the output value of XOUT. XMIN and XMAX enable the user to model the nonlinear saturation of a control signal by electronic hardware. The gain factor can be used to model the amplification or attenuation effect on the signal from such hardware. Variables G, XMIN, XMAX, and C# are input with FORTRAN variable names CBGAIN, CBXMIN, CBXMAX, and CBCON#, respectively.

Figure 16 presents the general schematic diagram of a control block. The number of input parameters on the left-hand side ranges from zero to three depending on the control-block operation number. On the other hand, there is always one output parameter from a control block. Its value can vary

TABLE VIII
CONTROL-BLOCK FUNCTION OPERATIONS

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
1	Absolute value	$XOUT = G \cdot ABS(X1).$	X1				
2	Arccosine	$XOUT = G \cdot ACOS(X1),$ XOUT in radians.	X1				
3	Add	$XOUT = G \cdot (X1 + X2).$	X1	X2			
4	Integerizer	$XOUT = G \cdot FLOAT(IFIX(X1)).$	X1				
5	Logical "and"	$XOUT = G$ IF((L1.EQ.1.0) .AND.(L2.EQ.1.0)); = 0.0 otherwise.	L1	L2			
6	Arcsine	$XOUT = G \cdot ASIN(X1),$ XOUT in radians.	X1				
7	Arctangent	$XOUT = G \cdot ATAN(X1),$ XOUT in radians.	X1				
8	Arctangent 2	$XOUT = G \cdot ATAN2(X1, X2),$ XOUT in radians.	X1	X2			
9	Constant	$XOUT = G \cdot C1.$				C1	
10	Cosine	$XOUT = G \cdot COS(X1),$ X1 in radians.	X1				
11	Dead band, dead zone, or dead space	$XOUT = G \cdot (X1 - C2)$ IF($X1 > C2$); = $G \cdot (X1 - C1)$ IF($X1 < C1$); or = 0.0 otherwise.	X1			C1	C2
12	Derivative	$XOUT = G \cdot (dX1/dt).$	X1	(X2)			

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
13	Double integrator with XOUT Limited	$XOUT = G \int [\int X1 \cdot dt + X2] \cdot dt + XOUT,$ <p> X1 and (X2) are reset to 0.0 if XOUT is against a limit and the sign of X1 does not change. X2 = 0.0 and XOUT = 0.0 initially. X2 is $\int X1 \cdot dt$ summed over all previous time steps. C1 = 0.0 or 1.0 is the polynomial order for approxi- mating the time dependence of X1 and its integral. </p>	X1	(X2)	(X3)	C1	(C2)
14	Divide	$XOUT = G \cdot X1 / X2.$	X1	X2			
15	Logical "Exclusive or"	$XOUT = G$ $IF((L1+L2).EQ.1.0);$ $= 0.0 \text{ otherwise.}$	L1	L2			
16	Logical "equivalent"	$XOUT = G$ $IF(L1.EQ.L2);$ $= 0.0 \text{ otherwise.}$	L1	L2			
17	Exponential	$XOUT = G \cdot EXP(X1).$	X1				
18	Logical "flip-flop"	$XOUT = G \text{ or } 0.0,$ <p> valued flip-flop output that changes state whenever L1 changes state (only if L3 = 1.0). </p>	L1	(L2)	L3		
19	Gate	$XOUT = G \cdot X1$ $IF(L2.EQ.1.0);$ $= 0.0$ $IF(L2.EQ.0.0).$	X1	L2			

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
20	Greater than or equal to	XOUT = G IF(X1.GE.X2); = 0.0 otherwise.	X1	X2			
21	Greater than	XOUT = G IF(X1.GT.X2); = 0.0 otherwise.	X1	X2;			
22	Input switch	XOUT = G*X1 IF(L3.EQ.1.0); = G*X2 IF(L3.EQ.0.0).	X1	X2	L3		
23	Integrate	XOUT = $G \int X1 \cdot dt + XOUT$, XOUT=0.0 initially. X1 is not reset to 0.0 when XOUT is against limits. C1 = 0.0 or 1.0 is the polynomial order for approximating the time dependence of X1.	X1			C1	(C2)
24	Integrate with mode control	XOUT = 0.0 IF((L2+L3).EQ.0.0), reset mode; = XOUT IF((L2+L3).EQ.1.0), hold mode; or = $G \int X1 \cdot dt + XOUT$ IF((L2+L3).EQ.2.0), integrate mode. C1 = 0.0 or 1.0 is the polynomial order for approximating the time dependence of X1.	X1	L2	L3	C1	(C2)
25	Logical "inclusive or"	XOUT = 0.0 IF((L1+L2).EQ.0.0); = G otherwise.	L1	L2			

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
26	First-order lag	XOUT = G*X0 where X0 is the problem time-domain output from the Laplace transform operator $1/(1 + C1*s)$ operating on X1 in the Laplace transform s domain; that is, X0 is the solution of the first-order differential equation $C1*dX0/dt + X0 = X1$.	X1			C1	
27	Logic delay	XOUT = 0.0 IF((L1.EQ.0.0).OR. (TIME.GT.(C1+C2))); = G IF((L1.EQ.1.0).AND. (TIME.LE.(C1+C2))), where (C2) is the TIME when L1 switches from 0.0 to 1.0.	L1	(L2)		C1	(C2)
28	Logic general-purpose counter	XOUT = 0.0 IF(L3.EQ.0.0), reset mode; = G times the number of times L1 has changed state since enabled (when L3 = 1.0), count mode.	L1	(L2)	L3		
29	Logic input switch	XOUT = G*L1 IF(L3.EQ.1.0); = G*L2 IF(L3.EQ.0.0).	L1	L2	L3		

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
30	Lead-lag transfer function	XOUT = G*X0 where X0 is the problem time-domain output from the Laplace transform operator $(1 + C1*s)/(1 + C2*s)$ operating on X1 in the Laplace transform s domain; that is, X0 is the solution of the first-order differential equation $C2*dX0/dt + X0 = C1*dX1/dt + X1$.	X1	(X2)	(X3)	C1	C2
31	Limited integrator	XOUT = $G*\int X1*dt + XOUT$, X1 is set to 0.0 if XOUT is against a limit and the sign of X1 does not change; XOUT = 0.0 initially. C = 0.0 or 1.0 is the polynomial order for approximating the time dependence of X1.	X1			C1	(C2)
32	Natural logarithm	XOUT = $G*ALOG(X1)$.	X1				
33	Less than or equal to	XOUT = G IF(X1.LE.X2); = 0.0 otherwise.	X1	X2			
34	Less than	XOUT = G IF(X1.LT.X2); = 0.0 otherwise.	X1	X2			
35	Maximum of two signals	XOUT = $G*AMAX1(X1,X2)$.	X1	X2			

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
36	Maximum during transient signals	XOUT = G*AMAX1(X1,XOUT).	X1				
37	Minimum of two	XOUT = G*AMTN1(X1,X2).	X1	X2			
38	Minimum during transient	XOUT = G*AMIN1(X1,XOUT).	X1				
39	Multiply	XOUT = G*X1*X2.	X1	X2			
40	Logical "not and"	XOUT = 0.0 IF((L1+L2).EQ.2.0); = G otherwise.	L1	L2			
41	Logical "not equal"	XOUT = G IF(L1.NE.L2); = 0.0 otherwise.	L1	L2			
42	Logical "not inclusive or"	XOUT = G IF((L1+L2).EQ.0.0); = 0.0 otherwise.	L1	L2			
43	Logical "not" or negation	XOUT = G IF(L1.EQ.0.0); = 0.0 IF(L1.EQ.1.0).	L1				
44	Positive difference	XOUT = G*(X1-X2) IF(X1.GT.X2); = 0.0 otherwise.	X1	X2			
45	Quantizer	XOUT = G*FLOAT (IFIX(X1+0.5)) IF(X1.GE.0.0); = G*FLOAT (IFIX(X1-0.5)) IF(X1.LT.0.0).	X1				
46	Ramp	XOUT = G*(TIME-C1) IF(TIME.GT.C1); = 0.0 otherwise.				C1	

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
47	Random number generator	XOUT = G*RANF(DUMY) IF(TIME.GE.C1); = 0.0 otherwise.				C1	
48	Sign function	XOUT = +G* X1 IF(X2.GE.0.0); = -G* X1 IF(X2.LT.0.0).	X1	X2			
49	Sine	XOUT = G*SIN(X1), X1 in radians.	X1				
50	Sign inversion	XOUT = -G*X1.	X1				
51	Second-order transfer function	XOUT = G*X0 where X0 is the problem time-domain output from the Laplace transform operator $1/(1 + C1*s + C2*s**2)$ operating on X1 in the Laplace transform s domain; that is, X0 is the solution of the second-order differential equation $C2*d(dX0/dt)/dt + C1*dX0/dt + X0 = X1$.	X1	(X2)	(X3)	C1	C2
52	Square root	XOUT = G*SQRT(X1).	X1				
53	Step	XOUT = G IF(TIME.GE.C1); = 0.0 otherwise.				C1	
54	Subtract	XOUT = G*(X1-X2).	X1	X2			

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
55	Tangent	$XOUT = G \cdot \tan(X1),$ X1 in radians.	X1				
56	Sum constant	$XOUT = G \cdot (X1 + C1).$	X1			C1	
57	Sum three	$XOUT = G \cdot (X1 + X2 + X3).$	X1	X2	X3		
58	Variable limiter	$XOUT = G \cdot X2$ IF(X1.GT.X2), at upper limit; $= G \cdot X3$ IF(X1.LT.X3), at lower limit; or $= G \cdot X1$ otherwise, between limits.	X1	X2	X3		
59	Weighted summer	$XOUT = G \cdot (C1 \cdot X1 + C2 \cdot X2).$	X1	X2		C1	C2
60	Exponentiate	$XOUT = G \cdot (X1^{**}X2), X1 > 0.$	X1	X2			
61	Zero-order hold	$XOUT = G \cdot X1$ IF(L2.EQ.1.0); $= XOUT$ otherwise.	X1	L2			
100	Time delay	$XOUT = G \cdot X1$ where X1 is evaluated at the time the control block is input, IF(TIME.LE.C1); $= G \cdot X1(TIME - C1)$ other- wise [X1(TIME-C1) is X1 evaluated at time (TIME-C1)]. The variable n is the number of storage table pairs for saving values of X1 over the last C1 seconds. [X1 is stored at intervals of approximately $C1/(n-1)s$; the control block will use linear interpolation to obtain the desired value of X1(TIME-C1).]	X1	n	(X3)	C1	

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
101	Function of one independent variable	XOUT = $G \cdot f_n(X1)$. The variable n is the number of function table pairs of values to be input.	X1	n	(X3)	(C1)	
200	PI Controller	XOUT = $A = A_0 + \Delta A$ in Fig. 14, where $X1 = ID$ number of F , $X2 = ID$ number of F_d when F_d is an input parameter rather than a constant value; $C1 = F_d$ constant value; $C2 = A_0$, initial XOUT; $G = (\Delta A / \Delta F)_{est}$; $XMIN = A_{min}$; and $XMAX = A_{max}$. A third input data card is required to specify Δt_d and τ . Refer to Fig. 14 for a schematic diagram of the functional form of this control block.	X1	X2		C1	C2

TABLE VIII (cont.)

No.	Control-Block Name	Control-Block Mathematical Operation ^a	Block ^{b,c} Input			Block ^c Const.	
			1	2	3	1	2
201	PID Controller	$XOUT = A = A_o + \Delta A$ in Fig. 15, where $X1 = ID$ number of F ; $X2 = ID$ number of F_d when F_d is an input parameter rather than a constant value; $C1 = F_d$ constant value; $C2 = A_o$, initial $XOUT$; $G = (\Delta A / \Delta F)_{est}$; $XMIN = A_{min}$; and $XMAX = A_{max}$. A third input data card is required to specify Δt_d , τ , and Wt . Refer to Fig. 15 for a schematic diagram of the functional form of this control block.	X1	X2	(X3)	C1	C2

^aXOUT appearing on the right-hand side of the defining equation indicates its value from the previous evaluation. G is a constant gain factor applied to the XOUT operation result. XOUT appearing on the left-hand side of the defining equation is constrained by constant lower and upper limits XMIN and XMAX in defining the control-block output value.

^bAn "X" parameter indicates a continuous variable; an "L" parameter indicates a logical (or discrete) parameter having a value of 0.0 or 1.0 only.

^cVariables enclosed in parentheses are not input variables but are used internally by the control block for data storage.

$$\Delta A_{PID} = (\Delta A / \Delta F)_{est} \left[\Delta F + (1 / \Delta t_d) \int \Delta F dt + \Delta t_d (d\Delta F / dt) + \Delta F \right]$$

Fig. 14.
Proportional plus integral controller diagram.

$$\Delta A_{PI} = (\Delta A / \Delta F)_{est} \left[\Delta F + (1 / \Delta t_d) \int \Delta F dt \right]$$

Fig. 15.
Proportional plus integral plus derivative controller diagram.

Fig. 16.
Control-block diagram.

continuously or stepwise depending on the type of control-block operation. To have the output value 0.0 or 1.0 when it is logical (ICBN = 5, 15, 16, 18, 20, 21, 25, 27, 28, 29, 33, 34, 40, 41, 42, and 43) requires that CBGAIN = 1.0 be input to the control block.

TRAC-PF1 evaluates control blocks by having driver subroutine CBSET call subroutines CONBLK for ICBN = 1 to 61, DELAY for ICBN = 100, and LININT for ICBN = 101. Subroutines CONBLK and DELAY are modified forms of subroutines with the same names written by M. Giles and J. Milton for the TRAC-BD1 computer program.⁴⁵ Their control-block operations ICBN = 56 (defining problem time) and 57 (setting trip status), which are done by signal variable ISVN = 0 and trips in TRAC-PF1, have been replaced by operations that sum a constant to an input parameter and sum three input parameters. The rectangular integration control blocks (ICBN = 13, 23, 24, and 31) have been further generalized to allow the user the option of selecting trapezoidal rule integration instead.

Before evaluating a control block, the signal variables and control blocks that define its input parameters need to be evaluated. When evaluating a control procedure with connected control blocks, the connecting arrows define the direction and order for evaluating the control blocks. Time lag produced by forward difference approximating the integrand (compared with evaluating the input parameters first using a backward difference approximation) has an unstabilizing effect. When the error to be corrected in the signal is increasing, corrective action is numerically delayed by a forward difference approximated integral controller. Eventually when enough

corrective action has been applied to start decreasing the error signal, the forward difference approximated integral controller delays the removal of corrective action causing the error signal to overshoot its desired zero value. The inherent weakness of integral controllers to overshoot and produce an oscillatory response that can become unstable⁴⁶ is enhanced by evaluating its integral with a forward difference approximation. Using a backward difference approximation has just the opposite effect. Its numerical difference error acts to reduce overshoot by the integral controller. This discussion only applies to the rectangular integration option (which is zero-order accurate). When trapezoidal rule integration (which is first-order accurate) is used, the input parameters must be evaluated first for the control-block algorithm to evaluate correctly.

Consider the very useful proportional plus integral (PI) controller shown in Fig. 14. The proportional plus integral plus derivative (PID) controller shown in Fig. 15 is an enhancement of the PI controller that uses the derivative to control the rate of the controller adjustment. Both controllers are control blocks that define control procedures for a component actions. The input PWR system parameter F and output component action A could be a pressure to control a valve, a mass flow rate to control a pump, a fluid level to control a feedwater pump or valve, or a pressure to control a heater. The purpose of these controllers is to compare the system parameter value with its desired value and to apply corrective action to return the system parameter to its desired value when it departs. They could be used to model an actual PI or PID electronic-circuit controller or to adjust a component action to maintain a quoted system parameter value.

The PI controller shown in Fig. 14 performs the following operations. In the lower-left corner of the figure, the sum constant control block subtracts from the PWR system parameter F the desired value F_d to define the ΔF error signal. The next three control blocks estimate the ΔA change in the component action from its initial value, which should cause ΔF to go to zero as the calculation proceeds. The integrate control block integrates ΔF from the initial time to the present. Its integral represents the accumulated error in F . The add control block sums its ΔF (proportional) and $\int \Delta F dt$ (integral) input signals with appropriate $(\Delta A/\Delta F)_{est}$ and $(\Delta A/\Delta F)_{est}/\Delta t_d$ gain factors to output the PI controller's estimated change in the component action

that is required from its initial value. $(\Delta A/\Delta F)_{est}/\Delta t_d * \Delta F \, dt$ corresponds to the ΔA_{PI} value that has accumulated up to the current time; $(\Delta A/\Delta F)_{est} * \Delta F$ corresponds to the desired instantaneous change in ΔA_{PI} at the current time that the PI controller estimates is needed to correct for the ΔF error still remaining. The first-order lag control block accounts for the fact that the $(\Delta A/\Delta F)_{est} * \Delta F$ instantaneous change in a component action may not be physically possible or numerically desirable. The maximum rate of change in ΔA is constrained by the CBCON1 time constant, τ , of the first-order lag control block. Through the value of τ , the maximum adjustment rate of the hardware can be modeled. When an instantaneous change in ΔA_{PI} over a time step is desired, the first-order lag control block evaluates a slower change in ΔA based on the first-order differential equation $\tau * d\Delta A/dt + \Delta A = \Delta A_{PI}$. The value of ΔA will lag the value of ΔA_{PI} in time by an amount based on the magnitude of τ . Finally, the sum constant control block in the lower-right corner of the figure sums the accumulated ΔA change in the component action since the start of the calculation to the component-action initial value, A_0 . For this controller, the output signal A is applied directly to the component action by defining a component-action table with no entry pairs, NXXXTB = 0.

5. Trips. Trips are ON-OFF logical switches for controlling the evaluation of component actions. When the controlling trip for a component action is ON, the component action is evaluated from the definition of its component-action table. When the controlling trip is OFF, the component action is not evaluated; it is held constant at its initial value if its trip has never been ON or optionally at its last evaluated value when its trip was ON or at a user-defined input value for when its trip is OFF after being ON. Trips also can be used to implement special time-step data, generate restart-data dumps, and terminate problem execution at the time the trip is set ON.

Determining the ON or OFF set status of a trip is based on the value of its user-defined trip signal. Over the trip signal value range, the user defines two or four set-point values that delimit two or three subranges labeled with ON or OFF set status. When the value of the trip signal lies within a given subrange, the trip is assigned the set-status label of that subrange. Table IX shows five of the ten possible trip signal-range types that define set status. The ON set status has two forms: ON_{forward} and ON_{reverse}. Trip-controlled component action is evaluated for both. They only

TABLE IX
TRIP SIGNAL-RANGE TYPES

ISRT Signal-Range Type Number	Trip Signal-Range Diagram With Subrange Set Status				
1	ON _{forward}			OFF	Trip Signal
		S ₁	S ₂		
2	OFF			ON _{forward}	Trip Signal
		S ₁	S ₂		
3	ON _{forward}			OFF	Trip Signal
		S ₁	S ₂	S ₃ S ₄ ON _{reverse}	
4	OFF			ON _{forward}	Trip Signal
		S ₁	S ₂	S ₃ S ₄ OFF	
5	ON _{forward}			OFF	Trip Signal
		S ₁	S ₂	S ₃ S ₄ ON _{forward}	

Making ISRT negative changes ON_{forward} to ON_{reverse} and ON_{reverse} to ON_{forward}.

ISRT Signal-Range Type Number	Description of How the Trip Set Status Is Changed
1	When ON _{forward} , trip is set to OFF when the trip signal $\geq S_2$. When OFF, trip is set to ON _{forward} when the trip signal $\leq S_1$.
2	When OFF, trip is set to ON _{forward} when the trip signal $\geq S_2$. When ON _{forward} , trip is set to OFF when the trip signal $\leq S_1$.
3	When ON _{forward} , trip is set to OFF when trip signal $\geq S_2$ and $< S_4$. When ON _{forward} , trip is set to ON _{reverse} when trip signal $\geq S_4$. When OFF, the trip is set to ON _{forward} when the trip signal $\leq S_1$. When OFF, the trip is set to ON _{reverse} when the trip signal $\geq S_4$. When ON _{reverse} , trip is set to OFF when trip signal $\leq S_3$ and $> S_1$. When ON _{reverse} , trip is set to ON _{forward} when trip signal $\leq S_1$.
4	When OFF (left), trip is set to ON _{forward} when signal $\geq S_2$ and $< S_4$. When ON _{forward} , trip is set to OFF when trip signal $\leq S_1$ or $\geq S_4$. When OFF (right), trip is set to ON _{forward} when signal $\leq S_3$ and $> S_1$.
5	When ON _{forward} (left), trip is set to OFF when signal $\geq S_2$ and $< S_4$. When OFF, trip is set to ON _{forward} when trip signal $\leq S_1$ or $\geq S_4$. When ON _{forward} (right), trip is set to OFF when signal $\leq S_3$ and $> S_1$.

differ with regard to the sign of the numerical value 1 for the ON set status. The numerical values associated with the three set-status flags in Table IX are -1 for $ON_{reverse}$, 0 for OFF, and +1 for $ON_{forward}$.

Input variable ISRT defines the signal-range type for a trip. Table IX shows the signal-range types for $ISRT = 1, 2, 3, 4,$ and 5 . Assigning a negative sign to these ISRT values and changing $ON_{forward}$ to $ON_{reverse}$ and $ON_{reverse}$ to $ON_{forward}$ defines the other five types. The criteria to decide when the set status of a trip is to be changed are stated in the lower half of Table IX. The present set status of the trip determines which criterion is to be used. The criteria and signal-range type definitions are based on the requirement that the set-point values satisfy $S_1 < S_2$ for $ISRT = \pm 1$ and ± 2 and $S_1 < S_2 < S_3 < S_4$ for $ISRT = \pm 3, \pm 4,$ and ± 5 .

For $ISRT = \pm 1$ and ± 2 , there are two set-status subranges. The trip signal needs to be equal or greater than the S_2 set-point value to change from the left to the right subrange set status. To change from the right to the left subrange set status, the trip signal needs to be equal or less than S_1 . When the trip signal value lies between S_1 and S_2 , the trip has the set status of the left or right subrange from which its signal came.

For $ISRT = \pm 3, \pm 4,$ and ± 5 , there are three set-status subranges. Changing to either of the other two set-status labels is determined in much the same way as for a two-subrange signal-range type. The trip-signal value is compared with S_1 or S_2 with a decision to change to left or middle set status and compared with S_3 or S_4 with a decision to change to the middle or right set status. The trip-signal value crossing two subranges during a time step will result in the set-status criteria being satisfied twice even though the last criterion being satisfied is the only one edited by TRAC for the time step.

Defining a trip signal range to have more than three set-status subranges can be done by joining two or more trips having the same trip signal and different set-point values. A trip-controlled trip (defined later in this section) is used to join them and to respond as if it were a four or more set-status subrange trip. Whereas trips with three set-status subranges are defined directly by $ISRT = \pm 3, \pm 4,$ and ± 5 , they could be constructed by joining two trips having two set-status subranges with a trip-controlled trip. Three set-status subrange trips have been defined directly, however, because

they are a convenient form for regulating a component action under trip control and save our having to define three trips to achieve that form.

Signal-range type ISRT = ± 3 is the form generally used to regulate a component action under trip control. The trip signal is the controlling parameter, and the component action is to be adjusted so that the trip signal lies within its desired value range from S_1 to S_4 . When the trip signal falls below S_1 , the left-subrange ON set status has the component action evaluated in a manner that causes the trip signal value to increase. When the trip signal rises above S_4 , the right-subrange ON set status adjusts the component action in the opposite manner to cause the trip signal value to decrease. For this application, the component-action table needs to have its independent-variable form defined by the change in its IXXSV variable value so that the ISET set-status value is applied as a factor to the independent variable of Table VI. This is done by defining the number of entry pairs in the component-action table to be negative, that is, NXXXTB < 0. As described above, the set-point values define the desired value range for the trip signal. The range can be as small or as large as the user feels is appropriate for constraining the trip-signal value based on trip control of the component action.

Each trip-signal set point is defined by a constant value with the possibility of a tabular function being applied to that value as a factor. The user inputs for each set point a constant set-point value to array variable SETP(I), $I = (1,2)$ or $I = (1,4)$ [that satisfies $S_1 < S_2$ or $S_1 < S_2 < S_3 < S_4$], and an ID flag to array variable IFSP(I) to indicate if a tabular function factor is to be applied to the SETP(I) value. No such factor is applied when IFSP(I) = 0; the set-point value is the constant SETP(I). Entering IFSP(I) $\neq$ 0 defines the ID number for a set-point factor table of tabular data to be input after the trip and trip signal defining data. The set-point factor-table independent variable is defined by a signal variable or a control-block output variable. The variable value and not the change in the variable value defines the independent variable of the table. When a set-point factor is to be applied to a set point, its table is linearly interpolated for each time step on the basis of the abscissa-coordinate signal-variable or control block output variable value. The input SETP(I) constant value is multiplied by the interpolated function value to determine

the set-point value that is used. Set-point factor tables are useful when set points for regulating a component-action change on the basis of some system parameter dependence. For example, the desired water level in the steam-generator-secondary downcomer might depend on the reactor power level. A trip with varying water-level set-point values, dependent on the reactor power level, could be used to control the secondary-loop feedwater pump or valve.

Associated with each set point is a delay time defined by input array variable DTSP(I), $I = (1,2)$ or $I = (1,4)$. The delay time provides a second criterion that needs to be satisfied before the trip set status is changed. The first criterion requires that the trip-signal value reach or cross the set-point value tested. Once that criterion is met, the second criterion then requires that the delay time of that set-point pass before changing the trip set status. With a delay time, the user is able to model the time necessary for the system hardware or the control room operator to process the controlling signal and initiate hardware action. Delay time should be defined with a nonnegative value (negative values are treated as zero). TRAC edits a message when each criterion is satisfied by a trip. For large delay times, it is possible for a number of first-criterion tests to be satisfied before their delay times pass. TRAC can handle up to five such delay-time pending set-status changes stacking up before the next one is forced to replace the last one in the stack. When it does, a warning message is printed. For a delay time-pending set-status change to stack up, the time its first criterion was met (based on linear interpolation of the trip-signal value to equal the set-point value) plus its delay time must be later than all pending times higher up in the stack. When that time is equal to or less than one or more pending times higher in the stack, they are replaced by this new entry. Through this mechanism, the user can prevent temporary spikes in a trip signal from setting a trip ON and its component action being evaluated. The user does this by defining shorter delay times for the set points that turn a trip OFF than for the set points that turn a trip ON. The difference between these two delay times is the required time interval the trip signal value needs to stay in the ON subrange to prevent a satisfied OFF criterion that follows from replacing its pending ON set-status change in the stack.

There are three forms for defining the trip signal: a signal parameter, a signal expression, or a trip set-status signal. Two input variables define the trip signal: ITST defines the trip-signal type number and IDSG defines the trip-signal ID number. A "signal-parameter" trip is defined by ITST = 1 and has a signal-parameter trip signal. That signal parameter is a signal variable with ID number IDSG when IDSG > 0 or a control-block output variable with ID number IDSG when IDSG < 0. A "signal-expression" trip is defined by ITST = 2 and has a signal-expression trip signal. The trip signal is an arithmetic expression operating on the values of one or more signal variables and control-block output variables. Its definition is input as trip-signal-expression input data with ID number IDSG. The form for that definition is described in the next paragraph. A trip-controlled trip (or "trip set-status signal" trip) is defined by ITST = 3 and has a trip set-status signal. This signal is the sum or product of the set-status values of two or more other trips. The ID numbers of those trips are input as trip-controlled trip-signal data with ID number IDSG. The set-status values of those trips are to be summed if IDSG > 0 or multiplied if IDSG < 0 to evaluate the trip-controlled trip signal.

Evaluating a signal-expression trip signal involves evaluating an arithmetic expression with one to ten arithmetic subexpressions. Each subexpression has an arithmetic operator and two arguments. The arithmetic operators are addition, subtraction, multiplication, division, exponentiation, maximum value, minimum value, and absolute value. Argument values are defined by signal variables, control-block output variables, input constants, or an earlier evaluated subexpression in the list of subexpressions. The value of the signal expression is the value of the last subexpression in its list. Through its arithmetic operators, a signal expression allows signal variables from different components of the modeled PWR system to be combined in defining the trip signal. Signal variables that define a subexpression argument can be flagged in the signal-expression definition for reevaluation only at the times its signal-expression trip is set ON. In this way, signal variables evaluated at different times as well as in different components can be combined in defining a trip signal.

The AND or OR logic of blocking or coincidence trips can be implemented with trip-controlled trips. Applying the AND logical operator defines a blocking trip that is ON only if all the trips assigned to it are ON. The trip-controlled trip that has this form multiplies ($IDSG < 0$) the set-status values of its assigned trips in defining the trip signal and uses a $ISRT = 2$ signal-range type with $0 < S_1 < S_2 < 1$. It turns out, in this case, that the trip-controlled trip signal has the same value (0 or 1) as its subrange set-status value. Applying the OR logical operator defines a coincidence trip that is ON only if one or more of the assigned trips are ON. Its corresponding trip-controlled trip adds ($IDSG > 0$) the set-status values of its assigned trips and uses the same signal-range type and set-point values as above. For a more general coincidence trip, we specify that a number N or more (where $1 \leq N \leq N_t$) of the N_t assigned trips need to be ON for the coincidence trip to be ON. Within AND or OR logic, this requires logical expressions having logical subexpressions. For example, if $N = 2$ of $N_t = 3$ assigned trips need to be ON for the coincidence trip to be ON, its logical expression would need to have the form: (Trip #1 AND Trip #2) OR (Trip #2 AND Trip #3) OR (Trip #3 AND Trip #1). The form of this logical expression will be different for different values of N or N_t . With trip-controlled trips, the required form is the sum of the set-status values of its assigned trips in all cases. The only difference is in defining the set points according to $(N-1) < S_1 < S_2 < N$. In this case, the trip-controlled trip signal value, which is the number of assigned trips that are ON, needs to be greater than S_2 (that is, the value N or greater) to meet the criterion for setting the trip-controlled trip ON.

The three trip-controlled trip examples above barely scratch the surface of the number of ways trip-controlled trips can be used to model AND/OR logical expressions. Switching from a $ISRT = 2$ to a $ISRT = 1$ signal-range type applies a NOT logical operator to the logical expression being modeled. Assigning a trip-controlled trip to the definition of another trip-controlled trip signal provides further modeling flexibility. The above discussion assumes that the ON set status of the assigned trips is $ON_{forward}$. Assigning trips with $ON_{reverse}$ set-status subranges to a trip-controlled trip signal provides another dimension for modeling possible logical expressions.

During input, trips are given ID numbers that assign them to the following functions:

1. to control component actions by defining their ID numbers to the general form variables IXXXTR in the component input data,
2. to define trip-controlled trip signals with their set-status values, and
3. to define the trip signals or set-status values by signal variables.

Trip ID numbers of magnitude 1 to 9999 are allowed. A negative ID number defines a trip that is to be evaluated during steady-state and transient calculations. A positive ID number trip, on the other hand, is evaluated only during transient calculations. During steady-state calculations, the set-status value specified by input-variable ISET and an initialized trip signal value of 10^{20} define a positive-ID trip constant state. A positive-ID trip can be used as a blocking trip during a steady-state or transient calculation when the trip-evaluated set status is the opposite of its input ISET value.

6. Control-Parameter Evaluation. Signal variables, control blocks, and trips are assigned ID numbers when input by the user. Their ID numbers provide the means for referencing their values for use in the control procedure. Their ID numbers also define the order in which they are to be evaluated. Within each control-parameter type (signal variables, control blocks, and trips), parameters are evaluated in the order of increasing magnitude of their ID numbers. Thus, control blocks are ordered for evaluation with their ID numbers decreasing in negative value; trips are ordered with their ID numbers increasing in magnitude with either a plus or minus sign. This is done by subroutine ORDER after the control-parameter data are input, and the control-parameter restart data with ID numbers different from those input are added on. For example, a control-block input with ID number -5 would replace a control block with the same ID number from the restart file. Subroutine ORDER would reorder the list of control blocks so that control block ID = -5 would be placed before control blocks with IDs < -6 and after control blocks with IDs > -5. A trip input with ID number 11 would replace a trip with the same ID from the restart file but not a trip with ID number -11. For the case of two trips having ID numbers with the same magnitude, that is, 11 and -11, subroutine ORDER does not change their relative positions in the trip list. With trip ID = 11 input and trip

ID = -11 added on to the trip list from the restart file, trip ID = -11 would follow after trip ID = 11 in the reordered list of trips. Subroutine ORDER is called once at the end of input (and restart) data processing to reorder the signal variable, control block, and trip lists. This saves having to search through ID numbers to determine that order when the control parameters are evaluated at the beginning of each time step.

Through ID numbers, the order for evaluating control parameters of a given type is defined. The order for evaluating control-parameter types is by default signal variables first, then control blocks, and finally trips. Since signal variables have almost all of their parameters defined by the modeled PWR system, it is appropriate to evaluate them first. The input parameters for control blocks are signal variables and control blocks that, with proper ordering of control blocks, means control blocks should be evaluated after signal variables. Trip signals are defined by signal variables, control blocks, and the set status of other trips. With proper ordering of trips, evaluation of trip signals should follow the evaluation of signal variables and control blocks.

In general, this approach is able to evaluate control-parameter values for the beginning of the time-step state of the system. There are a few situations, however, where such is not the case. Defining a trip signal or set status to be a signal variable (ISVN = 55 or 56) will give its value at the beginning of the previous time step when the signal variables are evaluated before their trips. In this case, they should be evaluated after their trips. A control-block controller with an implicit feedback loop (Fig. 17) is another exception. To evaluate X with the Add operator control block, $\ln(X)$ and thus X need be known. By evaluating each of the two control blocks once, no matter which is evaluated first, the value of X used to evaluate $\ln X$ will be one time step behind the value that should be used. Accumulation of such error over many time steps can cause the value of X to significantly lag its actual value in time. Instability can even result from that error. TRAC has not as yet been programmed to recognize such implicit-loop structures in order to implement internally an iterative loop evaluation able to determine the consistent solution state.

Fig. 17.
Implicit control-block loop example.

A multipass control-parameter evaluation procedure has been programmed in TRAC to aid the user in addressing the above two situations. Within each evaluation pass, the user decides which signal variables, control blocks, and trips (in that order) are to be evaluated. Trip-signal and set-status signal variables can then be evaluated on a second control-parameter evaluation pass after their defining trips were evaluated on the first pass. The implicit control-block loop can be reevaluated with as many passes as the user decides are needed for convergence. On the last loop evaluation pass, all control blocks whose input parameters are affected by the loop evaluation would then be evaluated. During each of the passes, the user specifies which control parameters, if any, are to be evaluated for each type. Those parameters that are evaluated span a range of ID numbers that the user specifies. All control parameters with ID numbers in that range are evaluated during that pass. An example of such a procedure follows. Assume the following control parameters are to be evaluated:

1. signal variables with IDs 3 to 35 define system (component) parameters and signal variables with IDs 39 to 72 define signal and set status from trips with IDs +7 to +18 as well as system parameters.

2. control blocks with IDs -1 to -12 require input parameters from signal variables with IDs 3 to 17 and provide input parameters for control blocks in an implicit loop, control blocks with IDs -13 to -17 are in an implicit loop for which five iterative evaluations are felt to be sufficient to converge on a consistent solution state and control blocks with IDs -18 to -42 require input parameters from the implicit loop control blocks and from signal variables.
3. trips with IDs ± 1 to ± 18 require signal variables with IDs 3 to 26 and control blocks with IDs -6 to -10 to define their signals and trips with IDs ± 19 to ± 30 require signal variables with IDs 18 to 72 and control blocks with IDs -5 to -40 to define their signals.

Evaluating these control parameters could be done with the five evaluation passes shown in Table X. After five passes (assuming convergence of the implicit loop evaluation) all control parameters would have values consistent with each other and the beginning of time-step state of the system.

TABLE X

ID NUMBERS OF CONTROL PARAMETERS EVALUATED DURING
EACH OF FIVE CONTROL-PARAMETER EVALUATION PASSES

<u>Evaluation Pass Number</u>	<u>Signal Variables</u>	<u>Control Blocks</u>	<u>Trips</u>
1	3 to 35	-1 to -17	± 1 to ± 18
2	39 to 72	-13 to -17	none
3	none	-13 to -17	none
4	none	-13 to -17	none
5	none	-13 to -42	± 19 to ± 30

IV. COMPONENT MODELS

This section describes the TRAC-PF1/MOD1 component models. A physical description of each component is presented along with a typical TRAC nodding diagram showing the conventions that are used to model the component. Mathematical models including finite-difference approximations are given only for those aspects of the component that are not covered in the basic hydrodynamics and heat-transfer descriptions (Sec. III). User options, restrictions on the use of the component, subroutines used by the component, and input/output information also are given. Detailed input specifications for each component are given in Sec. V.

A. Pipe

The PIPE component models the flow in a one-dimensional duct or pipe. A PIPE can be used alone in a problem, or it can be used as a connector between components to model a reactor system. The capability is provided to model area changes, wall heat sources, and heat transfer across the inner and outer wall surfaces. A wide selection of pipe materials is available within the code to represent the wall material in the wall-conduction calculation; additionally, the user can specify material properties in the input.

Figure 18 shows a typical nodding diagram for a PIPE containing a venturi tube and an abrupt area change. The numbers within the PIPE indicate cell numbers, and those above indicate cell-boundary numbers. The geometry is specified by providing a volume and length for each cell and a flow area and hydraulic diameter at each cell boundary. The junction variables, JUN1 and JUN2, provide reference numbers for connecting a pipe to other components. The numerical methods used to treat the thermal hydraulics in a PIPE are described in Sec. III.A.3.

Input options are available to allow for wall heat transfer, to use the full boiling curve, or to restrict heat transfer to forced convection, and to select wall-friction factors. Wall heat transfer can be omitted by setting the number of heat-transfer nodes (NODES) to zero. The CHF calculation can be bypassed by setting the input parameter ICHF to zero. Wall friction and losses caused by abrupt area changes are chosen by setting values of the input arrays, NFF and FRIC, at each cell interface. The choices for these arrays are described in the input specifications in Sec. V.D.5.e.

Fig. 18.
Pipe noding diagram.

By our setting NPOWTB to a nonzero number and NODES to zero, heat can be provided to a PIPE by a table of power vs time. The table provides total power, which is evenly distributed among all of the cells.

By setting parameter IACC to 1 or 2 (see PIPE input, Sec. V.C.5.e), a PIPE can be used to model an accumulator (ACCUM) component, discussed in Sec. IV.B.

Although a PIPE can be connected to any other component, including another PIPE, the user should keep the number of components to a minimum.

Detailed input for a PIPE module is processed by subroutines RPIPE and REPIPE. Subroutine RPIPE reads input data from the card input file. Subroutine REPIPE reads the corresponding data from the restart file. Initialization of the remaining variables is performed with subroutine IPIPE. This subroutine establishes the noding for wall heat transfer, sets the remaining fluid properties by calls to THERMO and FPROP, and initializes the boundary data by a call to J1D.

During problem execution, the solution procedure is controlled by routines PIPE1, PIPE2, and PIPE3. At the beginning of each time step, PIPE1 calls PREPER that in turn calls FWALL for wall friction and orifice loss coefficients, MPROP for wall metal properties, HTPIPE for wall HTC's, and FEMOM to set up the stabilizer motion equations. Routine PIPE1 also calls BKMOM for a final backward substitution on the motion equations. During the iterations for a time step, PIPE2 calls TF1D for the numerical hydrodynamics solution (see Sec. III.A.3) and J1D to update boundary arrays. After a time step is

completed successfully, PIPE3 calls CONSTB to set up the stabilizer mass and energy equations. Routine PIPE3 also calls POSTER that updates the wall temperatures with a call to CYLHT, computes new fluid properties (viscosity, heat capacity, and surface tension) with a call to FPROP, performs backward substitution on the stabilizer mass and energy equations and resets the boundary arrays with a call to JLD. If the time step fails to converge, THERMO is called to restore variables to their old values.

Output for a PIPE is managed by subroutine WPIPE. This subroutine prints the component number, junction numbers, iteration count, pressures, vapor fractions, saturation temperatures, liquid and vapor temperatures, liquid and vapor densities, liquid and vapor velocities, and wall friction factors. If wall heat transfer is included (NODES $\neq$ 0), then information on the heat-transfer regime, liquid and vapor wall HTC's, interfacial HTC, heat-transfer rate from the wall, wall temperature for critical heat flux, and wall temperature profiles also are provided.

B. Accumulator

An accumulator is a pressure vessel filled with ECC water and pressurized with nitrogen gas. During normal operation each accumulator is isolated from the reactor primary coolant system by a check valve. If the reactor-coolant-system pressure falls below the accumulator pressure, the check valves open and ECC water is forced into the reactor coolant system.

An accumulator component may be simulated by an ACCUM module in TRAC. This module can only be connected at one junction to other TRAC components. This connection is at the highest-numbered cell. It is assumed that cell 1 is closed, as shown in the typical noding diagram in Fig. 19, and that the accumulator is not connected to a nitrogen pressure source. Therefore, the nitrogen pressure results from the expansion of the initial gas volume.

The procedures for data input, initialization of arrays, advancement of time-dependent variables, and editing are similar to those given for a PIPE component (see Sec. IV.A). A sharp liquid-vapor interface is maintained by neglecting interfacial shear. In an accumulator the vapor-phase properties are those for nitrogen gas; therefore, interphase mass transfer cannot occur. The vapor-phase temperature minimum is not limited. Additionally, there is a phase separator at the accumulator discharge so that pure liquid is discharged. The accumulator walls are assumed to be adiabatic.

Fig. 19.
Accumulator noding diagram.

The output edit is similar to that for a PIPE one-dimensional component with the addition of three variables specific to an accumulator. These are (1) the discharge volumetric flow rate, (2) the total liquid volume discharged, and (3) the collapsed liquid level.

An accumulator also may be modeled with a PIPE component by setting the air partial pressures to the desired values. Thus, wall heat transfer can be included by setting NODES to a nonzero value. The air-steam vapor-phase temperature minimum is limited to 280 K by routine THERMO. An input switch activates the interface sharpener, (optional) phase separator at the discharge, and the additional edit as described above for the ACCUM component. The edit logic assumes that the component is vertical with the lowest-numbered cell at the top.

C. Break and Fill

The BREAK and FILL modules are used to impose boundary conditions at any one-dimensional component terminal junction. Consequently, these modules differ from the other component modules in that they do not model any system component per se and they do not perform any hydrodynamic or heat-transfer calculations. However, they are treated like any other component with respect to input, initialization, and identification procedures.

The BREAK module imposes a pressure boundary condition one cell away from its adjacent component, as shown in Fig. 20. The pressure boundary condition as well as the fluid properties associated with the BREAK may be specified as constants or functions of a system parameter defined through input BREAK tables. They also can be constant until a controlling trip is set ON and their evaluation is based on the BREAK tables. This module commonly is used to model the containment system in LOCA calculations.

A FILL module imposes a velocity boundary condition at the junction with its adjacent component, as shown in Fig. 21. For example, the ECC injection may be modeled with a FILL.

The velocity boundary condition as well as the fluid properties associated with a FILL are specified in one of three ways according to the FILL-type option selected. For the first type of FILL, the homogeneous fluid velocity and fluid properties are specified; for the second type, the mass

Fig. 20.
Break noding diagram.

Fig. 21.
Fill noding diagram.

flow and homogeneous fluid properties are specified; and for the third type, nonhomogeneous fluid velocities and fluid properties are specified. For each type of FILL, the relevant parameters may be constant, interpolated from input FILL tables, or constant until a controlling trip is set ON to require their evaluation from their tables. The independent variable of the table is a modeled-system parameter. When the table-evaluated FILL velocity or mass flow varies rapidly, using these values may lead to hydrodynamic instabilities. This situation may be avoided by using a weighted average of the previous value and the current table-determined value (see Sec. V.C.5.b).

The parameters needed to specify a FILL or a BREAK are described in Secs. V.C.5.b and V.C.5.d. It is suggested that the cell volume and length in a FILL or a BREAK be identical to those for the neighboring cell of the adjacent component. The pressure, void fraction, fluid temperatures, air partial pressure, and solute concentration specified for a FILL or a BREAK determine the properties of the fluid convected into the adjacent component if an inflow condition occurs. (By convention, inflow to the adjacent component corresponds to a positive FILL velocity and a negative BREAK velocity.) A FILL or a BREAK may not be connected directly to the VESSEL component.

D. Core

A CORE component is available in TRAC to analyze the reactor core in situations that do not demand a three-dimensional fluid-dynamics characterization.

This one-dimensional treatment can produce significant reduction in computer running time for a wide range of problems. The CORE component is a hybrid in nature. Wherever possible, we used the coding characteristic to the PIPE and VESSEL components.

The fluid-dynamics and exterior-wall conduction models are identical to those used by a PIPE component. Both are one-dimensional. In addition, any number of fuel rods may be introduced into the CORE component, although only the first (average) rod interacts thermally with the fluid. The rod heat-transfer model is identical to that used by the VESSEL component.

A typical noding diagram for a CORE component is shown in Fig. 22. Currently, connections can be made only at the first and last cells. Therefore, it has been necessary to model the upper and lower plenums using

Fig. 22.
Core noding diagram.

other one-dimensional components. The vessel downcomer has been modeled by attaching a PIPE to the CORE component. Therefore, bypass effects are difficult to model with this component. Detailed input specifications for a CORE component are provided in Sec. V.C.5.c. Input and output information is similar to that for the PIPE and VESSEL components.

E. Plenum

The PLENUM module, which models the thermal hydraulics of a large volume connected to an arbitrary number of one-dimensional components, is a single-cell component that acts like a momentum sink (for the case of flow out of the PLENUM through a given junction, the upstream velocity in the momentum-flux term is zero); however, all junction elevations and their orientations with respect to the PLENUM are preserved. There are single values for void fraction, liquid temperature, vapor temperature, and pressure in the PLENUM. At each junction, the code applies the standard one-dimensional, two-fluid momentum equations with the above mentioned restriction on the momentum-flux term. There is no requirement that the liquid and vapor velocities be equal at a given junction. The existence of a stratified flow is implied in the constitutive correlations if the mean fluid velocity in the PLENUM falls below a threshold value.

No junction data input is required for the PLENUM except for a list of the junction numbers connected to the component. The PLENUM requires one or more junctions. All pertinent junction information is obtained from the one-dimensional modules connected to the PLENUM. The user specifies as many PLENUM-side cell lengths as junctions, such that each junction has its own associated cell length. The PLENUM does not require identical cell lengths. The code uses the cell lengths, as necessary, to calculate the velocity for each junction. In particular, the GRAV parameter at a given junction (input only in the adjacent component) must be calculated using the cell lengths from the adjacent cell and the PLENUM.

Currently, the code does not permit heat structures to be used with the PLENUM. Also, signal variables should not point to PLENUMs; if needed, the signal variables should point to an adjacent cell in one of the connecting, one-dimensional components. A PLENUM cannot be directly connected to BREAK, FILL, VESSEL, or other PLENUM components.

PLENUM and PIPE data are processed similarly. Subroutine RPLEN reads the data from the input file (TRACIN), and subroutine REPLEN reads the data from the restart file (TRCRST). Subroutine IPLEN performs initialization of any remaining variables not provided by the input or restart files.

PIPE and PLENUM output edits also are similar.

Subroutines PLEN1, PLEN2, and PLEN3 perform the same functions for the PLENUM as PIPE1, PIPE2, and PIPE3 do for the PIPE.

F. Pressurizer

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

The PRIZER module simulates the pressurizer component. This module normally models the pressurizer itself with the surge line represented by a PIPE or TEE component. Figure 23, a typical noding diagram, shows that a PRIZER component may be connected at both junctions to other components. To calculate the collapsed liquid level we assume that cell 1 is at the upper end, which may be closed by connecting it to a zero-velocity FILL.* For steady-state calculations, the PRIZER module is replaced automatically by a BREAK equivalent on both sides. Thus, the thermal-hydraulic conditions in the PRIZER module during steady-state calculations remain unchanged except for the wall temperature, which is calculated from the conduction equation to obtain a steady-state wall temperature profile. The procedures for data input, initialization of arrays, advancement of time-dependent variables, and editing are similar to those given for a PIPE component (see Sec. IV.A).

*If the top of the pressurizer is connected to a zero-velocity FILL, a void fraction of 1.0 should be input in the FILL component to invoke the interface-sharpener model in cell 1 of the PRIZER.

Fig. 23.
Pressurizer noding diagram.

The PRIZER component includes heater/sprayer logic to serve as a system pressure controller but not to simulate exactly the actual heater/sprayer system.** The user specifies a desired pressure set point, PSET, and the pressure deviation, DPMAX, at which the heater sprayers add or remove a maximum power of QHEAT. The power that is input to the pressurizer fluid is directly proportional to the difference between PSET and P(1), the pressure in cell 1; that is,

$$Q_{\text{input}} = Q_{\text{HEAT}} \left[\frac{P_{\text{SET}} - P(1)}{D_{\text{PMAX}}} \right] ,$$

**The actual sprayer system can be modeled by setting up the TRAC model corresponding to the actual system spray configuration; the actual heater simulation can be achieved by modeling the bottom of the pressurizer by a separate one-cell PIPE component and by adding trip-controlled power into the coolant.

with the absolute value of Q_{input} less than or equal to Q_{HEAT} . This power is distributed over all fluid cells in the pressurizer, and the fraction of power input to the liquid in each cell is equal to the fraction of total liquid mass in that cell. Power is not added if the collapsed liquid level is less than the input parameter ZHTR. [The collapsed liquid level is calculated as follows: determine the total liquid volume in the PRIZER component; sequentially subtract from the total liquid volume the volume of the bottom cell (cell NCELLS), the next to the bottom cell (cell NCELLS-1), etc., until the cell that contains all of the remaining liquid volume is found; the collapsed liquid level is the sum of the cell lengths (Δx) of the filled cells plus a linearly interpolated (based on liquid fraction) Δx from the partially filled cell.] If pressure control is not desired, then Q_{HEAT} is set to zero.

Wall friction coefficients are calculated in routine FWALL by specifying a friction correlation option, NFF, along with the additive friction factors, FRIC, for each cell edge. The homogeneous flow friction correlation option (NFF = 1) is suggested for a pressurizer.

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

G. Pump

The PUMP module describes the interaction of the system fluid with a centrifugal pump. The model calculates the pressure differential across the pump and its angular velocity as a function of the fluid flow rate and the fluid properties. The model can treat any centrifugal pump and allows for the inclusion of two-phase effects.

The pump model is represented by a one-dimensional component with N cells ($N > 1$). Figure 24 shows a typical noding diagram for the pump component. The pump momentum is modeled as a source between cells 1 and 2. The source is positive for normal operation so that a pressure rise occurs from cell 1 to cell 2. Therefore, it is necessary to construct the cell noding such that the cell number increases in the normal flow direction.

Fig. 24.
Pump noding diagram.

The following considerations were important in creating the PUMP module:

1. compatibility with adjacent components should be maximized,
2. choking at the pump inlet or outlet should be predicted automatically, and
3. the calculated pressure rise across the pump should agree with that measured at steady-state conditions.

The first two criteria precluded the use of a lumped-parameter model. The PUMP module, therefore, combines the PIPE module with pump correlations.

The pump model is identical to the one-dimensional pipe model except that the momentum equations between cells 1 and 2 are rewritten as

$$\frac{v_{\ell}^{n+1} - v_{\ell}^n}{\Delta t} = \frac{[p_1^{n+1} - p_2^{n+1} + \Delta p^n + \left(\frac{\partial \Delta p}{\partial v}\right)^n (v_{\ell}^{n+1} - v_{\ell}^n)]}{(\langle \phi_m \rangle \bar{\Delta x})} - g \cos \theta \quad (212)$$

and

$$v_{g,\ell} = v_{\ell} \quad , \quad (213)$$

where ΔP is the pressure rise through the pump evaluated from the pump correlation. The steady-state solution of Eq. (212) is

$$\Delta P = P_2 - P_1 + g \cos \theta ,$$

which is the desired result. Friction does not enter explicitly into the pump motion equation. Therefore, additive friction is not allowed between cells 1 and 2 [FRIC (2) = 0.0].

It is necessary to evaluate ΔP and its derivative with respect to velocity for a pump cell only once each time step. The source is needed only in routines FEMOM and TFLDS1. This evaluation is performed by subroutine PUMPSR.

The pump correlation curves describe the pump head and torque response as a function of fluid volumetric flow rate and pump speed. Homologous curves (one curve segment represents a family of curves) are used for this description because of their simplicity. These curves describe, in a compact manner, all operating states of the pump obtained by combining positive or negative impeller velocities with positive or negative flow rates.

The following definitions are used in the subsequent development:

H = the pump head = $\frac{\Delta P}{\rho}$,

Q = the pump volumetric flow rate, and

Ω = the pump impeller angular velocity,

where ΔP is the pressure rise across the pump and ρ is the pump upstream mixture density. To allow one set of curves to be used for a variety of pumps, the following normalized quantities are used:

$$h \equiv \frac{H}{H_R} ,$$

$$q \equiv \frac{Q}{Q_R} , \text{ and}$$

$$\omega \equiv \frac{\Omega}{\Omega_R} ,$$

where H_R is the rated head (RHEAD) for the pump, Q_R is the rated volumetric flow (RFLOW), and Ω_R is the rated pump speed (ROMEGA). The pump similarity relations⁴⁷ show that

$$\frac{h}{\omega^2} = f\left(\frac{q}{\omega}\right) . \quad (214)$$

For small ω this correlation is not satisfactory, and the following combination of variables is used,

$$\frac{h}{q^2} = f\left(\frac{\omega}{q}\right) . \quad (215)$$

Correlation [Eq. (214)] is used in the range $0 \leq |q/\omega| \leq 1$ and results in two separate curves, one for $\omega > 0$ and one for $\omega < 0$. Correlation [Eq. (215)] is used in the range $0 \leq |\omega/q| < 1$ and yields two separate curves, one for $q > 0$ and one for $q < 0$. The four resulting curve segments, as well as the curve selection logic used in TRAC, are shown in Table XI.

To account for two-phase effects on pump performance, the pump curves are divided into two separate regimes. Data indicate that two-phase pump performance in the vapor-fraction range of 20-80% is degraded significantly in comparison with its performance at vapor fractions outside of this range. One set of curves describes the pump performance for single-phase fluid (0 or 100% vapor fraction), and another set describes the two-phase, fully degraded performance at some void fraction between 0 and 100%. For single-phase conditions the curve segments for correlation [Eq. (214)] are input as HSP1 for $\omega > 0$ and HSP4 for $\omega < 0$, and correlation [Eq. (215)] curve segments are

TABLE XI
DEFINITIONS OF THE FOUR CURVE SEGMENTS THAT DESCRIBE THE
HOMOLOGOUS PUMP HEAD CURVES^a

Curve Segment	$\left \frac{q}{\omega} \right $	ω	q	Correlation
1 4	$\left[\begin{array}{l} \leq 1 \\ \leq 1 \end{array} \right]$	$\begin{array}{l} > 0 \\ < 0 \end{array}$	$\left[\begin{array}{l} \\ \end{array} \right]$	$\left[\frac{h}{\omega^2} = f \left(\frac{q}{\omega} \right) \right]$
2 3	$\left[\begin{array}{l} > 1 \\ > 1 \end{array} \right]$	$\begin{array}{l} > 0 \\ < 0 \end{array}$	$\left[\begin{array}{l} > 0 \\ < 0 \end{array} \right]$	$\left[\frac{h}{q^2} = f \left(\frac{\omega}{q} \right) \right]$

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

input as HSP2 for $q > 0$ and HSP3 for $q < 0$. The fully degraded version of correlation [Eq. (214)] is input as curve HTP1 for $\omega > 0$ and HTP4 for $\omega < 0$. The fully degraded version of correlation [Eq. (215)] is input as HTP2 for $q > 0$ and HTP3 for $q < 0$.

The pump head at any vapor fraction is calculated from the relationship,

$$H = H_1 - M(\alpha) (H_1 - H_2) \quad , \quad (216)$$

where

H = the total pump head,

$H_1 = h_1 H_R$ = the single-phase pump head (h_1 is the nondimensional head from the single-phase homologous head curves),

$H_2 = h_2 H_R$ = the fully degraded pump head (h_2 is the nondimensional head from the fully degraded homologous head curves),

M = the head degradation multiplier (input as HDM), and

α = the vapor fraction.

To this point, no knowledge of density is required to calculate H from the homologous head curves. The upstream mixture density is always used to convert the total pump head H to ΔP , the pressure rise through the pump, by the definition $\Delta P = \rho H$.

The development of homologous torque curves parallels the previous development for homologous head curves. The dimensionless hydraulic torque is defined by

$$\beta \equiv \frac{T_{hy}}{T_R} ,$$

where T_{hy} is the hydraulic torque and T_R is the rated torque (RTORK). The convention used is that a positive T_{hy} works to retard positive pump angular velocity. The dimensionless torque β is correlated as either β/ω or β/q just as the dimensionless head was correlated. For single-phase conditions the correlations yield the corresponding four curve segments TSP1, TSP2, TSP3, and TSP4. The fully degraded correlations produce four corresponding curves TTP1, TTP2, TTP3, and TTP4. The homologous torque curve segments are correlated in the same manner as the head curve segments shown in Table XI (replace h with β). For the special case of $\omega = q = 0.0$, the code sets $\beta_1 = \beta_2 = 0.0$.

The single-phase torque T_1 is dependent upon the fluid density and is calculated from

$$T_1 = \beta_1 T_R \left(\frac{\rho}{\rho_R} \right) , \quad (217)$$

where β_1 is the dimensionless hydraulic torque from the single-phase homologous torque curves, ρ is the pump upstream mixture density, and ρ_R is the rated density (RRHO). The density ratio is needed to correct for the

density difference between the pumped fluid and the rated condition. Similarly, the fully degraded torque T_2 is obtained from

$$T_2 = \beta_2 T_R \left(\frac{\rho}{\rho_R} \right) ,$$

where β_2 is the dimensionless hydraulic torque from the fully degraded homologous torque curves. For two-phase conditions the impeller torque is calculated from

$$T = T_1 - N(\alpha) (T_1 - T_2) , \quad (218)$$

where T is the total impeller torque and $N(\alpha)$ is the torque degradation multiplier (input as TDM).

In addition to the homologous head and torque curves, the head and torque degradation multipliers defined in Eqs. (216) and (218) are required. These functions of void fraction are nonzero only in the vapor-fraction range where the pump head and torque are either partially or fully degraded.

The pump module treats the pump angular velocity as a constant (input) while the motor is energized. After a drive motor trip, the time rate of change for the pump angular velocity Ω is proportional to the sum of the moments acting on it and is calculated from the equation,

$$I \frac{d\Omega}{dt} = - \sum_i T_i = - (T + T_f + T_b) , \quad (219)$$

where I is the combined impeller, shaft, and motor assembly moment of inertia (EFFMI); T is the hydraulic torque on the impeller; T_f is the torque caused by friction; and T_b is the bearing and windage torque. We assume that T_f and T_b are

$$T_f = C_1 \frac{\Omega |\Omega|}{\Omega_R^2} \quad (220)$$

and

$$T_b = C_2 \frac{\Omega |\Omega|}{\Omega_R^2}, \quad (221)$$

where C_1 and C_2 are input constants (TFR1 and TFR2, respectively). The hydraulic torque T is evaluated using the homologous torque curves and Eq. (218); it is a function of the volumetric flow, the upstream void fraction, the upstream density, and the pump angular velocity. For time step $(n+1)$, Eq. (219) is evaluated explicitly,

$$\Omega^{n+1} = \Omega^n - \frac{\Delta t}{I} [T(Q, \alpha, \rho, \Omega) + (C_1 + C_2) \frac{\Omega^n |\Omega^n|}{\Omega_R^2}] \quad (222)$$

The wall heat transfer, wall friction, and CHF calculation options are the same for the PUMP module as for the PIPE module. In addition, the following options are specified: pump type (IPMPTY), motor action (IPMTR), reverse speed option (IRP), degradation option (IPM), and pump curve option (OPTION). The input variables IPMPTR and NPMPTX specify, respectively, the trip number for the pump trip initiation and the number of pairs of points in the pump-speed table (array SPTBL). If IPMPTR = 0, no pump trip action occurs, and the pump runs for the entire calculation at the constant speed (OMEGAN) specified in the input.

If the pump motor is energized (trip IPMPTR set OFF), the angular velocity is assumed to be the constant value specified (OMEGAN). If the motor is not energized (trip IPMPTR set ON), the pump speed is allowed to vary.

Two types of pumps are available. For pump type 1 (IPMPTY = 1), the pump-speed variation is specified by the input table. The pump is energized initially at a constant speed specified by input (OMEGAN). Trip IPMPTR may initiate a pump trip, after which the pump speed is taken from a pump-speed table (array SPTBL). The independent variable for the pump-speed table may be elapsed time since trip initiation or any other signal variable, as discussed in Sec. V.B. For pump type 1 the torque calculation is not used. Pump type 2 (IPMPTY = 2) is similar to option 1 except that a speed table is not input. Instead, the pump speed is calculated from Eq. (222) after a trip has occurred.

If the reverse speed option is specified (IRP = 1), the pump is allowed to rotate in both the forward and reverse directions. If reverse speed is not allowed (IRP = 0), the pump will rotate in the forward direction only. For this case, if negative rotation is calculated (after trip with pump type 2), the speed will be set to zero. If IRP = 0 and a negative pump speed is encountered (i.e., from the speed table), error messages will be printed by subroutines PUMPD, PUMPX, and PUMPSR (this is a fatal error).

If the degradation option is turned on (IPM = 1), the degraded pump head and torque are calculated from Eqs. (216) and (218). If the degradation option is turned off (IPM = 0), only the single-phase head and torque homologous curves are used [equivalent to setting $M(\alpha)$ and $N(\alpha)$ to zero in Eqs. (216) and (218)].

The user may specify pump homologous curves in the input (OPTION = 0) or alternatively may use the built-in pump curves (OPTION = 1 or 2). The first set (OPTION = 1) of built-in pump curves is based on the Semiscale Mod-1 system pump.⁴⁸⁻⁵¹ The Semiscale pump curves for single-phase homologous head (HSP), fully degraded two-phase homologous head (HTP), head degradation multiplier (HDM), single-phase homologous torque (TSP), and torque degradation

multiplier (TDM) are provided in Figs. 25-29, respectively. The second set (OPTION = 2) of built-in pump curves is based on the Loss-of-Fluid Test (LOFT) system pump.⁵² The LOFT pump curves for single-phase homologous head (HSP), fully degraded two-phase homologous head (HTP), head degradation multiplier (HDM), single-phase homologous torque (TSP), and torque degradation multiplier (TDM) are shown in Figs. 30-34, respectively. For lack of data, the fully degraded two-phase homologous torque curves (TTP) for both Semiscale and LOFT are zero. Where applicable, the curves are numbered corresponding to the conditions provided in Table XI.

Because these homologous curves are dimensionless, they can describe a variety of pumps by specifying the desired rated density, head, torque, volumetric flow, and angular velocity as input. We recommend that for full-scale PWR analyses, plant-specific pump curves be input; however, if such data are unavailable, the LOFT pump curves (OPTION = 2) generally should be used.

There are several restrictions and limitations in the current version of the PUMP module. Because there is no pump motor torque vs speed model, the pump speed is assumed to be input if the motor is energized. Pump noding is restricted such that the cell numbers increase in the normal flow direction (NCELLS $\geq$ 2), the pump momentum source is located between cells 1 and 2 of the pump model, and the additive friction (loss coefficient) between cells 1 and 2 is 0.0 [FRIC(2) = 0.0]. A flow area change should not be modeled between cells 1 and 2. Finally, the head degradation multiplier $M(\alpha)$ and the torque degradation multiplier $N(\alpha)$ are assumed to apply to all operating states of the pump.

The PUMP module input consists of the same geometric and hydrodynamic data and initial conditions that are required for the PIPE module. In addition, information specific to the PUMP is required, as described in the input specifications (Sec. V.C.5.g). The speed table (SPTBL) as well as the homologous pump curve arrays must be input in the following order:

$x(1), y(1), x(2), y(2), \dots, x(n), y(n).$

Fig. 25.
Semiscale single-phase homologous
head curves.

Fig. 26.
Semiscale fully degraded homologous
head curves.

Fig. 27.
Semiscale head degradation multi-
plier curve.

Fig. 28.
Semiscale single-phase homologous
torque curves.

Fig. 29.
Semiscale torque degradation
multiplier curve.

Fig. 30.
LOFT single-phase homologous
head curves.

Fig. 31.
LOFT fully degraded homologous
head curves.

Fig. 32.
LOFT head degradation multiplier
curve.

Fig. 33.

LOFT single-phase homologous torque curves.

Fig. 34.

LOFT torque degradation multiplier curve.

Here x is the independent variable and y is the dependent variable. Furthermore, the independent variables must increase monotonically on input, that is,

$$x(1) < x(2) < \dots < x(n-1) < x(n).$$

Linear interpolation is used within the arrays.

The pump data are processed in a manner similar to that for the PIPE component. Subroutine RPUMP reads data from the input file, and subroutine REPUMP reads data from the restart file. Subroutine RPUMP calls subroutines RDDIM and RDCRVS to read the pump curves; if the built-in pump curves are to be used, subroutine RDCRVS calls subroutine PUMPI to load the correct data. Subroutine IPUMP initializes the remaining variables.

Subroutines PUMP1, PUMP2, and PUMP3 perform the same functions for the PUMP component as PIPE1, PIPE2, and PIPE3 perform for the PIPE component. For the PUMP component, subroutine PREPER calls subroutine PUMPSR to calculate the momentum source and the pump speed. Subroutine PUMPSR calls subroutine PUMPX

to calculate the pump head and pump torque. Subroutine PUMPX calls subroutine PUMPD to evaluate the homologous head and homologous torque from the pump curves.

H. Steam Generator

In the steam generator, energy is transferred from the high-temperature, high-pressure primary coolant to the secondary fluid so that steam is produced to drive the turbines. All steam-generator primary flow paths are similar in that the reactor coolant enters a plenum, flows through a tube bundle where the coolant is in thermal contact with the secondary fluid, and discharges through an exit plenum. There are two basic designs, however, once-through and U-tube. In the once-through design the primary fluid enters an upper hemispherical head at the top of the steam generator, flows downward through the tube bundle, and exits through a lower hemispherical head and out the discharge nozzles. In the basic U-tube design, the lower plenum is divided into inlet and outlet plena by a vertical divider plate. The primary fluid enters the inlet plenum and flows into the tube region. The tubes of the U-tube design are in the shape of inverted U's. The flow then exits through the outlet plenum.

Secondary flow paths differ remarkably between the different steam generator designs. The locations of the main feedwater, auxiliary feedwater, and steam outlet, for example, vary considerably. In once-through steam generator designs, the main feedwater typically enters a downcomer region, which may include a flow path to the tube bundle region (aspirated design), allowing bypass steam to mix with the inlet flow. In the aspirated designs, steam is drawn into the downcomer by the condensing caused by the cold feedwater. The saturated mixture enters the lower region of the tube bundle and flows countercurrent to the primary fluid. As the secondary flow progresses upward through the bundle, it passes through nucleate-boiling and film-boiling heat-transfer regimes. The secondary flow field is superheated in the top of the steam generator. Superheated steam exits through an outer annulus used to heat the steam generator shell and minimize thermal expansion between the tubes and the shell. In most once-through designs, the auxiliary feedwater enters the tube region at the top of the steam generator where it is forced into the center of the bundle.

U-tube steam-generator designs are much more diverse. In the basic U-tube design, the subcooled main feedwater enters through a distribution ring at the top of an annular downcomer where it mixes with recirculating, saturated water from the moisture separators. The mixture descends through the downcomer and radially enters the tube bundle through a cylindrical gap at the bottom of the bundle. The secondary water is then heated by the reactor coolant as it moves up the bundle. The two-phase mixture enters two stages of moisture separators, which remove the liquid content directing it into the downcomer. Final drying of the steam may be accomplished using corrugated plate dryers. High-quality steam exits the top of the steam generator. Recirculation ratios (total mass flow to steam flow) vary with design and operating conditions. Typically, ratios of between 2.0 and 5.0 are realized. The auxiliary feedwater supply typically enters through the same nozzles as the main feedwater.

In a U-tube steam generator equipped with a counterflow preheater, the main feedwater enters the bottom of the steam generator through a small downcomer. The bottom of the steam generator is separated into two sections by a vertical divider plate between the hot and cold primary legs. The feedwater enters the semicylindrical section enclosing the cold leg of the tube bundle. This is the preheater or economizer region, which includes about one-third of the tube bundle height. In the preheater section, the flow progresses through a baffled region counter to the cold-leg flow direction and is heated to saturation. On exit from the preheater section, the secondary fluid mixes with the recirculated flow from the half-ring region enclosing the hot leg. This latter region is referred to as the evaporator section. The mixture progresses up the tube bundle and into the region containing the centrifugal moisture separators and dryers. The liquid removed in this region is directed into an annular downcomer. The downcomer directs flow either to the top of the preheater or through a gap under the preheater (thereby thermally separating the cold feedwater from the tube sheet) and into the evaporator region. Heat transfer in the evaporator section is by nucleate boiling. Most of the recirculated flow (~70%) is directed to the evaporator and a smaller amount to the top of the preheater. This flow split reduces the density differences between the hot- and cold-leg sides of the secondary at the preheater discharge level.

The U-tube steam generator, equipped with a split-flow preheater differs from the counterflow preheater design only in the design of the preheater section. The feedwater enters through two nozzles that direct the flow to an upper and lower section of the preheater. Approximately 70% of the feedwater is directed to the upper preheater section where the flow progresses through a baffled region counter to the reactor coolant flow direction. On exiting the upper preheater, the flow then mixes with the evaporator flow. The remainder (~30% of the inlet flow) progresses through the baffled region of the lower-preheater section parallel to the primary flow and enters the bottom of the evaporator. This flow split prevents the introduction of cold feedwater onto the tube sheet. Although there is a 70/30 split of feedwater entering the upper- and lower-preheater sections, leakage between the two sections results in about a 25/75 split exiting the respective regions.

In the U-tube steam generator designs, the auxiliary feedwater may enter through the same nozzles as the main feedwater or through a top feedwater ring into the annular downcomer. When injected into the downcomer, the auxiliary feedwater maintains a degree of subcooling to promote an increased recirculation ratio and prevents boiling of the recirculating flow, thereby providing improved thermal-hydraulic conditions.

The TRAC steam-generator model has been provided with sufficient generality to allow the user the ability to construct the geometry pertinent to his analysis. All flow paths associated with the steam-generator component employ the one-dimensional two-fluid analysis. Furthermore, the standard one-dimensional constitutive relations are used. Input is required for both a primary- and a secondary-flow path. It should be emphasized, however, that what is referred to as primary or secondary steam-generator flow paths need not necessarily be connected to the primary or secondary reactor-flow loops. That is, because of the generality associated with the steam-generator secondary, it is possible, for example, to construct the entire component using the secondary flow path. When this is done, the primary component must be isolated (hydraulically and thermally) from the secondary components. As a second example, a tube rupture problem could be modeled using the primary steam-generator component to model the intact tubes. The secondary components could then be used to model the broken tube as well as the secondary steam-generator flow path.

In the TRAC steam-generator model, the primary component may be either a one-dimensional PIPE or TEE. The primary component is used under typical conditions to represent the entire tube bank as a single, effective tube. Therefore, the volumes and flow areas for the primary fluid cells are based on all of the tubes within the tube bank; however, the hydraulic diameter is that of a single tube. The constitutive package (friction factors, interfacial quantities, etc.) used for the primary fluid-dynamic calculations is identical to that used for all of the TRAC one-dimensional (exvessel) components. The number of fluid volumes (cells) used to model the steam-generator primary is user-specified (NCELL1). Typically, two of the cells model the inlet and the exit plena; the remaining NCELL1-2 cells are located in the tube bundle.

The TRAC program can model a tee connection on the primary flow path. This option allows the user to model a tube rupture problem, for example. When the primary-tee option is selected, the user must specify the cell on the primary side to which the connection is to be made (JCLP), the angle at which the connection is to be made (COSP), and the number of fluid cells used to model the flow field on the side tube connection (NCLP). The definitions of JCLP, COSP, and NCLP are equivalent to JCELL, COST, and NCELL2 for the TEE component (Sec. IV.H). Three external connections, including the primary-tee connection, may be made to the steam-generator primary side. Similar to all one-dimensional components, initial conditions and flow geometry for the primary flow path are input using the LOAD format.

Because secondary flow paths differ remarkably between steam-generator designs, the TRAC steam-generator model allows the user to construct the secondary flow path pertinent to his analysis. Thus, once-through steam generators including aspirators or economizer sections and U-tube designs with counter- or split-flow preheaters and evaporator regions may be modeled. Downcomer and recirculation paths also may be included. An arbitrary number of external connections may be joined to the secondary flow path. Therefore, the number and the location of the main and auxiliary feedwater inlets as well as the steam exit may be varied. A connection also may be made to the secondary flow path to model a tube rupture.

The secondary flow path is constructed using a minimum of 1 to a maximum of 10 PIPEs and/or TEEs. The user must specify the number (NSCMP) of secondary components necessary to model adequately the steam generator for his

analysis. For each component, the type (STYPE = PIPE or TEE), the number of cells (NCLS and NCLT), the component number (NUMS), and the junction numbers (JSINT) are required. Secondary component and junction numbers that are unique for the entire system are suggested. Trips and signal variables that apply to the steam generator should refer to the component number NUM for the primary side and the appropriate NUMS for the secondary side. After the user specifies the global parameters necessary to construct the secondary flow, LOAD format is used to input the fluid-cell geometries and initial conditions similar to the PIPE component.

A second level networking capability with a generalized data structure has been included to analyze the secondary steam-generator components. This permits the user the ability to effectively represent the secondary flow paths and include the heat structures important to the steam-generator behavior. Furthermore, this added feature reduces the size of the matrices necessary for obtaining solutions for the networks external to the steam-general component.

The steam-generator component provides the ability to connect fluid cells with generalized, one-dimensional structures in an arbitrary manner. Therefore, thermal communication across the tube walls, the downcomer, the tube shell, the plenum divider plates, and the tube sheets may be modeled. Only a one-dimensional, cylindrical geometry currently is available for the wall conduction analysis. Cartesian geometry may be approximated by specifying a large radius. The user is restricted further to using the same number of NODES to model all conduction paths.

The one-dimensional conduction paths are located throughout the steam generator by specifying an interior and exterior component number (ICMP and OCMP, respectively) and the interior and exterior cell number (ICELL and OCELL, respectively) for each conduction path. A zero is used for ICMP and OCMP to indicate a primary fluid cell.

The first node of each conduction element is the interior and the last ($i = \text{NODES}$), the exterior. When referring to a cell located on the side tube of a TEE, the user should add the cell number, counting the cell next to the main tube as one, to the number of cells on the main side. Examples of the values that should be assigned to these parameters for an aspirated once-through steam generator and for a U-tube steam generator are provided in Tables XII and XIII, respectively. Schematics for these two steam-generator

TABLE XII

SPECIFICATION OF THE FLUID CELLS ASSOCIATED WITH THE CONDUCTION PATHS
FOR AN ASPIRATED ONCE-THROUGH STEAM GENERATOR

	<u>ICMP</u>	<u>ICELL</u>	<u>OCMP</u>	<u>OCELL</u>
Tube walls	0	2	31	1
	0	3	31	2
	0	4	31	3
	0	5	32	1
	0	6	32	2
Tube sheet	0	1	31	1
	0	7	32	2
Downcomer	31	1	30	3
	31	2	30	2
	32	1	32	4
	32	2	32	3

TABLE XIII

SPECIFICATION OF THE FLUID CELLS ASSOCIATED WITH THE CONDUCTION PATHS
FOR A U-TUBE STEAM GENERATOR WITH A COUNTERFLOW PREHEATER

	<u>ICMP</u>	<u>ICELL</u>	<u>OCMP</u>	<u>OCELL</u>
Tube walls	0	2	21	5
	0	3	21	2
	0	4	21	3
	0	5	21	4
	0	6	21	3
	0	7	21	2
	0	8	21	1
Tube sheet	0	1	21	5
	0	9	21	1
Divider Plate	0	1	0	9
Divider Plate	21	1	21	5
Downcomer	21	5	23	4
	21	2	23	3
	21	3	23	2
	24	4	23	1
Shell	21	1	0	0
	21	2	0	0
	21	3	0	0
	21	4	0	0

types are shown in Fig. 35. The only restriction to assigning fluid cells on each side of the conduction paths is that the same fluid cell cannot be assigned to both sides of the same conduction element. More than one conduction element may be associated with a given fluid cell. An external environment may be assigned to the exterior of a conduction path by setting both OCMP and OCELL to zero. The last node of that path then applies Newton's law as a boundary condition with the constant input values for the liquid and vapor HTC's and temperatures. The remaining conduction path input defines the element material, geometry, and initial conditions. When more than one value is required for a parameter, the first value is associated with the interior (first node) of the element. The heat-transfer surface area for a conduction path used to describe the tubes represents the total surface area for all tubes in the fluid cell under consideration. An internal check is made to assure the input values for the interior and exterior conduction path surface areas are consistent with the cylindrical geometry. The HTC's calculated on each side of the conduction element are based on the local fluid properties. The correlations are identical to those used for all one-dimensional components.

Output for the conduction paths is provided in two forms. The first provides information for each path. Temperature distributions as well as the fluid thermal state on each side of the element are available. Also, output is available on a fluid-cell basis, which allows the user insight into the energy available to each fluid cell from the steam-generator structures. When more than one conduction element is in contact with a fluid cell, these (effective) properties are defined to conserve energy. The values provided include

(1) effective HTC's,

$$h_{leff} = \frac{\sum_i (h_{li} A_i)}{A}, \text{ and}$$

PRIMARY

HEAT CONDUCTION
PATHS

4 SECONDARY COMPONENT
NUMBERS

2 SECONDARY JUNCTION
NUMBER

31 NUMBER CELL

Fig. 35.

TRAC steam-generator noding diagrams.

(a) Aspirated once-through steam generator and

(b) U-tube steam generator with a counterflow preheater.

(2) effective wall temperatures,

$$T_{l\text{eff}} = \frac{\sum_i (h_{l,i} A_i T_{wi})}{h_{l\text{eff}} A} ,$$

where $A = \sum_i A_i$. The values are summed over all surfaces associated with the fluid cell. ⁱ Similar relations apply to the vapor properties.

Input for the steam-generator component is processed by subroutines RSTGEN and RESTGN. RSTGEN obtains data from an input file (TRACIN), whereas RESTGN reads the data from a restart file (TRCRST). Initialization of any remaining variables not provided by the input or restart files is performed in the subroutine ISTGEN.

During problem execution, the solution procedure is controlled by subroutines STGEN1, STGEN2, and STGEN3. STGEN1 controls the prepass including calculation of wall friction and loss coefficients. Heat structure material properties and HTC's are obtained through a call to STGN1X. Solutions to the hydrodynamics equations are controlled by STGEN2. Finally, a postpass is obtained using STGEN3. The postpass includes updating fluid properties and a call to STGN3X, which provides the heat-path conduction analysis. Output is provided to a dump file (TRCDUMP) through subroutine DSTGEN and an output file (TRCOUT) with WSTGEN.

I. Tee

The TEE module models the thermal hydraulics of three piping branches, two of which lie along a common line, whereas the third enters at some angle β from the main axis of the other two (Fig. 36). In TRAC-PF1, the tee is treated as two PIPES, as indicated in Fig. 36. Beta is defined as the angle from the low-numbered end of PIPE 1 to PIPE 2. The low-numbered end of PIPE 2 always connects to PIPE 1. The first PIPE extends from cell 1 to cell NCELL1 and connects to PIPE 2 at cell JCELL. The second PIPE begins at cell 1 and ends at cell NCELL2.

The connection is affected through mass, momentum, and energy source terms in PIPE 1. PIPE 2 sees the connection as boundary conditions from cell JCELL in PIPE 1. Liquid may be prevented from entering the TEE secondary by

Fig. 36.
Tee noding diagram.

setting the value of $FRIC$ at that junction to a value greater than 10^{20} . However, no generalized separation model has been implemented. This $FRIC$ -based separator actually will work at any cell interface. Hence, caution should be exercised when introducing large values of $FRIC$ at other locations in a system.

Because the TEE is modeled essentially as two interconnected PIPES, the PIPE model description in Sec. IV.A should be referenced for additional information on the calculational sequence. Naturally, the sequence for a TEE includes separate calculations of the primary and secondary sides.

Detailed input specifications for a TEE component are given in Sec. V.C.5.1. Input and output information is very similar to that for a PIPE component except that two PIPES are involved in a TEE component.

J. Turbine

In the turbine, energy is removed from the fluid as a result of work performed by the turbine. The model calculates the momentum and energy losses and the angular velocity as a function of the fluid flow rate, fluid properties, and the turbine nozzle and blade geometry. These momentum and energy losses are subsequently subtracted from the TRAC momentum and energy equations respectively.

Each TURB module represents an individual turbine stage. Thus the number of TURB components required in the TRAC model is equal to the total number of individual stages associated with the turbines rather than the number of turbines. However, the code internally recognizes the "family" of stages belonging to a particular turbine, which facilitates turbine governing and overall turbine performance calculations that depend on individual stage performances. All the data that are common among the family (i.e., data pertaining to the turbine rather than individual stages, such as, the generator efficiency or the generator power demand), are entered under stage 1, and the other stages of the family access these data from stage 1. Modeling an individual stage with a TURB component allows the user complete flexibility for modeling extraction, regeneration, reheating, etc., using the other TRAC input modules.

In both the impulse and reaction turbines, the thermodynamics of the internal processes is basically the same. In the impulse turbine, the expansion of steam takes place in the nozzles or in fixed blades, and the kinetic energy of steam is converted into mechanical work at the blades; whereas in the reaction turbine, the steam is allowed to expand in moving blades also, thereby transferring the reaction energy into mechanical work. Details of this process are discussed in many standard text books on thermodynamics. Salisbury,⁵³ in particular, discusses the subject comprehensively. The steam expansion process through a turbine stage is shown in Fig. 37. Line AB represents isentropic expansion from pressure p_A to pressure p_B . Because of friction and other irreversible losses, the actual state of steam after expansion is B' and not B. Thus the steady-state energy equation gives

$$h_A + \frac{V_A^2}{2} = h_B + \frac{V_B^2}{2} = h_{B'} + \frac{V_{B'}^2}{2} + \frac{P}{\dot{m}}, \quad (223)$$

where $\dot{m}$ is the mass flow rate and P is the stage work per second. The velocity V_B is the ideal nozzle velocity, such that $P_{ideal} = \dot{m}V_B^2/2$, and is easily obtained using Eq. (223) along an isentrope.

Fig. 37.
Steam expansion through a turbine stage.

The stage power, P , can therefore be calculated as

$$P = \eta_{\text{stg}} P_{\text{ideal}} = \eta_{\text{stg}} \cdot \frac{V_B^2}{2}, \quad (224)$$

where η_{stg} is the stage efficiency.

The final state B' can be easily computed for a known η_{stg} under steady-state conditions using Eqs. (223), (224), the continuity equation, and the equation of state. This is the approach followed by Farman and Motloch⁵⁴ in the RETRAN code. However, a preferable approach is to make use of the transient, two-phase TRAC hydrodynamic equations with appropriate sink terms in the momentum and energy equations. The momentum and energy terms corresponding to the turbine power are extracted as shown in a typical noding diagram in Fig. 38. The energy is always extracted from cell number 2, whereas the momentum is extracted either from the second or the third cell

Fig. 38.

Turbine stage noding diagram depicting momentum and energy sink locations.

edge depending upon the flow direction. A minimum of three cells are required to model a TURB component. It is clear from Eq. (223) that the velocity at the turbine exit would have been V_B had no work been done by the turbine. Owing to the turbine work, the exit velocity is $V_{B'}$ instead of V_B . Thus the momentum loss in the turbine stage is

$$M = \dot{m}(V_B - V_{B'}) = A_j \rho_j V_j (V_B - V_{B'}) \quad , \quad (225)$$

where A is the area. Subscript j refers to the momentum sink cell edge. Also, velocity $V_{B'}$ is the same as V_j , the actual cell-edge velocity calculated by the code after it accounts for the momentum loss. Therefore, writing Eq. (225) in terms of pressure loss, Δp , gives

$$\Delta p = \rho_j V_j (V_B - V_j) \quad . \quad (226)$$

Experience has shown that translating the above pressure loss into an equivalent FRIC results in much improved code stability than subtracting Δp from the momentum equation directly (with its associated derivative $\partial \Delta p / \partial V_j$, of course). Therefore, writing Δp in terms of FRIC gives

$$\Delta p = \text{FRIC} \frac{\rho_j V_j^2 0.5(\Delta X_j + \Delta X_{j-1})}{d_j} ,$$

where d_j is the momentum source cell-edge diameter. Comparison of this equation with Eq. (226) leads to

$$\text{FRIC} = \frac{V_B - V_j}{V_j} \frac{d_j}{0.5(\Delta X_j + \Delta X_{j-1})} . \quad (227)$$

Because the above value of FRIC is applied at either cell edge 2 or cell edge 3 (depending upon flow direction), the user input additive FRIC values at these cell edges will be overwritten. Therefore FRIC(2) and FRIC(3) should always be input as 0.0.

The energy loss that should be taken out of the total energy equation is given by Eq. (224). However, TRAC-PF1/MOD1 uses the thermal energy equation, which is obtained after combining the total energy equation with the momentum equation. Some simple algebraic substitutions lead to the following expression for the sink term for the thermal energy equation.

$$P_{\text{enr}} = P - \frac{V_B + V_j}{2} M = P - A_j \frac{V_B + V_j}{2} \Delta p , \quad (228)$$

where P_{enr} is the amount to be extracted from the TRAC energy equation. The second term on the right hand side of Eq. (228) appears as a result of combining the momentum equation with the energy equation.

Equations (227) and (228) can, therefore, be used to account for momentum and energy losses as a result of the power produced by a turbine stage provided the stage efficiency is known.

The stage efficiency is given by

$$\eta_{stg} = \eta_{nb} - \phi_m - \phi_{rem} , \quad (229)$$

where η_{nb} is the nozzle-bucket efficiency to be obtained from the velocity diagram, ϕ_m is the moisture loss, and ϕ_{rem} are the remaining miscellaneous stage losses whose magnitudes are not easily definable. Term ϕ_{rem} includes nozzle-~~er~~ loss, windage loss, diaphragm-packing loss, etc. The moisture loss is included as a separate term because it is the most significant loss and its functional formulation is known. These losses are described in detail by Salisbury. Salisbury recommends the following expression for the moisture loss

$$\phi_m = 1.15 (1 - x) , \quad (230)$$

where x is the thermodynamic quality of steam.

The nozzle-bucket efficiency is calculated as

$$\eta_{nb} = \frac{\text{energy transfer to the blades}}{\text{available energy at the nozzle}}$$

$$= \frac{W \dot{m} \sum_{i=1}^{2n} V_{a_i}}{\dot{m} \frac{V_B^2}{2}} = \frac{2 W}{V_B^2} \sum_{i=1}^{2n} V_{a_i} , \quad (231)$$

where W is the moving blade velocity, V_a is the axial component of velocity relative to the moving blades, and n is the number of rows of moving blades. A vector diagram for two rows of moving blades is presented in Fig. 39, which

Fig. 39.
Velocity diagram for two rows of moving blades.

can be extended to an arbitrary number of rows by our recursively appending a stationary blade row and a moving blade row in pairs to Fig. 39. There is no limit on the number of rows allowed in a TURB module. If r is the fraction of stage energy transferred by reaction, the velocity vectors can be written as follows:

$$V_1 = C_n V_B (1-r)^{1/2}$$

$$V_2 = (V_1^2 + W^2 - 2 V_1 W \cos \alpha_1)^{1/2}$$

$$V_3 = [(C_b V_2)^2 + r \frac{C_r^2}{2n-1} V_B^2]^{1/2}$$

$$V_4 = (V_3^2 + W^2 - 2 V_3 W \cos \alpha_2)^{1/2}$$

$$V_5 = [(C_b V_4)^2 + r \frac{C_r^2}{2n-1} V_B^2]^{1/2}$$

$$V_6 = (V_5^2 + W^2 - 2 V_5 W \cos \alpha_3)^{1/2}$$

$$V_7 = [(C_b V_6)^2 + r \frac{C_r^2}{2n-1} V_B^2]^{1/2}$$

$$V_{a1} = V_1 \cos \alpha_1 - W$$

$$V_{a2} = V_3 \cos \alpha_2$$

$$V_{a3} = V_5 \cos \alpha_3 - W$$

$$V_{a4} = V_7 \cos \alpha_4 , \quad (232)$$

where C_n is the nozzle velocity coefficient, C_b is the bucket velocity coefficient, and C_r^2 is the fraction of total reaction energy actually delivered in all rows of blades. It is assumed that equal fractions of reaction energy are delivered in each blade row.

Although the remaining losses, ϕ_{rem} , required in Eq. (229) are not easily definable at off-design conditions, their magnitude is generally known at design conditions from the test data. In TRAC-PF1, the user is allowed an option of specifying the stage efficiency, η_{stg} , at design conditions. If η_{stg} is input, the code uses Eq. (229) to calculate ϕ_{rem} at design conditions. This value of ϕ_{rem} is then assumed constant throughout the transient. If the user does not input η_{stg} at design conditions, ϕ_{rem} is assumed to be zero.

Thus, to summarize, a TURB module performs the following sequence of calculations.

1. With the upstream and downstream pressures and velocities from the previous time step, the ideal nozzle velocity, V_B , is calculated and we assume steam is an ideal gas.
2. With the bucket velocity, W , from the previous time step, η_{nb} is calculated from Eqs. (231) and (232).
3. The stage efficiency, η_{stg} , is then calculated from Eq. (229).
4. Stage power, P , is calculated from Eq. (224) with $\dot{m}$ from the previous time step.
5. An equivalent FRIC for the momentum equation is calculated from Eq. (227) with V_j from the previous time step.
6. The amount to be extracted from the energy equation, P_{enr} , is then calculated from Eq. (228).

So far we have discussed how each stage is handled by a TURB module, which represents an individual stage. In general, a turbine has more than one stage, and the governing is accomplished for the turbine as a whole and not for individual stages because only the total load on the turbine is known. Also, the angular speed among the "family" of stages is the same because of direct coupling of the stages. Thus additional calculations that are common among the family of stages are required. These calculations are done after all the stages are processed, and these common data are stored under the first stage of the family.

Total turbine power is calculated as

$$P_{total} = \sum_{i=1}^m P_i , \quad (233)$$

where m is the total number of stages belonging to a turbine, i.e., the number of stages of the same family. However, the electrical generator power input is less than P_{total} because of the friction at the bearings of the turbine-generator shaft. Therefore, the power input to the generator, $P_{gen,input}$, is

$$P_{gen,input} = \sum_{i=1}^m P_i - \omega T_{fric} , \quad (234)$$

where ω is the turbine-generator angular speed, and T_{fric} is the frictional torque given by

$$T_{fric} = A + B \omega + C \omega^2 , \quad (235)$$

where A , B , and C are the user input coefficients. The generator output is therefore

$$P_{gen,output} = \eta_{gen} \left[\sum_{i=1}^m P_i - \omega T_{fric} \right] , \quad (236)$$

where η_{gen} is the generator efficiency, which is treated as constant. At design conditions, this output must be equal to the generator power demand. However, because of uncertainties in stage power calculations, friction torque, and generator efficiency, this equality cannot be exactly satisfied. Thus a correction efficiency, η_{corr} , is defined, such that

$$\eta_{corr} = \frac{\text{generator power demand at design conditions}}{\{\eta_{gen} \left[\sum_{i=1}^m P_i - \omega T_{fric} \right]\}_{\text{design conditions}}} .$$

This η_{corr} is calculated during initialization and is used as a constant multiplier during the entire transient. Thus Eq. (236) modifies into

$$P_{\text{gen,output}} = \eta_{\text{corr}} \eta_{\text{gen}} \left[\sum_{i=1}^m P_i - \omega T_{\text{fric}} \right] . \quad (237)$$

At equilibrium conditions, this output should be equal to the generator power demand, P_{demand} , which is input by the user in tabular form. If $P_{\text{gen,output}} > P_{\text{demand}}$, the steam flow through the turbine should be reduced and vice versa. To accomplish this and to bypass the excess steam flow, two special options in the VALVE component have been implemented (see VALVE input description, Sec. V.C.5.k). An IVTY = 5 option opens the valve with an increase in power demand. Such a valve could be added upstream of the turbine to control the steam supply to the turbine. Another option, IVTY = 6, automatically closes the valve when the power demand increases. This valve option may be found useful in the bypass line. Figure 40 shows two typical turbines (a two-stage throttle governed and a three-stage bypass governed) without any extractions to illustrate the use of these special valve options. As the power demand increases, more steam has to be supplied to the turbine, and in case of a bypass governed turbine, some additional steam has to be supplied to lower stages. Thus the turbine valves use IVTY = 5 option. However, as the steam flows through the turbines increase, the amount of steam bypassed must decrease. The turbine bypass valve therefore can be modeled using IVTY = 6 option. It might, however, be preferable to operate the turbine bypass valve using a controller in order to maintain a constant pressure in the steam generator.

The signal variable for the operation of these special type valves is defined as

$$S = \frac{P_{\text{demand}}}{P_{\text{gen,output}}} . \quad (238)$$

A value of $S > 1.0$ opens the IVTY = 5 valve and closes the IVTY = 6 valve, whereas $S < 1.0$ operates these valves in the other direction.

Fig. 40.

A typical nodding diagram showing the use of special valve options for modeling turbines.

The turbine speed is maintained constant as long as the plant is connected with the external load, i.e., $P_{demand} \neq 0.0$, to maintain constant grid frequency. To meet this power demand at the desired grid frequency, the steam supply to the turbine is adjusted as discussed above. However, the turbine is allowed to coast down at the receipt of turbine trip signal (which is generated by tripping off the generator power demand). The turbine speed in this case is determined by the angular momentum balance

$$I \frac{d\omega}{dt} = T_{turb} - T_{fric} - T_{loss} - T_{demand} \quad , \quad (239)$$

where I is the turbine-generator assembly moment of inertia, T_{turb} is the total turbine torque output from all stages, T_{loss} is the loss in torque as a

result of generator losses, and T_{demand} is the torque due to external load. However, because the turbine is allowed to coast down only when the external load is zero, $T_{\text{demand}} = 0.0$. Also, because the generator is not producing any power, $T_{\text{loss}} = 0.0$. Thus Eq. (239) simplifies to

$$T \frac{d\omega}{dt} = \frac{1}{\omega} \sum_{i=1}^m P_i - T_{\text{fric}} \quad . \quad (240)$$

The TURB data are processed in a manner similar to that for the PIPE component. Subroutine RTURB reads data from the input file (TRACIN), and subroutine RETURB reads data from the restart file (TRCRST). Initialization of any remaining variables not provided by the input or restart files is performed in subroutine ITURB.

Subroutines TURB1, TURB2, and TURB3 perform the same functions for the TURB component as PIPE1, PIPE2, and PIPE3 perform for the PIPE component. For the TURB component, subroutine TURB1 calls TRBPOW, which calculates turbine stage efficiency and power. Two additional subroutines, TRBPRES and TRBPST, are called during the prepass and postpass stages, respectively, to perform calculations that are common for a family of different stages related to the same turbine.

Wall friction coefficients are calculated in subroutine FWALL by specifying a friction correlation option, NFF, along with the additive friction factors, FRIC, for each cell edge. The homogeneous flow friction factor correlation option (NFF = 1) is suggested for a TURB component. Also, as explained earlier in this section, FRIC(2) and FRIC(3) should be set to zero.

The output edit for a TURB component is similar to a PIPE component with the addition of stage efficiency, stage power, and stage mass flow. In addition, quantities pertaining to the entire turbine are printed under the TURB component modeling the first stage. They are: generator power output, turbine speed, and turbine signal value S defined by Eq. (238).

K. Valve

The VALVE module is used to model various types of valves associated with light water reactors. The valve action is modeled by controlling the flow area and the hydraulic diameter at one cell interface of a one-dimensional component as shown in Fig. 41. The valve action may not be located at a valve component junction unless that junction is connected to a BREAK.

Two methods are provided for specifying the valve flow area. The flow area FA can be computed directly from a flow area fraction (FAVLVE) according to

$$FA = FAVLVE \cdot AVLVE ,$$

where AVLVE is the input value for the fully open valve flow area. Alternatively, the flow area may be computed from the relative position (XPOS) of the valve stem if we assume a guillotine-type cut of circular cross section. The relative valve-stem position of XPOS = 1 corresponds to a fully open valve with flow area AVLVE. In either case, the corresponding hydraulic diameter HD is computed from

$$\text{hydraulic diameter} = \frac{4 \text{ FA}}{P} \leq HVLVE ,$$

Fig. 41.
Valve noding diagram.

where P is the wetted perimeter of the guillotine-type cut opening and $HVLVE$ is the input value for the fully open valve hydraulic diameter.

The FA fraction or valve stem position is entered as a constant or a tabular function defined by a table. Use of a table may be trip-initiated according to the control option selected. To increase the flexibility to model various types of valves, two valve tables may be input for trip-controlled valves. The first table is used when the trip set status is $ON_{forward}$, and the second table is used when the trip set status is $ON_{reverse}$ (see Sec. V.C). The independent variable for the table is a modeled-system parameter defined by a signal variable or a control block.

Many different types of valves can be modeled because of the flexibility available to choose the independent variable for the valve action table and to implement table evaluation under trip control. Simple valves that either open or close on a trip may be modeled using an OFF-ON or ON-OFF type trip and a table that has relative time (since trip initiation) as the independent variable to obtain the desired rate of opening or closing. Valve leakage can be simulated by restricting the table minimum FA fraction or valve stem position to a value greater than zero. Simple valves can be used to model pipe breaks or the opening of rupture disks.

A simple check valve can be modeled by using a valve table with the appropriate pressure gradient as its independent variable. Alternatively, a check valve can be modeled as a trip-controlled valve with the pressure gradient used as the trip signal to trip on and the valve table used to control the rate of valve movement.

A steam-flow control valve [or power-operated relief valve (PORV)] can be modeled using an $ON_{reverse}$ -OFF- $ON_{forward}$ trip to control it with the start closing pressure, end closing pressure, end opening pressure, and start opening pressure as the respective trip set points. The rate of opening ($ON_{forward}$ state) can be defined by the first value table and the rate of closing ($ON_{reverse}$ state) by the second value table. The rate of opening and closing will be the same only if the first valve table is entered.

A PORV can be modeled by using a table with pressure as the independent variable and a step-like function for the flow area fraction or valve stem position. In this case, it is important that the step function not be too steep or the valve flow area may oscillate because of the coupling between the

flow through the valve and the pressure variable. A bank of PORVs can be modeled with a single valve component in the same manner by our using a multistep function to simulate the multiple pressure set points corresponding to the various valves.

The input parameters for the VALVE module are defined in Sec. V.C.5.k.

L. Vessel

The VESSEL module models a PWR vessel and its associated internals. The component is three-dimensional and uses a six-equation, two-fluid model to evaluate the flow through and around all internals of a PWR vessel including the downcomer, core, and upper and lower plena. Models incorporated into the VESSEL module are designed mainly for LOCA analysis, but the VESSEL module can be applied to other transient analyses as well. A mechanistic reflood model that can model quenching or dryout for an arbitrary number of quench fronts is included. The reactor power is modeled using point-reactor kinetics or by providing a power table in the problem input. Most of the detailed discussion of the fluid-dynamics, heat-transfer, and point-reactor kinetics equations and solution methods for the three-dimensional VESSEL module can be found in Sec. III. In this section, we discuss the VESSEL geometry and other important considerations.

A three-dimensional, two-fluid, thermal-hydraulic model in cylindrical coordinates describes the VESSEL flow. A regular cylindrical mesh, with variable mesh spacings in all three directions, encompasses the downcomer, core, and upper and lower plena of the VESSEL, as shown in Fig. 42. The user describes the mesh by specifying the radial, angular, and axial coordinates of the mesh-cell boundaries:

r_i $i = 1, \dots, \text{NRSX}$;

θ_j $j = 1, \dots, \text{NTSX}$;

and

z_k $k = 1, \dots, \text{NASX}$;

where NRSX is the number of rings, NTSX is the number of angular segments, and NASX is the number of axial levels. The point (r_i, θ_j, z_k) is a vertex in the coordinate mesh. Figure 43 illustrates the mesh construction. Mesh cells are formed as shown in Fig. 44 and identified by an axial level number and a cell number. For each axial level, the cell number is determined by counting the cells radially outward starting with the first angular segment and the innermost ring of cells, as shown in Fig. 43. Figure 44 also shows the relative face numbering convention that is used in connecting other components

Fig. 42.
Cell noding diagram for a typical
PWR vessel.

Fig. 43.
Vessel geometry, three-dimensional
mesh construction with 3 rings,
6 angular segments, and 7 axial
intervals.

Fig. 44.

Boundaries of a three-dimensional mesh cell. The face numbering convention also is shown. Faces 1, 2, and 3 are in the θ , z , and r directions, respectively.

to the vessel. Note that only three faces per mesh cell must be identified because the other faces will be defined by neighboring cells.

All fluid flow areas (on cell faces) and all fluid volumes are dimensioned so that the internal structure within the vessel can be modeled. Flow areas and fluid volumes are computed on the basis of the geometric mesh spacings and scaled according to factors supplied as input. The scaled volumes and flow areas then are used in the fluid-dynamics and heat-transfer calculations.

Flow restrictions and the volume occupied by the structure within each mesh cell are modeled through the use of these scale factors. For example, the downcomer walls are modeled by setting the appropriate flow area scale factors to zero. A feature is provided to do this automatically in the code if the upper, lower, and radial downcomer position parameters (IDCU, IDCL, and IDCR) are specified as described in the input section (Sec. V.C.5.1). (The NAMELIST parameter IGEOM3 can be used to permit setting non-zero flow-area fractions in the downcomer walls to model leakage flow paths; then IDCU, IDCL, and IDCR can be set so that downcomer and lower plenum global parameters are written to the graphics file.) Flow restrictions such as the top and bottom

core support plates require scale factors between zero and one. Figure 45 shows the cell faces that are scaled to model the downcomer and core support-plate flow restrictions.

Plumbing connections from other components to the VESSEL are made on the faces of the mesh cells. Only one connection per VESSEL cell is allowed, and each mesh cell in the VESSEL can have a component connected to it. Four input parameters are used to describe a connection: ISRL, ISRC, ISRF, and JUNS. The parameter ISRL defines the axial level in which the connection is made; ISRC is the mesh-cell number, as defined above; and ISRF is the face number, as defined in Fig. 44. If ISRF is positive, the connection is made on the face shown in the figure with the direction of positive flow inward into the cell. If ISRF is negative, the connection is made on the opposite face shown in the figure with the direction of positive flow also inward into the cell. (Face 1 is the azimuthal face at θ_j , and face -1 is the azimuthal face at θ_{j-1} . Face 2 is the axial face at z_k , and face -2 is the axial face at z_{k-1} . Face 3 is the radial face at r_i , and face -3 is the radial face at r_{i-1} .) The parameter JUNS identifies the one-dimensional component junction connected to this cell face. Figure 46 shows two VESSEL pipe connections. Note that internal as well as external connections are allowed. The user is cautioned against connecting to the VESSEL any component with a flow area that differs greatly from the flow area of the mesh-cell face to which it is connected because this can cause anomalous pressure gradients. Such a situation can be avoided by proper adjustment of the VESSEL geometry coordinate spacings.

A VESSEL option models the Babcock and Wilcox vent valves that are located in the wall between the upper plenum and downcomer. These vent valves permit flow directly from the upper plenum to the downcomer and out the cold leg for a cold-leg break. They are modeled as fixed areas in the outer radial surface of a vessel cell with a variable FRIC term to model opening and closing.

The user specifies the cells that have vent valves by giving the axial level, cell number, and total area of vent valves for each cell with vent valves in the outer radial surface. The user also specifies for each cell with vent valves: (1) the pressure drop for the valves to be closed, DPCVN; (2) the pressure drop for the valves to be open, DPOVN; (3) the FRIC value when the valves are closed to model leakage, FRCVN; and (4) the FRIC value

Fig. 45.

Fig. 46.

Flow restrictions and downcomer modeling. Pipe connections to the vessel.

when the valves are open, FROVN. The pressure drop is defined as the pressure of the inner radial cell minus the pressure of the outer radial cell. The code uses FRCVN when the pressure drop is less than DPCVN, uses FROVN when the pressure drop is greater than DPOVN, and interpolates for pressure drops between DPCVN and DPOVN.

The reactor core region in the VESSEL is specified by the upper, lower, and radial core positional parameters (ICRU, ICRL, and ICRR). These parameters define, respectively, the upper, lower, and radial boundaries of the cylindrical core region. The example provided in Fig. 47 shows a possible configuration in which $ICRU = 4$, $ICRL = 2$, and $ICRR = 2$. Each axial stack of

Fig. 47.
Core region inside the vessel.

mesh cells in the core region can contain an arbitrary number of fuel rods. One average rod represents the average of the ensemble of rods in each axial stack of mesh cells, and its thermal calculation couples directly to the fluid dynamics. The thermal analysis of any supplemental rods does not feed back or couple directly to the fluid-dynamics analysis. However, the local fluid conditions in the mesh cell are used to obtain rod temperature histories for the additional rods. A fuel-cladding interaction treatment and a reflood treatment are available for these calculations and are described in Sec. III.B.

Heat slabs of arbitrary thicknesses and surface areas can be defined in any mesh cell (including core regions) to model the heat capacity of structures within the vessel. A HTC is computed for each slab using the local fluid conditions. The temperature distribution is calculated based on a one-dimensional conduction model (refer to Sec. III.B.1.b). The thermal response of the slab properties is included. Furthermore, the code can account for an arbitrary number of interfaces between dissimilar materials.

The total power level in the core may be specified in terms of either power or reactivity with optional reactivity feedback. The solution of the point-reactor kinetics equations used in the latter case is described in Sec. III.C. The power or reactivity can be constant, determined from a table, or constant until a trip and then determined from a table. The independent variable of the table may be any signal-variable form as described in Sec. V.C.4.b.

For trip-initiated table use, the independent variable of the table can be modified by a rate factor that is a (tabular) function of the departure of the trip signal from the set point that turns off the trip. Consequently, override control of the core power level can be simulated. The flexibility that is available for the selection of the trip signal, trip set points, and delay times as well as the choice for the independent variable and associated rate factor used to specify the power or reactivity permits accurate modeling of a large class of transient conditions.

The spatial power distribution in the core is specified by separate axial- and horizontal-plane power shapes, plus a radial power distribution within the fuel rods. These spatial distributions are specified in relative units at input and are held constant throughout a problem except for the axial power shape. Through input, one or more axial power shapes may be employed with any signal variable used to interpolate among them.

The power density in fuel rod node i in cell j on core level k is given by the expression,

$$P(i,j,k) = S \cdot P_{tot} \cdot RDPWR(i) \cdot CPOWER(j) \cdot ZPOWER(k) \quad , \quad (241)$$

where P_{tot} is the total core power level, $RDPWR(i)$ is the relative power in fuel node i , $CPOWER(j)$ is the relative power in cell j , $ZPOWER(k)$ is the relative power at core elevation k , and S is the scale factor that normalizes the three input relative power distributions. The scale factor S is given by the expression,

$$S = \left[\sum_{i,j,k} \left(AREA(i) \cdot RDPWR(i) \cdot NRDX(j) \cdot CPOWER(j) \cdot \Delta z(k) \cdot ZPOWER(k) \right) \right]^{-1}, \quad (242)$$

where $AREA(i)$ is the cross-sectional area of fuel rod node i , $NRDX(j)$ is the number of fuel rods in cell j , and $z(k)$ is the height of core axial level k . For the analyses of user-specified supplemental rods, the power density in Eq. (224) is multiplied by an input power factor $RPKF(j)$ to obtain the power density for each additional fuel rod.

V. USER INFORMATION

This chapter describes how to set up a problem input data deck, obtain data dumps, restart problems from those dumps, and produce printer and graphics output files.

A. Input Organization and Format

The input deck is divided into six major sections: main, material-properties, interactive control-panel, control-parameter, component, and time-step data. These data blocks are contained in the TRACIN file and are read in the above order (Fig. 48). The main-data information block contains general parameters including title cards for problem identification, restart and dump information, transient and steady-state information, problem size information, and problem convergence criteria. This data block always is present in TRACIN.

Fig. 48.
TRAC input deck organization.

The user has the option to input material-properties data when the TRAC internally defined material properties are inappropriate. New properties may be entered for materials that TRAC does and does not model. These properties must be included in the TRACIN file for all restarts, because they are not written to the TRCDMP dump data file that becomes the renamed TRCRST restart data file.

The user inputs interactive control-panel data when he wishes to execute TRAC in the interactive mode. These data define the component locations for the PWR-system parameters that normally are monitored in the power-plant control room. Information that is not provided by the TRACIN file is obtained from the TRCRST restart data file. At present this capability is not maintained fully or documented; thus, it is not recommended for users outside of Los Alamos National Laboratory.

Control-parameter data define the control-procedure parameters that are used to control the PWR-system model: signal variables, control blocks, and trips as well as the order in which these three control-parameter types are evaluated. Signal variables define PWR-system parameters for control-block input, trip-signal definition, and component-action-table independent-variable definition. Control blocks are functional operators that operate on their input signals to produce an output signal. Their input signals are signal variables or the output signal from control blocks. A control block's output signal is used for the same applications as signal variables. Trips are ON-OFF switch controllers that provide a logic switch and specify when component actions are to be evaluated. The number of each control-parameter type is defined by the main data. When fewer of a particular control-parameter type are specified in TRACIN, the remainder comes from the TRCRST restart data file.

The component data block provides the main body of the input deck. This block contains a detailed description of every component in the problem unless the problem is reinitiated from a restart data dump. For restart problems, this block contains only additional or modified components. The rest of the component data is obtained from the restart file. There is a component data block in TRACIN unless all the component data are to be obtained from the restart file.

The time-step data block specifies maximum and minimum time-step sizes, edit frequencies, and the end of the problem. It always is present in TRACIN.

All numeric input data are read into the code with either an E14.6 or I14 format statement, by the LOAD subroutine or as NAMELIST data. Standard FORTRAN statements are used for formatted and NAMELIST reads. The LOAD subroutine provides additional flexibility to input array data.

The user can create his TRACIN input deck in strict accordance with the input specifications described in Sec. V.C. (formatted input) or in free format. If formatted input is selected, all data and array loading operations must be entered in the card columns specified in Sec. V.C. If free format is chosen, the input cards and the data on each card must adhere to the order specified in Sec. V.C, but the data do not have to be entered in the specified columns. In addition to the obvious convenience of not counting columns, free format gives the user greater flexibility in using comments to document his input deck and TRAC provides better diagnostics for input errors. The free-format option is discussed in detail in Sec. V.E.

The following sections describe the dump/restart feature, the input data format in detail, the LOAD subroutine read formats, the free-format option, the NAMELIST format, and the TRAC output files. Appendix E provides a sample input deck and a portion of this deck that was modified to illustrate various free-format possibilities.

B. Dump/Restart Feature

TRAC automatically generates a dump/restart data file named TRCDMP, which contains snapshots of the state of the system at various times during problem execution. Any one of these snapshots, called dumps, may be used to initialize all or part of the system for subsequent calculations. The times when dumps are generated are determined by several criteria. The user may specify a dump interval on the time-step cards. A dump will be created whenever this time interval has elapsed since the last dump. These dumps are added sequentially to the end of the TRCDMP file. A dump also may be initiated by the user with one or more designated trips. At the time the set status of any of those trips is set ON, a dump is added to the end of the TRCDMP file. This permits the restart of a problem when particular events of interest occur.

In addition to these user-specified dumps, TRAC automatically generates dumps at various times. A dump is generated at the end of the initialization stage; another dump is generated at the end of the steady-state or transient calculation and at intermediate points in the calculation based upon the central-processor-unit (CPU) time utilized by the job.

To use a dump file to initialize a subsequent calculation, the name of the file must be changed from TRCDMP to TRCRST. The time-step number DSTEP of the particular dump desired must be specified on Main-Data Card 3. (A message containing this dump time-step number is sent to the print file TRCOUT whenever a dump is written.) If the time-step number specified is negative, TRAC will use the dump with the largest time-step number and overwrite the negative value of DSTEP (specified on Main-Data Card 3) with the time-step number taken from that dump.

Data retrieved from the selected dump depend on the information that already has been found in the TRACIN file. Any component not defined by the input deck (as determined from the component numbers listed in the IORDER array in the Main Data) is initialized from the restart dump. Also, any signal variable, control block, and trip (with an ID number that has not already been defined by the TRACIN file) in the dump will be initialized with its defined state from the dump.

C. TRAC-PF1 Input Specifications

The TRAC input data are classified into six general data types:

- (1) main,
- (2) material properties,
- (3) interactive control panel,
- (4) control parameter,
- (5) component, and
- (6) time step.

1. Main Data. The main parameters are listed below in the order in which they are entered. This data block always must be supplied at the start of the input deck.

Main-Data Card 1. (Free format.) The first card of a TRACIN deck serves as the free-format ON-OFF switch, indicating whether the following cards are in free or TRAC format. It must be present, containing either the string FREE (free format), TRAC (TRAC format), or both strings (FREE overrides TRAC). This card is in free format; up to 80 columns may be used; the control string(s) and documentation may appear anywhere on the card.

Main-Data Card 2. (Format 4I14) NUMTCR, IEOS, INOPT, NMAT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NUMTCR	Number of title cards to be read. Note: At least one title card must be supplied.
15-28	IEOS	Air-water option. 0 = gas phase treated as steam-air mixture throughout system; 1 = gas phase treated as air throughout the system. Evaporation and condensation are inhibited.
29-42	INOPT	Specification for including or excluding NAMELIST group INOPTS data after the title cards. 0 = NAMELIST group INOPTS data omitted after the title cards; 1 = NAMELIST group INOPTS data inserted after the title cards.
43-56	NMAT	Number of different materials for which heat-conduction-related properties will be input. The material-properties data are not passed through the restart dump and, hence, must be in the input file for each restart.

Title Card(s). (Format 20A4) NUMTCR Cards

<u>Columns</u>	<u>Description</u>
1-80	Problem title information.

NAMelist Data Cards for Group INOPTS. (NAMelist format) This section is included only if the variable INOPT = 1. In this case one or more of the special input options described below may be specified. The format of this data is not checked during preprocessing and, therefore, should be entered carefully to avoid fatal input errors. The data are entered in columns 2-80 on one or more cards, beginning with "\$INOPTS" in column 2, and are terminated with a "\$" character. A more detailed discussion of the format for NAMelist input data is included in Sec. V.F (also see local FORTRAN manual). The following variables are included in the NAMelist group INOPTS, and one or more of them can be included in the NAMelist data to select desired options. Variables omitted from the data retain their default status.

<u>Variable</u>	<u>Description</u>
ALP	Default value for initial void fractions. Used when ISTOPT is nonzero. (Real format.)
CHM12, CHM22	Subcooled and two-phase multipliers, respectively, for choked-flow multiplier set 2 (default 1.0, 1.0).
CHM13, CHM23	Subcooled and two-phase multipliers, respectively, for choked-flow multiplier set 3 (default 1.0, 1.0).
CHM14, CHM24	Subcooled and two-phase multipliers, respectively, for choked-flow multiplier set 4 (default 1.0, 1.0).
CHM15, CHM25	Subcooled and two-phase multipliers, respectively, for choked-flow multiplier set 5 (default 1.0, 1.0).
HSTN	Default value for heat-slab temperatures in three-dimensional components. Used when ISTOPT is nonzero. (Real format.)
IADDED	Switch that adds a status message to the TRCMSG file. N = status message is added every Nth time step.
ICFLOW	Choked-flow model controller. 0 = model turned off; 1 = model using default multipliers turned on only for components connected to a BREAK (default). 2 = model using optional multipliers (NAMelist variables CHM12, CHM22; CHM13, CHM23; CHM14, CHM24; and CHM15, CHM25) turned on at cell-edges indicated in component input. (Note that this option requires additional array data for all one-dimensional hydrodynamics components.)

<u>Variable</u>	<u>Description</u>
IELV	<p>Switch that determines whether gravity (GRAV) terms or cell-centered elevations (ELEV), in meters, are to be input in the component data. When this option is selected, ELEV (dimensioned NCELLS) or cell-centered elevations should be input for GRAV array data cards in all components. In addition, a BREAK elevation BELV (BREAK component Card Number 5), a FILL elevation FELV (FILL component Card Number 4), and a VESSEL elevation shift SHELV (VESSEL component Card Number 13) are required.</p> <p>0 = gravity terms must be input (default); 1 = cell-centered elevations must be input.</p>
IGAS	<p>Flag for noncondensable gas.</p> <p>1 = air (default); 2 = hydrogen.</p>
IGEOM3	<p>Switch that determines, for all three-dimensional vessel components, if the areas between the downcomer and the inside of the vessel are to be set to zero.</p> <p>0 = areas to be set to zero (default); 1 = the user enters the values of the area fractions used.</p>
IKFAC	<p>Switch that determines whether additive loss coefficients (FRIC) or K factors are to be input in the component data. When this option is selected, K factors (dimensioned NCELLS+1) must replace the FRIC array input cards in all components. To input K factors that depend on flow direction, include the NFRCL or NFRCL3 options.</p> <p>0 = additive loss coefficients will be input (default); 1 = K factors will be input.</p>
IMFR	<p>Switch that sends the phasic mass flows to the TRCGRF file.</p> <p>1 = default; 3 = sends the phasic mass flows in the theta, radial, and axial directions.</p>
INVAN	<p>Option that selects either the T_{CHF} or T_{sat} values for the inverted annular switch.</p> <p>0 = T_{sat} value is selected (all code assessment was performed with this default option); 3 = T_{CHF} value is selected.</p>

<u>Variable</u>	<u>Description</u>
IPOWR, TPOWR	<p>Variables that control core power initialization during steady-state calculations.</p> <p>IPOWR = -1, TPOWR = ∞; core power is not turned on throughout the steady-state evaluation.</p> <p>IPOWR = -1, TPOWR = specified; turns on core power at time TPOWR.</p> <p>IPOWR = 0, TPOWR = ∞ (defaults); turns on core power at time based on built-in logic. (When steady-state liquid-velocity-change ratio falls below a certain value or when the absolute value of the liquid velocity exceeds a certain value.)</p> <p>IPOWR = 0, TPOWR = specified; turns on core power at time TPOWR or at time based on built-in logic, whichever occurs first.</p> <p>IPOWR = 1, TPOWR = anything; turns on core power at the beginning of the steady state.</p>
IPRCPV	<p>Switch that determines if control-panel-vector (CPV) parameters are processed.</p> <p>0 = process CPV parameters;</p> <p>1 = do not process CPV parameters (default).</p>
ISOLCN	<p>Solubility-parameters controller. (Solubility parameters characterize the dissolved material, which is followed by the solute tracker when ISOLUT = 1 on Card Number 6.)</p> <p>**Warning** No input solubility parameters are saved on dump/restart; thus, these parameters must be input for each restart.</p> <p>0 = use of default parameters for linear fit to solubility of orthoboric acid as a function of liquid temperature (default condition).</p> <p>1 = input parameters for linear fit to solubility of solute as a function of liquid temperature.</p>

<u>Variable</u>	<u>Description</u>
ISTOPT	<p>Steady-state option that allows the user to input only once certain parameters or default values that are used to initialize data arrays for other components. The default parameters also are input through the NAMELIST group INOPTS. The NAMELIST variables that can be assigned default values are ALP, VL, VV, TL, TV, TW, P, PA, QPPP, and HSTN. When ISTOPT is nonzero, the values of these variables are used to fill the corresponding arrays in all components except accumulators, pressurizers, valves, and steam-generator secondary sides. This option also can be used for transient calculations.</p> <p>0 = option off (default); 1 = option on. Those component arrays (excluding accumulators, pressurizers, valves, and steam-generator secondary sides), for which default values are included in the NAMELIST data, are filled with the default value. All cards that would contain data for defaulted arrays must be omitted from the input deck.</p> <p>2 = option on. Those component arrays (excluding accumulators, pressurizers, valves, and steam-generator secondary sides), for which default values are included in the NAMELIST data, are filled with the default value. Cards containing data for defaulted arrays must remain in the input deck but are overridden by the default value.</p>
NCRG	<p>Switch that decides if ICRRG (the outermost radial ring in the core) is read after VESSEL Card Number 4.</p> <p>0 = ICRRG is not read; 1 = ICRRG is read.</p>
NDIA1	<p>This variable can be used to force input of the heat-transfer diameter in addition to the hydraulic diameter, HD, to all one-dimensional components. When it is set to 2, the dimension of the HD array is doubled to 2*(NCELLS+1). Input decks must be changed so that (NCELLS+1) values end with an "E" for the hydraulic diameter. The next line begins an array of (NCELLS+1) values for the heat-transfer diameter.</p>
NDIA3	<p>This variable can be used to force input of the heat-transfer diameter in addition to the hydraulic diameter, HD, to all three-dimensional vessel components. When it is set to 2, input decks must be changed to accommodate the added heat-transfer diameter. The variables, HD-T, HD-Z, and HD-R, are input for the hydraulic diameter, followed immediately by a corresponding block containing the heat-transfer diameter.</p>

<u>Variable</u>	<u>Description</u>
NFRC1	<p>This variable can be used to force input of forward and reverse loss coefficients to all one-dimensional components. When it is set to 2, the dimension of the FRIC array is doubled to 2*(NCELLS+1). Input decks must be changed to provide two consecutive arrays of loss coefficients, each dimensioned NCELLS+1. Each array is in LOAD format and must be terminated with an "E." The first array provides loss coefficients that are used with positive velocities, and the second array provides loss coefficients used with negative velocities. To input these coefficients as K factors, use the IKFAC option.</p> <p>1 = standard FRIC input (default); 2 = two-way loss coefficients.</p>
NFRC3	<p>This variable can be used to force input of forward and reverse loss coefficients to all three-dimensional vessel components. When it is set to 2, input decks must be changed to accommodate the added reverse loss coefficients. The variables CFZL-T, CFZL-Z, CFZL-R, CFZV-T, CFZV-Z and CFZV-R are input as before to provide forward (positive velocity) loss coefficients. This block of input is immediately followed by a corresponding block containing the reverse loss coefficients (RCFZL-T, RCFZL-Z, RCFZL-R, RCFZV-T, RCFZV-Z, RCFZV-R). To input these coefficients as standard K factors, the IKFAC flag must be turned on.</p>
NOAIR	<p>Controls calculation of air partial pressure in one-dimensional components.</p> <p>0 = air partial pressures solved for (less efficient when no air in system); 1 = air partial pressures set automatically to zero (default). (The air partial-pressure arrays must be entered even if NOAIR = 1, in which case the arrays must be filled with 0.0.)</p>
NORMDP	<p>Dump in the noninteractive mode.</p> <p>0 = no (default if the code is interactive); 1 = yes.</p>
NORMRS	<p>Picks up restart from a normal noninteractive TRAC version.</p> <p>0 = no (default if the code is interactive); 1 = yes.</p>
P	<p>Default value for initial pressures. Used when ISTOPT is nonzero. (Real format.)</p>
PA	<p>Default value for initial air partial pressures. Used when ISTOPT is nonzero. (Real format.)</p>

<u>Variable</u>	<u>Description</u>
QPPP	Default value for volumetric heat distribution in the walls of one-dimensional components. Used when ISTOPT is nonzero. If this array is filled with the same nonzero constant, a uniform volumetric heat distribution results. (Real format.)
TL	Default value for initial liquid temperatures. Used when ISTOPT is nonzero. (Real format.)
TV	Default value for initial vapor temperatures. Used when ISTOPT is nonzero. (Real format.)
TW	Default value for initial wall temperatures. Used when ISTOPT is nonzero. (Real format.)
VL	Default value for initial liquid velocities. Used when ISTOPT is nonzero. (Real format.)
VV	Default value for initial vapor velocities. Used when ISTOPT is nonzero. (Real format.)

Note: If ISOLCN = 0 in the NAMELIST data, skip to Main-Data Card 3.

Solubility-Parameters Card. (Format 4E14.6) CNTLMN, CNMIN, CNTLMX, CNMAX

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	CNTLMN	Minimum liquid temperature (K) to use linear fit.
15-28	CNMIN	Solubility (kg solute/kg liquid) when liquid temperature at or below CNTLMN.
29-42	CNTLMX	Maximum liquid temperature (K) to use linear fit.
43-56	CNMAX	Solubility (kg solute/kg liquid) when liquid temperature at or above CNTLMX.

Main-Data Card 3. (Format 114,E14.6) DSTEP, TIMET

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DSTEP	Time-step number of dump to be used for restart. If DSTEP is less than zero, the last dump found will be used for restart.
15-28	TIMET	Problem start time. If DSTEP or TIMET is less than zero, the time obtained from the retrieved dump overrides the TIMET input value.

Main-Data Card 4. (Format 5I14) STDYST, TRANSI, NCOMP, NJUN, IPAK

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	STDYST	Steady-state calculation indicator. 0 = no steady-state calculation; 1 = generalized steady-state calculation; or 5 = static balance calculation (checks to see if zero flow can be achieved with the pumps turned off and no heat transfer).
15-28	TRANSI	Transient calculation indicator. 0 = no transient calculation; 1 = transient to be calculated.
29-42	NCOMP	Number of components. Note that a steam-generator component (Sec. V.C.5.h), including all of its secondary-side components, should be counted as <u>one</u> component.
43-56	NJUN	Number of junctions excluding internal junctions associated with the STGEN component.
57-70	IPAK	Water packing option. 0 = off; 1 = on.

Main-Data Card 5. (Format 3E14.6) EPSO, EPSI, EPSS

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	EPSO	Convergence criterion for outer iteration (suggested value = 1.0×10^{-3}).
15-28	EPSI	Convergence criterion for vessel iteration (suggested value = 1.0×10^{-5}).
29-42	EPSS	Convergence criterion for steady-state calculation (suggested value = 1.0×10^{-4}).

Main-Data Card 6. (Format 4I14) OITMAX, IITMAX, SITMAX, ISOLUT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	OITMAX	Maximum number of outer iterations (suggested value = 10).
15-28	IITMAX	Maximum number of vessel iterations (suggested value = 50; set to zero for direct inversion of the vessel matrix).

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	SITMAX	Maximum number of outer iterations for steady-state calculation (suggested value = 10).
43-56	ISOLUT	Solute (for example, boron in liquid coolant) tracking option. 0 = off; 1 = on. (Value <u>must not</u> be changed on a restart.)

Main-Data Card 7. (Format 5I14) NTSV, NTCB, NTCF, NTRP, NTCP

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NTSV	The number of signal variables from input and the restart file ($NTSV \geq 0$) [used to dimension variable storage].
15-28	NTCB	The number of control blocks from input and the restart file ($NTCB \geq 0$) [used to dimension variable storage].
29-42	NTCF	The total number of table entries for the tabular control blocks from input and the restart file ($NTCF \geq 0$) [used to dimension variable storage].
43-56	NTRP	The number of trips from input and the restart file ($NTRP \geq 0$) [used to dimension variable storage].
57-70	NTCP	The number of passes made each time step through the control-parameter evaluation of signal variables, control blocks, and trips ($NTCP \geq 0$) [two or more passes may be needed when the signal or set status of a trip is a signal-variable or control-block input parameter or when a controller contains an implicit control-block evaluation loop].

Component-List Card(s). [Format 5(3X,I11)] IORDER(i), i = (1,NCOMP)

Read by the LOAD routine.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
IORDER	NCOMP	Component numbers.

2. Material-Properties Data. If the TRAC internally defined material properties are inappropriate, the user may input his own data. Material-properties data are required when NMAT > 0 (word 4 on Main-Data Card 2). For each new material, the user must provide a unique material identifier (MATB > 50), the number of data-point sets provided for each material (PTBLN ≥ 2), and the data tables that specify the material properties (ρ , c_p , k , and ϵ) as a function of temperature (T). Linear interpolation is used to obtain property values for wall temperatures intermediate to those specified by the input tables. Extrapolation is not allowed (an error message results). The material-properties tables are not included in the dump; therefore, the tables must be included in TRACIN for a restart run.

Card Set 1. [Format 5(3X,I11)] MATB(i), i = (1,NMAT). Read by the LOAD routine.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
MATB	NMAT	New material identifiers, which require MATB(i) ≥ 50, i = (1,NMAT). These are the material ID numbers used in the component input to reference the input material properties instead of the built-in properties.

Card Set 2. [Format 5(3X,I11)] PTBLN(i), i = (1,NMAT). Read by the LOAD routine.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PTBLN	NMAT	Number of data-point sets provided for each of NMAT materials; material MATB(i) consists of PTBLN(i) data-point sets.

Card Set 3. Input NMAT data tables, one for each material MATB(i),
i = (1,NMAT). End each table with an E after the last entry.

Data Table i. [Format 5(3X,E11.5)] PRPTB(j,i), j = [1,5*PTBLN(i)]. (Read by
the LOAD routine.)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PRPTB(i)	5*PTBLN(i)	The material-properties data for material MATB(i), each point of which consists of the five variables in order T, ρ , c_p , k, and ϵ [where T is the temperature (K), ρ is the density ($\text{kg} \cdot \text{m}^{-3}$), c_p is the specific heat ($\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$), k is the thermal conductivity ($\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$), and ϵ is the emissivity]. Each material MATB(i) consists of PTBLN(i) points with the values of T increasing monotonically. The table array appears as $T_1, \rho_1, c_{p,1}, k_1, \epsilon_1, T_2, \rho_2, c_{p,2}, k_2, \epsilon_2, T_3, \dots, T_{\text{PTBLN}(i)}, \rho_{\text{PTBLN}(i)}, c_{p,\text{PTBLN}(i)}, k_{\text{PTBLN}(i)}, \epsilon_{\text{PTBLN}(i)}$. At least two points are required for each material, and the temperature range of the table must bound the range of application. Extrapolation is not allowed.

3. Interactive Control-Panel-Vector Data. These data are input only when TRAC is evaluated in the interactive mode. The CPV data cards are read when IPRCPV = 0 (an INOPTS NAMELIST parameter). These cards also define the source of data for evaluating and displaying signal-variable parameters 1 through 15. Loop and mnemonic name data not supplied from TRACIN are obtained from the restart file.

Card Number 1. (Format E14.6,3I14) CPVINT, JCOMPS(1), JCOMPS(2), JCELL(2)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	CPVINT	CPV print interval.
15-28	JCOMPS(1)	Reactor-power component number.
29-42	JCOMPS(2)	Primary-pressure component number.
43-56	JCELL(2)	Primary-pressure cell number.

Card Number 2. (Format 3I14, 2E14.6) JCOMPS(3), JCELL(3), JCOMPS(4), RDIAM, RMASS

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JCOMPS(3)	Containment pressure and temperature component number.
15-28	JCELL(3)	Containment pressure and temperature cell number.
29-42	JCOMPS(4)	Pressurizer water level component number.
43-56	RDIAM	Refueling storage tank diameter (m).
57-70	RMASS	Refueling storage tank water mass (kg).

Card Number 3. (Format 4I14) JDISCH(i), i = (1,4)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-56	JDISCH(i)	Component number at refueling storage tank discharge in loop i ($1 \leq i \leq 4$). This component must be a FILL.

Card Number 4. (Format 5I14) LOOPCT, KPRESS, KTEMP, KFLOW, KLEVEL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	LOOPCT	Number of loops in this model.
15-28	KPRESS	Pressure output units. 0 = MPa; 1 = psia.
29-42	KTEMP	Temperature output units. 0 = K; 1 = °F.
43-56	KFLOW	Flow output units. 0 = $\text{kg} \cdot \text{s}^{-1}$; 1 = $\text{lb} \cdot \text{s}^{-1}$.
57-70	KLEVEL	Level output units. 0 = m; 1 = ft.

Loop Data Cards. Input from 0 to LOOPCT (word 1 on CPV Card Number 4) of the following card set. If fewer than LOOPCT card sets are input, conclude these data with a blank card or a card having an integer zero in column 14 for the first input parameter, LPNUM (a zero must be entered explicitly if the free-format option is used). Data for the remaining loops will be obtained from the restart file.

Loop Card Number 1. (Format 5I14) LPNUM, ICOMPS(LPNUM,J), ICELLS(LPNUM,J),
J = (1,2)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	LPNUM	Loop ID number ($1 \leq \text{LPNUM} \leq \text{LOOPCT}$).
15-28	ICOMPS(LPNUM,1)	Hot-leg temperature component number.
29-42	ICELLS(LPNUM,1)	Hot-leg temperature cell number.
43-56	ICOMPS(LPNUM,2)	Cold-leg temperature component number.
57-70	ICELLS(LPNUM,2)	Cold-leg temperature cell number.

Loop Card Number 2. (Format 5I14) LOOPS(LPNUM), ICOMPS(LPNUM,J),
ICELLS(LPNUM,J), J = (3,4)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	LOOPS(LPNUM)	Number of physical loops represented by this loop.
15-28	ICOMPS(LPNUM,3)	Primary-liquid mass-flow component number.
29-42	ICELLS(LPNUM,3)	Primary-liquid mass-flow cell number.
43-56	ICOMPS(LPNUM,4)	ECCS-liquid mass-flow component number.
57-70	ICELLS(LPNUM,4)	ECCS-liquid mass-flow cell number.

Loop Card Number 3. (Format 5I14) ICOMPS(LPNUM,J), ICELLS(LPNUM,J), J = (5,6),
ICOMPS(LPNUM,9)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICOMPS(LPNUM,5)	Steam-generator secondary-side pressure component number.
15-28	ICELLS(LPNUM,5)	Steam-generator secondary-side pressure cell number.
29-42	ICOMPS(LPNUM,6)	Steam-generator secondary-side steam mass-flow component number.
43-56	ICELLS(LPNUM,6)	Steam-generator secondary-side steam mass-flow cell number.
57-70	ICOMPS(LPNUM,9)	Steam-generator secondary-side liquid-level component number.

Loop Card Number 4. (Format 4I14) ICOMPS(LPNUM,J), ICELLS(LPNUM,J), J = (7,8)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICOMPS(LPNUM,7)	Steam-generator secondary-side main-feedwater mass-flow component number.
15-28	ICELLS(LPNUM,7)	Steam-generator secondary-side main-feedwater mass-flow cell number.
29-42	ICOMPS(LPNUM,8)	Steam-generator secondary-side auxiliary-feedwater mass-flow component number.
43-56	ICELLS(LPNUM,8)	Steam-generator secondary-side auxiliary-feedwater mass-flow cell number.

4. Control-Parameter Data. Parameters and procedures used to control PWR-system operation are specified through the control-parameter data. Signal variables, control blocks, and trips are defined along with a multipass procedure for evaluating them at the start of each time step.

a. Multipass Control-Parameter Evaluation. Control parameters are evaluated in the following order: signal variables, control blocks, and trips. If a signal variable is to be evaluated after a control block or a trip or a control block is to be evaluated after a trip, two or more evaluation passes through the three control-parameter types are needed. For $NTCP \geq 2$ evaluation passes (word 5 on Main-Data Card 7), the following Control-Parameter List Cards are input to define the subrange of parameters to be evaluated for each control-parameter type during each evaluation pass.

Control-Parameter List Cards. [Format 5(3X,I11)] ISV1(i), ISV2(i), ICB1(i), ICB2(i), ITP1(i), ITP2(i), $i = (1, NTCP)$. Read by the LOAD routine. (Indicated columns are only examples; instead, the user may wish to input each of the NTCP pass parameters on a set of two or three cards with the remaining fields on a card skipped by using an s.)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
4-14	ISV1(1)	The smallest signal-variable ID number evaluated during the first control-parameter evaluation pass [$1 \leq ISV1(1)$].
18-28	ISV2(1)	The largest signal-variable ID number evaluated during the first control-parameter evaluation pass [$ISV1(1) \leq ISV2(1)$; input $ISV2(1) = 0$ if no signal variables are to be evaluated during the $i = 1$ first pass].
32-42	ICB1(1)	The smallest (in absolute value) control-block ID number evaluated during the first control-parameter evaluation pass [$ICB1(1) \leq -1$].
46-56	ICB2(1)	The largest (in absolute value) control-block ID number evaluated during the first control-parameter evaluation pass [$ICB2(1) \leq ICB1(1)$; input $ICB2(1) = 0$ if no control blocks are to be evaluated during the $i = 1$ first pass].

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
60-70	ITP1(1)	The smallest (in absolute value) trip ID number evaluated during the first control-parameter evaluation pass [$1 \leq ITP1(1) $].
4-14	ITP2(1)	The largest (in absolute value) trip ID number evaluated during the first control-parameter evaluation pass [$ ITP1(1) \leq ITP2(1) $; input ITP2(1) = 0 if no trips are to be evaluated during the i = 1 first pass].
18-28	ISV1(2)	The smallest signal-variable ID number evaluated during the second control-parameter evaluation pass [$1 \leq ISV1(2)$].
32-42	ISV2(2)	Etc.

b. Signal-Variable Data. Signal-variable data are defined when NTSV > 0 (word 1 on Main-Data Card 7). Signal variables define the input parameters for control blocks, the parameters for trip signals, the independent variable parameter for component-action tables, and the component action directly. Either NTSV or fewer signal variables are input. When fewer than NTSV signal variables are input, conclude the data with a blank card or a card having an integer zero for the first input parameter, IDSV. (A zero must be entered explicitly if the free-format option is used.) The remaining signal variables (for a total of NTSV) are obtained from the restart file. They are the signal variables on the restart file whose IDSV identification numbers differ from those defined here on input. After all signal-variable data are read from input and obtained from the restart file, the signal variables are reordered with their ID numbers increasing monotonically. Each signal variable is defined by the following card.

Signal-Variable Card. (Format 5I14) IDSV, ISVN, ILCN, ICN1, ICN2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDSV	Signal-variable ID number ($1 \leq IDSV \leq 9999$) [signal variables used to define a trip-signal expression require that $1 \leq IDSV \leq 399$].

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	ISVN	Signal-variable parameter number ($-56 \leq \text{ISVN} \leq 56$). See Table VII in Sec. III.E.3 for a list of the signal-variable parameter numbers vs their parameter descriptions. The sign of ISVN (for $\text{ISVN} \neq 0$) specifies how the parameter is defined. When $1 \leq \text{ISVN} \leq 56$, the signal variable is the parameter value. When $-40 \leq \text{ISVN} \leq -21$ and ICN1 and ICN2 are both nonzero, the signal variable is the difference between the parameter values at locations ICN1 and ICN2. When $-56 \leq \text{ISVN} \leq -1$ and either ICN1 or ICN2 or both are zero, the signal variable is the change in the parameter value over the previous time step. For $\text{ISVN} = 0$, the problem time parameter becomes the previous or present time-step size by defining $\text{ILCN} = -1$ or $+1$, respectively.
29-42	ILCN	The coolant loop number ($7 \leq \text{ISVN} \leq 15$), the component number ($18 \leq \text{ISVN} \leq 54$), or the trip ID number ($55 \leq \text{ISVN} \leq 56$) of the signal-variable parameter. The variable ILCN is not used when $1 \leq \text{ISVN} \leq 6$ or $16 \leq \text{ISVN} \leq 17$.
43-56	ICN1	The cell number of the first location in component ILCN where the signal-variable parameter is defined when $20 \leq \text{ISVN} \leq 40$.
57-70	ICN2	The cell number of the second location in component ILCN where the signal-variable parameter is defined when $20 \leq \text{ISVN} \leq 40$.

For the VESSEL and TEE (secondary side) components, $|\text{ICN1}|$ and $|\text{ICN2}|$ are defined by a composite number. For the VESSEL, it is the horizontal plane cell number times 1000 plus the axial level number. For the TEE secondary side, it is the total number of primary-side cells plus the secondary-side cell number. See Sec. III.E.3 for further information on defining cell and interface location composite numbers.

Further information is provided by the numerical signs of ICN1 and ICN2 for defining the signal-variable value. For $21 \leq \text{ISVN} \leq 40$, the signal variable is

- (1) the parameter value in cell |ICN1| when ICN2 = 0 or in cell |ICN2| when ICN1 = 0;
- (2) the maximum parameter value between cells |ICN1| and |ICN2| when ICN1 > 0 and ICN2 > 0;
- (3) the minimum parameter value between cells |ICN1| and |ICN2| when ICN1 < 0 and ICN2 < 0; and
- (4) the volume-averaged parameter value between cells |ICN1| and |ICN2| when ICN1 and ICN2 are of opposite sign.

When $-40 \leq \text{ISVN} \leq -21$ and both ICN1 and ICN2 are nonzero, the signal variable is the difference between the parameter value in cells |ICN1| and |ICN2| (that is, the parameter value in cell |ICN1| minus the parameter value in cell |ICN2|). If either ICN1 or ICN2 is zero when $-56 \leq \text{ISVN} \leq -1$, the signal variable is the change in the parameter value in cell |ICN2| or |ICN1| over the previous time step.

c. Control-Block Data. Control-block data are defined when NTCB > 0 (word 2 on Main-Data Card 7). Control blocks are mathematical functions that operate on one to three input parameters defined by signal variables and control blocks. The control-block output signal defines the input parameters for control blocks, the parameters for trip signals, the independent-variable parameter for component-action tables, and the component action directly. Either NTCB or fewer control blocks are input. When fewer than NTCB control blocks are input, conclude the data with a blank card or a card having an integer zero defining the first input parameter, IDCB (a zero must be entered explicitly if the free-format option is used). The remaining control blocks (for a total of NTCB) are obtained from the restart file. They are the control blocks on the restart file whose IDCB identification numbers differ from those defined on input. After all control-block data are read from input and obtained from the restart file, the control-blocks are reordered with the absolute value of their ID numbers (the value of -IDCB) increasing monotonically. Each control block is defined by the following two cards. When

the control block, a tabular function of one independent variable (ICBN = 101), additional data cards are needed to define the function table.

Control-Block Cards.

Card Number 1. (Format 5I14) IDCB, ICBN, ICB1, ICB2, ICB3

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDCB	Control-block ID number ($-9999 \leq \text{IDCB} \leq -1$).
15-28	ICBN	Control-block operation number ($1 \leq \text{ICBN} \leq 61$, $100 \leq \text{ICBN} \leq 101$, or $200 \leq \text{ICBN} \leq 201$). See Table VIII in Sec. III.E.4 for the list of control-block operation numbers and the mathematical description of the operation each performs.
29-42	ICB1	ID number for the first input parameter to the control block. $\text{ICB1} > 0$ defines a signal-variable parameter; $\text{ICB1} < 0$ defines a control-block output parameter.
43-56	ICB2	ID number for the second input parameter to the control block. $\text{ICB2} > 0$ defines a signal-variable parameter; $\text{ICB2} < 0$ defines a control-block output parameter. For $\text{ICBN} = 100$ or 101 , ICB2 is the number of entry pairs in the control block's function table.
57-70	ICB3	ID number for the third input parameter to the control block. $\text{ICB3} > 0$ defines a signal-variable parameter; $\text{ICB3} < 0$ defines a control-block output parameter.

Card Number 2. (Format 5E14.6) CBGAIN, CBXMIN, CBXMAX, CBCON1, CBCON2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	CBGAIN	Control-block gain factor.
15-28	CBXMIN	Control-block minimum value of its output parameter.
29-42	CBXMAX	Control-block maximum value of its output parameter.

Note: If CBGAIN, CBXMIN, and CBXMAX all are defined to be zero or defined on a blank record (card), TRAC internally defines $\text{CBGAIN} = 1.0$, $\text{CBXMIN} = -1.0 \times 10^{20}$, and $\text{CBXMAX} = 1.0 \times 10^{20}$.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	CBCON1	Control-block first constant.
57-70	CBCON2	Control-block second constant that is required by control blocks with operation numbers ICBN = 11, 30, 51, or 59. Control blocks with these operation numbers have XOUT initialized to zero. For all other operation numbers, CBCON2 defines the XOUT initial value for the control block.

If ICBN $\neq$ 101 (word 2 on Control-Block Card Number 1), omit Card Number 3.

Card Number 3. [Format 5(3X,I11)] CFTAB(i), i = (1,ICB2*2) Read by the LOAD routine.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
CFTAB	ICB2*2	Control-block function table data; input (table's independent-variable value associated with input parameter ID number ICB1, function value defining the control-block output parameter) pairs (*,*).

Note: If ICBN $\neq$ 200 or 201 (word 2 on Control-Block Card Number 1), omit Card Number 4.

Card Number 4. (Format 3E14.6) CBDT, CBTAU, CBWT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	CBDT	The Δt_d time constant that removes PI or PID controller error if convergence of the form $\Delta F(t) = \Delta F_0 \exp [(t_0 - t)/\Delta t_d]$ is assumed.
15-28	CBTAU	The τ time constant for the first-order lag function operation.
29-42	CBWT	The first constant W_t value for the weighted summer function operation when ICBN = 201.

d. Trip Data. Trip data are defined when $NTRP > 0$ (word 4 on Main-Data Card 7). There are seven categories of trip-input data. The first category, Trip-Dimension Variables Card, is always input when $NTRP > 0$. The five variables on this card and $NTRP$ define the variable storage required for the remaining six trip-input data categories. In each remaining category, none, part, or all of the data can be input. Any data that are not input are obtained from the restart file.

Trip-Dimension Variables Card. (Format 5I14) NTSE, NTCT, NTSF, NTDP, NTSD

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NTSE	The number of different signal-expression trip signals from input and the restart file ($NTSE \geq 0$) [used to dimension variable storage].
15-28	NTCT	The number of different trip-controlled trip signals from input and the restart file ($NTCT \geq 0$) [used to dimension variable storage].
29-42	NTSF	The number of different set-point factor tables referenced by trips from input and the restart file ($NTSF \geq 0$) [used to dimension variable storage].
43-56	NTDP	The number of trips from input and the restart file that generate a restart dump and possible problem termination when they are set ON ($NTDP \geq 0$) [used to dimension variable storage].
57-70	NTSD	The number of trip-controlled time-step data sets from input and the restart file that are used for time-step and edit control when their defined trips are set ON ($NTSD \geq 0$) [used to dimension variable storage].

Trip-Defining Variables Cards. Input from 0 to NTRP (word 4 on Main-Data Card 7) of the following card set. If fewer than NTRP card sets are input, conclude these data with a blank card or a card with an integer zero for the first input parameter, IDTP (a zero must be entered explicitly if the free-format option is used). The remaining trips that have trip IDTP identification numbers different from those input, will be obtained from the restart file.

Card Number 1. (Format 5I14) IDTP, ISRT, ISET, ITST, IDSG

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDTP	The trip ID number ($1 \leq IDTP \leq 9999$). Negative trip ID numbers have their trip set status evaluated during both the steady-state and transient calculations. Positive trip ID numbers have their trip set status evaluated only during the transient calculation with the input value of the trip set status, ISET, used during the steady-state calculation.
15-28	ISRT	The signal-range type number. Over the value range of the trip signal, the signal-range type number ISRT defines either two ($ISRT = \pm 1$ or ± 2) or three ($ISRT = \pm 3$, or ± 4) subranges with different set-status labels ($ON_{reverse}$, OFF, or $ON_{forward}$). See Table IX in Sec. III.E.5 for a description of these subranges and their delimiting set-point values for the eight possible values of ISRT ($1 \leq ISRT \leq 4$).
29-42	ISET	The initial trip set-status number (only used during steady state when $IDTP > 0$). -1 = $ON_{reverse}$, 0 = OFF, or 1 = $ON_{forward}$.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	ITST	The trip-signal type number. ± 1 = signal-variable trip, ± 2 = signal-expression trip, or ± 3 = trip-controlled trip. Making the ITST value negative omits editing of trip-status changes (when the trip-signal criterion is met and when the trip set status is changed).
57-70	IDSG	The ID number for the trip-signal variable when ITST = ± 1 (IDSG > 0 corresponds to IDSV in the signal-variable data and IDSG < 0 corresponds to IDCB in the control-block data), trip-signal expression when ITST = ± 2 (IDSG corresponds to IDSE in the trip-signal-expression data that follow), or trip-controlled trip signal when ITST = ± 3 (IDSG corresponds to IDTN in the trip-controlled trip data that follow).

Card Number 2. (Format 4E14.6) SETP(i), i = (1,NSP)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
SETP	NSP	The trip-signal set-point values shown as S# (where # = i) in the Sec. III.E.5 Table IX definition of ISRT (word 2 on Trip-Defining Variables Card 1). For ISRT = ± 1 or ± 2 , NSP = 2; for ISRT = ± 3 , or ± 4 , NSP = 4. The set-point values need to satisfy SETP(1) < SETP(2) when ISRT = ± 1 or ± 2 or SETP(1) < SETP(2) < SETP(3) < SETP(4) when ISRT = ± 3 , or ± 4 . [Caution: For trip-controlled trips with real-value trip signals that have discrete integer values (0.0, 1.0, 2.0, etc.), the set-point values should be midway between the two trip-signal values that change the trip's set status. Because of numerical roundoff when set-status values assigned to the trip signal are summed or multiplied, it is better to have the trip signal cross the set-point value rather than reach and equal it to satisfy the set-status change criterion. For example, use $S_1 = 0.4$ and $S_2 = 0.6$ rather than $S_1 = 0.0$ and $S_2 = 1.0$ when the trip signal from 0.0 to 1.0 or 1.0 to 0.0 is used to change the trip's set status.]

Card Number 3. (Format 4E14.6) DTSP(i), i = (1,NSP)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DTSP	NSP	The set-point delay times (s) after the trip signal crosses the set-point value to when the trip set status is changed. For ISRT = ± 1 or ± 2 , NSP = 2; for ISRT = ± 3 or ± 4 , NSP = 4.

Card Number 4. (Format 4I14) IFSP(i), i = (1,NSP)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
IFSP	NSP	The set-point factor-table ID numbers. The variable IFSP(i) corresponds to IDFT defined on the Trip Set-Point Factor-Table Card Number 1 that follows. Input IFSP(i) = 0 when no factor table is to be applied to SETP(i); that is, the set-point value remains constant during the problem. For ISRT = ± 1 or ± 2 , NSP = 2; for ISRT = ± 3 or ± 4 , NSP = 4.

If none of the trips input have ITST = ± 2 (word 4 on Trip-Defining Variables Card 1), omit the Trip-Signal-Expression Signal Cards.

Trip-Signal-Expression Signal Cards. Input the following card data for each different IDSG trip-signal identification number of trips with ITST = ± 2 that are input.

Card Number 1. (Format 3I14) IDSE, INSE, INCN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDSE	The trip-signal-expression signal ID number. This number corresponds to IDSG (word 5 on Trip-Defining Variables Card 1) for one or more of the input trips having ITST = ± 2 ($1 \leq IDSE < 9999$).
15-28	INSE	The number of subexpressions defining the signal expression ($1 \leq INSE \leq 10$).
29-42	INCN	The number of different constants referenced in the subexpressions defining the signal expression ($0 \leq INCN \leq 5$).

Input INSE cards of Card Number 2 to define the $J = (1, INSE)$ arithmetic subexpressions.

Card Number 2. (Format 3I14) ISE(i,J), i = (1,3)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ISE(1,J)	The arithmetic-operator ID number of the Jth arithmetic subexpression (see Table XIV).
15-28	ISE(2,J)	The first argument ID number of the Jth arithmetic subexpression.
29-42	ISE(3,J)	The second argument ID number of the Jth arithmetic subexpression.

TABLE XIV

ARITHMETIC-OPERATOR ID NUMBERS OF THE Jth ARITHMETIC SUBEXPRESSIONS

<u>ID Number</u>	<u>Operator</u>	<u>Arithmetic Subexpression</u>
1	Addition	(First argument ID number value) + (Second argument ID number value)
2	Subtraction	(First argument ID number value) - (Second argument ID number value)
3	Multiplication	(First argument ID number value) * (Second argument ID number value)
4	Division	(First argument ID number value) / (Second argument ID number value)
5	Exponentiation	(First argument ID number value) ** (Second argument ID number value)
6	Maximum value	MAX[(First argument ID number value), (Second argument ID number value)]
7	Minimum value	MIN[(First argument ID number value), (Second argument ID number value)]
8	Absolute value	ABS(First argument ID number value)

The first and second argument ID numbers define values that, when operated on by the arithmetic operator, give a value to their Jth arithmetic subexpression. There are four forms for the value of the first and second argument ID numbers. Their value is

- (1) a signal-variable or control-block output value evaluated each time step when their ID number is a signal-variable ID number $1 \leq \text{IDSV} \leq 399$ (word 1 of Signal-Variable Data) or a control-block ID number $-9999 \leq \text{IDCB} \leq -1$ (word 1 of Control-Block Data);
- (2) a signal-variable value evaluated initially and at time steps when the trip controlled by this signal expression is set to $\text{ON}_{\text{reverse}}$ or $\text{ON}_{\text{forward}}$ when their ID number is a signal-variable ID number IDSV plus 400 ($400 < \text{IDSV} + 400 < 800$);
- (3) a constant input on Card Number 3 that follows when its ID number is the i th subscript of $\text{SCN}(i)$ plus 800 ($800 < i + 800 < 806$); or
- (4) the value of an earlier subexpression j ($0 < j < J \leq \text{INSE}$) when their ID number is j plus 900 ($900 < j + 900 < 910$).

For example, the signal expression,

$$\max \left(\sqrt{(\text{IDSV} = 5) + (\text{IDSV} = 33)}, 1.0 \times 10^{-10} \right) ,$$

would be input as

1	2	3	4	5	
12345678901	23456789012	34567890123	45678901234	56789012345	6789012...
1		5		33	
5		901		801	
6		902		802	

where $\text{SCN}(1) = 0.5$, $\text{SCN}(2) = 1.0 \times 10^{-10}$, $\text{INCN} = 2$, and $\text{INSE} = 3$.

Note: If INCN = 0, omit Card Number 3.

Card Number 3. (Format 5E14.6) SCN(i), i = (1,INCN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
SCN	INCN	The constants used to evaluate the subexpressions.

If none of the trips being input have ITST = ± 3 (word 4 on Trip-Defining Variables Card 1), omit the Trip-Controlled Trip-Signal Cards.

Trip-Controlled Trip-Signal Cards. Input the following card data for each different IDSG trip-signal identification number of trips having ITST = ± 3 that are input.

Card Number 1. (Format 2I14) IDTN, INTN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDTN	The trip-controlled trip-signal ID number. This number corresponds to IDSG (word 5 on Trip-Defining Variables Card 1) for one or more of the input trips having ITST = ± 3 ($1 \leq ITST \leq 9999$).
15-28	INTN	The number of trip ID numbers whose ISET set-status values (word 3 on Trip-Defining Variables Card 1) are summed (IDTN > 0) or multiplied (IDTN < 0) to evaluate this trip-controlled trip signal ($2 \leq INTN \leq 10$).

Card Number 2. (Format 5I14) ITN(i), i = (1,INTN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ITN	INTN	The trip ID numbers whose ISET set-status values are summed (IDTN > 0) or multiplied (IDTN < 0) to evaluate this trip-controlled trip signal.

If all the trips have constant trip-signal set points because $IFSP(i) = 0$ (Trip-Defining Variables Card 4) was input for all the set points, omit the Trip Set-Point Factor-Table Cards.

Trip Set-Point Factor-Table Cards. Input the following card data for each different set-point factor-table ID number, $IFSP(i)$, defined in the input trips.

Card Number 1. (Format 3I14) IDFT, IDSG, INFT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDFT	The set-point factor-table ID number. This number corresponds to $IFSP(i)$ [Trip-Defining Variables Card 4] for one or more trip set points.
15-28	IDSG	The signal-variable or control-block ID number defining the set-point factor-table independent variable. This number corresponds to one of the ID numbers in the list of signal variables ($IDSG > 0$) or control blocks ($IDSG < 0$), either from input or from the restart file.
29-42	INFT	The number of set-point factor-table entry pairs ($2 \leq INFT \leq 10$).

Card Number 2. (Format 5E14.6) $FT(i)$, $i = (1, INFT*2)$.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
FT	$INFT*2$	Set-point factor-table data; input (table-independent-variable value associated with parameter ID number IDSG, set-point-factor value) pairs (*,-).

If $NTDP \leq 0$ (word 4 on the Trip-Dimension Variables Card), omit the Trip-Initiated Restart-Dump and Problem-Termination Cards.

Trip-Initiated Restart-Dump and Problem-Termination Cards.

Card Number 1. (Format 114) NDMP

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NDMP	The total number of trips from the input file and the restart dump that generate a restart dump and possible problem termination when the trips are set to $ON_{reverse}$ or $ON_{forward}$ ($0 \leq NDMP \leq NTDP$).

The input deck defines NDMP trips, and the $NTDP - NDMP$ remaining trips will be obtained from the restart file. If $NDMP = 0$, omit Card Number 2 because all $NTDP$ trip ID numbers will be obtained from the restart file.

Card Number 2. (Format 5114) IDMP(i), $i = (1, NDMP)$

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
IDMP	NDMP	The absolute value of trip ID numbers that generate a restart data dump when the trip is set to $ON_{reverse}$ or $ON_{forward}$. If IDMP(i) is given a negative sign, problem termination will occur after the restart dump is generated.

If $NTSD \leq 0$ (word 5 on the Trip-Dimension Variables Card), omit the Trip-Initiated Time-Step Data card set.

Trip-Initiated Time-Step Data Cards. Input from 0 to $NTSD$ of the following card set. If fewer than $NTSD$ sets are input, conclude these data with a blank card or a card having an integer zero defining the first parameter, NDID (a zero must be entered if the free-format option is used).

Card Number 1. (Format 2114) NDID, NTID

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NDID	The ID number for the following set of trip-initiated time-step data.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	NTID	The number of trip ID numbers that initiates the use of this time-step data set when any one of the trips is set to ON _{reverse} or ON _{forward} ($1 \leq \text{NTID} \leq 5$).

Card Number 2. (Format 5I14) ITID(i), i = (1,NTID)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ITID	NTID	The trip ID numbers that initiate use of this time-step data set when any one of the trips is set to ON _{reverse} or ON _{forward} .

Card Number 3. (Format 4E14.6) DTMIN, DTMAX, DTEND, DTSOF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DTMIN	The minimum time-step size (s).
15-28	DTMAX	The maximum time-step size (s).
29-42	DTEND	The problem time interval (s) during which these time-step data are used.
43-56	DTSOF	The next time step (s) [DTSOF > 0] or the factor DTSOF to be applied to the existing time step [DTSOF < 0] in defining the time step to be used at the start of the DTEND time interval when implementing these special time-step data.

Card Number 4. (Format 4E14.6) EDINT, GFINT, DMPIT, SEDINT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	EDINT	Print edit interval (s).
15-28	GFINT	Graphics edit interval (s).
29-42	DMPIT	Restart-dump edit interval (s).
43-56	SEDINT	Short-print edit interval (s).

Time-step data on Cards 3 and 4 replace the time-step data defined later in Sec. V.C.6 for a time interval DTEND (word 3 on Card Number 3) after any time-step data-set assigned trip is set to ON_{reverse} or ON_{forward}. This time-step data can be replaced by this or any other trip-controlled time-step data if any trip assigned to that time-step data set is set to ON_{reverse} or ON_{forward} before the time interval DTEND of this set passes.

5. Component Data. Either NCOMP (word 3 on Main-Data Card 4) or fewer sets of component cards are input. The sets may be input in any order. If fewer than NCOMP sets are input, the end of the component data is marked by a single card containing the characters END in columns 1-3. In this case the remaining components are initialized from the TRCRST file. The format of each set depends on the component type. The following is the input format for the components. All velocities are positive in the direction of ascending cell number. Most of the subscripted component data variables are processed by the LOAD subroutine described in Sec. V.D. Additional information on preparing component input data can be found in Sec. IV where the component models are described. All tables that are entered as pairs of numbers (x,y) must be supplied in ascending order of the independent variable x. In general, zero-dimensioned arrays are not input.

Each component requires a junction number, JUN, for each of its connecting points. A junction is the connection point between two components. A pipe requires two junction numbers, one for each end. A unique junction number must be assigned to each connecting point and referenced by both components to be connected. For example, if two pipes are joined, then the junction numbers of the connecting end of each pipe must be the same. No component may "wrap around" and connect to itself and no junction may have only one component connected to it. Any of the single-ended components (BREAK, FILL, or ACCUM) may be used to end a component line that is not a loop.

In the following input descriptions, the asterisk (*) indicates units of the defined variable and the hyphen (-) indicates dimensionless quantities.

Accumulator Component (ACCUM)

a. Accumulator Component (ACCUM).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-5	TYPE	Component type (ACCUM left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 3I14) NCELLS, JUN2, ICONC

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells.
15-28	JUN2	Junction number for junction adjacent to cell NCELLS. This must be the accumulator discharge.
29-42	ICONC	Flag for input of solute in the coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6)]. 0 = no input; 1 = dissolved solute only; 2 = both dissolved and plated-out solute.

ACCUM Array Cards. Seventeen sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m^3).
FA	NCELLS+1	Cell-edge flow areas (m^2).
FRIC	NCELLS+1	Additive loss coefficients (-). (See variables IKFAC and NFRC1 in the NAMELIST data for optional K factors and reverse loss-coefficients, respectively.)

Accumulator Component (ACCUM)

Note: Setting $FRIC > 10^{20}$ at a cell edge invokes the steam-separator model (only the gas phase is allowed to flow through the cell edge); setting $FRIC < -10^{20}$ invokes the liquid-separator model (only the liquid is allowed to flow through the cell edge). If the reverse additive loss-coefficient option ($NFRCl = 2$ in the NAMELIST data) is chosen, steam- and liquid-separator models may be used separately in each forward and reverse direction.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
GRAV	NCELLS+1	Gravity terms (-). The ratio of the elevation difference to the flow length between the centers of cell i and cell i-1. Positive GRAV indicates increasing elevation with increasing cell number. (Also see variable IELV in the NAMELIST data for optional cell-centered elevations.)
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIA1 in the NAMELIST data for optional heat-transfer diameters.)

Note: If $ICFLOW = 0$ or $ICFLOW = 1$ (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELLS+1	Cell-edge choked-flow model options: 0 = no choked-flow model; 1 = choked-flow calculation using default multipliers; 2-5 = choked-flow calculation using corresponding option multipliers (see NAMELIST data for multipliers). All nonzero values for ICFLG must be the same within a component.
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WARNING: Setting $ICFLG > 0$ at adjacent, closely spaced cell-edges can lead to numerical difficulties.

Accumulator Component (ACCUM)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
NFF	NCELLS+1	Friction-factor correlation options: 0 = constant friction factor, user input; 1 = homogeneous flow friction factor; -1 = homogeneous flow friction factor plus automatic form-loss computation (see Sec. III.A.1.d); 2 = annular-flow friction factor; -2 = annular-flow friction factor plus automatic form-loss computation; or -100 = form-loss computation only.
ALP	NCELLS	Initial void fractions (-).
VL	NCELLS+1	Initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).
Note: If ICONC = 0 (word 3 on Card Number 2), omit card set CONC.		
CONC	NCELLS	Initial ratio of solute mass to liquid coolant mass (-).
Note: If 1 ICONC = 0 or 1 (word 3 on Card Number 2), omit card set S.		
S	NCELLS	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).

Break Component (BREAK)

b. Break Component (BREAK).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-5	TYPE	Component type (BREAK left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) JUN1, IBTY, ISAT, IVDV, IOFF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JUN1	Junction number where break is located.
15-28	IBTY	Break-table type options: 0 = no tables read; 1 = read pressure table; 2 = read pressure and temperature tables; 3 = read above plus void fraction table; 4 = read above plus air partial pressure table; 5 = read above plus solute-to-coolant mass ratio table. (Requires ISOLUT = 1 on Main-Data Card 6.)
29-42	ISAT	Break temperature table use options (make consistent with IBTY): 0 = use TIN or single table for liquid and vapor temperatures (K), 1 = use TIN or table for liquid and set vapor to T_{sat} , 2 = use TIN or table for vapor and set liquid to T_{sat} , 3 = set liquid and vapor to T_{sat} , or 4 = use separate tables for liquid and vapor.

Break Component (BREAK)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	IVDV	<p>Momentum transport during flow in from the break (VVV term).</p> <p>0 = the velocity at the end of the break opposite the junction, must be set to the velocity at the break junction (VVV = 0).</p> <p>1 = the velocity at the end of the break opposite the junction, must be set to zero when computing VVV. This is recommended for breaks that model connections to pressure-suppression tanks or the atmosphere.</p>
57-70	IOFF	<p>The break fluid-state option, which defines the fluid state when the break table's controlling-trip is OFF after being ON [define IOFF when IBTR ≠ 0 (word 1 on Card Number 3)].</p> <p>0 = the last break table's interpolated fluid state is held constant.</p> <p>1 = define the initial fluid state.</p> <p>2 = input the pressure to be used, but maintain the fluid condition that existed when the trip was set OFF.</p> <p>3 = input a complete fluid state definition for when the controlling trip is OFF after being ON.</p>

Note: If IBTY < 1 (word 2 on Card Number 2), omit Card Number 3.

Card Number 3. (Format 5I14) IBTR, IBSV, NBTB, NBSV, NBRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IBTR	<p>The trip ID number that controls evaluation of the break table ($IBTR < 10000$). Input IBTR = 0 if there is no trip control.</p>
15-28	IBSV	<p>The break-table abscissa-coordinate variable ID number that defines the independent variable parameter for the IBTY = 1 to 4 tables. IBSV > defines the ID number for a signal-variable parameter; IBSV < 0 defines the ID number for a control-block output parameter.</p>

Break Component (BREAK)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	NBTB	The number of break-table pairs for break options IBTY = 1 to 4 (defined by the absolute value of NBTB). NBTB > 0 defines the independent-variable form to be the IBSV parameter value; NBTB < 0 defines the independent-variable form to be the change in the IBSV parameter over the last time step times the trip set-status value ISET when the break table is trip controlled; NBTB = 0 (for IBTY = 1 only) defines the break pressure to be the IBSV parameter value.
43-56	NBSV	The rate-factor table abscissa-coordinate variable ID number. NBSV > 0 defines the ID number for a signal-variable parameter; NBSV < 0 defines the ID number for a control-block output parameter; NBSV = 0 when NBRF ≠ 0 defines the difference between the trip signal and the set-point value that turns the trip OFF when the break table or tables are trip controlled.
57-70	NBRF	The number of rate-factor table pairs (defined by the absolute value of NBRF). The rate factor is applied as a factor to the independent variable of the break table or tables when the rate factor is defined. No rate factor is defined when NBSV and NBRF are both zero. NBRF > 0 defines the rate-factor table abscissa coordinate to be the NBSV parameter value; NBRF < 0 defines it to be the change in the NBSV parameter over the last time step times the trip set-status value ISET when IBTR ≠ 0; NBRF = 0 defines the rate factor to be the NBSV parameter value.

Card Number 4. (Format 5E14.6) DXIN, VOLIN, ALPIN, TIN, PIN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DXIN	Break-cell length (m), generally the same as its neighboring cell in the adjacent component. Used only when the flow is from the break into the adjacent component and for stratified-flow calculations.

Break Component (BREAK)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	VOLIN	Break-cell volume (m^3), generally the same as its neighboring cell in the adjacent component. Used only for stratified-flow calculations.
29-42	ALPIN	Initial mixture void fraction (-) at the break.
43-56	TIN	Initial mixture temperature (K) at the break.
57-70	PIN	Initial pressure (Pa) at the break.

Card Number 5. (Format 5E14.6) PAIN, CONCIN, RBMX, POFF, BELV

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	PAIN	Initial air partial pressure (Pa) at the break.
15-28	CONCIN	Ratio of initial solute mass to liquid mass at the break (-) [used only if ISOLUT = 1 (word 5 on Main-Data Card 6)].
29-42	RBMX	Maximum rate of change of the break pressure ($Pa \cdot s^{-1}$) [$0 \leq RBMX$].
43-56	POFF	Break pressure (Pa) when the controlling-trip is set OFF after being ON [used only when IBTY ≥ 1 and IOFF ≥ 2 (words 2 and 5 on Card Number 2)].
57-70	BELV	Break cell-centered elevation (m) [used only to compute GRAV array when IELV = 1].

Note: If IBTY < 1 (word 2 on Card Number 2), IBTR = 0 (word 1 on Card Number 3), or IOFF $\neq 3$ (word 5 on Card Number 2), omit Card Number 6.

Card Number 6. (Format 5E14.6) ALPOFF, TLOFF, TVOFF, PAOFF, CONOFF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ALPOFF	Break void fraction (-) when the controlling-trip is set OFF after being ON (input only when IBTY ≥ 3).

Break Component (BREAK)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	TLOFF	Break liquid temperature (K) when the controlling-trip is set OFF after being ON (input only when IBTY $\geq$ 2).
29-42	TVOFF	Break vapor temperature (K) when the controlling-trip is set OFF after being ON (input only when IBTY $\geq$ 2).
43-56	PAOFF	Break air partial pressure (Pa) when the controlling-trip is set OFF after being ON (input only when IBTY $\geq$ 4).
57-70	CONOFF	Break ratio of solute mass to coolant mass (-) when the controlling-trip is set OFF after being ON (input only when IBTY = 5).

Note: If IBTY < 1 (word 2 on Card Number 2) or NBTB = 0 (word 3 on Card Number 3), omit Card Number 7.

Card Number 7. (Format 5E14.6) PSCL, TLSCL, TVSCL, PASCL, CONSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	PSCL	Pressure scale factor. The dependent variable in the pressure table PTB is multiplied by this factor to obtain absolute pressure (input PSCL only if IBTY $\geq$ 1).
15-28	TLSCL	Liquid-temperature scale factor. The dependent variable in the liquid-temperature table TLTB is multiplied by this factor to obtain the absolute liquid temperature (K) [input TLSCL only if IBTY $\geq$ 2].
29-42	TVSCL	Vapor-temperature scale factor. The dependent variable in the vapor-temperature table TVTB is multiplied by this factor to obtain the absolute vapor temperature (K) [input TVSCL only if IBTY $\geq$ 2 and ISAT = 4].
43-56	PASCL	Air partial pressure scale factor. The dependent variable in the air partial pressure table PATB is multiplied by this scale factor to obtain the absolute air partial pressure (Pa) [input PASCL only if IBTY $\geq$ 4].

Break Component (BREAK)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	CONSCL	Ratio of solute mass to liquid-mass scale factor. The dependent variable in the solute mass to liquid-mass ratio table CONCTB is multiplied by this scale factor to obtain the absolute ratio value (input CONSCL only if IBTY = 5).

Note: If IBTY < 1 (word 2 on Card Number 2) or NBTB = 0 (word 3 on Card Number 3), omit the Break Array Cards.

BREAK Array Cards. Seven sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PTB	NBTB *2	Break pressure vs independent-variable-form table. Input (independent-variable form defined by IBSV and NBTB on Card Number 3, pressure) pairs (*,Pa).

Note: If IBTY < 2 (word 2 on Card Number 2), omit card set TLTB.

TLTB	NBTB *2	Break liquid temperature vs independent-variable-form table. Input (independent-variable form defined by IBSV and NBTB on Card Number 3, liquid temperature) pairs (*,K).
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Note: If IBTY < 2 (word 2 on Card Number 2) or ISAT ≠ 4 (word 3 on Card Number 2), omit card set TVTB.

TVTB	NBTB *2	Break vapor temperature vs independent-variable-form table. Input (independent-variable form defined by IBSV and NBTB on Card Number 3, vapor temperature) pairs (*,K).
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Break Component (BREAK)

Note: If IBTY < 3 (word 2 on Card Number 2), omit card set ALPTB.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ALPTB	NBTB *2	Break void-fraction vs independent-variable-form table. Input (independent-variable form defined by IBSV and NBTB on Card Number 3, vapor coolant volume fraction) pairs (*,-).

Note: If IBTY < 4 (word 2 on Card Number 2), omit card set PATB.

PATB	NBTB *2	Break air partial pressure vs independent-variable-form table. Input (independent-variable form defined by IBSV and NBTB on Card Number 3, air partial pressure) pairs (*,Pa).
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Note: If IBTY < 5 (word 2 on Card Number 2), omit card set CONCTB.

CONCTB	NBTB *2	Break solute mass to liquid-mass ratio vs independent-variable-form table. Input (independent-variable form defined by IBSV and NBTB on Card Number 3, ratio of solute mass to liquid mass) pairs [*,-].
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RFTB	NBRF *2	Rate-factor table for the break function table's independent-variable form defined by IVSV and NBTB on Card Number 3. Input (independent-variable form defined by NBSV and NBRF on Card Number 3, rate factor to be applied to the break function table's independent/variable) pairs (*,-).
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One-Dimensional Core Component (CORE)

c. One-Dimensional Core Component (CORE).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-4	TYPE	Component type (CORE, left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELLS, JUN1, JUN2, MAT, ICHF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells.
15-28	JUN1	Junction number for junction adjacent to cell 1 (assumed to be at the bottom of the component).
29-42	JUN2	Junction number for junction adjacent to cell NCELLS (assumed to be at the top of the component).
43-56	MAT	Material ID number of the wall (currently not used).
57-70	ICHF	CHF calculation flag. 0 = no; 1 = yes.

Card Number 3. (Format 3I14) ICONC, ICRU, ICRL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICONC	Flag for input of solute in the coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; 2 = both dissolved and plated-out solute.
15-28	ICRU	Power-region upper-boundary fluid-cell number (input ICRU = NCELLS if boundary is at JUN2).

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	ICRL	Power-region lower-boundary fluid-cell number (input ICRL = 0 if boundary is at JUN1).

Card Number 4. (Format 5I14) IRPWTY, NDGX, NDHX, NRTS, NHIST

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRPWTY	Neutronic-point-kinetics or reactor-power type option for defining programmed reactivity or reactor power (input parameters required for each option are shown in parentheses). Add 10 to the option value of IRPWTY if reactivity feedback is to be evaluated. For IRPWTY > 14, reactivity feedback is evaluated and edited, but is not used because reactor power is defined directly.

<u>IRPWTY</u>	<u>Option</u>
1	Reactor kinetics with constant REACT programmed reactivity (RPOWRI, REACT).
2	Reactor kinetics with table lookup of programmed reactivity (RPOWRI, IRPWSV, NRPWTB, RPWTB).
3	Reactor kinetics with an initial zero-programmed reactivity and trip-initiated constant REACT programmed reactivity (RPOWRI, IRPWTR, REACT).
4	Reactor kinetics with initial constant REACT programmed reactivity and trip-initiated table lookup of programmed reactivity (RPOWRI, REACT, IRPWTR, IRPWSV, NRPWTB, RPWTB).
5	Constant reactor power (RPOWRI).
6	Table lookup of reactor power (IRPWSV, NRPWTB, RPWTB).
7	Initial constant reactor power with trip-initiated table lookup of reactor power (RPOWRI, IRPWTR, IRPWSV, NRPWTB, RPWTB).

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	NDGX	The number of delayed-neutron groups. (If $NDGX \leq 0$ is input when $IRPWTY = 1, 2, 3, 4, 11, 12, 13, \text{ or } 14$, the code defaults to 6 delayed-neutron groups with the delayed-neutron constants defined internally; input $NDGX = 0$ when $IRPWTY = 5, 6, 7, 15, 16, \text{ or } 17$.)
29-42	NDHX	The number of decay-heat groups. (If $NDHX \leq 0$ is input when $IRPWTY = 1, 2, 3, 4, 11, 12, 13, \text{ or } 14$, the code defaults to 11 decay-heat groups with the decay-heat constants defined internally; input $NDHX = 0$ when $IRPWTY = 5, 6, 7, 15, 16, \text{ or } 17$.)
43-56	NRTS	The number of time steps between edits of the reactor power and reactivity feedback changes (default value is $NRTS = 10$).
57-70	NHIST	The number of (x,y) pairs in the power-history table. [Input $NHIST \geq 0$ when $IRPWTY = 1, 2, 3, 4, 11, 12, 13, \text{ or } 14$ (when $NHIST = 0$, no power-history table will be input; instead, delayed-neutron and decay-heat concentrations will be input unless $NDGX < 0$ and $NDHX < 0$ causing equilibrium concentrations to be defined internally); input $NHIST = 0$ when $IRPWTY = 5, 6, 7, 15, 16, \text{ or } 17$.]

Note: If $IRPWTY = 1, 5, 11, \text{ or } 15$ (word 1 on Card Number 4), omit Card Number 5.

Card Number 5. (Format 5I14) IRPWTR, IRPWSV, NRPWTB, NRPWSV, NRPWRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRPWTR	The trip ID number that controls evaluation of the reactivity-power table ($ IRPWTR < 10000$) [$0 < IRPWTR < 10000$ when $IRPWTY = 3, 4, 7, 13, 14, \text{ or } 17$; $IRPWTR = 0$ otherwise].

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	IRPWSV	The reactivity-power table abscissa-coordinate-variable ID number. The variable IRPWSV defines the independent-variable parameter for the reactivity-power table. IRPWSV > 0 defines the ID number for a signal-variable parameter; IRPWSV < 0 defines the ID number for a control-block output value ($0 < \text{IRPWSV} < 1000$ when IRPWTY = 2, 4, 6, 7, 12, 14, 16, or 17; IRPWSV = 0 otherwise).
29-42	NRPWTB	The number of reactivity-power table (x,y) pairs (defined by the absolute value of NRPWTB). When NRPWTB > 0, the independent-variable form for the table is the IRPWSV parameter; when NRPWTB < 0, the independent-variable form for the table is the change in the IRPWSV parameter over the last time step times the trip set-status value ISET when the reactivity-power table is trip controlled; when NRPWTB = 0, the reactivity-power table function is the IRPWSV parameter.
43-56	NRPWSV	The rate-factor table abscissa-coordinate-variable ID number. NRPWSV defines the independent-variable parameter for the rate factor that is applied to the independent variable of the reactivity-power table. NRPWSV > 0 defines the ID number for a signal-variable parameter; NRPWSV < 0 defines the ID number for a control-block output value; NRPWSV = 0 (when NRPWRF ≠ 0) defines the difference between the trip signal and the set-point value that turns the trip OFF when the reactivity-power table is trip controlled.

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NRPWRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NRPWRF). The rate factor is applied as a factor to the reactivity-power table's independent variable when the rate factor is defined. No rate factor is defined when NRPWSV and NRPWRF are both zero. NRPWRF > 0 defines the rate-factor table abscissa coordinate to be the NRPWSV parameter; NRPWRF < 0 defines it to be the change in the NRPWSV parameter over the last time step times the trip set-status value ISET when the reactivity-power table is trip controlled; NRPWRF = 0 defines the rate factor to be the NRPWSV parameter.

Card Number 6. (Format 5114) IZPWTR, IZPWSV, NZPWTB, NZPWSV, NZPWRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IZPWTR	The trip ID number that controls evaluations of the axial power-shape table (IZPWTR < 10000) [input IZPWTR = 0 when evaluation of the axial power-shape table is not trip controlled].
15-28	IZPWSV	The axial power-shape table abscissa-coordinate variable ID number. IZPWSV defines the independent-variable parameter for the axial power-shape table. IZPWSV > 0 defines the ID number for a signal-variable parameter; IZPWSV < 0 defines the ID number for a control-block output parameter.
29-42	NZPWTB	The number of axial power-shape table [x,y(z)] pairs (defined by the absolute value of NZPWTB). Each pair consists of an abscissa-coordinate value x and (ICRU-ICRL+1) [words 2 and 3 on Card Number 3] ordinate coordinate values of y(z) defining the axial power shape. NZPWTB > 0 defines the table's independent-variable form to be the IZPWSV parameter; NZPWPB < 0 defines the table's independent-variable form to be the change in the IZPWSV parameter over the last time step times the trip set-status value ISET when the axial power-shape table is trip controlled; NZPWTB = 0 defines the reactor-kinetic stable function to be the IZPWSV parameter.

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NZPWSV	The rate-factor table abscissa-coordinate variable ID number. NZPWSV defines the independent-variable parameter for the rate factor that is applied to the axial power-shape table's independent variable. NZPWSV > 0 defines the ID number for a signal-variable parameter; NZPWSV < 0 defines the ID number for a control-block output parameter; NZPWSV = 0 (when NZPWRF ≠ 0) defines the difference between the trip signal and the set-point value that turns the trip OFF when the axial power-shape table is trip controlled.
57-70	NZPWRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NZPWRF). The rate factor is applied as a factor to the axial power-shape table's independent variable when the rate factor is defined. No rate factor is defined when NZPWSV and NZPWRF are both zero. NZPWRF > 0 defines the rate-factor table's abscissa coordinate to be the NZPWSV parameter; NZPWRF < 0 defines it to be the change in the last time step times the trip set-status value ISET when the axial power-shape table is trip controlled; NZPWRF = 0 defines the rate factor to be the NZPWSV parameter.

Card Number 7. (Format 5I14) IRFTR, NMWRX, NFCI, NFCIL, NZMAX

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRFTR	Trip ID number for implementing the fuel-rod axial fine-mesh calculation during reflood (no axial fine-mesh calculation is performed if IRFTR = 0).
15-28	NMWRX	Metal-water reaction option. 0 = off; 1 = on.
29-42	NFCI	Fuel-cladding interaction (FCI) option (NFCI = 1 performs the dynamic gap conductance calculation). 0 = off; 1 = on.

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NFCIL	Maximum number of FCI calculations per time step (input NFCIL = 1 when NFCI = 1).
57-70	NZMAX	Maximum number of rows of nodes used in the fuel-rod conduction calculation.

Card Number 8. (Format 5I14) NRODS, NDRDS, NODES, NSLBS, NFBPWT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NRODS	Total number of calculational fuel rods.
15-28	NDRDS	Number of radial heat-transfer nodes in the fuel rods (input NDRDS ≥ 4 if NRODS > 0 fuel rods is specified; input NDRDS = 0 if NRODS = 0).
29-42	NODES	Number of heat-transfer nodes in the core wall. A value of 1 defaults to the lumped-parameter model. A value of 0 specifies no wall heat transfer.
43-56	NSLBS	Variable not used.
57-70	NFBPWT	Flag option to replace the radial or axial power shape with a user-defined shape used to average the reactivity-feedback parameters over the core. (For the input value, add 1 for a radial shape or 2 for an axial shape.)

Card Number 9. (Format 5E14.6) REACT, TNEUT, RPWOFF, RRPWMX, RPWSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	REACT	Initial programmed reactivity (IRPWTY = 1, 2, 4, 11, 12, or 14) or trip-initiated programmed reactivity (IRPWTY = 3 or 13) [REACT = $(k-1) \cdot k^{-1}$ where k is the reactor multiplication constant; both REACT and k have no units].
15-28	TNEUT	The prompt neutron lifetime (s) [TNEUT ≤ 0.0 defaults internally to TNEUT = 1.625×10^{-5} s].

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	RPWOFF	Programmed reactivity (-) [IRPWTY = 3, 4, 13, 14] or reactor power (W) [IRPWTY = 7 or 172 when the reactivity-power controlling trip is OFF after being ON (hold constant the last value of reactivity or power when the trip was ON when $RPWOFF \leq -1.0 \times 10^{19}$)].
43-56	RRPWMX	The maximum rate of change of programmed reactivity (s^{-1}) or reactor power ($W \cdot s^{-1}$) [RRPWMX ≥ 0.0].
57-70	RPWSCL	Reactivity-power table scale factor for programmed reactivity or reactor power. The dependent variable in table RPWTB is multiplied by RPWSCL to obtain the absolute value.

Card Number 10. (Format 5E14.6) RPOWRI, ZPWIN, ZPWOFF, RZPWMX, QP3IN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RPOWRI	Initial reactor power (W).
15-28	ZPWIN	The axial power-shape table's abscissa-coordinate variable value corresponding to the initial axial power shape.
29-42	ZPWOFF	The axial power-shape table's abscissa-coordinate variable value corresponding to the axial power-shape to be used when the fewer-shape table controlling trip is OFF after being ON (use the last evaluated axial power shape when the trip was ON when $ZPWOFF \leq -1.0 \times 10^{19}$).
43-56	RZPWMX	The maximum rate of change of any z-interface value in the axial power shape (s^{-1}) [RZPWMX ≥ 0.0].
57-70	QP3IN	Power (W) deposited in the wall and distributed according to the QPPP array.

Card Number 11. (Format 5E14.6) RADIN, TH, HOUTL, HOUTV, TOUTL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN	Inner radius (m) of the core wall.

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	TH	Core wall thickness (m).
29-42	HOUTL	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the core wall and liquid outside the core wall.
43-56	HOUTV	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the core wall and vapor outside the core wall.
57-70	TOUTL	Liquid temperature (K) outside core wall.

Note: See PIPE input description, Sec. V.C.5.e, for further comments on the HOUTL, HOUTV, TOUTL, and TOUTV heat-transfer parameters.

Card Number 12. (Format 5E14.6) TOUTV, PLDR, PDRAT, FUCRAC, HGAPO

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV	Vapor temperature (K) outside core wall.
15-28	PLDR	Pellet dish radius (m) [no calculation of pellet dishing is performed if PLDR = 0.0].
29-42	PDRAT	Fuel-rod pitch-to-diameter ratio (-).
43-56	FUCRAC	Fraction of the fuel <u>not</u> cracked (used only if NFCI = 1 on Card Number 7).
57-70	HGAPO	Fuel-rod gap conductance coefficient ($W \cdot m^{-2} \cdot K^{-1}$) [constant for NFCI = 0 on Card Number 7; initial value otherwise].

Card Number 13. (Format 3E14.6) DTXHT(1), DTXHT(2), DZNHT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DTXHT(1)	Maximum ΔT (K) above which rows of nodes are inserted in the fuel-rod conduction calculation during reflood for the nucleate and transition boiling regimes [suggested value: DTXHT(1) = 3.0].
15-28	DTXHT(2)	Maximum ΔT (K) above which rows of nodes are inserted in the fuel-rod conduction calculation during reflood for all boiling regimes except nucleate and transition [suggested value: DTXHT(2) = 10.0].

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	DZNHT	Minimum ΔZ (m) below which no additional rows are inserted in the fuel-rod conduction calculation during the reflood calculation (this value comes from the diffusion number).

Note: If reactivity feedback is not evaluated ($IRPWTY < 11$, word 1 on Card Number 4), omit Card Numbers 14-19. The reactivity-feedback input involves information on Card Numbers 14-19 and tables RCTF, RCTC, RCAL, and RCBM in the CORE Common-Rod Array Cards that follow. Information and an example that are useful in the determination of the correct values for $IRCJTB(I,J)$ on Card Numbers 14-17 are provided with the tables.

Card Numbers 14-17. (Format 5I14/5I14/5I14/5I14) $IRCJTB(I,J)$, $I = (1,4)$,
 $J = (1,4)$

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	$IRCJTB(1,J)$	The number of fuel-temperature T_f dependent entries in the Jth reactivity-coefficient table [$1 \leq IRCJTB(1,J)$].
15-28	$IRCJTB(2,J)$	The number of coolant-temperature T_c dependent entries in the Jth reactivity-coefficient table [$1 \leq IRCJTB(2,J)$].
29-42	$IRCJTB(3,J)$	The number of vapor-coolant void-fraction α dependent entries in the Jth reactivity-coefficient table [$1 \leq IRCJTB(3,J)$].
43-56	$IRCJTB(4,J)$	The number of boron B dependent entries in the Jth reactivity-coefficient table [$1 \leq IRCJTB(4,J)$].

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	IBU(J)	The boron unit's definition flag for the $\partial k/\partial X_J$ reactivity coefficient's x_J derivative parameter,

$$x_4 = \begin{Bmatrix} B_m \\ B_r \end{Bmatrix} \text{ for } IBU(4) = \begin{Bmatrix} 0 \text{ or } 1 \\ -2 \text{ or } -1 \end{Bmatrix} ,$$

and $f(T_f, T_c, \alpha, B)$ tabular dependence,

$$B = \begin{Bmatrix} B_m \\ B_r \end{Bmatrix} \text{ for } IBU(J) = \begin{Bmatrix} -1 \text{ or } 1 \\ -2 \text{ or } 0 \end{Bmatrix} ,$$

where B_m is the macroscopic density in the coolant-channel volume in $\text{kg} \cdot \text{m}^{-3}$ units, and B_r is the mass ratio of parts boron per million parts liquid coolant in ppm units.

The $J = 1$ card defines the fuel-temperature reactivity-coefficient table, the $J = 2$ card defines the coolant-temperature reactivity-coefficient table, the $J = 3$ card defines the vapor-coolant void-fraction reactivity-coefficient table, and the $J = 4$ card defines the boron reactivity-coefficient table. The reactivity coefficients are tabular functions of the four reactivity-feedback parameters, that is, J th coefficient = $f_J(T_f, T_c, \alpha, B)$, $J = 1, 2, 3$, or 4 .

Card Number 18. (Format 5I14) IRCJFM(J), $J = (1,4)$, ISNOTB

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRCJFM(1)	The form number for the fuel-temperature reactivity-coefficient type.
15-28	IRCJFM(2)	The form number for the coolant-temperature reactivity-coefficient type.
29-42	IRCJFM(3)	The form number for the vapor-coolant void-fraction reactivity-coefficient type.
43-56	IRCJFM(4)	The form number for the boron reactivity-coefficient type.

One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	ISNOTB	Flag that includes (excludes) the solute material in (from) the boron for the reactivity-feedback calculation. 0 = the solute is boron; 1 = the solute is <u>not</u> boron.

For the reactivity-coefficient forms, refer to Table IV on page 96 where $x = T_f$ (K) for $J = 1$, $x = T_c$ (K) for $J = 2$, $x = \alpha$ for $J = 3$, $x = B_r$ [when $IBU(4) = -2, -1$], or $x = B_m$ [when $IBU(4) = 0, 1$] for $J = 4$.

Card Number 19. (Format 5E14.6) POWEXP, BPP0, BPPl, BCRO, BCRL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	POWEXP	The exponent value to which the cell values of the power distribution are raised in defining the weighting function for averaging the reactivity-feedback parameters over the core volume (suggested value: POWEXP = 2.0). The averaging process over the core for the reactivity-feedback parameter X is defined by

$$\bar{X} = \frac{\sum_i^{\text{cells}} x_i m_i P_i^{\text{POWEXP}}}{\sum_i^{\text{cells}} m_i P_i^{\text{POWEXP}}},$$

where P_i is the power in cell i . For $X_i = T_{fi}$ or T_{ci} , m_i is the mass of the fuel or coolant, respectively, in cell i ; for $X_i = \alpha_i$ or B_i , $m_i = 1$.

15-28	BPP0	The zero-order coefficient of the first-order polynomial $BPP = BPP0 + BPPl * T_c$ that defines the effective (smeared and shielded) core-average concentration of burnable-poison pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3}$). See Eq. (177).
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One-Dimensional Core Component (CORE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	BPP1	The first-order coefficient of the first-order polynomial $BPP = BPP0 + BPP1 \cdot T_c$ defining the effective (smeared and core-average concentration of burnable-poison pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3} \cdot \text{K}^{-1}$)). T_c is the core-average coolant temperature. See Eq. (177).
43-56	BCR0	The zero-order coefficient of the first-order polynomial $BCR = BCR0 + BCR1 \cdot \rho_{\text{PROG}}$ defining the effective (smeared and shielded) core-average concentration of control-rod pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3}$). See Eq. (178).
57-70	BCR1	The first-order coefficient of the first-order polynomial $BCR = BCR0 + BCR1 \cdot \rho_{\text{PROG}}$ defining the effective (smeared and shielded) core-average concentration of the control-rod pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3}$). ρ_{PROG} is programmed reactivity and has no units. See Eq. (178).

CORE Array Cards. Twenty sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m^3).
FA	NCELLS+1	Cell-edge flow areas (m^2).
FRIC	NCELLS+1	Additive loss coefficients. (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELLS+1	Gravity terms. (See ACCUM input description, Sec. V.C.5.a.) Gravity terms must be greater than zero for the required orientation of a CORE component.
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)

One-Dimensional Core Component (CORE)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ICFLG	NCELLS+1	Cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCELLS+1	Friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)
ALP	NCELLS	Initial void fractions (-).
VL	NCELLS+1	Initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).

Note: If NODES = 0 (word 3 on Card Number 8), do not enter arrays QPPP, MATID, and TW.

QPPP	NODES*NCELLS	A nonnormalized power profile (-) in the core walls. Input for cell 1, node 1 through NODES; then for cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis (normalized $\text{QPPP}(i) = \text{QPPP}(i) / [\sum \text{QPPP}(i) * \text{VOL}(i)]$). Filling the array with zeros results in no power being deposited in the walls regardless of the settings of QP3IN, QP3TB, etc.
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One-Dimensional Core Component (CORE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
MATID	NODES-1	Array specifying material ID between radial nodes in wall. Dimension is 1 if NODES = 1 and 0 if NODES = 0. The following properties are built into the code: 6 = stainless steel, type 304; 7 = stainless steel, type 316; 8 = stainless steel, type 347; 9 = carbon steel, type A508; 10 = Inconel, type 718; or 12 = Inconel, type 600. (See Sec. V.C.2 to input material properties.)

Note: Material-properties ID numbers 1-5 and 11 are available only to the fuel-rod model.

TW	NODES*NCELLS	Initial wall temperatures (K). Input in the same order as QPPP.
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Note: If ICONC = 0 (word 1 on Card Number 3), omit card set CONC.

CONC	NCELLS	Initial ratio of solute mass to liquid mass (-).
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Note: If ICONC = 0 or 1 (word 1 on Card Number 3), omit card set S.

S	NCELLS	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).
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CORE Common-Rod Array Cards. Thirty-one sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
Z	NCELLS	Cumulative flow length (m) to the end of each cell from JUN1 (Card Number 2).
RDPWR	NDRDS	Relative radial power density at the node positions.
CPOWR	1	Relative power density for the average rod (suggested input, 1.0).

One-Dimensional Core Component (CORE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
RPKF	NRODS-1	Rod power-peaking factors (relative to the core average rod) for the additional rods.

Note: If NZPWTB = 0 on Card Number 6, omit card set ZPWTB.

ZPWTB	NZPWTB * [1+(ICRU-ICRL+1)]	Axial power-shape vs independent-variable-form table. Input [independent variable defined by IZPWSV and NZPWTB on Card Number 6, axial power-shape densities that have (ICRU-ICRL+1) values] pairs (*,-). The relative axial power densities that define the axial power shape are specified at the cell interfaces from one end of the fuel rod to the other. There are NZPWTB axial power shapes being input with each having (ICRU-ICRL+1) values.
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Note: If NZPWRF or NZPWTB = 0 on Card Number 6, omit card set NZPWRF.

ZPWRF	NZPWRF *2	Rate-factor table for the axial power-shape table's independent variable. Input [independent-variable form defined by NZPWSV and NZPWRF on Card Number 6, rate factor to be applied to the axial power-shape table's independent variable] pairs (*,-).
RDX	1	Number of fuel rods in the core (this is a real number, not an integer; fractional rods are allowed).
RADRD	NDRDS	Rod node radii (m) [cold].

One-Dimensional Core Component (CORE)

Note: Only one MATRD element may have the value 3; and MATRD(1) and MATRD(NDRDS-1) cannot be 3. Additional material properties can be input (Sec. V.C.2).

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>																										
MATRD	NDRDS-1	Fuel-rod-material ID numbers [dimension is 1 if NDRDS = 1 (word 2 on Card Number 8)].																										
		<table><tr><th><u>ID</u></th><th><u>Material Type</u></th></tr><tr><td>1</td><td>Mixed oxide fuel</td></tr><tr><td>2</td><td>Zircaloy</td></tr><tr><td>3</td><td>Fuel-clad gap gases</td></tr><tr><td>4</td><td>Boron-nitride cladding</td></tr><tr><td>5</td><td>Constantan/Nichrome heater wire</td></tr><tr><td>6</td><td>Stainless steel, type 304</td></tr><tr><td>7</td><td>Stainless steel, type 316</td></tr><tr><td>8</td><td>Stainless steel, type 347</td></tr><tr><td>9</td><td>Carbon steel, type A508</td></tr><tr><td>10</td><td>Inconel, type 718</td></tr><tr><td>11</td><td>Zircaloy dioxide</td></tr><tr><td>12</td><td>Inconel, type 600</td></tr></table>	<u>ID</u>	<u>Material Type</u>	1	Mixed oxide fuel	2	Zircaloy	3	Fuel-clad gap gases	4	Boron-nitride cladding	5	Constantan/Nichrome heater wire	6	Stainless steel, type 304	7	Stainless steel, type 316	8	Stainless steel, type 347	9	Carbon steel, type A508	10	Inconel, type 718	11	Zircaloy dioxide	12	Inconel, type 600
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10	Inconel, type 718																											
11	Zircaloy dioxide																											
12	Inconel, type 600																											

Note: If NRPWTB = 0 on Card Number 5, omit card set RPWTB.

RPWTB	NRPWTB *2	Programmed-reactivity or reactor-power vs independent-variable-form table. Input (independent-variable form defined by IRPWSV and NRPWTB on Card Number 5, programmed reactivity or reactor power as defined by IRPWTY) pairs (*,- or W).
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Note: If NRPWTB = 0 (word 3, Card Number 5) or NRPWRF = 0 (word 5, Card Number 5), omit card set RPWRF.

RPWRF	NRPWRF *2	Rate-factor table for the programmed-reactivity or reactor-power table's independent variable. Input (independent-variable form defined by NRPWSV and NRPWRF on Card Number 5, rate factor to be applied to the programmed-reactivity or reactor-power table's independent variable) pairs (*,-).
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One-Dimensional Core Component (CORE)

Note: If IRPWTY < 11 (word 1, Card Number 4), omit card sets RCTF, RCTC, RCAL, and RCMB. The following four tables are not entered with (x,y) pair values as is done for one-dimensional dependent tables. The general steps for entering tables RCTF, RCTC, RCAL, and RCBM are listed below.

1. Select the appropriate reactivity-coefficient form IRCJFM(J) and the appropriate boron units IBU(J) for the particular table J.
2. The user is allowed to specify only one set of points each for fuel temperature T_f , coolant temperature T_c , void fraction α , and boron B. The numbers of unique points for each of the above parameters are defined by IRCJTB(1,J), IRCJTB(2,J), IRCJTB(3,J), and IRCJTB(4,J). Each set of parameters must be increasing monotonically.
3. With T_c , α , and B constant, vary T_f through its range and specify the reactivity coefficients. Then, increment T_c , hold α and B constant, and vary T_f again. Continue incrementing T_c until the range of T_c is covered.
4. Reset T_f and T_c to their first values, increment α , and repeat step 3. Continue incrementing α until its range is covered.
5. Reset T_f , T_c , and α to their first values, increment B, and repeat steps 3 and 4. Continue incrementing B until its range is covered. At this point, all of the reactivity coefficients for table J should be specified.
6. To enter the table, define IRCJTB(1,J) values of T_f , IRCJTB(2,J) values of T_c , IRCJTB(3,J) values of α , and IRCJTB(4,J) values of B in that order. The values for each T_f , T_c , α , and B should be increasing monotonically. Now, enter IRCJTB(1,J)*IRCJTB(2,J)*IRCJTB(3,J)*IRCJTB(4,J) reactivity coefficients generated in steps 3-5 above in the same order in which they were generated. This completes table J.

One-Dimensional Core Component (CORE)

EXAMPLE FOR ENTERING TABLE RCTC

Select IRCJFM(2) = 1 and IBU(2) = 0.

Reactor-kinetics-feedback data generated by steps 3-5 for a table with one value for T_f , two values for T_c , one value for α , and two values for B.

T_f (K)	T_c (K)	α	B_r (ppm)	$(1/k) * (\partial k / \partial T_c)$ (K ⁻¹)
0.0	293.0	0.0	700.0	-4.8720×10^{-5}
0.0	616.5	0.0	700.0	-1.1567×10^{-3}
0.0	293.0	0.0	2800.0	-1.3944×10^{-5}
0.0	616.5	0.0	2800.0	-6.0648×10^{-4}

Because T_f and α do not vary, a value of 0.0 may be used. The free-format input of table RCTC follows:

0.0s				* fuel temp
293.0	616.5s			* coolant temp
0.0s				* void frac
700.0	2800.0s			* boron conc
-4.8720e-5	-1.1567e-3	-1.3944e-5	-6.0648e-4e	* reactivity coef

When fewer than five values are specified per record, the skip modifier "s" implies the data are continued on the next record.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
RCTF	IRCJTB(1,1)+IRCJTB(2,1)+ IRCJTB(3,1)+IRCJTB(4,1)+ (IRCJTB(1,1)*IRCJTB(2,1)* IRCJTB(3,1)*IRCJTB(4,1))	The fuel-temperature reactivity-coefficient table. Input IRCJTB(1,1) T_f values, IRCJTB(2,1) T_c values, IRCJTB(3,1) α values, IRCJTB(4,1) B_r values, and IRCJTB(1,1) * IRCJTB(2,1) * IRCJTB(3,1) * IRCJTB(4,1) fuel-temperature reactivity-coefficient values that define the four-dimensional dependent table.
RCTC	IRCJTB(1,2)+IRCJTB(2,2)+ IRCJTB(3,2)+IRCJTB(4,2)+ (IRCJTB(1,2)*IRCJTB(2,2)* IRCJTB(3,2)*IRCJTB(4,2))	The coolant-temperature reactivity-coefficient table.

One-Dimensional Core Component (CORE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
RCAL	IRCJTB(1,3)+IRCJTB(2,3)+ IRCJTB(3,3)+IRCJTB(4,3)+ (IRCJTB(1,3)*IRCJTB(2,3)* IRCJTB(3,3)*IRCJTB(4,3))	The vapor-coolant void-fraction reactivity-coefficient table.
RCBM	IRCJTB(1,4)+IRCJTB(2,4)+ IRCJTB(3,4)+IRCJTB(4,4)+ (IRCJTB(1,4)*IRCJTB(2,4)* IRCJTB(3,4)*IRCJTB(4,4))	The boron reactivity-coefficient table.

Note: If power option IRPWTY = 5, 6, 7, 15, 16, or 17 (word 1 on Card Number 4) is specified, omit card sets BETA, LAMDA, CDGN, LAMDH, EDH, CDHN, and PHIST.

Note: If NDGX $\leq$ 0 (word 2 on Card Number 4), omit card sets BETA and LAMDA. The default 6 group delay-neutron constants will be defined internally.

BETA	NDGX	The effective delayed-neutron fraction.
LAMDA	NDGX	The delayed-neutron decay constant (s^{-1}).

Note: Use card set CDGN only if NHIST = 0 and NDGX > 0 on Card Number 4.

CDGN	NDGX	The delayed-neutron precursor concentration (W).
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Note: If NDHX $\leq$ 0 (word 3 on Card Number 4), omit card sets LAMDH and EDH. The default 11 group decay-heat constants will be defined internally.

LAMDH	NDHX	Decay-heat decay constant (s^{-1}).
EDH	NDHX	Effective decay-heat energy fraction.

Note: Use card set CDHN only if NHIST = 0 and NDGX > 0 on Card Number 4.

CDHN	NDHX	The decay-heat concentration (W $\cdot$ s).
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One-Dimensional Core Component (CORE)

Note: If NHIST = 0 on Card Number 4, omit card set PHIST.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>																
PHIST	NHIST*2	Power-history table. Use (present time minus past time, reactor-core prompt-fission power at that past time) pairs (s,W). The first pair should be for the current power; that is, time interval 0.0, with the time interval for subsequent pairs being positive and increasing monotonically for each pair.																
NFAX	ICRU-ICRL	Number of permanent fine-mesh intervals per coarse-mesh interval added at the start of the reflood calculation [the total number of heat-transfer rows per fuel rod must be less than NZMAX (word 5 on Card Number 7)].																
FPUO2	1	Fraction of plutonium dioxide (PuO ₂) in mixed-oxide fuel.																
FTD	1	Fraction of theoretical fuel density.																
GMIX	7	Mole fraction of gap-gas constituents. Array is not used if NFCI = 0 but must be input. Enter data for each gas in the order indicated.																
		<table><tr><th><u>Index</u></th><th><u>Gas</u></th></tr><tr><td>1</td><td>Helium</td></tr><tr><td>2</td><td>Argon</td></tr><tr><td>3</td><td>Xenon</td></tr><tr><td>4</td><td>Krypton</td></tr><tr><td>5</td><td>Hydrogen</td></tr><tr><td>6</td><td>Air/nitrogen</td></tr><tr><td>7</td><td>Water vapor</td></tr></table>	<u>Index</u>	<u>Gas</u>	1	Helium	2	Argon	3	Xenon	4	Krypton	5	Hydrogen	6	Air/nitrogen	7	Water vapor
<u>Index</u>	<u>Gas</u>																	
1	Helium																	
2	Argon																	
3	Xenon																	
4	Krypton																	
5	Hydrogen																	
6	Air/nitrogen																	
7	Water vapor																	
GMLES	1	Moles of gap gas per fuel rod (currently not used, but must be input).																
PGAPT	1	Average gap-gas pressure (Pa) [not used if NFCI = 0, but must be input].																
PLVOL	1	Plenum volume (m ³) in each fuel rod above the pellet stack (currently not used, but must be input).																

One-Dimensional Core Component (CORE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PSLEN	1	Pellet-stack length (m) [currently not used, but must be input].
CLENN	1	Total cladding length (m) [currently not used, but must be input].

CORE Rod Array Cards. Two sets of cards, one for each of the following variables. Both card sets are input for each of NRODS (word 1 on Card Number 8) fuel rods, including the average rod and each additional rod. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
BURN	ICRU-ICRL+1	Fuel burnup (MWD/MTU).
RFTN	NDRDS*(ICRU-ICRL+1)	Initial fuel-rod temperatures (K).

d. Fill Component (FILL).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-4	TYPE	Component type (FILL left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 3I14) JUN1, IFTY, IOFF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JUN1	Junction number where fill is connected.
15-28	IFTY	<p>Fill-type option:</p> <ul style="list-style-type: none"> 1 = constant velocity, 2 = constant mass flow, 3 = constant generalized state, 4 = velocity vs independent-variable form, 5 = mass flow vs independent-variable form, 6 = generalized state vs independent-variable form, 7 = constant velocity until the controlling trip is set ON then velocity vs independent-variable form, 8 = constant mass flow until the controlling trip is set ON then mass flow vs independent-variable form, or 9 = constant generalized state until the controlling trip is set ON then generalized state vs independent-variable form.

Fill Component (FILL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	IOFF	<p>FILL fluid-state option defining the fluid state when the fill-table controlling trip is OFF after being ON [define IOFF when IFTY = 7, 8, or 9 (word 2 on Card Number 2)].</p> <p>0 = the last fill-table interpolated fluid state is held constant;</p> <p>1 = define the initial fluid state;</p> <p>2 = input the velocity (IFTY = 7 or 9) or mass flow (IFTY = 8) to be used but maintain the fluid condition that existed when the trip was set OFF; or</p> <p>3 = input a generalized fluid-state definition (IFTY = 9 only).</p>

Note: If IFTY < 4 (word 2 on Card Number 2), omit Card Number 3.

Card Number 3. (Format 5I14) IFTR, IFSV, NFTB, NFSV, NFRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IFTR	The trip ID number for controlling evaluation of the fill table for fill-type options IFTY = 7, 8, or 9 ($ IFTR < 10000$) [input IFTR = 0 when IFTY < 7].
15-28	IFSV	The fill-table abscissa-coordinate variable ID number that defines the independent-variable parameter in the IFTY = 4 to 9 tables. IFSV > 0 defines the ID number for a signal-variable parameter; IFSV < 0 defines the ID number for a control-block output parameter.
29-42	NFTB	The number of fill-table (x,y) pairs for fill-type options IFTY = 4 to 9 (defined by the absolute value of NFTB). NFTB > 0 defines the independent-variable form to be the IFSV parameter; NFTB < 0 defines the independent-variable form to be the change in the IFSV parameter over the last time step times the trip set status value ISET when IFTY = 7, 8, or 9; NFTB = 0 defines the FILL velocity or mass flow to be the IFSV parameter.

Fill Component (FILL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NFSV	The rate-factor table abscissa-coordinate variable ID number. $NFSV > 0$ defines the ID number for a signal-variable parameter; $NFSV < 0$ defines the ID number for a control-block output parameter; $NFSV = 0$ (when $NFRF \neq 0$) defines the difference between the trip signal and the set-point value that turns the trip OFF when the fill table is trip controlled.
57-70	NFRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NFRF). The rate factor is applied as a factor to the fill-table independent variable when the rate factor is defined. No rate factor is defined when NFSV and NFRF are both zero. $NFRF > 0$ defines the rate-factor table abscissa coordinate to be the NFSV parameter; $NFRF < 0$ defines it to be the change in the NFSV parameter over the last time step times the trip set-status value ISET when $1FTY = 7, 8, \text{ or } 9$; $NFRF = 0$ defines the rate factor to be the NFSV parameter.

Card Number 4. (Format 4E14.6) TWTOLD, RFMX, CONCIN, FELV

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TWTOLD	The fraction of the previous fill fluid state that is averaged with the fill-table-defined state to define the fill fluid state for this time step ($0.0 \leq TWTOLD < 1.0$; it is suggested that a value of 0.0 be used). To avoid hydrodynamic instabilities, a value as large as 0.9 may be needed when the fill table depends on a parameter, such as the adjacent component pressure, that couples strongly to the fill velocity or a parameter that varies rapidly with time.
15-28	RFMX	The maximum rate of change of fill velocity ($m \cdot s^{-2}$) or mass flow ($kg \cdot s^{-2}$) [$0 \leq RFMX$].
29-42	CONCIN	The initial ratio of solute mass to liquid-coolant mass (-) in the FILL composition [not used unless $ISOLUT = 1$ (word 5) on Main-Data Card 6)].

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	FELV	Fill cell-centered elevation (m) [used only to compute GRAV array when IELV = 1].

Card Number 5. (Format 5E14.6) DXIN, VOLIN, ALPIN, VLIN, TLIN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DXIN	Cell length (m), generally the same as its neighboring cell in the adjacent component. Currently not used.
15-28	VOLIN	Cell volume (m^3), generally the same as its neighboring cell in the adjacent component. Currently not used.
29-42	ALPIN	Initial coolant void fraction (-) for positive flow out of the fill.
43-56	VLIN	Initial liquid velocity ($\text{m} \cdot \text{s}^{-1}$); a positive value indicates flow into the adjacent component; a negative value indicates flow from the adjacent component (input for fill-type options IFTY = 1, 3, 7 or 9).
57-70	TLIN	Initial liquid temperature (K) for positive flow out of the fill.

Card Number 6. (Format 5E14.6) PIN, PAIN, FLOWIN, VVIN, TVIN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	PIN	Initial fill pressure (Pa).
15-28	PAIN	Initial fill air partial pressure (Pa).
29-42	FLOWIN	Initial mass flow ($\text{kg} \cdot \text{s}^{-1}$); a positive value indicates flow into the adjacent component; a negative value indicates flow from the adjacent component (input for fill-type options IFTY = 2 or 8).
43-56	VVIN	Initial vapor velocity ($\text{m} \cdot \text{s}^{-1}$); a positive value indicates flow into the adjacent component; a negative value indicates flow from the adjacent component (input for fill-type options IFTY = 3 or 9).

Fill Component (FILL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	TVIN	Initial vapor temperature (K) for positive flow (input for fill-type options IFTY = 3 or 9).

Note: If IFTY < 7 (word 2 on Card Number 2) or IOFF < 2 (word 3 on Card Number 2), omit Card Number 7.

Card Number 7. (Format 4E14.6) FLWOFF, VLOFF, VVOFF, ALPOFF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	FLWOFF	Mass flow ($\text{kg} \cdot \text{s}^{-1}$) when the controlling trip is set OFF after being ON (input when IFTY = 8).
15-28	VLOFF	Liquid-coolant velocity (IFTY = 9) or coolant-mixture velocity (IFTY = 7) when the controlling trip is set OFF after being ON (input when IFTY = 7 or 9).
29-42	VVOFF	Vapor-coolant velocity when the controlling trip is set OFF after being ON (input when IOFF = 3 and IFTY = 9).
43-56	ALPOFF	Fluid void fraction (-) for positive flow when the controlling trip is set OFF after being ON (input when IOFF = 3 and IFTY = 9).

Note: If IFTY $\neq$ 9 (word 2 on Card Number 2) or IOFF $\neq$ 3 (word 3 on Card Number 2), omit Card Number 8.

Card Number 8. (Format 5E14.6) TLOFF, TVOFF, POFF, PAOFF, CONOFF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TLOFF	Liquid temperature (K) for positive flow when the controlling trip is set OFF after being ON.
15-28	TVOFF	Vapor temperature (K) for positive flow when the controlling trip is set OFF after being ON.
29-42	POFF	Fill pressure (Pa) when the controlling trip is set OFF after being ON.

Fill Component (FILL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	PAOFF	Fill air partial pressure (Pa) when the controlling trip is set OFF after being ON.
57-70	CONOFF	Ratio of solute mass to liquid-coolant mass (-) when the controlling trip is set OFF after being ON.

Note: If IFTY < 4 (word 2 on Card Number 2) or NFTB = 0 (word 3 on Card Number 3), omit Card Number 9.

Card Number 9. (Format 2E14.6) VMSCL, VVSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	VMSCL	Liquid-velocity (IFTY = 4,6,7, or 9) or mass-flow (IFTY = 5 or 8) scale factor. The dependent variable in table VMTB is multiplied by this factor to obtain the absolute liquid velocity or absolute mass flow.
15-28	VVSCL	Vapor-velocity scale factor. The dependent variable in table VVTB is multiplied by this factor to obtain absolute vapor velocity (input when IFTY = 6 or 9).

Note: If IFTY ≠ 6 and IFTY ≠ 9 (word 2 on Card Number 2), omit Card Number 10.

Card Number 10. (Format 5E14.6) TLSCL, TVSCL, PSCL, PASCL, CONSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TLSCL	Liquid-temperature scale factor. The dependent variable in table TLTB is multiplied by this factor to obtain absolute liquid temperature.
15-28	TVSCL	Vapor-temperature scale factor. The dependent variable in table TVTB is multiplied by this factor to obtain absolute vapor temperature.
29-42	PSCL	Pressure scale factor. The dependent variable in table PTB is multiplied by this factor to obtain absolute pressure.

Fill Component (FILL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	PASCL "	Air partial pressure scale factor. The dependent variable in table PATB is multiplied by this factor to obtain absolute air partial pressure.
57-70	CONSCL	Ratio of solute mass to liquid-coolant mass scale factor. The dependent variable in table CONCTB is multiplied by this factor to obtain the absolute solute mass to liquid-coolant mass ratio.

Note: If IFTY < 4 (word 2 on Card Number 2) or NFTB = 0 (word 3 on Card Number 3), omit the Fill Array Cards.

FILL Array Cards. Nine sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
VMTB	NFTB *2	Liquid velocity (IFTY = 4,6,7, or 9) or mass flow (IFTY = 5 or 8) vs independent-variable-form table. Input (independent-variable form, liquid velocity or mass flow) pairs (*,m · s ⁻¹ or kg · s ⁻¹).

Note: If IFTY ≠ 6 or 9 on Card Number 2, omit card sets VVTB, TLTB, TVTB, ALPTB, PTB, and PATB.

VVTB	NFTB *2	Vapor-velocity vs independent-variable-form table. Input (independent-variable form, liquid temperature) pairs (*,m · s ⁻¹).
TLTB	NFTB *2	Liquid-temperature vs independent-variable-form table. Input (independent-variable form, liquid temperature) pairs (*,K).
TVTB	NFTB *2	Vapor-temperature vs independent-variable-form table. Input (independent-variable form, vapor temperature) pairs (*,K).
ALPTB	NFTB *2	Coolant void-fraction vs independent-variable-form table. Input (independent-variable form, coolant void fraction) pairs (*,-).

Fill Component (FILL)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PTB	NFTB *2	Pressure vs independent-variable-form table. Input (independent-variable form, pressure) pairs (*,Pa).
PATB	NFTB *2	Air partial pressure vs independent-variable-form table. Input (independent-variable form, air partial pressure) pairs (*,Pa).

Note: If ISOLUT = 0 on Main-Data Card 6 or IFTY ≠ 6 or 9 on Card Number 2, omit card set CONCTB.

CONCTB	NFTB *2	Ratio of solute mass to liquid-coolant mass vs independent-variable-form table. Input (independent-variable form, ratio of solute mass to liquid-coolant mass) pairs (*,-).
RFTB	NFRF *2	Rate-factor table for the fill-table's independent variable defined by IFSV and NFTB on Card Number 3. Input (independent-variable form defined by NFSV and NFRF on Card Number 3, rate factor to be applied to the fill-table independent variable) pairs (*,-).

Pipe Component (PIPE)

e. Pipe Component (PIPE).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-4	TYPE	Component type (PIPE left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELLS, NODES, JUN1, JUN2, MAT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells in the pipe component.
15-28	NODES	Number of radial heat-transfer nodes in the pipe wall. A value of 0 specifies no wall heat transfer.
29-42	JUN1	Junction number for junction adjacent to cell 1.
43-56	JUN2	Junction number for junction adjacent to cell NCELLS.
57-70	MAT	Material ID number of the wall (currently not used).

Card Number 3. (Format 4I14) ICHF, ICONC, IACC, IPOW

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICHF	CHF calculation flag. 0 = no; 1 = yes.
15-28	ICONC	Flag for input of solute in the coolant. (Requires ISOLUT = 1 on Main-Data Card 6.) 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.

Pipe Component (PIPE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	IACC	Accumulator model flag. (See ACCUM module description, Sec. IV.B.) 0 = no accumulator logic; 1 = calculation of water level, volumetric flow, and liquid volume discharge, and addition of interface sharpener; or 2 = same as (1) plus the phase separator at JUN2 (gas phase is never allowed to flow out of component).
43-56	IPOW	Presence of power deposited in the coolant flag. 0 = no; 1 = yes.

Note: If IPOW = 0 (word 4 on Card Number 3), omit Card Number 4.

Card Number 4. (Format 5I14) IPOWTR, IPOWSV, NPOWTB, NPOWSV, NPOWRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IPOWTR	The trip ID number that controls evaluation of the power-to-fluid table (POWTB) [IPOWTR < 10000] (input IPOWTR = 0 if there is to be no trip control, and the table will be evaluated in the transient).
15-28	IPOWSV	The independent-variable ID number for the power-to-fluid table (POWTB). IPOWSV > 0 defines the ID number for a signal-variable parameter; IPOWSV < 0 defines the ID number for a control-block output parameter.
29-42	NPOWTB	The number of (x,y) power-to-fluid table (POWTB) pairs (defined by the absolute value of NPOWTB). NPOWTB > 0 defines the table independent-variable form to be the IPOWSV parameter; NPOWTB < 0 defines the table independent-variable form to be the change in the IPOWSV parameter over the last time step times the trip set-status value ISET when the power-to-fluid table is trip controlled; NPOWTB = 0 defines the power to be the IPOWSV parameter.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NPOWSV	The independent-variable ID number for the rate factor that is applied to the power-to-fluid table (POWTB) independent variable. NPOWSV > 0 defines the ID number for a signal-variable parameter; NPOWSV < 0 defines the ID number for a control-block output parameter; NPOWSV = 0 (when NPOWRF ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power table is trip controlled.
57-70	NPOWRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NPOWRF). The rate factor is applied to the power-to-fluid table's (POWTB) independent variable when the rate factor is defined. No rate factor is defined when NPOWSV and NPOWRF are both zero. NPOWRF > 0 defines the rate-factor table's independent variable to be the NPOWSV parameter; NPOWRF < 0 defines it to be the change in the NPOWSV parameter over the last time step times the trip set-status value ISET when the power table is trip controlled; NPOWRF = 0 defines the rate factor to be the NPOWSV parameter.

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 5.

Card Number 5. (Format 5I14) IQP3TR, IQP3SV, NQP3TB, NQP3SV, NQP3RF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IQP3TR	The trip ID number that controls evaluation of the power-to-wall table (QP3TB) [IQP3TR < 10000] (input IQP3TR = 0 if there is to be no trip control, and the table will be evaluated in the transient).
15-28	IQP3SV	The independent-variable ID number of the power-to-wall table (QP3TB). IQP3SV > 0 defines the ID number for a signal-variable parameter; IQP3SV < 0 defines the ID number for a control-block output parameter.

Pipe Component (PIPE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	NQP3TB	The number of (x,y) power-to-wall table (POWTB) pairs (defined by the absolute value of NQP3TB). NQP3TB > 0 defines the table's independent-variable form to be the IQP3SV parameter; NQP3TB < 0 defines the table's independent-variable form to be the change in the IQP3SV parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; NQP3TB = 0 defines the power to the wall to be the IQP3SV parameter.
43-56	NQP3SV	The independent-variable ID number for the rate factor that is applied to the power-to-wall table's independent variable. NQP3SV > 0 defines the ID number for a signal-variable parameter; NQP3SV < 0 defines the ID number for a control-block output parameter; NQP3SV = 0 (when NQP3RF ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power-to-wall table is trip controlled.
57-70	NQP3RF	The number of (x,y) rate-factor table pairs (defined by the absolute value of NQP3RF). The rate factor is applied to the power-to-wall (QP3TB) table's independent variable when the rate factor is defined. No rate factor is defined when NQP3SV and NQP3RF are both zero. NQP3RF > 0 defines the rate-factor independent variable to be the NQP3SV parameter; NQP3RF < 0 defines it to be the change in the NQP3SV parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; NQP3RF = 0 defines the rate factor to be the NQP3SV parameter.

Card Number 6. (Format 5E14.6) RADIN, TH, HOUTL, HOUTV, TOUTL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN	Inner radius (m) of the pipe wall.
15-28	TH	Pipe wall thickness (m).

Pipe Component (PIPE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	HOUTL	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of pipe wall and liquid outside the pipe wall.
43-56	HOUTV	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of pipe wall and vapor outside the pipe wall.
57-70	TOUTL	Liquid temperature (K) outside the pipe wall.

Note: The four parameters, HOUTL, HOUTV, TOUTL, and TOUTV, allow flexibility in calculating possible heat losses from the outside of pipes. Typically, such heat losses are not important for fast transients or large-break LOCAs, and HOUTL and HOUTV can be set equal to zero. When heat losses are significant, they often can be approximated by a single HTC and a single external temperature.

Card Number 7. (Format 5E14.6) TOUTV, POWIN, POWOFF, RPOWMX, POWSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV	Vapor temperature (K) outside the pipe wall.
15-28	POWIN	Initial total power (W) deposited in the fluid (not input when IPOW = 0). The power is distributed linearly along the component.
29-42	POWOFF	Total power (W) deposited in the fluid when the controlling trip is OFF after being ON (not input when IPOW = 0). If POWOFF $\leq -1.0 \times 10^{19}$, the power to the fluid is held constant at the last table-evaluated power when the trip was ON.
43-56	RPOWMX	The maximum rate of change of power deposited in the fluid ($W \cdot s^{-1}$) [RPOWMX ≥ 0.0] (not input when IPOW = 0).
57-70	POWSCL	Scale factor for the power-to-fluid table. The dependent variable in table POWTB is multiplied by POWSCL to obtain the absolute power deposited in the fluid (not input when IPOW = 0 or NPOWTB = 0).

Pipe Component (PIPE)

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 8.

Card Number 8. (Format 4E14.6) QP3IN, QP3OFF, RQP3MX, QP3SCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	QP3IN	Initial power (W) deposited in the wall and distributed according to the QPPP array. If $QP3IN > 0.0$, it is the total power to the entire wall. When $QP3IN < 0.0$ is used, the initial power to the wall in each cell is $ QP3IN $, and the negative sign flags the power to the wall to be a cell-dependent vector of NCELLS (word 1 on Card Number 2) powers. Each (x,y) point of the power-to-wall table (for $QP3IN < 0.0$) has 1+NCELLS values [an independent-variable value x and NCELLS power values y(z) for cells 1 through NCELLS]. When the power-to-wall table is not being evaluated, the same power value of $ QP3IN $ or QP3OFF (if $QP3OFF > -1.0 \times 10^{19}$) is applied at each of the NCELLS cells.
15-28	QP3OFF	Power (W) to the wall when the controlling trip is OFF after being ON (maintain the last table-evaluated power when the trip was ON if $QP3OFF \leq -1.0 \times 10^{19}$).
29-42	RQP3MX	Maximum rate of change of the power to the wall ($W \cdot s^{-1}$) [$RQP3MX \geq 0.0$].
43-56	QP3SCL	Scale factor (-) for the power-to-wall table. The dependent variable in table QP3TB is multiplied by QP3SCL to obtain the absolute power to the wall.

PIPE Array Cards. Twenty-four sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m^3).
FA	NCELLS+1	Cell-edge flow areas (m^2).

Pipe Component (PIPE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
FRIC	NCELLS+1	Additive loss coefficients. (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELLS+1	Gravity terms. (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)
Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.		
ICFLG	NCELLS+1	Cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCELLS+1	Friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)
ALP	NCELLS	Initial void fractions (-).
VL	NCELLS+1	Initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).

Pipe Component (PIPE)

Note: If NODES = 0 (word 2 on Card Number 2), do not enter arrays QPPP, MATID, and TW.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
QPPP	NODES*NCELLS	A nonnormalized power profile (-) in the pipe walls. Input for cell 1, node 1 through NODES; then for cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis (normalized $QPPP(i) = QPPP(i)/[\sum QPPP(i)*VOL(i)]$). Filling the array with zeros results in no power being deposited in the walls regardless of the settings of QP3IN, QP3TB, etc.
MATID	NODES-1	Wall-material ID array specifying material ID between nodes. Dimension is 1 if NODES = 1 and 0 if NODES = 0. (See available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c; or see Sec. V.C.2 to input material properties.)
TW	NODES*NCELLS	Initial wall temperatures (K). Input in the same order as QPPP.
Note: If ICONC = 0 (word 2 on Card Number 3), omit card set CONC.		
CONC	NCELLS	Initial ratio of solute mass to liquid coolant mass (-).
Note: If ICONC = 0 or 1 (word 2 on Card Number 3), omit card set S.		
S	NCELLS	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).
Note: If NPOWTB = 0 on Card Number 4, omit card set POWTB.		
POWTB	NPOWTB *2	Power-to-fluid vs independent-variable-form table. Input (independent-variable form defined by IPOWSV and NPOWTB on Card Number 4, power) pairs (*,W). The power is deposited directly into the fluid in the pipe with a uniform volumetric power density along the pipe length.

Pipe Component (PIPE)

Note: If NPOWRF or NPOWTB = 0 on Card Number 4, omit card set POWRF.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
POWRF	NPOWRF *2	Rate-factor table for the POWTB table independent variable. Input (independent-variable form defined by NPOWSV and NPOWRF on Card Number 4, rate factor to be applied to the POWTB table independent variable) pairs (*,-).

Note: If NQP3TB = 0 on Card Number 5, omit card set QP3TB.

QP3TB	NQP3TB *2 when QP3IN>0; NQP3TB *(1+NCELLS) when QP3IN<0	Power-to-wall vs independent-variable-form table. Input (independent-variable form defined by IQP3SV and NQP3TB on Card Number 5, power-to-wall) pairs (*,W). If QP3IN > 0.0, the dependent variable specifies the total power to the entire wall; if QP3IN < 0.0, the dependent variable is a vector specifying the power to the wall at each cell beginning with cell 1.
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Note: If NQP3TB or NQP3RF = 0 on Card Number 5, omit card set QP3RF.

QP3RF	NQP3RF *2	Rate-factor table for the QP3TB table independent variable. Input (independent-variable form defined by NQP3SV and NQP3RF on Card Number 5, rate factor to be applied to the QP3TB table independent variable) pairs (*,-).
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f. Plenum Component (PLENUM).Card Number 1. (Format A6,8X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-6	TYPE	Component type (PLENUM left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 2I14) NPLJN, ICONC

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NPLJN	Number of plenum junctions ($\text{NPLJN} \geq 1$).
15-28	ICONC	Flag for input of solute in the coolant. (Requires ISOLUT = 1 on Main-Data Card 6.) 0 = no input; 1 = dissolved solute only; 2 = both dissolved and plated-out solute.

PLENUM Array Cards. Ten sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
JUNJ	NPLJN	Plenum junction numbers (-).
DX	NPLJN	Effective plenum-side cell lengths for junctions connected to the plenum (m).
VOL	1	Plenum volume (m^3).
ELEV	1	Cell-centered elevation. Used only when IELV = 1 in the NAMELIST data. However, the card set always must be input.
ALP	1	Initial void fraction (-).
TL	1	Initial liquid temperature (K).
TV	1	Initial vapor temperature (K).

Plenum Component (PLENUM)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
P	1	Initial pressure (Pa).
PA	1	Initial air partial pressure (Pa).
Note: If ICONC = 0 (word 2 on Card Number 2), omit card set BOR.		
BOR	1	Initial ratio of solute mass to liquid coolant mass (-).
Note: If ICONC = 0 or 1 (word 2 on Card Number 2), omit card set SOLID.		
SOLID	1	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).

Pressurizer Component (PRIZER)

g. Pressurizer Component (PRIZER).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-6	TYPE	Component type (PRIZER left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELLS, NODES, JUN1, JUN2, MAT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells in the pressurizer component.
15-28	NODES	Number of radial heat-transfer nodes in the pressurizer wall. A value of 0 specifies no wall heat transfer.
29-42	JUN1	Junction number for junction adjacent to cell 1.
43-56	JUN2	Junction number for junction adjacent to cell NCELLS. This must be the pressurizer discharge.
57-70	MAT	Material ID number of the wall (not used at present).

Card Number 3. (Format 2I14,E14.6) ICHF, ICONC, QP3IN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICHF	CHF calculation flag. 0 = no; 1 = yes.

Pressurizer Component (PRIZER)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	ICONC	Flag for input of solute in the liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.
29-42	QP3IN	Initial power (W) deposited in the wall and distributed according to the QPPP array. If QP3IN > 0.0, it is the total power to the entire wall. When QP3IN < 0.0 is used, the initial power to the wall in each cell is QP3IN , and the negative sign flags the power to the wall to be a cell-dependent vector of NCELLS (word 1 on Card Number 2) powers. Each (x,y) point of the power-to-wall table (for QP3IN < 0.0) has 1+NCELLS values [an independent-variable value x and NCELLS power values y(z) for cells 1 through NCELLS]. When the power-to-wall table is not being evaluated, the same power value of QP3IN or QP3OFF (if QP3OFF > -1.0×10^{19}) is applied at each of the NCELLS cells.

Card Number 4. (Format 5E14.6) RADIN, TH, HOUTL, HOUTV, TOUTL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN	Inner radius (m) of the pressurizer wall.
15-28	TH	Pressurizer wall thickness (m).
29-42	HOUTL	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the pressurizer wall and liquid outside the pressurizer wall.
43-56	HOUTV	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the pressurizer wall and vapor outside the pressurizer wall.
57-70	TOUTL	Liquid temperature (K) outside the pressurizer.

Note: See PIPE input description, Sec. V.C.5.e, for further comments on the HOUTL, HOUTV, TOUTL, and TOUTV heat-transfer parameters.

Pressurizer Component (PRIZER)

Card Number 5. (Format 5E14.6) TOUTV, QHEAT, PSET, DPMAX, ZHTR

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV	Vapor temperature (K) outside the pressurizer.
15-28	QHEAT	Total heater power (W).
29-42	PSET	Pressure set point (Pa) for heater/sprayer control.
43-56	DPMAX	Pressure differential (Pa) at which heater/sprayer has maximum power.
57-70	ZHTR	Water level (m) for heater cutoff.

PRIZER Array Cards. Twenty sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m ³).
FA	NCELLS+1	Cell-edge flow areas (m ²).
FRIC	NCELLS+1	Additive loss coefficients (-). (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELLS+1	Gravity terms (-). (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIA1 in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELLS+1	Cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
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Pressurizer Component (PRIZER)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
NFF	NCELLS+1	Friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.) The value NFF = 1 is suggested for this component.
ALP	NCELLS	Initial void fractions (-).
VL	NCELLS+1	Initial liquid velocities ($m \cdot s^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($m \cdot s^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).

Note: If NODES = 0 (word 2 on Card Number 2), do not input arrays QPPP, MATID, and TW.

QPPP	NODES*NCELLS	A nonnormalized power profile (-) in the pressurizer walls. Input for cell 1, node 1 through NODES; then for cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis (normalized $QPPP(i) = QPPP(i) / [\sum QPPP(i) * VOL(i)]$). Filling the array with zeros results in no power being deposited in the walls regardless of the settings of QP3IN, QP3TB, etc.
MATID	NODES-1	Wall-material ID array specifying material ID between nodes. Dimension is 1 if NODES = 1 and 0 if NODES = 0. (See available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c; or see Sec. V.C.2 to input material properties.)
TW	NODES*NCELLS	Initial wall temperatures (K) (input in the same order as QPPP).

Pressurizer Component (PRIZER)

Note: If ICONC = 0 (word 2 on Card Number 3), omit card set CONC.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
CONC	NCELLS	Initial ratio of solute mass to liquid coolant mass (-).

Note: If ICONC = 0 or 1 (word 2 on Card Number 3), omit card set S.

S	NCELLS	Initial macroscopic density of plated-out solute (kg m^{-3}).
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Pump Component (PUMP)

h. Pump Component (PUMP).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-4	TYPE	Component type (PUMP left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELLS, NODES, JUN1, JUN2, MAT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells in pump component (must be at least two).
15-28	NODES	Number of radial heat-transfer nodes in the wall. A value of 0 specifies no wall heat transfer.
29-42	JUN1	Junction number for junction adjacent to cell 1.
43-56	JUN2	Junction number for junction adjacent to cell NCELLS.
57-70	MAT	Material ID number of the wall (currently not used).

Card Number 3. (Format 5I14) ICHF, ICONC, IPMPTY, IRP, IPM

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICHF	CHF calculation flag. 0 = no; 1 = yes.
15-28	ICONC	Flag for input of solute in the liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.

Pump Component (PUMP)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	IPMPTY	Pump type. 1 = pump rotational speed is specified by table PMPTB when trip IPMPTR is set ON; 2 = pump rotational speed is calculated from Eq. (222) when trip IPMPTR is set ON.
43-56	IRP	Reverse speed option (only used for IPMPTY = 2). 0 = reverse rotation not allowed; 1 = reverse rotation allowed.
57-70	IPM	Degradation option. 0 = use single-phase homologous curves; 1 = use combined single-phase and fully degraded two-phase homologous curves.

Card Number 4. (Format 5114) IPMPTR, IPMPSV, NPMPTB, NPMPSV, NPMPRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IPMPTR	The trip ID number that controls the pump speed (zero implies a constant pump speed) [$ IPMPTR < 10000$]. If the trip set status is OFF initially, the pump speed is defined by a signal variable or control block with ID number NPMPSD (word 5 on Card Number 9) or by a constant initial pump speed OMEGAN (word 1 on Card Number 9) when NPMPSD = 0.
15-28	IPMPSV	The pump-table abscissa-coordinate variable ID number. IPMPSV defines the independent-variable parameter in the IPMPTY = 1 pump-speed table. IPMPSV > 0 defines the ID number for a signal-variable parameter; IPMPSV < 0 defines the ID number for a control-block output parameter. (If IPMPTY = 2 on Card Number 3, IPMPSV must be zero.)
29-42	NPMPTB	The number of (x,y) pump-speed table pairs (defined by the absolute value of NPMPTB). NPMPTB > 0 defines the table's independent-variable form to be the IPMPSV parameter; NPMPTB < 0 defines the table's independent-variable form to be the change in the IPMPSV parameter over the last time step times the trip set-status value ISET when the pump-speed table is trip controlled; NPMPTB = 0 defines the pump rotational speed to be the IPMPSV parameter (if IPMPTY = 2 on Card Number 3, NPMPTB must be zero).

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NPMPSV	The rate-factor table abscissa-coordinate variable ID number. NPMPSV defines the independent-variable parameter for the rate factor that is applied to the pump-speed table's independent variable. NPMPSV > 0 defines the ID number for a signal-variable parameter; NPMPSV < 0 defines the ID number for a control-block output parameter; NPMPSV = 0 (when NPMPRF = 0) defines the difference between the trip signal and the set-point value that turns the trip OFF (if IPMPTY = 2 on Card Number 3, NPMPSV must be zero).
57-70	NPMPRF	The number of (x,y) rate-factor table pairs (defined by the absolute value of NPMPRF). The rate factor is applied to the pump-speed table's independent variable when the rate factor is defined. No rate factor is defined when NPMPSV and NPMPRF are both zero. NPMPRF > 0 defines the rate-factor table's abscissa coordinate to be the NPMPSV parameter; NPMPRF < 0 defines it to be the change in the NPMPSV parameter over the last time step times the trip set-status value ISET when the pump-speed table is trip controlled; NPMPRF = 0 defines the rate factor to be the NPMPSV parameter (if IPMPTY = 2 on Card Number 3, NPMPRF must be zero.)

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 5.

Card Number 5. (Format 5I14) IQP3TR, IQP3SV, NQP3TB, NQP3SV, NQP3RF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IQP3TR	The trip ID number that controls evaluation of the power-to-wall table (QP3TB) [$ IQP3TR < 10000$]. (Input IQP3TR = 0 if there is to be no trip control, and the table will be evaluated in the transient.)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	IQP3SV	The independent-variable ID number for the power-to-wall table (QP3TB). IQP3SV > 0 defines the ID number for a signal-variable parameter; IQP3SV < 0 defines the ID number for a control-block output parameter.
29-42	NQP3TB	The number of (x,y) power-to-wall table (POWTB) pairs (defined by the absolute value of NQP3TB). NQP3TB > 0 defines the table's independent-variable form to be the IQP3SV parameter; NQP3TB < 0 defines the table's independent-variable form to be the change in the IQP3SV parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; NQP3TB = 0 defines the power to the wall to be the IQP3SV parameter.
43-56	NQP3SV	The independent-variable ID number for the rate factor that is applied to the power-to-wall table's independent variable. NQP3SV > 0 defines the ID number for a signal-variable parameter; NQP3SV < 0 defines the ID number for a control-block output parameter; NQP3SV = 0 (when NQP3RF ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power-to-wall table is trip controlled.
57-70	NQP3RF	The number (x,y) of rate-factor table pairs (defined by the absolute value of NQP3RF). The rate factor is applied as a factor to the power-to-wall table (QP3TB) independent variable when the rate factor is defined. No rate factor is defined when NQP3SV and NQP3RF are both zero. NQP3RF > 0 defines the rate-factor table's independent variable to be the NQP3SV parameter; NQP3RF < 0 defines it to be the change in the NQP3SV parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; NQP3RF = 0 defines the rate factor to be the NQP3SV parameter.

Pump Component (PUMP)

Card Number 6. (Format 5E14.6) RADIN, TH, HOUTL, HOUTV, TOUTL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN	Inner radius (m) of the pump wall.
15-28	TH	Pump wall thickness (m).
29-42	HOUTL	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the pump wall and liquid outside the pump wall.
43-56	HOUTV	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the pump wall and vapor outside the pump wall.
57-70	TOUTL	Liquid temperature (K) outside the pump wall.

Note: See PIPE input description, Sec. V.C.5.e, for further comments on the HOUTL, HOUTV, TOUTL, and TOUTV heat-transfer parameters.

Card Number 7. (Format 4E14.6) TOUTV, EFFMI, TFR1, TFR2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV	Vapor temperature (K) outside the pump wall.
15-28	EFFMI	Effective moment of inertia ($kg \cdot m^2$).
29-42	TFR1	Frictional torque coefficient [Eq. (220)] ($N \cdot m$).
43-56	TFR2	Bearing and windage torque coefficient [Eq. (221)] ($N \cdot m$).

Note: Update TKINERTIA in version 11.3 adds a variable inertia calculation to the PUMP component. The variable inertia calculation is used only if EFFMI (Card Number 7) is negative. Then, the pump inertia is calculated as follows.

```

inertia = EFFMI1
if (IPMPS.eq.0.and.omega.lt.OMTEST) IPMPS = 1
if (IPMPS.eq.0)
1 inertia = AEFFMI*(omega/romega)**2 + BEFFMI*(omega/romega) + CEFFMI

```


Pump Component (PUMP)

The parameters in capitals are new input parameters. Parameter omega is the current pump speed, and parameter romea is the rated pump speed. The parameter inertia is the moment of inertia used to calculate the pump speed following the trip. The six new parameters (EFFMI1, IPMPS, OMTEST, AEFFMI, BEFFMI, and CEFFMI) are defined below in the changes to the input description. Update TKINERTIA modifies common block PUMPVLTAB and subroutines RPUMP, REPUMP, and PUMPSR. These changes are transparent to the user if the variable pump inertia is not used. The changes to the PUMP component input description follow; these new cards are input after existing Card Number 7 only if EFFMI < 0.0.

Card Number 7+1. (Format 5E14.6) EFFMI1, AEFFMI, BEFFMI, CEFFMI, OMTEST
(Input this card only if variable EFFMI on Card Number 7 is negative.)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	EFFMI1	The alternate effective moment of inertia that is used after the pump speed falls below OMTEST ($\text{kg} \cdot \text{m}^2$).
15-28	AEFFMI	The coefficient for the $(\text{OMEGA}/\text{ROMEGA})^{**2}$ term in the calculation of the variable moment of inertia ($\text{kg} \cdot \text{m}^2$).
29-42	BEFFMI	The coefficient for the $(\text{OMEGA}/\text{ROMEGA})$ term in the calculation of the variable moment of inertia ($\text{kg} \cdot \text{m}^2$).
43-56	CEFFMI	The constant term in the calculation of the variable moment of inertia ($\text{kg} \cdot \text{m}^2$).
57-70	OMTEST	The pump speed below which EFFMI1 (the alternate effective moment of inertia) is used ($\text{rad} \cdot \text{s}^{-1}$).

Pump Component (PUMP)

Card Number 7+2. (Format I14) IPMPS (Input this card only if variable EFFMI on Card Number 7 is negative.)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IPMPS	Flag indicates whether or not the pump speed previously has dropped below OMTEST. 0 = the pump speed has been greater than OMTEST; 1 = the pump speed at some time has dropped below OMTEST.

Card Number 8. (Format 5E14.6) RHEAD, RTORK, RFLOW, RRHO, ROMEGA

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RHEAD	Rated head ($\text{Pa} \cdot \text{m}^3 \cdot \text{kg}^{-1}$, $\text{m}^2 \cdot \text{s}^{-2}$, or $\text{N} \cdot \text{m} \cdot \text{kg}^{-1}$). Head is defined as $\Delta p \cdot \rho^{-1}$.
15-28	RTORK	Rated torque ($\text{N} \cdot \text{m}$).
29-42	RFLOW	Rated volumetric flow ($\text{m}^3 \cdot \text{s}^{-1}$).
43-56	RRHO	Rated density ($\text{kg} \cdot \text{m}^{-3}$).
57-70	ROMEGA	Rated pump speed ($\text{rad} \cdot \text{s}^{-1}$).

Card Number 9. (Format 5E14.6I14) OMEGAN, OMGOFF, ROMGMX, OMGSCL, NPMPD

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	OMEGAN	Initial pump speed ($\text{rad} \cdot \text{s}^{-1}$) when NPMPD = 0.
15-28	OMGOFF	Pump speed ($\text{rad} \cdot \text{s}^{-1}$) when the controlling trip is OFF after being ON (maintain the last pump speed evaluated when the trip was ON if $\text{OMGOFF} \leq -1.0 \times 10^{19}$) [input only when IPMPTR $\neq$ 0].
29-42	ROMGMX	The maximum rate of pump-speed change ($\text{rad} \cdot \text{s}^{-2}$).
43-56	OMGSCL	Scale factor (-) for the pump-speed table. The dependent variable in table PMPTB is multiplied by OMGSCL to obtain absolute rotational speed.

Pump Component (PUMP)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NPMPSD	The ID number of the signal-variable parameter or control-block parameter that defines the pump rotational speed initially when the controlling trip is OFF (input NPMPSD = 0 if the initial pump speed is to be the constant OMEGAN).

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 10.

Card Number 10. (Format 4E14.6) QP3IN, QP3OFF, RQP3MX, QP3SCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	QP3IN	Initial power (W) deposited in the wall and distributed according to the QPPP array. If QP3IN > 0.0, it is the total power to the entire wall. When QP3IN < 0.0 is input, the initial power to the wall in each cell is QP3IN and the negative sign flags the power to the wall to be a cell-dependent vector of NCELLS (word 1 on Card Number 2) powers. Each (x,y) point of the power-to-wall table (for QP3IN < 0.0) has 1+NCELLS values (an independent-variable value x and NCELLS power values y(z) for cells 1 through NCELLS). When the power-to-wall table is not being evaluated, the same power value of QP3IN or QP3OFF (if QP3OFF > -1.0×10^{19}) is applied at each of the NCELLS cells.
15-28	QP3OFF	Power (W) to the wall when the controlling trip is OFF after being ON (maintain the last table-evaluated power when the trip was ON if QP3OFF $\leq -1.0 \times 10^{19}$).
29-42	RQP3MX	The maximum rate of change of the power to the wall ($W \cdot s^{-1}$) [RQP3MX ≥ 0.0].
43-56	QP3SCL	Scale factor (-) for the power-to-wall table. The dependent variable in table QP3TB is multiplied by QP3SCL to obtain the absolute power to the wall.

Card Number 11. (Format 114) OPTION

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	OPTION	Pump curve option number. 0 = user-specified pump, input following; 1 = use built-in Semiscale pump; or 2 = use built-in LOFT pump.

Card Set 12 and Pump Curve Cards are needed only if OPTION = 0. If OPTION = 1 or 2, skip to the Pump Array Cards. The user is referred to the pump model description in Sec. IV.F for definitions of the terms used below. Each homologous curve is divided into four curve segments. Each curve segment is denoted by the number appended to the curve name. The segments are defined by Table XI in Sec. IV.F.

Under certain conditions for OPTION = 0, some curves do not need to be entered. However, to avoid confusion, we recommend that all curves be entered when OPTION = 0. For IPMPTY = 1 and IPM = 0, curves HSP1 through HSP4 are required, and the remaining curves can be dummies. For IPMPTY = 1 and IPM = 1, curves HSP1 through HSP4, HTP1 through HTP4, and HDM are required, and the remaining curves can be dummies. For IPMPTY = 2 and IPM = 0, curves HSP1 through HSP4 and TSP1 through TSP4 are required, and the remaining curves can be dummies. For IPMPTY = 2 and IPM = 1, all curves are required. NDATA(I) must be greater than zero in Card Set 12.

Future code changes may restrict those curves that can be represented by dummy curves under various conditions.

Card Set 12. (Format 5114) NDATA(I) (I = 1,16), NHDM, NTDMFirst Card.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NDATA(1)	Number of pairs of points on the HSP1 curve.
15-28	NDATA(2)	Number of pairs of points on the HSP2 curve.

Pump Component (PUMP)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	NDATA(3)	Number of pairs of points on the HSP3 curve.
43-56	NDATA(4)	Number of pairs of points on the HSP4 curve.
57-70	NDATA(5)	Number of pairs of points on the HTP1 curve.

Second Card.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NDATA(6)	Number of pairs of points on the HTP2 curve.
15-28	NDATA(7)	Number of pairs of points on the HTP3 curve.
29-42	NDATA(8)	Number of paris of points on the HTP4 curve.
43-56	NDATA(9)	Number of pairs of points on the TSP1 curve.
57-70	NDATA(10)	Number of pairs of points on the TSP2 curve.

Third Card.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NDATA(11)	Number of pairs of points on the TSP3 curve.
15-28	NDATA(12)	Number of pairs of points on the TSP4 curve.
29-42	NDATA(13)	Number of pairs of points on the TTP1 curve.
43-56	NDATA(14)	Number of pairs of points on the TTP2 curve.
57-70	NDATA(15)	Number of pairs of points on the TTP3 curve.

Fourth Card.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NDATA(16)	Number of pairs of points on the TTP4 curve.
15-28	NHDM	Number of pairs of points on the HDM curve.
29-42	NTDM	Number of pairs of points on the TDM curve.

PUMP Curve Cards. Up to 18 sets of cards, one set for each curve listed in Card Set 12 that has nonzero data points. Use LOAD format. Data are entered in pairs $(x,y)_i$, $i = (1, \text{NDATA})$ where x is the independent variable and y is the dependent variable. The x_i values must increase monotonically from -1.0 to 1.0 for the homologous curves and from 0.0 to 1.0 for the multiplier curves. If information for a particular curve does not exist or if you desire to input a simple dummy curve, we suggest that the four points (-1.0, 0.0, 1.0, 0.0) be used. [The suggested dummy for HDM and TDM is (0.0, 0.0, 1.0, 0.0).]

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>	
HSP1	2*NDATA(1)	HSP1 curve	} single-phase homologous head curves.
HSP2	2*NDATA(2)	HSP2 curve	
HSP3	2*NDATA(3)	HSP3 curve	
HSP4	2*NDATA(4)	HSP4 curve	
HTP1	2*NDATA(5)	HTP1 curve	} fully degraded homologous head curves.
HTP2	2*NDATA(6)	HTP2 curve	
HTP3	2*NDATA(7)	HTP3 curve	
HTP4	2*NDATA(8)	HTP4 curve	
TSP1	2*NDATA(9)	TSP1 curve	} single-phase homologous torque curves.
TSP2	2*NDATA(10)	TSP2 curve	
TSP3	2*NDATA(11)	TSP3 curve	
TSP4	2*NDATA(12)	TSP4 curve	

Pump Component (PUMP)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>	
TTP1	2*NDATA(13)	TTP1 curve	} fully degraded homologous torque curves
TTP2	2*NDATA(14)	TTP2 curve	
TTP3	2*NDATA(15)	TTP3 curve	
TTP4	2*NDATA(16)	TTP4 curve	
HDM	2*NHDM	Head degradation multiplier.	
TDM	2*NTDM	Torque degradation multiplier.	

PUMP Array Cards. Twenty-four sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m ³).
FA	NCELLS+1	Cell-edge flow areas (m ²).
FRIC	NCELLS+1	Additive loss coefficients (-) [FRIC(2) must be 0.0]. (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELLS+1	Gravity terms (-). (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIA1 in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELLS+1	Cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCELLS+1	Friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)

Pump Component (PUMP)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ALP	NCELLS	Initial void fractions (-).
VL	NCELLS+1	Initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).

Note: If NODES = 0 (word 2 on Card Number 2), do not enter arrays QPPP, MATID, and TW.

QPPP	NODES*NCELLS	A nonnormalized power profile (W) in the pump walls. Input for cell 1, node 1 through NODES; then cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis (normalized $\text{QPPP}(i)/[\sum \text{QPPP}(i) * \text{VOL}(i)]$). Filling the array with ¹ zeros results in no power being deposited in the wall regardless of settings of QP3IN, QP3TB, etc.
MATID	NODES-1	Wall-material ID array specifying material ID between nodes. Dimension is 1 if NODES = 1 and 0 if NODES = 0. (See available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c, or Sec. V.C.2 to input material properties.)
TW	NODES*NCELLS	Initial wall temperatures (K). Input in the same order as QPPP.

Note: If ICONC = 0 (word 2 on Card Number 3), omit card set CONC.

CONC	NCELLS	Initial ratio of solute mass to liquid coolant mass.
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Pump Component (PUMP)

Note: If ICONC = 0 or 1 (word 2 on Card Number 3), omit card set S.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
S	NCELLS	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).

Note: If NPMPTB = 0 (word 3 on Card Number 4), omit card set PMPTB.

PMPTB	NPMPTB *2	Pump-speed vs independent-variable-form table. Input (independent-variable form defined by IPMPV and NPMPTB on Card Number 4, pump rotational speed) pairs (*,rad $\cdot$ s ⁻¹).
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Note: If NPMPTB = 0 (word 3 on Card Number 4) or NPMPRF = 0 (word 5 on Card Number 4), omit card set PMPRF.

PMPRF	NPMPRF *2	Rate-factor table for the pump-speed table's independent variable. Input (independent-variable form defined by NPMPSV and NPMPRF on Card Number 4, rate factor to be applied to the pump-speed table's independent variable) pairs (*,-).
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Note: If NQP3TB = 0 (word 3 on Card Number 5), omit card set QP3TB.

QP3TB	NQP3TB *2 when QP3IN > 0 NQP3TB *(1+NCELLS) when QP3IN<0	Power-to-wall vs independent-variable-form table. Input (independent-variable form defined by IQP3SV and NQP3TB on Card Number 5, power-to-wall pairs (*,W). If QP3IN > 0.0, the dependent variable specifies the total power to the entire wall; if QP3IN < 0.0, the dependent variable is a vector specifying the power to the wall at each cell beginning with cell 1.
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Pump Component (PUMP)

Note: If NQP3TB = 0 (word 3 on Card Number 5), or NQP3RF = 0 (word 5 on Card Number 5), omit card set QF3RF.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
QF3RF	NQP3RF *2	Rate-factor table for the QP3TB table's independent variable. Input (independent-variable form defined by NQP3SV and NQP3RF on Card Number 5, rate factor to be applied to the QP3TB table's independent variable) pairs (*,-).

Steam-Generator Component (STGEN)

i. Steam-Generator Component (STGEN).

General Input Data

The general input data, required to provide a global description of the steam-generator component, consist of the following cards.

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-5	TYPE	Component type (STGEN left-justified).
15-28	NUM	Component ID number (must be unique for each component).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELL1, NTUBE, NODES, NSCMP, MAT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELL1	Number of fluid cells on the primary side.
15-28	NTUBE	Number of one-dimensional conduction paths used to model the tube walls.
29-42	NODES	Number of radial heat-transfer nodes in the tube walls (NODES $\geq$ 1). (Currently use NODES = NDHT; see word 2 on Card Number 7.)
43-56	NSCMP	Number of components (pipes or tees) used to construct the secondary flow path.
57-70	MAT	Currently not used.

Card Number 3.. (Format 4I14) ICONC, ICHF1, JUN11, JUN12

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICONC	Flag for input of solute in the primary liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.

Steam-Generator Component (STGEN)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	ICHF1	Indicator for CHF calculation on the primary side. 0 = no CHF calculation; 1 = CHF calculation.
29-42	JUN11	Junction number for the junction adjacent to cell 1 on the primary side.
43-56	JUN12	Junction number for the junction adjacent to cell NCELL1 on the primary side.

Card Number 4. (Format 4I14) ICNC2, ICHF2, JUN21, JUN22

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICNC2	Flag for input of solute in the secondary liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.
15-28	ICHF2	Indicator for the CHF calculation on the secondary side. 0 = no CHF; 1 = CHF calculation.
29-42	JUN21	Currently not used.
43-56	JUN22	Currently not used.

Card Number 5. (Format 3I14,1E14.6) JUNP, JCLP, NCLP, COSP

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JUNP	Junction number for the free end of the side channel of the primary-component TEE. If the primary component is not a TEE, input zero.
15-28	JCLP	Junction cell for the primary-component TEE. If the primary component is not a TEE, input zero.

Steam-Generator Component (STGEN)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
23-42	NCLP	Number of cells on the side channel of the primary-component TEE. If NCLP = 0, the primary-side component is a PIPE; if NCLP > 0, the primary-side component is a TEE.
43-56	COSP	Cosine of the angle from the low-numbered side of the main channel to the side channel for primary TEE. If the primary component is not a TEE, input zero.

Card Number 6. (Format 3I14) JUNS1, JUNS2, NSJUN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JUNS1	Currently not used.
15-28	JUNS2	Currently not used.
29-42	NSJUN	Total number of junctions associated with the secondary-side components of the steam generator.

Card Number 7.* (Format 2I14) NGHT, NDHT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NGHT	Number of generalized heat-transfer surfaces (in addition to those used to model tube walls).
15-28	NDHT	Number of nodes used to model heat conduction in the generalized surfaces (NDHT $\geq$ 1). (Currently use NDHT = NODES; see word 3 on Card Number 2.)

*This card is included to allow in the future for the capability to use different numbers of nodes in the tube walls and the generalized heat-transfer surfaces.

Card Number 8. (Format 3E14.6) RADIN, TH, QP3IN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN	Currently not used.

Steam-Generator Component (STGEN)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	TH	Currently not used.
29-42	QP3IN	Power (W) deposited in the wall and distributed according to the QPPP array.

Secondary-Component Description Cards. NSCMP cards are required; each card is used to specify (A10,4X,2I14) STYPE, NCLS, NCLT. The secondary-component input data must be input in the order specified by this card set.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-5	STYPE	Secondary-component type (PIPE or TEE).
15-28	NCLS	Number of fluid cells in the main tube.
29-42	NCLT	Number of side-leg fluid cells if STYPE = TEE.

Primary-Side Input Data

The primary-side input data are required to specify the primary-side geometry and initial conditions. Seventeen sets of cards must be provided for each of the following variables (LOAD format is used). If the primary-side component is a TEE, input data for main channel here; side-channel data for a primary TEE is input after all the data for the secondary components and before the data for the generalized heat-conduction paths.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELL1	Cell lengths (m) on the primary side.
VOL	NCELL1	Primary-side cell volumes (m^3) for all tubes.
FA	NCELL1+1	Primary-side cell-edge flow areas (m^2) for all tubes.
FRIC	NCELL1+1	Primary-side additive loss coefficients. (See ACCUM input description, Sec. V.C.5.a.)

Steam-Generator Component (STGEN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
GRAV	NCELL1+1	Gravity terms. (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELL1+1	Primary-side hydraulic diameters (m) for a single tube. (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)
Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.		
ICFLG	NCELL1+1	Primary-side cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCELL1+1	Primary-side friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)
ALP	NCELL1	Primary-side initial void fractions (-).
VL	NCELL1+1	Primary-side initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELL1+1	Primary-side initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELL1	Primary-side initial liquid temperatures (K).
TV	NCELL1	Primary-side initial vapor temperatures (K).
P	NCELL1	Primary-side initial pressures (Pa).
PA	NCELL1	Primary-side initial air partial pressures (Pa).

Note: If ICONC = 0 (word 1 on Card Number 3), omit card set CONC.

CONC	NCELL1	Primary-side initial solute mass to liquid mass ratio.
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Steam-Generator Component (STGEN)

Note: If ICONC = 0 or 1 (word 1 on Card Number 3), omit card set S.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
S	NCELL1	Primary-side initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).

Secondary-Side Input Data

The secondary-side input data are required to specify the secondary-side geometry and initial conditions. NSCMP sets of cards are required. The secondary-component input data are read in the same order as provided in the secondary-component description cards (after Card Number 8).

Card Number 1. (Format 4I14) JSINT (3I14), NUMS (I14)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JSINT (1,I)	Junction number adjacent to cell 1.
15-28	JSINT(2,I)	Junction number adjacent to cell NCLS(I).
29-42	JSINT(3,I)	Junction number for the free end of a TEE. If the particular component is not a TEE, input zero.
43-56	NUMS(I)	Secondary-component number. Secondary-component numbers should be unique for the problem under consideration to facilitate the use of trips and signal variables. This holds for the entire system, including other STGEN secondary sides.

Seventeen cards (or sets of cards) must be provided for each of the following variables to describe either the secondary PIPE component or the main channel of a secondary TEE component (LOAD format is used).

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCLS(I)	Main-channel cell lengths (m).
VOL	NCLS(I)	Main-channel volumes (m^3).
FA	NCLS(I)+1	Main-channel cell-edge flow areas (m^2).
FRIC	NCLS(I)+1	Main-channel additive loss coefficients. (See ACCUM input description, Sec. V.C.5.a.)

Steam-Generator Component (STGEN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
GRAV	NCLS(I)+1	Main-channel gravity terms. (See ACCUM input description, Sec. V.C.5.a.)
HD	NCLS(I)+1	Main-channel hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCLS(I)+1	Main-channel cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCLS(I)+1	Main-channel friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)
ALP	NCLS(I)	Main-channel initial void fractions (-).
VL	NCLS(I)+1	Main-channel initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCLS(I)+1	Main-channel initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCLS(I)	Main-channel initial liquid temperatures (K).
TV	NCLS(I)	Main-channel initial vapor temperatures (K).
P	NCLS(I)	Main-channel initial pressures (Pa).
PA	NCLS(I)	Main-channel initial air partial pressures (Pa).

Note: If ICNC2 = 0 (word 1 on Card Number 4), omit card set CONC.

CONC	NCLS(I)	Main-channel initial solute mass to liquid mass ratio.
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Note: If ICNC2 = 0 or 1 (word 1 on Card Number 4), omit card set S.

S	NCLS(I)	Main-channel initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).
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Steam-Generator Component (STGEN)

If the secondary component is a TEE, the following input is required to model the side channel.

Card 1. (E14.6,I14) COSS(I), JCLT(I)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	COSS(I)	Cosine of the angle from the low-numbered side of the main channel to the side channel.
15-28	JCLT(I)	Main-channel cell number to which the side channel is attached.

Seventeen cards (or sets of cards) must be provided to input the following variables to describe the side channel of a secondary TEE component (LOAD format is used).

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCLT(I)	Side-channel cell lengths (m).
VOL	NCLT(I)	Side-channel volumes (m ³).
FA	NCLT(I)+1	Side-channel, cell-edge flow areas (m ²).
FRIC	NCLT(I)+1	Side-channel additive loss coefficients. (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCLT(I)+1	Side-channel gravity terms. (See ACCUM input description, Sec. V.C.5.a.)
HD	NCLT(I)+1	Side-channel hydraulic diameters (m). (See variable NDIA1 in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCLT(I)+1	Side-channel cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCLT(I)+1	Side-channel friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)

Steam-Generator Component (STGEN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ALP	NCLT(I)	Side-channel initial void fractions (-).
VL	NCLT(I)+1	Side-channel initial liquid velocities ($m \cdot s^{-1}$).
VV	NCLT(I)+1	Side-channel initial vapor velocities ($m \cdot s^{-1}$).
TL	NCLT(I)	Side-channel initial liquid temperatures (K).
TV	NCLT(I)	Side-channel initial vapor temperatures (K).
P	NCLT(I)	Side-channel initial pressures (Pa).
PA	NCLT(I)	Side-channel initial air partial pressures (Pa).

Note: If ICNC2 = 0 (word 1 on Card Number 4), omit card set CONC.

CONC	NCLT(I)	Side-channel initial solute mass to liquid mass ratio.
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Note: If ICNC2 = 0 or 1 (word 1 on Card Number 4), omit card set S.

S	NCLT(I)	Side-channel initial macroscopic density of plated-out solute ($kg \cdot m^{-3}$).
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Note: This completes the input for a given secondary component. Repeat the secondary-side input data until NSCMP components have been entered.

Primary-Tee Side-Channel Input (NCLP $\neq$ 0)

If the primary component is a TEE, the following input data are required to specify the primary-tee side-channel geometry and initial conditions. Seventeen sets of cards must be provided for each of the following variables (LOAD format is used).

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCLP	Primary-tee side-channel cell lengths (m).

Steam-Generator Component (STGEN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
VOL	NCLP	Primary-tee side-channel volumes (m^3).
FA	NCLP+1	Primary-tee side-channel cell-edge flow areas (m^2).
FRIC	NCLP+1	Primary-tee side-channel additive loss coefficients. (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCLP+1	Primary-tee side-channel gravity terms. (See ACCUM input description, Sec. V.C.5.a.)
HD	NCLP+1	Primary-tee side-channel hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)
Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.		
ICFLG	NCLP+1	Primary-tee side-channel cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCLP+1	Primary-tee side-channel friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)
ALP	NCLP	Primary-tee side-channel initial void fractions (-).
VL	NCLP+1	Primary-tee side-channel initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCLP+1	Primary-tee side-channel initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCLP	Primary-tee side-channel initial liquid temperatures (K).
TV	NCLP	Primary-tee side-channel initial vapor temperatures (K).
P	NCLP	Primary-tee side-channel initial pressures (Pa).

Steam-Generator Component (STGEN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PA	NCLP	Primary-tee side-channel initial air partial pressures (Pa).

Note: If ICONC = 0 (word 1 on Card Number 3), omit card set CONC.

CONC	NCLP	Primary-tee side-channel initial solute mass to liquid mass ratio.
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Note: If ICONC = 0 or 1 (word 1 on Card Number 3), omit card set S.

S	NCLP	Primary-tee side-channel initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).
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Generalized Heat-Conduction-Path Input (NTUBE + NGHT $\neq$ 0)

The heat-conduction input is required to specify heat-conduction paths between arbitrary fluid volumes internal to the steam-generator component. The same fluid volume cannot be specified on both sides of a heat-conduction path. Nineteen sets of cards are required (LOAD format is used).

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ICMP	(NTUBE+NGHT)	Inner-wall component number (use zero for a primary cell).
ICELL	(NTUBE+NGHT)	Inner-wall fluid-cell number (ICELL > 0). (See Sec. IV.G for a description of cell counting.)
OCMP*	(NTUBE+NGHT)	Outer-wall component number (use zero for a primary cell).
OCELL*	(NTUBE+NGHT)	Outer-wall fluid cell number. If OCELL = 0, the corresponding OCOMP must be zero. (See Section IV.G for a description of cell counting.)

* Used to specify a constant external environment when OCOMP = OCELL = 0 at the conditions of HOLG, HOVG, TOLG, and TOVG. These parameters are convenient for modeling heat losses from the system. Refer to Sec. IV.G.

Steam-Generator Component (STGEN)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
MATG	(NDHT-1)*(NTUBE+NGHT)	Material ID number specified at locations between nodes for each conduction path. If NDHT = 1, the dimension of this array is (NTUBE + NGHT). See available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c, or Sec. V.C.2 to input material properties.
RADIG	(NTUBE+NGHT)	Conduction-path inner radius (m).
TH	(NTUBE+NGHT)	Conduction-path thickness (m).
QPPG	NDHT*(NTUBE+NGHT)	Volumetric heat sources $W \cdot m^{-3}$ (currently not used).
TWGN	NDHT*(NTUBE+NGHT)	Initial wall temperatures (K).
HILG	(NTUBE+NGHT)	Currently not used.
HIVG	(NTUBE+NGHT)	Currently not used.
TILG	(NTUBE+NGHT)	Currently not used.
TIVG	(NTUBE+NGHT)	Currently not used.
WAIG	(NTUBE+NGHT)	Inner-wall surface area (m^2) [WAIG(i) > 0.0].
HOLG*	(NTUBE+NGHT)	Exterior liquid heat-transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$).
HOVG*	(NTUBE+NGHT)	Exterior vapor heat-transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$).
TOLG*	(NTUBE+NGHT)	External-environment liquid temperature (K).
TOVG*	(NTUBE+NGHT)	External-environment vapor temperature (K).
WAOG	(NTUBE+NGHT)	Outer-wall surface area (m^2). (Input WAOG(i) = WAIG(i)*[1.+TH(i)/RADIG(i)]).

*Used to specify a constant external environment when OCMP = OCELL = 0 at the conditions of HOLG, HOVG, TOLG, and TOVG. These parameters are convenient for modeling heat losses from the system. Refer to Sec. IV.G.

Tee Component (TEE)

j. Tee Component (TEE).

Card Number 1. (Format A10,4X,14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-3	TYPE	Component type (TEE left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 3I14, E14.6, I14) JCELL, NODES, MAT, COST, ICHF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	JCELL	Junction cell number.
15-28	NODES	Number of radial heat-transfer nodes in the tee wall. A value of 0 specifies no wall heat transfer.
29-42	MAT	Material ID number of the wall (currently not used).
43-56	COST	Cosine of the angle from the low-numbered side of the main tube to the side tube.
57-70	ICHF	CHF calculation flag. 0 = no; 1 = yes.

Card Number 3. (Format 5I14) ICONC1, NCELL1, JUN1, JUN2, IPOW1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICONC1	Flag for input of solute in the main-tube liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.
15-28	NCELL1	Number of fluid cells in the tee main tube.
29-42	JUN1	Junction number for the junction adjacent to cell 1.

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	JUN2	Junction number for the junction adjacent to cell NCELL1.
57-70	IPOW1	Presence of power deposited in the tee main-tube coolant flag. 0 = no; 1 = yes.

Note: If IPOW1 = 0 (word 5 on Card Number 3), omit Card Number 4.

Card Number 4. (Format 5I14) IPWTR1, IPWSV1, NPWTB1, NPWSV1, NPWRF1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IPWTR1	The trip ID number that controls evaluation of the power-to-fluid table (POWTB) for the tee main tube ($ IPWTR1 < 10000$). (Input IPWTR1 = 0 if there is to be no trip control, and the table will be evaluated in the transient.)
15-28	IPWSV1	The independent-variable ID number for the power-to-fluid table (POWTB) for the tee main tube. IPWSV1 > 0 defines the ID number for a signal-variable parameter; IPWSV1 < 0 defines the ID number for a control-block output parameter.
29-42	NPWTB1	The number of (x,y) power-to-fluid table's (POWTB) pairs for the tee main tube (defined by the absolute value of NPWTB1). NPWTB1 > 0 defines the table's independent-variable form to be the IPWSV1 parameter; NPWTB1 < 0 defines the table's independent-variable form to be the change in the IPWSV1 parameter over the last time step times the trip set-status value ISET when the power-to-fluid table is trip controlled; NPWTB1 = 0 defines the power to be the IPWSV1 parameter.

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NPWSV1	The independent-variable ID number for the rate factor that is applied to the tee main-tube power-to-fluid table's independent variable. NPWSV1 > 0 defines the ID number for a signal-variable parameter; NPWSV1 < 0 defines the ID number for a control-block output parameter; NPWSV1 = 0 (when NPWRF1 ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power table is trip controlled.
57-70	NPWRF1	The number of (x,y) rate-factor table pairs (defined by the absolute value of NPWRF1). The rate factor is applied as a factor to the tee main-tube power-to-fluid (POWTB) table independent variable when the rate factor is defined. No rate factor is defined when NPWSV1 and NPWRF1 are both zero. NPWRF1 > 0 defines the rate-factor table's independent variable to be the NPWSV1 parameter; NPWRF1 < 0 defines it to be the change in the NPWSV1 parameter over the last time step times the trip set-status value ISET when the tee main-tube power table is trip controlled; NPWRF1 = 0 defines the rate factor to be the NPWSV1 parameter.

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 5.

Card Number 5. (Format 5I14) IQPTR1, IQPSV1, NQPTB1, NQPSV1, NQPRF1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IQPTR1	The trip ID number that controls evaluation of the power-to-wall table (QP3TB) for the tee main tube ($ IQPTR1 < 10000$). (Input IQPTR1 = 0 if there is to be no trip control, and the table will be evaluated in the transient.)

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	IQPSV1	The independent-variable ID number for the tee main-tube power-to-wall table (QP3TB). IQPSV1 > 0 defines the ID number for a signal-variable parameter; IQPSV1 < 0 defines the ID number for a control-block output parameter.
29-42	NQPTB1	The number of (x,y) power-to-wall table's (POWTB) pairs for the tee main tube (defined by the absolute value of NQPTB1). NQPTB1 > 0 defines the table's independent-variable form to be the IQPSV1 parameter; NQPTB1 < 0 defines the table's independent-variable form to be the change in the IQPSV1 parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled. NQPTB1 = 0 defines the power to the wall to be the IQPSV1 parameter.
43-56	NQPSV1	The independent-variable ID number for the rate factor that is applied to the tee main-tube power-to-wall table's independent variable. NQPSV1 > 0 defines the ID number for a signal-variable parameter; NQPSV1 < 0 defines the ID number for a control-block output parameter; NQPSV1 = 0 (when NQPRF1 ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power-to-wall table is trip controlled.
57-70	NQPRF1	The number of (x,y) rate-factor table pairs (defined by the absolute value of NQPRF1). The rate factor is applied as a factor to the tee main-tube power-to-wall table's (QP3TB) independent variable when the rate factor is defined. No rate factor is defined when NQPSV1 and NQPRF1 are both zero. NQPRF1 > 0 defines the rate-factor table's independent variable to be the NQPSV1 parameter; NQPRF1 < 0 defines it to be the change in the NQPSV1 parameter over the last time step times the trip set-status value ISET when the tee main-tube power-to-wall table is trip controlled; NQPRF1 = 0 defines the rate factor to be the NQPSV1 parameter.

Tee Component (TEE)

Card Number 6. (Format 5E14.6) RADIN1, TH1, HOUTL1, HOUTV1, TOUTL1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN1	Inner radius (m) of the tee main-tube wall.
15-28	TH1	Wall thickness (m) of the tee main tube.
29-42	HOUTL1	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the tee main-tube wall and liquid outside the tee main-tube wall.
43-56	HOUTV1	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the tee main-tube wall and vapor outside the tee main-tube wall.
57-70	TOUTL1	Liquid temperature (K) outside the tee main-tube wall.

Note: See PIPE input description, Sec. V.C.5.e, for further comments on the HOUTL1, HOUTV1, TOUTL1, and TOUTV1 heat-transfer parameters.

Card Number 7. (Format 5E14.6) TOUTV1, PWIN1, PWOFF1, RPWMX1, PWSCL1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV1	Vapor temperature (K) outside the tee main-tube wall.
15-28	PWIN1	Initial total power (W) deposited in the tee main-tube fluid (not used when IPOW1 = 0). The power is distributed linearly along the component.
29-42	PWOFF1	Total power (W) deposited in the tee main-tube fluid when the controlling trip is OFF after being ON (not used if IPOW1 = 0 or IPWTR1 = 0). If $PWOFF1 \leq -1.0 \times 10^{19}$, the power to the fluid is held constant at the last table-evaluated power when the trip was ON.
43-56	RPWMX1	The maximum rate of change of the tee main-tube power ($W \cdot s^{-1}$) deposited in the fluid ($RPWMX1 \geq 0.0$) [not input if IPOW1 = 0].

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	PWSCL1	Scale factor for the power-to-fluid table. The dependent variable in table POWTB1 is multiplied by PWSCL1 to obtain absolute power deposited in the fluid (not used if IPOW1 = 0 or NPWTB1 = 0).

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 8.

Card Number 8. (Format 4E14.6) QPIN1, QPOFF1, RQPMX1, QPSCL1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	QPIN1	Initial power (W) deposited in the tee main-tube wall and distributed according to the QPPP array. If QPIN1 > 0.0, it is the total power to the entire wall. When QPIN1 < 0 is input, the power to the wall in each cell is QPIN1 , and the negative sign flags the power to the wall to be a cell-dependent vector of NCELL1 (word 2 on Card Number 3) powers. Each (x,y) point of the power-to-wall table (for QPIN1 < 0.0) has 1+NCELL1 values [an independent-variable value x and NCELL1 power values y(z) for cells 1 through NCELL1]. When the power-to-wall table is not being evaluated, the same power value of QPIN1 or QPOFF1 (if QPOFF1 > -1.0×10^{19}) is applied at each of the NCELL1 cells.
15-28	QPOFF1	Power (W) to the tee main-tube wall when the controlling trip is OFF after being ON (maintain the last table-evaluated power when the trip was ON if QPOFF1 $\leq -1.0 \times 10^{19}$).
29-42	RQPMX1	The maximum rate of change of the power to the wall for the tee main-tube ($W \cdot s^{-1}$) [RQPMX1 ≥ 0.0].
43-56	QPSCL1	Scale factor (-) for the power-to-wall table for the tee main tube. The dependent variable in table QP3TB1 is multiplied by QPSCL1 to obtain the absolute power to the wall.

Tee Component (TEE)

Card Number 9. (Format 4I14) ICONC2, NCELL2, JUN3, IPOW2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICONC2	Flag for input of solute in the tee side-tube liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.
15-28	NCELL2	Number of fluid cells in the tee side tube.
29-42	JUN3	Junction number at the free end of the side tube adjacent to cell NCELL2.
43-56	IPOW2	Presence of power deposited in the tee side-tube liquid coolant flag. 0 = no; 1 = yes.

Note: If IPOW2 = 0 (word 4 on Card Number 9), omit Card Number 10.

Card Number 10. (Format 5I14) IPWTR2, IPWSV2, NPWTB2, NPWSV2, NPWRF2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IPWTR2	The trip ID number that controls evaluation of the power-to-fluid table (POWTB) for the tee side tube ($ IPWTR2 < 10000$). (Input IPWTR2 = 0 if there is to be no trip control, and the table will be evaluated in the transient.)
15-28	IPWSV2	The independent-variable ID number for the tee side-tube power-to-fluid table (POWTB). IPWSV2 > 0 defines the ID number for a signal-variable parameter; IPWSV2 < 0 defines the ID number for a control-block output parameter.

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	NPWTB2	The number of (x,y) power-to-fluid table's (POWTB) pairs for the tee side tube (defined by the absolute value of NPWTB2). NPWTB2 > 0 defines the table's independent-variable form to be the IPWSV2 parameter; NPWTB2 < 0 defines the table's independent-variable form to be the change in the IPWSV2 parameter over the last time step times the trip set-status value ISET when the tee side-tube power-to-fluid table is trip controlled; NPWTB2 = 0 defines the power to be the IPWSV2 parameter.
43-56	NPWSV2	The independent-variable ID number for the rate factor that is applied to the tee side-tube power-to-fluid table's independent variable. NPWSV2 > 0 defines the ID number for a signal-variable parameter; NPWSV2 < 0 defines the ID number for a control-block output parameter; NPWSV2 = 0 (when NPWRF2 ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power table is trip controlled.
57-70	NPWRF2	The number of (x,y) rate-factor table pairs (defined by the absolute value of NPWRF2). The rate factor is applied as a factor to the tee side-tube power-to-fluid table's (POWTB) independent variable when the rate factor is defined. No rate factor is defined when NPWSV2 and NPWRF2 are both zero. NPWRF2 > 0 defines the rate-factor table's independent variable to be the NPWSV2 parameter; NPWRF2 < 0 defines it to be the change in the NPWSV2 parameter over the last time step times the trip set-status value ISET when the tee side-tube power table is trip controlled; NPWRF2 = 0 defines the rate factor to be the NPWSV2 parameter.

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 11.

Card Number 11. (Format 5I14) IQPTR2, IQPSV2, NQPTB2, NQPSV2, NQPRF2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IQPTR2	The trip ID number that controls evaluation of the power-to-wall table (QP3TB) for the tee side tube ($ IQPTR2 < 10000$). (Input IQPTR2 = 0 if there is to be no trip control, and the table will be evaluated in the transient.)
15-28	IQPSV2	The independent-variable ID number for the tee side-tube power-to-wall table (QP3TB). IQPSV2 > 0 defines the ID number for a signal-variable parameter; IQPSV2 < 0 defines the ID number for a control-block output parameter.
29-42	NQPTB2	The number of (x,y) power-to-wall table's (POWTB) pairs for the tee side tube (defined by the absolute value of NQPTB2). NQPTB2 > 0 defines the table's independent-variable form to be the IQPSV2 parameter; NQPTB2 < 0 defines the table's independent-variable form to be the change in the IQPSV2 parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; NQPTB2 = 0 defines the power to the wall to be the IQPSV2 parameter.
43-56	NQPSV2	The independent-variable ID number for the rate factor that is applied to the tee side-tube power-to-wall table's independent variable. NQPSV2 > 0 defines the ID number for a signal-variable parameter; NQPSV2 < 0 defines the ID number for a control-block output parameter; NQPSV2 = 0 (when NQPRF2 $\neq 0$) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power-to-wall table is trip controlled.

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NQPRF2	The number of (x,y) rate-factor table pairs (defined by the absolute value of NQPRF2). The rate factor is applied as a factor to the tee side-tube power-to-wall table (QP3TB) independent variable when the rate factor is defined. No rate factor is defined when NQPSV2 and NQPRF2 are both zero. NQPRF2 > 0 defines the rate-factor table's independent variable to be the NQPSV2 parameter; NQPRF2 < 0 defines it to be the change in the NQPSV2 parameter over the last time step times the trip set-status value ISET when the tee side-tube power-to-wall table is trip controlled; NQPRF2 = 0 defines the rate factor to be the NQPSV2 parameter.

Card Number 12. (Format 5E14.6) RADIN2, TH2, HOUTL2, HOUTV2, TOUTL2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN2	Inner radius (m) of the tee side-tube wall.
15-28	TH2	Wall thickness (m) of the tee side tube.
29-42	HOUTL2	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the tee side-tube wall and liquid outside the tee side-tube wall.
43-56	HOUTV2	HTC ($W \cdot m^{-2} \cdot K^{-1}$) between outer boundary of the tee side-tube wall and vapor outside the tee side-tube wall.
57-70	TOUTL2	Liquid temperature (K) outside the tee side-tube wall.

Note: See PIPE input description, Sec. V.C.5.e, for further comments on the HOUTL2, HOUTV2, TOUTL2, and TOUTV2 heat-transfer parameters.

Card Number 13. (Format 5E14.6) TOUTV2, PWIN2, PWOFF2, RPWMX2, PWSCL2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV2	Vapor temperature (K) outside the tee side-tube wall.

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	PWIN2	Initial total power (W) deposited in the tee side-tube fluid (not used when IPOW2 = 0). The power is distributed linearly along the component.
29-42	PWOFF2	Total power (W) deposited in the side-tube fluid when the controlling trip is OFF after being ON (not used when IPOW2 = 0 or IPWTR2 = 0). If $PWOFF2 \leq -1.0 \times 10^{19}$, the power to the fluid is held constant at the last table-evaluated power when the trip was ON.
43-56	RPWMX2	The maximum rate of change of the power tee side-tube power ($W \cdot s^{-1}$) deposited in the fluid ($RPWMX1 \geq 0.0$) [not used when IPOW2 = 0].
57-70	PWSCL2	Scale factor for the power-to-fluid table. The dependent variable in table POWTB2 is multiplied by PWSCL2 to obtain absolute power deposited in the fluid (not used if IPOW2 = 0 or NPWTB2 = 0).

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 14.

Card Number 14. (Format 4E14.6) QPIN2, QPOFF2, RQPMX2, QPSCL2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	QPIN2	Initial power (W) deposited in the tee side-tube wall and distributed according to the QPPP array. If QPIN2 > 0.0, it is the total power to the entire wall. When QPIN2 < 0.0 is input, the initial power to the wall in each cell is QPIN2 , and the negative sign flags the power to the wall to be a cell-dependent vector of NCELL2 (word 2 on Card Number 9) powers. Each (x,y) point of the power-to-wall table (for QPIN2 < 0.0) has 1+NCELL2 values [an independent-variable value x and NCELL2 power values y(z) or cells 1 through NCELL2]. When the power-to-wall table is not being evaluated, the same power value of QPIN2 or QPOFF2 > 0.0 (if QPOFF2 > -1.0×10^{19}) is applied at each of the NCELL2 cells.

Tee Component (TEE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	QPOFF2	Power (W) to the tee side-tube wall when the controlling trip is OFF after being ON (maintain the last table-evaluated power when the trip was ON if $QPOFF2 \leq -1.0 \times 10^{19}$).
29-42	RQPMX2	The maximum rate of change of the tee side-tube power to the wall ($W \cdot s^{-1}$) [$RQPMX2 \geq 0.0$].
43-56	QPSCL2	Scale factor (-) for the tee side-tube power-to-wall table. The dependent variable in table QP3TB2 is multiplied by QPSCL2 to obtain the absolute power to wall.

TEE Array Cards. Forty-eight sets of cards, one for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELL1	Main-tube tube lengths (m).
VOL	NCELL1	Main-tube cell volumes (m^3).
FA	NCELL1+1	Main-tube cell-edge flow areas (m^2).
FRIC	NCELL1+1	Main-tube additive loss coefficients (-). (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELL1+1	Main-tube gravity terms (-). (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELL1+1	Main-tube hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELLS+1	Main-tube cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
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Tee Component (TEE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
NFF	NCELL1+1	Friction-factor correlation options for main tube (see ACCUM input description, Sec. V.C.5.a).
ALP	NCELL1	Main-tube initial void fractions (-).
VL	NCELL1+1	Main-tube initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELL1+1	Main-tube initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELL1	Main-tube initial liquid temperatures (K).
TV	NCELL1	Main-tube initial vapor temperatures (K).
P	NCELL1	Main-tube initial pressures (Pa).
PA	NCELL1	Main-tube initial air partial pressures (Pa).

Note: If NODES = 0 (word 2 on Card Number 2), do not enter arrays QPPP, MATID, and TW.

QPPP	NODES*NCELLS	A nonnormalized power profile (-) in the tee main-tube walls. Input for cell 1, node 1 through NODES; then cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis (normalized $QPPP(i)/[\sum QPPP(i) * VOL(i)]$). Filling the array ¹ with zeros results in no power being deposited in the wall regardless of settings of QP3IN, QP3TB, etc.
MATID	NODES-1	Wall-material ID array specifying material ID between nodes in the tee-main tube. Dimension is 1 if NODES = 1 and 0 if NODES = 0 (see available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c, or see Sec. V.C.2 to input material properties).

Tee Component (TEE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
TW	NODES*NCELL1	Tee main-tube initial wall temperatures (K) input in the same order as QPPP.
Note: If ICONC1 = 0 (word 1 on Card Number 3), omit card set CONC.		
CONC	NCELL1	Initial ratio of solute mass to liquid coolant mass in the tee main tube.
Note: If ICONC2 = 0 or 1 (word 1 on Card Number 9), omit card set S.		
S	NCELL1	Initial macroscopic density of plated-out solute in the tee side tube ($\text{kg} \cdot \text{m}^{-3}$).
Note: If NPWTB1 = 0 (word 3 on Card Number 4), omit card set POWTB1.		
POWTB1	NPWTB1 *2	Power-to-fluid vs independent-variable-form table for the tee main tube. Input (independent-variable form defined by IPWSV1 and NPWTB1 on Card Number 4, power) pairs (*,W). The power is deposited directly into the tee main-tube fluid with a uniform volumetric power density along the tube length.
Note: If NPWTB1 = 0 (word 3 on Card Number 4) or NPWRF1 = 0 (word 5 on Card Number 4), omit card set POWRF1.		
POWRF1	NPWRF1 *2	Rate-factor table for the tee main-tube POWTB table's independent variable. Input (independent-variable form defined by NPWSV1 and NPWRF1 on Card Number 4, rate factor to be applied to the POWTB table's independent variable) pairs (*,-).

Tee Component (TEE)

Note: If NQPTB1 = 0 (word 3 on Card Number 5), omit card set QP3TB1.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
QP3TB1	NQPTB1 *2 when QPIN1 > 0; NQPTB1 *(1+NCELL1) QPIN1 < 0	Power-to-wall independent-variable-form table for the tee main tube. Input (independent-variable form defined by IQPSV1 and when NQPTB1 on Card Number 5, power-to-wall) pairs (*,W). If QP3IN > 0.0, the dependent variable specifies the total power to the entire wall; if QP3IN < 0.0, the dependent variable is a vector specifying the power to the wall at each cell beginning with cell 1.

Note: If NQPTB1 = 0 (word 3 on Card Number 5) or NQPRF1 = 0 (word 5 on Card Number 5), omit card set QP3RF1.

QP3RF1	NQPRF1 *2	Rate-factor table for the tee main-tube QP3TB table's independent variable. Input (independent-variable form defined by NQPSV1 and NQPRF1 on Card Number 5, rate factor to be applied to the QP3TB table's independent variable) pairs (*,-).
DX	NCELL2	Side-tube cell lengths (m).
VOL	NCELL2	Side-tube cell volumes (m ³).
FA	NCELL2+1	Side-tube cell-edge flow areas (m ²).
FRIC	NCELL2+1	Side-tube additive loss coefficients (-). (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELL2+1	Side-tube gravity terms (-). (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELL2+1	Side-tube hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELL2+1	Side-tube cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
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Tee Component (TEE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
NFF	NCELL2+1	Friction-factor correlation options for side tube (see ACCUM input description, Sec. V.C.5.a).
ALP	NCELL2	Side-tube initial void fractions (-).
VL	NCELL2+1	Side-tube initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELL2+1	Side-tube initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELL2	Side-tube initial liquid temperatures (K).
TV	NCELL2	Side-tube initial vapor temperatures (K).
P	NCELL2	Side-tube initial pressures (Pa).
PA	NCELL2	Side-tube initial air partial pressures (Pa).

Note: If NODES = 0 (word 2 on Card Number 2), do not enter arrays QPPP, MATID, and TW.

QPPP	NODES*NCELLS	A nonnormalized power profile (-) in the tee side-tube walls. Input for cell 1, node 1 through NODES; then cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis ($\text{normalized } QPPP(i)/[\sum QPPP(i) * VOL(i)]$). Filling the array ¹ with zeros results in no power being deposited in the wall regardless of settings of QP3IN, QP3TB, etc.
MATID	NODES-1	Wall-material ID array specifying material ID between nodes in the tee-side tube. Dimension is 1 if NODES = 1 and 0 if NODES = 0 (see available built-in properties listed with the array MATID in CORE input, Sec. V.C.5.c, or see Sec. V.C.2 to input material properties).

Tee Component (TEE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
TW	NODES*NCELL2	Tee side-tube initial wall temperatures (K) input in the same order as QPPP.

Note: If ICONC2 = 0 (word 1 on Card Number 9), omit card set CONC.

CONC	NCELL2	Initial ratio of solute mass to liquid coolant mass in the tee side tube.
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Note: If ICONC1 = 0 or 1 (word 1 on Card Number 3), omit card set S.

S	NCELL2	Initial macroscopic density of plated-out solute in the tee main tube ($\text{kg} \cdot \text{m}^{-3}$).
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Note: If NPWTB2 = 0 (word 3 on Card Number 10), omit card set POWTB2.

POWTB2	NPWTB2 *2	Power-to-fluid vs independent-variable-form table for the tee side tube. Input (independent-variable form defined by IPWSV2 and NPWTB2 on Card Number 10, power) pairs (*,W). The power is deposited directly into the tee side-tube fluid with a uniform volumetric power density along the tube length.
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Note: If NPWTB2 = 0 (word 3 on Card Number 10) or NPWRF2 = 0 (word 5 on Card Number 10), omit card set POWRF.

POWRF	NPWRF2 *2	Rate-factor table for the tee side-tube POWTB table's independent variable. Input (independent-variable form defined by NPWSV2 and NPWRF2 on Card Number 10, rate factor to be applied to the POWTB table's independent variable) pairs (*,-).
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Tee Component (TEE)

Note: If NQPTB2 = 0 (word 3 on Card Number 11), omit card set QP3TB2.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
QP3TB2	NQPTB2 *2 when QPIN2 > 0; NQPTB2 *(1+NCELL2) when QPIN2 < 0	Power-to-wall vs independent-variable form table for the tee side tube. Input (independent-variable form defined by IQPSV2 and IQPSV2 and NQPTB2 on Card Number 11, power-to-wall) pairs (*,W). If QP3IN > 0.0, the dependent variable specifies the total power to the entire wall; if QP3IN < 0.0, the dependent variable is a vector specifying the power to the wall at each cell beginning with cell 1.

Note: If NQPTB2 = 0 (word 3 on Card Number 11) or NQPRF2 = 0 (word 5 on Card Number 11), omit card set QP3RF2.

QP3RF2	NQPRF2 *2	Rate-factor table for the tee side-tube QP3TB table's independent variable. Input (independent-variable form defined by NQPSV2 and NQPRF2 on Card Number 11, rate factor to be applied to the QP3TB table's independent variable) pairs (*,-).
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Turbine Component (TURB)

k. Turbine Component (TURB). Each turbine stage is modeled as a separate TURB component.)

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TYPE	Component type (TURB left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 99$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELLS, JUN1, JUN2, ICONC, IPOW

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells in the component.
15-28	JUN1	Junction number for junction adjacent to cell 1.
29-42	JUN2	Junction number for junction adjacent to cell NCELLS.
43-56	ICONC	Flag for input of solute in the liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.
57-70	IPOW	Power-to-fluid flag. 0 = no; 1 = yes.

Turbine Component (TURB)

Note: If IPOW = 0 (word 5 on Card Number 2), omit Card Numbers 3 and 4.

Card Number 3. (Format 5I14) IPOWTR, IPOWSV, NPOWTB, NPOWSV, NPOWRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IPOWTR	The trip ID number that controls evaluation of the power-to-fluid table (POWTB) [$ IPOWTR < 10000$] (input IPOWTR = 0 if there is to be no trip control and the table will be evaluated in the transient.)
15-28	IPOWSV	The independent-variable ID number for the power-to-fluid table (POWTB). IPOWSV > 0 defines the ID number for a signal-variable parameter; IPOWSV < 0 defines the ID number for a control-block output parameter.
29-42	NPOWTB	The number of (x,y) power-to-fluid table's (POWTB) pairs (defined by the absolute value of NPOWTB). NPOWTB > 0 defines the table's independent-variable form to be the IPOWSV parameter; NPOWTB < 0 defines the table's independent-variable form to be the change in the IPOWSV parameter over the last time step times the trip set-status value ISET when the power-to-fluid table is trip controlled; NPOWTB = 0 defines the power to be the IPOWSV parameter.
43-56	NPOWSV	The independent-variable ID number for the rate factor that is applied to the power-to-fluid table's independent variable. NPOWSV > 0 defines the ID number for a signal-variable parameter; NPOWSV < 0 defines the ID number for a control-block output parameter; NPOWSV = 0 (when NPOWRF ≠ 0) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power table is trip controlled.

Turbine Component (TURB)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NPOWRF	The number of (x,y) rate-factor table pairs (defined by the absolute value of NPOWRF). The rate factor is applied as a factor to the power-to-fluid table's (POWTB) independent variable when the rate factor is defined. No rate factor is defined when NPOWSV and NPOWRF are both zero. NPOWRF > 0 defines the rate-factor table's independent variable to be the NPOWSV parameter; NPOWRF < 0 defines it to be the change in the NPOWSV parameter over the last time step times the trip set-status value ISET when the power table is trip controlled; NPOWRF = 0 defines the rate factor to be the NPOWSV parameter.

Card Number 4. (Format 4E13.6) POWIN, POWOFF, RPOWMX, POWSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	POWIN	Initial total power (W) deposited in the turbine fluid (not used when IPOW = 0). The power is distributed linearly along the component.
15-28	POWOFF	Total power (W) deposited in the turbine fluid when the controlling trip is OFF after being ON (not used if IPOWTR = 0). If $\text{POWOFF} \leq -1.0 \times 10^{19}$, the power to the fluid is held constant at the last table-evaluated power when the trip was ON.
29-42	RPOWMX	The maximum rate of change of power ($\text{W} \cdot \text{s}^{-1}$) deposited in the turbine fluid ($\text{RPOWMX} \geq 0.0$) [not used when IPOW = 0].
43-56	POWSCL	Scale factor for the power-to-fluid table. The dependent variable in the POWTB table is multiplied by POWSCL to obtain absolute power deposited in the fluid (not used when IPOW = 0 or NPOWTB = 0).

Turbine Component (TURB)

Card Number 5. (Format 2I14, E14.6) ISTG, NEFCON, EFFDSN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ISTG	Turbine stage number this TURB component represents (if there is only one stage in the turbine, ISTG = 1).
15-28	NEFCON	Flag to indicate whether the stage efficiency is to be treated as a constant. NEFCON = 0, the efficiency of the stage to be computed internally. NEFCON = 1, the stage efficiency to be treated as a constant.
29-42	EFFDSN	Stage efficiency at design conditions (include windage loss, diaphragm-packing loss, moisture loss, and nozzle-end loss; thus, stage efficiency equals nozzle-bucket efficiency minus all the losses listed above). Note: If NEFCON = 1, EFFDSN value will be used for stage efficiency under all conditions. If NEFCON = 0, the stage efficiency at the off-design condition will be calculated using EFFDSN. If NEFCON = 0 and EFFDSN = 0.0, the code calculates a realistic value of EFFDSN from quantities input on Card Numbers 6-8 and Card Set 15.

Note: All the quantities entered on Card Number 6 should be consistent with the design efficiency, EFFDSN (word 3 on Card Number 5).

Card Number 6. (Format 5E14.6) PRES1, PRES2, QUALTY, SUPRHT, FLOW

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	PRES1	Stage upstream design pressure.
15-28	PRES2	Stage downstream design pressure.
29-42	QUALTY	Stage upstream design quality of steam (if superheated, QUALTY = 1.0).
43-56	SUPRHT	Stage upstream degree of superheat of steam at design conditions (if wet steam, SUPRHT = 0.0).

Turbine Component (TURB)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	FLOW	Mixture mass flow at design conditions.

Note: If NEFCON $\neq$ 0 (word 2 on Card Number 5), omit Card Numbers 7 and 8.

Card Number 7. (Format 5E14.6) DIA, COEF1, COEF2, COF3SQ, REACTN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DIA	Pitch circle diameter of the buckets.
15-28	COEF1	Nozzle coefficient. The nozzle exit velocity is calculated by multiplying the ideal isentropic velocity by COEF1.
29-42	COEF2	Bucket coefficient. Defined in the same manner as COEF1.
43-56	COF3SQ	Fraction of reaction energy actually delivered in the entire stage [reaction loss coefficient based on the energy (velocity ²) instead of velocity].
57-70	REACTN	Degree of reaction at design conditions (if impulse stage, REACTN = 0.0).

Card Number 8. (Format 114) NROWS

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NROWS	Number of rows of moving blades.

Note: If ISTG $\neq$ 1 (word 1 on Card Number 5), omit Card Numbers 9 to 13 and Card Set Number 14.

Card Number 9. (Format 114) NSTGES

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NSTGES	Total number of stages associated with the entire turbine.

Turbine Component (TURB)

Card Number 10. (Format 5114) ITRBTR, ITRBSV, NTRBTB, NTRBSV, NTRBRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ITRBTR	The trip ID number that controls the evaluation of the generator power-demand table ($ ITRBTR < 10000$) [$ITRBTR = 0$ implies constant power demand].
15-28	ITRBSV	The generator power-demand table abscissa-coordinate variable ID number. $ITRBSV > 0$ defines the ID number for a signal-variable parameter; $ITRBSV < 0$ defines the ID number for a control-block output parameter.
29-42	NTRBTB	The number of (x,y) generator power-demand table's pairs (defined by the absolute value of NTRBTB). $NTRBTB > 0$ defines the table's independent-variable form to be the ITRBSV parameter; $NTRBTB < 0$ defines the table's independent-variable form to be the change in the ITRBSV parameter over the last time step times the trip set-status value ISET; $NTRBTB = 0$ defines the generator power-demand to be the ITRBSV parameter.
43-56	NTRBSV	The rate-factor table's abscissa-coordinate variable ID number. NTRBSV defines the independent-variable parameter for the rate-factor table that is applied as a factor to the generator power-demand table's independent variable. $NTRBSV > 0$ defines the ID number for a signal-variable parameter; $NTRBSV < 0$ defines the ID number for a control-block output parameter; $NTRBSV = 0$ (when $NTRBRF \neq 0$) defines the difference between the trip signal and the set-point value that turns the trip OFF.
57-70	NTRBRF	The number of (x,y) rate-factor table's pairs (defined by the absolute value of NTRBRF). $NTRBRF > 0$ defines the rate-factor table's abscissa coordinate to be the NTRBSV parameter; $NTRBRF < 0$ defines it to be the change in the NTRBSV parameter over the last time step times the trip set-status value ISET; $NTRBRF = 0$ defines the rate factor to be the NTRBSV parameter.

Turbine Component (TURB)

Card Number 11. (Format 4E14.6) POWOP, POPOFF, RPOPMX, POPSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	POWOP	Initial generator operating power (W).
15-28	POPOFF	Generator operating power (W) when the generator operating-power controlling trip is OFF after being ON (maintain the last table-evaluated generator operating power when the trip was ON if POPOFF $\leq -1.0 \times 10^{19}$) [not input when ITRBTR = 0].
29-42	RPOPMX	The maximum rate of change of generator operating power ($W \cdot s^{-1}$) [RPOPMX ≥ 0.0].
43-56	POPSCL	Generator operating-power scale factor. The dependent variable in the generator operating-power TRBTB table is multiplied by POPSCS to obtain absolute generator operating power.

Card Number 12. (Format 4E14.6) POWD, OMEGD, OMEGOP, EFGEN

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	POWD	Generator design power (W) [must be consistent with parameters entered on Card Number 6 and EFFDSN entered on Card Number 5].
15-28	OMEGD	Turbine/generator design speed ($rad \cdot s^{-1}$) [must be consistent with POWD, parameters entered on Card Number 6, and EFFDSN entered on Card Number 5].
29-42	OMEGOP	Turbine/generator initial operating speed ($rad \cdot s^{-1}$).
43-56	EFGEN	Generator efficiency.

Card Number 13. (Format 4E14.6) ATORK, BTORK, CTORK, INRTA

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ATORK	Turbine/generator friction torque zero-order coefficient ($N \cdot m$ or $Pa \cdot m^3$) [torque is calculated as $ATORK + BTORK \cdot \omega + CTORK \cdot \omega^2$, where ω is the turbine speed].

Turbine Component (TURB)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	BTORK	Turbine/generator friction torque first-order coefficient ($N \cdot m \cdot W^{-1}$).
29-42	CTORK	Turbine/generator friction torque second-order coefficient ($N \cdot m \cdot W^{-2}$).
43-56	INRTA	Moment of inertia of the entire turbine/generator assembly ($kg \cdot m^2$).

Card Set 14. Three sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
NCOMP	NSTGES-1	Component numbers for the associated stages that complete the entire turbine assembly.

Note: If NTRBTB = 0 (word 3 on Card Number 9), omit card set TRBTB.

TRBTB	NTRBTB *2	Generator power demand vs independent-variable-form table. Input (independent-variable form defined by NTRBTB and ITRBSV on Card Number 10, generator power demand) pairs (*,W).
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Note: If NTRBTB = 0 (word 3 on Card Number 9) or NTRBRF = 0 (word 5 on Card Number 9), omit card set TRBRF.

TRBRF	NTRBRF *2	Rate-factor table for the generator power-demand table's independent variable. Input (independent-variable form defined by NTRBSV and NTRBRF on Card Number 10, rate factor to be applied to the generator power-demand table's independent variable) pairs (*,-).
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Note: If NEFCON $\neq$ 0 (word 2 on Card Number 5), omit Card Set 15.

Card Set 15. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ANGL	NROWS*2	Nozzle exit and blade angles (degrees). Input as follows: steam exit angle from the nozzle, first moving blade exit angle, first stationary blade exit angle, second moving blade exit angle, etc.

TURB Array Cards. Nineteen sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m ³).
FA	NCELLS+1	Cell-edge flow areas (m ²).
FRIC	NCELLS+1	Additive loss coefficients (-) [FRIC(2) and FRIC(3) must be 0.0]. (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELLS+1	Gravity terms (-). (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIAL in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELLS+1	Cell-edge choked-flow model options (see ACCUM input description, Sec. V.C.5.a). The value ICFLG = 0 is suggested for this component.
NFF	NCELLS+1	Friction-factor correlation options (see ACCUM input description, Sec. V.C.5.a). The value NFF = 1 is suggested for this component.

Turbine Component (TURB)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
ALP	NCELLS	Initial void fractions (-).
VL	NCELLS+1	Initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).
Note: If ICONC = 0 (word 4 on Card Number 2), omit card set CONC.		
CONC	NCELLS	Initial ratio of solute mass to liquid coolant mass.
Note: If ICONC = 0 or 1 (word 4 on Card Number 2), omit card set S.		
S	NCELLS	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).
Note: If IPOW (word 5 on Card Number 2) or NPOWTB (word 3 on Card Number 3), omit card set POWTB.		
POWTB	NPOWTB *2	Power-to-fluid vs independent-variable-form table. Input (independent-variable form defined by IPOWSV and NPOWTB on Card Number 3, power) pairs (*,W). The power is deposited directly into the fluid in the turbine with a uniform volumetric power density along the turbine length.

Turbine Component (TURB)

Note: If IPOW = 0 (word 5 on Card Number 2), NPOWTB = 0 (word 3 on Card Number 3), or NPOWRF = 0 (word 5 on Card Number 3), omit card set POWRF.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
POWRF	NPOWRF *2	Rate-factor table for the POWTB table's independent variable. Input (independent-variable form defined by NPOWSV and NPOWRF on Card Number 3, rate factor to be applied to the POWTB table's independent variable) pairs (*,-).

Valve Component (VALVE)

1. Valve Component (VALVE).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-5	TYPE	Component type (VALVE left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NCELLS, NODES, JUN1, JUN2, MAT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NCELLS	Number of fluid cells (must be at least two).
15-28	NODES	Number of radial heat-transfer nodes in valve wall. A value of 0 specifies no wall heat transfer.
29-42	JUN1	Junction number for junction adjacent to cell 1.
43-56	JUN2	Junction number for junction adjacent to cell NCELLS.
57-70	MAT	Material ID number of the wall (currently not used).

Card Number 3. (Format 5I14) ICHF, ICONC, LVTY, IVPS, NVTB2

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICHF	CHF calculation flag. 0 = no; 1 = yes.
15-28	ICONC	Flag for input of solute in the liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.

Valve Component (VALVE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	IVTY	<p>Valve-type option.</p> <p>0 = constant flow area;</p> <p>1 = flow-area fraction vs independent-variable-form table is evaluated;</p> <p>2 = relative valve-stem position (0.0 = fully closed, 1.0 = fully opened) vs independent-variable-form table is evaluated;</p> <p>3 = constant flow area until trip is set ON, then flow-area fraction vs independent-variable-form table is evaluated;</p> <p>4 = constant relative valve-stem position until trip is set ON, then relative valve-stem position vs independent-variable-form table is evaluated;</p> <p>5 = valve is to be operated by a special turbine-component signal where increase in generator power demand opens the valve; or</p> <p>6 = Similar to IVTY = 5 except that an increase in generator power demand closes the valve.</p>
43-56	IVPS	<p>The mesh-cell-interface number where the valve flow area is adjusted ($1 < IVPS < NCELLS+1$ unless a BREAK component is at the VALVE component junction; then IVPS can equal 1 or NCELLS+1).</p>

Valve Component (VALVE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NVTB2	The number of second valve table (x,y) pairs (defined by the absolute value of NVTB2). Input NVTB2 = 0 when IVTY = 0, 1, 2, 5, or 6. For IVTY = 3 or 4, NVTB2 > 0 defines the table's independent-variable form to be the IVSV parameter; NVTB2 < 0 defines the table's independent-variable form to be the change in the IVSV parameter over the last time step times the trip set-status value ISET when the valve table is trip controlled; NVTB2 = 0 (when NVTB1 = 0) defines the valve flow-area fraction or relative valve-stem position to be the IVSV parameter value. When NVTB2 = 0 and NVTB1 ≠ 0, no second valve table is defined. Only the first valve table is used. When NVTB2 ≠ 0, NVTB2 and NVTB1 have the same numerical sign, and the first valve table is used when the controlling trip is set to ON _{forward} , and the second valve table is used when the trip is set to ON _{reverse} . NVTB1 = 0, and NVTB2 ≠ 0 is invalid.

Note: For valve-type option IVTY = 5 or 6, variables NVTB2 and IVSV, NVTB1, NVSV, and NVRF on Card Number 4 are defined by zero or left blank, and the arrays VTB1, VTB2, and VRF are not input.

Card Number 4. (Format 5I14) IVTR, IVSV, NVTB1, NVSV, NVRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IVTR	The trip ID number for valve-type option when IVTY = 3 or 4 ($ IVTR < 10000$) or the component number of turbine stage 1 for valve-type option when IVTY = 5 or 6 ($1 \leq IVTR \leq 999$).
15-28	IVSV	The valve-table abscissa-coordinate variable ID number. IVSV defines the independent-variable parameter for the valve-type option IVTY = 1 to 4 tables. IVSV > 0 defines the ID number for a signal-variable parameter; IVSV < 0 defines the ID number for a control-block output parameter.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	NVTB1	The number of first valve table (x,y) pairs (defined by the absolute value of NVTB1). Input NVTB1 = 0 when IVTY = 0, 5 or 6. For IVTY = 1 to 4, NVTB1 > 0 defines the table's independent-variable form to be the IVSV parameter; NVTB1 < 0 defines the table's independent-variable form to be the change in the IVSV parameter over the last time step times the trip set-status value ISET when the valve table is trip controlled; NVTB1 = 0 defines the valve flow-area fraction or relative valve-stem position (depending on the value of IVTY) to be the IVSV parameter.
43-56	NVSV	The rate-factor table abscissa-coordinate variable ID number. NVSV defines the independent-variable parameter for the rate factor that is applied to the first (and second when defined) valve table's independent variable. NVSV > 0 defines the ID number for a signal-variable parameter; NVSV < 0 defines the ID number for a control-block output parameter; NVSV = 0 (when NVRF ≠ 0) defines the difference between the trip signal and the set-point value that turns the trip OFF.
57-70	NVRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NVRF). The rate factor is applied as a factor to the first (and second when defined) valve table's independent variable when the rate factor is defined. No rate factor is defined when NVSV and NVRF are both zero. NVRF > 0 defines the rate-factor table's abscissa coordinate to be the NVSV parameter; NVRF < 0 defines it to be the change in the NVSV parameter over the last time step times the trip set-status value ISET when the valve table is trip controlled; NVRF = 0 defines the rate factor to be the NVSV parameter.

Valve Component (VALVE)

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 5.

Card Number 5. (Format 5I14) IQP3TR, IQP3SV, NQP3TB, NQP3SV, NQP3RF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IQP3TR	The trip ID number that controls evaluation of the power-to-wall table (QP3TB) [$ IQP3TR < 10000$] (input $IQP3TR = 0$ when there is to be no trip control, and the table will be evaluated in the transient.)
15-28	IQP3SV	The independent-variable ID number for the power-to-wall table (QP3TB). $IQP3SV > 0$ defines the ID number for a signal-variable parameter; $IQP3SV < 0$ defines the ID number for a control-block output parameter.
29-42	NQP3TB	The number of (x,y) power-to-wall table (POWTB) pairs (defined by the absolute value of NQP3TB). $NQP3TB > 0$ defines the table's independent-variable form to be the IQP3SV parameter; $NQP3TB < 0$ defines the table's independent-variable form to be the change in the IQP3SV parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; $NQP3TB = 0$ defines the power to the wall to be the IQP3SV parameter.
43-56	NQP3SV	The independent-variable ID number for the rate factor that is applied to the power-to-wall table's independent variable. $NQP3SV > 0$ defines the ID number for a signal-variable parameter; $NQP3SV < 0$ defines the ID number for a control-block output parameter; $NQP3SV = 0$ (when $NQP3RF \neq 0$) defines the independent variable to be the difference between the trip signal and the set-point value that turns the trip OFF when the power-to-wall table is trip controlled.

Valve Component (VALVE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NQP3RF	The number of (x,y) rate-factor table pairs (defined by the absolute value of NQP3RF). The rate factor is applied as a factor to the power-to-wall table's (QP3TB) independent variable when the rate factor is defined. No rate factor is defined when NQP3SV and NQP3RF are both zero. NQP3RF > 0 defines the rate-factor table's independent variable to be the NQP3SV parameter; NQP3RF < 0 defines it to be the change in the NQP3SV parameter over the last time step times the trip set-status value ISET when the power-to-wall table is trip controlled; NQP3RF = 0 defines the rate factor to be the NQP3SV parameter.

Card Number 6. (Format 2I14) IVTROV, IVTYOV

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IVTROV	The trip ID number that overrides trip ID number IVTR (word 1 on Card Number 4) and opens (ON _{forward}) or closes (ON _{reverse}) the valve at the constant rate RVOV (word 2 on Card Number 7) when the trip is ON (input IVTROV = 0 when IVTY = 5 or 6) [$ IVTROV < 10000$].
15-28	IVTYOV	The type of flow-area adjustment by RVOV when the overriding trip IVTROV is ON (not used when IVTY = 5 or 6). 0 = flow-area fraction per second; 1 = relative valve-stem position per second.

Card Number 7. (Format 4E14.6) RVMX, RVOV, FMINOV, FMAXOV

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RVMX	The maximum rate of valve flow-area fraction or relative valve-stem position adjustment (s^{-1}).
15-28	RVOV	The rate of valve flow-area adjustment when the overriding trip IVTROV is ON (s^{-1}) [not used when IVTY = 5 or 6].

Valve Component (VALVE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	FMINOV	The minimum flow-area fraction (IVTYOV = 0) or minimum relative valve-stem position (IVTYOV = 1) during valve adjustment by the overriding trip IVTROV ($0 \leq \text{FMINOV} < \text{FMAXOV}$).
43-56	FMAXOV	The maximum flow-area fraction (IVTYOV = 0) or maximum relative valve-stem position (IVTYOV = 1) during valve adjustment by the overriding trip IVTROV ($\text{FMINOV} < \text{FMAXOV} \leq 1.0$).

Card Number 8. (Format 5E14.6) RADIN, TH, HOUTL, HOUTV, TOUTL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RADIN	Inner radius (m) of the valve wall.
15-28	TH	Valve wall thickness (m).
29-42	HOUTL	HTC ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) between outer boundary of the valve wall and the liquid outside the valve wall.
43-56	HOUTV	HTC ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) between outer boundary of the valve wall and the vapor outside the valve wall.
57-70	TOUTL	Liquid temperature (K) outside the valve wall.

Note: See PIPE input description, Sec. V.C.5.e, for further comments on the HOUTL, HOUTV, TOUTL, and TOUTV heat-transfer parameters.

Card Number 9. (Format 5E14.6) TOUTV, AVLVE, HVLVE, FAVLVE, XPOS

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	TOUTV	Vapor temperature (K) outside the valve wall.
15-28	AVLVE	Valve adjustable-interface flow area (m^2) when the valve is at a flow-area fraction or relative valve-stem position of 1.0 corresponding to 100% open.

Valve Component (VALVE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
29-42	HVLVE	Valve adjustable-interface hydraulic diameter (m) when the valve is 100% open.
43-56	FAVLVE	Initial flow-area fraction at the valve adjustable-interface IVPS (word 4 on Card Number 3). If FAVLVE < 0.0 or > 1.0, FAVLVE is evaluated based on the input XPOS.
57-70	XPOS	Initial relative valve-stem position at the valve-adjustable interface IVPS (0.0 = no flow area, valve closed; 1.0 = AVLVE flow area, valve 100% opened). If $0.0 \leq \text{FAVLVE} \leq 1.0$ is input, a consistent value for XPOS is evaluated in TRAC based on the valve stem controlling a guillotine closure of a circular flow-area cross section. Otherwise, a consistent value of FAVLVE is evaluated in TRAC based on $0.0 \leq \text{XPOS} \leq 1.0$ that is input.

Note: If NODES < 1 (word 2 on Card Number 2), omit Card Number 10.

Card Number 10. (Format 4E14.6) QP3IN, QP3OFF, RQP3MX, QP3SCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	QP3IN	Initial power (W) deposited in the wall and distributed according to the QPPP array. If QP3IN > 0.0, it is the total power to the entire wall. When QP3IN < 0.0 is input, the initial power to the wall in each cell is QP3IN , and the negative sign flags the power to the wall to be a cell-dependent vector of NCELLS (word 1 on Card Number 2) powers. Each (x,y) point of the power-to-wall table (for QP3IN < 0.0) has 1+NCELLS values [an independent-variable value x and NCELLS power values y(z) for cells 1 through NCELLS]. When the power-to-wall table is not being evaluated, the same power value of QP3IN or QP3OFF (if QP3OFF > -1.0×10^{19}) is applied at each of the NCELLS cells.

Valve Component (VALVE)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	QP3OFF	Power (W) to the wall when the controlling trip is OFF after being ON (maintain the last table-evaluated power when the trip was ON if $QP3OFF \leq -1.0 \times 10^{19}$).
29-42	RQP3MX	The maximum rate of change of the power to the wall ($W \cdot s^{-1}$) [$RQP3MX \geq 0.0$].
43-56	QP3SCL	The scale factor (-) for the power-to-wall table. The dependent variable in table QP3TB is multiplied by QP3SCL to obtain the absolute power to the wall.

VALVE Array Cards. Twenty-five sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
DX	NCELLS	Cell lengths (m).
VOL	NCELLS	Cell volumes (m^3).
FA	NCELLS+1	Cell-edge flow areas (m^2).
FRIC	NCELLS+1	Additive loss coefficients (-). (See ACCUM input description, Sec. V.C.5.a.)
GRAV	NCELLS+1	Gravity terms (-). (See ACCUM input description, Sec. V.C.5.a.)
HD	NCELLS+1	Hydraulic diameters (m). (See variable NDIA1 in the NAMELIST data for optional heat-transfer diameters.)

Note: If ICFLOW = 0 or ICFLOW = 1 (default) in the NAMELIST data, do not input array ICFLG.

ICFLG	NCELLS+1	Cell-edge choked-flow model options. (See ACCUM input description, Sec. V.C.5.a.)
NFF	NCELLS+1	Friction-factor correlation options. (See ACCUM input description, Sec. V.C.5.a.)
ALP	NCELLS	Initial void fractions (-).

Valve Component (VALVE)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
VL	NCELLS+1	Initial liquid velocities ($\text{m} \cdot \text{s}^{-1}$).
VV	NCELLS+1	Initial vapor velocities ($\text{m} \cdot \text{s}^{-1}$).
TL	NCELLS	Initial liquid temperatures (K).
TV	NCELLS	Initial vapor temperatures (K).
P	NCELLS	Initial pressures (Pa).
PA	NCELLS	Initial air partial pressures (Pa).
<p>Note: If NODES = 0 (word 2 on Card Number 2), do not enter arrays QPPP, MATID, and TW.</p>		
QPPP	NODES*NCELLS	A nonnormalized power profile (-) in the valve walls. Input for cell 1, node 1 through NODES; then cell 2, node 1 through NODES; etc. If the array is filled with the same nonzero constant, a uniform volumetric heat source for the wall results. The code will normalize the power profile on a node-volume basis (normalized $\text{QPPP}(i)/[\sum \text{QPPP}(i) \text{VOL}(i)]$). Filling the array with ¹ zeros results in no power being deposited in the wall regardless of settings of QP3IN, QP3TB, etc.
MATID	NODES-1	Wall-material ID array specifying material ID between nodes. Dimension is 1 if NODES = 1 and 0 if NODES = 0 (see available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c, or see Sec. V.C.2 to input material properties).
TW	NODES*NCELLS	Initial wall temperatures (K) input in the same order as QPPP.
<p>Note: If ICONC = 0 (word 2 on Card Number 3), omit card set CONC.</p>		
CONC	NCELLS	Initial ratio of solute mass to liquid coolant mass.

Valve Component (VALVE)

Note: If ICONC = 0 or 1 (word 2 on Card Number 3), omit card set S.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
S	NCELLS	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).

Note: If NVTB1 = 0 (word 3 on Card Number 4), omit card set VTB1.

VTB1	NVTB1 *2	First valve-adjustment table. Input (independent-variable form defined by IVSV and NVTB1 on Card Number 4, flow-area fraction or relative valve-stem position) pairs (*,-). Table VTB1 is used when IVTY = 1 to 4.
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Note: If NVTB2 = 0 (word 5 on Card Number 3), omit card set VTB2.

VTB2	NVTB2 *2	Second valve-adjustment table. Input (independent-variable form defined by IVSV on Card Number 4 and NVTB2 on Card Number 3, flow-area fraction or relative valve-stem position) pairs (*,-). If NVTB2 $\neq$ 0 when IVTY = 3 or 4, define the flow-area fraction or relative valve-stem position values in the second valve-adjustment table to vary in the same direction as they do in the first valve-adjustment table; that is, if the flow-area fraction or relative valve-stem position increases in going from left to right in the first valve-adjustment table, define them to increase in going from left to right in the second valve-adjustment table as well.
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Note: If NVTB1 = 0 (word 3 on Card Number 4) or NVRF = 0 (word 5 on Card Number 4), omit card set VRF.

VRF	NVRF *2	Rate-factor table for the first and second valve-adjustment table's independent variable. Input (independent-variable form defined by NVSV and NVRF on Card Number 4, rate factor to be applied to the valve-adjustment table's independent variable) pairs (*,-).
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Valve Component (VALVE)

Note: If NQP3TB = 0 (word 3 on Card Number 5), omit card set QP3TB.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
QP3TB	NQP3TB *2 when QP2IN > 0; NQP3TB *(1+NCELLS)	Power-to-wall independent-variable-form table. Input (independent-variable form defined by IQP3SV and NQP3TB when QP3IN < 0 on Card Number 5, power-to-wall) pairs (*,W). If QP3IN > 0.0, the dependent variable specifies the total power to the entire wall; if QP3IN < 0.0, the dependent variable is a vector specifying the power to the wall at each cell beginning with cell 1.

Note: If NQP3RF = 0 (word 3 on Card Number 5) or NQP3RF = 0 (word 5 on Card Number 5), omit card set QP3RF.

QP3RF	NQP3RF *2	Rate-factor table for the QP3TB table's independent variable. Input (independent-variable form defined by NQP3SV and NQP3RF on Card Number 5, rate factor to be applied to the QP3TB table's independent variable) pairs (*,-).
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Vessel Component (VESSEL)

m. Vessel Component (VESSEL).

Card Number 1. (Format A10,4X,2I14,A30) TYPE, NUM, ID, CTITLE

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-6	TYPE	Component type (VESSEL left-justified).
15-28	NUM	Component ID number (must be unique for each component, $1 \leq \text{NUM} \leq 999$).
29-42	ID	User ID number (arbitrary).
43-72	CTITLE	Hollerith component description.

Card Number 2. (Format 5I14) NASX, NRSX, NTSX, NCSR, IVSSBF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NASX	Number of axial (z) segments (levels).
15-28	NRSX	Number of radial (r) segments (rings).
29-42	NTSX	Number of azimuthal (θ) segments (sectors). Setting NTSX = 1 forces two-dimensional Cartesian (slab) geometry in the VESSEL.
43-56	NCSR	Number of cell-interface sources (component connections).
57-70	IVSSBF	Internal vessel boundary-condition flag; 0 = no internal boundary conditions (default); 2 = first axial level acts as a FILL, last axial level acts as a BREAK; 20 = first axial level acts as a BREAK, last axial level acts as a FILL; or 22 = both the first and last axial levels act as BREAKS.

Vessel Component (VESSEL)

Card Number 3. (Format 5I14) IDCU, IDCL, IDCR, ICRU, ICRL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IDCU	Axial segment level at which the upper elevation is the downcomer upper-boundary elevation. If no downcomer is present, input IDCU = 0 (this is the necessary and sufficient condition to indicate no downcomer as far as automatically setting flow areas to zero).
15-28	IDCL	Axial-segment level at which the upper elevation is the downcomer lower-boundary elevation (if IDCU = 0, input IDCL = 0).
29-42	IDCR	Radial-segment ring at which the outer radius forms the downcomer inner-radial boundary (if IDCU = 0, input IDCR = 0).
43-56	ICRU	Axial-segment level at which the upper elevation is the core upper-boundary elevation (if no core is present, input ICRU = 0).
57-70	ICRL	Axial-segment level at which the upper elevation is the core lower-boundary elevation (if no core is present, input ICRL = 0).

Card Number 4. (Format 5I14) ICRR, ILCSP, IUCSP, IUHP, ICONC

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	ICRR	Radial-segment ring at which the outer radius forms the core outer radial boundary (if no core is present, input ICRR = 0).
15-28	ILCSP	Axial-segment level at which the upper elevation is the lower-core support-plate elevation as used for graphics output [defaults to the value of ICRL (word 5 on Card Number 3) if ILCSP = 0].
29-42	IUCSP	Axial-segment level at which the upper elevation is the upper-core support-plate elevation as used for graphics output [defaults to the value of ICRU (word 4 on Card Number 3) if IUCSP = 0].

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	IUHP "	Axial-segment level at which the upper elevation is the upper-head support-plate elevation as used for graphics output [defaults to the value of IDCU (word 1 on Card Number 3) if IUHP = 0].
57-70	ICONC	Flag for input of solute in the liquid coolant. [Requires ISOLUT = 1 (word 5 on Main-Data Card 6).] 0 = no input; 1 = dissolved solute only; or 2 = both dissolved and plated-out solute.

Card Number 5. (Format 4I14) NFFA, NFFR, NFFT, NVENT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NFFA	Axial friction-factor correlation option (input NFFA = 0).
15-28	NFFR	Radial friction-factor correlation option (input NFFR = 0).
29-42	NFFT	Azimuthal friction-factor correlation option (input NFFT = 0).
43-56	NVENT	Number of vent valves in the VESSEL component. No vent valve or a maximum of one vent valve per connection between cells is allowed; therefore, actual valves may have to be lumped together for each cell.

Card Number 6. (Format 5114) IRPWTY, NDGX, NDHX, NRTS, NHIST

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRPWTY	Neutronic point-kinetics or reactor-power-type option for defining programmed reactivity or reactor power (input parameters required for each option are shown in parentheses). Add 10 to the option value of IRPWTY if reactivity feedback is to be evaluated. For IRPWTY > 14, reactivity feedback is evaluated and edited but is not used because reactor power is defined directly.

<u>IRPWTY</u>	<u>Option</u>
1	Reactor kinetics with constant REACT programmed reactivity (RPOWRI, REACT).
2	Reactor kinetics with table lookup of programmed reactivity (RPOWRI, IRPWSV, NRPWTB, RPWTB).
3	Reactor kinetics with an initial zero programmed reactivity and trip-initiated constant REACT programmed reactivity (RPOWRI, IRPWTR, REACT).
4	Reactor kinetics with initial constant REACT programmed reactivity and trip-initiated table lookup of programmed reactivity (RPOWRI, REACT, IRPWTR, IRPWSV, NRPWTB, RPWTB).
5	Constant reactor power (RPOWRI).
6	Table lookup of reactor power (IRPWSV, NRPWTB, RPWTB).
7	Initial constant reactor power with trip-initiated table lookup of reactor power (RPOWRI, IRPWTR, IRPWSV, NRPWTB, RPWTB).

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	NDGX	The number of delayed-neutron groups (if $NDGX \leq 0$ is input when $IRPWTY = 1, 2, 3, 4, 11, 12, 13, \text{ or } 14$, the code defaults to 6 delayed-neutron groups with the delayed-neutron constants defined internally; input $NDGX = 0$ when $IRPWTY = 5, 6, 7, 15, 16, \text{ or } 17$).
29-42	NDHX	The number of decay-heat groups (if $NDHX \leq 0$ is input when $IRPWTY = 1, 2, 3, 4, 11, 12, 13, \text{ or } 14$, the code defaults to 11 decay-heat groups with the decay-heat constants defined internally; input $NDHX = 0$ when $IRPWTY = 5, 6, 7, 15, 16, \text{ or } 17$).
43-56	NRTS	The number of time steps between edits of the reactor power and reactivity feedback changes (default value is $NRTS = 10$).
57-70	NHIST	The number of (x,y) pairs in the power-history table [input $NHIST \geq 0$ when $IRPWTY = 1, 2, 3, 4, 11, 12, 13, \text{ or } 14$ (when $NHIST = 0$, no power-history table will be input; instead, delayed-neutron and decay-heat concentrations will be input unless $NDSX \neq 0$ and $NDHX \neq 0$ causing equilibrium concentrations to be defined internally); input $NHIST = 0$ when $IRPWTY = 5, 6, 7, 15, 16, \text{ or } 17$].

Note: If $IRPWTY = 1, 5, 11, \text{ or } 15$ (word 1 on Card Number 6), omit Card Number 7.

Card Number 7. (Format 5I14) $IRPWTR, IRPWSV, NRPWTB, NRPWSV, NRPWRF$

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRPWTR	The trip ID number that controls evaluation of the reactivity-power table ($ IRPWTR < 10000$) [$0 < IRPWTR < 10000$ when $IRPWTY = 3, 4, 7, 13, 14, \text{ or } 17$; $IRPWTR = 0$ otherwise].

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	IRPWSV	The reactivity-power table's abscissa-coordinate variable ID number. IRPWSV defines the independent-variable parameter for the reactivity-power table. IRPWSV > 0 defines the ID number for a signal-variable parameter; IRPWSV < 0 defines the ID number for a control-block output parameter ($0 < \text{IRPWSV} < 10000$ when IRPWTY = 2, 4, 6, 7, 12, 14, 16, or 17; IRPWSV = 0 otherwise).
29-42	NRPWTB	The number of reactivity-power table (x,y) (defined by the absolute value of NRPWTB). NRPWTB > 0 defines the table's independent-variable form to be the IRPWSV parameter; NRPWTB < 0 defines the table's independent-variable form to be the change in the IRPWSV parameter over the last time step times the trip set-status value ISET when the reactivity-power table is trip controlled; NRPWTB = 0 defines the reactivity-power table's function to be the IRPWSV parameter.
43-56	NRPWSV	The rate-factor table abscissa-coordinate variable ID number. NRPWSV defines the independent-variable parameter for the rate factor that is applied to the reactivity-power's table independent variable. NRPWSV > 0 defines the ID number for a signal-variable parameter; NRPWSV < 0 defines the ID number for a control-block output parameter; NRPWSV = 0 (when NRPWRF ≠ 0) defines the difference between the trip signal and the set-point value that turns the trip OFF when the reactivity-power table is trip controlled.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	NRPWRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NRPWRF). The rate factor is applied as a factor to the reactivity-power table's independent variable when the rate factor is defined. No rate factor is defined when NRPWSV and NRPWRF are both zero. NRPWRF > 0 defines the rate-factor table's abscissa coordinate to be the NRPWSV parameter; NRPWRF < 0 defines it to be the change in the NRPWSV parameter over the last time step times the trip set-status value ISET when the reactivity-power table is trip controlled; NRPWRF = 0 defines the rate factor to be the NRPWSV parameter.

Card Number 8. (Format 5114) IZPWTR, IZPWSV, NZPWTB, NZPWSV, NZPWRF

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IZPWTR	The trip ID number that controls evaluations of the axial power-shape table ($ IZPWTR < 10000$) [input IZPWTR = 0 when evaluation of the axial power-shape table is not trip controlled].
15-28	IZPWSV	The axial power-shape table's abscissa-coordinate variable ID number. IZPWSV defines the independent-variable parameter for the axial power-shape table. IZPWSV > 0 defines the ID number for a signal-variable parameter; IZPWSV < 0 defines the ID number for a control-block output parameter.
29-42	NZPWTB	The number of axial power-shape table (x,y,z) pairs (defined by the absolute value of NZPWTB). Each pair consists of an abscissa coordinate value x and ICRU-ICRL+1 (Card Number 3) ordinate coordinate values of y(z) defining the axial power shape. NZPWTB > 0 defines the table's independent-variable form to be the IZPWSV parameter; NZPWTB < 0 defines the table's independent-variable form to be the change in the IZPWSV parameter over the last time step times the trip set-status value ISET when the axial power-shape table is trip controlled. NZPWTB = 0 defines the reactor-kinetics table's function to be the IZPWSV parameter.

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NZPWSV	The rate-factor table's abscissa-coordinate variable ID number. NZPWSV defines the independent-variable parameter for the rate factor that is applied to the axial power-shape table's independent variable. NZPWSV > 0 defines the ID number for a signal-variable parameter; NZPWSV < 0 defines the ID number for a control-block output parameter; NZPWSV = 0 (when NZPWRF ≠ 0) defines the difference between the trip signal and the set-point value that turns the trip OFF when the axial power-shape table is trip controlled.
57-70	NZPWRF	The number of rate-factor table (x,y) pairs (defined by the absolute value of NZPWRF). The rate factor is applied as a factor to the axial power-shape table's independent variable when the rate factor is defined. No rate factor is defined when NZPWSV and NZPWRF are both zero. NZPWRF > 0 defines the rate-factor table's abscissa coordinate to be the NZPWSV parameter; NZPWRF < 0 defines it to be the change in the NZPWSV parameter over the last time step times the trip set-status value ISET when the axial power-shape table is trip controlled; NZPWRF = 0 defines the rate factor to be the NZPWSV parameter.

Card Number 9. (Format 5I14) IRFTR, NMWRX, NFCI, NFCIL, NZMAX

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRFTR	Trip ID number for implementing the fuel-rod axial fine-mesh calculation during reflood (no axial fine-mesh calculation is performed if IRFTR = 0).
15-28	NMWRX	Metal-water reaction option. 0 = off; 1 = on.
29-42	NFCI	Fuel-clad interaction (FCI) option (NFCI = 1 performs the dynamic gap conductance calculation). 0 = off; 1 = on.

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
43-56	NFCIL	Maximum number of FCI calculations per time step (input NFCIL = 1 when NFCI = 1).
57-70	NZMAX	Maximum number of rows of nodes used in the fuel-rod conduction calculation.

Card Number 10. (Format 5I14) NRODS, NODES, NODHS, INHSMX, NFBPWT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	NRODS	Total number of calculational fuel rods within the vessel ($NRODS \geq ICRN*NTSX$, the number of core mesh cells in the horizontal plane).
15-28	NODES	Number of radial heat-transfer nodes in the fuel rods (input $NODES \geq 4$ if a core region with $NRODS > 0$ fuel rods is specified; input $NODES = 0$ if no core is specified).
29-42	NODHS	The number of heat-transfer nodes in all the vessel slabs. A value of 1 defaults to the lumped-parameter model ($NODHS \geq 1$).
43-56	INHSMX	The maximum number of interfaces between dissimilar materials in the vessel slabs ($INHSMX \geq 1$; an internal check is made and an error message is printed for inconsistent values).
57-70	NFBPWT	Flag option to replace the radial, axial, or horizontal-plane power shape with a user-defined shape used to average the reactivity-feedback parameters over the core. (For the input value, add 1 for a radial shape, 2 for a axial shape, and 4 for an horizontal-plane shape.)

Card Number 11. (Format 5E14.6) REACT, TNEUT, RPWOF, RRPWMX, RPWSCL

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	REACT	Initial programmed reactivity ($IRPWTY = 1, 2, 4, 11, 12, 14$) or trip-initiated programmed reactivity ($IRPWTY = 3$ or 13) [$REACT = (k - 1) \cdot k^{-1}$ where k is the reactor multiplication constant; both REACT and k have no units].

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	TNEUT	The prompt neutron lifetime (s) [TNEUT ≤ 0.0 defaults internally to TNEUT = 1.625×10^{-5} s].
29-42	RPWOFF	Programmed reactivity (-) [IRPWTY = 3, 4, 13, 14] or reactor power (W) [IRPWTY = 7 or 17] when the reactivity-power controlling trip is OFF after being ON; hold constant the last evaluated value when the trip was ON when RPWOFF $\leq -1.0 \times 10^{19}$.
43-56	RRPWMX	The maximum rate of change of programmed reactivity (s^{-1}) or reactor power ($W \cdot s^{-1}$) [RRPWMX ≥ 0.0].
57-70	RPWSCL	Reactivity-power table's scale factor for programmed reactivity or reactor power. The dependent variable in table RPWTB is multiplied by RPWSCL to obtain the absolute value.

Card Number 12. (Format 4E14.6) RPOWRI, ZPWIN, ZPWOFF, RZPWMX

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	RPOWRI	Initial reactor power (W).
15-28	ZPWIN	The axial power-shape table's abscissa-coordinate variable value corresponding to the initial axial power shape.
29-42	ZPWOFF	The axial power-shape table's abscissa-coordinate variable value corresponding to the axial power shape to be used when the axial power-shape table's controlling trip is OFF after being ON (use the last evaluated axial power shape when the trip was ON when ZPWOFF $\leq -1.0 \times 10^{19}$).
43-56	RZPWMX	The maximum rate of change of any z-interface value in the axial power shape (s^{-1}) [RZPWMX ≥ 0.0].

Vessel Component (VESSEL)

Card Number 13. (Format 5E14.6) SHEL¹_UV, PLDR, PDRAT, FUCRAC, HGAPO

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	SHEL ¹ _U V	In the coordinate system in which the cell-centered elevations of the one-dimensional components are specified, SHEL ¹ _U V is the elevation of the bottom of the vessel. This parameter is used only when IELV = 1 in NAMELIST.
15-28	PLDR	Pellet dish radius (m) [no calculation of pellet dishing is performed if PLDR = 0.0].
29-42	PDRAT	Fuel-rod pitch-to-diameter ratio (-).
43-56	FUCRAC	Fraction of the fuel <u>not</u> cracked (use only if NFCI = 1 on Card Number 9).
57-70	HGAPO	Fuel-rod gap conductance coefficient ($W \cdot m^{-2} \cdot K^{-1}$) [constant for NFCI = 0 on Card Number 9, initial value otherwise].

Card Number 14. (Format 3E14.6) DTXHT(1), DTXHT(2), DZNHT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DTXHT(1)	Maximum ΔT (K) above which rows of nodes are inserted in the fuel-rod conduction calculation during reflood for the nucleate and transition boiling regimes [suggested value: DTXHT(1) = 3.0].
15-28	DTXHT(2)	Maximum ΔT (K) above which rows of nodes are inserted in the fuel-rod conduction calculation during reflood for all boiling regimes except nucleate and transition [suggested value: DTXHT(2) = 10.0].
29-42	DZNHT	Minimum ΔZ (m) below which no additional rows are inserted in the fuel-rod conduction calculation during the reflood calculation (this value comes from the diffusion number).

Vessel Component (VESSEL)

Note: If reactivity feedback is not evaluated $IRPWTY < 11$ (word 1 on Card Number 6), omit Card Numbers 15 to 17.

Note: Card Number 15 has four cards input: the $J = 1$ card defines the fuel temperature reactivity-coefficient table, the $J = 2$ card defines the coolant temperature reactivity-coefficient table, the $J = 3$ card defines the vapor coolant void-fraction reactivity-coefficient table, and the $J = 4$ card defines the boron material concentration reactivity-coefficient table.

Card Number 15. (Format 5I14/5I14/5I14/5I14) $IRCJTB(I,J)$, $I=(1,4)$, $J=(1,4)$

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	$IRCJTB(1,J)$	The number of fuel temperature T_F dependent entries in the J th reactivity-coefficient table $[1 \leq IRCJTB(1,J)]$.
15-28	$IRCJTB(2,J)$	The number of coolant temperature T_C dependent entries in the J th reactivity-coefficient table $[1 \leq IRCJTB(2,J)]$.
29-42	$IRCJTB(3,J)$	The number of vapor coolant void-fraction α dependent entries in the J th reactivity-coefficient table $[1 \leq IRCJTB(3,J)]$.
43-56	$IRCJTB(4,J)$	The number of boron mass to coolant mass ratio (in ppm) B_r dependent entries in the J th reactivity-coefficient table $[1 \leq IRCJTB(4,J)]$.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	IBU(J)	The boron unit's definition flag for the $\partial k/\partial X_J$ reactivity coefficient's x_J derivative parameter,

$$x_4 = \begin{Bmatrix} B_m \\ B_r \end{Bmatrix} \text{ for } IBU(4) = \begin{Bmatrix} 0 \text{ or } 1 \\ -2 \text{ or } -1 \end{Bmatrix},$$

and $f(T_f, T_c, \alpha, B)$ tabular dependence,

$$B = \begin{Bmatrix} B_m \\ B_r \end{Bmatrix} \text{ for } IBU(J) = \begin{Bmatrix} -1 \text{ or } 1 \\ -2 \text{ or } 0 \end{Bmatrix},$$

where B_m is the macroscopic density in the coolant-channel volume in $\text{kg} \cdot \text{m}^{-3}$ units, and B_r is the mass ratio of parts boron per million parts liquid coolant in ppm units.

Note: On Card Number 16, the reactivity-coefficient type form numbers are defined as follows: $IRCJFM(J) = 0$ for $\partial k/\partial x$, $IRCJFM(J) = 1$ for $(1/k) \cdot \partial k/\partial x \approx \partial R/\partial x$, $IRCJFM(J) = 2$ for $x \cdot \partial k/\partial x$, and $IRCJFM(J) = 3$ for $(x/k) \cdot \partial k/\partial x \approx x \cdot \partial R/\partial x$ where $x = T_f$ (K) for $J = 1$, $x = T_c$ (K) for $J = 2$, $x = \alpha$ for $J = 3$, and $x = \text{boron}$ for $J = 4$ (see variable IBU(J), word 5 on Card Number 15, for boron units).

Card Number 16. (Format 5114) $IRCJFM(J)$, $J = (1,4)$, ISNOTB

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IRCJFM(1)	The form number for the fuel temperature reactivity-coefficient type.
15-28	IRCJFM(2)	The form number for the coolant temperature reactivity-coefficient type.
29-42	IRCJFM(3)	The form number for the vapor coolant void fraction reactivity-coefficient type.
43-56	IRCJFM(4)	The form number for the boron material concentration reactivity-coefficient type.

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
57-70	ISNOTB	Flag to exclude solute material from the boron for the reactivity-feedback calculation. 0 = no (the solute is assumed to be boron); 1 = yes.

Card Number 17. (Format 5E14.6) POWEXP, BPP0, BPP1, BCRO, BCR1

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	POWEXP	The exponent value to which the cell values of the power distribution are raised in defining the weighting function for averaging the reactivity-feedback parameters over the core (suggested value: POWEXP = 2.0). For additional information, see the definition of POWEXP in the CORE input (Sec. V.C.5.c, Card Number 19).
15-28	BPP0	The zero-order coefficient of the first-order polynomial $B_{mBPP} = BPP0 + BPP1 \cdot T_c$ defining the effective (smeared and shielded) core-averaged concentration of burnable-poison pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3}$). See Eq. (177).
29-42	BPP1	The first-order coefficient of the first-order polynomial $B_{mBPP} = BPP0 + BPP1 \cdot T_c$ defining the effective (smeared and shielded) core-averaged concentration of burnable-poison pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3} \cdot \text{K}^{-1}$). The core-averaged coolant temperature is T_c . See Eq. (177).
43-56	BCRO	The zero-order coefficient of the first-order polynomial $B_{mBCR} = BCRO + BCR1 \cdot \rho_{\text{PROG}}$ defining the effective (smeared and shielded) core-averaged concentration of control-rod-pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3}$). See Eq. (178).
57-70	BCR1	The first-order coefficient of the first-order polynomial $B_{mBCR} = BCRO + BCR1 \cdot \rho_{\text{PROG}}$ defining the effective (smeared and shielded) core-averaged concentration of control-rod-pin boron in the coolant-channel volume ($\text{kg} \cdot \text{m}^{-3}$). Programmed reactivity, ρ_{PROG} , has no units. See Eq. (178).

Vessel Component (VESSEL)

VESSEL Geometry Cards. Three sets of cards, one set for each of the following variables. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
Z	NASX	Upper elevations (m) of axial-segment levels (referenced to zero elevation at the bottom interface of the first axial-segment level in the vessel).
RAD	NRSX	Outer radii (m) of radial-segment rings.
TH	NTSX	Theta angles (radians or degrees) at azimuthal-segment ends. For NTSX = 1, the VESSEL component is two-dimensional, and x-y Cartesian (slab) geometry applies.

Omit the next two card types if NVENT = 0 (word 4 on Card Number 5).

VESSEL Vent-Valve Location and Area Cards. (Format 2I14,E14.6) IZV, KV,
AVENT One card per cell with the vent valve on the outer radial surface.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	IZV	Axial-segment level in the vessel.
15-28	KV	Horizontal-plane relative-cell number.
29-42	AVENT	Total area (m**2) of the vent valve in outer radial wall of the cell.

VESSEL Vent-Valve Pressure-Drop and Friction-Loss Cards.

(Format 4E14.6) DPCVN, DPOVN, FRCVN, FROVN
One card per cell with the vent valve on the outer radial surface.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DPCVN	Maximum pressure drop (Pa) between the inner and outer radial cells for the vent valve to be closed.

Vessel Component (VESSEL)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
15-28	DPOVN	Minimum pressure drop (Pa) between the inner and outer radial cells for the vent valve to be opened.
29-42	FRCVN	Additive friction-loss coefficient for the vent valve in its closed position.
43-55	FROVN	Additive friction-loss coefficient for the vent valve in its open position.

VESSEL Source Cards. (Format 4I14) LISRL, LISRC, LISRF, LJUNS
 One card for each of the NCSR (word 4 on Card Number 2) component-connection sources. See vessel description, Sec. IV.K.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	LISRL	Axial-segment level number associated with the source.
15-28	LISRC	Horizontal-plane relative-cell number associated with the source.
29-42	LISRF	Face number associated with the source. 1 = azimuthal direction; 2 = axial direction; or 3 = radial direction. A positive number indicates a connection to the top, outer radius or second azimuthal face of the cell; a negative number indicates a connection to the bottom, inner radius or first azimuthal face of the cell.
43-56	LJUNS	Junction number associated with the component source.

Vessel Component (VESSEL)

VESSEL Core Cards. Thirty-one sets of cards, one for each of the following variables. Omit these cards if there is no core. Use LOAD format.

Note: See Sec. IV.K for precise definitions of the following parameters and the ordering convention: used for reading in the data. Many parameters are read in with dimension ICRR*NTSX (word 1 on Card Number 4 and word 3 on Card Number 2). These parameters are supplied for each (r,θ) mesh cell in the horizontal-plane core region. Each such cell constitutes one of the axial channels in the core formed by a stack of mesh cells with the same (r,θ) mesh boundaries. Each (r,θ) mesh cell encloses a number of fuel rods and their associated coolant channels.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
RDPWR	NODES	Relative radial-power density at the node positions.
CPOWER	ICRR*NTSX	Relative power density in each (r,θ) mesh cell in the horizontal plane for the average fuel rod.
IDROD	NRODS-ICRR*NTSX	Horizontal-plane cell numbers where the additional fuel rods are placed.
RPKF	NRODS-ICRR*NTSX	Fuel-rod power-peaking factors (relative to the average fuel rod in the mesh cell) for the additional rods.

Note: If NZPWTB = 0 (word 3 on Card Number 8), omit card set ZPWTB.

ZPWTB	NZPWTB * (1+(ICRU-ICRL+1))	Axial power-shape vs independent-variable form table. Input [independent-variable form defined by IZPWSV and NZPWTB on Card Number 8, axial power-shape densities having (ICRU-ICRL+1) values] pairs (*,-). The relative axial-power densities defining the axial-power shape are specified at the axial-segment level interfaces from one end of the fuel rod to the other. There are NZPWTB axial power shapes being input with each having (ICRU-ICRL+1) values.
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Vessel Component (VESSEL)

Note: If NZPWTB = 0 (word 3 on Card Number 8) or NZPWRF = 0 (word 5 on Card Number 8), omit card set ZPWRF.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
ZPWRF	NZPWRF *2	Rate-factor table for the axial power-shape table's independent variable. Input (independent-variable form defined by NZPWSV and NZPWRF on Card Number 8, rate factor to be applied to the axial power-shape table independent variable) pairs (*,-).

RDX	ICRR*NTSX	Number of fuel rods in each (r,θ) mesh cell of the core (these are real numbers, not integers; fractional rods are allowed).
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RARD	NODES	Fuel-rod radii (m) [cold].
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Note: Only one MATRD element may have the value 3; and MATRD(1) and MATRD(NODES-1) cannot be 3. Additional material properties can be input (Sec. V.C.2).

MATRD	NODES-1	Fuel-rod material ID numbers [dimension is 1 if NODES = 1 (word 2 on Card Number 10)].
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<u>ID</u>	<u>Material Type</u>
1	Mixed-oxide fuel
2	Zircaloy
3	Fuel-clad gap gases
4	Boron-nitride insulation
5	Constantan/Nichrome heater wire
6	Stainless steel, type 304
7	Stainless steel, type 316
8	Stainless steel, type 347
9	Carbon steel, type A508
10	Inconel, type 718
11	Zircaloy dioxide
12	Inconel, type 600

Vessel Component (VESSEL)

Note: If NRPWTB = 0 (word 3 on Card Number 7), omit card set RPWTB.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
RPWTB	NRPWTB *2	Programmed-reactivity or reactor-power vs independent-variable-form table. Input (independent-variable form defined by IRPWSV and NRPWTB on Card Number 7, programmed reactivity or reactor power as defined by IRPWTY) pairs (*,- or W).

Note: If NRPWTB = 0 (word 3 on Card Number 7) or NRPWRF = 0 (word 5 on Card Number 7), omit card set RPWRF.

RPWRF	NRPWRF *2	Rate-factor table for the programmed-reactivity or reactor-power table's independent variable. Input (independent-variable form defined by NRPWSV and NRPWRF on Card Number 6, rate factor to be applied to the programmed-reactivity or reactor-power table's independent variable) pairs (*,-).
-------	-----------	---

Note: If IRPWTY < 11 (word 1 on Card Number 6), omit card sets RCTF, RCTC, RCAL, and RCBM. Additional information pertinent to these card sets is given in the note and example preceding the description of card set RCTF in the CORE input (Sec. V.C.5.c).

RCTF	IRCJTB(1,1)+IRCJTB(2,1)+ IRCJTB(3,1)+IRCJTB(4,1)+ (IRCJTB(1,1)*IRCJTB(2,1)* IRCJTB(3,1)*IRCJTB(4,1))	The fuel-temperature reactivity-coefficient table. Input IRCJTB(1,1) T_F values, IRCJTB(2,1) T_C values, IRCJTB(3,1) α values, IRCJTB(4,1) B_r values, and IRCJTB(1,1)*IRCJTB(2,1)*IRCJTB(3,1)*IRCJTB(4,1) fuel-temperature reactivity-coefficient values that define the four-dimensionally dependent table. [Note: this table and the following three tables are <u>not</u> entered with (x,y) pair values as is done for the one-dimensionally dependent tables.]
RCTC	IRCJTB(1,2)+IRCJTB(2,2)+ IRCJTB(3,2)+IRCJTB(4,2)+ (IRCJTB(1,2)*IRCJTB(2,2)* IRCJTB(3,2)*IRCJTB(4,2))	The coolant-temperature reactivity-coefficient table.

Vessel Component (VESSEL)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
RCAL	IRCJTB(1,3)+IRCJTB(2,3)+ IRCJTB(3,3)+IRCJTB(4,3)+ (IRCJTB(1,3)*IRCJTB(2,3)* IRCJTB(3,3)*IRCJTB(4,3))	The vapor-coolant void-fraction reactivity-coefficient table.
RCBM	IRCJTB(1,4)+IRCJTB(2,4)+ IRCJTB(3,4)+IRCJTB(4,4)+ (IRCJTB(1,4)*IRCJTB(2,4)* IRCJTB(3,4)*IRCJTB(4,4))	The boron-mass-concentration reactivity-coefficient table.

Note: If power option [IRPWTY = 5, 6, 7, 15, 16, or 17 (word 1 on Card Number 6)] is specified, omit card sets BETA, LAMDA, CDGN, LAMDH, EDH, CDHN, and PHIST.

Note: If $NDGX \leq 0$ (word 2 on Card Number 6) was input, omit card sets BETA and LAMDA. The default 6 group delay-neutron constants will be defined internally.

BETA	NDGX	The effective delayed-neutron fraction.
LAMDA	NDGX	The delayed-neutron decay constant (s^{-1}).

Note: Use card set CDGN only if $NDGX > 0$ (word 2 on Card Number 6) and NHIST = 0 (word 5 on Card Number 6) were input.

CDGN	NDGX	The delayed-neutron precursor concentration (W).
------	------	--

Note: If $NDHX \leq 0$ (word 3 on Card Number 6) was input, omit card sets LAMDH and EDH. The default 11 group decay-heat constants will be defined internally.

LAMDH	NDHX	The decay-heat decay constant (s^{-1}).
EDH	NDHX	The effective decay-heat energy fraction.

Vessel Component (VESSEL)

Note: Use card set CDHN only if NDHX > 0 (word 3 on Card Number 6) and NHIST = 0 (word 5 on Card Number 6) were input.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
CDHN	NDHX	The decay-heat concentration (W · s).

Note: If NHIST = 0 (word 5 on Card Number 6), omit card set PHIST.

PHIST	NHIST*2	Power-history table. Input (present time minus past time, reactor-core prompt-fission power at that past time) pairs (s,W) [the first pair should be for the present power, that is, the time interval 0.0, with the time interval for subsequent pairs being positive and increasing monotonically for each pair].
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NFAX	ICRU-ICRL	Number of permanent fine-mesh intervals per coarse-mesh interval added at the start of the reflood calculation [the total number of heat-transfer rows per fuel rod must be less than NZMAX (word 5 on Card Number 9)].
------	-----------	---

FPUO2	ICRR*NTSX	Fraction of plutonium dioxide (PuO ₂) in mixed-oxide fuel.
-------	-----------	--

FTD	ICRR*NTSX	Fraction of theoretical fuel density.
-----	-----------	---------------------------------------

GMIX	ICRR*NTSX*7	Mole fraction of gap-gas constituents. Array is not used if NFCI = 0 but must be input. Enter data for each gas in the order indicated.
------	-------------	---

<u>Index</u>	<u>Gas</u>
1	Helium
2	Argon
3	Xenon
4	Krypton
5	Hydrogen
6	Air/nitrogen
7	Water vapor

GMLES	ICRR*NTSX	Moles of gap gas per fuel rod (not used, but must be input).
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Vessel Component (VESSEL)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
PGAPT	ICRR*NTSX	Average gap-gas pressure (Pa) [not used if NFCI = 0, but must be input].
PLVOL	ICRR*NTSX	Plenum volume (m^3) in each fuel rod above the pellet stack (not used, but must be input).
PSLEN	ICRR*NTSX	Pellet-stack length (m) [not used, but must be input].
CLENN	ICRR*NTSX	Total cladding length (m) [not used, but must be input].

VESSEL Level Cards. Thirty sets of cards, one for each of the following variables. Use LOAD format. The 30 sets of cards are input for each axial segment level, or if desired, an entire level can be repeated by a single REPEAT LEVEL card. (See description after the level data description.)

Note: The following parameters (dimensioned NRSX*NTSX defined on Card Number 2) are read in for each (r,θ) mesh cell at each axial-segment level, that is, they extend over the entire vessel horizontal plane for each axial-segment level. Because a separate data set is read for each axial-segment level, these parameters are supplied for all mesh cells in the vessel.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
HSA	NRSX*NTSX	Heat-slab area (m^2) [if no slab is desired in a cell, input 0.0 for the area].
HSX	NODHS*NRSX*NTSX	Heat-slab node position (m). For each cell, HSX should increase monotonically; the first node sees the adiabatic boundary, and node NODHS (word 3 on Card Number 10) sees the fluid heat-transfer boundary. All NODHS values for a given cell are input together. The code assumes Cartesian geometry. When NODHS = 1, HSX is the thickness of the heat slab.

Vessel Component (VESSEL)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
CFZL-T	NRSX*NTSX	Liquid additive-friction-loss coefficients (θ -direction).
CFZL-Z	NRSX*NTSX	Liquid additive-friction-loss coefficients (z-direction).
CFZL-R	NRSX*NTSX	Liquid additive-friction-loss coefficients (r-direction).
CFZV-T	NRSX*NTSX	Vapor additive-friction-loss coefficients (θ -direction) [this variable is not used in this code version].
CFZV-Z	NRSX*NTSX	Vapor additive-friction-loss coefficients (z-direction).
CFZV-R	NRSX*NTSX	Vapor additive friction-loss coefficients (r-direction).

Note: See variable IKFAC and NFRC3 in the NAMELIST data for optional K factors and reverse loss coefficients, respectively.

VOL	NRSX*NTSX	Cell fluid volume fractions.
FA-T	NRSX*NTSX	Cell fluid-edge average-area fractions (θ -direction).
FA-Z	NRSX*NTSX	Cell fluid-edge average-area fractions (z-direction).
FA-R	NRSX*NTSX	Cell fluid-edge average-area fractions (r-direction).
HD-T	NRSX*NTSX	Hydraulic diameters (m) [θ -direction].
HD-Z	NRSX*NTSX	Hydraulic diameters (m) [z-direction] (for heat-transfer purposes, do not input the axial hydraulic diameter as 0.0).
HD-R	NRSX*NTSX	Hydraulic diameters (m) [r-direction].

Note: See variable NDIA3 in the NAMELIST data for optional heat-transfer diameters.

HSTN	NODHS*NRSX*NTSX	Heat-slab temperatures (K) [do not input temperatures of 0.0 K].
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Vessel Component (VESSEL)

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
MATHS	(NODHS-1)*NRSX*NTSX	Heat-slab material ID numbers specifying the material between nodes. All material ID numbers must be defined. (See available built-in properties listed with array MATID in the CORE input, Sec. V.C.5.c, or see Sec. V.C.2 to input material properties.) [Input (NODHS*NRSX*NTSX) when NODHS = 1; NODHS = 0 is not allowed.]
ALPN	NRSX*NTSX	Vapor fraction (-).
VVN-T	NRSX*NTSX	Vapor velocity ($\text{m} \cdot \text{s}^{-1}$) [θ -direction].
VVN-Z	NRSX*NTSX	Vapor velocity ($\text{m} \cdot \text{s}^{-1}$) [z-direction].
VVN-R	NRSX*NTSX	Vapor velocity ($\text{m} \cdot \text{s}^{-1}$) [r-direction].
VLN-T	NRSX*NTSX	Liquid velocity (θ -direction).
VLN-Z	NRSX*NTSX	Liquid velocity (z-direction).
VLN-R	NRSX*NTSX	Liquid velocity (r-direction).
TVN	NRSX*NTSX	Vapor temperature (K).
TLN	NRSX*NTSX	Liquid temperature (K).
PN	NRSX*NTSX	Pressure (Pa).
PAN	NRSX*NTSX	Air partial pressure (Pa).

Note: If ICONC = 0 (word 5 on Card Number 4), omit card set CONC.

CONC	NRSX*NTSX	Initial ratio of solute mass to liquid coolant mass.
------	-----------	--

Note: If ICONC = 0 or 1 (word 5 on Card Number 4), omit card set S.

S	NRSX*NTSX	Initial macroscopic density of plated-out solute ($\text{kg} \cdot \text{m}^{-3}$).
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Vessel Component (VESSEL)

REPEAT LEVEL Card. (Format A12,2X,I14) This card can be used to repeat the data from one level to another. As many of these cards can be used as needed. Each REPEAT LEVEL card should be placed after the data for the preceding level and before the data for the next level. These cards may be used consecutively.

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-12	AREP	The character string: "REPEAT LEVEL"
15-18	NLEV	The number of the level to be repeated. The value of NLEV must be greater than zero but less than the number of the level to be defined.

VESSEL Fuel-Rod Cards. Two sets of cards, one for each of the following variables. Both card sets are input for each of NRODS (word 1 on Card Number 10) fuel rods, including each average rod and each additional rod. Omit these cards if there is no core. Use LOAD format.

<u>Variable</u>	<u>Dimension</u>	<u>Description</u>
BURN	(ICRU-ICRL+1)	Fuel burnup (MWD/MTU).
RFTN	NODES*(ICRU-ICRL+1)	Initial fuel-rod temperatures (K).

6. Time-Step Data. The last data block of input information is the time-step cards for directing the calculation and output edit. The problem time span is separated into time domains. Each domain (specified by two cards) may have different minimum and maximum time-step sizes and edit intervals. Any number of time domains may be input. The end of the calculation is specified by making the minimum time-step size a negative number. The format of each set of two time-step cards follows.

Card Number 1. (Format 4E14.6) DTMIN, DTMAX, TEND, RTWFP

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	DTMIN	Minimum allowable time-step size (s) for this time domain.
15-28	DTMAX	Maximum allowable time-step size (s) for this time domain.
29-42	TEND	End time (s) of this time domain.
43-56	RTWFP	Ratio between heat-transfer and fluid-dynamics time-step sizes. (Normally used only for steady-state calculations: suggested value = 10.0; a negative value of RTWFP forces the use of a scaling RTWFP even during a transient.)

Card Number 2. (Format 4E14.6) EDINT, GFINT, DMPINT, SEDINT

<u>Columns</u>	<u>Variable</u>	<u>Description</u>
1-14	EDINT	Print-edit time interval (s) for this time domain.
15-28	GFINT	Graphics-edit time interval (s) for this time domain.
29-42	DMPINT	Restart-dump time interval (s) for this time domain.
43-56	SEDINT	Short-print-edit time interval (s) for this time domain.

D. LOAD Subroutine

The TRAC program uses the LOAD subroutine to read most subscripted array variables. The arrays may be read in floating point or integer format. The input card images for subscripted variables consist of up to six fields. The first five fields consist of an (A1), a repeat count (I2) [for operations R, M, and I], and a floating point or integer data constant (E11.2 or I11) [except for operations E and S]. The sixth field can be used for the operation E only if the array data end in the fifth field. In formatted input decks, cards with an asterisk in column 1 are ignored and may be used for spacers or for comments.

Seven operations are defined. These operations and an explanation of each are listed below.

<u>Operation</u>	<u>Description</u>
F	Fill array starting at current data index with data constant
BLANK	No action
R	Repeat data constant I2 times
M	Multiple repeat. Repeat data constant 10*I2 times
I	Interpolate between data constant and succeeding data constant with I2 points
E	End of data array (<u>must</u> be followed by at least one blank)
S	Skip to next card

Some restrictions in the use of the LOAD format are

1. end of data for an array must be signaled by E,
2. overstore or partial fill of an array is not allowed,
3. integer interpolation is not allowed, and
4. data for different arrays must be on different records.

Following are examples of the use of the options listed above to fill an array of dimension 11 with data.

EXAMPLE 1. Fill an integer array with a value of 61.

F^^^^^^^^61E

EXAMPLE 2. Use of the repeat option to fill an array with a value of 1.2.

R11^^^^1.2^^E

EXAMPLE 3. Use of the skip option.

R.2.....15.....16S

R.5.....17.....18.....19.....20E

EXAMPLE 4. Use of the multiple repeat option to fill an array
with 101 values.

M10.....1.56E-2......0156E

EXAMPLE 5. Use of the interpolation option to get points
1.0, 2.0, 3.0, ..., 11.0.

I.9.....1.....11.E

E. Free Format

Appendix E shows part of a TRACIN deck in free format that illustrates the points discussed here.

Section V.F gives the TRAC-PF1/MOD1 input specifications for formatted input. When the free-format option is chosen, TRAC-PF1/MOD1 internally converts a free-format TRACIN deck to a new deck in TRAC format that is written to a file called TRCINP. File TRCINP is read subsequently and automatically by the standard input routines. Therefore, to use the free-format option, all cards must be kept in the same order as shown in Sec. V.C, and all variables must stay in the same order on those cards. Input records may be up to 80 columns long. All data that is not read by the LOAD routine must be delimited by at least one blank column. (However, data may start in column 1 or end in column 80.) Array data to be read by the LOAD routine may be blank delimited; delimited by any of the LOAD control characters, F, R, S, I, M, or E; or delimited by a control-character repeat count. (The integer zero should be entered explicitly.) As with the formatted input, free-format arrays read by the LOAD subroutine are limited to a maximum of five data entries per input card image.

Note the following examples, all of which will run in free-format mode.

F¹⁰1.0E+07E

also TRAC format

F¹1.0E+07E

F¹1.0E+07E

F1.0E+07E

F¹⁰1.0E+07¹⁰E

etc.

free format

R10¹⁰1.0E+07R²2¹⁰1.1E+07

also TRAC format; both modes read 10 repeats, 2 repeats

R1¹⁰1.0E+07

free-format reads 1 repeat; TRAC format (I2) reads 10 repeats

R¹10¹1.0E+07¹R²2¹1.1E+07

R¹⁰10¹⁰1.0E+07R²2¹⁰1.1E+07

R¹⁰101.0E+07¹⁰R²2¹1.1E+07

etc.

free format; all three read 10 repeats, 2 repeats

Note the R¹⁰101.0E+07 example. The free-format parser scans to the first character after the R; it includes the next character in the repeat count if that character is a nonblank numeric. There is one exception to this rule: a situation such as R¹12.3456E+07, where the control character is followed by one space, a two-digit repeat count, and a nonblank column. To facilitate conversion of existing TRAC-format decks, this field is assumed to indicate 1 repeat of 12.3456E+07, not 11 of 2.3456E+07. The following examples will give 11 repeats:

R11²2.3456E+07

R¹11²2.3456E+07

R¹112.3456E+07

R112.3456E+07

The E character of the LOAD subroutine is recognized as part of the string 'E^'^ so the three columns after the E should be blank. The E can appear in column 78, 79, or 80 with any remaining columns blank.

The LOAD data must be 11 characters or less; non-LOAD data, 14 or less.

The requirement to blank-delimit data carries with it the requirements that embedded and significant trailing blanks be entered explicitly as zero. The user of the free-format option also should note that to run previously formatted decks that have all-blank 14-column fields meant to represent zero, the zero must be entered explicitly. Of course, this is not necessary for trailing fields. In this regard, note for example the one-dimensional component variable IHYDRO that currently is not used by TRAC-PF1/MOD1. A dummy value must be input for this variable.

The NAMELIST input currently is implemented using CDC-FTN-FORTRAN. The format is essentially free, but there are a few restrictions that are discussed in Sec. V.F.

1. Free-Format Comments, Problem Title Cards, and Hollerith Component Descriptions. Free-format TRACIN decks may be annotated with user comments. These comments must be delimited by asterisks (*) in unbroken strings of any length. The first card of the deck is an exception to this requirement. Comments and their delimiters are equivalent to blank columns. Should an input record have an odd number of comment delimiters (where *, **, ***, ****, etc. are all considered to be a single delimiter), everything on the record to the right of the last delimiter is considered a comment. The code will attempt to read information after even-numbered comment delimiters and before odd-numbered delimiters as input data. Entire records may be comments, for example, by making the first nonblank character an asterisk and not inserting any more comment delimiters on the line. Comments and comment cards may appear anywhere in the deck except

1. in and immediately before the problem title cards,
2. before Main Control Card Number 1, or
3. within NAMELIST group records (see additional comments on NAMELIST in Sec. V.C).

The NUMTCR title cards immediately following Main Control Card Number 2 (from which NUMTCR is read) are written to TRCINP exactly as they are read: asterisks, blank cards, and all. Blank and comment cards may appear between

the first two main control cards and immediately after the NUMTCR title cards. Hollerith descriptions of individual components (the CTITLE information) are written to TRCINP, left-justified, starting in column 43. Asterisk strings in component descriptions are treated as comment delimiters.

2. Free-Format Input-Error Handling. The free-format option provides advantages over formatted runs in handling of many types of input errors. Free-format input error handling occurs during two stages, first as TRACIN is being converted to TRCINP and later as TRCINP is being read. In the first stage, when an error is detected (such as detectable errors that might arise from failure to blank-delimit data properly, for example, using 1.OE.07 instead of 1.OE07 or 1.OE+07) processing of the record in question is halted immediately, subroutine ERROR is called to send warning messages, and the record is flagged with `\*ERROR` starting in column 75 before it is written to TRCINP. Currently, warning messages will stop after 50 cards have been detected in error, but the input processing will continue. In the second stage, under most circumstances a fatal FORTRAN input error will not force an immediate program abort; the entire deck will be processed and appropriate error messages issued before program termination. An exception to this situation occurs in the case of fatal NAMELIST errors.

In situations where there are no errors detected but input problems are suspected, it is suggested that the user inspect the file TRCINP, where faulty records may be readily apparent.

F. NAMELIST Format

The NAMELIST statement is an extremely useful--but nonstandard--FORTRAN statement that can be used to input selectively values to subsets of groups of variables named in a program. The user-convenience features in TRAC available through NAMELIST input options are described in Sec. V.C, "TRAC-PF1 Input Specifications." The TRAC NAMELIST options are implemented using NAMELIST as described in the CDC-FTN-FORTRAN manual. (A somewhat more flexible NAMELIST is available at Los Alamos.) The reader is referred to the FTN manual for details. Here we point out that, although NAMELIST is essentially in free format, there are certain restrictions. At present these restrictions apply to all TRAC input decks, whether or not the TRAC free-format option is selected.

The restrictions include the following (where Los Alamos-available extensions are indicated in parentheses).

1. Hollerith constants are not allowed (allowed).
2. The first column of all physical records is ignored [terminating dollar sign (\$) can appear in any column].
3. There must be no embedded blanks in the string \$NAME, where NAME is a NAMELIST group name; there must be at least one trailing blank. The initial \$ must appear in column 2.
4. Free-format *-delimited user comments are not allowed on NAMELIST cards. Also, free-format comment cards are not allowed among the physical records of a NAMELIST group record, although all-blank cards are allowed.

As an example, the following five cards might be used to input data for the NAMELIST group INOPTS (described in Sec. V.C).

```
123456789...
```

```
^ $INOPTS^ IELV=1,^^ IKFAC^=^1,
```

```
^^^ ISTOPT=2,
```

```
^ ALP=0.,VL=0.,VV=0.,TL=550.,TV=550.,
```

```
^^P=1.55E+07,PA=0.,QPPP=0.,^TW=5.5E+02,HSTN=550.,
```

```
^ $END
```

G. Output Files

Figure 49 shows the files read and written by TRAC during a problem. We discussed the two input files, TRACIN and TRCRST, in Sec. V.A, the free-format option output-input file TRCINP in Sec. V.E, and the dump output file, TRCDMP, in Sec. V.B. This section describes the remaining three output files, TRCOUT, TRCGRF, and TRCMMSG.

The TRCOUT file contains printer output. This file is produced with standard FORTRAN write statements contained in the various component module output subroutines.

Included are complete descriptions of the problem input file that was read by the code and the time edits that are produced with a frequency specified on the time-step cards. Each time edit includes a printout of results from each component in a problem. The component output includes pressures, temperatures, and other important results. The TRAC error messages,

Fig. 49.
TRAC input and output files.

if any, also are written in the TRCOUT file. Appendix F describes these messages. Section IV gives a more complete description of individual component output.

The TRCGRF file contains graphics output and is a structured binary file produced with unformatted write statements. This file structure is discussed in Sec. VI.C. A Livermore Time-Sharing System (LTSS) library computer code, GRIT, generates plots of the problem calculation from the TRCGRF file. A versatile graphics package TRAP/EXCON also has been developed to produce high-quality plots and movies from the TRCGRF file. This package is designed for the Los Alamos National Laboratory CDC 7600 computer and is documented separately.

The TRCMSG file contains warning messages that are sometimes produced by various computational modules within TRAC. These warnings, written with formatted input/output (I/O), indicate difficulty with the progress of the problem.

VI. PROGRAMMING DETAILS

A. Overall Code Organization

During TRAC development, much attention was paid to the programming techniques. The decision was made to strive for a code structure that minimizes the problems of maintaining and extending the code. In addition, we attempted to program in a manner that is understandable to knowledgeable persons in the LWR safety field and that reduces the difficulties of implementing TRAC at other sites and/or computers. We also recognized that we should take advantage of the Laboratory's efficient computing facility. In this case, the system includes CDC 7600 computers running LTSS and Cray computers running CTSS. In conflict situations, we ranked the importance of these goals in the order in which they have been presented. Whenever possible, we segregated specialized coding to subprograms that perform specific, low-level service functions.

To attain these goals, our philosophy has been modularity. The TRAC program is modular in two important ways. Because it analyzes reactor systems that consist of specific types of components, the program contains subroutines that treat each component type. The TRAC components are described in Sec. IV. This modularity simplifies both the subroutine programming and the data associated with particular components. For example, because fuel rods are associated only with the VESSEL and CORE components, no fuel-rod data are referenced nor are fuel-rod calculations performed by the subroutines that treat any other component.

Second, the TRAC program is functionally modular; that is, each TRAC subprogram performs a specific function. If the performance of a function requires modification, only those routines that perform that function must be altered. For example, if the dump/restart capability needs modification, only those routines that perform the dump/restart for the affected components require changes. Some low-level subprograms are used by all components, thereby strengthening this modularity. The most important low-level routines and a brief description of their functions are listed in Table XV. All TRAC subroutines are described in App. G.

In its simplest form, TRAC has no overlays, and all data reside in the main memory. One overlay structure is available, as is a split in data storage between small- and large-core memories. Some modifications of the

TABLE XV
IMPORTANT LOW-LEVEL SUBPROGRAMS

<u>Subprogram</u>	<u>Description</u>
BKMOM	Initiates backward substitution for stabilizing momentum equations.
BKSSTB	Initiates backward substitution for stabilizing mass and energy equations.
CHEN	Uses Chen correlation to evaluate the forced convection nucleate boiling HTC.
CHF	Evaluates the critical heat flux based on a local-conditions formulation.
CHOK	Calculates choked phasic velocities and their derivatives.
CLEAR	Sets an array to a constant value.
CONBLK	Computes controller outputs.
CYLHT	Calculates temperature fields in a cylindrical annulus.
ERROR	Processes error conditions.
FEMOM	Sets up stabilizing momentum equations.
FF3D	Makes final pass update for all variables in three-dimensional vessel.
FLUX	Calculates mass flow at boundary of one-dimensional components for use in mass inventory.
FPROP	Calculates values for fluid enthalpy, transport properties, and surface tension.
FWALL	Computes a two-phase friction factor.
HTCOR	Computes HTCs from material surfaces to vapor and liquid.
HTPIPE	Averages velocities and generates HTCs for one-dimensional components.
HTVSSL	Averages velocities and generates HTCs for the vessel.
INNER	Performs an inner iteration for a one-dimensional component.
J1D	Fills boundary array at component junctions.

TABLE XV (cont.)

<u>Subprogram</u>	<u>Description</u>
JUNSOL	Determines junction parameters for connecting and sequencing components.
MFROD	Orders fuel-rod property selection and evaluates an average temperature for property evaluation.
MPROP	Orders structure property selection and evaluates an average temperature for property evaluation.
POSTER	Performs postpass calculation for a one-dimensional component.
PREPER	Performs prepass calculation for a one-dimensional component.
RDLCM	Transfers data from LCM into SCM.
RKIN	Integrates the neutron point-kinetics equations.
RODHT	Calculates the fuel-rod temperature field.
SAVBD	Moves boundary information into component arrays.
SCMLCM	Transfers the fixed-length, variable-length, and pointer tables to LCM.
SETBD	Stores component information into boundary arrays.
SLABHT	Calculates the slab temperatures.
SOUND	Calculates the homogeneous-equilibrium sound speed required in the choked-flow calculations.
STBME	Sets up stabilizing mass and energy equations.
TF1D	Controls solution of the hydrodynamic equations for one-dimensional components.
TFIDS	Linearizes the basic mass and energy equations and performs the initial eliminations on the linear equations.
TF1DS1	Solves the basic motion equations for the new time velocity as a linear function of the new time pressure. It also evaluates the interfacial heat-transfer coefficients and areas.
TF1DS3	Does the backward substitution for the equations obtained in TF1DS after the solution of the network matrix.

TABLE XV (cont.)

<u>Subprogram</u>	<u>Description</u>
TF3DE	Evaluates constitutive relations for interfacial heat transfer and shear; makes an initial evaluation of new time velocities.
TF3DI	Sets up the linearized three-dimensional finite-difference equations.
THERMO	Calculates thermodynamic properties of water.
TRIP	Returns status of a TRIP.
TRPSET	Sets up trip status flags.
VOLV	Calculates cell-averaged phase velocities for one-dimensional components.
WARRAY	Writes a real array to TRCOUT.
WIARR	Writes an integer array to TRCOUT.
WRLCM	Transfers a given number of words from SCM to LCM.

overlay structure may be quickly obtained by changing cards flagged by the OVLAY definition in the Update (or Historian) source deck for TRAC.

Functional modularity within TRAC is taken a step further by its division into overlays. The use of an overlay structure originally was mandated by computer size limitations because the small CDC 7600 core memory, where all executable instructions must reside, is limited to 65 536 60-bit words. This division isolates functional subunits within TRAC. Figure 50 displays a calling tree of the TRAC overlays. Table XVI briefly describes the function of each overlay. Overlays are loaded at Los Alamos by declaring the entry routine for each overlay, then satisfying all subsequent subroutine references from a global binary library of TRAC subroutines. The Cray version of TRAC does not need to be overlaid. However, we recommend that the user keep the input and initialization overlays to minimize memory charges.

The TRAC component modularity can be seen in the data structure as well as in the program structure. We used the data modularity in a manner that can efficiently utilize a CDC 7600 computer. The CDC 7600 central memory is

TABLE XVI
TRAC OVERLAYS

<u>Overlay</u>	<u>Description</u>
MAIN	Controls overall flow of calculation. (The MAIN overlay also contains many service routines used throughout the code.)
INPUT	Controls reading input and restart files and analyzes piping loops.
RDCOMP	Inputs and stores one-dimensional component data.
RDCOM3	Inputs and stores vessel data.
RDREST	Reads and stores data from a restart dump file.
INIT	Controls initialization of component data and graphics tables.
ICMP	Initializes component data.
IGRF	Initializes graphics table.
DMPIT	Performs restart dumps.
PREP	Controls prepass for all components.
PREP1D	Performs the prepass calculations for one-dimensional components.
PREP3D	Performs prepass calculations for all three-dimensional vessel components.
TRIPS	Evaluates signal variables and determines the set status of trips.
OUTER	Controls one complete outer iteration for all components.
OUT1D	Does an iteration on the basic finite-difference flow equations for all one-dimensional components.
OUT3D	Does an outer iteration on all vessel components.
POST	Performs postpass for all components.
EDIT	Adds an edit at the current time to the TRCOUT file.
GRAF	Adds a graphics edit at the current time to the TRCGRF file.
CLEAN	Closes all output files.

Fig. 50.
TRAC overlay structure.

divided into two segments: small core memory (SCM) and large core memory (LCM). The central processor unit (CPU) must retrieve the instruction stream from SCM, which is limited in size, but may retrieve data from either segment. Single-word accesses to SCM require between 27.5 and 275 ns to complete. Single-word accesses to the 512 000-word LCM require 1760 ns to complete. For transfers of large data blocks between SCM and LCM, the transfer time per word is as low as 27.5 ns.

To take advantage of this feature, TRAC divides the data for each component into four blocks. These are the fixed-length table, the variable-length table, the pointer table, and the array data. The first three of these blocks are stored in SCM in the COMMON blocks, FLTAB, VLTAB, and PTAB, respectively. The structure of the FLTAB COMMON area is the same for all components. The variables in the VLTAB and PTAB COMMON areas differ from one component to another. Appendix I describes the fixed-length, variable-length, and pointer tables for each component.

The array data are stored in SCM within the dynamic storage array. The location of individual arrays is determined by the value of variables in the pointer table. Dynamic storage of data arrays permits effective use of space for many different problems. The array data for all components are contained in the SCM blank COMMON dynamic area. The pointer tables for all one-dimensional components have a common structure. The first 117 pointers locate the basic hydrodynamic, thermodynamic, and heat-transfer information and have the same interpretation for all one-dimensional components. The next 12 pointers locate data for wall heat transfer in those components that support the calculation. This common structure permits construction of low-level subroutines that can manipulate data for any one-dimensional component, for example, subroutine INNER in overlay OUT1D.

When large-core memory is used, data for a particular component are stored in the dynamic SCM areas only while TRAC processes that component. At other times the data are retained in LCM. Two service subroutines, RDLCM and WRLCM, use the efficient block-transfer capability to transfer data to and from SCM as required. Processing of a component by TRAC begins with the transfer of its component data from LCM to SCM and the computation of the pointer variables based on the available space in the dynamic storage array. The processing of this component ends with the reverse data transfer from SCM to LCM. Figure 51 shows the relationship between SCM and LCM storage areas.

In addition to the data that refer to a particular component, TRAC uses many variables to describe the overall state of the calculation. These variables are grouped according to their use into several other COMMON areas. Appendix H describes the structure of these COMMON areas, which are identical throughout TRAC.

The overall sequence of calculations is directed by the main program. Overlay INPUT always is invoked at the start of each TRAC execution to read component and control input data. The component data are initialized by overlay INIT. The reactor power level is set to zero at this point. The steady-state calculation (if requested) is performed by subroutine STEADY. Output operations are performed using the EDIT, GRAF, and DUMP overlays as required. During the steady-state calculation, the reactor power is turned on after the fluid flow rates have been established. This is to prevent high rod temperatures early in the steady-state calculation when the flow rates are

Fig. 51.
Relationships between SCM and LCM storage areas.

small. If no steady-state calculation is performed, the reactor power is turned on by subroutine STEADY in preparation for the transient calculation, which is performed by subroutine TRANS. Overlays EDIT, GRAF, and DUMP are invoked by TRANS to generate output as required. Overlay CLEAN is invoked to close all output files at the end of the problem or when a fatal error occurs.

B. Input Processing

The processing of all TRAC input information is performed by the INPUT overlay and its sub-overlays RDCOMP, RDCOM3 and RDREST. This information is of two types: input data cards retrieved from the input file, TRACIN, and restart information from the problem restart file, TRCRST. In addition to obtaining the input data from the appropriate location, these overlays also organize the component data in memory, assign the array pointer variables for every component, allocate one fixed segment of the blank COMMON area, and analyze the problem loop structure.

Subroutine INPUT is the entry point for overlay INPUT and controls the input process. The main control parameters (see Sec. V.C.1) are read from the TRACIN file by subroutine INPUT. Using this information, INPUT allocates one fixed segment of the SCM blank COMMON area, as described in Table XVII. The remainder of the fixed segment of SCM is allocated by subroutine INIT. At the end of each of the overlays, INPUT and INIT, these fixed segments are moved to the end of the dynamic SCM area. (This is done to facilitate special handling of this area on the Laboratory computer.) The signal-variable and trip data from the TRACIN file are read and processed by subroutine RCNTL, which creates the CNTL array described in Fig. 52. Subroutine RDCOMP reads the one-dimensional component data from the TRACIN file, assigns pointer values to the data, and then stores the data. RDCOM3 performs a similar function for the vessel component. Signal-variable, trip, and component data not contained in file TRACIN are retrieved from the restart file TRCRST by subroutine RDREST, which is analogous to RDCOMP, as described below. Finally, INPUT utilizes the subroutines ASIGN and SRTLPL to fill the component LCM pointer array and to sort system components.

Subroutine RDCOMP invokes a component input routine to process each component. Table XVIII lists these routines. Input routines for one-dimensional components utilize subroutine RCOMP to read data that are common to all one-dimensional components. Subroutine RDCOMP determines each component type by reading the first input card. When a component type "END" is encountered, RDCOMP knows that all component input has been read. The component input routines perform the following functions: read input cards for a component, store data in the component data tables and write them to LCM, assign relative pointers for the component array data, and fill in the JUN

TABLE XVII

FIXED SEGMENT ALLOCATIONS FOR THE BLANK COMMON AREA

<u>Pointer</u>	<u>Dimension</u>	<u>Array Description</u>
LTITLE	20*(NUMTCR+2)	Problem title and version information (stored using only the first four bytes of each word).
LORDER	NCOMP	Component numbers stored in the order used for iteration.
LILCMP	NCOMP	Component LCM pointers stored in the order in which components were read.
LNBR	NCOMP	Component numbers stored in the order in which components were read.
LCOMPT	NCOMP	Component LCM pointers stored in the order used for iteration.
LIITNO	NCOMP	Number of inner iterations during the last outer iteration for each component (in the order used for iteration).
LLCON	NCOMP	Number of times each component was the last to converge since last edit.
LJUN	8*NJUN	The JUN array for storage of the junction-component pairs.
LJSEQ	NJUN	Junction numbers in the order in which junctions occur in the junction-component array.
LVSI	NJUN	Junction flow reversal indicators in the order in which junctions occur in the junction-component array.
LBD	56*NJUN	Boundary array data.
LMAT	NMAT	Pointer for additional material-property ID number.
LPTBLN	NMAT	Pointer for the number of entry groups in the user-defined material-property tables.
LPRPTB	SNTAB	Pointer to the user-defined material-property tables.

TABLE XVII (cont.)

<u>Pointer</u>	<u>Dimension</u>	<u>Array Description</u>
LCNTL	KPTT ^a	Signal-variable, trip, and controller data array described in Fig. 52.
LMSCT	NVCON	Temporary storage for vessel pressure changes adjacent to sources.
LMCMSh	NVCON	Storage for coarse-mesh number of vessel source cells or absolute cell index if direct vessel solution is used.
LIVCON	NVCON+1	Pointer to network junction numbers that connect to a vessel.
LJOUT	IT+1 ^b	Storage area for pointers that locate the beginning of each system loop within data for IOU.
LNVCNL	IT+1	IA(LNVCNL+IL-1) points to the elements of IVCON and IVLJN that begin the IL th loop.
LLOOPN	IT+1	IA(LLOOPN+IL-1) gives the element of the IORDER array that begins the IL th loop.
LNSIGP	IT	NSIGP(IL) is NSIG(IL) plus the number of steam generators in loop IL.
LNSIG	IT	NSIG(IL) is the total number of components excluding breaks and fills in a loop.
LNJN	IT	NJN(IL) is the number of network junctions in loop IL.
LIVLJN	NVCON+1	IVLJN(I) is the vessel junction number corresponding to the network junction number given by IVCON(I).
LI0U	IT2 ^c	Network junction numbers for the junctions of all components excluding breaks and fills.
LVRH	NJNT	Storage for explicit information to evaluate equations of motion at network junctions.

TABLE XVII (cont.)

<u>Pointer</u>	<u>Dimension</u>	<u>Array Description</u>
LDVB	NJNT	Storage for the right-hand side of the network junction equations or the changes in junction velocities.
LDREV	NJNT	Storage for right-hand side of the vapor stabilizer equation.
LDREL	NJNT	Storage for right-hand side of the liquid stabilizer equation.
LDRA	NJNT	Storage for right-hand side of the air stabilizer equation.
LDRC	NJNT	Storage for the right-hand side of the solute concentration equation.
LIDPCV	NVCON	Pointers to coefficients stored in DPCV.
LDPVC	J ^e	Locator that shows the beginning of coefficients to evaluate the derivatives of junction velocities with respect to vessel pressures.
LAOU	JC ^f	Network junction coefficient matrix.
LOD	4*NJNMX	Temporary storage for intercomponent coupling information.

^aEquals $7*NTSV+80*NTRP+38*NTSE+12*NTCT+23*NTSF+NTDP+15*NTSD+10$.

^bEquals $(NVCON + \text{the number of BREAKS} + \text{the number of FILLS})/2 + 2$.

^cEquals $MAXO\{3, 3*[IA(LJOUT + NLOOPS) - 1]\}$.

^dThe amount of storage needed for all the primary-coolant loops) + 2.

^eEquals product of the number of junctions in each loop and the number of vessel connections in each loop summed over all loops.

^fEquals $MAXO[NVCON*2*(JNVSSL+1), NJNMX*(NJNMX+2)]$.

KPTT	Length of trip data array
NTSV	Number of signal variables
NTRP	Number of trips
NTCN	Number of controllers (currently not used)
NTSE	Number of signal-expression trips
NTCT	Number of trip-controlled trips
NTSF	Number of set-point factor tables
NTDP	Number of trips that generates restart dumps and possible problem termination
NTSD	Number of trip time-step data sets
Signal-Variable Data	7*NTSV entries
General Trip Data	80*NTRP entries
Signal-Expression Trip Data	38*NTSE entries
Trip-Controlled Trip Data	12*NTCT entries
Trip Set-Point Factor Tables	23*NTSF entries
Trip, Dump, and Termination Data	NTDP+1 entries
Trip Time-Step Data	15*NTSD entries

Fig. 52.
Signal-variable and trip data.

TABLE XVIII
COMPONENT INPUT SUBROUTINES

<u>Component Type</u>	<u>Card Input</u>	<u>Restart Input</u>
ACCUM	RACCUM	REACCM
BREAK	RBREAK	REBRK
CORE	RCORE	RECORE
FILL	RFILL	REFILL
PIPE	RPIPE	REPIPE
PRIZER	RPRIZR	REPRZR
PUMP	RPUMP	REPUMP
STGEN	RSTGEN	RESTGN
TEE	RTEE	RETEE
TURB	RTURB	RETURB
VALVE	RVLVE	REVLVE
VESSEL	RVSSL	REVSSL

array. The JUN array is doubly subscripted, JUN(4,2*NJUN). The second index indicates the order in which the junction-component pair was encountered during input. The four values of the first index are described in Table XIX. The boundary array data are stored in a doubly dimensioned array, BD(56,NJUN), whose second index indicates the order in which the junctions occur in the input data. The data in this array indicate the current condition of the adjacent component. Because both components connected to the junction use the same storage space, the JUN array reflects the state of the last of these components processed. The fluid properties are evaluated at one of three space points:

1. at the edge of the mesh cell closest to the junction,
2. at the mid-point of that mesh cell, or
3. at the other edge of that mesh cell.

The specific elements of the array are shown in Table XX.

Subroutine RDREST opens restart file TRCRST and finds the dump corresponding to the requested time-step number (Main-Data Card 3). (If the requested time step is negative, RDREST uses the last dump.) This dump then is used to initialize the components and trips that were not found in the TRACIN file, with the component restart subroutines listed in Table XVIII. Restart subroutines for one-dimensional components utilize subroutine RECOMP to read data that are common to all one-dimensional components. The detailed

TABLE XIX
FIRST INDEX FOR THE JUNCTION-COMPONENT PAIR ARRAY

<u>Index</u>	<u>Description</u>
1	Junction number.
2	Component number.
3	Component type.
4	Junction direction flag. = 0, if positive flow in this component is into the component at this junction, or = 1, if positive flow in this component is out of the component at this junction.

TABLE XX
BOUNDARY ARRAY DATA

<u>Index</u>	<u>Description</u>
1	Width of the adjacent mesh cell.
2	Volume of the adjacent mesh cell.
3	Old mixture density at space point 2.
4	Product of new vapor density and void fraction ($\alpha \rho_g$) at space point 2.
5	Product of liquid density and liquid fraction $[(1 - \alpha) \rho_l]$ at space point 2.
6	Sign multiplier used on velocities in the adjacent component for consistency.
7	Old void fraction at space point 2.
8	Old vapor density at space point 2.
9	Old liquid density at space point 2.
10	New liquid velocity at space point 3.

TABLE XX (cont.)

<u>Index</u>	<u>Description</u>
11	New vapor velocity at space point 3.
12	Contribution to liquid momentum at space point 1 if there is a tee junction at point 2.
13	Contribution to vapor momentum at space point 1 if there is a tee junction at point 2.
14	Old pressure at space point 2.
15	New void fraction at space point 2.
16	New vapor density at space point 2.
17	New liquid density at space point 2.
18	New stabilizer liquid velocity at space point 3.
19	New stabilizer vapor velocity at space point 3.
20	Further contribution to liquid momentum at point 1 if there is a tee junction at space point 2.
21	Further contribution to vapor momentum at point 1 if there is a tee junction at space point 2.
22	New pressure at space point 2.
23	New liquid velocity at space point 1.
24	New vapor velocity at space point 1.
25	Surface tension at space point 2.
26	Derivative of liquid velocity at point 1 with respect to pressure at space point 2.
27	Derivative of vapor velocity at point 1 with respect to pressure at space point 2.
28	New macroscopic liquid energy density $[(1 - \alpha)\rho_l e_l]$ at space point 2.
29	New macroscopic vapor energy density $(\alpha\rho_g e_g)$ at space point 2.
30	Vapor viscosity at space point 2.

TABLE XX (cont.)

<u>Index</u>	<u>Description</u>
31	Liquid viscosity at space point 2.
32	Flow area at space point 1.
33	Hydraulic diameter at space point 1.
34	Old stabilizer liquid velocity at space point 3.
35	Old stabilizer vapor velocity at space point 3.
36	Component type of last component to enter data into this array.
37	Component number of last component to enter data into this array.
38	Old bit flags for donor-cell logic and detecting crossings of the saturation line.
39	Old air density (ρ_a) at space point 2.
40	New macroscopic air density ($\alpha\rho_a$) at space point 2.
41	Old macroscopic vapor density ($\alpha\rho_g$) at space point 2.
42	Old macroscopic liquid density $[(1 - \alpha)\rho_l]$ at space point 2.
43	Old macroscopic vapor energy density ($\alpha\rho_g e_g$) at space point 2.
44	Old macroscopic liquid energy density $[(1 - \alpha)\rho_l e_l]$ at space point 2.
45	Void fraction at the beginning of the previous time step at space point 2.
46	Old macroscopic air density ($\alpha\rho_a$) at space point 2.
47	Old partial pressure of air at space point 2.
48	Old vapor temperature at space point 2.
49	Old liquid temperature at space point 2.
50	Vapor velocity averaged for space point 2.

TABLE XX (cont.)

<u>Index</u>	<u>Description</u>
51	Liquid velocity averaged for space point 2.
52	Droplet interfacial-drag coefficient for space point 3.
53	New bit flag information for space point 2.
54	Gravity vector at point 3.
55	New solute concentration at point 2.
56	New phase change rate at point 2.

structure of the restart file is described in Sec. VI.F in conjunction with the dump capability.

Subroutine SRTLTP sorts through the components of the system and groups them by loops that are isolated from one another by a vessel component. The IORDER array is rearranged to reflect this grouping and to provide a convenient order within each group for the flow network solution procedure.

C. Component Initialization

The transient or steady-state calculation cannot be initiated directly from the input data. Many arrays and variables for each component are required that are not read by overlay INPUT. Overlay INIT initializes these data based on the values of the input information. It also creates a table that supplies information to the graphics routines. The entry point subroutine, INIT, controls the initialization process by calling ICOMP and IGRAF. Subroutine ICOMP completes the component data tables, and IGRAF initializes the graphics capability.

Subroutine ICOMP checks the junction input data (stored in the junction component pair array JUN) to ensure that the system is configured properly, then fills in the JSEQ and VSI arrays in the fixed segment of the blank COMMON area (Table XVII). Then, ICOMP initializes the data for each one-dimensional component by transferring the component data from LCM to SCM, adjusting the array pointers to reflect the origin of the array data, invoking the appropriate component initialization subroutine (listed in Table XXI), and then returning the initialized data to LCM. For each three-dimensional

component, ICOMP invokes subroutine CIVSSL. Subroutine CIVSSL transfers the component data from LCM to SCM; adjusts the array pointers; calls the initialization routine, IVSSL; and then returns the initialized data to LCM.

The component initialization routines initialize geometric and heat-transfer arrays; initialize fluid properties by calling subroutines THERMO and FPROP; and initialize the junction data array, as described in Table XIX, by using subroutine JLD. Other individual and array variables are initialized for specific components. Most of the one-dimensional component initialization routines use subroutines COMPI and IPROP to initialize the data that are common among one-dimensional components.

The subroutine SETNET provides information to the individual components through the IOU array for passing on to the network junction matrix described in Sec. III.D.

The graphics initialization subroutine, IGRAF, creates the TRCGRF file; writes the header, catalog, and geometric data onto the file; and places the catalog in a LCM storage area. The catalog, which contains information about the data to be written on the TRCGRF file during the course of a problem, is constructed by the component graphics initialization routines listed in Table XXI. The data to be edited for each component are specified in these routines. Each datum type adds one entry to the catalog. This entry

TABLE XXI
COMPONENT INITIALIZATION SUBROUTINES

<u>Component Type</u>	<u>Initialization Routine</u>	<u>Graphics Initialization Routine</u>
ACCUM	IACCUM	IGACUM
BREAK	IBRK	IGBRAK
CORE	ICORE	IGCORE
FILL	IFILL	IGFILL
PIPE	IPIPE	IGPIPE
PRIZER	IPRIZR	IGPRZR
PUMP	IPUMP	IGPUMP
STGEN	ISTGEN	IGSTGN
TEE	ITEE	IGTEE
TURB	ITURB	IGTURB
VALVE	IVLVE	IGVLVE
VESSEL	IVSSL	IGVSSL

describes the data location and identifies it with the variable name containing the data and a three-word Hollerith field. The catalog stored in LCM is interrogated later by subroutine GRAF to create each graphics edit.

D. Transient Calculation

1. General. The transient calculation is directed by subroutine TRANS. The system state is advanced through time by a sequence of prepass, outer iteration, and postpass calculations that TRANS requests by invoking overlay PREP, subroutine HOUT, and overlay POST, respectively. In these calculations one or more sweeps are made through all the components in the system. To provide the output requested by the user, TRANS invokes the EDIT, DUMP, and GRAF overlays by calling subroutine PSTEPQ.

Subroutine TRANS is structured as shown in Fig. 53. The major control variables within the time-step loop are: NSTEP, the current time-step number; TIMET, the time since the transient began; DELT, the size of the current time step; and OITNO, the current outer iteration number. The time-step loop begins with the selection of the time-step size, DELT, by subroutine TIMSTP. A prepass is performed for each component by overlay PREP. At this point, if the current time step is zero, TRANS calls in the EDIT overlay to print the system state at the beginning of the transient. Subroutine TRANS then calls subroutine HOUT that performs one or more outer iterations to solve the basic hydrodynamic equations. Each outer iteration is performed by overlay OUTER and corresponds to one iteration in a Newton solution procedure for the fully coupled difference equations for the flow network (see Sec. III.D.). The outer iteration loop normally completes when the outer iteration convergence criterion (EPSO on Main-Data Card 5) is met. This criterion is applied to the maximum fractional change in the pressures throughout the system during the last iteration.

The outer iteration loop alternatively may terminate when the number of outer iterations reaches a user-specified limit (OITMAX on Main-Data Card 6). In this case, TRAC restores the state of all components to that at the beginning of the time step, halves the time-step size (with the constraint that DELT be greater than or equal to DTMIN), and continues the calculation with the new time-step size.

Fig. 53.
Flow diagram for transient calculations.

When the outer iteration converges, TRANS calls in the POST overlay to perform a postpass. The time-step number then is incremented and TIMET is increased by DELT. A calculation is complete when TIMET reaches the last time specified on the time-step input cards.

2. Time-Step Selection and Output Control. The transient calculation interval is a sequence of time domains specified by the user on the time-step input cards. During each of these domains, the minimum and maximum time-step sizes and the edit, dump, and graphics intervals are fixed. When the EDIT, DUMP, and GRAF overlays are invoked, they calculate the time when the next output of the associated type is to occur. When TRANS finds that TIMET has reached or exceeded the indicated time, the corresponding output overlay is invoked again. Whenever a new time domain is reached, the output indicators are set to the requested time plus the new value of the appropriate interval.

Subroutine TIMSTP reads the time-step control cards and evaluates the size of the next time step. At the beginning of the transient, DELT is set to the minimum size specified for the first time domain. At other times, TIMSTP applies several algorithms, implemented in subroutine NEWDLT, to evaluate the size of the next time step. Subroutine TIMSTP then limits DELT to values between the minimum and maximum specified for this time step, unless the minimum time-step size is greater than the computed Courant limit in three-dimensional regions. In this case, DELT is set equal to the Courant limit.

Two types of algorithms, inhibitive and promotional, are implemented in subroutine NEWDLT to evaluate the next time step. The inhibitive algorithms limit the new time-step size to ensure stability and to reduce errors. The promotional algorithm increases the time-step size to improve computational efficiency.

Iteration counts are used by both the inhibitive and promotional algorithms. Both the number of outer iterations (MAXIT) and the number of vessel iterations (IIBIG) required for the previous time step are utilized. If MAXIT is less than four and IIBIG is below 70% of the maximum allowed number of vessel iterations (input as IITMAX), the promotional algorithm increases the time-step size (DELT) by 5%. If MAXIT exceeds five, DELT is reduced by the factor $5/\text{MAXIT}$; if IIBIG exceeds $0.7 \cdot \text{IITMAX} + 1$, DELT is reduced by $(7 \cdot \text{IITMAX} + 10) / (10 \cdot \text{IIBIG})$.

If a new time-step size was estimated in this manner, NEWDLT then invokes the remaining inhibitive algorithms to reduce DELT, if needed for stability or accuracy. The Courant condition in three forms is applied to ensure stability. The three forms use the new, old, and extrapolated fluid velocities to evaluate the limit. The accuracy limits are based on the fractional changes in pressure and void fraction and the calculated error in the new total vessel mass.

During the last outer iteration calculation of the previous time step, the maximum changes in the pressure and void fraction over all fluid cells are evaluated. (Cells in which the void fraction is below 1% are not considered in evaluating the maximum fractional change of the void fraction.) The fractional pressure change ordinarily is limited by the outer convergence criterion, EPSO. If the maximum number of outer iterations is input as one, however, this is not the case. In this instance NEWDLT compares the maximum fractional pressure change (VARERM) to 0.1. If the change exceeds 10%, a maximum time-step size of $0.1 \cdot \text{DELT} / \text{VARERM}$ is imposed. Similarly, if the maximum void-fraction change (DAMX) exceeds 0.5, a maximum time-step size of $0.5 \cdot \text{DELT} / \text{DAMX}$ is used.

The error in the vessel mass inventory caused by the previous time step is evaluated by subtracting the mass at the previous time step and the net mass flow into the vessel from the new mass inventory. If the fractional mass error exceeds 0.01%, another maximum time-step size is evaluated as $10^{-4} \cdot \text{DELT}$ divided by the mass error.

Another maximum time-step size calculation is based on the maximum liquid, vapor, slab, and rod temperature changes during the last time step. For temperature changes that exceed 20 K, the smallest value of $\text{DELT} \cdot 20. / \Delta T$ is used.

The diffusion number for the rod conduction calculation, DIFMIN, also is used to evaluate a maximum time-step size. It is evaluated as DIFMIN if DIFMIN is nonzero or 1.0×10^8 if DIFMIN is zero.

3. Prepass Calculations. The prepass calculation uses the system state at the completion of the previous time step to evaluate numerous quantities to be used during the outer iteration. The prepass begins by evaluating trip-signal variables and determining the set position of all trips. The prepass then loops over all components in the system and performs

an extra loop over all one-dimensional components. Each component begins the prepass by moving the values calculated during the last time step into the storage area for old time values. (See App. I for a variables list.) Next, wall and interfacial friction coefficients are calculated, and an initial forward elimination on the stabilizer motion equations is performed. For components that require heat-transfer calculations, the prepass also evaluates material properties and HTC's. A second pass through all one-dimensional components is required to do the backward substitution on the stabilizer equations of motion.

The prepass for vessel components can be more complex. Besides calculating material properties and HTC's for both average and hot rods, the prepass evaluates quench-front positions and fine-mesh properties if the reflood segment is under way, as indicated by the reflood flag NRFD.

The prepass calculation is controlled by overlay PREP, whose entry point routine has the same name. Subroutine PREP first processes all one-dimensional components by calling PREP1D, which loads data for each component into SCM, invoking the appropriate component prepass subroutine (see Table XXII), then transfers the component data back to LCM. The prepass for all three-dimensional components is performed by PREP3D, which is called once by PREP after all one-dimensional components have been processed.

The one-dimensional component prepass routines utilize the common low-level routines SAVBD, PREPER, SVSET, TRPSET, CONBLK, and SETBD to avoid redundant coding. Subroutine SAVBD retrieves boundary data from adjacent components, stores it in the appropriate array locations, and moves data for the last completed time step into the old time arrays. Subroutine PREPER evaluates wall friction by calling FWALL, evaluates interfacial friction coefficients and begins solution of the stabilizer equations of motion by calling FEMOM, and uses subroutines MPROP and HTPIPE to evaluate material properties and HTC's. For a specific component any or all of these steps may occur under the control of the PREPER argument list.

Subroutine SVSET uses current values of system state variables to evaluate trip-signal variables. Subroutine TRPSET uses the current signal-variable values to set the status of trips. (This is in contrast to subroutine TRIP that interrogates the trip status in preparation for specific consequences of trips.) Subroutine CONBLK models system controllers by

TABLE XXII
ITERATION SUBROUTINES

<u>Component Type</u>	<u>Prepass</u>	<u>Outer</u>	<u>Postpass</u>
ACCUM	ACCUM1	ACCUM2	ACCUM3
BREAK	BREAK1	BREAK2	BREAK3
CORE	COREC1	COREC2	COREC3
FILL	FILL1	FILL2	FILL3
PIPE	PIPE1	PIPE2	PIPE3
PRIZER	PRIZR1	PRIZR2	PRIZR3
PUMP	PUMP1	PUMP2	PUMP3
STGEN	STGEN1	STGEN2	STGEN3
TEE	TEE1	TEE2	TEE3
TURB	TURB1	TURB2	TURB3
VALVE	VLVE1	VLVE2	VLVE3
VESSEL	VSSL1	VSSL2	VSSL3

processing specified inputs through predefined control blocks. Subroutine SETBD uses the information in the component data arrays to reset the boundary data at both ends of a component.

Each three-dimensional component is processed by subroutine VSSL1, which PREP3D calls between loading and unloading the appropriate data areas. Subroutine VSSL1 uses subroutine RKIN to solve the reactor-kinetics problem; subroutine HTVSSL to evaluate fluid cell HTC's; and CORE1 to evaluate rod HTC's, fine-mesh properties, and quench-front positions.

4. Outer Iterations. The hydrodynamic state of the system is analyzed in TRAC by a sequence of Newton iterations that use full inversion of the linearized equations for each external loop and vessel at each iteration (see Sec. III.D). Throughout the sequence of iterations that constitute a time step (each called an outer iteration within TRAC), the properties evaluated during the prepass and the previous postpass remain fixed. These include wall and rod temperatures, HTC's, wall friction factors, relative velocities, and quench-front positions. The remaining fluid properties are varied to obtain hydrodynamic model solutions.

Each call to overlay OUTER completes a single outer (Newton) iteration. Subroutine OUTER, which is the entry point routine of this overlay, controls the overall structure of an outer iteration, as presented in Fig. 54. Both

Fig. 54.
Outer iteration flow diagram.

the forward-elimination and backward-substitution sweeps through the external loops are performed by subroutine OUT1D and the associated outer iteration routines. The calculations that these routines perform are controlled by the common variable IBKS, which is set by subroutine OUTER. Subroutine OUT3D solves the hydrodynamic equations for all vessel components (IBKS = 0) or updates boundary data (IBKS = 1).

All one-dimensional components in a particular external loop are handled by a single call to subroutine OUT1D. This routine loads the data blocks for a component into SCM, then invokes the appropriate component outer iteration subroutine (as listed in Table XXII), and returns the data to LCM. Subroutine OUT3D works in a similar manner, except that all three-dimensional components use the single subroutine VSSL2.

The outer iteration subroutines for one-dimensional components utilize subroutine INNER to perform common functions. Subroutine INNER retrieves boundary information from the boundary arrays, tests other boundary information for consistency, calls subroutine TF1D to perform the appropriate hydrodynamic calculation, and resets the boundary data arrays by calling subroutine J1D. Subroutine TF1D invokes subroutines TF1DS1, TF1DS and TF1DS3 to solve the basic semi-implicit finite-difference equations.

Subroutine VSSL2 solves the appropriate problem (depending on the value of IBKS) for a single vessel component. Subroutines TF3DE and TF3DI are invoked to linearize the hydrodynamic equations. The linear system then is solved by one of two methods depending on the value of the input variable IITMAX. A value of IITMAX = 0 causes direct inversion of the vessel matrix. If IITMAX > 0, the system is solved by Gauss-Seidel iteration with coarse-mesh acceleration. Subroutine VELCK then is utilized to check for velocity sign changes. If any are found, TF3DI is called for the appropriate cells to relinearize the necessary equations.

Subroutine STDIR sets up the vessel matrix for direct inversion when IITMAX = 0. Subroutine SOLVE is called to solve the linear system and then subroutine BACIT stores the new time pressures that were calculated. Subroutine ITR1 is utilized to solve the system by Gauss-Seidel iteration when IITMAX > 0. Subroutines SREBAL and SOLVE are called to set up and solve the coarse-mesh equations for coarse-mesh rebalance. Next, subroutine BREBAL is invoked to apply the coarse-mesh scaling factor to the new time pressures.

5. Postpass Calculations and Backup. After the system hydrodynamic state has been evaluated by a sequence of outer iterations, TRAC performs a postpass to solve the stabilizer mass and energy equations and to determine both mixture properties and wall and rod temperatures. These are based on the new fluid conditions. Overlay POST performs this postpass. The same overlay also implements the time-step backup procedure. Time-step backup is caused by failure of the outer iteration process or extreme changes in void fraction. When failure occurs, the outer iteration counter, OITNO, is set equal to -100, and overlay POST is invoked. Under these conditions, POST returns the component data arrays to their state at the beginning of the time step.

Subroutine POST is the entry point for this overlay. Subroutine POST first processes all one-dimensional components by loading the proper data into SCM, calling the appropriate component postpass subroutine (see Table XXII), and then returning the data to LCM. Then POST invokes subroutine POST3D to handle all three-dimensional components. Subroutine POST3D loads the vessel data areas, calls VSSL3, and returns the vessel data to LCM for each vessel in the problem.

The one-dimensional component postpass subroutines use the low-level routines SAVBD, POSTER, and SETBD to retrieve boundary conditions; to evaluate the stabilizer equations, wall temperatures, mixture properties, and transport properties; and to reset the boundary arrays, respectively.

The vessel processor, VSSL3, first must invoke subroutine FF3D to complete the hydrodynamic calculation, then call subroutine CORE3 to evaluate rod temperatures.

When in the backup mode the postpass subroutine for each component moves data as necessary within the time-dependent array area, then uses subroutine THERMO to reinitialize the thermodynamic property arrays.

6. Vessel Data Structure. All array data for any one-dimensional component are loaded into the core whenever that component is processed. Because the amount of array data is much larger for the three-dimensional VESSEL component, this is not possible for components of this type. Therefore, the array data for the VESSEL component are subdivided. There are three categories of VESSEL array data: component, level, and rod.

The component data arrays describe the overall VESSEL state. These arrays are loaded into SCM before VESSEL processing begins and remain there throughout the VESSEL calculation.

The level data arrays contain fluid-dynamics and wall-temperature data organized by axial level within the VESSEL. A data management subroutine, MANAGE, is used by all VESSEL subroutines to load single levels into SCM and to replace them in LCM. There are never more than three levels of data in SCM at one time. These arrays are rotated through the SCM area during the fluid-dynamics calculation by the VESSEL iteration subroutines.

The rod data arrays contain detailed information about the heat-transfer calculation in the fuel rods. These data are organized by fuel rod so that only data pertaining to the rod under study are in SCM at once. These data arrays are loaded into (and unloaded from) the blank COMMON area by calls to the MANAGE subroutine. Subroutines CORE1 and CORE3 coordinate the rod heat-transfer calculations including the management of rod data.

In addition to solving the data space problem, the organization of the VESSEL array data improves the calculation efficiency by grouping data by their use. However, it introduces a communication problem between the fluid-dynamics and heat-transfer calculations because some data must be in both the rod and the level arrays. This problem is resolved by a data transfer between the rod and the level data arrays. On a CDC 7600 this transfer is performed by direct LCM to LCM copies using subroutine LCMOVE during the prepass calculation.

E. Steady-State Calculations

Subroutine STEADY directs steady-state calculations. The calculation sequence of this subroutine is similar to that of the transient driver subroutine TRANS. Both STEADY and TRANS use subroutine HOUT to perform a group of outer iterations. The same sequence of iterations used for transient calculations also is used to advance the steady-state calculation. The main difference is the addition of steady-state convergence tests to STEADY. To provide output requested by the user, STEADY invokes the EDIT, DUMP, and GRAF overlays by calling subroutine PSTEPQ. These overlays are described in Sec. VI.F. Subroutine STEADY is called by the main program whether or not a steady-state calculation has been requested. If no steady-state calculation

is required, STEADY simply initializes the VESSEL power and returns control to the main program.

The steady-state calculation to be performed is determined by the value of the input variable STDYST on Main-Data Card 4, as described in the input specifications in Sec. V.C.1. The code sets the steady-state indication flag, ISTDY, to 1 and the transient calculation time, TIMET, to -1 to begin the steady-state calculations. In steady-state calculations the time variable is STIME instead of TIMET. These values of ISTDY and TIMET have the effects indicated in Table XXIII.

The time-step control in STEADY is identical to that implemented in TRANS. This includes the selection of the time-step size, the output timing, and the restarting of time steps if the outer iteration limit is exceeded. (In STEADY the input variable SITMAX, from Main-Data Card 6, is used as a delimiter in place of OITMAX.) The maximum normalized rates of change are calculated by subroutines TF1DS3 and FF3D. These rates and their locations in the system are transmitted to STEADY through the variables FMX and LOK in COMMON block SCON. Tests for steady-state convergence are performed every 100 time steps and before every edit. The maximum normalized rates of change and their locations are included in the printed output, as shown in Table XXIV. The minimum value of the axial velocity (MINVEL) and its maximum normalized rate of change (FMXLVZ) in the vessel determine when the reactor power should be turned on. Once MINVEL exceeds 0.5 m/s or FMXLVZ falls below 0.5, the reactor power is set to the input value, RPOWRI (specified on Card

TABLE XXIII

STEADY-STATE CALCULATION EFFECTS

<u>Subroutine</u>	<u>Effects</u>
PRIZR1 PRIZR2 PRIZR3	Bypass calculation of fluid and thermal conditions, and cause cataloging of mass flow through the system junctions.
PUMP2	Causes momentum source to be time averaged.
TIMSTP	Multiplies time-step size for heat transfer by RTWFP.
TRPSET	Causes trips with positive ID numbers not to be activated.

TABLE XXIV

EXAMPLE OF A STEADY-STATE CONVERGENCE EDIT

STEADY-STATE TIME-STEP NUMBER 114, CONVERGED IN 2 ITERATIONS.

TIME = 5.187×10^{-2} DELT = 2.480×10^{-3}

<u>Variable</u>	<u>Maximum Change Ratio</u>	<u>Component</u>	<u>Cell</u>
Pressure	-5.228985×10^{-1}	1	43
Liquid velocity	3.85848×10^1	14	1
Vapor velocity	0.	0	0
Void fraction	0.	0	0
Liquid temperature	-2.00387×10^{-2}	6	2
Vapor temperature	2.12964×10^{-2}	0	0
Air pressure	0.	0	0

Number 12 of the vessel input data or Card Number 10 of the core input data). The generalized steady state completes when all normalized rates of change are below the user-specified convergence criterion, EPSS (on Main-Data Card 5) or when STIME reaches the end of the last time domain specified in the steady-state time-step input cards.

Both steady-state and transient calculations may be performed in one computer run. The end of the generalized steady-state time-step cards is signified by a single card containing a -1.0 in columns 11-14. The transient time-step input cards should follow immediately. If the generalized steady state converges before reaching the end of the last time domain, the remaining steady-state time-step input cards are read so that the transient calculation proceeds correctly.

Figure 55 is a flow diagram for the steady-state calculation.

Fig. 55.
Flow diagram for steady-state calculation.

F. Output Processing

The TRAC program produces five output files: TRCOUT, TRCMSG, TRCGRF, TRCDMP, and TRCINP. The first of these files is in printer format and contains a user-oriented analysis of the calculation. During the input process, an input data description is placed in this file. At selected times during the calculation, overlay EDIT is invoked to add to this file a description of the current system state. The TRCGRF and TRCDMP files are binary files designed to allow analysis by graphics postprocessing programs and problem restart by TRAC, respectively. The TRCGRF file is created and the header, catalog, and geometric data are written into it during the initialization phase. File TRCDMP is created immediately thereafter by overlay DUMP. The TRCMSG file is in printer format and contains diagnostic messages concerning the progress of the calculation. File TRCINP is only created when the TRACIN input file is in free format. The data from TRACIN is written into file TRCINP in a form that can be read by the TRAC input routines. TRCINP is then used as the input file to TRAC.

Subroutine WCOMP, which is called by the entry point routine EDIT, directs the addition of a time-step edit to the TRCOUT file. Subroutine WCOMP writes general overall data first, then invokes lower level routines to describe the state of each component. For one-dimensional components, WCOMP directly calls the appropriate component edit subroutine. Table XXV lists the component edit subroutines. These routines invoke subroutine ECOMP to write the data common between one-dimensional components. For three-dimensional components, WCOMP calls subroutine CWVSSL, which loads the component data tables into SCM and then invokes the component edit subroutine WVSSL. The component edit routines add the data that are important for that component to the TRCOUT file in an appropriate format.

After initialization by IGRAF, the time-edit data are added to the TRCGRF file by overlay GRAF. This overlay contains the single subroutine, GRAF, which uses the LCM graph data area. The TRCGRF file is a structured binary file written with unformatted write statements and containing information for graphics processing.

TABLE XXV
COMPONENT EDIT SUBROUTINES

<u>Component Type</u>	<u>First-Level Subroutine</u>	<u>Lower-Level Subroutine</u>
ACCUM	--	WACCUM
BREAK	--	WBREAK
CORE	--	WCORE
FILL	--	WFILL
PIPE	--	WPIPE
PRIZER	--	WPRIZR
PUMP	--	WPUMP
STGEN	--	WSTGEN
TEE	--	WTEE
TURB	--	WTURB
VALVE	--	WVLVE
VESSEL	CWVSSL	WVSSL

Data contained on the TRCGRF file may be divided into four sections:

1. general information,
2. catalog information,
3. geometric information, and
4. time-edit data.

These data appear on the file in the above order, as shown in Fig. 56. The structure of the general information section of the file is given in Fig. 57. This section contains title cards for problem identification and size information needed to describe the problem and the remainder of the file. The catalog section (Fig. 58) contains information that is used to describe the data stored in the time-edit section. The geometric section contains information relating to the cell structure of components. The time-edit section is made up of blocks of data as shown in Fig. 59. Individual arrays within each block are packed to save space. A block is written at each graphics edit taken during the course of a problem. The number of time-edit blocks written on the file is determined by the graphics edit frequency specified on the time-step cards. The last block is followed by a word "EOF" to signify the "end of file."

Fig. 56.
Overall graphics file structure.

Fig. 57.
Structure of graphics file general information section.

FIRST PACKED WORD OF DESCRIPTION

ICOMP	NUM	ITYPE	NWRD
-------	-----	-------	------

SECOND PACKED WORD OF DESCRIPTION

ILRN	KPT	NSKIP	IPOS
------	-----	-------	------

ICOMP -- TRAC-assigned component number
 NUM -- User-assigned component number
 ITYPE -- Data type
 NWRD -- Number of unpacked words stored
 ILRN -- Level or rod number
 KPT -- Relative pointer to data in TRCGRF
 NSKIP -- Data skip frequency
 IPOS -- Relative pointer to where data were extracted
 from TRAC data base

Fig. 58.
 Structure of graphics file catalog.

Fig. 59.
Structure of graphics file time-edit data section.

The structure and lengths of the time-edit blocks are identical to one another, minimizing the required catalog information. The catalog is made up of NCTX data entries with one catalog entry for each data type in a block. This relationship is displayed in Fig. 60. Each catalog entry contains six words that provide a data description and a pointer, relative to the beginning of the block, to a specific section in each block. A catalog entry may describe a single variable or a data array. The word count also is included in the catalog. The data types stored are pressures, temperatures, void fractions, and other important system parameters.

The TRCDMP file is a structured binary file written with unformatted write statements. It contains sufficient data to restart the calculation from the current state, as described in Sec. VI.B. This file is created by a sequence of calls to overlay DUMP. The entry point subroutine, DMPIT, writes the dump header data and calls the component dump subroutines, which are listed in Table XXVI.

Figures 61-63 show the resulting file structure. This structure permits easy location of specific dumps and specific components within each dump. This reduces the effort required to restart the problem.

Figure 61 shows the overall dump-file structure with a general information section at the beginning followed by a series of time-edit blocks. A block is written at each dump edit taken during a problem. The number of time-edit blocks written on the file is determined by the dump-edit frequency specified on the time-edit cards. The last block is followed by the word "EOF" to signify the "end of file."

The structure of each time-edit block in the dump file is illustrated in Fig. 62. Data from each component is included in the component dump section shown at the bottom of the figure. Figure 63 shows a more detailed structure of the component dump section.

G. Storage Requirements

Although maximum use is made of dynamic storage allocation within TRAC, there are limitations on the complexity of problems that may be simulated. These limitations arise from the finite extent of the component data storage areas, as listed in Table XXVII. These limitations are imposed on the complexity of single components as well as on the system as a whole.

Fig. 61.
Dump-file overall structure.

ETIME	Current time
NSTEP	Time-step number
DELT	Time-step size
OITNO	Outer iteration number
V MAXT	Maximum Courant number
V MAXO	Maximum Courant number found during current time step
VMNEW	Vessel water mass (liquid and vapor) at t^{n+1}
VMOLD	Vessel water mass (liquid and vapor) at t^n
VMCON	Net water mass convected into vessel during the interval $t^{n+1} - t^n$
DAMX	Error caused by relative change in void fraction
DAU	Maximum increase in void fraction
DAL	Maximum decrease in void fraction
OAU	Maximum increase in void fraction after a decrease
OAL	Maximum decrease in void fraction after an increase
VERERM	Maximum variable error
IIBIG	Maximum number of inner iterations per outer iteration
ISOLUT	Flag indicating the presence of a solute field
CPV Flag	Optional data for interactive edits. If this word contains 6hCPVECT, NCPV and CPV data arrays are present; if not, NTRX begins here.
NCPV	Length of CPV data table (may be zero)
CPV Data	CPV data table
NTRX	Number of trips
Signal-Variable, Trip, and Controller Data	Signal-variable, trip, and controller data array
} Component dump	

Fig. 62.
Structure of dump-file time-edit data section.

Fig. 63.
Component dump structure.

TABLE XXVI
COMPONENT DUMP SUBROUTINES

<u>Component Type</u>	<u>Subroutine</u>
ACCUM	DCOMP
BREAK	DBRK
CORE	DCORE
FILL	DFILL
PIPE	DCOMP
PRIZER	DCOMP
PUMP	DPUMP
STGEN	DCOMP
TEE	DCOMP
TURB	DTURB
VALVE	DVLVE
VESSEL	DVSSL

TABLE XXVII
TRAC STORAGE ALLOCATIONS

<u>Storage Area</u>	<u>Size (Words)</u>
COMMON/LCMSP/	131 071
BLANK COMMON	20 000

Figure 64 displays the organization of the blank COMMON dynamic storage area in SCM. The fixed segment, which is described in Table XVII, contains information that is used by all system component subroutines and, therefore, must remain in SCM throughout the calculation.

The area that remains, marked as the component data area in Fig. 64, is available to each component when its data is in SCM. Each component type requires varying amounts of array space. Other than CORE, the required space for component types that are modeled with one-dimensional fluid dynamics is linear in the number of fluid cells, the number of heat-transfer nodes, and the product of these numbers. The CORE component requires additional space for storage of rod data. In any case, the space is assigned by the appropriate input routine (RPIPE, REPIPE, etc.), and the total amount of SCM

Fig. 64.
Blank COMMON dynamic storage area organization.

space required for each component is stored in the fixed-length table variable LENARR.

The array data for the VESSEL component are subdivided into three categories: component, level, and rod. The component data arrays describe the overall VESSEL state and remain in SCM throughout the VESSEL calculation. The variable LENARR contains the number of words of space in the component data area. The level and rod data arrays are transferred to SCM only when they are needed. The hydrodynamic variables for each axial level in the VESSEL are transferred between SCM and LCM as a unit. At certain points in the calculation, data for three distinct levels must be in SCM simultaneously. Therefore the SCM space required for each level is three times its length ($3 \times \text{LENLD}$). In a similar manner, the heat-transfer data for each fuel rod are transferred between SCM and LCM as a unit. Because the data for only one rod must be in SCM at any point in the calculation, the rod data may extend over the available space in SCM. Storage requirements for each rod are given by LENRD. Level data and rod data do not reside in SCM simultaneously. All of the allocation of this space is accomplished in the subroutines RVSSL and REVSSL.

In addition to the component, level, and rod data arrays, $\text{NVCELL} \times (\text{NVCELL} + 2)$ words of SCM space are needed for VESSEL components. This space is needed either for direct inversion of the vessel matrix when $\text{IITMAX} = 0$ or for solving the system by Gauss-Seidel iteration with coarse-mesh acceleration when $\text{IITMAX} > 0$. If $\text{IITMAX} = 0$, then NVCELL is the total number of vessel cells. If $\text{IITMAX} > 0$, NVCELL is the total number of vessel coarse-mesh regions.

The finite extent of the LCM component storage area (COMMON block LCMSF) limits the total amount of component data that can be handled in a calculation. This amount is found by summing the SCM array requirements including all VESSEL levels and rods and adding the space required for the fixed-length, variable-length, and pointer tables for each component. The graphics catalog, discussed in Sec. VI.F, also is stored in this LCM block. This area requires one word for each component plus six words for every catalog entry. Figure 65 shows the organization of LCMSF.

Fig. 65.
LCM data organization.

H. TRAC for Various Machine Configurations

At Los Alamos both our CDC 7600 and Cray versions of TRAC are maintained within a single CDC Update program library. Machine-dependent coding is isolated with Update *IF DEF cards. This capability was installed in a way that makes conversion to other computers and operating systems much simpler than was possible with previous versions of TRAC.

The available definitions are summarized in Table XXVIII. For a CDC machine we recommend starting with the definitions S7600, OVLAY, and TENB. For a Cray the appropriate definitions are CRAY, NOLCM, and EIGHTB. The variable dimension (VDM) definition is used at Los Alamos to implement dynamic run-time array storage, for both CDC (SCM and LCM storage) and Cray versions. The VDM option requires local operating system features to allocate memory. Currently, a static memory version is not in the coding for Cray or other machines with large contiguous memories (that is, NOLCM machines). To implement VDM on the Los Alamos Crays, two system calls are used: one to obtain the code's field length, and another to expand memory as the input deck is read. An update is available at Los Alamos to implement static memory NOLCM versions. This update will be incorporated in TRAC in the near future. In the meantime, new NOLCM users should contact the Los Alamos TRAC group to obtain this update if they wish to use a static memory code.

When TRAC is implemented on a local computer, we recommend that any necessary changes be made with updates to the original program library and that the original sequence numbers for the code be retained. As corrections and minor improvements are made at Los Alamos, the Update decks will be based on the original update sequencing. These code changes will be made available to authorized users through a dial-up connection to a Los Alamos computer.

TABLE XXVIII
TRAC DEFINITIONS

<u>Definition</u>	<u>Description</u>
S7600	Coding is unique to the CDC 7600 Scope system.
L7600	Coding is unique to the CDC 7600 LTSS system.
CRAY	Coding is unique to Cray computers.
OVLAY	On--code is overlaid. Off--code is not overlaid (intended for CDC computers).
FOURB	Coding is unique to a machine with four 8-bit bytes in a word.
EIGHTB	Coding is unique to a machine with eight 8-bit bytes in a word.
TENB	Coding is unique to a machine with ten 6-bit bytes in a word.
NOLCM	A machine with a contiguous memory (no LCM such as the CDC 7600 has).
HEX	On--use hexadecimal numbers. Off--use octal numbers.
VDM	Use variable-dimension memory.
LANL	On--codes are unique to Los Alamos.
INTERACT	On--create interactive version (currently not supported).

APPENDIX A

THERMODYNAMIC AND TRANSPORT FLUID PROPERTIES

The thermodynamic and transport properties subroutines used in TRAC are based on polynomial fits to steam table data for water, and ideal gas behavior for the noncondensable gas component. Transport property fits were obtained from Ref. 55. The thermodynamic property routines are used by all TRAC component modules. Tables A-I through A-VI, which list the values of the constants, are given at the end of this appendix.

I. THERMODYNAMIC PROPERTIES

Subroutine THERMO supplies thermodynamic properties for TRAC. The input variables are the total pressure, the partial pressure of the noncondensable gas component, and the liquid and gas-phase temperatures. The output variables include the saturation temperature corresponding to total pressure; the saturation temperature corresponding to the partial pressure of steam; the specific internal energies of liquid, gas phase, and noncondensable; the saturated liquid and steam enthalpies corresponding to the partial pressure of steam; the liquid, gas-phase and noncondensable densities; the derivatives of saturation temperatures and saturation enthalpies with respect to pressure; and, finally, the partial derivatives of liquid, steam, and noncondensable internal energies and densities with respect to pressure (at constant temperature) and with respect to temperature (at constant pressure).

The range of validity for the thermodynamic properties supplied by THERMO is

$$273.15 \text{ K} \leq T_l \leq 713.94 \text{ K} ,$$

$$273.15 \text{ K} \leq T_g \leq 3000.0 \text{ K} ,$$

and

$$1.0 \text{ Pa} \leq p \leq 45.0 \times 10^6 \text{ Pa} .$$

If THERMO is provided with data outside this range, it adjusts the data to the corresponding limit and issues a warning message.

Equations for the various properties used in THERMO are given below. Values of the constants are given in Tables A-I and A-II.

A. Saturation Properties

1. Relationship Between Saturation Temperature and Pressure. For $p_s < 90\,564.66$ Pa and $T_s < 370.4251$ K, the enthalpy of evaporation h_{gvs} is represented accurately as a linear function of temperature, such that,

$$h_{gvs} = 3\,180\,619.59 - 2\,470.2120 T_s .$$

The Clausius-Clapeyron equation, which assumes that steam is an ideal gas and neglects liquid volume compared to steam volume, can be written as

$$\frac{dp_s}{dT_s} = \frac{h_{gvs}}{R_v T_s^2} ,$$

where R_v is the gas constant for steam. Substituting for h_{gvs} and integrating using the boundary condition $p_s = 24821$ Pa at $T_s = 338$ K, gives

$$p_s = 24821 (T_s/338)^{-5.3512} \exp [20.387(T_s - 338)/T_s] .$$

TRAC calculations require determination of T_s from given p_s , which can only be calculated by trial and error from the above equation. Instead of iterating on the above equation, a simplified logic for calculating T_s is used that guarantees solution in a single iteration with an error of only a fraction of a percent. First, an approximate value of T_s is calculated from

$$T_{s, \text{approx}} = \frac{2263}{6.064 - 0.434 \ln (p_s/100\,000)} ,$$

which gives $T_{s,approx}$ within a few degrees of its actual value. The actual value of T_s then is calculated by integrating the Clausius-Clapeyron equation assuming constant h_{lvs} between $T_{s,approx}$ and T_s , which gives

$$T_s = \frac{T_{s,approx}}{1 - \frac{R_v T_{s,approx}}{h_{lvs,approx}} \ln \left(\frac{p_s}{p_{s,approx}} \right)},$$

where $h_{lvs,approx}$ and $p_{s,approx}$ are calculated corresponding to $T_{s,approx}$ using the equations given above. For $p_s \geq 9.056466 \times 10^4$ Pa and $T_s \geq 370.4251$ K ,

$$p_s = \frac{1}{A_{14}} \left(\frac{T_s - C_3}{C_1} \right)^{\frac{1}{C_2}}$$

and

$$\frac{dp_s}{dT_s} = \frac{p_s}{C_2 (T_s - C_3)}.$$

2. Internal Energy of Steam. For $p_v \leq 69\,738.3980$ Pa, where p_v is the partial pressure of steam,

$$e_{vs} = h_{vs} - \frac{p_v}{\rho_{vs}} = h_{vs} - R_v T_s$$

and

$$\frac{de_{vs}}{dp_v} = \frac{dh_{vs}}{dp_v} - R_v \frac{dT_s}{dp_v},$$

where

$$h_{vs} = -42.4793 + 4186.8 (T_s - 273.15) + h_{lvs}$$

and

$$\frac{dh_{vs}}{dp_v} = 4186.8 \frac{dT_s}{dp_v} + \frac{dh_{lvs}}{dp_v} = (4186.8 - 2470.2120) \frac{dT_s}{dp_v} .$$

For $69\,738.3980 < p_v \leq 88\,487.7383$ Pa ,

$$e_{vs} = h_{vs} - \frac{p_v}{\rho_{vs}} = h_{vs} - e_{vs} (\gamma_s - 1)$$

where

$$\gamma_s = C_9 + C_{10} p_v + C_{11} p_v^2 .$$

Therefore,

$$e_{vs} = \frac{h_{vs}}{\gamma_s}$$

and

$$\frac{de_{vs}}{dp_v} = \frac{1}{\gamma_s} \left(\frac{dh_{vs}}{dp_v} - e_{vs} \frac{d\gamma_s}{dp_v} \right) ,$$

with h_{vs} still given by the expression under $p_v \leq 69\,738.3980$ Pa regime. For $88\,487.7383 < p_v \leq C_{21}$ Pa ,

$$e_{vs} = C_6 + \frac{C_7}{C_8 + p_v}$$

and

$$\frac{de_{vs}}{dp_v} = - \frac{C_7}{(C_8 + p_v)^2} .$$

For $p_v > C_{21}$ Pa ,

$$e_{vs} = C_{12} + (C_{14}p_v + C_{13})p_v$$

and

$$\frac{de_{vs}}{dp_v} = C_{13} + A_{17}p_v .$$

3. Heat Capacity of Steam at Constant Pressure. Although the heat capacity of steam is not an output variable from THERMO, it is required in subsequent steam property calculations. For $p_v < 90\,564.66$ Pa,

$$C_{pvs} = 1748.7825 + 3.5107478 T_s - 2.2509364 \times 10^{-2} T_s^2 \\ + 4.0515323 \times 10^{-5} T_s^3$$

and

$$\frac{dc_{pvs}}{dp_v} = \frac{dT_s}{dp_v} (3.5107478 - 4.5018729 \times 10^{-2} T_s + 1.2154597 \times 10^{-4} T_s^2) ,$$

where T_s is the saturation temperature corresponding to the partial pressure of steam. For $p_v \geq 90\,564.66$ Pa,

$$c_{pvs} = C_{52} + C_{54} T_1 + C_{53} T_1^2 + \frac{C_{56}}{T_1} + \frac{C_{55}}{T_1^2}$$

and

$$\frac{dc_{pvs}}{dp_v} = -A_{15} \frac{dT_s}{dp_v} (C_{54} + 2 C_{53} T_1 - \frac{C_{56}}{T_1^2} - 2 \frac{C_{55}}{T_1^3}) ,$$

where $T_1 = 1 - A_{15} T_s$.

4. Enthalpy of Steam. For $p_v \leq 88\,487.7383$ Pa ,

$$h_{vs} = -42.4793 + 4186.8 (T_s - 273.15) + h_{l,vs}$$

and

$$\frac{dh_{vs}}{dp_v} = 4186.8 \frac{dT_s}{dp_v} + \frac{dh_{l,vs}}{dp_v} = (4186.8 - 2470.2120) \frac{dT_s}{dp_v} .$$

For $p_v > 88\,487.7383$ Pa ,

$$h_{vs} = e_{vs} \gamma_s$$

and

$$\frac{dh_{vs}}{dp_v} = \gamma_s \frac{de_{vs}}{dp_v} + e_{vs} \frac{d\gamma_s}{dp_v} ,$$

where (1)

$$\gamma_s = C_9 + C_{10} p_v + C_{11} p_v^2 , \quad \text{for } 69\,738.3980 < p_v \leq C_{21} \text{ Pa} , \text{ and}$$

$$= C_{15} + C_{16} p_v + C_{17} p_v^2 , \quad \text{for } p_v > C_{21} \text{ Pa} .$$

5. Density of Steam. The density of steam is calculated as

$$\rho_{vs} = \frac{p_v}{(\gamma_{s-1}) e_{vs}} ,$$

where

$$\gamma_s = \frac{h_{vs}}{e_{vs}} , \quad \text{for } p_v \leq 69\,738.3980 \text{ Pa}$$

$$= C_9 + C_{10} p_v + C_{11} p_v^2 , \quad \text{for } 69\,738.3980 < p_v \leq C_{21} \text{ Pa}$$

$$= C_{15} + C_{16} p_v + C_{17} p_v^2 , \quad \text{for } p_v > C_{21} \text{ Pa} .$$

6. Enthalpy of Liquid.

$$h_{ls} = e_{ls} + \frac{p}{\rho_{ls}}$$

and

$$\frac{dh_{ls}}{dp} = \frac{de_{ls}}{dT_s} \frac{dT_s}{dp} + \frac{1}{\rho_{ls}} - \frac{p}{\rho_{ls}^2} \left[\left(\frac{\partial \rho_{ls}}{\partial p} \right)_T + \left(\frac{\partial \rho_{ls}}{\partial T} \right)_p \frac{dT_s}{dp} \right] ,$$

where e_{ls} , ρ_{ls} , and their derivatives are evaluated using the liquid equations given below.

B. Liquid Properties

1. Internal Energy. The liquid internal energy is calculated by adding a correction term to the internal energy at saturation (corresponding to saturation pressure at liquid temperature), that is,

$$e_l = e_l(T_l, PSL) + ELP \quad ,$$

where PSL is the saturation pressure corresponding to T_l , and

$$ELP = (p - PSL) \left(\frac{\partial e_l}{\partial p} \right)_{T_l} \quad ,$$

where $(\partial e_l / \partial p)_{T_l}$ is calculated from the following expression.

$$\left(\frac{\partial e_l}{\partial p} \right)_{T_l} = C_{k0} [1 - \exp(C_{k4} \cdot PSL)] + C_{k2} \cdot PSL^2 \quad .$$

Therefore, the internal energy derivative with respect to T_l is calculated as

$$\left(\frac{\partial e_l}{\partial T_l} \right)_p = \left\{ \frac{\partial}{\partial T_l} [e_l(T_l, PSL)] \right\}_p + ERT \quad ,$$

where

$$\begin{aligned} ERT = \left[\frac{\partial}{\partial T_l} (ELP) \right]_p &= \{ C_{k0} [-1 + (1 - C_{k4} p + C_{k4} \cdot PSL) \exp(C_{k4} \cdot PSL)] \\ &+ C_{k2} [2p \cdot PSL - 3 \cdot PSL^2] \} \frac{d}{dt_l} (PSL) \quad . \end{aligned}$$

There are four temperature domains used in evaluating the liquid internal energy.

a. $T_l \leq 370.4251 \text{ K.}$

$$e_l = -42.4793 + 4186.8 \cdot \text{TLC} + \text{ELP}$$

and

$$\left(\frac{\partial e_l}{\partial T_l}\right)_p = 4186.8 + \text{ERT} ,$$

where $\text{TLC} = T_l - 273.15$.

b. $370.4251 < T_l < 548.15 \text{ K.}$

$$e_l = \text{ELC0} + \text{ELC1} \cdot \text{TLC} + \text{ELC2} \cdot \text{TLC}^2 + \text{ELC3} \cdot \text{TLC}^3 + \text{ELC4} \cdot \text{TLC}^4 + \text{ELP}$$

and

$$\left(\frac{\partial e_l}{\partial T_l}\right)_p = \text{DELCO} + \text{DELCl} \cdot \text{TLC} + \text{DELc2} \cdot \text{TLC}^2 + \text{DELc3} \cdot \text{TLC}^3 + \text{ERT} .$$

c. $548.15 \leq T_l \leq 611.15 \text{ K.}$

$$e_l = \text{ELD0} + \text{ELD1} \cdot \text{TLC} + \text{ELD2} \cdot \text{TLC}^2 + \text{ELD3} \cdot \text{TLC}^3 + \text{ELD4} \cdot \text{TLC}^4 + \text{ELP}$$

and

$$\left(\frac{\partial e_l}{\partial T_l}\right)_p = \text{DELDO} + \text{DELD1} \cdot \text{TLC} + \text{DELD2} \cdot \text{TLC}^2 + \text{DELD3} \cdot \text{TLC}^3 + \text{ERT} .$$

d. $T_\ell > 611.15 \text{ K.}$

$$e_\ell = \text{ELE0} + \text{ELE1} \cdot \text{TLC} + \text{ELE2} \cdot \text{TLC}^2 + \text{ELE3} \cdot \text{TLC}^3 + \text{ELE4} \cdot \text{TLC}^4 + \text{ELP} ,$$

and

$$\left(\frac{\partial e_\ell}{\partial T_\ell} \right)_p = \text{DELE0} + \text{DELE1} \cdot \text{TLC} + \text{DELE2} \cdot \text{TLC}^2 + \text{DELE3} \cdot \text{TLC}^3 + \text{ERT} .$$

2. Density. Define $\text{PBAR} = 1.0 \times 10^{-5} p$ and $\text{TLC} = T_\ell - 273.15$.
There are three temperature domains.

a. $T_\ell > 525.15 \text{ K.}$

$$\rho_\ell = 1.43 + \frac{1000}{(\text{CVH1} + \text{CVH2} \cdot \text{PBAR} + \text{CVH3} \cdot \text{PBAR}^2 + \beta_1 \cdot \text{TLC} + \gamma_1 \cdot \text{TLC}^2)} ,$$

$$\begin{aligned} \left(\frac{\partial \rho_\ell}{\partial p} \right)_{T_\ell} = & - (\rho_\ell - 1.43)^2 \cdot 1.0 \times 10^{-8} \{ \text{CVH2} + 2 \cdot \text{CVH3} \cdot \text{PBAR} \\ & + \text{TLC}(\text{CVH5} + 2 \cdot \text{CVH6} \cdot \text{PBAR}) + \text{TLC}^2(\text{CVH8} + 2 \cdot \text{CVH9} \cdot \text{PBAR}) \} , \end{aligned}$$

and

$$\left(\frac{\partial \rho_\ell}{\partial T_\ell} \right)_p = - (\rho_\ell - 1.43)^2 \cdot 1.0 \times 10^{-3} (\beta_1 + 2 \cdot \gamma_1 \cdot \text{TLC}) ,$$

where

$$\beta_1 = \text{CVH4} + \text{CVH5} \cdot \text{PBAR} + \text{CVH6} \cdot \text{PBAR}^2$$

and

$$\gamma_1 = \text{CVH7} + \text{CVH8} \cdot \text{PBAR} + \text{CVH9} \cdot \text{PBAR}^2 .$$

b. $T_\ell < 521.15 \text{ K.}$

$$\rho_\ell = \frac{1000}{(\text{CVL1} + \text{CVL2} \cdot \text{PBAR} + \text{CVL3} \cdot \text{PBAR}^2 + \beta_1 \cdot \text{TLC} + \gamma_1 \cdot \text{TLC}^2)} - 2.01 ,$$

$$\left(\frac{\partial \rho_\ell}{\partial p}\right)_{T_\ell} = -(\rho_\ell + 2.01)^2 \cdot 1.0 \times 10^{-8} \{ \text{CVL2} + 2 \cdot \text{CVL3} \cdot \text{PBAR} \\ + \text{TLC}(\text{CVL5} + 2 \cdot \text{CVL6} \cdot \text{PBAR}) + \text{TLC}^2(\text{CVL8} + 2 \cdot \text{CVL9} \cdot \text{PBAR}) \} .$$

$$\left(\frac{\partial \rho_\ell}{\partial T_\ell}\right)_p = -(\rho_\ell + 2.01)^2 \cdot 1.0 \times 10^{-3} (\beta_1 + 2 \cdot \gamma_1 \cdot \text{TLC}) ,$$

where

$$\beta_1 = \text{CVL4} + \text{CVL5} \cdot \text{PBAR} + \text{CVL6} \cdot \text{PBAR}^2$$

and

$$\gamma_1 = \text{CVL7} + \text{CVL8} \cdot \text{PBAR} + \text{CVL9} \cdot \text{PBAR}^2 .$$

c. $521.15 \text{ K} \leq T_\ell \leq 525.15 \text{ K.}$ An average of the functions in (a) and (b) above is used in this range. Call the two values $\rho_{\ell a}$ and $\rho_{\ell b}$, then

$$\rho_\ell = \left(\frac{525.15 - T_\ell}{4.0}\right)\rho_{\ell b} + \left(\frac{T_\ell - 521.15}{4.0}\right)\rho_{\ell a} ,$$

$$\left(\frac{\partial \rho_\ell}{\partial p}\right)_{T_\ell} = \left(\frac{525.15 - T_\ell}{4.0}\right) \left(\frac{\partial \rho_{\ell b}}{\partial p}\right)_{T_\ell} + \left(\frac{T_\ell - 521.15}{4.0}\right) \left(\frac{\partial \rho_{\ell a}}{\partial p}\right)_{T_\ell} ,$$

and

$$\left(\frac{\partial \rho_\ell}{\partial T_\ell}\right)_p = \left(\frac{525.15 - T_\ell}{4.0}\right) \left(\frac{\partial \rho_{\ell b}}{\partial T_\ell}\right)_p + \left(\frac{T_\ell - 521.15}{4.0}\right) \left(\frac{\partial \rho_{\ell a}}{\partial T_\ell}\right)_p + \frac{\rho_{\ell a} - \rho_{\ell b}}{4.0} .$$

d. Residual Void Correction. After evaluation in Secs. (a) through (c), ρ_ℓ and its derivatives are corrected to reflect a residual void fraction. In the following, the values calculated by (a) through (c) above are denoted by a tilde ($\sim$).

i. $p \geq 4.0 \times 10^5 \text{ Pa.}$

$$\left(\frac{\partial \rho_\ell}{\partial T_\ell}\right)_p = \left(1 - \frac{1000}{p}\right) \left(\frac{\partial \tilde{\rho}_\ell}{\partial T_\ell}\right)_p ,$$

$$\left(\frac{\partial \rho_\ell}{\partial p}\right)_{T_\ell} = \left(1 - \frac{1000}{p}\right) \left(\frac{\partial \tilde{\rho}_\ell}{\partial p}\right)_{T_\ell} + \frac{1000 \tilde{\rho}_\ell}{p^2} ,$$

and

$$\rho_\ell = \left(1 - \frac{1000}{p}\right) \tilde{\rho}_\ell .$$

ii. $p < 4.0 \times 10^5 \text{ Pa.}$

$$\left(\frac{\partial \rho_\ell}{\partial T_\ell}\right)_p = (0.995 + 6.25 \times 10^{-9} p) \left(\frac{\partial \tilde{\rho}_\ell}{\partial T_\ell}\right)_p ,$$

$$\left(\frac{\partial \rho_\ell}{\partial p}\right)_{T_\ell} = (0.995 + 6.25 \times 10^{-9} p) \left(\frac{\partial \tilde{\rho}_\ell}{\partial p}\right)_{T_\ell} + 6.25 \times 10^{-9} \tilde{\rho}_\ell ,$$

and

$$\rho_\ell = (0.995 + 6.25 \times 10^{-9} p) \tilde{\rho}_\ell .$$

C. Vapor Properties

1. Superheated Steam. $(T_g - T_s) > 0$, where T_s is the saturation temperature corresponding to partial pressure of steam.

The specific heat of steam at constant pressure is approximated as

$$c_{pv} = \left(\frac{\partial h_v}{\partial T_g} \right)_{p_v} = \frac{c_{pv,ideal}}{2} \left[1 + \frac{T_g}{(T_g^2 - \beta)^{1/2}} \right] ,$$

where

$$\beta = T_s^2 \left[1 - \frac{1}{(A_{11} c_{pvs} - 1)^2} \right] .$$

Integrating along constant p_v line gives

$$h_v = h_{vs} + \frac{c_{pv,ideal}}{2} [(T_g - T_s) + (T_g^2 - \beta)^{1/2} - \frac{T_s}{A_{11} c_{pvs} - 1}] .$$

The internal energy of vapor is therefore calculated as

$$e_v = e_{vs} + \frac{c_{pv,ideal}}{2} [(T_g - T_s) + (T_g^2 - \beta)^{1/2} - \frac{T_s}{A_{11} c_{pvs} - 1}] \\ - p_v \left(\frac{1}{\rho_v} - \frac{1}{\rho_{vs}} \right) .$$

The calculations are divided into two domains based on the value of c_{pvs} .

a. $c_{pvs} < c_{pv,ideal}$. The steam density is calculated as

$$\rho_v = \frac{p_v}{(\gamma_s - 1) e_{vs} + R_v (T_g - T_s)} ,$$

which gives

$$e_v = e_{vs} + \frac{c_{pv,ideal}}{2} [(T_g - T_s) + (T_g^2 - \beta)^{1/2} - \frac{T_s}{A_{11} c_{pvs}^{-1}}] - R_v (T_g - T_s) .$$

Therefore,

$$\left(\frac{\partial \rho_v}{\partial T_g}\right)_{p_v} = - \frac{\rho_v R_v}{(\gamma_s - 1) e_{vs} + R_v (T_g - T_s)} = - \frac{\rho_v^2 R_v}{p_v} ,$$

$$\left(\frac{\partial \rho_v}{\partial p_v}\right)_{T_g} = \rho_v \left\{ \frac{1}{p_v} - \left[e_{vs} \frac{d\gamma_s}{dp_v} + (\gamma_s - 1) \frac{de_{vs}}{dp_v} - R_v \frac{dT_s}{dp_v} \right] \left[\frac{1}{(\gamma_s - 1) + R_v (T_g - T_s)} \right] \right\} ,$$

$$\left(\frac{\partial e_v}{\partial T_g}\right)_{p_v} = \frac{c_{pv,ideal}}{(1 - \frac{\beta}{2})} - R_v ,$$

and

$$\left(\frac{\partial e_v}{\partial p_v}\right)_{T_g} = - \frac{1}{2} \left[\left(\frac{\partial e_v}{\partial T_g}\right)_{p_v} + R_v \right] \left[\left(1 - \frac{\beta}{2}\right) \eta_p + \frac{1}{\eta} \frac{d\beta}{dp_v} \right] ,$$

where

$$\eta = A_{11} [e_v - e_{vs} + R_v(T_g - T_s)] + T_s \left[1 + \frac{1}{A_{11}c_{pvs} - 1} \right] ,$$

$$\begin{aligned} \eta_p' &= \left(\frac{\partial \eta}{\partial p_v} \right)_{T_g} - A_{11} \left(\frac{\partial e_v}{\partial p_v} \right)_{T_g} \\ &= -A_{11} \left[\frac{de_{vs}}{dp_v} - R_v \frac{dT_s}{dp_v} \right] + \left[1 + \frac{1}{A_{11}c_{pvs} - 1} \right] \frac{dT_s}{dp_v} \\ &\quad - \frac{A_{11} T_s}{(A_{11}c_{pvs} - 1)^2} \frac{dc_{pvs}}{dp_v} , \end{aligned}$$

and

$$\frac{d\beta}{dp_v} = \frac{2}{T_s} \left[\beta \left(\frac{dT_s}{dp_v} \right) + \frac{T_s^3 A_{11}}{(A_{11}c_{pvs} - 1)^3} \left(\frac{dc_{pvs}}{dp_v} \right) \right] .$$

Note: If ρ_v is less than zero, the vapor density and its derivatives are superceded by

$$\rho_v = \frac{p_v}{R_v T_g} ,$$

$$\left(\frac{\partial \rho_v}{\partial T_g} \right)_{p_v} = -\frac{\rho_v}{T_g} ,$$

and

$$\left(\frac{\partial \rho_v}{\partial p_v} \right)_{T_g} = \frac{\rho_v}{p_v} .$$

b. $c_{pvs} \geq c_{pv,ideal}$. The steam density is calculated as

$$\rho_v = \frac{p_v}{(\gamma_s - 1) e_{vs} + c_{26}(e_v - e_{vs})} ,$$

which gives

$$e_v = e_{vs} + A_{12}[(T_g - T_s) + (T_g^2 - \beta)^{1/2} - \frac{T_s}{(A_{11}c_{pvs} - 1)}] .$$

Therefore,

$$\left(\frac{\partial \rho_v}{\partial T_g}\right)_{p_v} = - \left(\frac{\partial e_v}{\partial T_g}\right)_{p_v} \left[\frac{c_{26} \rho_v}{(\gamma_s - 1) e_{vs} + c_{26}(e_v - e_{vs})} \right] ,$$

$$\begin{aligned} \left(\frac{\partial \rho_v}{\partial p_v}\right)_{T_g} &= \rho_v \left\{ \frac{1}{p_v} - [e_{vs} \left(\frac{d\gamma_s}{dp_v}\right) + (\gamma_s - c_{24}) \frac{de_{vs}}{dp_v}] \right. \\ &\quad \times \left. \left[\frac{1}{(\gamma_s - 1) e_{vs} + c_{26}(e_v - e_{vs})} \right] \right\} + \left(\frac{\partial \rho_v}{\partial e_v}\right)_{p_v} \left(\frac{\partial e_v}{\partial p_v}\right)_{T_g} , \end{aligned}$$

$$\left(\frac{\partial e_v}{\partial T_g}\right)_{p_v} = \frac{c_{vv,ideal}}{\left(1 - \frac{\beta}{\kappa^2}\right)} ,$$

and

$$\left(\frac{\partial e_v}{\partial p_v}\right)_{T_g} = - \frac{1}{2} \left(\frac{\partial e_v}{\partial T_g}\right)_{p_v} \left[\left(1 - \frac{\beta}{\kappa^2}\right) \kappa'_p + \frac{1}{\kappa} \frac{d\beta}{dp_v} \right] ,$$

where

$$\kappa = A_{13}(e_v - e_{vs}) + T_s \left[1 + \frac{1}{(A_{11}c_{pvs} - 1)} \right] ,$$

$$\begin{aligned} \kappa'_p &= \left(\frac{\partial \kappa}{\partial p_v} \right) T_g - A_{13} \left(\frac{\partial e_v}{\partial p_v} \right) T_g \\ &= -A_{13} \frac{de_{vs}}{dp_v} + \left[1 + \frac{1}{A_{11}c_{pvs} - 1} \right] \frac{dT_s}{dp_v} \\ &\quad - \frac{A_{11}T_s}{(A_{11}c_{pvs} - 1)^2} \frac{dc_{pvs}}{dp_v} , \end{aligned}$$

and

$$\left(\frac{\partial \rho_v}{\partial e_v} \right)_{p_v} = \frac{-C_{26}\rho_v}{[(\gamma_s - 1)e_{vs} + C_{26}(e_v - e_{vs})]} .$$

Note: If ρ_v exceeds $0.9 \rho_\ell$, the vapor density and its derivatives are superceded by

$$\rho_v = 0.9 \rho_\ell ,$$

$$\left(\frac{\partial \rho_v}{\partial T_g} \right)_{p_v} = 0.9 \left(\frac{\partial \rho_\ell}{\partial T_\ell} \right)_p ,$$

and

$$\left(\frac{\partial \rho_v}{\partial p_v} \right)_{T_g} = 0.9 \left(\frac{\partial \rho_\ell}{\partial p} \right)_{T_\ell} .$$

2. Subcooled Vapor. $(T_g - T_s) \leq 0$ The density and its derivatives are calculated in the same manner as for the superheated vapor case above. The internal energy and its derivatives are given below.

$$e_v = e_{vs} + (T_g - T_s) \frac{c_{pvs}}{C_{24}} ,$$

$$\left(\frac{\partial e_v}{\partial T_g} \right)_{p_v} = \frac{c_{pvs}}{C_{24}} ,$$

$$\left(\frac{\partial e_v}{\partial p_v} \right)_{T_g} = - \left(\frac{\partial e_v}{\partial T_g} \right)_{p_v} \left\{ \frac{dT_s}{dp_v} - \left(\frac{C_{24}}{c_{pvs}} \right) \left[\frac{de_{vs}}{dp_v} + \frac{(e_v - e_{vs})}{c_{pvs}} \left(\frac{dc_{pvs}}{dp_v} \right) \right] \right\} .$$

3. Noncondensable Gas (Air).

a. Internal Energy.

$$e_a = c_{va} T_g ,$$

$$\left(\frac{\partial e_a}{\partial T_g} \right)_{p_a} = c_{va} ,$$

and

$$\left(\frac{\partial e_a}{\partial p_a} \right)_{T_g} = 0.0 .$$

b. Density.

$$\rho_a = \frac{p_a}{R_a T_g} ,$$

$$\left(\frac{\partial \rho_a}{\partial p_a} \right)_{T_g} = \frac{1}{R_a T_g} ,$$

and

$$\left(\frac{\partial \rho_a}{\partial T_g} \right)_{p_a} = - R_a \rho_a \left(\frac{\partial \rho_a}{\partial p_a} \right)_{T_g} ,$$

where R_a is the gas constant for the noncondensable gas.

II. TRANSPORT PROPERTIES

Subroutine FPROP is used to obtain transport properties for water and the noncondensable gas. The input variables for this routine are the saturation temperature, pressure, enthalpies of each phase, vapor density, and the vapor temperature. The output transport variables include the latent heat of vaporization, surface tension, constant pressure specific heat, viscosity, and thermal conductivity of steam, the liquid, and the noncondensable gas. The transport property calls are function calls within the FPROP subroutine. The polynomial equation fits for the transport properties used in FPROP are described. Note that the curve fits for σ and $c_{p\ell}$ have been updated since TRAC-PlA. Values of the constants are given in Tables A-III through A-VI.

A. Latent Heat of Vaporization

The latent heat of vaporization is calculated as

$$h_{lv} = h_{vs} - h_{ls} ,$$

where h_{vs} and h_{ls} are calculated according to App. A.I.A.

B. Constant Pressure Specific Heats

Constants used in this section are given in Table A-III.

$$c_{p\ell} = \{ h_{\ell} [h_{\ell} (D_{0\ell} + D_{1\ell} p) + (C_{0\ell} + C_{1\ell} p)] + B_{0\ell} + B_{1\ell} p \}^{-1}$$

and

$$c_{pv} = C_{1g} + C_{2g} T_g + \frac{C_{3g} p}{(C_{5g} T_g - C_{6g})^{2.4}} + \frac{C_{4g} p^3}{(C_{5g} T_g - C_{6g})^9} .$$

Because these values are used only for calculating heat-transfer coefficients, these fits were chosen for simplicity and smoothness and are not necessarily consistent with those derivable from the thermodynamic routines.

The specific heat of the noncondensable gas is assumed constant and is given in Table A-I.

C. Fluid Viscosities

1. Liquid. Constants used in this section are given in Table A-IV. The evaluation of liquid viscosity is divided into three different enthalpy ranges. For $h_\ell \leq h_1$,

$$\mu_\ell = [A_{0\ell} + A_{1\ell}x + A_{2\ell}x^2 + A_{3\ell}x^3 + A_{4\ell}x^4] \\ - [B_{0\ell} + B_{1\ell}\eta + B_{2\ell}\eta^2 + B_{3\ell}\eta^3](p - p_1) \quad ,$$

where

$$x = (h_\ell - c_{0n})h_0$$

and

$$\eta = (h_\ell - e_{c0n})e_{h0} \quad .$$

In the range $h_1 < h \leq h_2$,

$$\mu_\ell = [E_{0\ell} + E_{1\ell}h_\ell + E_{2\ell}h_\ell^2 + E_{3\ell}h_\ell^3] \\ + [F_{0\ell} + F_{1\ell}h_\ell + F_{2\ell}h_\ell^2 + F_{3\ell}h_\ell^3](p - p_1) \quad .$$

For $h_\ell > h_2$,

$$\mu_\ell = [D_{0\ell} + D_{1\ell}z + D_{2\ell}z^2 + D_{3\ell}z^3 + D_{4\ell}z^4] \quad ,$$

where

$$z = (h_\ell - c_n)h_{00} \quad .$$

2. Steam. Constants used in this section are given in Table A-V.
Three vapor temperature ranges are used to represent the data.

a. $T_g \leq T_1$

$$\mu_v = [B_{1g}(T_g - 273.15) + C_{1g}] - \rho_v[D_{1g} - E_{1g}(T_g - 273.15)] .$$

If $\mu_v < 10^{-7}$, it is set to that value.

b. $T_1 < T_g < T_2$

$$\begin{aligned} \mu_v = & B_{1g}(T_g - 273.15) + C_{1g} + \rho_v[F_{1g} + F_{2g}(T_g - 273.15) \\ & + F_{3g}(T_g - 273.15)^2 + F_{4g}(T_g - 273.15)^2] \\ & + \rho_v[G_{1g} + G_{2g}(T_g - 273.15) + G_{3g}(T_g - 273.15)^2 \\ & + G_{4g}(T_g - 273.15)^3] (A_{0g} + A_{1g}\rho_v + A_{2g}\rho_v^2) . \end{aligned}$$

c. $T_g \geq T_2$

$$\mu_v = B_{1g}(T_g - 273.15) + C_{1g} + \rho_v(A_{0g} + A_{1g}\rho_v + A_{2g}\rho_v^2) .$$

3. Noncondensable Gas.

a. Air. If the noncondensable gas is air, two ranges of T_g are used.

i. $T_g \leq 502.15$ K.

$$\mu_a = H_{a1} + H_{a2}(T_g - 273.15) + H_{a3}(T_g - 273.15)^2 .$$

ii. $T_g > 502.15$ K.

$$\mu_a = H_{b1} + H_{b2}(T_g - 273.15) + H_{b3}(T_g - 273.15)^2 .$$

b. Hydrogen. If the noncondensable gas is hydrogen, the viscosity is calculated as

$$\mu_a = H_{c1} + H_{c2} T_g + H_{c3} T_g^2 .$$

D. Fluid Thermal Conductivities

The liquid thermal conductivity is given by

$$k_l = A_{l0} + A_{l1}x_k + A_{l2}x_k^2 + A_{l3}x_k^3 ,$$

where

$$x_k = \frac{h_l}{h_0} ,$$

and the constants are given in Table A-VI.

The steam thermal conductivity is given by

$$k_v = x_1 + \rho_v \left[x_2 + \frac{C_{p_v}}{(T_g - 273.15)^{4.2}} \right] ,$$

where

$$x_1 = A_{g0} + A_{g1}(T_g - 273.15) + A_{g2}(T_g - 273.15)^2 + A_{g3}(T_g - 273.15)^3$$

and

$$x_2 = B_{g0} + B_{g1}(T_g - 273.15) + B_{g2}(T_g - 273.15)^2 .$$

However, the minimum permitted value for k_v is 1.0×10^{-4} .

The thermal conductivity of the noncondensable gas is assumed constant and is given in Table A-VI.

E. Surface Tension

The surface tension is given by

$$\sigma = 0.2358 \left(1 - 0.625 \frac{647.3 - T_s}{647.3} \right) \left(\frac{647.3 - T_s}{647.3} \right)^{1.256} .$$

III. VERIFICATION

The thermodynamic and transport property fits¹⁷ used in TRAC have been compared with steam table data over a wide range of parameters. The agreement is satisfactory in the saturation region and in the superheated steam region for $p < p_{\text{critical}}$ and $T_g < 823.0$ K. For example, the saturation temperature corresponding to a given pressure is always calculated within a maximum error of ± 1 K. However, in most situations the error is significantly smaller. The agreement also is good in the subcooled water region for $T_l < T_{\text{critical}}$.

Further verification was performed by comparing the TRAC polynomial fits with the WATER package⁵⁵ over a wider range of nonequilibrium [99 K of both superheat and subcooling (liquid superheat or vapor subcooling exceeding 99 K are highly unlikely in reactor applications)] for pressures up to 20 MPa. The comparisons showed good agreement for both the thermodynamic and transport properties throughout the saturation and nonequilibrium regions except for very extreme cases. However, at high degrees of subcooling or superheat, some minor inconsistencies were noticed. Because there are no data in these extreme cases, it is impossible to compare TRAC and the WATER package adequately.

In conclusion, for most TRAC applications the thermodynamic and transport property routines provide realistic values up to critical point. The simplified polynomial fits provide an efficient and low-cost method compared to other approaches such as steam table interpolation.

TABLE A-1
POLYNOMIAL CONSTANTS FOR THERMO

C_1	= 117.8	C_{24}	= 1.3
C_2	= 0.223	C_{26}	= C_{24}^{-1} = 0.3
C_3	= 255.2	C_{28}	= 1.0×10^5
C_4	= 958.75	C_{40}	= 273.0
C_5	= -0.856 6	C_{41}	= 239.36
C_6	= 2.619 410 618 $\times 10^6$	C_{42}	= 2.786 7
C_7	= -4.995×10^{10}	C_{43}	= -5.776 26
C_8	= 3.403×10^5	C_{44}	= 3.938
C_9	= 1.066 554 48	C_{45}	= 1.0×10^{-6}
C_{10}	= 1.02×10^{-8}	C_{47}	= 1.0×10^3
C_{11}	= -2.548×10^{-15}	C_{48}	= -0.15×10^3
C_{12}	= 2.589 600 $\times 10^6$	C_{49}	= -20.0
C_{13}	= 6.350×10^{-3}	C_{51}	= 0.657×10^{-6}
C_{14}	= $-1.058 2 \times 10^{-9}$	C_{52}	= 2.996 018 036 $\times 10^3$
C_{15}	= 1.076 4	C_{53}	= 9.700 016 602 $\times 10^3$
C_{16}	= 3.625×10^{-10}	C_{54}	= -8.448 077 393 $\times 10^3$
C_{17}	= -9.063×10^{-17}	C_{55}	= 8.349 824
C_{20}	= R_V = 461.4975	C_{56}	= 3.495 194 44 $\times 10^2$
C_{21}	= 2.0×10^6	C_{k0}	= $-8.329 595 \times 10^{-4}$
C_{23}	= 647.3	C_{k2}	= $-2.245 825 \times 10^{-17}$
		C_{k4}	= $-1.450 382 \times 10^{-6}$

TABLE A-I (cont.)

ELC0 = $1.758\ 80 \times 10^4$	ELE0 = $2.283\ 789\ 029 \times 10^9$
ELC1 = $3.737\ 452 \times 10^3$	ELE1 = $-2.622\ 156\ 77 \times 10^7$
ELC2 = $3.934\ 036$	ELE2 = $1.129\ 486\ 67 \times 10^5$
ELC3 = $-0.015\ 038\ 190$	ELE3 = $-2.162\ 339\ 85 \times 10^2$
ELC4 = $3.011\ 387 \times 10^{-5}$	ELE4 = $0.155\ 283\ 438$
ELD0 = $6.185\ 27 \times 10^6$	CVL1 = $2.252\ 62$
ELD1 = $-8.145\ 47 \times 10^4$	CVL2 = $0.014\ 859\ 4$
ELD2 = $4.465\ 98 \times 10^2$	CVL3 = $-7.154\ 88 \times 10^{-5}$
ELD3 = $-1.041\ 16$	CVL4 = $0.010\ 458\ 8$
ELD4 = $9.260\ 22 \times 10^{-4}$	CVL5 = $-1.029\ 62 \times 10^{-4}$
CVH1 = $1.002\ 136\ 23$	CVL6 = $5.091\ 35 \times 10^{-7}$
CVH2 = $-5.632\ 785 \times 10^{-5}$	CVL7 = $2.592\ 66 \times 10^{-5}$
CVH3 = $-8.971\ 304\ 77 \times 10^{-9}$	CVL8 = $1.724\ 1 \times 10^{-7}$
CVH4 = $-2.282\ 874\ 59 \times 10^{-5}$	CVL9 = $-8.984\ 19 \times 10^{-10}$
CVH5 = $4.765\ 967\ 87 \times 10^{-7}$	c_{pa} = 1004.832 for air and
CVH6 = $5.021\ 318 \times 10^{-10}$	= $14\ 533.2$ for hydrogen.
CVH7 = $4.101\ 156\ 58 \times 10^{-6}$	R_a = 287.0280 for air and
CVH8 = $-3.803\ 989\ 08 \times 10^{-9}$	= 4124.1761 for hydrogen
CVH9 = $-1.421\ 997\ 52 \times 10^{-12}$	R_v = 461.4975

TABLE A-II

DERIVED CONSTANTS FOR THERMODYNAMIC PROPERTIES OF WATER AND NONCONDENSABLE GAS

$A_1 = C_1 \cdot C^2 / C_{28}$	$A_{11} = 2 \cdot C_{26} / (C_{24} \cdot C_{20}) = 2 / c_{pv,ideal}$
$A_2 = C_2 - 1.0$	$A_{13} = A_{11} \cdot (1.0 + C_{26}) = 2 / c_{vv,ideal}$
$A_3 = -C_4 \cdot C^5 / C_{23}$	$A_{12} = 1.0 / A_{13}$
$A_4 = C_5 - 1.0$	$A_{14} = 1.0 / C_{28}$
$A_5 = C_{45} \cdot C_{49}$	$A_{15} = 1.0 / C_{23}$
$A_6 = 2 \cdot C_{45} \cdot C_{48}$	$A_{16} = 2 \cdot C_{11}$
$A_7 = 4 \cdot C_{44} \cdot C_{45}$	$A_{17} = 2 \cdot C_{14}$
$A_8 = 3 \cdot C_{43} \cdot C_{45}$	$A_{18} = 2 \cdot C_{17}$
$A_9 = 2 \cdot C_{42} \cdot C_{45}$	$A_{19} = 2 \cdot C_{48} \cdot C_{45}$
$A_{10} = C_{41} \cdot C_{45}$	$A_{20} = C_{45} \cdot C_{49}$
$DELCO = ELC1$	$DELDO = ELD1$
$DELC1 = 2 \cdot ELC2$	$DELD1 = 2 \cdot ELD2$
$DELC2 = 3 \cdot ELC3$	$DELD2 = 3 \cdot ELD3$
$DELC3 = 4 \cdot ELC4$	$DELD3 = 4 \cdot ELD4$
$DELEO = ELE1$	$c_{pv,ideal} = C_{24} R_v / C_{26}$
$DELE1 = 2 \cdot ELE2$	$c_{vv,ideal} = R_v / C_{26}$
$DELE2 = 3 \cdot ELE3$	$c_{va} = c_{pa} - R_a$
$DELE3 = 4 \cdot ELE4$	

TABLE A-III

BASIC CONSTANTS FOR TRANSPORT PROPERTIES OF WATER AND AIR

$$\begin{aligned}
 H_{g0} &= 2.739\ 623\ 397 \times 10^6 \\
 H_{g1} &= 3.758\ 844\ 554 \times 10^{-2} \\
 H_{g2} &= -7.163\ 990\ 945 \times 10^{-9} \\
 H_{g3} &= 4.200\ 231\ 947 \times 10^{-16} \\
 H_{g4} &= 9.850\ 752\ 122 \times 10^{-24}
 \end{aligned}$$

$$\begin{aligned}
 B_{0l} &= 2.394\ 907 \times 10^{-4} & B_{1l} &= -5.196\ 250 \times 10^{-13} \\
 C_{0l} &= 1.193\ 203 \times 10^{-11} & C_{1l} &= 2.412\ 704 \times 10^{-18} \\
 D_{0l} &= -3.944\ 067 \times 10^{-17} & D_{1l} &= -1.680\ 771 \times 10^{-24}
 \end{aligned}$$

$$\begin{aligned}
 C_{1g} &= 1.688\ 359\ 68 \times 10^3 \\
 C_{2g} &= 0.602\ 985\ 6 \\
 C_{3g} &= 4.820\ 979\ 623 \times 10^2 \\
 C_{4g} &= 2.953\ 179\ 05 \times 10^7 \\
 C_{5g} &= 1.8 \\
 C_{6g} &= 4.60 \times 10^2
 \end{aligned}$$

TABLE A-IV

LIQUID VISCOSITY CONSTANTS

$$\begin{aligned}
 A_{0\ell} &= 1.299\ 470\ 229 \times 10^{-3} \\
 A_{1\ell} &= -9.264\ 032\ 108 \times 10^{-4} \\
 A_{2\ell} &= 3.810\ 470\ 61 \times 10^{-4} \\
 A_{3\ell} &= -8.219\ 444\ 458 \times 10^{-5} \\
 A_{4\ell} &= 7.022\ 437\ 984 \times 10^{-6}
 \end{aligned}$$

$$\begin{aligned}
 B_{0\ell} &= -6.595\ 9 \times 10^{-12} \\
 B_{1\ell} &= -6.763 \times 10^{-12} \\
 B_{2\ell} &= -2.888\ 25 \times 10^{-12} \\
 B_{3\ell} &= 4.452\ 5 \times 10^{-13}
 \end{aligned}$$

$$\begin{aligned}
 D_{0\ell} &= 3.026\ 032\ 306 \times 10^{-4} \\
 D_{1\ell} &= -1.836\ 606\ 896 \times 10^{-4} \\
 D_{2\ell} &= 7.567\ 075\ 775 \times 10^{-5} \\
 D_{3\ell} &= -1.647\ 878\ 879 \times 10^{-5} \\
 D_{4\ell} &= 1.416\ 457\ 633 \times 10^{-6}
 \end{aligned}$$

$$\begin{aligned}
 E_{0\ell} &= 1.452\ 605\ 261\ 2 \times 10^{-3} \\
 E_{1\ell} &= -6.988\ 008\ 498\ 5 \times 10^{-9} \\
 E_{2\ell} &= 1.521\ 023\ 033\ 4 \times 10^{-14} \\
 E_{3\ell} &= -1.230\ 319\ 494\ 6 \times 10^{-20}
 \end{aligned}$$

$$\begin{aligned}
 F_{0\ell} &= -3.806\ 350\ 753\ 3 \times 10^{-11} \\
 F_{1\ell} &= 3.928\ 520\ 767\ 7 \times 10^{-16} \\
 F_{2\ell} &= -1.258\ 579\ 929\ 2 \times 10^{-21} \\
 F_{3\ell} &= 1.286\ 018\ 078\ 8 \times 10^{-27}
 \end{aligned}$$

$$\begin{aligned}
 h_0 &= 8.581\ 289\ 699 \times 10^{-6} \\
 c_{0n} &= 4.265\ 884 \times 10^4 \\
 p_i &= 6.894\ 575\ 293 \times 10^5
 \end{aligned}$$

$$\begin{aligned}
 h_{00} &= 3.892\ 077\ 365 \times 10^{-6} \\
 e_{c0n} &= 5.535\ 88 \times 10^4 \\
 h_1 &= 2.76 \times 10^5
 \end{aligned}$$

$$\begin{aligned}
 e_{h0} &= 6.484\ 503\ 981 \times 10^{-6} \\
 c_n &= 4.014\ 676 \times 10^5 \\
 h_2 &= 3.94 \times 10^5
 \end{aligned}$$

TABLE A-V

VAPOR VISCOSITY CONSTANTS

$$\begin{aligned} A_{0g} &= 3.53 \times 10^{-8} \\ A_{1g} &= 6.765 \times 10^{-11} \\ A_{2g} &= 1.021 \times 10^{-14} \end{aligned}$$

$$\begin{aligned} B_{1g} &= 0.407 \times 10^{-7} \\ C_{1g} &= 8.04 \times 10^{-6} \\ D_{1g} &= 1.858 \times 10^{-7} \\ E_{1g} &= 5.9 \times 10^{-10} \end{aligned}$$

$$\begin{aligned} F_{1g} &= -0.2885 \times 10^{-5} \\ F_{2g} &= 0.2427 \times 10^{-7} \\ F_{3g} &= -0.6789333 \times 10^{-10} \\ F_{4g} &= -0.6317037037 \times 10^{-13} \end{aligned}$$

$$\begin{aligned} G_{1g} &= 176.0 \\ G_{2g} &= -1.6 \\ G_{3g} &= 0.0048 \\ G_{4g} &= -0.474074074 \times 10^{-5} \end{aligned}$$

$$\begin{aligned} H_{a1} &= 1.708 \times 10^{-5} \\ H_{a2} &= 5.927 \times 10^{-8} \\ H_{a3} &= 8.14 \times 10^{-11} \end{aligned}$$

$$\begin{aligned} H_{b1} &= 1.735 \times 10^{-5} \\ H_{b2} &= 4.193 \times 10^{-8} \\ H_{b3} &= 1.09 \times 10^{-11} \end{aligned}$$

$$\begin{aligned} H_{c1} &= 4.175 \times 10^{-6} \\ H_{c2} &= 1.588 \times 10^{-8} \\ H_{c3} &= 7.6705 \times 10^{-13} \end{aligned}$$

$$\begin{aligned} T_1 &= 573.15 \\ T_2 &= 648.15 \end{aligned}$$

TABLE A-VI
THERMAL CONDUCTIVITY CONSTANTS

$$\begin{aligned}h_0 &= 5.815 \times 10^5 \\A_{\lambda 0} &= 0.573\,738\,622 \\A_{\lambda 1} &= 0.253\,610\,355\,1 \\A_{\lambda 2} &= -0.145\,468\,269 \\A_{\lambda 3} &= -0.013\,874\,724\,85\end{aligned}$$

$$C = 2.148\,2 \times 10^5$$

$$\begin{aligned}A_{g0} &= 1.76 \times 10^{-2} \\A_{g1} &= 5.87 \times 10^{-5} \\A_{g2} &= 1.04 \times 10^{-7} \\A_{g3} &= -4.51 \times 10^{-11}\end{aligned}$$

$$\begin{aligned}B_{g0} &= 1.035\,1 \times 10^{-4} \\B_{g1} &= 0.419\,8 \times 10^{-6} \\B_{g2} &= -2.771 \times 10^{-11}\end{aligned}$$

$$k_a = \left\{ \begin{array}{l} 0.0228 \text{ for air} \\ 0.3094 \text{ for hydrogen} \end{array} \right\}$$

APPENDIX B

MATERIAL PROPERTIES

I. INTRODUCTION

An extensive library of temperature-dependent material properties is incorporated in the TRAC code. The entire library is accessible by the vessel component; however, the ex-vessel components have access to structural material-property sets only. There are 12 sets of material properties that comprise the library; each set supplies values for thermal conductivity, specific heat, density, and spectral emissivity for use in the heat-transfer calculations. The first 5 sets and set 11 contain properties for nuclear heated or electrically heated fuel-rod simulation. Included are nuclear fuels, Zircaloy cladding, fuel-cladding gap gases, electrical heater-rod filaments, electrical heater-rod insulating material, and Zircaloy dioxide. Sets 6-10 and 12 are for structural materials including stainless steels, carbon steel, and Inconels. In addition, fuel and cladding coefficients of thermal expansion obtained from MATPRO⁵⁶ subroutines FTHEX and CDTHEX are available when the gap-conductance thermal-expansion model is used.

Figure B-1 illustrates the calling tree for obtaining the property values. The subroutines MFROD and MPROP are simple processors for calculating the average temperature and calling the appropriate subroutine based on the user-specified material index. Subroutine FROD controls the fuel-cladding gap conductance and fuel-rod thermal conduction calculations. The material indexes in the library are

- 1 -- mixed-oxide fuel;
- 2 -- Zircaloy;
- 3 -- gap gases;
- 4 -- boron-nitride insulation;
- 5 -- Constantan/Nichrome heater;
- 6 -- stainless steel, type 304;
- 7 -- stainless steel, type 316;
- 8 -- stainless steel, type 347;
- 9 -- carbon steel, type A508;
- 10 -- Inconel, type 718;
- 11 -- Zircaloy dioxide; and
- 12 -- Inconel, type 600.

Gap-gas properties are calculated only when the dynamic fuel-cladding gap HTC option is used (NFCI = 1).

Fig. B-1.
Material-properties code organization.

II. NUCLEAR FUEL MIXED-OXIDE PROPERTIES

Subroutine MFUEL calculates the properties for mixed-oxide (UO_2 and PuO_2) nuclear fuels. Values obtained are influenced by three user-specified input variables: the fraction of theoretical density, the fraction of plutonium oxide in the fuel, and the fuel burnup. Property changes upon melting are not included in this code version.

A. Density

The mixed-oxide fuel density is calculated with a correction factor to account for thermal expansion, which is assumed to be axisymmetric,

$$\rho = \frac{d}{\left(1 + 3 \frac{\Delta L}{L}\right)},$$

where

$$\rho = \text{density (kg/m}^3\text{)},$$

$$d = f_{\text{TD}} [(1 - f_{\text{PuO}_2}) \rho_{\text{UO}_2} + f_{\text{PuO}_2} \rho_{\text{PuO}_2}],$$

$$f_{\text{TD}} = \text{fraction of theoretical fuel density},$$

$$f_{\text{PuO}_2} = \text{weight fraction of PuO}_2 \text{ in the fuel},$$

$$\rho_{\text{UO}_2} = 1.097 \times 10^4,$$

$$\rho_{\text{PuO}_2} = 1.146 \times 10^4,$$

and

$$\frac{\Delta L}{L} = \text{linear thermal expansion.}$$

The value calculated for the linear thermal expansion is based on the MATPRO formulation,⁵⁶

$$\frac{\Delta L}{L_0} = K_1 T - K_2 + K_3 \exp(-E_D/kT) ,$$

where

$\frac{\Delta L}{L_0}$ = linear strain caused by thermal expansion (equal to 300 K, unitless) ,

T = temperature (K) , and

k = Boltzmann's constant (1.38×10^{-23} J/K) .

The constants K_1 , K_2 , K_3 , and E_D are listed below.

Constant	Uranium Dioxide	Plutonium Dioxide	Units
K_1	1.0×10^{-5}	9.0×10^{-6}	K^{-1}
K_2	3.0×10^{-3}	2.7×10^{-3}	Unitless
K_3	4.0×10^{-2}	7.0×10^{-2}	Unitless
E_D	6.9×10^{-20}	7.0×10^{-20}	J

B. Specific Heat

The mixed-oxide fuel specific heat correlations are taken from the MATPRO reports,^{56,57}

$$c_p = 15.496 \frac{b_1 b_4^2 \exp(b_4/T)}{T^2 [\exp(b_4/T) - 1]^2} + 2b_2 T + \frac{b_3 b_5}{b_6 T^2} \exp(-b_5/b_6 T) ,$$

where c = specific heat capacity (J/kg · K) and T = fuel temperature (K). The constants b_1 through b_6 are listed below.

<u>Constants</u>	<u>Uranium Dioxide (Ref. 56)</u>	<u>Mixed Oxides (Ref. 57)</u>
b_1	19.145	19.53
b_2	7.847×10^{-4}	9.25×10^{-4}
b_3	5.643×10^6	6.02×10^6
b_4	535.285	539.0
b_5	37 694.6	40 100.0
b_6	1.987	1.987

C. Thermal Conductivity

The mixed-oxide fuel thermal conductivity correlations are taken from the MATPRO report⁵⁶ and include porosity and density correction factors. For $T_c \leq T_1$,

$$k = c \left[\frac{c_1}{c_2 + T_c} + c_3 \exp(c_4 T_c) \right] ,$$

and for $T_c > T_1$,

$$k = c [c_5 + c_3 \exp(c_4 T_c)] ,$$

where

$$T_c = \text{temperature } (^{\circ}\text{C}) ,$$

$$c = 100.0 \left[\frac{1 - \beta (1 - f_{TD})}{1 - 0.05} \right] ,$$

$$\beta = c_6 + c_7 T_c ,$$

f_{TD} = fraction of theoretical density .

The constants c_1 through c_7 and T_1 are listed below.

<u>Constants</u>	<u>Uranium Dioxide</u>	<u>Mixed Oxides</u>
c_1	40.4	33.0
c_2	464.0	375.0
c_3	1.216×10^{-4}	1.54×10^{-4}
c_4	1.867×10^{-3}	1.71×10^{-3}
c_5	0.019 1	0.017 1
c_6	2.58	1.43
c_7	-5.8×10^{-4}	0.0
T_1	1 650.0	1 550.0

D. Spectral Emissivity

The mixed-oxide spectral emissivity is calculated as a function of temperature based on the MATPRO correlations.

The values for uranium-dioxide and mixed-oxide fuels are assumed equivalent:

$$\epsilon = 0.870 7 \quad \text{for } T \leq 1\,000 \text{ C} ,$$

$$\epsilon = 1.311 - 4.404 \times 10^{-4} T \quad \text{for } 1\,000 < T \leq 2\,050 \text{ C} ,$$

and

$$\epsilon = 0.408 3 \quad \text{for } T > 2\,050 \text{ C} .$$

III. ZIRCALOY CLADDING PROPERTIES

Subroutine MZIRC calculates the properties for Zircaloy and oxidized Zircaloy cladding. The values obtained are for Zircaloy-4. Zircaloy-2 properties are assumed to be identical. The equations used are based on the correlations in the MATPRO report.⁵⁶

A. Density

Zircaloy cladding exhibits an asymmetric thermal expansion behavior. Thermal expansion is calculated in the radial and axial directions, and these effects are included in the density calculation,

$$\rho = \frac{6.551.4}{1 + [2(\frac{\Delta L}{L})_r + (\frac{\Delta L}{L})_z]} ,$$

where

$$(\frac{\Delta L}{L})_r = -2.373 \times 10^{-4} + 6.721 \times 10^{-6} T_c$$

and

$$(\frac{\Delta L}{L})_z = -2.506 \times 10^{-5} + 4.441 \times 10^{-6} T_c ,$$

for $T \leq 1\,073.15$;

$$(\frac{\Delta L}{L})_r = 5.139\,5 \times 10^{-3} - 1.12 \times 10^{-5} (T_c - 1\,073.15)$$

and

$$(\frac{\Delta L}{L})_z = 3.527.7 \times 10^{-3} - 1.063\,85 \times 10^{-5} (T_c - 1\,073.15) ,$$

for $1\,073.15 < T \leq 1\,273.15$;

$$(\frac{\Delta L}{L})_r = -6.8 \times 10^{-3} + 9.7 \times 10^{-6} T_c$$

and

$$(\frac{\Delta L}{L})_z = -8.3 \times 10^{-3} + 9.7 \times 10^{-6} T_c ,$$

for $T_c > 1\,273.15$; and $T_c = \text{temperature } (^{\circ}\text{C})$.

B. Specific Heat

Because Zircaloy undergoes a phase change (alpha to beta) from 1 090 to 1 248 K, with a resultant sharp spike in the specific heat value during the transition, the specific heat is calculated by linear interpolation. Table B-I is used for $T \leq 1\,248$ K. For $T > 1\,248$ K, $c_p = 356$ J/kg $\cdot$ K.

C. Thermal Conductivity

Four-term polynomials are used to calculate the Zircaloy and oxidized Zircaloy thermal conductivities. The Kelvin temperature is the independent variable; the polynomial constants are listed below.

<u>Constants</u>	<u>Zirconium</u>	<u>Zirconium Dioxide</u>
a_0	7.51	1.96
a_1	2.09×10^{-2}	-2.41×10^{-4}
a_2	-1.45×10^{-5}	6.43×10^{-7}
a_3	7.67×10^{-9}	-1.95×10^{-10}

The form of the polynomial used in this section and the subsequent material properties sections is

$$y = a_0 + a_1x + a_2x^2 + \cdot \cdot \cdot + a_mx^m \cdot$$

D. Spectral Emissivity

The emissivity of Zircaloy is temperature dependent, and the emissivity of Zircaloy oxide is temperature and time dependent. For simplicity, a constant value of $\epsilon = 0.75$ is used.

IV. FUEL-CLADDING GAP-GAS PROPERTIES

Subroutine MGAP calculates values for the gap-gas mixture thermal conductivity that are used in predicting gap HTC's. The method is taken from the MATPRO report⁵⁶ and is based on calculating mixture values for seven possible constituent gases:

$$k_{\text{gap}} = \sum_{i=1}^n \left(\frac{k_i x_i}{x_i + \sum_{\substack{j=1 \\ j \neq i}}^n \psi_{ij} x_j} \right) ,$$

where

k_{gap} = gap mixture thermal conductivity (W/m • K) ,

$$\psi_{ij} = \phi_{ij} \left[1 + 2.41 \frac{(M_i - M_j)(M_i - 0.142 M_j)}{(M_i + M_j)^2} \right] ,$$

$$\phi_{ij} = \frac{\left[1 + \left(\frac{k_i}{k_j} \right)^{1/2} \left(\frac{M_i}{M_j} \right)^{1/4} \right]^2}{2^{3/2} \left(1 + \frac{M_i}{M_j} \right)^{1/2}} ,$$

k_i = constituent gas thermal conductivity (W/m • K), M_i = constituent gas molecular weight, and x_i = constituent gas mole fraction.

The seven constituent gases considered are helium, argon, xenon, krypton, hydrogen, air/nitrogen, and water vapor. Except for water vapor, their thermal conductivities are defined:

$$k = aT^b ,$$

where T = temperature (K). The constants in the above thermal conductivity equation for various gases are listed below.

Gas	a	b
helium	3.36×10^{-3}	0.668
argon	3.421×10^{-4}	0.701
xenon	4.0288×10^{-5}	0.872
krypton	4.726×10^{-5}	0.923
hydrogen	1.6355×10^{-3}	0.8213
air/nitrogen	2.091×10^{-4}	0.846

For water vapor the following correlation is used:

$$k_{\text{steam}} = \left(-2.8516 \times 10^{-8} + 9.424 \times 10^{-10}T - 6.004 \times 10^{-14}T^2 \right) \frac{p}{T} \\ + \frac{1.009 p^2}{T^2(T - 273)^{4.2}} - 8.4083 \times 10^{-3} - 1.19998 \times 10^{-5}T \\ - 6.706 \times 10^{-8}T^2 - 4.51 \times 10^{-11}T^3 ,$$

where p is the gap-gas pressure (N/m²).

When the gap dimension shrinks to the order of the gas mean-free path, a correction factor is applied to the light-gas thermal conductivities to account for the change in energy exchange between the gas and the surface. Again, if the MATPRO recommendations⁵⁶ are used, the correction factor for hydrogen and helium is

$$k = \frac{k_1}{1 + fk_1} ,$$

where

$$f = \frac{0.2103 T_g}{P_g \lambda} ,$$

T_g is the average gap-gas temperature (K), and λ is the characteristic fuel rms roughness equal to 4.389×10^{-6} m.

V. ELECTRICAL FUEL-ROD INSULATOR (BN) PROPERTIES

Subroutine MBN calculates values for boron-nitride insulators that are used in electrically heated nuclear fuel-rod simulators. Magnesium oxide insulators are assumed to have roughly equivalent values.

A. Density

A constant value of 2002 kg/m^3 from Ref. 58 is used.

B. Specific Heat

A four-term polynomial is used to calculate the specific heat. The independent variable is temperature in degrees Fahrenheit, and the constants, which are modifications of those reported in an EPRI report,⁵⁹ are listed below.

a_0	a_1	a_2	a_3
760.59	1.795 5	-8.6704×10^{-4}	1.5896×10^{-7}

C. Thermal Conductivity

The boron-nitride thermal conductivity calculation is based on a conversion to SI units of a curve fit reported in Ref. 60:

$$k = 25.27 - 1.365 \times 10^{-3} T_f ,$$

where k is the thermal conductivity (W/m · K) and T_f is the temperature ($^{\circ}\text{F}$).

D. Spectral Emissivity

A constant value of unity is used for the boron-nitride spectral emissivity.

VI. ELECTRICAL FUEL-ROD HEATER-COIL (CONSTANTAN) PROPERTIES

Subroutine MHTR calculates property values for Constantan heater coils as used in electrically heated nuclear fuel-rod simulators. We assume that Nichrome coils, used in some installations in place of Constantan, have similar properties. The correlations used are from Ref. 60.

A. Density

A constant value of 8393.4 kg/m^3 is used.

B. Specific Heat

The specific heat is

$$c_p = 110 T_f^{0.2075} ,$$

where c_p is the specific heat ($\text{J/kg} \cdot \text{K}$) and T_f is the temperature ($^{\circ}\text{F}$).

C. Thermal Conductivity

The thermal conductivity is

$$k = 29.18 + 1.683 \times 10^{-3} (T_f - 100) ,$$

where k is the thermal conductivity ($\text{W/m} \cdot \text{K}$) and T_f is the temperature ($^{\circ}\text{F}$).

D. Spectral Emissivity

A constant value of unity is used.

VII. STRUCTURAL MATERIAL PROPERTIES

Subroutine MSTRCT supplies property values for six types of structural materials normally used in LWRs: stainless steel, type 304; stainless steel, type 316; stainless steel, type 347; carbon steel, type A508; and Inconel, types 600 and 718. These properties were obtained from Refs. 60-62. A tabulation of the correlations used is given in Tables B-II through B-VII.

TABLE B-I
SPECIFIC HEAT VS TEMPERATURE

<u>T (K)</u>	<u>c_p(J/kg • K)</u>
300	281
400	302
640	381
1 090	375
1 093	502
1 113	590
1 133	615
1 153	719
1 173	816
1193	770
1213	619
1 233	469
1 248	356

TABLE B-II
STRUCTURAL MATERIAL PROPERTIES
STAINLESS STEEL, TYPE 304

<u>Property</u>	<u>Independent Variable</u>	<u>Polynomial Constants</u>	<u>Reference Number</u>
ρ	T	$a_0 = 7\,984.0$	61
		$a_1 = -2.651 \times 10^{-1}$	
		$a_2 = -1.158 \times 10^{-4}$	
		$a_0 = 426.17$	
c_p	T_f	$a_1 = 0.438\,16$	61
		$a_2 = -6.375\,9 \times 10^{-4}$	
		$a_3 = 4.480\,3 \times 10^{-7}$	
		$a_4 = -1.072\,9 \times 10^{-10}$	
k	T	$a_0 = 8.116$	61
		$a_1 = 1.618 \times 10^{-2}$	
ϵ	-	$a_0 = 0.84$	61

ρ = density (kg/m^3)

c_p = specific heat ($\text{J}/\text{kg} \cdot \text{K}$)

k = thermal conductivity ($\text{W}/\text{m} \cdot \text{K}$)

T = temperature (K)

T_f = temperature ($^{\circ}\text{F}$)

$y = a_0 + a_1x + a_2x^2 + \dots + a_mx^m$

TABLE B-III
STRUCTURAL MATERIAL PROPERTIES
STAINLESS STEEL, TYPE 316

<u>Property</u>	<u>Independent Variable</u>	<u>Polynomial Constants</u>	<u>Reference Number</u>
ρ	T	$a_0 = 8\ 084.0$	62
		$a_1 = -4.209 \times 10^{-1}$	
		$a_2 = -3.894 \times 10^{-5}$	
c_p	T_f	$a_0 = 426.17$	62
		$a_1 = 0.438\ 16$	
		$a_2 = -6.375\ 9 \times 10^{-4}$	
		$a_3 = 4.480\ 3 \times 10^{-7}$	
k	T	$a_4 = -1.072\ 9 \times 10^{-10}$	62
		$a_1 = 1.571 \times 10^{-2}$	
β	-	$a_0 = 0.84$	62

ρ = density (kg/m^3)

c_p = specific heat ($\text{J}/\text{kg} \cdot \text{K}$)

k = thermal conductivity ($\text{W}/\text{m} \cdot \text{K}$)

T = temperature (K)

T_f = temperature ($^{\circ}\text{F}$)

$y = a_0 + a_1x + a_2x^2 + \dots + a_mx^m$

TABLE B-IV
STRUCTURAL MATERIAL PROPERTIES
STAINLESS STEEL, TYPE 347

<u>Property</u>	<u>Independent Variable</u>	<u>Polynomial Constants</u>	<u>Reference Number</u>
ρ	-	$a_0 = 7\ 913.0$	60
c_p	$(T_f - 240)$	$a_0 = 502.416$	
		60	
		$a_1 = 0.098\ 4$	
		$a_0 = 14.192\ 6$	
k	T_f		60
		$a_1 = 7.269 \times 10^{-3}$	
ϵ	-	$a_0 = 0.84$	60

ρ = density (kg/m³)

c_p = specific heat (J/kg · K)

k = thermal conductivity (W/m · K)

T = temperature (K)

T_f = temperature (°F)

$y = a_0 + a_1x + a_2x^2 + \dots + a_mx^m$

TABLE B-V
STRUCTURAL MATERIAL PROPERTIES
CARBON STEEL, TYPE 508

<u>Property</u>	<u>Independent Variable</u>	<u>Polynomial Constants</u>	<u>Reference Number</u>
ρ	T_f	$a_0 = 7\ 859.82$	61
		$a_1 = -2.642\ 8 \times 10^{-2}$	
		$a_2 = -4.547\ 1 \times 10^{-4}$	
		$a_3 = 3.311 \times 10^{-7}$	
		$a_0 = 400.48$	
c_p	T_f	$a_1 = 0.458\ 2$	61
		$a_2 = 6.553\ 2 \times 10^{-4}$	
		$a_3 = 5.370\ 6 \times 10^{-7}$	
		$a_0 = 66.155\ 8$	
		$a_1 = -1.438\ 6 \times 10^{-2}$	
k	T_f	$a_2 = -2.698\ 7 \times 10^{-4}$	61
		$a_3 = 1.830\ 6 \times 10^{-6}$	
		$a_4 = -6.067\ 3 \times 10^{-9}$	
		$a_5 = 1.052\ 4 \times 10^{-11}$	
		$a_6 = -9.160\ 3 \times 10^{-15}$	
ϵ	-	$a_7 = 3.159\ 7 \times 10^{-18}$	61
		$a_0 = 0.84$	

ρ = density (kg/m^3)

c_p = specific heat ($\text{J/kg} \cdot \text{K}$)

k = thermal conductivity ($\text{W/m} \cdot \text{K}$)

T = temperature (K)

T_f = temperature ($^{\circ}\text{F}$)

$y = a_0 + a_1x + a_2x^2 + \dots + a_mx^m$

TABLE B-VI
STRUCTURAL MATERIAL PROPERTIES
INCONEL, TYPE 718

<u>Property</u>	<u>Independent Variable</u>	<u>Polynomial Constants</u>	<u>Reference Number</u>
ρ	T_f	$a_0 = 8\ 233.4$	61
		$a_1 = -1.835\ 1 \times 10^{-1}$	
		$a_2 = -9.841\ 5 \times 10^{-6}$	
		$a_3 = -6.534\ 3 \times 10^{-9}$	
		$a_0 = 413.18$	
c_p	T_f		61
		$a_1 = 0.120\ 4$	
k	T_f	$a_0 = 10.804\ 6$	61
		$a_1 = 3.829 \times 10^{-3}$	
ρ	-	$a_0 = 0.84$	61

ρ = density (kg/m^3)

c_p = specific heat ($\text{J/kg} \cdot \text{K}$)

k = thermal conductivity ($\text{W/m} \cdot \text{K}$)

T = temperature (K)

T_f = temperature ($^{\circ}\text{F}$)

$y = a_0 + a_1x + a_2x^2 + \dots + a_mx^m$

TABLE B-VII
STRUCTURAL MATERIAL PROPERTIES
INCONEL, TYPE 600^a

<u>Property</u>	<u>Independent Variable</u>	<u>Polynomial Constants</u>	<u>Reference Number</u>
ρ	T_f	$a_0 = 5.261\ 008 \times 10^{-2}$	61
		$a_1 = -1.345\ 453 \times 10^{-2}$	
		$a_2 = -1.194\ 367 \times 10^{-7}$	
		$a_0 = 0.101\ 445\ 6$	
		$a_1 = 4.378\ 952 \times 10^{-5}$	
		$a_2 = -2.046\ 138 \times 10^{-8}$	
c_p	T_f	$a_3 = 3.418\ 111 \times 10^{-11}$	61
		$a_4 = -2.060\ 318 \times 10^{-13}$	
		$a_5 = 3.682\ 836 \times 10^{-16}$	
		$a_6 = -2.458\ 648 \times 10^{-19}$	
		$a_7 = 5.597\ 571 \times 10^{-23}$	
		$a_0 = 8.011\ 332$	
k	T_f	$a_1 = 4.643\ 719 \times 10^{-3}$	61
		$a_2 = 1.872\ 857 \times 10^{-6}$	
		$a_3 = -3.914\ 512 \times 10^{-9}$	
		$a_4 = 3.475\ 513 \times 10^{-12}$	
		$a_5 = -9.936\ 696 \times 10^{-16}$	
ρ	-	$a_0 = 0.84$	61

ρ = density (kg/m³)

c_p = specific heat (J/kg · K)

k = thermal conductivity (W/m · K)

T = temperature (K)

T_f = temperature (°F)

$y = a_0 + a_1x + a_2x^2 + \dots + a_mx^m$

^aInconel, type 600 coefficients are in British units; then ρ is multiplied by 16.018 46; c_p , by $4.186\ 8 \times 10^{-3}$; and k , by 1.729 577.

APPENDIX C

SETS NUMERICAL METHOD

This appendix provides a simplified description of the numerical methods and solution procedures. Only simple single-phase flow equations are used, but generalization to the full TRAC equation set is relatively straightforward.

The SETS method is designed to propagate information needed for stability with minimal implicit coupling between spatial nodes. Information about pressure wave propagation is provided with a basic step, which is simply a semi-implicit equation set. A stabilizing step then is added to provide information about the transport of fluid density, energy, and momentum across cell boundaries. Because the stabilizing step is separated from the basic step, this approach has the further advantage that existing semi-implicit codes can be converted to the SETS method with relative ease.

I. BASIC EQUATIONS

To demonstrate the TRAC-PF1 numerical methods, we consider a simplified model for one-dimensional, single-phase flow in a pipe. The differential equations for this model are listed below.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho V = 0 \quad , \quad (C-1)$$

$$\frac{\partial \rho e}{\partial t} + \nabla \cdot \rho e V = -p \nabla \cdot V + h (T_w - T) \quad , \quad (C-2)$$

and

$$\frac{\partial V}{\partial t} + V \cdot \nabla V = -\frac{1}{\rho} \nabla p - K V |V| \quad . \quad (C-3)$$

Here, K is a wall friction coefficient that may be a function of velocity and fluid properties, h is a heat-transfer coefficient multiplied by the heat-transfer area per volume of fluid, and T_w is a pipe wall temperature.

A staggered spatial mesh is used for the finite-difference equations, with thermodynamic properties evaluated at the cell centers and the velocity evaluated at the cell edges. Only difference equations on the one-dimensional version of this mesh are demonstrated, but the generalization to two- and three-dimensional versions is not difficult. To ensure stability and to maintain consistency with differencing in previous TRAC versions, flux terms at cell edges use donor-cell averages of the form

$$\begin{aligned}\langle YV \rangle_{j+1/2} &= Y_j V_{j+1/2} \quad , \quad V_{j+1/2} \geq 0 \\ &= Y_{j+1} V_{j+1/2} \quad , \quad V_{j+1/2} < 0 \quad .\end{aligned}\tag{C-4}$$

Here Y may be any state variable. Other forms of this average may maintain stability with higher-order spatial accuracy, but they have not been carefully studied. With this notation the one-dimensional finite-difference divergence operator is

$$\nabla_j \cdot (YV) = \frac{(A_{j+1/2} \langle YV \rangle_{j+1/2} - A_{j-1/2} \langle YV \rangle_{j-1/2})}{\text{vol}_j} \quad ,\tag{C-5}$$

where A is the area of the cell edge and vol_j the cell volume. The term WV becomes

$$\begin{aligned}V_{j+1/2} \nabla_{j+1/2} V &= \frac{V_{j+1/2} (V_{j+1/2} - V_{j-1/2})}{\Delta x_{j+1/2}} \quad , \quad V_{j+1/2} \geq 0 \\ &= \frac{V_{j+1/2} (V_{j+3/2} - V_{j+1/2})}{\Delta x_{j+1/2}} \quad , \quad V_{j+1/2} < 0 \quad ,\end{aligned}\tag{C-6}$$

where $\Delta x_{j+1/2} = 0.5 (\Delta x_j + \Delta x_{j+1})$. This choice of $\Delta x_{j+1/2}$ for Eq. (C-6) is necessary for more accurate calculation of pressure drops in pipes modeled with a nonuniform mesh than is provided with a donor cell $\Delta x_{j+1/2}$.

For the flow model given by Eqs. (C-1)-(C-3), the combination of basic and stabilizer equation sets can be written in several ways without significantly affecting the results. For example, the stabilizer step may precede the basic step for all equations, or the basic step may be done before the stabilizer step. When the SETS method is adapted to the two-fluid model for two-phase flow, several orderings of the difference equations can cause growing oscillations from feedback through interfacial friction terms. Some of these feedback problems are rather subtle and occur only when the one-dimensional mesh forms a closed loop. One ordering that is always stable begins with the stabilizer step for the equations of motion, continues with a solution of the basic equation set for all equations, and ends with a stabilizer step for the mass and energy equations. For this ordering, the SETS finite-difference equations for Eqs. (C-1)-(C-3) are

STABILIZER EQUATION OF MOTION

$$\begin{aligned}
 & \frac{(\tilde{v}_{j+1/2}^{n+1} - v_{j+1/2}^n)}{\Delta t} + v_{j+1/2}^n \nabla_{j+1/2} \tilde{v}^{n+1} \\
 & + \beta (\tilde{v}_{j+1/2}^{n+1} - v_{j+1/2}^n) \nabla_{j+1/2} \tilde{v}^n \\
 & + \frac{1}{\langle \rho \rangle_{j+1/2}^n \Delta x_{j+1/2}} (p_{j+1}^n - p_j^n) \\
 & + K_{j+1/2}^n (2 \tilde{v}_{j+1/2}^{n+1} - v_{j+1/2}^n) |v_{j+1/2}^n| = 0 \quad , \quad (C-7)
 \end{aligned}$$

where

$$\begin{aligned}
 \beta &= 0, \quad \nabla_{j+1/2} \tilde{v}^n < 0 \\
 1, \quad \nabla_{j+1/2} \tilde{v}^n > 0 \quad ;
 \end{aligned}$$

BASIC EQUATIONS

$$\begin{aligned}
 & \frac{(v_{j+1/2}^{n+1} - v_{j+1/2}^n)}{\Delta t} + v_{j+1/2}^n \nabla_{j+1/2} \tilde{v}^{n+1} \\
 & + \beta (v_{j+1/2}^{n+1} - v_{j+1/2}^n) \nabla_{j+1/2} \tilde{v}^n \\
 & + \frac{1}{\langle \rho \rangle_{j+1/2}^n \Delta x_{j+1/2}} (\tilde{p}_{j+1}^{n+1} - \tilde{p}_j^{n+1}) \\
 & + \kappa_{j+1/2}^n (2 v_{j+1/2}^{n+1} - v_{j+1/2}^n) |v_{j+1/2}^n| = 0 \quad ; \quad (C-8)
 \end{aligned}$$

$$\frac{(\tilde{\rho}_j^{n+1} - \rho_j^n)}{\Delta t} + \nabla_j \cdot (\rho^n v^{n+1}) = 0 \quad ; \quad (C-9)$$

$$\begin{aligned}
 & \frac{(\tilde{\rho}_j^{n+1} \tilde{e}_j^{n+1} - \rho_j^n e_j^n)}{\Delta t} + \nabla_j \cdot (\rho^n e^n v^{n+1}) \\
 & + \tilde{p}_j^{n+1} \cdot_j (v^{n+1}) - \bar{h}_j^n (T_{wj}^n - \tilde{T}_j^{n+1}) = 0 \quad ; \quad (C-10)
 \end{aligned}$$

and

STABILIZER MASS AND ENERGY EQUATIONS

$$\frac{(\rho_j^{n+1} - \rho_j^n)}{\Delta t} + \nabla_j \cdot (\rho^{n+1} v^{n+1}) = 0 \quad ; \quad (C-11)$$

$$\begin{aligned}
 & \frac{(\rho_j^{n+1} e_j^{n+1} - \rho_j^n e_j^n)}{\Delta t} + \nabla_j \cdot (\rho^{n+1} e^{n+1} v^{n+1}) \\
 & + \tilde{p}_j^{n+1} \cdot_j (v^{n+1}) - \bar{h}_j^n (T_{wj}^n - \tilde{T}_j^{n+1}) = 0 \quad . \quad (C-12)
 \end{aligned}$$

A tilde above a variable indicates that it is the result of an intermediate step and is not the final value for the time step.

Equations (C-8)-(C-10) are very similar to a one-dimensional single-phase version of the difference equations used for the TRAC vessel component. These semi-implicit equations can be obtained by dropping all tildes from Eqs. (C-8)-(C-10) and replacing the WV and friction terms in Eq. (C-8) with $v_{j+1/2}^n \nabla_{j+1/2} v^n$ and $K_{j+1/2}^n v_{j+1/2}^{n+1} |v_{j+1/2}^n|$, respectively. In addition, the pressure work term for the three-dimensional energy equation is $p^n \nabla \cdot v^{n+1}$ rather than $p^{n+1} \nabla \cdot v^{n+1}$. This change in the work term was made because, in the three-dimensional numerics, only the linearized flow equations are solved, and the linearized form of $p^{n+1} \nabla \cdot v^{n+1}$ can produce nonphysical results for sudden, unexpected changes in pressure.

The heat-transfer term $\bar{h}^n (T_w^n - T^{n+1})$ is written in this form to minimize coupling between the hydrodynamic and heat-transfer solution procedures. To maintain stability in regions of rapid change of h , $\bar{h}^n$ is an average of the heat-transfer coefficient evaluated at time level n and the averaged coefficient from level $n-1$ ($\bar{h}^n = 0.45 h^n + 0.55 \bar{h}^{n-1}$).

The material Courant stability limit is eliminated by treatment of the terms VVV , $\nabla \cdot \rho V$, and $\nabla \cdot \rho e V$ during the two steps. These are the terms involved in the information propagation that was discussed in the introduction. Additional robustness has been obtained with the particular form for the friction terms and the use of nonzero values of β in the WV terms. These special terms for friction and WV are obtained by linearizing similar terms that are fully implicit in velocity ($K_{j+1/2}^n v_{j+1/2}^{n+1} |v_{j+1/2}^n|$ and $v_{j+1/2}^{n+1} \nabla_{j+1/2} v^{n+1}$).

Equation (C-7) simply represents a tridiagonal linear system in the unknown $\tilde{v}^{n+1}$ and is solved first (by TRAC in subroutines FEMON and BKSMMOM). Next, the coupled nonlinear system given by Eqs. (C-8)-(C-10) is solved (in TF3DE, TF3DI, and FF3D for the three-dimensional and TF1DS1, TF1DS, and TF1DS3 for the one-dimensional equations). Once these equations are solved, v^{n+1} is known; hence, Eqs. (C-11) and (C-12) are simple tridiagonal linear systems, with unknowns ρ_j^{n+1} and $\rho_j^{n+1} e_j^{n+1}$, respectively (solved by STBME and BKSSTB).

When this equation set is adapted to flow in complex piping networks, the pure tridiagonal structure is lost. However, the matrices are still sparse and easily solved (Sec. III.D).

A standard linear stability analysis predicts unconditional stability for this set of difference equations, a result verified by a large number of computational test problems. However, at very large time steps, functional forms for the friction factor containing a strong velocity dependence can drive instabilities, as can a strong void-fraction dependence for interfacial friction in the two-fluid model. This is why the method is referred to as stability enhancing rather than unconditionally stable.

Because the basic form of the finite-difference operators (both spatial and temporal) is consistent between the two steps, the order of accuracy of the full SETS equations is the same (first order in space and time) as the basic semi-implicit Eqs. (C-8)-(C-10). This consistency appears necessary to prevent feedback oscillations between the two steps. It also has the advantage of ensuring that, for modest time-step sizes, the results of any SETS calculation approach those of the basic semi-implicit equations.

The SETS method is especially valuable when applied to the full two-fluid model for two-phase flow. For this model, the stabilizer equations add less than 20% to the computational cost per cell per step of the basic equation set. A fully implicit method multiplies this cost by a factor of 6. The full finite-difference equations for the two-fluid model are given in Sec. III, including a useful variation on the finite-difference divergence operator.

II. SOLUTION OF THE BASIC EQUATION SET

The first step in the solution of the basic (semi-implicit) equation set rearranges the motion equation to obtain the new time velocity as a linear function of new time pressures. In TRAC this is accomplished in the subroutines TF3DE and TFlDS1. For Eq. (C-8), this step results in the relation

$$v_i^{n+1} = \frac{v_i^n - \Delta t [v_i^n \nabla_i (\tilde{v}^{n+1} - \beta \tilde{v}^n) - K_i^n v_i^n |v_i^n| + \frac{\tilde{p}_{j+1}^{n+1} - \tilde{p}_j^{n+1}}{\langle \phi \rangle_i^n \Delta x_i}]}{1 + \Delta t (2K_i^n |v_i^n| + \beta \nabla_i \tilde{v}^n)}, \quad (C-13)$$

where $i = j + 1/2$. Given this relation, the derivatives of velocity with respect to pressure are

$$\frac{dv_{j+1/2}^{n+1}}{dp_j^{n+1}} = \frac{\Delta t}{\langle \rho \rangle_i^n \Delta x_i (1 + K_i^n \Delta t |v_i^n| + \Delta t \beta \nabla_i \tilde{v}^n)} \quad (C-14)$$

and

$$\frac{dv_{j+1/2}^{n+1}}{dp_{j+1}^{n+1}} = - \frac{dv_{j+1/2}^{n+1}}{dp_j^{n+1}} . \quad (C-15)$$

Equation (C-13) and thermodynamic equations giving $\rho(p, T)$ and $e(p, T)$ are substituted into Eqs. (C-9) and (C-10) to give a coupled system of nonlinear equations with unknowns p_j^{n+1} and T_j^{n+1} (tildes have been dropped to simplify notation). Solution of this system is obtained with a standard Newton iteration. Given the latest estimates $\hat{p}_j^{n+1}$ and $\hat{T}_j^{n+1}$ for pressures and temperatures, we assume the solution is

$$p_j^{n+1} = \hat{p}_j^{n+1} + \delta p_j \quad (C-16)$$

and

$$T_j^{n+1} = \hat{T}_j^{n+1} + \delta T_j . \quad (C-17)$$

After substituting Eqs. (C-13)-(C-17) into the basic equation set, making the necessary Taylor series expansions, and after discarding nonlinear terms in δp_j and δT_j , we find the resulting linear mass and energy equations are

$$\begin{aligned}
& \frac{\partial \rho}{\partial T} \Big|_j^{n+1} \delta T_j + \frac{\partial \rho}{\partial p} \Big|_j^{n+1} \delta p_j - \left(\frac{A_{j+1/2} \rho_{j+1/2}^n \Delta t}{\text{vol}_j} \frac{dv_{j+1/2}^{n+1}}{dp_j^{n+1}} \right) (\delta p_{j+1} - \delta p_j) \\
& - \left(\frac{A_{j-1/2} \rho_{j-1/2}^n \Delta t}{\text{vol}_j} \frac{dv_{j-1/2}^{n+1}}{dp_j^{n+1}} \right) (\delta p_j - \delta p_{j-1}) \\
& = \rho_j^n - \rho_j^{n+1} - \Delta t \nabla_j \cdot (\rho^n v^{n+1})
\end{aligned} \tag{C-18}$$

and

$$\begin{aligned}
& (\rho_j^{n+1} \frac{\partial e}{\partial T} \Big|_j^{n+1} + e_j^{n+1} \frac{\partial \rho}{\partial T} \Big|_j^{n+1} + \Delta t \bar{h}_j^{n+1}) \delta T_j \\
& + (\rho_j^{n+1} \frac{\partial e}{\partial p} \Big|_j^{n+1} + e_j^{n+1} \frac{\partial \rho}{\partial p} \Big|_j^{n+1} + \Delta t \nabla_j \cdot v^{n+1}) \delta p_j \\
& - (\rho_j^{n+1} + \rho_{j+1/2}^n e_{j+1/2}^n) \left(\frac{A_{j+1/2} \Delta t}{\text{vol}_j} \frac{dv_{j+1/2}^{n+1}}{dp_j^{n+1}} \right) (\delta p_{j+1} - \delta p_j) \\
& - (\rho_j^{n+1} + \rho_{j-1/2}^n e_{j-1/2}^n) \left(\frac{A_{j-1/2} \Delta t}{\text{vol}_j} \frac{dv_{j-1/2}^{n+1}}{dp_j^{n+1}} \right) (\delta p_j - \delta p_{j-1}) \\
& = \rho_j^n e_j^n - \rho_j^{n+1} e_j^{n+1} - \Delta t [\nabla_j \cdot \rho^n e^n v^{n+1} \\
& + p_j^{n+1} \nabla_j \cdot v^{n+1} - \bar{h}_j^n (T_{w,j}^n - T_j^{n+1})]
\end{aligned} \tag{C-19}$$

The normal procedure for starting this linearization is to make an initial estimate for the new time pressure and temperature of $p^{n+1} = p^n$ and $T^{n+1} = T^n$. However, when SETS is used, an extra call to the thermodynamic subroutines can be saved by taking $p^{n+1} = \tilde{p}^n$ and $T^{n+1} = \tilde{T}^n$.

Equations (C-18) and (C-19) can be abbreviated as

$$B_j \begin{pmatrix} \delta p_j \\ \delta T_j \end{pmatrix} = \underline{b}_j + \underline{c}_j(\delta p_{j+1} - \delta p_j) - \underline{d}_j(\delta p_j - \delta p_{j-1}) \quad , \quad (C-20)$$

where B is a 2×2 matrix. For the one-dimensional numerics, this equation is multiplied by B^{-1} (accomplished with a linear system solver), which yields

$$-d'_{1,j} \delta p_{j-1} + (1 + d'_{1,j} + c'_{1,j}) \delta p_j - c'_{1,j} \delta p_{j+1} = b'_{1,j} \quad (C-21)$$

and

$$\delta T_j = b'_{2,j} + c'_{2,j}(\delta p_{j+1} - \delta p_j) - d'_{2,j}(\delta p_j - \delta p_{j-1}) \quad , \quad (C-22)$$

where $\underline{b}' = B^{-1}\underline{b}$, etc. All coefficients are stored, and then the set of equations represented by Eq. (21) is solved for all δp_j . Finally, the known values for pressure variations are substituted into Eq. (C-22) to obtain temperature changes and used with Eqs. (C-14) and (C-15) to obtain updated velocities. Given these changes, the next estimates for new time pressures and temperatures are generated and used to obtain densities and energies. If changes in δT and δp are too large, these estimates are used to return to Eqs. (C-16) and (C-17) to relinearize for another iteration of the one-dimensional equations. As previously noted, the three-dimensional flow equations are not relinearized. In this case, time-step controls are used to assure the accuracy of a single linearization.

One-dimensional equation linearization and initial reduction are accomplished in TF1DS. The linear variations selected for the full two-fluid equation set are δp , δT_ℓ , δT_g , δP_a , and $\delta \alpha$. The three-dimensional linearization, performed by TF3DI, is done somewhat differently. The variations obtained are δp , $\delta \alpha$, $\delta(\alpha T_g)$, and $\delta((1 - \alpha)T_\ell)$, and the equations are rearranged so that solution is for δP , α^{n+1} , $\alpha^{n+1} T_g^{n+1}$, and $(1 - \alpha^{n+1}) T_\ell^{n+1}$.

rather than for the original variations. The partial pressure of air is eliminated from the three-dimensional equation set by algebraic manipulations with the noncondensable mass equation. Backward substitution to obtain new values of pressures, temperatures, and void fractions is performed by TF1DS3 (one-dimensional) and FF3D (three-dimensional).

The principal difference in solution procedures between the one- and three-dimensional equation sets occurs in the actual solution for the linearized pressure [Eq. (C-21)]. For one dimension, direct-solution techniques are always employed. If too many cells are present in the three-dimensional model, an iterative method is applied. (See Sec. III.A.2.b.)

Note from the form of Eqs. (C-18) and (C-19) that the Jacobian for the system is reevaluated on each iteration. This reevaluation may not always be necessary but, for steam-water flows with phase change, it is often important for rapid convergence of the iteration.

APPENDIX D

CHOKED-FLOW MODEL

The TRAC-PF1/MOD1 two-phase, two-component choked-flow model was developed from first principles using the characteristic analysis approach. The TRAC-PF1/MOD1 subcooled choked-flow model is a modified form of the Burnell model. In this appendix we discuss these choked-flow models and their implementation in TRAC-PF1/MOD1. We compared the TRAC-PF1/MOD1 choked-flow models with the Burnell model for subcooled flow and with the homogeneous-equilibrium model (HEM) for two-phase flow. These comparisons agree well under homogeneous conditions. TRAC-PF1/MOD1 results from models using the choking criteria agree well with those using a fine mesh (natural choking). Code-data comparisons between the separate-effects tests of the Marviken facility and the Edwards' blowdown experiment also are favorable.

I. INTRODUCTION

Because TRAC-PF1/MOD1 fluid-dynamics equations for one-dimensional components use a multistep procedure that allows the material Courant condition to be violated, the choking calculations can be done simply by using a sufficiently fine mesh for components with smooth area changes. However, the TRAC-PF1/MOD1 quasi-steady choked-flow model saves computational time because it allows a much coarser mesh. For components with abrupt area changes, a one-dimensional fine mesh can cause erroneous natural-choking results. For all such cases, a separate choking model is almost a necessity. Thus, a choking model not only improves computational efficiency but also accounts for effects such as sharp area changes, surface roughness, and three-dimensional modeling, etc. Section D-II describes the TRAC-PF1/MOD1 choked-flow model. Section D-III compares this model with other conventional models and the test data. Section D-IV discusses the important conclusions.

II. FEATURES

A. Two-Phase Flow Choking Criterion

The TRAC-PF1/MOD1 two-phase choking model is an extension of one developed by Ransom and Trapp⁶³ that incorporates an additional inert gas component. As suggested by Ransom and Trapp, we assume that thermal equilibrium exists between the phases. The validity of this assumption has not been investigated in the presence of an inert gas. However, this assumption is not an inherent feature of the TRAC-PF1/MOD1 model and can be changed easily, if necessary.

The two-fluid flow field under thermal equilibrium is described by the inert-gas continuity equation, the overall continuity equation, two phasic momentum equations, and the mixture energy equation. When the nondifferential source terms are omitted (because they do not enter into characteristic analysis), the equations are

$$\frac{\partial}{\partial t} (\alpha \rho_a) + \frac{\partial}{\partial x} (\alpha \rho_a V_g) = 0 \quad , \quad (D-1)$$

$$\frac{\partial \rho_m}{\partial t} + \frac{\partial}{\partial x} (\rho_m V_m) = 0 \quad , \quad (D-2)$$

$$\begin{aligned} \alpha \rho_g \left[\frac{\partial V_g}{\partial t} + V_g \frac{\partial V_g}{\partial x} \right] + \alpha \frac{\partial p}{\partial x} \\ + C\alpha(1 - \alpha) \rho_m \left[\frac{\partial V_g}{\partial t} + V_g \frac{\partial V_g}{\partial x} - \frac{\partial V_l}{\partial t} - V_l \frac{\partial V_l}{\partial x} \right] = 0 \quad , \end{aligned} \quad (D-3)$$

$$\begin{aligned} (1 - \alpha) \rho_l \left[\frac{\partial V_l}{\partial t} + V_l \frac{\partial V_l}{\partial x} \right] + (1 - \alpha) \frac{\partial p}{\partial x} \\ + C\alpha(1 - \alpha) \rho_m \left[\frac{\partial V_l}{\partial t} + V_l \frac{\partial V_l}{\partial x} - \frac{\partial V_g}{\partial t} - V_g \frac{\partial V_g}{\partial x} \right] = 0 \quad , \end{aligned} \quad (D-4)$$

and

$$\frac{\partial}{\partial t} (\rho_m s_m) + \frac{\partial}{\partial x} [\alpha \rho_g V_g s_g + (1 - \alpha) \rho_l V_l s_l] = 0 \quad , \quad (D-5)$$

where C is the virtual mass coefficient; s is the entropy; and subscripts a , g , l , and m refer to the noncondensable gas, gas phase (air-vapor mixture), liquid, and air-vapor-liquid mixture, respectively. The last terms in Eqs. (D-3) and (D-4) represent interphasic force terms caused by relative acceleration. These terms are discussed in detail in Refs. 64 and 65. Following Ransom and Trapp's formulation, the energy equation is written in the form of the mixture-specific entropy that is conserved for adiabatic flow (neglecting irreversibilities associated with interphasic mass transfer and relative phase acceleration). However, no basic difficulty in the analysis is experienced if the mixture energy equation is written in terms of the internal energy or the enthalpy.

In the thermal-equilibrium case, ρ_a , ρ_v , ρ_l , s_a , s_v , and s_l are known functions of p_a and p_v . If we assume that Dalton's law of partial pressures applies, Eqs. (D-1)-(D-5) can be written in terms of the five unknowns p_a , p_v , α , V_g , and V_l . The matrix representation of these equations is

$$A(\bar{U}) \frac{\partial \bar{U}}{\partial t} + B(\bar{U}) \frac{\partial \bar{U}}{\partial x} = 0 \quad , \quad (D-6)$$

where the $\bar{U}$ consists of p_a , p_v , α , V_g , and V_l . The characteristic roots, λ_i , of the above system of equations are defined as the roots of the fifth-order polynomial,

$$\text{determinant } (A\lambda + B) = 0 \quad . \quad (D-7)$$

Choking occurs when the signal propagating with the largest velocity relative to the fluid is stationary; that is, the maximum value of the real part of a characteristic root, $\lambda_{i, \text{re}, \text{max}}$, is zero. Equation (D-7) is extremely difficult to solve analytically. Thus, TRAC-PF1/MOD1 obtains the characteristic roots of Eq. (D-7) numerically. This method advantageously maintains generality and facilitates computations under different assumptions. The next three paragraphs describe the calculational sequence for the TRAC-PF1/MOD1 two-phase choking criterion.

1. The solution of Eq. (D-7) requires that p_a , p_v , α , ρ_a , ρ_v , ρ_ℓ , s_a , s_v , s_ℓ , and their derivatives be specified at the cell edge where the choking criterion is applied. However, these quantities are known only at the cell center. Direct use of the cell-center quantities yields erroneous results caused by the presence of steep gradients near the choking plane. Therefore, an estimate of the thermodynamic state at the cell edge is necessary. This estimate is obtained by our assuming a constant entropy process between the cell center and the cell edge and by our iterating for the cell-edge pressure to maximize the mass flux (a classical technique used in generating the HEM tables). In addition to the thermodynamic state at the cell edge, this technique also gives the homogeneous-equilibrium sound speed, a_{HE} , that is used as a first estimate for the largest characteristic root. (When the nonhomogeneous effects are not dominant, the desired root is close to the homogeneous-equilibrium sound speed.)

2. If a constant phase slip (V_g/V_ℓ) is maintained, Eq. (D-7) yields intermediate time-level values of $v_g^{n+1/2}$ and $v_\ell^{n+1/2}$, so that $\lambda_{i, \text{re}, \text{max}} = 0$. The intermediate time-level mixture velocity, $v_m^{n+1/2}$, then is compared with the current value of the mixture velocity, v_m . If $v_m^{n+1/2} < v_m$, the flow is choked.

3. By our using V_g and V_ℓ when the flow is unchoked or $v_g^{n+1/2}$ and $v_\ell^{n+1/2}$ when the flow is choked, the solution of the TRAC-PF1/MOD1 hydrodynamic equations yields new time-step values, v_g^{n+1} and v_ℓ^{n+1} .

B. Subcooled-Flow Choking Criterion

During the subcooled blowdown phase, the fluid changes phase at the break because the containment pressure is much lower than the saturation pressure corresponding to the system fluid temperature. The transition from single- to two-phase flow, which is accompanied by discontinuous change in the fluid bulk modules, leads to a large discontinuity in the sound speed at the break. The physical process occurring during the subcooled blowdown phase is described briefly in the following paragraphs. Reference 64 discusses this phenomenon in greater detail.

Figure D-1 shows a converging-diverging nozzle. The pressure downstream is such that the vapor just begins to flash at the throat. The flow upstream of the throat is subsonic. However, because the sound speed is discontinuous when the fluid becomes saturated and because the mass conservation dictates

Fig. D-1.
Subcooled choking process when nucleation begins at the throat.

that the velocity just upstream of the throat must be equal to the velocity just downstream of the throat (where the fluid has only a miniscule void fraction), the flow is supersonic throughout the diverging section. Thus, the nozzle does not contain any point where the Mach number, M , equals one. Figure D-1 also shows the velocity profile and the sound speeds for this situation.

The velocity at the throat is calculated from Bernoulli's equation,

$$V_e = \left[V_c^2 + \frac{2(p_c - p_e)}{\rho_m} \right]^{1/2} , \quad (D-8)$$

where subscripts c and e refer to the cell-center (upstream) and the cell-edge (throat) conditions, respectively. The throat pressure, p_e , is equal to the nucleation pressure, p_{nuc} , and can be considerably lower than the local

saturation pressure, p_s , because thermal nonequilibrium causes nucleation delay.

Any further reduction in the downstream pressure does not affect the flow because the disturbance cannot move upstream where the flow is supersonic in the diverging section. Thus, Eq. (D-8) gives the throat velocity for a containment pressure lower than this pressure value (which is the case for most problems of interest in LWR applications). Next we consider the situation when the subcooled choked flow, as described above, exists initially, and the upstream pressure is lowered. As the upstream pressure decreases, the pressure at the throat remains equal to p_{nuc} , and again Eq. (D-8) can be used to calculate the throat velocity. However, the throat velocity decreases because the upstream pressure decreases. If the upstream pressure is lowered further, a point is reached when V_e equals a_{HE} . Any further reduction in the upstream pressure moves the point where p equals p_{nuc} upstream. In this case, the flow in the subcooled zone and the two-phase zone upstream of the throat is subsonic. The flow at the throat is sonic with V_e equal to a_{HE} ; the flow in the diverging section is supersonic. If the upstream pressure is reduced further, the p_{nuc} point moves upstream until complete two-phase flow exists. Therefore, the maximum of the Burnell expression and the homogeneous-equilibrium sound speed give the subcooled choking criterion. Thus,

$$V_{\ell} = \max \left\{ a_{HE}, \left[V_c^2 + \frac{2(p_c - p_e)}{\rho_m} \right]^{1/2} \right\} . \quad (D-9)$$

We implemented a nucleation delay model, developed by Jones,⁶⁶ in TRAC-PF1/MOD1 to calculate the cell-edge pressure, p_e , from the saturation pressure, p_s ,

$$p_e = p_s - \max \left\{ 0.0, 0.258 \frac{\sigma^{1.5} \left(\frac{T_l}{T_c} \right)^{13.76} \left[1 + 13.25 \left(- \frac{1}{1.01325 \times 10^{11}} \frac{Dp}{Dt} \right)^{0.8} \right]^{0.5}}{(kT_c)^{0.5} \left(1 - \frac{p_g}{p_l} \right)} \right. \\ \left. - 27(0.072)^2 \left(\frac{A_e}{A_c} \right)^2 \frac{\rho_l v_e^2}{2} \right\}, \quad (D-10)$$

where D/Dt is the substantial derivative, k is the Boltzmann constant, T_c is the critical temperature, and σ is the surface tension.

The calculational sequence is similar to that for the two-phase model. The homogeneous-equilibrium sound speed is calculated by maximizing the mass flux, as described in Sec. D-II.A. The liquid-phase choking velocity, the only unknown quantity, is set explicitly by using Eq. (D-9), which gives $v_l^{n+1/2}$.

C. Single-Phase Vapor Choking Criterion

The single-phase vapor choking velocity is calculated by isentropically expanding the vapor to maximize the mass flux.

D. Transition Regimes

Because there is a discontinuity in the sound speed during the transition from liquid to two-phase flow, the flow during this transition regime must be analyzed carefully. In TRAC-PF1/MOD1, this transition is handled by linear interpolation between the subcooled ($\alpha \leq 0.01$) and the two-phase ($\alpha \geq 0.1$) regimes.

The transition from the two-phase to the vapor regime is smooth because the two-phase characteristic solution approaches the homogeneous-equilibrium limit as $\alpha \rightarrow 1$. Thus, this transition is made by switching the calculational logic at $\alpha = 0.999$.

III. RESULTS

Section D-III.A compares the TRAC-calculated results with the test data from other conventional models under approximately homogeneous conditions to investigate the validity of the TRAC model under such conditions. Section D-III.B compares the TRAC-PF1/MOD1 choking calculations with the test data from models using fine mesh and from some separate-effects facilities.

A. Comparison of the TRAC-PF1/MOD1 Choked-Flow Model with Other Models

The primary requirement for an accurate choked-flow model is that it yield results that are close to the homogeneous-equilibrium calculations when the flow approaches such a homogeneous limit, because the nonhomogeneous effects are only of secondary importance in most situations. Therefore, the homogeneous-equilibrium sound speed calculated by TRAC-PF1/MOD1 should agree with the true sound speed. Figure D-2 compares the TRAC-calculated homogeneous-equilibrium sound speed with that obtained from the tables of D. G. Hall⁶⁷ for different void fractions at a 560-K saturation temperature. The agreement between the calculations and the tables is excellent.

Fig. D-2.

Comparison of the TRAC-PF1/MOD1 two-phase homogeneous-equilibrium sound speed with that obtained from the HEM tables in Ref. 67.

Figure D-3 compares the TRAC-calculated subcooled critical flow with that from the Burnell model and from the HEM for stagnation pressures ranging from 7.1 MPa (saturated liquid) to 15.0 MPa (subcooled liquid) at a constant 560-K temperature. The Burnell model is the modified-Burnell model from RELAP4/MOD6 (Ref. 68), that accounts for nucleation delay by an empirical expression. The HEM mass flux represents a lower limit on the mass flux. As desired, the TRAC-PF1/MOD1 model calculations give results that are similar to those for the Burnell model. The minor discrepancy between the TRAC-PF1/MOD1 choked-flow and the Burnell models is caused primarily by the difference between the nucleation-delay models.

Figure D-4 compares the TRAC-PF1/MOD1 two-phase critical-flow model calculations with the HEM data at 560-K saturation temperature. Again, the agreement is good. The TRAC-PF1/MOD1 calculated results differ from the HEM data because the nonhomogeneous effects are not accounted for in the HEM. Larger differences between the results obtained from the two models are expected when the upstream phasic velocities differ. (The flow upstream of the break was assumed to be stagnant for this calculation.)

Fig. D-3.

Comparison of the subcooled critical mass fluxes. The TRAC-PF1/MOD1 calculations, the test data from the Burnell model, and the HEM tables in Ref. 67 were used.

Fig. D-4.

Comparison of the TRAC-calculated two-phase critical mass flux with the test data from the HEM tables in Ref. 67.

B. Comparison of the TRAC-PF1/MOD1 Choked-Flow Model Calculations with the Fine-Mesh Calculations and the Test Data

A true test of the accuracy of a choking model is its ability to predict results similar to those obtained using an extremely fine mesh (natural choking) for geometries with smooth area changes. Therefore, the TRAC-PF1/MOD1 choking calculations are compared with the fine-mesh results and the test data from Tests 4 (Ref. 69) and 24 (Ref. 70) of the Marviken test facility and the Edwards' blowdown experiment.⁷¹

1. Marviken Test Facility. The Marviken full-scale critical-flow tests assess the ability of computer codes to predict large pressure-vessel blowdowns. The four major components of this facility are a pressure vessel, originally designed to be part of the Marviken nuclear power plant; a discharge pipe; a test nozzle with the minimum flow area in the system; and a rupture-disk assembly. Figure D-5 shows the vessel that still includes part of the core superstructure and the moderator tank plus three gratings installed to eliminate vortex formation. Figure D-6 shows the other components. All elevations in both figures are measured relative to the

Fig. D-5.
Marviken pressure vessel.

Fig. D-6.
Marviken discharge pipe, test nozzle, and rupture-disk assembly.

vessel bottom. Pressure and temperature transducers are located along the vessel and the discharge pipe, as shown in Figs. D-5 and D-6. The signals from the various transducers are processed through a signal-conditioning unit with its channels connected to a pulse-code modulation system.

Before a test is run, the vessel is partially filled with deionized water and heated by removing water from the vessel bottom, passing it through an electric heater, and returning it to the steam dome at the vessel top. This procedure produces a complicated initial temperature distribution in the vessel. A saturated steam dome fills the vessel region above the initial water level. The test is initiated by releasing the rupture disks and is terminated by closing a ball valve in the discharge pipe. We specifically chose Marviken Tests 4 and 24 because Test 4 had the longest nozzle (and Test 24, the shortest) in the entire test series.

The TRAC-PF1/MOD1 model for Marviken Tests 4 and 24 included four components. A zero-velocity FILL component modeled the vessel upper boundary. A PIPE component modeled the vessel above 2.6 m, including the maximum diameter region plus the top cupola. Another PIPE component modeled the lower part of the vessel, the discharge pipe, the nozzle, and the rupture-disk assembly. A BREAK component provided a pressure boundary condition at the rupture-disk assembly lower boundary. For the fine-noding cases, the nozzles were modeled with 30 cells (15 in the converging section and 15 in the straight portion with a minimum cell length of 0.025 m) for Test 4 and with 12 cells (5 in the converging section and 7 in the straight portion with a minimum cell length of 0.02 m) for Test 24. When using the choked-flow model, the nozzles in both tests were modeled by only two cells, one in the converging section and the other simulating the entire straight section, with the choked-flow model invoked at the downstream edge of the second cell.

Figures D-7 and D-8 show the TRAC-PF1/MOD1 mass flows and pressure histories with the choking model and the fine noding compared with the test data. The measured mass flows are derived from velocity (pitot-static) and vessel differential-pressure measurements. The pitot-static data curve is valid throughout the transient, whereas the vessel differential-pressure curve is valid only after 5 s. The choking calculations give almost identical results to those for the fine-mesh case. Both the choked-flow and the fine-mesh calculations also agree well with the test data except during the

Fig. D-7.

Comparison of the nozzle mass flows for Marviken Test 4 between the test data and the TRAC-PF1/MOD1 models. The fine-mesh and choking criteria were used.

Fig. D-8.

Comparison of the system pressure histories for Marviken Test 4 between the test data and the TRAC-PF1/MOD1 models. The fine-mesh and choking criteria were used.

subcooled blowdown phase when the mass flow is underpredicted by an average of 10%. The dip in the measured pressure during the first 3 s of the transient indicates a significantly more pronounced nucleation delay than predicted by the TRAC-PF1/MOD1 model.

Figures D-9 and D-10 show the mass flows and pressure histories for Test 24. The agreement between the choking calculation and the results obtained from the fine-mesh case is not as good as for Test 4. This discrepancy is attributed to the predominance of nonequilibrium effects between the phases caused by the short nozzle length. These nonequilibrium effects are not modeled in the TRAC-PF1/MOD1 choking calculation. (The straight sections of the nozzles for Tests 4 and 24, respectively, were 1.5 and 0.166 m long with L/D ratios of 2.95 and 0.33.)

To investigate the importance of nonequilibrium effects in Test 24, we made a sensitivity run with the "frozen" assumption (using a seven-equation characteristic model without differential-type mass-transfer terms) in the characteristic solution. Figures D-11 and D-12 show the mass flows and the pressure histories for the new calculations. Using the choking model, we find the mass flow now is overpredicted and the pressure underpredicted compared with the mass flow and pressure from the fine-mesh results. The assumption that thermal equilibrium exists between the phases even in the absence of a noncondensable gas may not be valid in all situations.

2. Edwards' Blowdown Experiment. The Edwards' horizontal-pipe blowdown experiment studied depressurization phenomena of initially nonflowing subcooled water. The experimental apparatus consisted of a 4.096-m-long, straight steel pipe with a 0.073-m i.d. The apparatus was designed for a maximum 17.24-MPa pressure at temperatures to 616.5 K. The discharge end of the horizontal pipe was sealed with a 0.0127-m-thick glass disk.

The pipe was filled with demineralized water; a hydraulic pump and a control valve regulated the system pressure. The pipe was evacuated by a vacuum pump before it was filled with water. Before the glass disk was ruptured, the pipe was isolated from the supply tank to prevent the discharge of cold water into the pipe during blowdown. Pressure transducers were located at gauge stations GS-1 to GS-7, and a temperature transducer was located at GS-5 (Fig. D-13). Also provided at GS-5 were two aluminum alloy disk windows for transient void-fraction measurements, which used an x-ray

Fig. D-9.

Comparison of the nozzle mass flows for Marviken Test 24 between the test data and the TRAC-PF1/MOD1 models. The fine-mesh and choking criteria were used.

Fig. D-10.

Comparison of the system pressure histories for Marviken Test 24 between the test data and the TRAC-PF1/MOD1 models. The fine-mesh and choking criteria were used.

Fig. D-11.

Comparison of the nozzle mass flows for Marviken Test 24 between the test data and the TRAC-PF1/MOD1 models. The fine-mesh and choking criteria obtained from the seven-equation frozen model were used.

Fig. D-12.

Comparison of the system pressure histories for Marviken Test 24 between the test data and the TRAC-PF1/MOD1 models. The fine-mesh and choking criteria obtained from the seven-equation frozen model were used.

Fig. D-13.
Edwards' horizontal-pipe blowdown experiment (adapted from Ref. 71).

absorption system. The pipe was insulated and heated electrically. The operating procedure required that degassed water completely fill the pipe. The pipe was pressurized cold to 25% above the initial depressurization 7-MPa test pressure and checked for leaks. Next, the pressure was reduced to 3.45 MPa and heat was applied gradually for 1.5 h. During the heating of the water, the system pressure was maintained at 3.45 MPa above the saturation pressure to prevent liquid flashing. The temperature variation along the pipe was limited by adjusting the voltage control for each heater. The system initially was brought to an approximately uniform 515-K temperature* and 7-MPa pressure. Because the isolating valve between the pipe and storage tank was closed, the glass disk ruptured, and the data were recorded automatically.

The TRAC-PF1/MOD1 model consisted of a zero-velocity FILL component to simulate the closed end of the pipe, two PIPE components coupled in series, and a BREAK component. Near the discharge end of the pipe, the minimum cell

*There is some uncertainty in the initial temperature profile. However, we used exactly identical initial conditions both in the choking and in the fine-mesh calculations to maintain the validity of the comparison between the two calculations.

lengths were 0.00509 m for the fine-mesh case and 0.17325 m for the choked-flow model. The choking model was applied at the discharge end, which had the minimum cross-sectional area in the system. We had to estimate this area because fragments of glass remained intact during the experiment.

Figure D-14 compares the measured and calculated pressure histories near the middle of the pipe (GS-4). The agreement between the choking and the fine-mesh calculations again is good with the choking calculational results being closer to the data than the fine-mesh results. Although the discharge mass flow was not measured, the good pressure comparison between the calculations and the test data suggests good mass-flow calculations as well.

IV. CONCLUSIONS

The two-phase, two-component choked-flow model in TRAC-PF1/MOD1 was developed from first principles with a minimal amount of empiricism. The model assumes that thermal equilibrium exists between the phases in the presence or absence of an inert gas. The eigenvalues for the system of coupled differential equations are obtained numerically. This generality

Fig. D-14.

Comparison of the system pressure histories for the Edwards' blowdown experiment between the test data and the TRAC-PF1/MOD1 calculations. The fine-mesh and choking criteria were used.

gives the user the freedom to investigate and incorporate differential equations derived under different assumptions. The model yields results similar to those obtained using a fine mesh for components with smooth area changes. However, the quantitative agreement with the fine-mesh calculations is deficient for Marviken Test 24, which has a short nozzle, because the equilibrium assumption may be improper in that case. The results also compare well with other conventional models (the modified Burnell and the HEM). A good mass-flow comparison between the TRAC-PF1/MOD1 two-phase model and the HEM was obtained because the upstream fluid was stagnant, which gives minimal nonhomogeneous effects. However, for other two-phase situations, where the upstream liquid and vapor velocities differ significantly from each other, the nonhomogeneous effects may be very important. Comparisons of the TRAC-PF1/MOD1 calculations with the data from the separate-effects Marviken tests and Edwards' blowdown experiment also were favorable.

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APPENDIX E

PWR SAMPLE PROBLEM

This PWR sample problem shows the setup of a large, complicated TRAC problem requiring extensive application of trips and control blocks. Anticipated transient experiment L6-1 (Ref. 72) conducted in the Loss-of-Fluid Test (LOFT) facility at Idaho National Engineering Laboratory was chosen to demonstrate the modeling techniques. Section E-I discusses the LOFT system briefly. Section E-II summarizes Test L6-1. Section E-III describes the TRAC one-dimensional model including the application of the powerful trip and control-block capability available in TRAC-PF1/MOD1. Section E-IV discusses the steady-state calculation. The transient calculation is delineated in Sec. E-V. Finally, Secs. E-VI.A and E-VI.B include listings of the steady-state and transient input decks, respectively. Section E-VI.C lists a three-dimensional TRAC VESSEL input configuration that is equivalent to the one-dimensional configuration used in Sec. E-VI.A.

I. LOFT SYSTEM DESCRIPTION

The LOFT facility is a 50-MW (thermal) PWR with instrumentation to measure and provide data on the thermal-hydraulic condition throughout the system. Operation of the LOFT system is typical of large [~ 1000 MW (electric)] commercial PWR operations. The facility consists of a reactor vessel with a nuclear core; an intact loop with an active steam generator, pressurizer, and two primary-coolant pumps (PCPs) connected in parallel; a broken loop with simulated pump, simulated steam generator, and two quick-opening blowdown valve assemblies; a blowdown suppression system; and an emergency core-coolant (ECC) injection system that includes two low-pressure injection-system (LPIS) pumps, two high-pressure injection-system (HPIS) pumps, and two accumulators. An isometric drawing and a piping schematic of this system are shown in Figs. E-1 and E-2, respectively. Reference 72 contains additional details on the LOFT system.

Fig. E-1.
LOFT facility configuration (Ref. 72).

Fig. E-2.
LOFT piping schematic with instrumentation (Ref. 72).

II. TEST DESCRIPTION

Experiment L6-1 simulated a loss-of-steam load in a large PWR and was initiated by closing the main steam flow control valve (MSFCV). The pressurizer cycling heaters were on at experiment initiation but were shut off at 6.1 s as the primary-coolant system (PCS) pressure increased. The system pressure continued to rise because of impaired secondary-side heat removal capability. The pressurizer spray, which was initiated at 9.1 s to reduce PCS pressure, was continued until 30.4 s. The PCS pressure continued to rise and caused the reactor to scram at 21.8 s. Immediately after the reactor scram, the primary system started to depressurize. The MSFCV, which automatically began opening at 22.2 s, reduced steam-generator secondary-side pressure and was closed at 40.6 s. Low system pressure caused the pressurizer backup heaters to come on at 32.5 s. The MSFCV again opened and closed automatically at 91.2 s and 104.4 s, respectively, and was manually opened and closed starting at 312.6 s. The pressurizer backup heaters turned off at 415.4 s. The experiment was terminated at 700 s.

The blowdown suppression system was not used in this experiment. We connected the broken loop to the intact loop through one-inch warm-up lines to prevent broken-loop stagnation.

III. TRAC ONE-DIMENSIONAL MODEL

Figures E-3, E-4, and E-5 show the loop, the steam generator, and the vessel arrangement, respectively. Figure E-6 shows an equivalent vessel configuration that uses the TRAC three-dimensional VESSEL component. An input listing for this three-dimensional model is given in Sec. E-VI.C. The junction and component numbers are shown in squares and circles, respectively. These junctions and component numbers can be used as guides when referring to the input listings in Sec. E-VI. The one-dimensional input model, which was used for the L6-1 calculation, consists of 39 components containing a total of 144 cells and 48 junctions. Table E-I lists the components. The input model corresponds to the LOFT hardware configuration with the following exceptions:

1. The pressure suppression system is not modeled because it was not used in the experiment.
2. The HPIS is represented by a FILL (component 17). The remaining ECC system is omitted from the TRAC model because there were no accumulator or LPIS injections in the L6 series of experiments.

Fig. E-3.
TRAC model for the LOFT facility.

Fig. E-4.
Steam-generator secondary-side noding for the LOFT facility.

Fig. E-5.
One-dimensional vessel noding for the LOFT facility.

Fig. E-6.
Three-dimensional vessel noding combining all the components shown in Fig. E-5.

TABLE E-I
TRAC MODEL COMPONENTS

<u>Component Number^a</u>	<u>Component Type</u>	<u>Description</u>	<u>Junction Numbers^b</u>	<u>Number of Fluid Cells (Primary Side, Secondary Side)^c</u>
1	TEE	Intact-loop hot leg	9,74,10	2,3
2	STGEN	Steam generator	2,3,25,22	10,13
20	PIPE	Steam-generator secondary-side riser	24,21	5
22	TEE	Steam-generator secondary-side downcomer	23,24,25	4,1
21	TEE	Steam-generator secondary-side steam downcomer	21,22,23	2,1
3	TEE	Pump suction	4,5,73	3,1
4	PUMP	Pump 2	4,6	2
5	PUMP	Pump 1	5,7	2
6	TEE	Pump discharge	7,66,6	2,1
7	TEE	Intact-loop cold leg	8,29,14	3,1
8	PRIZER	Pressurizer bottom section	64,10	1
9	TEE	Pressurizer top section and spray	60,62,68	5,1
10	VALVE	Pressurizer spray control valve	67,68	3
11	TEE	Intact-loop cold leg and pressurizer spray source	66,8,67	1,1
12	PIPE	Pressurizer lower middle section	61,64	1
13	PRIZER	Pressurizer upper middle section	60,61	6
17	FILL	HPIS	14	1

TABLE E-I (cont.)

<u>Component Number^a</u>	<u>Component Type</u>	<u>Description</u>	<u>Junction Numbers^b</u>	<u>Number of Fluid Cells (Primary Side, Secondary Side)^c</u>
23	VALVE	Steam-line valve	22,26	6
24	FILL	Steam-generator secondary side	25	1
25	BREAK	Steam-generator secondary- side pressure set point	26	1
29	TEE	Vessel inlet annulus and broken-loop cold-leg connection	46,1,34	1,1
30	TEE	Vessel lower plenum	96,35,36	2,1
31	TEE	Broken-loop hot leg	45,32,43	6,3
33	TEE	Vessel upper plenum	83,39,40	2,1
34	TEE	Vessel upper plenum and broken-loop hot-leg connection	48,45,40	1,1
35	FILL	Vessel upper-head zero-velocity fill	39	1
36	TEE	Vessel lower plenum	95,37,86	2,1
37	CORE	Nuclear reactor core	37,38	4
40	TEE	Vessel bypass and intact-loop cold-leg connection	29,46,47	1,1
41	TEE	Broken-loop cold leg	1,44,43	2,2
43	TEE	Vessel upper plenum and intact-loop hot-leg connection	48,9,47	1,1
62	BREAK	Pressure-operated relief valve pressure set point	63	1
63	VALVE	Pressure-operated relief valve	62,63	2

TABLE E-I (cont.)

<u>Component Number^a</u>	<u>Component Type</u>	<u>Description</u>	<u>Junction Numbers^b</u>	<u>Number of Fluid Cells (Primary Side, Secondary Side)^c</u>
73	TEE	Pump suction	73,3,77	3,2
74	TEE	Intact-loop hot leg	74,2,78	2,2
75	PIPE	Broken-loop cold-leg outlet	44,42	1
77	VALVE	Broken-loop hot-leg warm-up recirculation line	77,32	2
78	VALVE	Broken-loop cold-leg warm-up recirculation line	78,42	2
83	TEE	Vessel upper plenum and core bypass	38,83,84	2,2
86	TEE	Vessel lower plenum and core bypass	86,36,84	1,1
95	TEE	Vessel lower plenum and downcomer bypass	35,95,97	1,2
96	TEE	Vessel downcomer and downcomer bypass	34,96,97	6,6

^aThe total number of components, excluding the steam-generator secondary-side components, is 39.

^cThe total number of computational cells is 144.

^bThe total number of junctions, excluding the steam-generator secondary-side internal junctions, is 48.

It should be noted from Fig. E-3 that instead of modeling the pressurizer with a single PRIZER module, we modeled the top part of the pressurizer with a TEE, and the rest with two PRIZER modules with a PIPE in the middle. The TEE at the top was necessary to allow two connections, one for the spray and the other for the power-operated relief valve (PORV). (Note: The pressurizer spray option available in TRAC does not simulate the true spray system. It is only a means of controlling the system pressure. Therefore, for most practical problems of interest, the spray should be modeled by modeling the system hardware configuration accurately.) The pipe near the bottom was necessary for us to model the pressurizer heaters accurately, by utilizing the option for direct power into the coolant available in a PIPE module. [There were three problems in using the heater option available in the PRIZER module: (1) the pressurizer heater option does not control the heaters in the manner they were operated in the experiment; (2) the LOFT system has two banks of heaters, which could not be simulated using the pressurizer heater option; and (3) the pressurizer heater option would have equally distributed the energy everywhere in the liquid, whereas the energy is actually added only to the liquid near the bottom of the pressurizer.] More discussion on how the heaters are simulated exactly using trip-controlled direct power into the coolant will follow in this section.

Reference 73 reports that the LOFT spray valve (VALVE 10) has a leak area of $\sim 2.5\%$ of its full-open value. The LOFT pressurizer is, therefore, never in a true steady-state condition because the heater and spray flow contributions do not exactly balance. To insure a steady state that is consistent with the experimental conditions at the start of the transient, we have added trip-controlled direct power into the coolant to the side leg of TEE 9 during the steady-state calculation to bring this cold spray liquid to saturation. This small heat contribution is terminated automatically at the start of the transient because the controlling trip goes off. Therefore, this heater has no effect on the anticipated transient portion of the analysis.

The structural heat losses in the LOFT facility were reported by Ollikkala⁷⁴ as follows. A 6-kW heat loss from the pressurizer, a 10-kW heat loss from the steam-generator secondary side, and a total of 174-kW heat loss from the primary system (excluding the pressurizer). These heat losses are incorporated in the TRAC model. With our assumption that the surrounding air

temperature was 305 K, we calculated average film coefficients based on outside surface areas of the pressurizer, the steam-generator secondary side, and the primary system.

The reactor power is modeled using point kinetics with reactivity feedback. The reactor kinetics parameters were determined from the experimental core power history during steady state.

All the automatic controls are modeled using the extensive trip and control capability available in TRAC-PF1/MOD1, and they correspond to the actual system hardware configuration. A total of 24 signal variables, 21 trips, and 29 control blocks are required to model the entire LOFT control system. The trip set points needed for the modeling of the controls are listed in Table E-II. The sources of information for these set points include the best-estimate prediction,⁷³ the quick-look report,⁷⁵ the experiment data report,⁷² and the posttest analysis report.⁷⁶ We resolved some of the discrepancies apparent in these sources among the set points by determining the actual test conditions from the experiment data report⁷² at times when the events actually took place. The important controls are described below. Refer to the input listing in Sec. E-VI.A and the TRAC input instructions⁷⁷ to follow these controls in detail.

A. Pressurizer Heaters

As discussed earlier in this section, the heaters are simulated by adding direct power into the coolant in PIPE 12. These heaters are easily controlled using only four trips. No control blocks are required. The two kinds of heaters in the LOFT facility are the 36-kW cycling heaters that are first to come on at low-pressure signal and last to go off on high-pressure signal, and the 12-kW backup heaters that supplement the cycling heaters if their power is insufficient to maintain the system pressure. The cycling and backup heaters are controlled by trips 13 and 14, respectively. These trips, having positive IDs, are not evaluated during the steady state. However, a trip set status, ISET, of 1 is input for trip 13, which sets the trip to ON_{forward} during steady state. The reason for doing this will soon be obvious.

The PIPE module allows only one power table to be input. One obvious approach to model the two banks of heaters would have been to split PIPE 12 into two separate PIPE components and input the two heater powers separately.

TABLE E-II
MAJOR TRIP SET POINTS FOR TEST L6-1

<u>Parameter</u>	<u>Set Point</u>
System low-pressure scram (MPa)	14.36
System high-pressure scram (MPa)	15.77
Intact-loop hot-leg high-temperature scram (K)	583.3
Low primary-coolant mass flow (kg/s)	433.5
High core-averaged power scram (MW)	51.5
Steam-generator secondary-side low liquid-level scram (M)	2.0
Power-operated relief valve-opening set point (MPa)	16.70
Power-operated relief valve-closing set point (MPa)	16.56
Pressurizer spray on	15.24
Pressurizer spray off	14.90
Pressurizer cycling heaters on (MPa)	14.75
Pressurizer cycling heaters off (MPa)	14.93
Pressurizer backup heaters on (MPa)	14.62
Pressurizer backup heaters off (MPa)	14.80
HPIS on (MPa)	13.297
HPIS off (MPa)	15.500
MSFCV opening set point before reactor scram (MPa)	5.425
MSFCV closing set point before reactor scram (MPa)	5.315
MSFCV opening set point after reactor scram	
between 0 and 75 s (MPa)	6.99
between 75 and 200 s (MPa)	6.9764
between 200 s and end of transient (MPa)	6.9464
MSFCV closing set point after reactor scram	
between 0 and 75 s (MPa)	6.7500
between 75 and 200 s (MPa)	6.6500
between 200 s and end of transient (MPa)	6.6000

However, it is possible to model both banks of heaters using only one PIPE component as described below.

A trip-controlled trip, number -24, is defined whose signal value is the sum of the ISET values of trips 13, 14, 7, and 7. (Trip 7, whose ISET = -1 during steady state, goes off at the start of the transient.) Note that a minus sign for trip -24 allows it to be evaluated during steady state. Trip -24 generates signal variable 23, which is used as the independent variable of component 12 power table (see Card Number 4 for component 12 in the input).

During steady state, the ISET values of trips 13, 14, and 7 are 1, 0, and -1, respectively. Therefore, signal variable 23 has a value of $1 + 0 - 1 - 1 = -1$, and trip -24 set status is ON_{reverse}. The power input from the table is, therefore, 398 W, which is balanced by the heat loss to the environment from component 12. This is done to achieve a true steady state in the component.

At the start of the transient, trip 7 turns off. However, because trip 13 has an initial ISET value of 1, signal variable 23 has a value of 1 and trip -24 is ON_{forward}. The power table gives a value of 36 kW, equal to the cycling heater power. Because the cycling heaters in the test were on at the initiation of the experiment, we input ISET = 1 for trip 13 to achieve the desired result. Therefore, it is obvious from the power table that if both trips 13 and 14 are off, the power input is zero. If either one of them is on, the power input is 36 kW, and if both of them are on, the power input is 48 kW. The TRAC model, therefore, simulates the actual system because the trip set points prohibit trip 14 from turning on unless trip 13 is already on, or prohibit trip 13 from turning off unless trip 14 is off. In other words, the model works because the cycling heaters always turn on first and turn off last. As a result, the heater power is either 0, 36 kW, or $36 + 12 = 48$ kW, but never 12 kW.

B. Pressurizer Liquid Level

The pressurizer liquid level is not a control parameter. However, this level is calculated in the models using control blocks -1, -2, and -3, (control blocks are always designated by negative numbers to distinguish them from signal variables) for plotting purposes only. The control-block logic is shown in Fig. E-7. (Liquid level for a simple PRIZER module is calculated

Fig. E-7.
Pressurizer liquid-level calculation using control blocks.

(internally by TRAC and output to the graphics file, without use of user-defined signal variables or control blocks.)

Control block -1 sums up the liquid levels in components 8 and 12 (signal variables 8 and 9). Control block -2 adds to this liquid level, the liquid level in component 13 (signal variable 18). There is no need to add component 9 liquid level because component 9 is always full of vapor. Finally, the calculated liquid level is offset by -0.11 m in control block -3. This is necessary because of slight differences in the actual pressurizer geometry and the geometry implied in the TRAC model (right circular cylinder). The value of -0.11 m-offset was estimated from the initial conditions, when equal initial masses of liquid in the test and the data led to a discrepancy of 0.11 m.

C. Pump-Speed Controller

The pump speeds are controlled during steady state to achieve the desired coolant mass flow. Because the pumps were running during the transient, the pump speeds are not changed in the TRAC model after the end of steady state.

Figure E-8 shows a schematic of the macro pump controller. Control block -50 receives an intact-loop hot-leg mass-flow signal and sets up upper and lower limits to this mass-flow value to avoid division by zero. Control block -55 generates the desired mass-flow value. Control block -60 calculates the ratio of the desired and actual mass flows. The new pump speed can be calculated as: present pump speed times the ratio of desired and actual mass flows. However, this approach was found to give oscillatory mass flows because of slow system response. To alleviate the problem, control block -62 is added, which along with control block -65 effectively results in 90% old, 10% new arithmetic averaging of old and new pump speeds. The sole purpose of control block -70 is to adjust the pump speed only during steady state. During steady state, control block -70 output is its input from control block -65. However, during the transient, control block -70 output is the value of signal variable 6, which is the present pump speed. Therefore, the pump speed is not changed during the transient.

D. Steam-Generator Secondary-Side Feedwater Controller

The feedwater control provides the means for stable control of the fluid inventory in the steam-generator secondary side. The difference between the actual and desired levels provides the basic error signal for the system. The desired programmed level at zero power is 2.9464 m above the top of the tube sheet and is a 0.00508-m increment in level for each MW of core power.

A steam flow signal is required by the feedwater control system to obtain a satisfactory transient response, which reduces the steady-state level error that would occur without it.

A block diagram of the feedwater control system is shown in Fig. E-9. Control block -4 receives its input as the steam mass flow, and converts the input into an equivalent feedwater valve flow area fraction. Control block -5 converts this flow area fraction into an equivalent feedwater valve stem position, which is required to balance the steam flow exactly. Therefore, if

Signal Variables

Control Blocks

Fig. E-8.
Pump-speed control system.

Signal Variables

Control Blocks

Fig. E-9.

Steam-generator secondary-side feedwater control system.

the liquid level in the steam generator is below its desired value, the feedwater valve opening should be larger than the above value, and vice versa.

The liquid-level calculation is based on total liquid inventory in the steam-generator secondary side. Control blocks -6 through -9 calculate the total steam volume on the secondary side. A plot of the collapsed liquid level versus the liquid volume is available in the LOFT system description.⁷⁷ Reference 77 also reports that the total water volume at full power (50 MW) is 2.52 m^3 , which corresponds to an uncollapsed liquid level of 3.2004 m; whereas, the liquid volume based on a collapsed liquid level of 3.2004 m is 3.8166 m^3 . Therefore, we generated a plot of uncollapsed liquid level versus the liquid volume from the collapsed liquid-level plot by multiplying its volume by a ratio of $2.52/3.8166$. Knowing the total secondary volume, we then converted this plot into the uncollapsed liquid level as a function of the total steam-generator secondary-side steam volume. Control block -11 uses this information to calculate the steam-generator secondary-side liquid level.

Control block -10 calculates the desired liquid level corresponding to the actual core power from the formula, liquid level = $2.9464 + 0.00508 \times \text{core power in MW}$. Control block -12 calculates the error, desired liquid level minus actual liquid level, and translates the error into an equivalent valve stem position increment (or decrement) by using a gain factor of 3.149606 (Ref. 73). Control block -13 adds this value to the stem position required to just balance the steam flow. The output from control block -13 is, therefore, the desired stem position.

To stabilize the control of the liquid level, a feedback signal representative of the input is needed. The feedwater regulating-valve position is used as the feedback signal for the LOFT system. Control blocks -14 and -15 simulate this feedback. Control block -14 calculates the difference between the desired stem position and the current stem position, which is not allowed to exceed a magnitude of 0.05 (maximum rate of stem fraction movement is 0.05/s). The integrator (control block -15), therefore, gives the value of the new stem position.

Control blocks -16 and -17 are added to the control system to account for the feedwater pump trip that occurs as soon as the reactor scram is initiated, which stops the feedwater flow within 2 s. Finally, control block -18 changes the valve stem position into the flow area fraction. The

actual feedwater mass flow as a function of the flow area fraction is input in FILL 24.

E. Steam-Generator Secondary-Side Steam-Flow Valve Controller

Automatic control of the steam-flow valve is provided to maintain the desired secondary-side pressure. However, different pressures are required to be maintained before and after the reactor scram. A block diagram of the steam-flow valve control system is shown in Fig. E-10. Control block -41 outputs the trip set status (ISET) value of either trip -21, which is used to govern the pressure before the reactor scram, or trip 20, depending on whether trip 20 is on or off. The purpose of trip 20 is to start a forced valve action at the desired time. For Test L6-1, this action is to start closing the valve at the start of the transient. The output from control block -41 is, therefore, 0, -1, or 1, which requires the valve to remain stationary, closed, or open, respectively. Control block -42 outputs the signal from control block -41 before the reactor scram and trip 22 signal (trip 22 controls the secondary-side pressure) after reactor scram. A gain factor of 0.05 for control block -42 corresponds to the valve-stem fractional movement rate of 0.05 per second. Thus, control block -42 output is 0, -0.05, or 0.05, which determines whether the valve should remain stationary, start closing at a rate of 0.05 valve-stem fraction per second, or start opening at a rate of 0.05 valve-stem fraction per second. An integrator (control block -43) determines the new valve-stem position from its present value. Finally, control block -44 translates the valve-stem position into an equivalent flow area fraction.

It should be noted that trip 22, which controls the secondary pressure after the reactor scram, has associated trip set-point factor tables for both the upper and lower set points. These were necessary because the trip set points were observed to vary slightly during the experiment.

One final note on the control system is in order. As discussed above, this TRAC model has some signal variables that represent trip set-status or trip-signal values. Consequently, these signal variables cannot be evaluated before the trip data are processed. However, TRAC first processes the signal variables, then the control blocks, and finally the trips. Therefore, it was necessary to make two passes through the control parameters (cards 109-114 in Sec. E-VI.A).

Signal Variables

Control Blocks

Fig. E-10.

Steam-generator secondary-side steam-flow valve control system.

IV. STEADY-STATE CALCULATION

Based on the geometry and the noding described in Sec. E-III, we performed a steady-state calculation using the generalized steady-state TRAC option. The calculation took 109 s of Cray-1 CPU time to simulate 200 s of reactor steady-state time at an average 0.51-s time step. As noted in Sec. E-VI.A, all the initial velocities were zero. At the beginning of the calculation, the reactor power was automatically set to zero. At 0.02 s, the liquid velocity in the core was large enough to turn on the core power. All major primary-system parameters, such as pressures, velocities, and temperatures, converged to their steady-state values in ~ 30 s. However, it took another ~ 30 s for the secondary-side parameters to converge.

Figures E-11 through E-15 show the upper-plenum pressure, the pump number 1 speed (pump number 2 speed is identical to that for pump number 1), the primary-coolant mass flow, and the steam-generator inlet and outlet temperatures, respectively. As indicated earlier, these parameters are converged to their steady-state values by ~ 30 s. The pump-speed controller

Fig. E-11.
Steady-state upper-plenum pressure for Test L6-1.

Fig. E-12.
Steady-state pump number 1 speed for Test L6-1.

Fig. E-13.
Steady-state primary-coolant mass flow for Test L6-1.

Fig. E-14.
Steady-state steam-generator primary-side inlet temperature for Test L6-1.

Fig. E-15.
Steady-state steam-generator primary-side outlet temperature for Test L6-1.

performance is excellent and is able to bring the loop flow to its steady-state value within the first few seconds.

Secondary-side parameters are presented in Figs. E-16 through E-19. The pressure (Fig. E-16) reaches its steady-state value at ~60 s. The initial pressure spike near 10 s was caused by the steady state being initiated with the MSFCV fully closed, with this valve having a finite rate of opening. The secondary-side liquid level (Fig. E-17) is converged by ~50 s. However, as seen in Fig. E-18, it takes ~10 s more for the feedwater flow to converge to a reasonably steady value. Even then the flow behavior is somewhat erratic. However, the feedwater controller works well, because its purpose is to maintain a steady liquid level. The feedwater flow oscillations have almost no impact on the rest of the system behavior. The steam flow also is converged in ~60 s (Fig. E-19).

V. TRANSIENT CALCULATION

The transient calculation was started from the last dump of the steady-state calculation. No new signal variables, controls, trips, or components were input at the start of the transient. This restart deck (Sec. E-VI.B),

Fig. E-16.
Steady-state steam-generator secondary-side pressure for Test L6-1.

Fig. E-17.
Steady-state steam-generator secondary-side liquid level for Test L6-1.

Fig. E-18.
Steady-state steam-generator secondary-side feedwater mass flow for Test L6-1.

Fig. E-19.

Steady-state steam-generator secondary-side steam mass flow for Test L6-1.

therefore, constitutes the minimum amount of input required during a restart. The Cray-1 CPU time required to simulate a 700-s system transient was 228 s at an average 0.78-s time step. The TRAC calculation, therefore, ran over three times faster than real time.

The initial conditions and specified test parameters used in Test L6-1 are listed in Table E-III. The TRAC steady-state calculation closely approximates the actual test conditions. Table E-IV lists the main events during the transient for the test and the calculation. The measured and calculated times agree well with the exception of pressurizer heater operation. This discrepancy is caused by minor differences in the experimental and calculated system pressures.

The TRAC calculation was run up to 700 s, but because most events of interest were over during the early part of the transient, the comparisons are presented between 0 and 250 s of the transient only for clarity in the figures. All the calculated parameters we compared with the experiment remained consistently within the measurement uncertainty in the 250- to 700-s time span.

TABLE E-III
TEST L6-1 INITIAL CONDITIONS

<u>Parameter</u>	<u>Actual</u>	<u>Calculated</u>
Core power (MW)	36.9	36.9 ^a
Pressurizer pressure (MPa)	14.78	14.78 ^a
Pressurizer liquid volume (m ³)	0.63	0.63 ^a
Primary-coolant mass flow (kg/s)	478.5	478.6
Intact-loop cold-leg temperature (K)	552.8	552.8
Intact-loop hot-leg temperature (K)	567.5	567.6
Pump speeds (rad/s)	334	344 ^b
Steam-generator secondary-side pressure (MPa)	5.37	5.39 ^c
Steam-generator secondary-side liquid level (m)	3.183	3.135 ^d
Steam-generator secondary-side mass flow (kg/s)	20.1	19.2

^aSpecified as input parameter.

^bControlled to maintain the desired primary-coolant mass flow during the steady-state calculation.

^cControlled within maximum and minimum values of 5.425 MPa and 5.315 MPa, respectively. (See Table E-II.)

^dControlled as specified according to the expression, liquid level = 2.9464 + 0.00508 × core power in MW, which gives a desired liquid level of 3.134 m for 36.9 MW core power. However, the experimental liquid level was out of specification.

TABLE E-IV
TEST L6-1 SEQUENCE OF EVENTS

Event	Experimental Time (s)	Calculated Time (s)
MSFCV started to close	2.0 ^a	2.0
Pressurizer cycling heaters off	6.1	8.1
Pressurizer spray on	9.1	10.7
Reactor scrammed	21.8	19.1
MSFCV started to open	22.2	22.1
Pressurizer spray off	30.4	32.7
Pressurizer cycling heaters on	31.4	34.4
Pressurizer backup heaters on	32.5	36.1
MSFCV started to close	33.2 ^b	33.5
MSFCV started to open	91.2	94.0
MSFCV started to close	99.2 ^b	100.7
Pressurizer backup heaters off	-c	288.4
MSFCV started to open	312.6	314.4
MSFCV started to close	333.2 ^{b,d}	321.6
Pressurizer backup heaters on	-c	328.0
Pressurizer backup heaters off	415.4	399.8
Pressurizer cycling heaters off	-c	475.8
Transient terminated	700.0	700.8

^aThe valve closing was reported to have been initiated at 0.0 s. However, the data show an ~2-s time delay before any movement in the valve position was observed.

^bOnly the times when the valve was fully closed were reported in Ref. 72. The times when the valve started to close were estimated from the times when the valve was fully closed, the maximum valve-stem position when the valve was open, and the valve-stem movement rate.

^cNot observed in the experiment.

^dQuestionable because such a large time span when the valve was open would discharge several times the mass of steam actually observed to discharge in the experiment and would reduce the secondary-side pressure drastically.

Figure E-20 shows a comparison between the calculated and experimental core powers. Because the calculated reactor scram occurred 2.7 s before that observed in the experiment (Table E-IV), the calculated power decay occurred earlier than the data. The power, though considerably within the data uncertainty, is somewhat overpredicted after the reactor scram. This is because the experimental curve lies within the deadband range of the detector. Thus, the actual discrepancy, if any, may be much smaller than that observed in Fig. E-20.

Figure E-21 compares the TRAC-calculated and the measured pressurizer pressures. The calculation is consistently within the uncertainty of the measurement. At ~10 s, the pressurizer spray temporarily reduces the primary-side pressure, which is predicted by the calculation. The reactor scram also is calculated at about the right time (~20 s). Both in the calculation and in the experiment, the reduced pressure turns off the pressurizer spray at ~30 s, and ~3 s later the pressurizer heaters turn on. The pressure drop near 100 s, which is caused by high secondary-side pressure, corresponds to the MSFCV opening. TRAC correctly and accurately predicts all events.

Fig. E-20.
Comparison of the TRAC-calculated with the measured core powers for Test L6-1.

Fig. E-21.

Comparison of the TRAC-calculated with the measured pressurizer pressures for Test L6-1.

The primary-coolant mass-flow comparison between the calculation and the data is shown in Fig. E-22. The agreement is excellent. A small constant offset between the calculation and the data is caused by a difference between the published steady-state mass flow,⁷² which was used in the pump-speed controller, and the data channel plotted.

Figure E-23 shows the steam-generator secondary-side feedwater flow comparison between the test data and the calculation. The feedwater controller correctly calculates the flow. Figures E-24 and E-25 show excellent agreement between the calculated and the measured steam-generator secondary-side steam mass flows and steam-generator secondary-side pressures, respectively. The steam-flow controller performance is, therefore, excellent. The apparent small discrepancy between the observed and calculated steam mass flows when the MSFCV is fully closed is caused by an unknown amount of leakage through the MSFCV. However, because the measured flow is within the deadband range of the instrument, the actual discrepancy may be insignificant. We did not model any leakage through the valve. Finally, Fig. E-26 compares the

Fig. E-22.

Comparison of the TRAC-calculated with the measured primary-coolant mass flows for Test L6-1.

Fig. E-23.

Comparison of the TRAC-calculated with the measured steam-generator secondary-side feedwater mass flows for Test L6-1.

Fig. E-24.

Comparison of the TRAC-calculated with the measured steam-generator secondary-side steam mass flows for Test L6-1.

Fig. E-25.

Comparison of the TRAC-calculated with the measured secondary-side pressures for Test L6-1.

Fig. E-26.

Comparison of the TRAC-calculated with the measured pressurizer liquid-level histories for Test L6-1.

TRAC-calculated and the measured liquid-level histories. The calculation is within the measurement uncertainty.

VI. INPUT LISTINGS

This section contains three separate input listings. The first is a complete steady-state one-dimensional input deck for the calculations described previously. The second is a restart input deck that begins the transient calculation. Finally, the third listing presents a three-dimensional vessel input (to start a steady-state run) that is equivalent to the one-dimensional input. However, the three-dimensional VESSEL for this listing was extracted from a LOFT input deck used to model another transient (large-break Test L2-3) and, therefore, represents identical geometry but not identical initial and boundary conditions. (Note there is no reactivity calculation in the input.) This listing demonstrates how the vessel can be modeled using the three-dimensional vessel-modeling capability. In this case, all the components shown in Fig. E-5 were combined into a single three-dimensional VESSEL component as shown in Fig. E-6. A detailed description of

another sample TRAC three-dimensional VESSEL is given in App. C of the TRAC-PD2 users' manual.⁷⁸ The geometrical considerations given there also apply to TRAC-PF1/MOD1.

A. Steady-State One-Dimensional Input for LOFT L6-1

	1	2	3	4	5	6	7	8
CARD	1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890							
1	FREE							
2		80	0	1	0			
3	LOFT TEST L6-1, PF1/MOD1 DEVELOPMENTAL ASSESSMENT CALCULATION.							
4								
5	DECK PERFORMS STEADY STATE CALCULATION.							
6								
7	DECK PREPERATION BEGAN IN OCTOBER 1982. THE DECK IS BASED ON MEIER'S							
8	L9-1/L3-3 DECK.							
9								
10	VOLUME, LENGTH, AND GRAV ARRAYS FOR 1-D COMPONENTS ADJUSTED TO							
11	AGREE WITH EG&G LETTER (D. L. REEDER TO T. KNIGHT, "TRANSMITTAL							
12	OF LOFT INFORMATION," REED-4-80, MAY 15, 1980) OR TO LOFT							
13	SYSTEM AND TEST DESCRIPTION (5.5 FT NUCLEAR CORE 1 LOCES) (TREE-1208,							
14	NUREG/CR-0247, JULY 1978 -- D. L. REEDER).							
15								
16	THE STEAM GENERATOR NODING WAS CHANGED BECAUSE OF RECENT TRAC CHANGES IN							
17	THE STEAM GENERATOR MODEL.							
18								
19	COMPONENT 3 (PUMP SUCTION) -- LENGTH AND VOLUME DISTRIBUTION							
20	NOT EXACT, BUT TOTAL VOLUME AGREES.							
21								
22	COMPONENT 6 (PUMP DISCHARGE) AND COMPONENT 7 (INTACT LOOP COLD LEG) --							
23	LENGTH AND VOLUME DISTRIBUTION NOT EXACT. TOTAL VOLUME FOR BOTH							
24	COMPONENTS TOGETHER IS CORRECT. SOME LENGTH ADDED IN FOR							
25	VESSEL NOZZLE.							
26								
27	VALVE COMPONENT 23 -- FRIC(6) SET TO FORCE STEADY STATE VALVE OPENING							
28	THAT PREVENTS THE VALVE FROM REACHING UPPER OPENING SET POINT DURING							
29	PRESSURE RISE FOLLOWING SCRAM. MINIMUM FLOW AREA (ALEAK) ADJUSTED TO							
30	GIVE APPROPRIATE PRESSURE DECAY FOLLOWING PRESSURE PEAK (A REASONABLE							
31	LEAKAGE FLOW RELATIVE TO THE REPORTED LEAKAGE).							
32								
33	COMPONENT 31 (BROKEN LOOP HOT LEG) -- SHOULD INVESTIGATE FLOW							
34	AREAS AND HYDRAULIC DIAMETERS BEFORE USING FOR HOT LEG BREAK,							
35	ALTHOUGH THEY APPEAR GENERALLY CORRECT. ALSO, RESET FRIC ARRAY							
36	BASED ON MEASURED DATA. LAST CELL TERMINATES AT THE							
37	ISOLATION VALVE POSITION (POSITION OF GATE).							
38								
39	CONTROL OF REFLOOD ASSIST BYPASS VALVE (RABV) LEAKAGE IS THROUGH							
40	WALL FRICTION (WITH TWO-PHASE MULTIPLIER) INSTEAD OF FRIC (WITHOUT							
41	TWO-PHASE MULTIPLIER).							
42								
43	REFLOOD ASSIST BYPASS LINE VOLUMES AND ELEVATIONS APPEAR TO BE							
44	OVERSTATED, BUT INFORMATION ON VALVE VOLUMES IS LACKING.							
45	THE ELEVATION DIFFERENCE IS APPROXIMATELY 0.1 M.							
46	NO CORRECTIONS WERE MADE.							
47								
48	FUEL PELLET OUTSIDE RADIUS WAS ADJUSTED TO GIVE							
49	A GAP WIDTH OF 0.08 MM, WHICH WAS DETERMINED FOR L2-2 TEMPERATURE							
50	COMPARISONS TO YIELD BEST FIT. THE GAP CLOSURE REPRESENTS A							

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51 COMPROMISE TO THE FRAPCON CALCULATIONS (EG&G, INFORMAL)
52 SHOWING GAP CLOSURE AND FUEL THERMAL CONDUCTIVITY DEGRADATION.
53
54 VESSEL VOLUMES CORRESPOND TO TABLE IX, P 121 OF TREE-1208
55 (D. L. REEDER, LOFT SYSTEM AND TEST DESCRIPTION). CORE AND UPPER
56 PLENUM HAVE COMPENSATING VOLUME ERRORS OF 1.9061E-4 M**3 (UPPER
57 PLENUM HIGH). THE DOWNCOMER AND LOWER PLENUM ALSO HAVE COMPENSATING
58 (BUT UNDETERMINED) VOLUME ERRORS. THE FLOW AREAS SHOULD BE
59 CHECKED FOR LARGE BREAK APPLICATIONS.
60
61 PRESSURE DROPS AROUND THE SYSTEM WERE CORRECTED PRIOR TO THE
62 L3-2 PRETEST PREDICTION. THE REFLOOD ASSIST BYPASS LINES WERE
63 CONNECTED AT THAT TIME.
64
65 THE SYSTEM HEAT LOSSES ARE ACCOUNTED FOR THROUGH HEAT TRANSFER
66 FROM THE EXTERNAL AREAS OF THE PIPING HEAT SLABS TO THE ENVIRONMENT
67 THROUGH HOUTV. THE SINK TEMPERATURE IS ASSUMED TO BE 305.37 K.
68 IN ORDER TO ESTIMATE HOUTV, THE HEAT LOSSES ARE ASSUMED TO BE 174 KW
69 FROM THE PRIMARY SYSTEM (EXCLUDING THE PRESSURIZER), 6 KW FROM THE
70 PRESSURIZER, AND 10 KW FROM THE STEAM GENERATOR SECONDARY.
71 (EGG-LOFT-5983, AUGUST 1982, P19).
72
73 COMPONENTS 31 AND 41 (BROKEN LOOP HOT AND COLD LEGS) HAVE
74 BEEN CONNECTED (AS IN L3-2) THROUGH THE REFLOOD ASSIST
75 BYPASS LINES WITH 5% FLOW (USED HD TO ACCOUNT FOR HYDRAULIC
76 LOSS IN WALL FRICTION WITH TWO-PHASE MULTIPLIER INSTEAD OF FRIC).
77
78 COMPONENT ORDER IN INPUT:
79      1  8 12 13  9 63 62 10 11 74 78  2 24 23 25 73 77  3  4  5  6  7
80      17 31 75 41 40 29 96 95 86 30 83 36 37 33 35 34 43
81
82
83
84 *****NAMELIST DATA*****
85 $INOPTS ICFLOW=2 5
86
87 *****MAIN CONTROL CARDS*****
88      0      0.000000      *MCC 01
89      1      0      39      48      1 *MCC 02
90 1.00000E-3 1.00000E-5 1.00000E-4 1.00000E-3 *MCC 03
91      10      0      25      *MCC 04
92 *NTSV* 24 *NTCB* 29 *NTCF* 138 *NTRP* 21 *NTCP* 2 *MCC 05
93      1      2      3      4      5 *IORDER
94      6      7      8      9      10 *IORDER
95      11      12      13S *IORDER
96      17S *IORDER
97      23      24      25S *IORDER
98      29      30S *IORDER
99      31      33      34      35S *IORDER
100     36      37      40S *IORDER

```

CARD 1234567890123456789012345678901234567890123456789012345678901234567890

101	41	43S			*IORDER
102	62	63S			*IORDER
103	73	74	75S		*IORDER
104	77	78S			*IORDER
105	83S				*IORDER
106	86S				*IORDER
107	95S				*IORDER
108	96E				*IORDER
109	1	18S			*ISV
110	-1	-15S			*ICB
111	1	-24S			*ITP
112	19	24S			*ISV
113	-16	-70S			*ICB
114	1	0E			*ITP

115 *****SIGNAL VARIABLE DATA*****

116	1	0			* PROBLEM TIME	SV01
117	2	21	9		1* SYSTEM PRESSURE	SV02
118	3	23	1		1* HOT LEG TEMP	SV03
119	4	32	1		3* HOT LEG MASS FLOW	SV04
120	5	21	9		1* PRIZER PRESSURE	SV05
121	6	41	4		* PUMP SPEED	SV06
122	7	21	7		4* HPIS PRESSURE	SV07
123	8	20	8	1	1* PRZR BOT LIQ LEV	SV08
124	9	20	12	1	1* PRZR MID LIQ LEV	SV09
125	10	18	37		* REACTOR POWER	SV10
126	11	27	20	1	-5* SGS PIPE20 ALP	SV11
127	12	27	22	1	-4* SGS TEE22 MN ALP	SV12
128	13	21	21		2* SGS DOME PRESSURE	SV13
129	14	29	23		6* SGS STEAM FLOW	SV14
130	15	27	22		5* SGS TEE22 SID ALP	SV15
131	16	27	21	1	-2* SGS TEE21 MN ALP	SV16
132	17	27	21		3* SGS TEE21 SID ALP	SV17
133	18	20	13	6	1* PRZR TOP LIQ LEV	SV18
134	19	56	23		* TRIP 23 ISET	SV19
135	20	56	20		* TRIP 20 ISET	SV20
136	21	56	-21		* TRIP 21 ISET	SV21
137	22	56	22		* TRIP 22 ISET	SV22
138	23	55	-24		* TRIP 24 SIGNAL	SV23
139	24	56	15		* TRIP 15 ISET	SV24

140 *****CONTROL BLOCK DATA*****

141						
142	PRESSURIZER LIQUID LEVEL CALCULATION FOR PLOTTING					
143	*					
144	-1	3	8	9	*CB01	
145	1.000000	0.000000	1.350000		*CB01	
146	-2	3	-1	18	*CB02	
147	1.000000	0.000000	1.750000		*CB02	
148	-3	56	-2		*CB03	
149	1.000000	0.000000	1.640000	-0.110000	*CB03	
150	*	SGS FEEDWATER PUMP MACRO CONTROLLER				

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151	-4	101	14	7		*CB04
152	1.000000	0.000000	1.000000			*CB04
153	0.000000	0.000000	6.870000	0.200000S		*CB04
154	13.720000	0.391700	20.580000	0.577000S		*CB04
155	27.440000	0.756200	37.130000	1.000000S		*CB04
156	999.000000	1.000000E				*CB04
157	-5	101	-4	19		*CB05
158	1.000000	0.000000	1.000000			*CB05
159	0.000000	0.000000	0.189400	0.025000S		*CB05
160	0.246200	0.050000	0.337100	0.100000S		*CB05
161	0.391700	0.136000	0.412900	0.150000S		*CB05
162	0.473500	0.200000	0.526500	0.250000S		*CB05
163	0.568200	0.300000	0.613600	0.350000S		*CB05
164	0.651500	0.400000	0.689400	0.450000S		*CB05
165	0.719700	0.500000	0.750000	0.550000S		*CB05
166	0.784100	0.600000	0.848500	0.700000S		*CB05
167	0.897700	0.800000	0.954500	0.900000S		*CB05
168	1.000000	1.000000E				*CB05
169	-6	59	12	15		*CB06
170	1.000000	0.000000	1.280323	1.264108	0.016215	*CB06
171	-7	59	16	17		*CB07
172	1.000000	0.000000	2.617779	2.234813	0.382966	*CB07
173	-8	3	-6	-7		*CB08
174	1.000000	0.000000	3.898102			*CB08
175	-9	59	11	-8		*CB09
176	1.000000	0.000000	6.670213	2.772111	1.000000	*CB09
177	-10	101	10	2		*CB10
178	1.000000	2.946400	3.200400			*CB10
179	0.000000	2.946400	5.0000E+07	3.200400E		*CB10
180	-11	101	-9	10		*CB11
181	1.000000	0.000000	5.610300			*CB11
182	0.000000	5.610300S				*CB11
183	2.266048	5.610300	2.594344	4.681000S		*CB11
184	4.150213	3.200400	4.417293	2.946400S		*CB11
185	4.835973	2.544000	5.029433	2.350000S		*CB11
186	5.405128	1.886000	5.840249	1.246000S		*CB11
187	6.670213	0.000000E				*CB11
188	-12	54	-10	-11		*CB12
189	3.149606	-8.390235	10.080000			*CB12
190	-13	3	-12	-5		*CB13
191	1.000000	0.000000	1.000000			*CB13
192	-14	54	-13	-15		*CB14
193	7.000000	-0.050000	0.050000			*CB14
194	-15	23	-14			*CB15
195	1.000000	0.000000	1.000000			*CB15
196	-16	23	19			*CB16
197	-0.500000	-1.000000	0.000000			*CB16
198	-17	3	-15	-16		*CB17
199	1.000000	0.000000	0.634857			*CB17
200	-18	101	-17	19		*CB18

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201		1.000000	0.000000	0.806548			*CB18
202	R02	0.000000	2.5000E-02	1.8940E-01	5.0000E-02	2.4620E-01	*CB18
203		1.0000E-01	3.3710E-01	1.3600E-01	3.9170E-01	1.5000E-01	*CB18
204		4.1290E-01	2.0000E-01	4.7350E-01	2.5000E-01	5.2650E-01	*CB18
205		3.0000E-01	5.6820E-01	3.5000E-01	6.1360E-01	4.0000E-01	*CB18
206		6.5150E-01	4.5000E-01	6.8940E-01	5.0000E-01	7.1970E-01	*CB18
207		5.5000E-01	7.5000E-01	6.0000E-01	7.8410E-01	7.0000E-01	*CB18
208		8.4850E-01	8.0000E-01	8.9770E-01	9.0000E-01	9.5450E-01	*CB18
209	R02	1.0000E+00E					*CB18
210	*	SGS STEAM FLOW CONTROL VALVE MACRO CONTROLLER					
211		-20	1	20			*CB20
212		1.0000E+00	0.000000	1.0000E+00			*CB20
213		-41	22	20	21	-20	*CB41
214		1.0000E+00	-1.0000E+00	1.0000E+00			*CB41
215		-42	22	22	-41	19	*CB42
216		5.0000E-02	-5.0000E-02	5.0000E-02			*CB42
217		-43	23	-42			*CB43
218		1.0000E+00	0.000000	1.0000E+00			*CB43
219		-44	101	-43	12		*CB44
220		1.0000E+00	0.000000	1.0000E+00			*CB44
221	R02	0.000000	1.0000E-01	7.3360E-02	2.0000E-01	1.5334E-01	*CB44
222		3.0000E-01	2.4500E-01	4.0000E-01	3.4000E-01	5.0000E-01	*CB44
223		4.4000E-01	5.7500E-01	5.1733E-01	6.0000E-01	5.4666E-01	*CB44
224		7.0000E-01	6.6000E-01	8.0000E-01	7.7248E-01	9.0000E-01	*CB44
225		8.8665E-01	R02 1.0000E+00E				*CB44
226	*	PUMP SPEED MACRO CONTROLLER					
227		-50	1	4			*CB50
228		1.000000	1.0000E-20	1.000000E+3			*CB50
229		-55	9				*CB55
230		1.000000	478.500000	478.500000	478.500000		*CB55
231		-60	14	-55	-50		*CB60
232		0.100000	0.000000	0.200000			*CB60
233		-62	56	-60			*CB62
234		1.000000	0.900000	1.100000	0.900000		*CB62
235		-65	39	-62	6		*CB65
236		1.000000	200.000000	500.000000			*CB65
237		-70	22	6	-65	24	*CB70
238		1.000000	200.000000	500.000000			*CB70
239							
240		*****TRIP DATA*****					
241		0	2	2	0	0	*TRIP DIM
242	*	SYSTEM LOW PRESSURE SCRAM TRIP					
243		1	1	0	1	2	*TRIP01
244		14.3600E+6	14.3610E+6				*TRIP01
245		0.000000	0.000000				*TRIP01
246		0	0				*TRIP01
247	*	SYSTEM HIGH PRESSURE SCRAM TRIP					
248		2	2	0	1	2	*TRIP02
249		15.7690E+6	15.7700E+6				*TRIP02
250		0.000000	0.000000				*TRIP02

251								*TRIP02
252 *		INTACT LOOP HOT LEG HIGH TEMPERATURE SCRAM TRIP						
253	3	2	0	1			3	*TRIP03
254	5.8320E+02	5.8330E+02						*TRIP03
255	0.000000	0.000000						*TRIP03
256	0	0						*TRIP03
257 *		INTACT LOOP LOW MASS FLOW SCRAM TRIP						
258	4	1	0	1			4	*TRIP04
259	433.500000	434.000000						*TRIP04
260	2.000000	0.000000						*TRIP04
261	0	0						*TRIP04
262 *		HIGH CORE-AVERAGED POWER SCRAM TRIP						
263	5	2	0	1			10	*TRIP05
264	5.1000E+07	5.1500E+07						*TRIP05
265	0.000000	0.000000						*TRIP05
266	0	0						*TRIP05
267 *		SGS DOWNCOMER LOW LIQUID LEVEL SCRAM TRIP						
268	6	1	0	1			-11	*TRIP06
269	2.0000E+00	2.0100E+00						*TRIP06
270	0.000000	0.000000					/1	*TRIP06
271	0	0						*TRIP06
272 *		STEADY STATE OR TRANSIENT FLAG TRIP						
273	7	-1	-1	1			1	*TRIP07
274	-2.0000E-05	-1.0000E-05						*TRIP07
275	0.000000	0.000000						*TRIP07
276	0	0						*TRIP07
277 *		SGS FEEDWATER AND STEAM FLOW CONTROL VALVE TRIP						
278	8	2	1	1			1	*TRIP08
279	-2.0000E-05	-1.0000E-05						*TRIP08
280	0.000000	0.000000						*TRIP08
281	0	0						*TRIP08
282 *		WARM-UP LINES TRIP						
283	9	2	0	1			1	*TRIP09
284	-2.0000E-05	1.0000E+20						*TRIP09
285	0.000000	0.000000						*TRIP09
286	0	0						*TRIP09
287 *		INTACT LOOP PUMP SHUTDOWN TRIP						
288	10	2	0	1			1	*TRIP10
289	-2.0000E-05	1.0000E+20						*TRIP10
290	0.000000	0.000000						*TRIP10
291	0	0						*TRIP10
292 *		PRESSURIZER POWER-OPERATED RELIEF VALVE TRIP						
293	11	-3	0	1			5	*TRIP11
294	1.6560E+07	1.6570E+07	1.6690E+07	1.6700E+07				*TRIP11
295	0.000000	0.000000	0.000000	0.000000				*TRIP11
296	0	0	0	0				*TRIP11
297 *		PRESSURIZER SPRAY VALVE TRIP						
298	12	-3	0	1			5	*TRIP12
299	14.9000E+6	15.0000E+6	15.1400E+6	15.2400E+6				*TRIP12
300	0.000000	1.00000E+4	1.00000E+4	0.000000				*TRIP12

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301	0	0	0	0		*TRIP12
302	*	PRESSURIZER CYCLING HEATERS TRIP FLAG				
303	13	1	1	1	5	*TRIP13
304	14.7500E+6	14.9300E+6				*TRIP13
305	0.000000	0.000000				*TRIP13
306	0	0				*TRIP13
307	*	PRESSURIZER BACKUP HEATERS TRIP FLAG				
308	14	1	0	1	5	*TRIP14
309	14.6200E+6	14.8000E+6				*TRIP14
310	0.000000	0.000000				*TRIP14
311	0	0				*TRIP14
312	*	STEADY STATE OR TRANSIENT FLAG TRIP				
313	15	2	0	1	1	*TRIP15
314	-2.0000E-05	-1.0000E-05				*TRIP15
315	0.000000	0.000000				*TRIP15
316	0	0				*TRIP15
317	*	ECC LOW PRESSURE HPIS TRIP				
318	17	1	0	1	2	*TRIP17
319	13.2970E+6	15.5000E+6				*TRIP17
320	0.000000	0.000000				*TRIP17
321	0	0				*TRIP17
322	*	SGS STEAM FLOW CONTROL VALVE CLOSURE TRIP				
323	*	FORCED CLOSURE AT START OF L6-1 TRANSIENT				
324	20	-2	0	1	1	*TRIP20
325	-2.0000E-05	-1.0000E-05				*TRIP20
326	0.000000	2.000000				*TRIP20
327	0	0				*TRIP20
328	*	SGS PRESSURE REGULATION TRIP PRIOR TO REACTOR SCRAM				
329	-21	-3	0	1	13	*TRIP21
330	5.3150E+06	5.3200E+06	5.4200E+06	5.4250E+06		*TRIP21
331	0.000000	0.000000	0.000000	0.000000		*TRIP21
332	0	0	0	0		*TRIP21
333	*	SGS PRESSURE REGULATION TRIP AFTER REACTOR SCRAM				
334	22	-3	0	1	13	*TRIP22
335	6.7500E+6	6.8800E+6	6.8900E+6	6.9900E+6		*TRIP22
336	0.000000	1.00000E+4	1.00000E+4	2.500000		*TRIP22
337	2	0	0	1		*TRIP22
338	*	COINCIDENCE SCRAM TRIP				
339	23	2	0	3	1	*TRIP23
340	4.0000E-01	6.0000E-01				*TRIP23
341	1.00000E+4	0.000000				*TRIP23
342	0	0				*TRIP23
343	*	TRIP-CONTROLLED TRIP FOR PRESSURIZER HEATERS				
344	-24	-3	-1	3	2	*TRIP24
345	-6.0000E-01	-4.0000E-01	4.0000E-01	6.0000E-01		*TRIP24
346	0.000000	0.000000	0.000000	0.000000		*TRIP24
347	0	0	0	0		*TRIP24
348	*	TRIP-CONTROLLED TRIP 23 SIGNAL (COINCIDENCE TRIP)				
349	1	6				*TP23SIG
350	1	2	3	4	5	*TP23SIG

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351          6                                     *TP23SIG
352 *          TRIP-CONTROLLED TRIP 24 SIGNAL (PRESSURIZER HEATERS)
353          2          4                                     *TP24SIG
354          13         14          7          7          *TP24SIG
355 *          TRIP SET POINT FACTOR TABLE FOR TRIP 22
356          1          1          6                                     *SPFT1
357          0.000000          1.000000          75.000000          1.000000          75.100000 *SPFT1
358          0.998054          200.000000          0.998054          200.100000          0.993763 *SPFT1
359          1.00000E+4          0.993763                                     *SPFT1
360 *          TRIP SET POINT FACTOR TABLE FOR TRIP 22
361          2          1          6                                     *SPFT2
362          0.000000          1.000000          75.000000          1.000000          75.100000 *SPFT2
363          0.985185          200.000000          0.985185          200.100000          0.977778 *SPFT2
364          1.00000E+4          0.977778                                     *SPFT2
365
366 *****COMPONENT DATA*****
367 TEE          1          1 INTACT LOOP HOT LEG
368          2          4          7          0.000000          1 *CN 02
369          0          2          9          74          0 *CN 03
370          0          0          0          0          0 *CN 05
371          0.14209          0.03571          0.000000          12.270127          305.370000 *CN 06
372          305.370000          0.000000          0.000000          1.0000E+20          1.000000 *CN 07
373          0.000000          0.000000          1.0000E+20          1.000000          *CN 08
374          0          3          10          0          *CN 09
375          0          0          0          0          0 *CN 11
376          2.33005E-02          8.69680E-03          0.000000          12.270127          305.370000 *CN 12
377          305.370000          0.000000          0.000000          1.0000E+20          1.000000 *CN 13
378          0.000000          0.000000          1.0000E+20          1.000000          *CN 14
379          2.219700          1.079200E          *DX P
380          0.149887          6.85272E-2E          *VOL P
381 R03 6.34253E-2E          *FA P
382          1.00000E-4R02          0.000000E          *FRIC P
383 R03 0.000000E          *GRAV P
384 R03 0.284180E          *HD P
385 F          0E          *ICFLG P
386 F          2E          *NFF P
387 F          0.000000E          *ALP P
388 F          0.000000E          *VL P
389 F          0.000000E          *VV P
390 F          567.500000E          *TL P
391 F          567.500000E          *TV P
392 F          14.7800E+6E          *P P
393 F          0.000000E          *PA P
394 F          0.000000E          *QPPP P
395 F          7E          *MATID P
396 F          567.500000E          *TW P
397          2149.85E-3          2642.77E-03          2221.69E-3E          *DX S
398          3114.87E-6          3695.37E-6          5705.88E-6E          *VOL S
399 R03 1449.29E-6          5732.12E-6E          *FA S
400          0.165298          5.50315E-3          4.66877E-3          4.66877E-3E          *FRIC S

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401		0.545100R02	0.000000	0.604100E						*GRAV	S
402	R03	4295.68E-5	8543.04E-5E							*HD	S
403	F	0E								*ICFLG	S
404	F	2E								*NFF	S
405	F	0.000000E								*ALP	S
406	F	0.000000E								*VL	S
407	F	0.000000E								*VV	S
408		614.107628	614.107628	614.107628E						*TL	S
409		614.107628	614.107628	614.107628E						*TV	S
410	F	14.7800E+6E								*P	S
411	F	0.000000E								*PA	S
412	F	0.000000E								*QPPP	S
413	F	7E								*MATID	S
414	R04	614.107628R04	614.107628R04	614.107628E						*TW	S
415	*-----										
416	PRIZER		8	8	PRESSURIZER	BOTTOM					
417		1	4	64	10		9	*CN	02		
418		1	0					*CN	03		
419		0.424180	0.074930	0.000000	2.741114	305.370000		*CN	04		
420		305.370000	0.000000	0.000000	0.000000	0.000000		*CN	05		
421		0.200000E						*DX			
422		0.012770E						*VOL			
423		0.565263	5.73212E-3E					*FA			
424		0.000000	4.66877E-3E					*FRIC			
425		-1.000000	-0.604100E					*GRAV			
426		0.848360	8.54304E-2E					*HD			
427	F	0E						*ICFLG			
428	F	2E						*NFF			
429		0.000000E						*ALP			
430	F	0.000000E						*VL			
431	F	0.000000E						*VV			
432		614.107628E						*TL			
433		614.107628E						*TV			
434		14.7800E+6E						*P			
435		0.000000E						*PA			
436	F	0.000000E						*QPPP			
437	F	9E						*MATID			
438	F	614.107628E						*TW			
439	*-----										
440	PIPE		12	12	PRESSURIZER	LOWER MIDDLE					
441		1	4	61	64		9	*CN	02		
442		1	0	0	1			*CN	03		
443		-24	23	8	0		0	*CN	04		
444		0	0	0	0		0	*CN	05		
445		0.424180	0.074930	0.000000	2.741114	305.370000		*CN	06		
446		305.370000	0.000000	0.000000	1.0000E+20	1.000000		*CN	07		
447		0.000000	0.000000	1.0000E+20	1.000000			*CN	08		
448		0.150000E						*DX			
449		8.47894E-2E						*VOL			
450	F	0.565263E						*FA			

451	F	0.000000E					*FRIC		
452	F	-1.000000E					*GRAV		
453	F	0.848360E					*HD		
454	F	0E					*ICFLG		
455	F	2E					*NFF		
456		0.000000E					*ALP		
457	F	0.000000E					*VL		
458	F	0.000000E					*VV		
459		614.107628E					*TL		
460		614.107628E					*TV		
461		14.7800E+6E					*P		
462		0.000000E					*PA		
463	F	0.000000E					*QPPP		
464	F	9E					*MATID		
465	F	614.107628E					*TW		
466		-1.250000	398.000000	-0.750000	398.000000S		*POWTB		
467		-0.500000	0.000000	0.500000	0.000000S		*POWTB		
468		0.750000	3.60000E+4	1.250000	3.60000E+4S		*POWTB		
469		1.750000	4.80000E+4	2.250000	4.80000E+4E		*POWTB		
470	*	-----							
471	PRIZER		13	13	PRESSURIZER UPPER MIDDLE				
472		6	4	60	61	9	*CN	02	
473		1	0				*CN	03	
474		0.424180	0.074930	0.000000	2.741114	305.370000	*CN	04	
475		305.370000	0.000000	0.000000	0.000000	0.000000	*CN	05	
476		0.400000R05	0.200000E				*DX		
477		0.202587R05	0.113053E				*VOL		
478	F	0.565263E					*FA		
479	F	0.000000E					*FRIC		
480	F	-1.000000E					*GRAV		
481	F	0.848360E					*HD		
482	F	0E					*ICFLG		
483	F	2E					*NFF		
484		1.000000	0.290325R04	0.000000E			*ALP		
485	F	0.000000E					*VL		
486	F	0.000000E					*VV		
487	F	614.107628E					*TL		
488	F	614.107628E					*TV		
489	F	14.7800E+6E					*P		
490	F	0.000000E					*PA		
491	F	0.000000E					*QPPP		
492	F	9E					*MATID		
493	F	614.107628E					*TW		
494	*	-----							
495	TEE		9	9	PRIZER TOP AND PRIZER SPRAY				
496		1	4	9	0.000000	1	*CN	02	
497		0	5	60	62	0	*CN	03	
498		0	0	0	0	0	*CN	05	
499		0.424180	0.074930	0.000000	2.741114	305.370000	*CN	06	
500		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07	

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S01		0.000000	0.000000	1.0000E+20	1.000000		*CN	08
S02		0	1	68	1		*CN	09
S03		7	1	5	0	0	*CN	10
S04		0	0	0	0	0	*CN	11
S05		0.023300	0.008797	0.000000	12.270127	305.370000	*CN	12
S06		305.370000	0.000000	0.000000	1.0000E+20	1.00000E+4	*CN	13
S07		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
S08		0.130732R04	0.100000E				*DX	P
S09		0.066211	7.30420E-4R03	7.06858E-5E			*VOL	P
S10		0.565263	1.76715E-2R04	7.06858E-4E			*FA	P
S11	F	0.000000E					*FRIC	P
S12	F	1.000000E					*GRAV	P
S13		0.848360	0.150000R04	3.00000E-2E			*HD	P
S14	F	0E					*ICFLG	P
S15	F	2E					*NFI	P
S16	F	1.000000E					*ALP	P
S17	F	0.000000E					*VL	P
S18	F	0.000000E					*VV	P
S19	F	614.107628E					*TL	P
S20	F	614.107628E					*TV	P
S21	F	14.7800E+6E					*P	P
S22	F	0.000000E					*PA	P
S23	F	0.000000E					*QPPP	P
S24	F	9E					*MATID	P
S25	F	614.107628E					*TW	P
S26	F	0.046022E					*DX	S
S27	F	6.66991E-5E					*VOL	S
S28		1.44929E-4	1.44929E-3E				*FA	S
S29	F	0.000000E					*FRIC	S
S30	F	-1.000000E					*GRAV	S
S31	F	4.29568E-2E					*HD	S
S32	F	0E					*ICFLG	S
S33	F	2E					*NFI	S
S34	F	0.000000E					*ALP	S
S35	F	0.000000E					*VL	S
S36	F	0.000000E					*VV	S
S37	F	614.107628E					*TL	S
S38	F	614.107628E					*TV	S
S39	F	14.7800E+6E					*P	S
S40	F	0.000000E					*PA	S
S41	F	0.000000E					*QPPP	S
S42	F	6E					*MATID	S
S43	F	614.107628E					*TW	S
S44		0.000000	0.000000	0.100000	0.500000S		*POWTB2	
S45		50.000000	0.500000	60.000000	1.000000S		*POWTB2	
S46		1.00000E+4	1.000000E				*POWTB2	
S47	*-----							
S48	VALVE		63	63	PORV VALVE			
S49		2	0	62	63	7	*CN	02
S50		1	0	3	3	0	*CN	03

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551		11	1	-2	0	0	*CN	04
552		0	0				*CN	06
553		1.0000E+20	0.000000	0.000000	1.000000		*CN	07
554		0.002899	0.010000	0.000000	0.000000	305.370000	*CN	08
555		305.370000	2.39300E-5	5.20000E-3	0.000000	0.000000	*CN	09
556	F	0.100000E					*DX	
557	F	-1.000000E					*VOL	
558	R02	7.06860E-4	2.39300E-5E				*FA	
559	F	0.000000E					*FRIC	
560	F	1.000000E					*GRAV	
561	R02	3.00000E-2	5.20000E-3E				*HD	
562	R02	0	1E				*ICFLG	
563	R02	2	0E				*NFF	
564	F	1.000000E					*ALP	
565	F	0.000000E					*VL	
566	F	0.000000E					*VV	
567	F	614.107628E					*TL	
568	F	614.107628E					*TV	
569	F	14.7800E+6E					*P	
570	F	0.000000E					*PA	
571		0.000000	0.000000	5.000000	1.000000E		*VTB1	
572	*-----							
573	BREAK		62	62	PRIZER PORV BREAK			
574		63	0	3	1	0	*CN	02
575		0.100000	2.39300E-6	1.000000	305.370000	8.68736E+4	*CN	04
576		0.000000	0.000000	1.0000E+20	8.68736E+4	0.000000	*CN	05
577	*-----							
578	VALVE		10	10	PRIZER SPRAY CONTROL VALVE			
579		3	4	67	68	7	*CN	02
580		1	0	3	2	0	*CN	03
581		12	1	-2	0	0	*CN	04
582		0	0	0	0	0	*CN	05
583		0	0				*CN	06
584		1.0000E+20	0.000000	0.000000	1.000000		*CN	07
585		0.033000	0.008697	0.000000	12.270127	305.370000	*CN	08
586		305.370000	1.44900E-3	4.29570E-2	0.025000	-1.000000	*CN	09
587		0.000000	0.000000	1.0000E+20	1.000000		*CN	10
588	R02	0.566000	0.700000E				*DX	
589	R02	8.20300E-4	1.01450E-3E				*VOL	
590	F	1.44929E-3E					*FA	
591		0.000000	10.500000	0.000000	0.000000E		*FRIC	
592	F	1.000000E					*GRAV	
593	F	4.29568E-2E					*HD	
594	F	0E					*ICFLG	
595	F	2E					*NFF	
596	F	0.000000E					*ALP	
597	F	0.000000E					*VL	
598	F	0.000000E					*VV	
599	F	450.000000E					*TL	
600	F	450.000000E					*TV	

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651	F	14.7800E+6E								*P	S
652	F	0.000000E								*PA	S
653	F	0.000000E								*QPPP	S
654	F	7E								*MATID	S
655	F	450.000000E								*TW	S
656	*-----										
657	TEE		74		74	RECIR LINE FROM IL HL TO BL CL					
658		1	4		7	0.000000		1		*CN	02
659		0	2		74	2		0		*CN	03
660		0	0		0	0		0		*CN	05
661		0.142090	0.035710		0.000000	12.270127		305.370000		*CN	06
662		305.370000	0.000000		0.000000	1.0000E+20		1.000000		*CN	07
663		0.000000	0.000000		1.0000E+20	1.000000				*CN	08
664		0	2		78	0				*CN	09
665		0	0		0	0		0		*CN	11
666		0.023300	0.008797		0.000000	0.000000		305.370000		*CN	12
667		305.370000	0.000000		0.000000	1.0000E+20		1.000000		*CN	13
668		0.000000	0.000000		1.0000E+20	1.000000				*CN	14
669		1.016000	1.625600E							*DX	P
670		4.95548E-2	0.111610E							*VOL	P
671	R02	6.34253E-2	5.16000E-2E							*FA	P
672		0.000000	5.39400E-2		0.118300E					*FRIC	P
673		0.000000			0.423700E					*GRAV	P
674	R02	0.284180	0.256300E							*HD	P
675	F	0E								*ICFLG	P
676	F	2E								*NFF	P
677	F	0.000000E								*ALP	P
678	F	0.000000E								*VL	P
679	F	0.000000E								*VV	P
680	F	567.500000E								*TL	P
681	F	567.500000E								*TV	P
682	F	14.7800E+6E								*P	P
683	F	0.000000E								*PA	P
684	F	0.000000E								*QPPP	P
685	F	7E								*MATID	P
686	F	567.500000E								*TW	P
687	F	5.000000E								*DX	S
688	F	7.24650E-3E								*VOL	S
689	R03	1.44930E-3E								*FA	S
690	F	0.000000E								*FRIC	S
691		0.000000	0.000000		0.000000E					*GRAV	S
692	R03	4.29600E-2E								*HD	S
693	F	0E								*ICFLG	S
694	F	2E								*NFF	S
695	F	0.000000E								*ALP	S
696	F	0.000000E								*VL	S
697	F	0.000000E								*VV	S
698	F	552.800000E								*TL	S
699	F	552.800000E								*TV	S
700	F	14.7800E+6E								*P	S

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701	F	0.000000E								*PA	S
702	F	0.000000E								*QPPP	S
703	F	7E								*MATID	S
704	F	552.800000E								*TW	S
705	*-----										
706	VALVE		78		78	RECIRC VLVE (IL HL TO BL CL)					
707		2	0		78	42		7	*CN	02	
708		1	0		3	2		0	*CN	03	
709		9	1		-2	0		0	*CN	04	
710		0	0						*CN	06	
711		1.0000E+20	0.000000		0.000000	1.000000			*CN	07	
712		0.033000	0.008697		0.000000	0.000000		305.370000	*CN	08	
713		305.370000	1.44900E-3		4.29570E-2	1.000000		1.000000	*CN	09	
714	F	0.500000E							*DX		
715	F	-1.000000E							*VOL		
716	R02	1.44930E-3	1.28580E-5E						*FA		
717	R02	0.000000	6.52460E-3E						*FRIC		
718	F	0.000000E							*GRAV		
719	R02	4.29600E-2	4.04620E-3E						*HD		
720	F	0E							*ICFLG		
721	F	2E							*NFF		
722	F	0.000000E							*ALP		
723	F	0.000000E							*VL		
724	F	0.000000E							*VV		
725	F	552.800000E							*TL		
726	F	552.800000E							*TV		
727	F	14.7800E+6E							*P		
728	F	0.000000E							*PA		
729		0.000000	1.000000		0.500000	0.000000E			*VTB1		
730	*-----										
731	STGEN		2		2	STEAM GENERATOR					
732		10	8		4	3		9	*CN	02	
733		0	1		2	3			*CN	03	
734		0	1		25	22			*CN	04	
735		0	0		0	0.000000			*CN	05	
736		0	0		5				*CN	06	
737		17	4						*CN	07	
738		5.10540E-3	1.24460E-3						*CN	08	
739	PIPE		5		0				*SECONDARY PIPE	20	
740	TEE		4		1				*DOWNCOMER TEE	22	
741	TEE		2		1				*STEAM DOME TEE	21	
742	*-----PRIMARY SIDE										
743		9.63600E-1R03	5.68950E-1		9.63600E-1E				*DX	P	
744		3.79500E-1R08	8.59500E-2		3.79500E-1E				*VOL	P	
745		5.16000E-2R09	1.51100E-1		5.16000E-2E				*FA	P	
746		0.118300R09	0.000000		0.215600E				*FRIC	P	
747		0.423700R04	1.000000		0.000000R04	-1.000000		-0.711600E	*GRAV	P	
748		2.56300E-1R09	1.02110E-2		2.56000E-1E				*HD	P	
749	F	0E							*ICFLG	P	
750		2R09	1		2E				*NFF	P	

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751	F	0.000000E								*ALP	P
752	F	0.000000E								*VL	P
753	F	0.000000E								*VV	P
754	I08	567.500000	552.800000E							*TL	P
755	I08	567.500000	552.800000E							*TV	P
756	F	14.7800E+6E								*P	P
757	F	0.000000E								*PA	P
758	*-----SECONDARY SIDE										
759		24	21	0		20	*PIPE	20			
760	R04	5.68950E-1	1.11150E+0E							*DX	
761	R04	4.43562E-1	9.97863E-1E							*VOL	
762		2.18898E-1R03	7.79615E-1R02	8.97762E-1E						*FA	
763		2.000000R05	0.000000E							*FRIC	
764		0.000000R05	1.00000E+0E							*GRAV	
765	R05	6.35000E-3	1.06910E+0E							*HD	
766	F	0E								*ICFLG	
767	F	1E								*NFF	
768	R04	0.000000	0.864489E							*ALP	
769	F	0.000000E								*VL	
770	F	0.000000E								*VV	
771	F	541.571343E								*TL	
772	F	541.571343E								*TV	
773	F	5.3700E+6E								*P	
774	F	0.000000E								*PA	
775	*-----										
776		23	24	25		22	*TEE	22			
777	R02	7.41000E-1	1.70685E+0	5.68950E-1E						*DX	P
778	R02	3.82966E-1	3.73632E-1	1.24544E-1E						*VOL	P
779	R02	5.16842E-1R03	2.18898E-1E							*FA	P
780	R04	0.000000	2.000000E							*FRIC	P
781		-3.37626E-1R03	-1.000000	0.000000E						*GRAV	P
782	R02	2.54000E-1R02	1.01600E-1	6.35000E-3E						*HD	P
783	F	0E								*ICFLG	P
784	F	1E								*NFF	P
785		1.000000	0.796734R02	0.000000E						*ALP	P
786	F	0.000000E								*VL	P
787	F	0.000000E								*VV	P
788	F	541.571343E								*TL	P
789	F	541.571343E								*TV	P
790	F	5.3700E+6E								*P	P
791	F	0.000000E								*PA	P
792		0.000000	2								
793		2.000000E								*DX	S
794		1.62146E-2E								*VOL	S
795	F	8.10732E-3E								*FA	S
796	F	0.000000E								*FRIC	S
797	F	0.000000E								*GRAV	S
798	F	1.01600E-1E								*HD	S
799	F	0E								*ICFLG	S
800	F	1E								*NFF	S

801		0.000000E					*ALP	S
802	F	0.000000E					*VL	S
803	F	0.000000E					*VV	S
804		525.000000E					*TL	S
805		525.000000E					*TV	S
806		5.3700E+6E					*P	S
807	F	0.000000E					*PA	S
808	*-----							
809		21	22	23	21 *TEE 21			
810	F	1.11150E+0E					*DX	P
811		9.97863E-1	1.23695E+0E				*VOL	P
812		8.97762E-1	1.58904E+0	4.63292E-2E			*FA	P
813		0.000000	1.0000E+30	2.44600E-1E			*FRIC	P
814		1.000000E					*GRAV	P
815	R02	1.06910E+0	2.42900E-1E				*HD	P
816	F	0E					*ICFLG	P
817	F	1E					*NFF	P
818	F	1.000000E					*ALP	P
819	F	0.000000E					*VL	P
820	F	0.000000E					*VV	P
821	F	541.571343E					*TL	P
822	F	541.571343E					*TV	P
823	F	5.3700E+6E					*P	P
824	F	0.000000E					*PA	P
825		0.000000	1					
826		7.41000E-1E					*DX	S
827		3.82966E-1E					*VOL	S
828	F	5.16842E-1E					*FA	S
829	F	0.000000E					*FRIC	S
830	F	-3.37626E-1E					*GRAV	S
831	F	2.54000E-1E					*HD	S
832	F	0E					*ICFLG	S
833	F	1E					*NFF	S
834		1.000000E					*ALP	S
835	F	0.000000E					*VL	S
836	F	0.000000E					*VV	S
837		541.571343E					*TL	S
838		541.571343E					*TV	S
839		5.3700E+6E					*P	S
840	F	0.000000E					*PA	S
841	*-----HEAT STRUCTURES							
842	R08	OR05	OR06	20R04	22R02	21E	*ICMP	
843		2	3	4	5	6	*ICELL	
844		7	8	9S			*ICELL	
845	R03	1R02	10S				*ICELL	
846		1	2	3	4R02	5	*ICELL	
847		1	2	3	4S		*ICELL	
848		2	3E				*ICELL	
849	R08	20R05	OR06	22R04	OR02	OE	*OCMP	
850		1	2	3R02	4	3	*OCELL	

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851		2	1S				*OCELL
852	R02	0	10R02	0S			*OCELL
853		4R03	3	2	1S		*OCELL
854	R04	0R02	0E				*OCELL
855	R24	12R06	9R03	6R06	9S		*MATG
856	R18	6R18	9E				*MATG
857	R08	5.10540E-3	0.685800	5.10540E-3	10.000000	0.685800	*RADIG
858		5.10540E-3R04	0.644525R02	0.571500R06	0.711200E		*RADIG
859	R08	1.24460E-3	0.088900	6.18435E-3	0.031750	0.088900	*TH
860		6.18435E-3R06	0.012700R06	0.053975E			*TH
861	F	0.000000E					*QPPG
862	R32	541.571343R12	567.500000R08	552.800000R48	541.571343E		*TWGN
863	F	0.000000E					*HILG
864	F	0.000000E					*HIVG
865	F	0.000000E					*TILG
866	F	0.000000E					*TIVG
867	R08	33.898952	1.388600	17.287714	0.738780	1.388600	*WAIG
868		17.287714R04	2.304060	2.660813	2.848255	2.214599	*WAIG
869		3.311234	7.627232	2.542411	4.966850	4.407869E	*WAIG
870	R08	0.000000R05	0.000000R06	0.000000R06	0.000000E		*HOLG
871	R08	0.000000R05	0.000000R06	0.000000R06	1.580119E		*HOVG
872	R08	0.000000R02	305.370000	0.000000R02	305.370000R06	0.000000	*TOLG
873	R06	305.370000E					*TOLG
874	R08	0.000000R02	305.370000	0.000000R02	305.370000R06	0.000000	*TOVG
875	R06	305.370000E					*TOVG
876	R08	42.162876	1.568604	38.228926	0.738780	1.568604	*WAOG
877		38.228926R04	2.349460	2.719942	2.911549	2.382671	*WAOG
878		3.562533	8.206085	2.735362	5.343799	4.742394E	*WAOG
879	*-----						
880	FILL		24	24	STEAM GENERATOR FEEDWATER		
881		25	8	0			*CN 02
882		8	-18	6	0	0	*CN 03
883		0.000000	1.0000E+20	0.000000			*CN 04
884		2.000000	1.62146E-2	0.000000	0.000000	479.000000	*CN 05
885		5.3700E+6	0.000000	20.100000	0.000000	479.000000	*CN 06
886		1.000000	1.000000				*CN 09
887		0.000000	0.000000	0.200000	6.870000S		*VMTB
888		0.391700	13.720000	0.577000	20.580000S		*VMTB
889		0.756200	27.440000	1.000000	37.130000E		*VMTB
890	*-----						
891	VALVE		23	23	STEAM LINE VALVE		
892		6	0	22	26	7	*CN 02
893		1	0	3	6	0	*CN 03
894		8	-44	0	0	0	*CN 04
895		0	0				*CN 06
896		1.0000E+20	0.000000	0.000000	1.000000		*CN 07
897		0.121400	0.015100	0.000000	0.000000	305.370000	*CN 08
898		305.370000	4.09446E-2	0.228325	0.569330	0.620000	*CN 09
899	F	5.01191E					*DX
900	F	2.32198E-1E					*VOL

901	F	4.63292E-2E					*FA
902		0.244600R04	0.000000	6.490000	0.000000E		*FRIC
903		1.000000R06	0.000000E				*GRAV
904	F	0.2429E					*HD
905	R05	0	1	OE			*ICFLG
906	F	1E					*NFF
907	F	1.000000E					*ALP
908	F	0.000000E					*VL
909	F	0.000000E					*VV
910	F	541.571343E					*TL
911	F	541.571343E					*TV
912	R05	5.3700E+6	2.1500E+6E				*P
913	F	0.000000E					*PA
914	*	-----					
915	BREAK		25	25 STM GEN SEC BRK			
916		26	0	3	1	0	*CN 02
917		5.011910	0.232198	1.000000	488.000000	2.1500E+6	*CN 04
918		0.000000	0.000000	1.0000E+20	2.1500E+6	0.000000	*CN 05
919	*	-----					
920	TEE		73	73 RECIR LINE FROM	IL CL TO BL HL		
921		1	4	7	0.000000	1	*CN 02
922		0	3	73	3	0	*CN 03
923		0	0	0	0	0	*CN 05
924		0.142090	0.035710	0.000000	12.270127	305.370000	*CN 06
925		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN 07
926		0.000000	0.000000	1.0000E+20	1.000000		*CN 08
927		0	2	77	0		*CN 09
928		0	0	0	0	0	*CN 11
929		0.023300	0.008697	0.000000	0.000000	305.370000	*CN 12
930		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN 13
931		0.000000	0.000000	1.0000E+20	1.000000		*CN 14
932		0.657050R02	0.622300E				*DX P
933		3.86855E-2	4.00000E-2	5.00481E-2E			*VOL P
934	R02	6.34249E-2	6.87143E-2	5.16000E-2E			*FA P
935	R03	0.000000	0.215600E				*FRIC P
936		0.039657	1.000000	0.999875	0.711600E		*GRAV P
937	R02	0.284174	0.295787	0.256000E			*HD P
938	F	OE					*ICFLG P
939	F	2E					*NFF P
940	F	0.000000E					*ALP P
941	F	0.000000E					*VL P
942	F	0.000000E					*VV P
943	F	552.800000E					*TL P
944	F	552.800000E					*TV P
945	F	14.7800E+6E					*P P
946	F	0.000000E					*PA P
947	F	0.000000E					*QPPP P
948	F	7E					*MATID P
949	F	552.800000E					*TW P
950	F	5.000000E					*DX S

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951	F	7.24650E-3E								*VOL	S
952	R03	1.44930E-3E								*FA	S
953	F	0.000000E								*FRIC	S
954		0.000000	0.253949		0.000000E					*GRAV	S
955	R03	0.042960E								*HD	S
956	F	0E								*ICFLG	S
957	F	2E								*NFF	S
958	F	0.000000E								*ALP	S
959	F	0.000000E								*VL	S
960	F	0.000000E								*VV	S
961	F	567.500000E								*TL	S
962	F	567.500000E								*TV	S
963	F	14.7800E+6E								*P	S
964	F	0.000000E								*PA	S
965	F	0.000000E								*QPPP	S
966	F	7E								*MATID	S
967	F	567.500000E								*TW	S
968	*-----										
969	VALVE		77		77	RECIRC VLVE (IL CL TO BL HL)					
970		2	0		77	32		7		*CN	02
971		1	0		3	2		0		*CN	03
972		9	1		-2	0		0		*CN	04
973		0	0							*CN	06
974		1.0000E+20	0.000000		0.000000	1.000000				*CN	07
975		0.033000	0.008697		0.000000	0.000000		305.370000		*CN	08
976		305.370000	1.44900E-3		4.29570E-2	1.000000		1.000000		*CN	09
977	F	0.500000E								*DX	
978	F	-1.000000E								*VOL	
979	R02	1.44930E-3	0.051956E							*FA	
980	R02	0.000000	0.203800E							*FRIC	
981	F	0.000000E								*GRAV	
982	R02	4.29600E-2	0.257201E							*HD	
983	F	0E								*ICFLG	
984	F	2E								*NFF	
985	F	0.000000E								*ALP	
986	F	0.000000E								*VL	
987	F	0.000000E								*VV	
988	F	567.500000E								*TL	
989	F	567.500000E								*TV	
990	F	14.7800E+6E								*P	
991	F	0.000000E								*PA	
992		0.000000	1.000000		0.500000	0.000000E				*VTB1	
993	*-----										
994	TEE		3		3	PUMP SUCTION					
995		2	4		7	0.000000		1		*CN	02
996		0	3		4	5		0		*CN	03
997		0	0		0	0		0		*CN	05
998		0.14209	0.03571		0.000000	12.270127		305.370000		*CN	06
999		305.370000	0.000000		0.000000	1.0000E+20		1.000000		*CN	07
1000		0.000000	0.000000		1.0000E+20	1.000000				*CN	08

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1001	0	1	73	0			*CN	09
1002	0	0	0	0	0		*CN	11
1003	0.14209	0.03571	0.000000	12.270127	305.370000		*CN	12
1004	305.370000	0.000000	0.000000	1.0000E+20	1.000000		*CN	13
1005	0.000000	0.000000	1.0000E+20	1.000000			*CN	14
1006	6.35E-1	1.80340	6.35E-1E				*DX	P
1007	2746.75E-5	0.11438	2746.75E-5E				*VOL	P
1008	3661.31E-5R02	6342.49E-5	3.66131E-2E				*FA	P
1009	F 0.000000E						*FRIC	P
1010	-0.62659	-0.5522	0.5522	0.62659E			*GRAV	P
1011	215.91E-3R02	2841.74E-4	215.91E-3E				*HD	P
1012	F 0E						*ICFLG	P
1013	F 2E						*NFF	P
1014	F 0.000000E						*ALP	P
1015	F 0.000000E						*VL	P
1016	F 0.000000E						*VV	P
1017	F 552.800000E						*TL	P
1018	F 552.800000E						*TV	P
1019	F 14.7800E+6E						*P	P
1020	F 0.000000E						*PA	P
1021	F 0.000000E						*QPPP	P
1022	F 7E						*MATID	P
1023	F 552.800000E						*TW	P
1024	0.657050E						*DX	S
1025	3.86855E-2E						*VOL	S
1026	R02 6.34249E-2E						*FA	S
1027	R02 0.000000E						*FRIC	S
1028	0.000000	0.039657E					*GRAV	S
1029	R02 0.284174E						*HD	S
1030	F 0E						*ICFLG	S
1031	F 2E						*NFF	S
1032	F 0.000000E						*ALP	S
1033	F 0.000000E						*VL	S
1034	F 0.000000E						*VV	S
1035	F 552.800000E						*TL	S
1036	F 552.800000E						*TV	S
1037	F 14.7800E+6E						*P	S
1038	F 0.000000E						*PA	S
1039	F 0.000000E						*QPPP	S
1040	F 7E						*MATID	S
1041	F 552.800000E						*TW	S
1042	*-----							
1043	PUMP	4	4	PUMP NO. 2				
1044	2	4	4	6	7	*CN	02	
1045	1	0	1	1	1	*CN	03	
1046	10	1	-11	0	0	*CN	04	
1047	0	0	0	0	0	*CN	05	
1048	0.107950	0.028580	0.000000	12.270127	305.370000	*CN	06	
1049	305.370000	317.438000	3.681250	231.186000		*CN	07	
1050	941.540000	500.000000	0.315000	614.000000	369.661000	*CN	08	

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1051		334.239321	-1.000000	1.0000E+20	335.318435	-70	*CN	09
1052		0.000000	0.000000	1.0000E+20	1.000000		*CN	10
1053		2					*CN	11
1054	F	1352.13E-3E					*DX	
1055	F	4955.48E-5E					*VOL	
1056	F	3661.31E-5E					*FA	
1057	F	0.000000E					*FRIC	
1058		0.62659R02	0.000000E				*GRAV	
1059	F	215.91E-3E					*HD	
1060	F	0E					*ICFLG	
1061		2	0	2E			*NFF	
1062	F	0.000000E					*ALP	
1063	F	0.000000E					*VL	
1064	F	0.000000E					*VV	
1065	F	552.800000E					*TL	
1066	F	552.800000E					*TV	
1067	F	14.7800E+6E					*P	
1068	F	0.000000E					*PA	
1069	F	0.000000E					*QPPP	
1070	F	7E					*MATID	
1071	F	552.800000E					*TW	
1072		0.000000	1.000000	5.000000	0.645161S		*PMPTB	
1073		10.000000	0.435484	18.000000	0.225806S		*PMPTB	
1074		20.000000	0.129032	25.000000	0.064516S		*PMPTB	
1075		30.000000	0.044355	40.000000	0.024806S		*PMPTB	
1076		44.000000	0.019355	46.500000	0.000000S		*PMPTB	
1077		1.00000E+4	0.000000E				*PMPTB	
1078	*-----							
1079	PUMP		5	5	PUMP NO. 1			
1080		2	4	5	7	7	*CN	02
1081		1	0	1	1	1	*CN	03
1082		10	1	-11	0	0	*CN	04
1083		0	0	0	0	0	*CN	05
1084		0.107950	0.028580	0.000000	12.270127	305.370000	*CN	06
1085		305.370000	317.438000	3.681250	231.186000		*CN	07
1086		941.540000	500.000000	0.315000	614.000000	369.661000	*CN	08
1087		334.239321	-1.000000	1.0000E+20	335.318435	-70	*CN	09
1088		0.000000	0.000000	1.0000E+20	1.000000		*CN	10
1089		2					*CN	11
1090	F	1352.13E-3E					*DX	
1091	F	4955.48E-5E					*VOL	
1092	F	3661.31E-5E					*FA	
1093	F	0.000000E					*FRIC	
1094		0.62659R02	0.000000E				*GRAV	
1095	F	215.91E-3E					*HD	
1096	F	0E					*ICFLG	
1097		2	0	2E			*NFF	
1098	F	0.000000E					*ALP	
1099	F	0.000000E					*VL	
1100	F	0.000000E					*VV	

1101	F	552.800000E					*TL		
1102	F	552.800000E					*TV		
1103	F	14.7800E+6E					*P		
1104	F	0.000000E					*PA		
1105	F	0.000000E					*QPPP		
1106	F	7E					*MATID		
1107	F	552.800000E					*TW		
1108		0.000000	1.000000	5.000000	0.645161S		*PMPTB		
1109		10.000000	0.435484	18.000000	0.225806S		*PMPTB		
1110		20.000000	0.129032	25.000000	0.064516S		*PMPTB		
1111		30.000000	0.044355	40.000000	0.024806S		*PMPTB		
1112		44.000000	0.019355	46.500000	0.000000S		*PMPTB		
1113		1.00000E+4	0.000000E				*PMPTB		
1114	*	-----							
1115	TEE		6	6 PUMP DISCHARGE					
1116		2	4	7	0.000000		1 *CN	02	
1117		0	2	7	66		0 *CN	03	
1118		0	0	0	0		0 *CN	05	
1119		0.10795	0.02858	0.000000	12.270127	305.370000	*CN	06	
1120		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07	
1121		0.000000	0.000000	1.0000E+20	1.000000		*CN	08	
1122		0	1	6	0		*CN	09	
1123		0	0	0	0		0 *CN	11	
1124		0.10795	0.02858	0.000000	12.270127	305.370000	*CN	12	
1125		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13	
1126		0.000000	0.000000	1.0000E+20	1.000000		*CN	14	
1127		130.81E-2	55.588E-2E				*DX	P	
1128		4785.57E-5	3315.38E-5E				*VOL	P	
1129	R02	3661.31E-5	6342.49E-5E				*FA	P	
1130	R02	0.000000	2.201E-2E				*FRIC	P	
1131	F	0.000000E					*GRAV	P	
1132	R02	215.91E-3	0.284174E				*HD	P	
1133	F	0E					*ICFLG	P	
1134	F	2E					*NFF	P	
1135	F	0.000000E					*ALP	P	
1136	F	0.000000E					*VL	P	
1137	F	0.000000E					*VV	P	
1138	F	552.800000E					*TL	P	
1139	F	552.800000E					*TV	P	
1140	F	14.7800E+6E					*P	P	
1141	F	0.000000E					*PA	P	
1142	F	0.000000E					*QPPP	P	
1143	F	7E					*MATID	P	
1144	F	552.800000E					*TW	P	
1145		542.92E-3E					*DX	S	
1146		2543.94E-5E					*VOL	S	
1147	F	3661.31E-5E					*FA	S	
1148	F	0.000000E					*FRIC	S	
1149	F	0.000000E					*GRAV	S	
1150	F	215.91E-3E					*HD	S	

1151	F		OE					*ICFLG	S	
1152	F		2E					*NFF	S	
1153	F		0.000000E					*ALP	S	
1154	F		0.000000E					*VL	S	
1155	F		0.000000E					*VV	S	
1156	F		552.800000E					*TL	S	
1157	F		552.800000E					*TV	S	
1158	F		14.7800E+6E					*P	S	
1159	F		0.000000E					*PA	S	
1160	F		0.000000E					*QPPP	S	
1161	F		7E					*MATID	S	
1162	F		552.800000E					*TW	S	
1163	*	-----								
1164	TEE		7		7	INTACT LOOP COLD LEG				
1165		2	4		7	0.000000	1	*CN	02	
1166		0	3		8	29	0	*CN	03	
1167		0	0		0	0	0	*CN	05	
1168		0.14209	0.03571		0.000000	12.270127	305.370000	*CN	06	
1169		305.370000	0.000000		0.000000	1.0000E+20	1.000000	*CN	07	
1170		0.000000	0.000000		1.0000E+20	1.000000		*CN	08	
1171		0	1		14	0		*CN	09	
1172		0	0		0	0	0	*CN	11	
1173		4.36626E-2	1.34874E-2		0.000000	0.000000	305.370000	*CN	12	
1174		305.370000	0.000000		0.000000	1.0000E+20	1.000000	*CN	13	
1175		0.000000	0.000000		1.0000E+20	1.000000		*CN	14	
1176		116.84E-2	7087.35E-4		1.3970E			*DX	P	
1177		7419.05E-5	4474.09E-5		8.86029E-2E			*VOL	P	
1178	F	6342.49E-5E						*FA	P	
1179		2.20100E-2R02	0.000000		0.001000E			*FRIC	P	
1180	F	0.000000E						*GRAV	P	
1181	F	2841.74E-4E						*HD	P	
1182	F	OE						*ICFLG	P	
1183	F	2E						*NFF	P	
1184	F	0.000000E						*ALP	P	
1185	F	0.000000E						*VL	P	
1186	F	0.000000E						*VV	P	
1187	F	552.800000E						*TL	P	
1188	F	552.800000E						*TV	P	
1189	F	14.7800E+6E						*P	P	
1190	F	0.000000E						*PA	P	
1191	F	0.000000E						*QPPP	P	
1192	F	7E						*MATID	P	
1193	F	552.800000E						*TW	P	
1194		1.500E						*DX	S	
1195		8983.81E-6E						*VOL	S	
1196	F	598.92E-5E						*FA	S	
1197		0.000000	0.3338E					*FRIC	S	
1198		-1.000000	0.000000E					*GRAV	S	
1199	F	8732.52E-5E						*HD	S	
1200	F	OE						*ICFLG	S	

1201	F		2E				*NFF	S
1202	F		0.000000E				*ALP	S
1203	F		0.000000E				*VL	S
1204	F		0.000000E				*VV	S
1205	F	500.000000E					*TL	S
1206	F	500.000000E					*TV	S
1207	F	14.7800E+6E					*P	S
1208	F	0.000000E					*PA	S
1209	F	0.000000E					*QPPP	S
1210	F		7E				*MATID	S
1211	F	500.000000E					*TW	S
1212	*	-----						
1213	FILL		17		17 HPIS INJECTION			
1214		14	8		1		*CN	02
1215		17	1		-12	0	*CN	03
1216		0.000000	1.0000E+20		0.000000		*CN	04
1217		1.500000	8.98381E-3		0.000000	0.000000	*CN	05
1218		14.7800E+6	0.000000		0.000000	0.000000	*CN	06
1219		1.000000	1.000000				*CN	09
1220		0.000000	0.000000		0.200000	0.243750S	*VMTB	
1221		1.600000	3.887500		20.600000	3.893750S	*VMTB	
1222		21.600000	1.475000		22.600000	0.375000S	*VMTB	
1223		23.600000	0.250000		26.600000	0.159375S	*VMTB	
1224		33.600000	0.125000		39.600000	0.125000S	*VMTB	
1225		40.100000	0.000000		1.00000E+4	0.000000E	*VMTB	
1226	*	-----						
1227	TEE		31		31 BROKEN LOOP HOT LEG			
1228		1	4		7	0.000000	1	*CN 02
1229		0	6		45	32	0	*CN 03
1230		0	0		0	0	0	*CN 05
1231		0.14209	0.03571		0.000000	12.270127	305.370000	*CN 06
1232		305.370000	0.000000		0.000000	1.0000E+20	1.000000	*CN 07
1233		0.000000	0.000000		1.0000E+20	1.000000		*CN 08
1234		0	3		43	0		*CN 09
1235		0	0		0	0	0	*CN 11
1236		0.10795	0.02858		0.000000	12.270127	305.370000	*CN 12
1237		305.370000	0.000000		0.000000	1.0000E+20	1.000000	*CN 13
1238		0.000000	0.000000		1.0000E+20	1.000000		*CN 14
1239		2.548984	2.408029		3.750796	2.168533	1.829369	*DX P
1240		2.001044E						*DX P
1241		1.69381E-1	9.8451E-2		3.52044E-1	9.5904E-2	6.0297E-2	*VOL P
1242		7.0984E-2E						*VOL P
1243		6.3425E-2	6.3425E-2R02		1.07862E-1	9.426E-3	8.365E-3	*FA P
1244		5.1956E-2E						*FA P
1245		0.0001	0.000000		0.9026	0.9391	0.3710	*FRIC P
1246		0.0405	0.2038E					*FRIC P
1247		0.000000	0.1652		0.90507	-0.8476	-0.9399	*GRAV P
1248		0.6218	0.000E					*GRAV P
1249		0.284176	0.284176		0.370587	0.370587	0.109551	*HD P
1250		0.103201	0.257201E					*HD P

1251	F		OE					*ICFLG	P
1252	F		2E					*NFF	P
1253	F		0.000000E					*ALP	P
1254	F		0.000000E					*VL	P
1255	F		0.000000E					*VV	P
1256	F		567.500000E					*TL	P
1257	F		567.500000E					*TV	P
1258	F		14.7800E+6E					*P	P
1259	F		0.000000E					*PA	P
1260	F		0.000000E					*QPPP	P
1261	F		7E					*MATID	P
1262	F		567.500000E					*TW	P
1263			1.3890	0.8140	5.1044E			*DX	S
1264			0.0540	0.0314	0.1986E			*VOL	S
1265	F		3.88E-2E					*FA	S
1266	R03		0.000000	0.000000E				*FRIC	S
1267			0.000000	0.224200	0.191200	0.000000E		*GRAV	S
1268	R03		2.223E-1	1.410E-3E				*HD	S
1269	F		OE					*ICFLG	S
1270	F		2E					*NFF	S
1271	F		0.000000E					*ALP	S
1272	F		0.000000E					*VL	S
1273	F		0.000000E					*VV	S
1274	F		552.800000E					*TL	S
1275	F		552.800000E					*TV	S
1276	F		14.7800E+6E					*P	S
1277	F		0.000000E					*PA	S
1278	F		0.000000E					*QPPP	S
1279	F		7E					*MATID	S
1280	F		552.800000E					*TW	S
1281	*								
1282	PIPE		75		75 BL CL OUTLET PIPE				
1283		1	0		44	42	7	*CN	02
1284		1	0		0	0		*CN	03
1285		0.958804	0.159919	0.000000	0.000000	305.370000		*CN	06
1286		305.370000	0.000000	0.000000	1.0000E+20	1.000000		*CN	07
1287		0.500000E						*DX	
1288		0.028705E						*VOL	
1289		0.063427	1.28580E-5E					*FA	
1290		0.017900	6.52460E-3E					*FRIC	
1291	F	0.000000E						*GRAV	
1292		0.284180	4.04620E-3E					*HD	
1293	F	OE						*ICFLG	
1294	F	2E						*NFF	
1295	F	0.000000E						*ALP	
1296	F	0.000000E						*VL	
1297	F	0.000000E						*VV	
1298	F	552.800000E						*TL	
1299	F	552.800000E						*TV	
1300	F	14.7800E+6E						*P	

	F	0.000000E		*PA
1301	*	-----		
1302	TEE	41	41 BROKEN LOOP COLD LEG	
1303		2	4	7
1304		0	2	1
1305		0	0	0
1306		0.14209	0.03571	0.000000
1307		305.370000	0.000000	0.000000
1308		0.000000	0.000000	1.0000E+20
1309		0	2	43
1310		0	0	0
1311		0.10795	0.02858	0.000000
1312		305.370000	0.000000	0.000000
1313		0.000000	0.000000	1.0000E+20
1314		1.185782	1.185782E	
1315		6.8075E-2	6.8075E-2E	
1316		0.141925R02	0.063425E	
1317		0.001	0.1099	0.0179E
1318	F	0.000000E		
1319	R03	2.8418E-1E		
1320	F	0E		
1321	F	2E		
1322	F	0.000000E		
1323	F	0.000000E		
1324	F	0.000000E		
1325	F	0.000000E		
1326	F	552.800000E		
1327	F	552.800000E		
1328	F	14.7800E+6E		
1329	F	0.000000E		
1330	F	0.000000E		
1331	F	7E		
1332	F	552.800000E		
1333		0.8850	7.2834E	
1334		3.0330E-2	2.768E-1E	
1335	F	0.0388E		
1336	R02	0.000000	0.000000E	
1337		0.000000	0.199000	0.000000E
1338	R02	2.223E-1	1.410E-3E	
1339	F	0E		
1340	F	2E		
1341	F	0.000000E		
1342	F	0.000000E		
1343	F	0.000000E		
1344	F	552.800000E		
1345	F	552.800000E		
1346	F	14.7800E+6E		
1347	F	0.000000E		
1348	F	0.000000E		
1349	F	7E		
1350	F	552.800000E		

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1351 *-----
1352 TEE                                40      40 VESSEL COLD LEG
1353          1          4          6      0.000000          1 *CN 02
1354          0          1          29      46          0 *CN 03
1355          0          0          0          0          0 *CN 05
1356      1.4209E-01      1.5907E-01      0.000000      0.000000      305.370000 *CN 06
1357      305.370000      0.000000      0.000000      1.0000E+20      1.000000 *CN 07
1358          0.000000      0.000000      1.0000E+20      1.000000          *CN 08
1359          0          1          47          0          *CN 09
1360          0          0          0          0          0 *CN 11
1361      5.0000E-02      5.0000E-02      0.000000      0.000000      305.370000 *CN 12
1362      305.370000      0.000000      0.000000      1.0000E+20      1.000000 *CN 13
1363          0.000000      0.000000      1.0000E+20      1.000000          *CN 14
1364 F      1.0000E-01E          *DX P
1365 F      8.2790E-03E          *VOL P
1366          0.063425      0.141925E *FA P
1367          0.001000      0.000000E *FRIC P
1368 F      0.000000E          *GRAV P
1369 F      2.8418E-01E          *HD P
1370 F          0E          *ICFLG P
1371 F          2E          *NFF P
1372 F      0.000000E          *ALP P
1373 F      0.000000E          *VL P
1374 F      0.000000E          *VV P
1375 F      552.800000E          *TL P
1376 F      552.800000E          *TV P
1377 F      14.7800E+6E          *P P
1378 F      0.000000E          *PA P
1379 F      0.000000E          *QPPP P
1380 F          6E          *MATID P
1381 F      552.800000E          *TW P
1382 F      1.0000E-01E          *DX S
1383 F      7.8540E-04E          *VOL S
1384 F      7.8540E-03E          *FA S
1385 F      0.000000E          *FRIC S
1386 F      0.000000E          *GRAV S
1387      1.0000E-01      2.5150E-04E          *HD S
1388 F          0E          *ICFLG S
1389 F          2E          *NFF S
1390 F      0.000000E          *ALP S
1391 F      0.000000E          *VL S
1392 F      0.000000E          *VV S
1393 F      552.800000E          *TL S
1394 F      552.800000E          *TV S
1395 F      14.7800E+6E          *P S
1396 F      0.000000E          *PA S
1397 F      0.000000E          *QPPP S
1398 F          6E          *MATID S
1399 F      552.800000E          *TW S
1400 *-----

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1401	TEE		29	29	VESSEL COLD LEG AND DOWNCOMER		
1402		1	10	6	0.000000	1	*CN 02
1403		0	1	46	1	0	*CN 03
1404		0	0	0	0	0	*CN 05
1405		1.4209E-01	1.5907E-01	0.000000	0.000000	305.370000	*CN 06
1406		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN 07
1407		0.000000	0.000000	1.0000E+20	1.000000		*CN 08
1408		0	1	34	0		*CN 09
1409		0	0	0	0	0	*CN 11
1410		9.2000E-01	1.3600E-01	0.000000	0.000000	305.370000	*CN 12
1411		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN 13
1412		0.000000	0.000000	1.0000E+20	1.000000		*CN 14
1413	F	0.70974E+0E					*DX P
1414	F	1.0073E-01E					*VOL P
1415	F	0.141925E					*FA P
1416		0.000000	1.00000E-3E				*FRIC P
1417	F	0.000000E					*GRAV P
1418	F	2.8418E-01E					*HD P
1419	F	0E					*ICFLG P
1420	F	2E					*NFF P
1421	F	0.000000E					*ALP P
1422	F	0.000000E					*VL P
1423	F	0.000000E					*VV P
1424	F	552.800000E					*TL P
1425	F	552.800000E					*TV P
1426	F	14.7800E+6E					*P P
1427	F	0.000000E					*PA P
1428	F	0.000000E					*QPPP P
1429	F	6E					*MATID P
1430	F	552.800000E					*TW P
1431	F	0.100000E					*DX S
1432	F	1.41925E-2E					*VOL S
1433	F	1.41925E-1E					*FA S
1434	F	0.000000E					*FRIC S
1435	F	-0.999850E					*GRAV S
1436	F	1.0000E-01E					*HD S
1437	F	0E					*ICFLG S
1438	F	2E					*NFF S
1439	F	0.000000E					*ALP S
1440	F	0.000000E					*VL S
1441	F	0.000000E					*VV S
1442	F	552.800000E					*TL S
1443	F	552.800000E					*TV S
1444	F	14.7800E+6E					*P S
1445	F	0.000000E					*PA S
1446	F	0.000000E					*QPPP S
1447	F	6E					*MATID S
1448	F	552.800000E					*TW S
1449	*	-----					
1450	TEE		96	96	VSSL DNCMR AND DNCMR BYPASS		

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1451		1	10	6	0.000000	1	*CN	02
1452		0	6	34	96	0	*CN	03
1453		0	0	0	0	0	*CN	05
1454		0.940000	0.136000	0.000000	0.000000	305.370000	*CN	06
1455		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07
1456		0.000000	0.000000	1.0000E+20	1.000000		*CN	08
1457		0	6	97	0		*CN	09
1458		0	0	0	0	0	*CN	11
1459		1.480000	0.127000	0.000000	0.000000	305.370000	*CN	12
1460		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1461		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
1462		0.795500	0.895500	0.533000	0.330000	0.432000	*DX	P
1463		0.381000E					*DX	P
1464		0.117847	0.132039	7.07414E-2	4.37986E-2	5.73364E-2	*VOL	P
1465		5.05676E-2E					*VOL	P
1466	F	0.141925E					*FA	P
1467	F	0.000000E					*FRIC	P
1468		-0.999850F	-1.000000E				*GRAV	P
1469	F	0.100000E					*HD	P
1470	F	0E					*ICFLG	P
1471	F	2E					*NFF	P
1472	F	0.000000E					*ALP	P
1473	F	0.000000E					*VL	P
1474	F	0.000000E					*VV	P
1475	F	552.800000E					*TL	P
1476	F	552.800000E					*TV	P
1477	F	14.7800E+6E					*P	P
1478	F	0.000000E					*PA	P
1479	F	0.000000E					*QPPP	P
1480	F	6E					*MATID	P
1481	F	552.800000E					*TW	P
1482		0.795500	0.895500	0.533000	0.330000	0.432000	*DX	S
1483		0.381000E					*DX	S
1484	F	-1.000000E					*VOL	S
1485	F	0.014760E					*FA	S
1486	F	0.000000E					*FRIC	S
1487		0.000000R06	-1.000000E				*GRAV	S
1488	F	0.063500E					*HD	S
1489	F	0E					*ICFLG	S
1490	F	2E					*NFF	S
1491	F	0.000000E					*ALP	S
1492	F	0.000000E					*VL	S
1493	F	0.000000E					*VV	S
1494	F	552.800000E					*TL	S
1495	F	552.800000E					*TV	S
1496	F	14.7800E+6E					*P	S
1497	F	0.000000E					*PA	S
1498	F	0.000000E					*QPPP	S
1499	F	6E					*MATID	S
1500	F	552.800000E					*TW	S

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1501 *-----
1502 TEE                      95          95 VSSL MID LP AND DNCMR BYPASS
1503                1          10          6          0.000000          1 *CN 02
1504                0          1          35          95          0 *CN 03
1505                0          0          0          0          0 *CN 05
1506          0.940000      0.136000      0.000000      0.000000      305.370000 *CN 06
1507      305.370000      0.000000      0.000000      1.0000E+20      1.000000 *CN 07
1508          0.000000      0.000000      1.0000E+20      1.000000      *CN 08
1509                0          2          97          0          *CN 09
1510                0          0          0          0          0 *CN 11
1511          1.480000      0.127000      0.000000      0.000000      305.370000 *CN 12
1512      305.370000      0.000000      0.000000      1.0000E+20      1.000000 *CN 13
1513          0.000000      0.000000      1.0000E+20      1.000000      *CN 14
1514          0.100000E      *DX P
1515          0.034005E      *VOL P
1516 F          0.340050E      *FA P
1517 F          0.000000E      *FRIC P
1518 F          0.000000E      *GRAV P
1519 F          0.100000E      *HD P
1520 F          0E      *ICFLG P
1521 F          2E      *NFF P
1522 F          0.000000E      *ALP P
1523 F          0.000000E      *VL P
1524 F          0.000000E      *VV P
1525 F      552.800000E      *TL P
1526 F      552.800000E      *TV P
1527 F      14.7800E+6E      *P P
1528 F          0.000000E      *PA P
1529 F          0.000000E      *QPPP P
1530 F          6E      *MATID P
1531 F      552.800000E      *TW P
1532          0.432000      0.847000E      *DX S
1533 F      -1.000000E      *VOL S
1534 F          0.014760E      *FA S
1535 F          0.000000E      *FRIC S
1536          0.000000F      1.000000E      *GRAV S
1537 F          0.063500E      *HD S
1538 F          0E      *ICFLG S
1539 F          2E      *NFF S
1540 F          0.000000E      *ALP S
1541 F          0.000000E      *VL S
1542 F          0.000000E      *VV S
1543 F      552.800000E      *TL S
1544 F      552.800000E      *TV S
1545 F      14.7800E+6E      *P S
1546 F          0.000000E      *PA S
1547 F          0.000000E      *QPPP S
1548 F          6E      *MATID S
1549 F      552.800000E      *TW S
1550 *-----

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CARD 12345678901234567890123456789012345678901234567890123456789012345678901234567890

1551	TEE		86	86	CORE BYPASS			
1552		1	4	6	0.000000	1	*CN	02
1553		0	1	86	36	0	*CN	03
1554		0	0	0	0	0	*CN	05
1555		0.331970	0.016343	0.000000	0.000000	305.370000	*CN	06
1556		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07
1557		0.000000	0.000000	1.0000E+20	1.000000		*CN	08
1558		0	1	84	0		*CN	09
1559		0	0	0	0	0	*CN	11
1560		1.549400	0.016343	0.000000	0.000000	305.370000	*CN	12
1561		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1562		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
1563		0.050000E					*DX	P
1564		2.06605E-2E					*VOL	P
1565	F	0.413210E					*FA	P
1566	F	0.000000E					*FRIC	P
1567	F	0.000000E					*GRAV	P
1568	F	0.100000E					*HD	P
1569	F	0E					*ICFLG	P
1570	F	2E					*NFF	P
1571	F	0.000000E					*ALP	P
1572	F	0.000000E					*VL	P
1573	F	0.000000E					*VV	P
1574	F	552.800000E					*TL	P
1575	F	552.800000E					*TV	P
1576	F	14.7800E+6E					*P	P
1577	F	0.000000E					*PA	P
1578	F	0.000000E					*QPPP	P
1579	F	6E					*MATID	P
1580	F	552.800000E					*TW	P
1581		2.049500E					*DX	S
1582	F	-1.000000E					*VOL	S
1583	F	1.24118E-2E					*FA	S
1584	F	0.000000E					*FRIC	S
1585	F	1.000000E					*GRAV	S
1586	F	0.003500E					*HD	S
1587	F	0E					*ICFLG	S
1588	F	2E					*NFF	S
1589	F	0.000000E					*ALP	S
1590	F	0.000000E					*VL	S
1591	F	0.000000E					*VV	S
1592	F	552.800000E					*TL	S
1593	F	552.800000E					*TV	S
1594	F	14.7800E+6E					*P	S
1595	F	0.000000E					*PA	S
1596	F	0.000000E					*QPPP	S
1597	F	6E					*MATID	S
1598	F	552.800000E					*TW	S
1599	*							
1600	TEE		30	30	VESSEL LOWER PLENUM OUTSIDE			

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1601		1	10	6	0.000000	1	*CN	02
1602		0	2	96	35	0	*CN	03
1603		0	0	0	0	0	*CN	05
1604		9.4000E-01	1.3600E-01	0.000000	0.000000	305.370000	*CN	06
1605		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07
1606		0.000000	0.000000	1.0000E+20	1.000000		*CN	08
1607		0	1	36	0		*CN	09
1608		0	0	0	0	0	*CN	11
1609		5.0000E-02	5.0000E-02	0.000000	0.000000	305.370000	*CN	12
1610		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1611		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
1612		8.4700E-01	4.3200E-01E				*DX	P
1613		1.18892E-1	1.5429E-01E				*VOL	P
1614	RO2	1.41925E-1	3.4005E-01E				*FA	P
1615	F	0.000000E					*FRIC	P
1616	RO2	-1.000000	0.000000E				*GRAV	P
1617	F	1.0000E-01E					*HD	P
1618	F	0E					*ICFLG	P
1619	F	2E					*NFF	P
1620	F	0.000000E					*ALP	P
1621	F	0.000000E					*VL	P
1622	F	0.000000E					*VV	P
1623	F	552.800000E					*TL	P
1624	F	552.800000E					*TV	P
1625	F	14.7800E+6E					*P	P
1626	F	0.000000E					*PA	P
1627	F	0.000000E					*QPPP	P
1628	F	6E					*MATID	P
1629	F	552.800000E					*TW	P
1630	F	1.0000E-01E					*DX	S
1631	F	4.1321E-02E					*VOL	S
1632	F	4.1321E-01E					*FA	S
1633	F	0.000000E					*FRIC	S
1634	F	0.000000E					*GRAV	S
1635	F	1.0000E-01E					*HD	S
1636	F	0E					*ICFLG	S
1637	F	2E					*NFF	S
1638	F	0.000000E					*ALP	S
1639	F	0.000000E					*VL	S
1640	F	0.000000E					*VV	S
1641	F	552.800000E					*TL	S
1642	F	552.800000E					*TV	S
1643	F	14.7800E+6E					*P	S
1644	F	0.000000E					*PA	S
1645	F	0.000000E					*QPPP	S
1646	F	6E					*MATID	S
1647	F	552.800000E					*TW	S
1648	*-----							
1649	TEE		83	83	UPPER PLENUM AND CORE BYPASS			
1650		2	4	6	0.000000	1	*CN	02

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1651		0	2	38	83	0	*CN	03
1652		0	0	0	0	0	*CN	05
1653		0.331970	0.016343	0.000000	0.000000	305.370000	*CN	06
1654		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07
1655		0.000000	0.000000	1.0000E+20	1.000000		*CN	08
1656		0	2	84	0		*CN	09
1657		0	0	0	0	0	*CN	11
1658		1.549400	0.016343	0.000000	0.000000	305.370000	*CN	12
1659		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1660		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
1661	R02	0.895455E					*DX	P
1662	R02	0.300250E					*VOL	P
1663		0.163564R02	0.124118E				*FA	P
1664		0.010000R02	0.000000E				*FRIC	P
1665	F	1.000000E					*GRAV	P
1666	F	0.012200E					*HD	P
1667	F	0E					*ICFLG	P
1668		1R02	2E				*NFF	P
1669	F	0.000000E					*ALP	P
1670	F	0.000000E					*VL	P
1671	F	0.000000E					*VV	P
1672	F	567.500000E					*TL	P
1673	F	567.500000E					*TV	P
1674	F	14.7800E+6E					*P	P
1675	F	0.000000E					*PA	P
1676	F	0.000000E					*QPPP	P
1677	F	6E					*MATID	P
1678	F	567.500000E					*TW	P
1679	R02	0.895455E					*DX	S
1680	F	-1.000000E					*VOL	S
1681	F	1.24118E-2E					*FA	S
1682	F	0.000000E					*FRIC	S
1683		0.000000F	-1.000000E				*GRAV	S
1684	F	0.003500E					*HD	S
1685	F	0E					*ICFLG	S
1686	F	2E					*NFF	S
1687	F	0.000000E					*ALP	S
1688	F	0.000000E					*VL	S
1689	F	0.000000E					*VV	S
1690	F	552.800000E					*TL	S
1691	F	552.800000E					*TV	S
1692	F	14.7800E+6E					*P	S
1693	F	0.000000E					*PA	S
1694	F	0.000000E					*QPPP	S
1695	F	6E					*MATID	S
1696	F	552.800000E					*TW	S
1697	-----							
1698	TEE		36	36	VESSEL LOWER PLENUM INSIDE			
1699		2	0	6	0.000000	1	*CN	02
1700		0	2	95	37	0	*CN	03

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1701		3.3197E-01	4.9029E-02	0.000000	0.000000	305.370000	*CN	06
1702		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07
1703		0	1	86	0		*CN	09
1704		5.0000E-02	5.0000E-02	0.000000	0.000000	305.370000	*CN	12
1705		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1706		4.3200E-01	8.4700E-01E				*DX	P
1707		1.46955E-1	2.31723E-1E				*VOL	P
1708	R02	3.4005E-01	1.63564E-1E				*FA	P
1709	R02	0.000000	2.44366E-2E				*FRIC	P
1710		0.000000R02	1.0000E+00E				*GRAV	P
1711	R02	1.0000E-01	1.2200E-02E				*HD	P
1712	F	0E					*ICFLG	P
1713	R02	2	1E				*NFF	P
1714	F	0.000000E					*ALP	P
1715	F	0.000000E					*VL	P
1716	F	0.000000E					*VV	P
1717	F	552.800000E					*TL	P
1718	F	552.800000E					*TV	P
1719	F	14.7800E+6E					*P	P
1720	F	0.000000E					*PA	P
1721	F	0.5000E-01E					*DX	S
1722	F	2.06605E-02E					*VOL	S
1723	F	4.1321E-01E					*FA	S
1724	F	0.000000E					*FRIC	S
1725	F	0.000000E					*GRAV	S
1726	F	1.0000E-01E					*HD	S
1727	F	0E					*ICFLG	S
1728	F	2E					*NFF	S
1729	F	0.000000E					*ALP	S
1730	F	0.000000E					*VL	S
1731	F	0.000000E					*VV	S
1732	F	552.800000E					*TL	S
1733	F	552.800000E					*TV	S
1734	F	14.7800E+6E					*P	S
1735	F	0.000000E					*PA	S
1736	*-----							
1737	CORE		37	37	NUCLEAR REACTOR CORE			
1738		4	37	38	6	1	*CN	02
1739		0	4	0			*CN	03
1740		14	6	11	5		*CN	04
1741		23	1	-14	0	0	*CN	05
1742		0	1	1	0	0	*CN	06
1743		0	1	1	1	5	*CN	07
1744		3	10	4	0	0	*CN	08
1745		0.000000	1.6250E-05	-1.0000E+20	1.0000E+00	1.0000E+00	*CN	09
1746		3.6900E+07	0.000000	0.000000	0.000000		*CN	10
1747		0.331970	0.016343	0.000000	0.000000	305.370000	*CN	11
1748		305.370000	0.000000	1.334100	0.700000	1.00000E+3	*CN	12
1749		0.000000	0.000000	0.000000			*CN	13
1750		12	1	1	1		*CN	14

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1801		-1.6090E-03	-5.8000E-05	-1.6000E-04	-2.5400E-04	-4.2400E-04	*RCTC
1802		-6.0700E-04	-9.0100E-04	-1.3770E-03	-4.3600E-05	-1.1500E-04	*RCTC
1803		-1.8600E-04	-3.3900E-04	-4.9600E-04	-7.4200E-04	-1.1450E-03	*RCTC
1804		-2.9200E-05	-7.0200E-05	-1.2100E-04	-2.4900E-04	-3.8600E-04	*RCTC
1805		-5.9300E-04	-9.3600E-04	-1.6600E-05	-2.8800E-05	-5.4500E-05	*RCTC
1806		-1.6500E-04	-2.7600E-04	-4.4400E-04	-7.2200E-04E		*RCTC
1807	ROS	0.000000E					*RCAL
1808	ROS	0.000000E					*RCBM
1809		0.000169	0.000832	0.002640	0.001220	0.001380	*BE1A
1810		0.000247E					*BETA
1811		3.870000	1.400000	0.311000	0.115000	0.031700	*LAMDA
1812		0.012700E					*LAMDA
1813		9.9163E+07	1.3495E+09	1.9276E+10	2.4089E+10	9.8847E+10	*CDGN
1814		4.4156E+10E					*CDGN
1815		1.7720E+00	5.7740E-01	6.7430E-02	6.2140E-03	4.7390E-04	*LAMDH
1816		4.8100E-05	5.3440E-06	5.7260E-07	1.0360E-07	2.9590E-08	*LAMDH
1817		7.5850E-10E					*LAMDH
1818		2.9900E-03	8.2500E-03	1.5500E-02	1.9350E-02	1.1650E-02	*EDH
1819		6.4500E-03	2.3100E-03	1.6400E-03	8.5000E-04	4.3000E-04	*EDH
1820		5.7000E-04E					*EDH
1821		6.2263E+04	5.2723E+05	8.4818E+06	1.1486E+08	9.0869E+08	*CDHN
1822		4.0742E+09	2.5550E+09	1.9468E+09	1.0161E+09	5.1462E+08	*CDHN
1823		6.8247E+08E					*CDHN
1824	F	0E					*NFAX
1825	F	0.000000E					*FPUO2
1826	F	9.3000E-01E					*FTD
1827		9.8101E-01	0.000000	1.0103E-02	1.7830E-03	0.000000	*GMIX
1828		7.0991E-03	0.000000E				*GMIX
1829	F	1.0000E+00E					*GMLES
1830	F	3.1300E+05E					*PGAPT
1831	F	0.000000E					*PLVOL
1832	F	0.000000E					*PSLEN
1833	F	0.000000E					*CLENN
1834	F	0.000000E					*BURN
1835	F	552.800000E					*RFTN
1836	F	0.000000E					*BURN
1837	F	552.800000E					*RFTN
1838	F	0.000000E					*BURN
1839	F	552.800000E					*RFTN
1840	*-----						
1841	TEE		33	33	VESSEL UPPER PLENUM		
1842		1	4	6	0.000000	1	*CN 02
1843		0	2	83	39	0	*CN 03
1844		0	0	0	0	0	*CN 05
1845		3.3197E-01	4.9029E-02	0.000000	0.000000	305.370000	*CN 06
1846		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN 07
1847		0.000000	0.000000	1.0000E+20	1.000000		*CN 08
1848		0	1	40	0		*CN 09
1849		0	0	0	0	0	*CN 11
1850		1.4209E-01	4.9029E-02	0.000000	0.000000	305.370000	*CN 12

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1851		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1852		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
1853		2.8418E-01	7.7000E-01E				*DX	P
1854		3.52978E-2	2.58172E-1E				*VOL	P
1855		0.124118R02	0.124458E				*FA	P
1856	F	0.000000E					*FRIC	P
1857	F	1.0000E+00E					*GRAV	P
1858	F	1.2200E-02E					*HD	P
1859	F	0E					*ICFLG	P
1860	F	2E					*NFF	P
1861	F	0.000000E					*ALP	P
1862	F	0.000000E					*VL	P
1863	F	0.000000E					*VV	P
1864	F	567.500000E					*TL	P
1865	F	567.500000E					*TV	P
1866	F	14.7800E+6E					*P	P
1867	F	0.000000E					*PA	P
1868	F	0.000000E					*QPPP	P
1869	F	6E					*MATID	P
1870	F	567.500000E					*TW	P
1871	F	0.109737E					*DX	S
1872	F	1.36577E-2E					*VOL	S
1873	F	0.124458E					*FA	S
1874	F	0.000000E					*FRIC	S
1875	F	0.000000E					*GRAV	S
1876	F	2.8418E-01E					*HD	S
1877	F	0E					*ICFLG	S
1878	F	2E					*NFF	S
1879	F	0.000000E					*ALP	S
1880	F	0.000000E					*VL	S
1881	F	0.000000E					*VV	S
1882	F	567.500000E					*TL	S
1883	F	567.500000E					*TV	S
1884	F	14.7800E+6E					*P	S
1885	F	0.000000E					*PA	S
1886	F	0.000000E					*QPPP	S
1887	F	6E					*MATID	S
1888	F	567.500000E					*TW	S
1889	*-----							
1890	FILL		35	35 VESSEL HEAD				
1891		39	1	0			*CN	02
1892		0.000000	1.0000E+20	0.000000			*CN	04
1893		0.770000	0.258172	0.000000	0.000000	567.500000	*CN	05
1894		14.7800E+6	0.000000	0.000000	0.000000	567.500000	*CN	06
1895	*-----							
1896	TEE		34	34 VESSEL HOT LEG CONNECTION				
1897		1	0	6	0.000000	1	*CN	02
1898		0	1	48	45	0	*CN	03
1899		1.4209E-01	4.9029E-02	0.000000	0.000000	305.370000	*CN	06
1900		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07

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1901		0	1	40	0		*CN	09
1902		1.4209E-01	4.9029E-02	0.000000	0.000000	305.370000	*CN	12
1903		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1904	F	4.0000E-01E					*DX	P
1905	F	2.6087E-02E					*VOL	P
1906	F	6.3425E-02E					*FA	P
1907		0.000000	0.000100E				*FRIC	P
1908	F	0.000000E					*GRAV	P
1909	F	2.8418E-01E					*HD	P
1910	F	0E					*ICFLG	P
1911	F	2E					*NFF	P
1912	F	0.000000E					*ALP	P
1913	F	0.000000E					*VL	P
1914	F	0.000000E					*VV	P
1915	F	567.500000E					*TL	P
1916	F	567.500000E					*TV	P
1917	F	14.7800E+6E					*P	P
1918	F	0.000000E					*PA	P
1919	F	0.109737E					*DX	S
1920	F	1.36577E-2E					*VOL	S
1921	F	0.124458E					*FA	S
1922	F	0.000000E					*FRIC	S
1923	F	0.000000E					*GRAV	S
1924	F	2.8418E-01E					*HD	S
1925	F	0E					*ICFLG	S
1926	F	2E					*NFF	S
1927	F	0.000000E					*ALP	S
1928	F	0.000000E					*VL	S
1929	F	0.000000E					*VV	S
1930	F	567.500000E					*TL	S
1931	F	567.500000E					*TV	S
1932	F	14.7800E+6E					*P	S
1933	F	0.000000E					*PA	S
1934	*-----							
1935	TEE		43	43	VESSEL HOT LEG			
1936		1	4	6	0.000000	1	*CN	02
1937		0	1	48	9	0	*CN	03
1938		0	0	0	0	0	*CN	05
1939		1.4209E-01	4.9029E-02	0.000000	0.000000	305.370000	*CN	06
1940		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	07
1941		0.000000	0.000000	1.0000E+20	1.000000		*CN	08
1942		0	1	47	0		*CN	09
1943		0	0	0	0	0	*CN	11
1944		5.0000E-02	5.0000E-02	0.000000	0.000000	305.370000	*CN	12
1945		305.370000	0.000000	0.000000	1.0000E+20	1.000000	*CN	13
1946		0.000000	0.000000	1.0000E+20	1.000000		*CN	14
1947	F	1.0000E-01E					*DX	P
1948	F	6.5218E-03E					*VOL	P
1949	F	6.3425E-02E					*FA	P
1950		0.000000	0.000100E				*FRIC	P

1951	F	0.000000E				*GRAV	P
1952	F	2.8418E-01E				*HD	P
1953	F	0E				*ICFLG	P
1954	F	2E				*NFF	P
1955	F	0.000000E				*ALP	P
1956	F	0.000000E				*VL	P
1957	F	0.000000E				*VV	P
1958	F	567.500000E				*TL	P
1959	F	567.500000E				*TV	P
1960	F	14.7800E+6E				*P	P
1961	F	0.000000E				*PA	P
1962	F	0.000000E				*QPPP	P
1963	F	6E				*MATID	P
1964	F	567.500000E				*TW	P
1965	F	1.0000E-01E				*DX	S
1966	F	7.8540E-04E				*VOL	S
1967	F	7.8540E-03E				*FA	S
1968	F	0.000000E				*FRIC	S
1969	F	0.000000E				*GRAV	S
1970		1.0000E-01	2.5150E-04E			*HD	S
1971	F	0E				*ICFLG	S
1972	F	2E				*NFF	S
1973	F	0.000000E				*ALP	S
1974	F	0.000000E				*VL	S
1975	F	0.000000E				*VV	S
1976	F	552.800000E				*TL	S
1977		552.800000E				*TV	S
1978	F	14.7800E+6E				*P	S
1979	F	0.000000E				*PA	S
1980	F	0.000000E				*QPPP	S
1981	F	6E				*MATID	S
1982	F	552.800000E				*TW	S
1983							
1984		*****TIME STEP DATA*****					
1985		1.00000E-3	1.000000	200.000000	10.000000	0	
1986		20.000000	1.000000	20.000000	10.000000		
1987		-1.000000					
1988		END					

B. Restart Input Deck for a Transient Calculation for LOFT L6-1

CARD	1	2	3	4	5	6	7	8
1	FREE	1	0	1	0			
2								
3	LOFT TEST L6-1, PF1/MD1 RESTART DECK							
4								
5	*****							
6	SINOPTS ICFLOW=2 5							
7	*****							
8	*****							
9	*****							
10	0.000000	-1	0	1	39	48	1	*MCC 01
11	1.00000E-3	0	1.00000E-5	1.00000E-4	1.00000E-3			*MCC 02
12	10	10	0	25				*MCC 04
13	*NTSV* 24	*NTCB* 29	*NTCF* 138	*NTRP* 21	*NTCP* 2			*MCC 05
14	1	2	3	4	5			*IORDER
15	6	7	8	9	10			*IORDER
16	11	12	13	14	15			*IORDER
17	17S	23	24	25S				*IORDER
18	29	30S						*IORDER
19	31	33	34	35S				*IORDER
20	36	37	40S					*IORDER
21	41	43S						*IORDER
22	62	63S						*IORDER
23	73	74	75S					*IORDER
24	77	78S						*IORDER
25	83S							*IORDER
26	86S							*IORDER
27	95S							*IORDER
28	96E							*IORDER
29	1	18S						*ISV
30	-1	-15S						*ICB
31	1	-24S						*ITP
32	19	24S						*ISV
33	-16	-70S						*ICB
34	1	0E						*ITP
35	*****							
36	*****							
37	*****							
38	0							
39	*****							
40	*****							
41	*****							
42	*****							
43	*****							
44	*****							
45	*****							
46	*****							

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```
47 *****COMPONENT DATA*****
48 END
49
50 *****TIME STEP DATA*****
51      1.00000E-3      1.000000      250.00000      10.000000      0
52      10.000000      0.500000      10.000000      10.000000
53      1.00000E-3      1.000000      700.00000      10.000000      0
54      25.000000      1.000000      50.000000      10.000000
55      -1.000000
56      END
```

C. LOFT Three-Dimensional VESSEL Input

This input corresponds to the vessel components shown in Fig. E-5.

CARD	1	2	3	4	5	6	7	8
1	*-----							
2	VESSEL	\	50	50	VESSEL			
3	*							
4	*BASED ON /PD2IA/LOFT/L2-3/RUN1/L2-3INO WITH FOLLOWING MODIFICATIONS:							
5	*							
6	* OCT/NOV 1982, PTG							
7	* - INCORPORATE DISTRIBUTED HEAT SLABS							
8	* - CHANGE INITIAL HSTN'S FROM 593 K TO 570 K TO HELP INHIBIT							
9	* FILM BOILING AT START OF STEADY STATE RUN							
10	* - MINOR CHANGE TO LEVEL 3 DOWNCOMER FA-T AND Z (TO .375)							
11	*							
12	* OCT 1983, PTG							
13	* - REVISE AXIAL POWER SHAPE PER PC & TK							
14	*							
15		12	4	4	4			*CARD 2
16		12	2	3	8		3	*CARD 3
17		3				*ICONC=0*		*CARD 4
18		0	0	0	*NVENT=0*			*CARD 5
19	*IRPWTY*	7	*NDGX*	0	*NDHX*	0	*NRTS*	*CARD 6
20	*IRPWTR*	100	*IRPWSV*	1	*NRPWTB*	-19	*NRPWSV*	*CARD 7
21	*IZPWTR*	0	*IZPWSV*	1	*NZIPWTB*	1	*NZIPWSV*	*CARD 8
22	*IRFTR*	101	*NMWRX*	1	*NFCI*	1	*NFCIL*	*CARD 9
23	*NRODS*	16	*NODES*	10	*NODHS*	4	*INHSMX*	*CARD 10
24	*REACT*	0.	*TNEUT*	0.	*RPWOFF*	-1.E20	*RRPWMX*	*CARD 11
25	*RPOWRI*	36.E6	*ZPWIN*	0.	*ZPWOFF*	0.	*RZPWMX*	
	*CARD 12							
26	*SHELV*	0.	*PLDR*	0.	*PDRAT*	1.336	*FUCRAC*	*CARD 13
27	*DTXHT(1)*4.0	*DTXHT(2)*50.	*DZNHT*	1.0E-3				*CARD 14
28	**SKIPPED**							*CARD 15
29	**SKIPPED**							*CARD 16
30	**SKIPPED**							*CARD 17
31		.632	.732	1.379	1.684		1.912	*Z
32		2.141	2.598	3.055	3.500		4.846	*Z
33		5.130	5.900E					*Z
34		0.105	0.231	0.329	0.470E			*RADIUS
35	1.570796327	3.141592654	4.712388981	6.283185308E				*THETA
36	11	10	3	1				*SOURCE
37	11	15	3	9				*SOURCE
38	11	12	3	31				*SOURCE
39	11	13	3	41				*SOURCE
40	0.955	0.960	0.965	0.975		0.990		*RDPWR
41	1.016	1.060R 3	0.000E					*RDPWR
42	R 4	1.4312R 4	1.1191R 4	0.7295E				*CPOWR
43	1	4	5	9E				*IDROD
44	R 2	1.0640R 1	1.1510R 1	0.5922E				*RPKF
45	*(DUMMY)* 1.0S							*ZPWTB
46		0.592	1.390	1.576	1.481		0.742	*ZPWTB
47		0.030E						*ZPWTB
48	R 4	40.50R 4	152.7R 4	131.8E				*RDX
49		0.0	7.7449E-4	1.5489E-3	2.3235E-3	3.0979E-3		*RADRD
50		3.8725E-3	4.66260E-3	4.74220E-3	5.0508E-3	5.3594E-3E		*RADRD

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51	R 6	1	3R 2	2E		*MATRD
52		0.0	36.00E+6	0.1	2.512E+6S	*RPWTB
53		1.0	2.163E+6	2.0	2.081E+6S	*RPWTB
54		5.0	1.937E+6	10.0	1.794E+6S	*RPWTB
55		15.0	1.687E+6	20.0	1.615E+6S	*RPWTB
56		50.0	1.364E+6	75.0	1.256E+6S	*RPWTB
57		100.0	1.184E+6	125.0	1.148E+6S	*RPWTB
58		150.0	1.112E+6	200.0	1.041E+6S	*RPWTB
59		300.0	9.330E+5	400.0	8.612E+5S	*RPWTB
60		500.0	7.895E+5	600.0	7.536E+5S	*RPWTB
61		1000.0	6.459E+5E			*RPWTB
62	F	0E				*NFAX
63	F	0.0E				*FPUO2
64	F	0.93E				*FTD
65		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
66		7.09910E-3	0.00000E+0S			
67		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
68		7.09910E-3	0.00000E+0S			
69		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
70		7.09910E-3	0.00000E+0S			
71		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
72		7.09910E-3	0.00000E+0S			
73		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
74		7.09910E-3	0.00000E+0S			
75		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
76		7.09910E-3	0.00000E+0S			
77		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
78		7.09910E-3	0.00000E+0S			
79		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
80		7.09910E-3	0.00000E+0S			
81		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
82		7.09910E-3	0.00000E+0S			
83		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
84		7.09910E-3	0.00000E+0S			
85		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
86		7.09910E-3	0.00000E+0S			
87		9.81010E-1	0.00000E+0	1.01030E-2	1.78300E-3	0.00000E+0
88		7.09910E-3	0.00000E+0E			
89	F	1.0E				*GMLES
90	F	3.13E5E				*PGAPT
91	F	0.0E				*PLVOL
92	F	0.0E				*PSLEN
93	F	0.0E				*CLENN
94	R 4	0.0087R 4	0.0333R 4	0.0431R 4	0.344E	*HSA LEVEL 1
95		0.0	0.09	0.1	0.105S	*HSX
96		0.0	0.09	0.1	0.105S	*HSX
97		0.0	0.09	0.1	0.105S	*HSX
98		0.0	0.09	0.1	0.105S	*HSX
99		0.0	0.09	0.1	0.105S	*HSX
100		0.0	0.09	0.1	0.105S	*HSX

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101		0.0	0.09	0.1	0.105S	*HSX
102		0.0	0.09	0.1	0.105S	*HSX
103		0.0	0.09	0.1	0.105S	*HSX
104		0.0	0.09	0.1	0.105S	*HSX
105		0.0	0.09	0.1	0.105S	*HSX
106		0.0	0.09	0.1	0.105S	*HSX
107		0.0	0.09	0.1	0.105S	*HSX
108		0.0	0.09	0.1	0.105S	*HSX
109		0.0	0.09	0.1	0.105S	*HSX
110		0.0	0.09	0.1	0.105S	*HSX
111	F	0.0E				*CFZL-T
112	F	0.0E				*CFZL-Z
113	F	0.0E				*CFZL-R
114	F	0.0E				*CFZV-T
115	F	0.0E				*CFZV-Z
116	F	0.0E				*CFZV-R
117	F	1.0E				*VOL
118	F	1.0E				*FA-T
119	F	1.0E				*FA-Z
120	F	1.0E				*FA-R
121	F	0.1E				*HD-T
122	F	0.1E				*HD-Z
123	F	0.1E				*HD-R
124	F	5.70000E+2E				*HSTN
125	F	6E				*MATHS
126	F	0.0E				*ALPN
127	F	0.0E				*VVN-T
128	F	0.0E				*VVN-Z
129	F	0.0E				*VVN-R
130	F	0.0E				*VLN-T
131	F	0.0E				*VLN-Z
132	F	0.0E				*VLN-R
133	F	6.15000E+2E				*TVN
134	F	5.93000E+2E				*TLN
135	F	1.50600E+7E				*PN
136	F	0.0E				*PAN
137	R12	0.0R 4	0.0956E			*HSA LEVEL 2
138		0.0	0.09	0.1	0.105S	*HSX
139		0.0	0.09	0.1	0.105S	*HSX
140		0.0	0.09	0.1	0.105S	*HSX
141		0.0	0.09	0.1	0.105S	*HSX
142		0.0	0.09	0.1	0.105S	*HSX
143		0.0	0.09	0.1	0.105S	*HSX
144		0.0	0.09	0.1	0.105S	*HSX
145		0.0	0.09	0.1	0.105S	*HSX
146		0.0	0.09	0.1	0.105S	*HSX
147		0.0	0.09	0.1	0.105S	*HSX
148		0.0	0.09	0.1	0.105S	*HSX
149		0.0	0.09	0.1	0.105S	*HSX
150		0.0	0.09	0.1	0.105S	*HSX

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151		0.0	0.09	0.1	0.105S	*HSX
152		0.0	0.09	0.1	0.105S	*HSX
153		0.0	0.09	0.1	0.105E	*HSX
154	F	.0E				*CFZL-T
155	F	0.0E				*CFZL-Z
156	F	0.0E				*CFZL-R
157	F	0.0E				*CFZV-T
158	F	0.0E				*CFZV-Z
159	F	0.0E				*CFZV-R
160	F	1.0E				*VOL
161	F	1.0E				*FA-T
162	R12	.409R 4	.401E			*FA-Z
163	F	1.0E				*FA-R
164	F	.1E				*HD-T
165	F	.1E				*HD-Z
166	F	.1E				*HD-R
167	F	5.70000E+2E				*HSTN
168	F	6E				*MATHS
169	F	0.0E				*ALPN
170	F	0.0E				*VVN-T
171	F	0.0E				*VVN-Z
172	F	0.0E				*VVN-R
173	F	0.0E				*VLN-T
174	F	0.0E				*VLN-Z
175	F	0.0E				*VLN-R
176	F	6.15000E+2E				*TVN
177	F	5.93000E+2E				*TLN
178	F	1.50600E+7E				*PN
179	F	0.0E				*PAN
180	R 4	0.1526R 4	0.5868R 4	0.7606R 4	0.9407E	*HSA LEVEL 3
181		0.0	0.034	0.044	0.049S	*HSX
182		0.0	0.034	0.044	0.049S	*HSX
183		0.0	0.034	0.044	0.049S	*HSX
184		0.0	0.034	0.044	0.049S	*HSX
185		0.0	0.034	0.044	0.049S	*HSX
186		0.0	0.034	0.044	0.049S	*HSX
187		0.0	0.034	0.044	0.049S	*HSX
188		0.0	0.034	0.044	0.049S	*HSX
189		0.0	0.034	0.044	0.049S	*HSX
190		0.0	0.034	0.044	0.049S	*HSX
191		0.0	0.034	0.044	0.049S	*HSX
192		0.0	0.034	0.044	0.049S	*HSX
193		0.0	0.09	0.1	0.105S	*HSX
194		0.0	0.09	0.1	0.105S	*HSX
195		0.0	0.09	0.1	0.105S	*HSX
196		0.0	0.09	0.1	0.105E	*HSX
197	F	0.0E				*CFZL-T
198	F	0.0E				*CFZL-Z
199	F	0.0E				*CFZL-R
200	F	0.0E				*CFZV-T

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201	F	0.0E					*CFZV-Z
202	F	0.0E					*CFZV-R
203	R12	.932R 4	0.375E				*VOL
204	R12	.9R 4	.375E				*FA-T
205	R12	0.481R 4	.375E				*FA-Z
206	F	.9E					*FA-R
07	R12	1.22E-2R 4	0.100E				*HD-T
208	R12	1.22E-2R 4	0.100E				*HD-Z
209	R12	1.22E-2R 4	0.100E				*HD-R
210	F	5.70000E+2E					*HSTN
211	F	6E					*MATHS
212	F	0.0E					*ALPN
213	F	0.0E					*VVN-T
214	F	0.0E					*VVN-Z
215	F	0.0E					*VVN-R
216	F	0.0E					*VLN-T
217	F	0.0E					*VLN-Z
218	F	0.0E					*VLN-R
219	F	6.15000E+2E					*TVN
220	F	5.93000E+2E					*TLN
221	F	1.50600E+7E					*PN
222	F	0.0E					*PAN
223	R 8	0.0R 4	0.1590R 4	0.4435E			*HSA LEVEL 4
224		0.0	0.034	0.044	0.049S		*HSX
225		0.0	0.034	0.044	0.049S		*HSX
226		0.0	0.034	0.044	0.049S		*HSX
227		0.0	0.034	0.044	0.049S		*HSX
228		0.0	0.034	0.044	0.049S		*HSX
229		0.0	0.034	0.044	0.049S		*HSX
230		0.0	0.034	0.044	0.049S		*HSX
231		0.0	0.034	0.044	0.049S		*HSX
232		0.0	0.034	0.044	0.049S		*HSX
233		0.0	0.034	0.044	0.049S		*HSX
234		0.0	0.034	0.044	0.049S		*HSX
235		0.0	0.034	0.044	0.049S		*HSX
236		0.0	0.09	0.1	0.105S		*HSX
237		0.0	0.09	0.1	0.105S		*HSX
238		0.0	0.09	0.1	0.105S		*HSX
239		0.0	0.09	0.1	0.105E		*HSX
240	F	0.0E					*CFZL-T
241	F	0.0E					*CFZL-Z
242	F	0.0E					*CFZL-R
243	F	0.0E					*CFZV-T
244	F	0.0E					*CFZV-Z
245	F	.0E					*CFZV-R
246	R12	.518R 4	.375E				*VOL
247	R12	0.251R 4	.362E				*FA-T
248	R12	0.481R 4	.401E				*FA-Z
249	F	.251E					*FA-R
250	R12	1.22E-2R 4	0.100E				*HD-T

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251	R12	1.22E-2R 4	0.100E				*HD-Z
252	R12	1.22E-2R 4	0.100E				*HD-R
253	F	5.70000E+2E					*HSTN
254	F	6E					*MATHS
255	F	0.0E					*ALPN
256	F	0.0E					*VVN-T
257	F	0.0E					*VVN-Z
258	F	0.0E					*VVN-R
259	F	0.0E					*VLN-T
260	F	0.0E					*VLN-Z //
261	F	0.0E					*VLN-R
262	F	6.15000E+2E					*TVN
263	F	5.93000E+2E					*TLN
264	F	1.50600E+7E					*PN
265	F	0.0E					*PAN
266	R 8	0.0R 4	0.1189R 4	0.3315E			*HSA LEVEL 5
267		0.0	0.034	0.044	0.049S		*HSX
268		0.0	0.034	0.044	0.049S		*HSX
269		0.0	0.034	0.044	0.049S		*HSX
270		0.0	0.034	0.044	0.049S		*HSX
271		0.0	0.034	0.044	0.049S		*HSX
272		0.0	0.034	0.044	0.049S		*HSX
273		0.0	0.034	0.044	0.049S		*HSX
274		0.0	0.034	0.044	0.049S		*HSX
275		0.0	0.034	0.044	0.049S		*HSX
276		0.0	0.034	0.044	0.049S		*HSX
277		0.0	0.034	0.044	0.049S		*HSX
278		0.0	0.034	0.044	0.049S		*HSX
279		0.0	0.09	0.1	0.105S		*HSX
280		0.0	0.09	0.1	0.105S		*HSX
281		0.0	0.09	0.1	0.105S		*HSX
282		0.0	0.09	0.1	0.105E		*HSX
283	F	0.0E					*CFZL-T
284	F	0.0E					*CFZL-Z
285	F	0.0E					*CFZL-R
286	F	0.0E					*CFZV-T
287	F	0.0E					*CFZV-Z
288	F	0.0E					*CFZV-R
289	R12	.518R 4	.375E				*VOL
290	R12	0.251R 4	.362E				*FA-T
291	R12	0.481R 4	.401E				*FA-Z
292	F	.251E					*FA-R
293	R12	1.22E-2R 4	0.100E				*HD-T
294	R12	1.22E-2R 4	0.100E				*HD-Z
295	R12	1.22E-2R 4	0.100E				*HD-R
296	F	5.70000E+2E					*HSTN
297	F	6E					*MATHS
298	F	0.0E					*ALPN
299	F	0.0E					*VVN-T
300	F	0.0E					*VVN-Z

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301	F	0.0E					*VVN-R
302	F	0.0E					*VLN-T
303	F	0.0E					*VLN-Z
304	F	0.0E					*VLN-R
305	F	6.15000E+2E					*TVN
306	F	5.93000E+2E					*TLN
307	F	1.50600E+7E					*PN
308	F	0.0E					*PAN
309	R 8	0.0R 4	0.1194R 4	0.3330E			*HSA LEVEL 6
310		0.0	0.034	0.044	0.049S		*HSX
311		0.0	0.034	0.044	0.049S		*HSX
312		0.0	0.034	0.044	0.049S		*HSX
313		0.0	0.034	0.044	0.049S		*HSX
314		0.0	0.034	0.044	0.049S		*HSX
315		0.0	0.034	0.044	0.049S		*HSX
316		0.0	0.034	0.044	0.049S		*HSX
317		0.0	0.034	0.044	0.049S		*HSX
318		0.0	0.034	0.044	0.049S		*HSX
319		0.0	0.034	0.044	0.049S		*HSX
320		0.0	0.034	0.044	0.049S		*HSX
321		0.0	0.034	0.044	0.049S		*HSX
322		0.0	0.09	0.1	0.105S		*HSX
323		0.0	0.09	0.1	0.105S		*HSX
324		0.0	0.09	0.1	0.105S		*HSX
325		0.0	0.09	0.1	0.105E		*HSX
326	F	0.0E					*CFZL-T
327	F	0.0E					*CFZL-Z
328	F	0.0E					*CFZL-R
329	F	0.0E					*CFZV-T
330	F	0.0E					*CFZV-Z
331	F	0.0E					*CFZV-R
332	R12	.518R 4	.375E				*VOL
333	R12	0.251R 4	.362E				*FA-T
334	R12	0.481R 4	.401E				*FA-Z
335	F	.251E					*FA-R
336	R12	1.22E-2R 4	0.100E				*HD-T
337	R12	1.22E-2R 4	0.100E				*HD-Z
338	R12	1.22E-2R 4	0.100E				*HD-R
339	F	5.70000E+2E					*HSTN
340	F	6E					*MATHS
341	F	0.0E					*ALPN
342	F	0.0E					*VVN-T
343	F	0.0E					*VVN-Z
344	F	0.0E					*VVN-R
345	F	0.0E					*VLN-T
346	F	0.0E					*VLN-Z
347	F	0.0E					*VLN-R
348	F	6.15000E+2E					*TVN
349	F	5.93000E+2E					*TLN
350	F	1.50600E+7E					*PN

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351	F	0.0E					*PAN
352	R 8	0.0R 4	0.2383R 4	0.6645E			*HSA LEVEL 7
353		0.0	0.034	0.044	0.049S		*HSX
354		0.0	0.034	0.044	0.049S		*HSX
355		0.0	0.034	0.044	0.049S		*HSX
356		0.0	0.034	0.044	0.049S		*HSX
357		0.0	0.034	0.044	0.049S		*HSX
358		0.0	0.034	0.044	0.049S		*HSX
359		0.0	0.034	0.044	0.049S		*HSX
360		0.0	0.034	0.044	0.049S		*HSX
361		0.0	0.034	0.044	0.049S		*HSX
362		0.0	0.034	0.044	0.049S		*HSX
363		0.0	0.034	0.044	0.049S		*HSX
364		0.0	0.034	0.044	0.049S		*HSX
365		0.0	0.09	0.1	0.105S		*HSX
366		0.0	0.09	0.1	0.105S		*HSX
367		0.0	0.09	0.1	0.105S		*HSX
368		0.0	0.09	0.1	0.105E		*HSX
369	F	0.0E					*CFZL-T
370	F	0.0E					*CFZL-Z
371	F	0.0E					*CFZL-R
372	F	0.0E					*CFZV-T
373	F	0.0E					*CFZV-Z
374	F	0.0E					*CFZV-R
375	R12	.518R 4	.375E				*VOL
376	R12	0.251R 4	.362E				*FA-T
377	R12	0.481R 4	.401E				*FA-Z
378	F	.251E					*FA-R
379	R12	1.22E-2R 4	0.100E				*HD-T
380	R12	1.22E-2R 4	0.100E				*HD-Z
381	R12	1.22E-2R 4	0.100E				*HD-R
382	F	5.70000E+2E					*HSTN
383	F	6E					*MATHS
384	F	0.0E					*ALPN
385	F	0.0E					*VVN-T
386	F	0.0E					*VVN-Z
387	F	0.0E					*VVN-R
388	F	0.0E					*VLN-T
389	F	0.0E					*VLN-Z
390	F	0.0E					*VLN-R
391	F	6.15000E+2E					*TVN
392	F	5.93000E+2E					*TLN
393	F	1.50600E+7E					*PN
394	F	0.0E					*PAN
395	R 8	0.0R 4	0.2383R 4	0.6645E			*HSA LEVEL 8
396		0.0	0.034	0.044	0.049S		*HSX
397		0.0	0.034	0.044	0.049S		*HSX
398		0.0	0.034	0.044	0.049S		*HSX
399		0.0	0.034	0.044	0.049S		*HSX
400		0.0	0.034	0.044	0.049S		*HSX

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401	0.0	0.034	0.044	0.049S	*HSX
402	0.0	0.034	0.044	0.049S	*HSX
403	0.0	0.034	0.044	0.049S	*HSX
404	0.0	0.034	0.044	0.049S	*HSX
405	0.0	0.034	0.044	0.049S	*HSX
406	0.0	0.034	0.044	0.049S	*HSX
407	0.0	0.034	0.044	0.049S	*HSX
408	0.0	0.09	0.1	0.105S	*HSX
409	0.0	0.09	0.1	0.105S	*HSX
410	0.0	0.09	0.1	0.105S	*HSX
411	0.0	0.09	0.1	0.105E	*HSX
412 F	0.0E				*CFZL-T
413 F	0.0E				*CFZL-Z
414 F	0.0E				*CFZL-R
415 F	0.0E				*CFZV-T
416 F	0.0E				*CFZV-Z
417 F	.0E				*CFZV-R
418 R12	.518R 4	.375E			*VOL
419 R12	0.251R 4	.362E			*FA-T
420 R12	0.481R 4	.401E			*FA-Z
421 F	.251E				*FA-R
422 R12	1.22E-2R 4	0.100E			*HD-T
423 R12	1.22E-2R 4	0.100E			*HD-Z
424 R12	1.22E-2R 4	0.100E			*HD-R
425 F	5.70000E+2E				*HSTN
426 F	6E				*MATHS
427 F	0.0E				*ALPN
428 F	0.0E				*VVN-T
429 F	0.0E				*VVN-Z
430 F	0.0E				*VVN-R
431 F	0.0E				*VLN-T
432 F	0.0E				*VLN-Z
433 F	0.0E				*VLN-R
434 F	6.15000E+2E				*TVN
435 F	5.93000E+2E				*TLN
436 F	1.50600E+7E				*PN
437 F	0.0E				*PAN
438 R 4	0.7208R 4	2.7708R 4	.232R 4	1.2243E	*HSA LEVEL 9
439	0.0	.00073	.00147	.0022S	*HSX
440	0.0	.00073	.00147	.0022S	*HSX
441	0.0	.00073	.00147	.0022S	*HSX
442	0.0	.00073	.00147	.0022S	*HSX
443	0.0	.00073	.00147	.0022S	*HSX
444	0.0	.00073	.00147	.0022S	*HSX
445	0.0	.00073	.00147	.0022S	*HSX
446	0.0	.00073	.00147	.0022S	*HSX
447	0.0	.034	.044	.049S	*HSX
448	0.0	.034	.044	.049S	*HSX
449	0.0	.034	.044	.049S	*HSX
450	0.0	.034	.044	.049S	*HSX

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451		0.0	0.09	0.1	0.105S	*HSX
452		0.0	0.09	0.1	0.105S	*HSX
453		0.0	0.09	0.1	0.105S	*HSX
454		0.0	0.09	0.1	0.105E	*HSX
455	F	0.0E				*CFZL-T
456	R 4	0.0R 4	1.2R 4	0.5R 4	0.0E	*CFZL-Z
457	F	0.0E				*CFZL-R
458	F	0.0E				*CFZV-T
459	R 4	0.0R 4	1.2R 4	0.5R 4	0.0E	*CFZV-Z
460	F	0.0E				*CFZV-R
461	R12	0.951R 4	.375E			*VOL
462	R12	0.366R 4	.362E			*FA-T
463	R 4	0.85R 8	0.366R 4	0.4010E		*FA-Z
464	F	0.3660E				*FA-R
465	R12	1.22E-2R 4	0.100E			*HD-T
466	R12	1.22E-2R 4	0.100E			*HD-Z
467	R12	1.22E-2R 4	0.100E			*HD-R
468	F	5.70000E+2E				*HSTN
469	F	6E				*MATHS
470	F	0.0E				*ALPN
471	F	0.0E				*VVN-T
472	F	0.0E				*VVN-Z
473	F	0.0E				*VVN-R
474	F	0.0E				*VLN-T
475	F	0.0E				*VLN-Z
476	F	0.0E				*VLN-R
477	F	6.15000E+2E				*TVN
478	F	5.93000E+2E				*TLN
479	F	1.50600E+7E				*PN
480	F	0.0E				*PAN
481	R 4	0.6641R 4	2.5528R 4	.702R 4	1.2228E	*HSA LEVEL 10
482		0.0	.0005	.001	.0015S	*HSX
483		0.0	.0005	.001	.0015S	*HSX
484		0.0	.0005	.001	.0015S	*HSX
485		0.0	.0005	.001	.0015S	*HSX
486		0.0	.0005	.001	.0015S	*HSX
487		0.0	.0005	.001	.0015S	*HSX
488		0.0	.0005	.001	.0015S	*HSX
489		0.0	.0005	.001	.0015S	*HSX
490		0.0	.034	.044	.049S	*HSX
491		0.0	.034	.044	.049S	*HSX
492		0.0	.034	.044	.049S	*HSX
493		0.0	.034	.044	.049S	*HSX
494		0.0	0.09	0.1	0.105S	*HSX
495		0.0	0.09	0.1	0.105S	*HSX
496		0.0	0.09	0.1	0.105S	*HSX
497		0.0	0.09	0.1	0.105E	*HSX
498	F	0.0E				*CFZL-T
499	F	0.0E				*CFZL-Z
500	F	0.0E				*CFZL-R

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551	R12	1.22E-2R 4	0.100E			*HD-T
552	R12	1.22E-2R 4	0.100E			*HD-Z
553	R12	1.22E-2R 4	0.100E			*HD-R
554	F	5.70000E+2E				*HSTN
555	F	6E				*MATHS
556	F	0.0E				*ALPN
557	F	0.0E				*VVN-T
558	F	0.0E				*VVN-Z
559	F	0.0E				*VVN-R
560	F	0.0E				*VLN-T
561	F	0.0E				*VLN-Z
562	F	0.0E				*VLN-R
563	F	6.15000E+2E				*TVN
564	F	5.93000E+2E				*TLN
565	F	1.50600E+7E				*PN
566	F	0.0E				*PAN
567	R 4	0.5227R 4	2.0093R 4	.402R 4	0.0E	*HSA LEVEL 12
568		0.0	.0005	.001	.0015S	*HSX
569		0.0	.0005	.001	.0015S	*HSX
570		0.0	.0005	.001	.0015S	*HSX
571		0.0	.0005	.001	.0015S	*HSX
572		0.0	.0005	.001	.0015S	*HSX
573		0.0	.0005	.001	.0015S	*HSX
574		0.0	.0005	.001	.0015S	*HSX
575		0.0	.0005	.001	.0015S	*HSX
576		0.0	.034	.044	.049S	*HSX
577		0.0	.034	.044	.049S	*HSX
578		0.0	.034	.044	.049S	*HSX
579		0.0	.034	.044	.049S	*HSX
580		0.0	0.09	0.1	0.105S	*HSX
581		0.0	0.09	0.1	0.105S	*HSX
582		0.0	0.09	0.1	0.105S	*HSX
583		0.0	0.09	0.1	0.105E	*HSX
584	F	0.0E				*CFZL-T
585	F	0.0E				*CFZL-Z
586	F	0.0E				*CFZL-R
587	F	0.0E				*CFZV-T
588	F	0.0E				*CFZV-Z
589	F	0.0E				*CFZV-R
590	R12	0.951R 4	.000E			*VOL
591	R12	0.366R 4	.362E			*FA-T
592	R12	0.365R 4	.401E			*FA-Z
593	F	0.3660E				*FA-R
594	R12	1.22E-2R 4	0.100E			*HD-T
595	R12	1.22E-2R 4	0.100E			*HD-Z
596	R12	1.22E-2R 4	0.100E			*HD-R
597	F	5.70000E+2E				*HSTN
598	F	6E				*MATHS
599	F	0.0E				*ALPN
600	F	0.0E				*VVN-T

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601	F	0.0E	*VVN-Z
602	F	0.0E	*VVN-R
603	F	0.0E	*VLN-T
604	F	0.0E	*VLN-Z
605	F	0.0E	*VLN-R
606	F	6.15000E+2E	*TVN
607	F	5.93000E+2E	*TLN
608	F	1.50600E+7E	*PN
609	F	0.0E	*PAN
610	F	0.0E	*BURN 1
611	F	5.59000E+2E	*RDTN 1
612	F	0.0E	*BURN 2
613	F	5.59000E+2E	*RDTN 2
614	F	0.0E	*BURN 3
615	F	5.59000E+2E	*RDTN 3
616	F	0.0E	*BURN 4
617	F	5.59000E+2E	*RDTN 4
618	F	0.0E	*BURN 5
619	F	5.59000E+2E	*RDTN 5
620	F	0.0E	*BURN 6
621	F	5.59000E+2E	*RDTN 6
622	F	0.0E	*BURN 7
623	F	5.59000E+2E	*RDTN 7
624	F	0.0E	*BURN 8
625	F	5.59000E+2E	*RDTN 8
626	F	0.0E	*BURN 9
627	F	5.59000E+2E	*RDTN 9
628	F	0.0E	*BURN 10
629	F	5.59000E+2E	*RDTN 10
630	F	0.0E	*BURN 11
631	F	5.59000E+2E	*RDTN 11
632	F	0.0E	*BURN 12
633	F	5.59000E+2E	*RDTN 12
634	F	0.0E	*BURN 13
635	F	5.59000E+2E	*RDTN 13
636	F	0.0E	*BURN 14
637	F	5.59000E+2E	*RDTN 14
638	F	0.0E	*BURN 15
639	F	5.59000E+2E	*RDTN 15
640	F	0.0E	*BURN 16
641	F	5.59000E+2E	*RDTN 16
642	*		

APPENDIX F

TRAC ERROR MESSAGES

Subroutine ERROR handles errors diagnosed by TRAC. The subroutine uses the level number associated with each error listed below to determine its course of action.

<u>Level</u>	<u>Actions</u>
1, 3	Fatal error, stop problem.
2	Nonfatal error, continue problem.
4	Fatal error, add dump to the TRCDMP file, then stop problem.
-4	Problem stopped by user.

The error messages are written to the TRCOUT and TRCMSG files and to the terminal. The message begins with the name of the subroutine, bounded by asterisks (*...*), which detected the error. Because of this format and because implementation of TRAC on various computers differs, we have used the subroutine name to alphabetize the following list of error messages. If an error message occurs that is not found in the following list, we suggest that you inspect the coding in the subroutine listed in the message for more detail.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
BFIN	1	DATA SET EOF ERROR	An illegal end-of-file was found when the data were read.
BFIN	1	DATA SET TYPE ERROR	An error occurred when the data were read in the binary format.
BFOUT	1	DATA SET TYPE ERROR	An error occurred when the data were written in a binary format.
BITS	1	ILLEGAL BIT SPECIFIED	An attempt was made to set bit beyond the word length.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
BREAKX	1	BK TABLE LOOKUP ERROR	An error exists in interpolating a break table.
CBSET	1	C-BLOCK ID NOT FOUND TO SET NFLG	The first input parameter ID number for the control block could not be found in the list on control blocks so that it could be flagged with this control block's new flag.
CBSET	1	C-BLOCK ID NOT FOUND TO SET OFLG	The first input parameter ID number for this control block could not be found in the list of control blocks so that it could be flagged with this control block's old flag.
CBSET	1	CNTL.BLK. ID NOT FOUND	One of the control-block input parameters has a negative ID number that could not be found in the list of control blocks.
CBSET	1	ERROR IN TABLE LOOKUP	An error was detected by subroutine LININT while it was linearly interpolating in the control-block FNGL table.
CBSET	1	SIG. VAR. ID NOT FOUND	One of the control-block input parameters has a positive ID number that could not be found in the list of signal variables.
CHBD	2	BOUNDARY ERROR DETECTED	Adjacent components have mismatched geometry.
CHF	1	TCHF FAILED TO CONVERGE	The calculation failed to converge on a unique critical heat-flux wall temperature.
CHKSR	2	TWO VESSEL SOURCES LOCATED IN ONE CELL	The VESSEL input specifies two sources in one fluid cell.
CHKSR	2	VESSEL SOURCE POSITION ERROR	The specified source position is impossible.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
CHOKE	2	CHARACTERISTIC SOLUTION DID NOT CONVERGE	The two-phase characteristic solution using a quick-solution search was bounded, but complete convergence could not be obtained within allowed iterations.
CHOKE	2	CONVERGENCE FAILED IN GREV	The system's routine GREV has trouble calculating all the eigen values of the two-phase characteristic solution.
CHOKE	2	LARGEST CHARACTERISTIC ROOT WAS COMPLEX	An informative message is printed under debug mode only.
CHOKE	2	NEGATIVE DFLDP CALCULATED, ASSUMED ZERO	The calculated derivative $\partial V_g / \partial \rho$ was negative because the round-off errors should always be > 0.0 . Therefore, the derivative was set to 0.0.
CHOKE	2	NEGATIVE DFVDP CALCULATED ASSUMED ZERO	The calculated derivative $\partial V_g / \partial \rho$ was negative because the round-off errors should be > 0.0 . Therefore, the derivative was set to 0.0.
CHOKE	2	ONLY APPROXIMATE SOLUTION OBTAINED	The normal two-phase choking solution maintains constant phasic slip. However, because of convergence problems, this condition could not be satisfied, but rather the relative velocity between the phases was approximately maintained.
CHOKE	2	QUICK SOLUTION SEARCH FAILED	An informative message is printed under debug mode only.
CIVSSL	1	CONNECTIONS COMPUTED AFTER VESSEL	The component calculational sequence must compute the connections before the vessel.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
CIVSSL	1	IORDER PROBLEM	The calculational sequence must compute the component connected to the vessel before it calculates the vessel.
CIVSSL	1	JUNCTION PROBLEM	A component adjacent to the VESSEL cannot be found.
CIVSSL	1	VESSEL CONNECTED TO A FILL	A VESSEL cannot be connected to a FILL.
CIVSSL	1	VESSEL CONNECTED TO BREAK	A VESSEL cannot be connected to a BREAK.
CONBLK	1	BAD CNTL-BLOCK OPERATION NUMBER	A control-block operation number does not lie between 1 and 61.
CONBLK	1	IMPROPER LLAG BLOCK CONSTANTS	The lead-lag transfer function control block 30 has a first constant that is negative or a second constant that is zero or negative.
CONBLK	1	IMPROPER SOTF BLOCK CONSTANTS	The second-order transfer function control block 51 has a first constant that is negative or a second constant that is zero or negative.
CONBLK	1	INVALID CNTL-BLOCK INPUT VALUES	A control block is defined with invalid input parameter values.
CONBLK	1	INVALID DEAD-FUNCTION CONSTANTS	The dead control block 11 has a second constant that is less than the first constant.
CONBLK	1	NONPOSITIVE LAG TIME	The first-order LAG transfer function control block 26 has a first constant that is zero or negative.
CONVRT	1	ARRAY DIMENSIONS EXCEEDED	The α subroutine, which extracts a vessel deck for modification and re-input, assumes that there are no more than 25 axial, radial, or theta zones.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
COREC1	1	REACTOR POWER INITIALIZED	The reactor core's total power is turned on to its input initial value.
COREC3	1	INSUFFICIENT SCM SPACE	Insufficient SCM is available for this CORE.
CTAIN1	1	CONTAINMENT MODULE NOT YET IMPLEMENTED	Containment component will be in a future TRAC version.
CTAIN2	1	CONTAINMENT MODULE NOT YET IMPLEMENTED	Containment component will be in a future TRAC version.
CTAIN3	1	CONTAINMENT MODULE NOT YET IMPLEMENTED	Containment component will be in a future TRAC version.
DELAY	1	ERROR IN DELAY TIME TABLE LOOKUP	An error was detected by subroutine LININT when it tried to linearly interpolate the time delay table on a control block 100.
DMPIT	3	DUMP FILE DEFINE ERROR	File TRCDMP could not be created.
DMPIT	3	TYPE NOT RECOGNIZED	An invalid component type was encountered.
ELGR	2	FORM LOSS VALUE TOO HIGH	The input value of a form loss was such that when the code converted it into an equivalent FRIC, the FRIC value exceeded 10^{20} . A FRIC value exceeding 10^{20} will invoke the steam separator model at the cell edge under consideration. Obviously, such was not the user's intention, otherwise the user would have input a form-loss value exceeding 10^{20} in the first place.
EOVLY	2	OVERLAY UNLOAD ERROR	An illegal overlay sequence exists.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
EVFXXX	1	NEED LOCAL DIM.GT.50	Local array FXXX0 is dimensioned 50; for components with more than 50 mesh cells, subroutine EVFXXX cannot evaluate a QPPP factor for each mesh cell.
EVFXXX	1	TABLE LOOKUP ERROR	Subroutine LININT encountered an error while trying to linearly interpolate the component-action table value for the situation when the controlling trip is OFF after being ON.
EVLTAB	1	CNTL. BLOCK NOT FOUND	The negative ID number that defines the independent variable of the component-action table was not specified in the control-block list.
EVLTAB	1	SIGNAL VAR. NOT FOUND	The positive ID number that defines the independent variable of the component-action table was not specified in the signal-variable list.
EVLTAB	1	TABLE LOOKUP ERROR	Subroutine LININT found an error when evaluating the component-action table.
FILLX	1	GENSTATE FILL TABLE LOOKUP ERROR	There are zero entries in the FILL table.
GETBIT	1	ILLEGAL BIT SPECIFIED	The specified bit position is either too small or too large.
GRAF	1	DATA TYPE ERROR	There is an invalid data type in the graphics catalog.
GRAF	1	SCM OVERFLOW	There is insufficient SCM for packing graphics data.
GRFPUT	2	ERROR IN GRAPHICS OUTPUT	Integer is too large to be packed into a 15-bit word.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
HOUT	1	OUTER ITERATION DID NOT CONVERGE	The outer-iteration procedure failed three consecutive times.
ICOMP	1	FATAL INPUT ERRORS	An error was encountered during component data initialization causing JFLAG .NE. 0 at the end of subroutine ICOMP.
ICOMP	1	FRICTION LOSS HIGHER THAN TURBINE OUTPUT OUTPUT	The friction torque coefficients specified for the turbine are so large that the friction loss exceeds the normal design power from all stages.
ICOMP	1	INCONSISTENT JUNCTION NUMBERS	Inconsistent specification of junction numbers was made.
ICOMP	1	JUNCTION COUNT ERROR	The number of junctions specified is inconsistent with the number found.
ICOMP	1	JUNCTION NUMBERS WRONG	The junctions are assigned incorrectly.
ICOMP	1	SCM OVERFLOW	Insufficient SCM is available to load problem.
ICOMP	1	TURBINE STAGES INCONSISTENT WITH INPUT	The user specified component numbers of the associated turbine stages under stage 1. This specification is not consistent with the other TURB components input.
ICOMP	1	UNRECOGNIZED COMPONENT	The component type was not recognized.
ICOMP	1	WRONG TURB COMPONENT NUMBER ON VALVE	The VALVE component for IVTY option of 5 or 6 requires a TURB component number. This number is inconsistent with the TURB components input.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
ICORE	1	BAD FUEL-ROD POWER SUM	The input parameters for the fuel-rod geometry, number, and power distribution are invalid. A nonpositive, unnormalized power from all fuel rods was evaluated.
IGRAF	1	COMPONENT TYPE NOT RECOGNIZED	An invalid component type was encountered.
IGRAF	1	GRAPHICS FILE ALLOCATION FAILURE	An I/O error occurred while allocated space was sought for graphics file.
IGRAF	1	NO LCM SPACE FOR GRAPH CATALOG	Insufficient LCM is available.
IGRAF	1	NO SCM SPACE FOR GRAPH CATALOGUE	Problem too large to run with current code. User must reduce nodes or alter code.
IGRAF	1	SCM OVERFLOW	Insufficient SCM is available.
INPUT	1	DUPLICATE COMPONENT NUMBERS	Two components with the same number were found in the TRACIN file.
INPUT	1	FATAL INPUT ERROR(S)	A fatal input error was found when an input or restart file was read.
INPUT	1	FILE TRACIN DOES NOT EXIST	The input deck does not exist.
INPUT	1	INOPTS NAMELIST DATA NOT FOUND	The NAMELIST option was specified; however, the NAMELIST data for group INOPTS are not in the TRACIN file.
INPUT	1	NO SPACE FOR BUFFERS	Insufficient LCM is available for I/O buffers.
INPUT	2	SCM OVERFLOW	Insufficient SCM is available for this problem. The user must reduce the number of nodes or redo the INPUT overlay.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
INPUT	2	SOLUBILITY PARAMETERS NOT REASONABLE	The solubility parameters entered for option ISOLCN do not define a reasonable linear relationship between solubility and temperature or may generate negative solubilities.
INPUT	1	TOO MANY CELLS FOR DIRECT INVERSION (LIMIT = 100)	The user requested direct inversion of a VESSEL matrix when the VESSEL has more than 100 cells. This limit may be bypassed on machines with larger memories.
INPUT	1	VERSION INFORMATION EXCEEDS LCM	The version information exceeds its allocated LCM space.
IOVLY	1	A-ARRAY OVERFLOW	The main SCM data array is too small. This message occurs only for the CDC 7600 version with a fixed A-dimension (~25000 words). Routine IOVLY directly issues diagnostic statistics. The global problem data are started at the high end of A, and the available space is smaller than the total dimension of A.
IOVLY	1	ERROR INITIALIZING SCM	Subroutine SETSCM found an error.
IOVLY	1	SCM SPACE TOO SMALL FOR OVERLAY	Insufficient SCM is available for this overlay.
ISTGEN	1	2 nd JNCTS. OF 1 CELL COMP. EXT.	Code cannot find two internal secondary junction numbers that have the same value.
ISTGEN	2	JUNCTION ERROR	Error in the specification of the secondary internal junction numbers of the steam generator.
IVLVE	1	INVALID VALVE LOCATION	The valve interface where the flow area is adjustable does not lie between two cells within the VALVE component.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
IVSSL	1	BAD FUEL-ROD POWER SUM	The input parameters for the fuel-rod geometry, number, and power distribution are invalid. A nonpositive, unnormalized power from all fuel rods was evaluated.
JFIND	1	JUNCTION PROBLEM	A junction number could not be located in the junction sequence array.
LOAD	2	ARRAY FILLED BUT OPERATION END NOT FOUND	When the array data were read, an E was not specified after the array was filled. The user also should check for an additional incorrect entry for this array.
LOAD	2	DATA OVERFLOWED ARRAY REPEAT COUNT RESET TO ONE	When the array data were read, a repeat operation overfilled the array.
LOAD	2	INPUT ERROR ENCOUNTERED ON CARD NO. XXXX, REST OF COMPONENT SKIPPED	The array-reading routine found an error flag on a card set by the free-format input-option preprocessor routine. Execution of TRAC stops after the entire input deck is processed.
LOAD	2	INPUT ERROR--NEW, UNEXPECTED COMPONENT ENCOUNTERED	When the array data for a component were loaded, data for an additional component or an "END" card was specified.
LOAD	2	INPUT ERROR--UNEXPECTED NAMELIST DATA ENCOUNTERED	When the array data were loaded, NAMELIST data were found.
LOAD	2	INTEGER INTERPOLATION NOT ALLOWED	When an integer array was read, an interpolation operation was specified.
LOAD	2	NOT ENOUGH DATA TO FILL ARRAY	Insufficient data were entered to fill an array.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
LOAD	2	OPERATION END ENCOUNTERED BUT INTERPOLATION INCOMPLETE	When the array data were read, an end flag (E) was specified before both end-points of an interval to be interpolated were read.
LOAD	2	REAL DATA ENCOUNTERED IN INTEGER ARRAY	Real data were found in an integer array.
LOAD	2	REPEAT COUNT LESS THAN ONE, COUNT RESET TO ONE	When the array data were read, a repeat count of less than one was found.
LOAD	2	REPEAT LEVEL CARD MISPLACED	When the array data were read, a repeat-level card was found.
LOAD	2	UNDEFINED OPERATION REPEAT COUNT SET TO ONE	When the array data were read, an undefined load operation was specified.
LOAD	2	UNEXPECTED END-OF-FILE REACHED	When the array data were read, an unexpected end-of-file was found.
LOAD	2	ZERO OR FEWER INTERPOLA- TIONS--OPERATION TREATED AS BLANK	When the array data were read, an interpolation count of less than one was specified.
LOCPMP	1	VARIABLE NAME NOT RECOGNIZED	A programming error occurred when the user tried to locate the position of a TURBINE variable in its common block.
LOCTEE	1	VARIABLE NAME NOT RECOGNIZED	A programming error occurred when the user tried to locate the position of a TURBINE variable in its common block.
LOCTRB	1	VARIABLE NAME NOT RECOGNIZED	A programming error occurred when the user tried to locate the position of a TURBINE variable in its common block.
LOCVLV	1	VARIABLE NAME NOT RECOGNIZED	A programming error occurred when the user tried to locate the position of a VALVE variable in its common block.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
LPCON	1	MISSING VESSEL JUNCTION	An invalid vessel junction number was found in the vessel junction data area.
LPCON	1	NO PUMP IN PRINCIPAL LOOP	No pump was found in the loop description.
LPCON	1	NO STGEN IN PRINCIPAL LOOP	No steam generator was found in the loop description.
MAIN	1	NO SPACE FOR VERSION INFORMATION	Insufficient LCM is available for version information.
MANAGE	1	LEVEL PROBLEM	The requested core level or rod number does not exist.
MANAGE	1	SCM MEMORY OVERFLOW	Insufficient SCM is available.
MODCMP	3	ERROR CHANGING COMPONENT	An error occurred when a component was modified. This will be preceded by a more specific error message (interactive mode only).
MODCMP	3	TYPE NOT RECOGNIZED	The component type specified is not available in TRAC.
MODIFY	-4	HALTED FOR MANUAL RESTART	A component has been modified using the interactive mode.
MSTRCT	2	INCORRECT TABULAR MAT. I.D.	A wall-material identifier could not be located.
MSTRCT	2	TEMPERATURE OUTSIDE TABLE RANGE	Wall temperature is outside range of the tabular material data.
NXTCMP	1	END-OF-FILE REACHED WHEN SEARCHING FOR NEXT COMPONENT	When the data for a new component were read, an end-of-file was found.
ORIENT	1	NO JUNCTION MATCH	A junction connected to a tee or steam generator in the JUN array was not found.
OUTLD	1	COMPONENT TYPE NOT RECOGNIZED	Invalid component type was encountered.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
OUT3D	1	COMPONENT TYPE NOT RECOGNIZED	Invalid component type was encountered.
OUTER	1	FATAL ERROR	A fatal error occurred.
POST	1	COMPONENT TYPE NOT RECOGNIZED	Invalid component type was encountered.
POST3D	1	COMPONENT TYPE NOT RECOGNIZED	Invalid component type was encountered.
POSTER	1	NO SCM SPACE FOR CYLHT	Insufficient SCM is available.
PRCINT	2	ABORTED BY CONTROLLER	The user aborted this run (interactive mode only). No cleanup is done.
PRCINT	2	INTERRUPTED--CONTINUED	The user continued the program after an interruption (interactive mode only).
PRCINT	-4	STOPPED BY REQUEST	The user stopped the run (interactive mode only). Run terminates normally.
PREINP	2-1	INPUT ERROR DETECTED IN TRACIN	The free-format input-option preprocessor routine found an input error. Possible causes include a missing positive character (for example, I.O.E. 07), the omission of the first (format-option switch) card, or a simple typographical error. An immediate fatal error occurs if the first card is incorrect. In all other cases, a flag is set that stops execution after the entire deck is processed.
PREP1D	1	COMPONENT TYPE NOT RECOGNIZED	Invalid component type was encountered.
PREP3D	1	COMPONENT TYPE NOT RECOGNIZED	Invalid component type was encountered.
PUMPD	1	CANNOT LOCATE HEAD CURVE	The PUMP regime is outside the data base.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
PUMPD	1	CANNOT LOCATE TORQUE CURVE	The PUMP regime is outside the data base.
PUMPSR	1	ERROR IN ROUTINE PUMPX	An error was encountered when a pump head or torque was evaluated.
PUMPSR	1	INSUFFICIENT SCM SPACE	Insufficient SCM is available for PUMP since calculations.
PUMPSR	1	PUMP SPEED NOT FOUND	The signal-variable or control-block ID number NPMPSD that defines the initial pump speed directly could not be found in the signal-variable or control-block list of ID numbers.
RIMACH	1	I OUT OF BOUNDS	The number of machine constants (required for the determination of eigenvalues) should be at least 1 but should not exceed 5. This number is out of bounds.
RACCUM	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change dimension VLT in GENVLT.
RBREAK	2	ERROR IN TABLE SPECIFICATIONS	Incompatible BREAK options were selected.
RBREAK	2	IBTY INCONSISTENT WITH ISOLUT	A solute-concentration table cannot be used at a BREAK unless the solute-tracker flag (ISOLUT) is set to one.
RBREAK	2	LCM OVERFLOW	Insufficient LCM is available for this BREAK.
RBREAK	2	PAIN MUST NOT BE GREATER THAN PIN	The air partial pressure at the BREAK may not exceed the total pressure at the BREAK.
RBREAK	2	SCM OVERFLOW	Insufficient SCM is available for this BREAK.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RCOMP	2	ICFLG MUST BE .LE.5	Only five sets of multipliers are allowed in the choked-flow model.
RCOMP	2	ICONC & ISOLUT ARE INCONSISTENT	Solute concentrations were entered before the ISOLUT option was selected.
RCOMP	2	INCONSISTENT VALUES FOR ICFLG	All nonzero values for ICFLG for each component must be the same.
RCOMP	2	NEGATIVE FRIC. GE. -1.0E+20 NOT ALLOWED	An additive friction-factor of less than -10^{20} can be used to select the liquid-separator model. In all other cases, the additive friction factor must be positive.
RCOMP	2	NFF MUST BE 0, 1, 2, -1, -2, OR -100	The only NFF options in TRAC are 0, 1, 2, -1, -2, or -100.
RCOMP	2	PA MUST NOT BE GREATER THAN P	The air partial pressure may not exceed the total pressure for a hydrodynamic cell.
RCORE	2	INCONSISTENT INIT & TABLE REACT-POWER	The reactivity-power-table's interpolated value for the independent-variable value of 0.0 differs from the initial reactivity or power value.
RCORE	2	INCONSISTENT Z LENGTHS	The input values for the height of each core level are not increasing monotonically.
RCORE	2	LCM OVERFLOW	Insufficient LCM is available for this CORE.
RCORE	2	NZMAX .LT. NCRZ+1 +SUM NFAX(I)	The number of rows of rod conduction nodes is less than the minimum specified for re-flood calculations.
RCORE	2	SCM OVERFLOW	Insufficient SCM is available for this CORE.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RCORE	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RCNTL	2	# OF SET PT. FAC. TABLES GT. 25 DIM.	The number of set-point factor tables is greater than the local dimension of array IFSP (25), which stores the set-point factor-table ID numbers.
RCNTL	2	# OF T.S.E. OR T.C.T. GT. 25 DIM.	The number of trip-signal expressions or trip-controlled trips is greater than the local dimension of array ISEN (25) or ITCN (25). These arrays are used to store the signal ID numbers that are compared to the signal ID numbers in the input.
RCNTL	2	BAD CONTROL-BLOCK TABLE STORAGE	The total number of control-block FNG1 table values exceeds the number of values specified by NTCF (Main-Control Card Number 5).
RCNTL	2	BAD SIG. EXP. OPERATOR	The arithmetic-operator ID number for a subexpression within the signal-expression definition has an invalid input value of less than one or greater than eight.
RCNTL	2	BAD TRIP ID DEFINITION	A trip ID has an absolute value that is 0 or greater than 9999.
RCNTL	2	INVALID TRIP SET STATUS DEFINED	The trip set-status variable ISET has an invalid input value.
RCNTL	2	SET POINT FACT. TAB. # PAIRS.GT.10	The set-point factor table has more than 10 data pairs.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RCNTL	2	SET PT.FAC.TABLE DIM. TOO SMALL	The number of set-point factor-table parameters is less than the storage allocated for such parameters by variable NTSF.
RCNTL	2	TRIP-CONTROL TRIP DIM. TOO SMALL	The number of trip-controlled trip-signal parameters is less than the storage allocated for such parameters by variable NTCT.
RCNTL	2	TRIPS DOING DUMPS DIM. TOO SMALL	The number of trip IDs that produce restart dumps is greater than the storage allocated for such parameters by variable NTDF.
RCNTL	2	TRIP SIGNAL EXP. DIM. TOO SMALL	The number of trip signal-expression parameters is greater than the storage allocated for such parameters by variable NTSE.
RCPVEC	2	BAD LOOP COUNT GIVEN FOR CONTROL PANEL VECTOR	An incorrect number of reactor coolant loops was specified. The number must be 1, 2, 3, or 4.
RCPVEC	2	BAD LOOP NUMBER ASSUMED	The interactive-edit input specifies a loop that does not exist.
RDCOMP	1	COMPONENT TYPE NOT RECOGNIZED	An invalid component type was specified.
RDDIM	2	ILLEGAL PUMP CURVE OPTION	An illegal PUMP option was specified on PUMP Card Number 9.
RDREST	1	COMPONENT DATA NOT FOUND	Data for a specific component were not found in the input or the restart file.
RDREST	1	DUMP TIME NOT FOUND ON RESTART FILE	The restart dump at the time specified in the input file is not in the restart file.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RDREST	1	FILE TRCRST DOES NOT EXIST	Component data were omitted from the input deck, and a restart dump file to initialize the missing components cannot be found.
RDREST	1	ISOLUT FROM TRCRST AND TRACIN DIFFER	The solute-tracking options in the input and the restart-file data differ. The ISOLUT parameter must be set either to ON or to OFF in both files.
RDREST	1	NO DUMPS ON FILE	Incomplete dumps are specified in the TRCRST file.
RDREST	1	RESTART FILE INCOMPATIBLE WITH THIS PROBLEM	The restart file cannot be used with this TRAC version.
RDREST	1	RESTART: FILE OPEN ERROR	An I/O error occurred when the restart file was opened.
RDREST	1	TYPE NOT RECOGNIZED IN RESTART	An invalid component type was specified.
REACCM	2	POINTER TABLE MISMATCH	The accumulator (ACCUM) pointer table does not match the restart-file data.
READI	1	INPUT ERROR--ENCOUNTERED UNEXPECTED LOAD DATA	A load operation was found when integer data in I14 format were read.
READI	1	INPUT ERROR--NEW COMPONENT OR END WAS ENCOUNTERED UNEXPECTEDLY	Data for a new component were found before all of the data for the current component were read.
READI	1	INPUT ERROR--REAL DATA ENCOUNTERED IN INTEGER FIELD	Real data were found when integer data in I14 format were read.
READI	2	INPUT ERROR--UNEXPECTED NAMELIST DATA ENCOUNTERED	When integer data in I14 format were read, NAMELIST data were found.
READI	2	REPEAT LEVEL CARD MISPLACED	A repeat-level card was found when integer data in I14 format were read.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
READI	1	UNEXPECTED END-OF-FILE REACHED	An end-of-file was found when integer data in I14 format were read.
READR	1	INPUT ERROR--NEW COMPONENT WAS ENCOUNTERED UNEXPECTEDLY	Data for a new component were found before all of the data for the current component were read.
READR	1	INPUT ERROR--UNEXPECTED LOAD DATA ENCOUNTERED	A load operation was found when reading nonarray real data in E14.6 format.
READR	2	INPUT ERROR--UNEXPECTED NAMELIST DATA ENCOUNTERED	When reading real data in E14.6 format, NAMELIST data were found.
READR	2	REPEAT LEVEL CARD MISPLACED	A REPEAT LEVEL card was found when reading real data in E14.6 format.
READR	1	UNEXPECTED END-OF-FILE REACHED	An end-of-file was found when reading real data in E14.6 format.
REBRK	1	ERROR IN TABLE SPECIFICATIONS	An error stopped the pro- cessing of input data.
REBRK	1	FATAL ERROR	An error stopped the pro- cessing of the input data.
REBRK	2	LCM OVERFLOW	Insufficient LCM is available for the BREAK data from the restart file.
REBRK	2	POINTER TABLE MISMATCH	The BREAK pointer table does not match the restart-file data.
REBRK	2	SCM OVERFLOW	Insufficient SCM is available for the BREAK data from the restart file.
RECNTL	1	CONTROL BLOCKS EXCEED DIMENSION	The amount of control-block data in the input and the re- start files exceeds its stor- age allocation on Main- Control Card 5.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RECNTL	1	CONTROL PARA. STORAGE TOO SMALL	The variable storage that was allocated by the input data for the signal variables, control blocks, and trips is too small to contain the remaining data from the restart file.
RECNTL	1	NUMBER TRIPS EXCEED DIMENSION	The number of trips with different ID numbers from the input and the restart files exceeds the input data-storage dimension.
RECNTL	1	SET-PT-FACTOR TABLES EXCEED DIM	The number of different set-point factor-table ID numbers in the input and the restart files exceeds the input data-storage dimension.
RECNTL	1	SIG. VARIABLES EXCEED DIMENSION	The number of signal variables with different ID numbers in the input and the restart files exceeds the input data-storage dimension.
RECNTL	1	TIME STEP DATA EXCEED DIMENSION	The number of trip-controlled time-step data sets with different ID numbers in the input and the restart files exceeds the input data-storage dimension.
RECNTL	1	TOO MANY DMP TRIPS FROM RESTART	The number of trip ID numbers in the input and the restart files exceeds the input data-storage dimension. These trip ID numbers when set to ON generate restart dumps.
RECNTL	1	TOO MANY SETPOINT-FACTOR TABLES	The number of set-point factor tables in the restart file exceeds the input data-storage dimension.
RECNTL	1	TOO MANY SP. TIME STEP DATA SETS	The number of trip-controlled time-step data sets in the restart file exceeds the input data-storage dimension.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RECNTL	1	TOO MANY TRIPS GENERATING DUMPS	The number of trip ID numbers in the restart file exceeds the input data-storage dimension. These trip ID numbers when set to ON generate restart dumps.
RECNTL	1	TOO MANY TRIP-SIG. EXPRESSIONS	The number of signal expressions in the restart file exceeds the input data-storage dimension.
RECNTL	1	TRIP-SIGNAL EXPS. EXCEED DIMEN.	The number of signal-expression ID numbers in the input and the restart files exceeds the input data-storage dimension.
RECNTL	1	TRP-CONT-TRP SIGNALS EXCEED DIM.	The number of trip-controlled trip ID numbers with different ID numbers in the input and the restart files exceeds the input data-storage dimension.
RECORE	2	LCM OVERFLOW	Insufficient LCM is available for this CORE.
RECORE	2	POINTER TABLE MISMATCH	The CORE pointer table does not match the restart-file data.
RECORE	2	SCM OVERFLOW	Insufficient SCM is available for this CORE.
REFILL	1	FATAL ERROR	An error stopped the processing of the input data.
REFILL	2	LCM OVERFLOW	Insufficient LCM is available for the FILL data from the restart file.
REFILL	2	POINTER TABLE MISMATCH	The FILL pointer table does not match the restart-file data.
REFILL	2	SCM OVERFLOW	Insufficient SCM is available for this FILL.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
REPIPE 17	2	POINTER TABLE MISMATCH	The PIPE pointer table does not match the restart-file data.
REPRZR	2	POINTER TABLE MISMATCH	The pressurizer (PRIZER) pointer table does not match the restart-file data.
REPUMP	2	POINTER TABLE MISMATCH	The PUMP pointer table does not match the restart-file data.
REPUMP	1	SCM OVERFLOW	Insufficient SCM is available for the PUMP data from the restart file.
RETEE	2	POINTER TABLE MISMATCH	The TEE pointer table does not match the restart-file data.
RETURB	2	POINTER TABLE MISMATCH	The restart pointers do not match the original pointers. Probably a newer code version with updated pointers was used for the restart, whereas an older version was used for the previous run.
REVOLVE	2	POINTER TABLE MISMATCH	The VALVE pointer table does not match the restart-file data.
REVSSL	2	LCM OVERFLOW	Insufficient LCM is available for the VESSEL data from the restart file.
REVSSL	2	POINTER TABLE MISMATCH	The VESSEL pointer table does not match the restart-file data.
REVSSL 18	2	SCM OVERFLOW	Insufficient SCM is available for the VESSEL data from the restart file.
RFILL	2	BAD FILL TYPE OPTION	An illegal FILL option was specified on FILL Card Number 2.
RFILL	2	BAD TRIP ID DEFINITION	An incorrect trip ID of -1, <-9999, or >9999 was specified.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RFILL	2	IFSV = 0 WHEN IFTY.GT.3	A FILL table, based on IFTY > 4, cannot be defined because no table independent-variable ID number was specified.
RFILL	2	INCONSISTENT INIT AND TABLE FLOW	The initial values for the FILL table and for the FILL initial state are not equal.
RFILL	2	LCM OVERFLOW	Insufficient LCM is available for the FILL data from the input file.
RFILL	2	PAIN MUST NOT BE GREATER THAN PIN	The air partial pressure is greater than the total pressure in a FILL.
RFILL	2	SCM OVERFLOW	Insufficient SCM is available for the FILL data from the input file.
RFILL	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RPIPE	2	INCONSISTENT INIT & TABLE POWER	The initial values for the PIPE power-to-fluid table POWTB and for the PIPE power-to-fluid variable POWIN are not equal.
RPIPE	2	INCONSISTENT INIT & TABLE QPPPF	The initial values for the PIPE power-to-wall table QP3TB and for the PIPE power-to-wall variable QP3IN are not equal.
RPIPE	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RPPH	1	CONVERGENCE FAILURE EVALUATING PUMP SPEED	The PUMP speed to achieve the needed head could not be calculated.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RPRIZR	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RPUMP	2	BAD TRIP ID DEFINITION	An incorrect trip ID of -1, <-9999, or >9999 was specified.
RPUMP	2	FRIC(2) .NE. 0.	The value for FRIC(2) must be 0.0 in the PUMP.
RPUMP	2	INCONSISTENT INIT & TABLE QPPPF	The initial values for the power-to-wall table QP3TB and for the power-to-wall variable QP3IN are not equal.
RPUMP	2	INCONSISTENT INIT & TABLE SPEED	The initial values for the PUMP-speed table and for the PUMP speed are not equal.
RPUMP	2	IPMPDV.NE.0	The independent-variable ID number for the PUMP-speed table should not be defined for PUMP-type 2.
RPUMP	2	NCELLS.LT.2	An incorrect number of PIPE fluid cells was specified. The PIPE must have at least two fluid cells.
RPUMP	2	NPMPRF.NE.0	The number of the rate-factor table's entry pairs should be zero for PUMP-type 2.
RPUMP	2	NPMPSV.NE.0	The independent-variable ID number for the rate-factor table assigned to the PUMP-speed table should not be defined for PUMP-type 2.
RPUMP	2	NPMPTB.NE.0	The number of the PUMP-speed table's entry pairs should be zero for PUMP-type 2.
RPUMP	2	PUMP TYPE NOT RECOGNIZED	An incorrect PUMP type was specified.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RPUMP	2	QPPP-F TABLE PARAM BAD	The power-to-wall table QP3TB is defined but its independent-variable ID number is zero.
RPUMP	2	SPEED TABLE PARAM. BAD	The signal-variable ID number for the rotational-speed-table's independent variable for PUMP-type 1 is invalid. The PUMP-type variable IPMPY must be either 1 or 2.
RPUMP	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RSTGEN	2	GEN.H.T. IDI .EQ. IDO	The same fluid volume was specified for both sides of the same heat-transfer surface in the steam generator.
RSTGEN	2	H.T. I.D.ERROR	The component number (ICMP or OCOMP) for a heat-transfer surface in the steam generator is incorrect.
RSTGEN	2	JUNS2 ERROR	The value of JUNS2 is incorrect; if NSCMP = 1 or JUNS1 = 0, then JUNS2 = 0.
RSTGEN	2	NODES.NE.NDHT	The number of nodes in the steam-generator tubes and in the additional heat-transfer surfaces must be equal.
RSTGEN	2	NO. EXT. JUN. .LT. 2	The number of external junctions on the steam-generator secondary side is incorrect. The number must be two or more.
RSTGEN	2	NSCMP ERROR	The number of secondary internal components is incorrect; the limits are $1 < \text{NSCMP} < 10$.
RSTGEN	2	TYPE ERROR	The secondary component is not a PIPE or TEE.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RSTGEN	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RSTGEN	2	WALL AREAS INCONSISTENT	The internal and external wall areas for a generalized heat transfer are inconsistent with cylindrical geometry; thus, the energy will be calculated incorrectly in the wall-conduction calculation.
RTEE	2	INCONSISTENT INIT & TABLE POWER1	The TEE primary-side initial values for the power-to-fluid table POWTB and for the power-to-fluid variable PWIN1 are not equal.
RTEE	2	INCONSISTENT INIT & TABLE POWER2	The TEE secondary-side initial values for the power-to-fluid table POWTB and for the power-to-fluid variable PWIN2 are not equal.
RTEE	2	INCONSISTENT INIT & TABLE QPPPF1	The TEE primary-side initial values for the power-to-wall table QP3TB and for the power-to-wall variable QPIN1 are not equal.
RTEE	2	INCONSISTENT INIT & TABLE QPPPF2	The TEE secondary-side initial values for the power-to-wall table QP3TB and for the power-to-wall variable QPIN2 are not equal.
RTURB	2	#STAGES.LT.1	A turbine (TURB) must have at least one stage.
RTURB	2	INCONSISTENT INIT AND TABLE GEN POWER	The turbine power table's initial power and the initial operating power POWOP have different values.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RTURB	2	NCELLS.LT.3	The number of cells in the turbine component (TURB) is incorrect; this component must have at least three cells.
RTURB	2	NROWS.GT.2	A maximum of two rows of moving blades is allowed in a turbine stage.
RTURB	2	POWER TABLE PARAM. BAD	Direct power into the coolant table is defined, but its independent-variable ID number is zero.
RTURB	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	Instructions were given in the TRCOUT file to increase LENDIM in BLKDAT and to change the dimension in GENVLT.
RVLVE	2	BAD FIRST VALVE TABLE	A second VALVE table is defined, but a first VALVE table is not defined.
RVLVE	2	BAD QPPPF TABLE SIGNAL	The QPPP-factor table is defined, but its independent-variable ID is zero.
RVLVE	2	BAD OVERRIDING TRIP VALVE ADJUST RATE	The overriding trip's VALVE adjustment rate is negative.
RVLVE	2	BAD OVERRIDING TRIP VALVE RANGE	The overriding trip's minimum and maximum VALVE closure states do not lie between 0 and 1.
RVLVE	2	BAD OV TRIP VALVE TYPE	An overriding trip is defined, but its VALVE type IVTYOV is not 0 or 1.
RVLVE	2	BAD TRIP ID DEFINITION	The trip ID number is greater than the maximum allowed value of 9999.
RVLVE	2	BAD VALVE TABLE DEFINE	The number of pair entries in the first VALVE table is inconsistent with the VALVE option IVTY value.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RVLVE	2	BAD VALVE TABLE MAX ADJUST RATE	The VALVE's maximum adjustment rate is negative.
RVLVE	2	BAD VALVE TABLE SIGNAL	The signal variable ID number defining the VALVE table's independent variable is inconsistent with the VALVE option IVTY value.
RVLVE	2	BAD VALVE TABLE TRIP	A nonzero trip ID number is input when the VALVE type option indicates no trip control, or a zero trip ID number is input when the VALVE is to be trip controlled.
RVLVE	2	BAD VALVE TYPE OPTION	The VALVE option parameter IVTY has an input value outside the 0 to 6 defined range.
RVLVE	2	FAVLVE & XPOS INVALID	The input values of FAVLVE and XPOS are both outside their 0 to 1 physical range.
RVLVE	2	INCONSISTENT INIT & FIRST TABLE	The first VALVE table's initial value and the initial VALVE closure state (FAVLVE or XPOS) have different values.
RVLVE	2	INCONSISTENT INIT & SECOND TABLE	The second VALVE table's initial value and the initial VALVE closure state (FAVLVE or XPOS) have different values.
RVLVE	2	INCONSISTENT INIT & TABLE QPPF	The QPPP-factor table's initial value and the initial QPPP factor QFPIN have different values.
RVLVE	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	In the TRCOUT file instructions are given to increase LENDIM in BLKDAT and change the dimension in GENVLT.
RVSSL	2	BAD TRIP ID DEFINITION	A trip ID number was either input equal to -1, less than -9999, or greater than 9999.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RVSSL	2	CORE ENTIRELY BLOCKED	The core flow area in the axial direction is zero at a VSSL level causing axial flow blockage through the core.
RVSSL	2	ICONC & ISOLUT ARE INCONSISTENT	The input values for ICONC and ISOLUT are not consistent with each other.
RVSSL	2	ILLEGAL REPEAT LEVEL NUMBER USED	An illegal level number was read from a REPEAT LEVEL card.
RVSSL	2	ILLEGAL VALUE FOR IVSSBF	The only legal values for IVSSBF are 0, 2, 20, and 22.
RVSSL	2	INCONSISTENT CORE DEFINING DATA	Indicates either $NASX < IDCU$ or $NRSX < IDCR$ or $IDCL > IDCU$ when a downcomer region is present ($IDCU \neq 0$, $IDCL \neq 0$, $IDCR \neq 0$).
RVSSL	2	INCONSISTENT CORE DIM PARAMETERS	The core region model parameters ICRU, ICRL, ICRR, NODES, NCRX, and NCRZ are defined inconsistently.
RVSSL	2	INCONSISTENT INIT & TABLE REACT-POWER	The reactivity-power table at its relative abscissa coordinate value of 0.0 and the initial reactivity or power have different values.
RVSSL	2	INCONSISTENT LEVEL ELEVATIONS	Indicates input values for which $Z(I + 1) < Z(I)$.
RVSSL	2	INCONSISTENT REACT-POWER TABLE	The IRPWTY reactor-power-type option parameters and the IRPWSV defined presence or absence of a reactor-power table are inconsistent.
RVSSL	2	INCONSISTENT REACT-POWER TRIP	The IRPWTY reactor-power type option parameter and the IRPWTR defined trip control option are inconsistent.
RVSSL	2	INCONSISTENT RING RADII	Indicates input values for which $R(I + 1) < R(I)$.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RVSSL	2	INCONSISTENT SLAB INTERFACE DATA	An incorrect value for INHSMX was input.
RVSSL	2	INCONSISTENT THETA ANGLES	Indicates input values for which $\theta(I + 1) < \theta(I)$.
RVSSL	2	INVALID REACT-POWER TYPE OPTION	The IRPWTY reactor-power type option parameter's value is outside the defined range.
RVSSL	2	LCM OVERFLOW	LCM area overflowed while VESSEL data were read from an input file.
RVSSL	2	NOT ENOUGH FUEL RODS	Indicates NRODS < ICRR * NTSX (need at least one rod in each r, θ region of the core).
RVSSL	2	NZMAX.LT.NCRZ+1 + SUM NFAX(I)	The number of allowable rows of rod conduction nodes is less than the minimum speci- fied by the user for reflood calculations.
RVSSL	2	PAN MUST NOT BE GREATER THAN PN	The air partial pressure is greater than the total pressure in a cell of a VSSL level.
RVSSL	2	SCM OVERFLOW	SCM area overflowed while VESSEL data were read from an input file.
RVSSL	2	THETA ANGLES ASSUMED IN DEGREES	The theta angles are being input in units of degrees rather than radians and will be converted to radian units.
RVSSL	1	UNEXPECTED END-OF-FILE	An end-of-file was encoun- tered while reading VESSEL level data.
RVSSL	2	VESSEL CONV. CRITERIA TOO LOOSE	The convergence criterion for vessel iteration (EPSI) was set to a value greater than 1.0×10^{-5} .
RVSSL	2	VESSEL ITERATION MAXIMUM .LT.50	The maximum number of vessel iterations (IITMAX) is less than 50.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
RVSSL	2	VLT EXCEEDS ITS LIMIT SEE TRCOUT	In the TRCOUT file, instructions are given to increase LENDIM in BLKDAT and change the dimension in GENVLT.
SCMLCM	2	LCM OVERFLOW	Insufficient LCM is available for storing component data.
SCMLCM	2	SCM OVERFLOW	Insufficient SCM is available for reading in component array data.
SETCMP	2	CONTAINMENT MODULE NOT IMPLEMENTED	A control panel vector input card has specified a containment component.
SETCMP	2	TURBINE MODULE NOT IMPLEMENTED	This version of the interactive facility does allow use of the turbine component in control panel vector input.
SETCPV	1	SPECIFICATION ERRORS FORCE TERMINATION	An error has been discerned while central panel vector input cards were processed. A flag is set so TRAC will halt after all input cards have been processed.
SGEEV	1	JOB.NE. 0, AND N .GT. LDV	The user has requested eigenvector calculation in addition to the eigenvalues. However, the leading dimension of the array V, where eigenvectors are stored, is less than the order of the input matrix A.
SGEEV	2	LDA. GT.LDV, ELEMENTS OF A OTHER THAN N BY N INPUT ELEMENTS HAVE BEEN CHANGED	The leading dimension of array V, where eigenvectors are stored, should be equal to the order of the input matrix A. If this is not the case, the elements of A are rearranged.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
SGEEV	2	LDA. LT.LDV, ELEMENTS OF V OTHER THAN THE THE N BY N OUTPUT ELEMENTS HAVE BEEN CHANGED	The leading dimension of array V, where eigenvectors are stored, should be equal to the order of the input matrix A. If this is not the case, the elements of A are rearranged.
SGEEV	1	N .GT. LDA	The order of the input matrix A exceeds the leading dimension of A.
SGEEV	1	N .LT. 1	The order of the input matrix A is less than 1.
SOUND	2	CANNOT CONVERGE ON PAIR AT THE CELL EDGE	Cannot converge on the non- condensable gas partial pres- sure while the conditions at the cell edge are estimated from the cell-center values.
SOUND	2	CANNOT FIND POSITIVE FLOW PRESSURE	When the flow is maximized by iteration of the cell-edge pressure, no physically real- istic pressure value gives positive flow. This should never happen except under some extreme nonequilibrium conditions.
SOUND	2	CANNOT FIND THE EQUILIBRIUM CONDITION	Calculating the thermodynamic equilibrium condition in the presence of a noncondensable requires an iterative type solution, which did not con- verge.
SOUND	2	CANNOT FIND THE MAXIMUM FLOW POINT	When the flow is maximized by iteration of the cell-edge pressure, the decrease in pressure (down to physically realistic values) always keeps increasing the flow. Thus, the choking condition is never determined.
SOUND	2	SOUND SPEED SOLUTION DID NOT CONVERGE	The iterative solution, for determining the choking point, by iterating on the cell-edge pressure while maximizing the mass flux, did not converge.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
SRCHCL	2	NOT IN COMPONENT LIST	A component number specified on a central panel vector input card is not in the component list (interactive only).
SRTLPL	1	SRTLPL FAILURE	SRTLPL failed because of errors in component input data related to junction numbers. See file TRCOUT for additional clues.
STEADY	1	STEADY STATE NOT CONVERGED	The problem did not reach a steady state within the specified time domains.
STGN3X	1	INSUFFICIENT SPACE FOR CYLHT	Insufficient SCM is available.
SVSET	1	TRIP ID NOT FOUND	The trip ID number assigned to a signal variable defining the trip-signal or set-status value could not be found in the list of trip ID numbers.
SVSET3	1	NEED LOCAL DIM.GT.50	There are more than 50 local values in subroutine SVSET3 that need to be saved for the VESSEL component while two or more axial levels are searched for signal-variable evaluation.
TEMPL	1	TOO MANY ITERATIONS	The temperature cannot be evaluated from values of the enthalpy and pressure.
THERMO	2	LIQUID TEMP LIMIT EXCEEDED	The liquid temperature in some cell has fallen below 280 K or has risen above 647 K.
THERMO	2	PRESSURE LIMIT EXCEEDED	The pressure in some cell has fallen below 1.0×10^3 or risen above 1.9×10^7 .
THERMO	2	VAPOR TEMP LIMIT EXCEEDED	The vapor temperature in some cell has fallen below 280 K.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
TIMCHK	2	TERMINATING DUE TO TIME LIMIT	The CPU time limit was reached before the end of the problem.
TIMSTP	4	CANNOT REDUCE TIME STEP FURTHER	The time step was reduced to the minimum allowed, and the outer iteration failed to converge.
TRIP	1	INVALID TRIP ID NUMBER	The set status of a requested trip ID number is undefined.
TRPSET	1	CNTL BLOCK NOT FOUND	A control-block ID number that defines a subexpression argument value for the trip signal could not be found in the list of control-block ID numbers.
TRPSET	1	CNTL SIGNAL NOT FOUND	A control-block ID number that defines the trip signal could not be found in the list of control-block ID numbers.
TRPSET	1	EXP. SIGNAL NOT FOUND	A signal-variable ID number that defines a subexpression argument value for the trip-signal could not be found in the list of signal-variable ID numbers.
TRPSET	1	SET-P-FACTOR TABLE ID NOT FOUND	The set-point-factor table's ID number was not found in the list of set-point-factor table ID numbers.
TRPSET	1	SIGNAL EXP. NOT FOUND	A signal-expression ID number that defines the trip-signal could not be found in the list of signal-expression ID numbers.
TRPSET	1	S-P-FAC TABLE CON BLK NOT FOUND	The control-block ID number that defines the set-point-factor table's independent variable was not found in the list of control-block ID numbers.

<u>Subroutine</u>	<u>Level</u>	<u>Message</u>	<u>Explanation</u>
TRPSET	1	S-P-FAC TABLE SIG VAR NOT FOUND	The signal-variable ID number that defines the set-point-factor table's independent variable was not found in the list of signal-variable ID numbers.
TRPSET	1	TOO MANY PENDING ISET CHANGES	There are too many delay time pending set-status changes for a trip.
TRPSET	1	TRIP-CONT TRIP SIGNAL NOT FOUND	The trip-controlled trip signal ID number that defines the trip-controlled trip signal could not be found in the list of trip-controlled trip-signal ID numbers.
TRPSET	1	TRIP SIGNAL NOT FOUND	A signal-variable ID number that defines the trip-signal could not be found in the list of signal-variable ID numbers.
VLVEX	2	TURBINE CANNOT MEET POWER DEMAND	The turbine has been overloaded so much that with the governing valve fully open, it still cannot meet the power demand. This situation could sometimes temporarily occur under highly transient conditions when the steam flow through the turbine has not caught up with the power demand.
VSSL1	2	REACTOR POWER INITIALIZED	The reactor core's total power is turned on to its input initial value.

APPENDIX G
TRAC SUBPROGRAMS

<u>Name</u>	<u>Function</u>
ACCM1X	Evaluates accumulator (ACCUM) water level.
ACCMBD	Sets boundary array for the accumulator (ACCUM) component.
ACCUM1	Controls accumulator (ACCUM) prepass.
ACCUM2	Controls accumulator (ACCUM) outer iteration.
ACCUM3	Controls accumulator (ACCUM) postpass.
ALLBLK	Tests for all blanks in specified substring of string.
ASIGN	Assigns the component LCM pointers according to the iteration number.
ASTPLN	Calculates mass and energy fluxes at the PLENUM junctions during postpass.
AUXPLN	Calculates mass and energy fluxes at the PLENUM junctions during the outer iteration.
BACIT	Initiates backward substitution after direct vessel matrix inversion.
BALANC	Support subroutine for SGEEV.
BALBAK	Support subroutine for SGEEV.
BDPLEN	Fills the PLENUM boundary array.
BFALOC	Allocates files and buffers for buffered I/O.
BFCLOS	Empties buffers and closes file.
BFIN	Initiates binary input subroutine.
BFOUT	Initiates binary output subroutine.
BITS	Manages bit address flags.
BKMOM	Initiates backward substitution for stabilizing momentum equations.
BKSMOM	Backward substitution for stabilizing momentum equations.

<u>Name</u>	<u>Function</u>
BKSSTB	Initiates backward substitution for stabilizing mass and energy equations.
BLKDATA	Initializes common variables in a block data statement.
BREAK1	Controls BREAK prepass.
BREAK2	Controls BREAK outer iteration.
BREAK3	Controls BREAK postpass.
BREAKX	Evaluates BREAK pressure, temperature, and void fraction.
BREBAL	Initiates backward substitution after coarse-mesh rebalance in the VESSEL.
CBSET	Controls the evaluation of control blocks ICB1 to ICB2 where subroutine CBSET previously was called ICBP times.
CDTHEX	Calculates the diametral thermal expansion of Zircaloy as a function of temperature.
CELLAV	Calculates cell-averaged quantities that are required for the interphasic heat-transfer calculation for one-dimensional components.
CHBD	Checks boundary data.
CHBSAV	Transfers selected BD array data into the A array required for the accumulator phase-separation model.
CHBSET	Stores data in the BD array temporarily to check for the consistency in the junction data.
CHEN	Uses Chen correlation to evaluate the forced convection nucleate boiling HTC.
CHF	Evaluates the CHF based on a local-conditions formulation.
CHF1	Applies Biasi CHF correlation.
CHKBD	Checks for the consistency in the boundary-array data during initialization.
CHKSR	Checks VESSEL source locations.
CHOKE	Establishes the choked phasic velocities and their derivatives.

<u>Name</u>	<u>Function</u>
CIVSSL	Transfers vessel data from LCM to SCM so that the remaining data can be initialized.
CLEAN	Closes TRAC output files.
CLEAR	Sets an array to a constant value.
COMP1	Performs various A-array loading tasks common to most one-dimensional components.
CONBLK	Computes all 61 types of control-block outputs that do not require table storage (that is, except for "DLAY" and FNG1").
CONC	Returns maximum solubility (kg solute/kg water) for species ISPEC at pressure P and water temperature TL.
CONSTB	Drives subroutine STBME.
CONVRT	Takes absolute areas and converts them into fractional areas.
CORE1	Evaluates rod HTC's and tracks quench fronts.
CORE3	Evaluates rod temperature distributions.
COREC1	Controls CORE prepass.
COREC2	Controls CORE outer iteration.
COREC3	Controls CORE postpass.
CORGEO	Writes out the geometric data for a one-dimensional CORE.
CORROD	Writes out the rod data for a one-dimensional core.
CPLL	Calculates specific heat of liquid water as a function of enthalpy and pressure.
CPVEC3	Evaluates the control-panel vector parameters.
CPVPRT	Prints the control-panel status, which is called from PSETQ.
CPVV1	Calculates specific heat of water vapor as a function of temperature and pressure.
CTAIN1	Controls containment prepass.

<u>Name</u>	<u>Function</u>
CTAIN2	Controls containment outer iteration.
CTAIN3	Controls containment postpass.
CWSSL	Transfers VESSEL data from LCM to SCM so that they can be printed.
CYLHT	Calculates temperature fields in a cylinder.
DBRK	Generates BREAK data dump.
DCODF	Calculates a numeric code based on data types.
DCOMP	Dumps one-dimensional component data.
DCORE	Generates CORE data dump.
DEEQ	Kataoka and Ishii entrainment model. ¹⁹
DELAY	Provides a time-delay function for the input variable (XIN). The output (XOUT) is played back with the value that the input had TAU seconds previously. Linear interpolation is used for playback when (TIMET minus TAU) falls between two stored time values. The user specifies the number of table storage pairs (NINT) to be saved. Both the time and the value of the input are stored in the table array as pairs of points.
DELTAR	Calculates transient fuel-cladding gap spacing (only if NFCI = 1).
DFHT	Calculates the dispersed flow wall-to-fluid HTC for use in the transition and film-boiling heat-transfer regimes.
DFILL	Generates FILL data dump.
DMPIT	Generates overlay dump.
DPIPE	Generates PIPE data dump.
DPLEN	Generates PLENUM data dump.
DPUMP	Generates PUMP data dump.
DSTGEN	Generates steam-generator (STGEN) data dump.
DTEE	Generates TEE data dump.
DTURB	Generates turbine (TURB) data dump.

<u>Name</u>	<u>Function</u>
DVLVE	Generates VALVE data dump.
DVSSL	Generates VESSEL data dump.
ECOMP	Writes hydrodynamic and heat-transfer information for one-dimensional components to output file.
EDIT	Begins entry routine for overlay edit.
ELGR	Converts cell elevations to the slope between cells and converts K factors to TRAC friction coefficients.
ENABIN	Enables and processes (CTRL-E)I interrupts.
ENDDMP	Empties dump buffers and closes dump file.
ENDGRF	Empties graphics buffers and closes graphics file.
EOVLY	Closes overlay bookkeeping.
ERRGET	Sets error trap indicators.
ERROR	Processes different kinds of error conditions.
ERRTRP	Processes trapped errors.
ESTGEN	Evaluates steam-generator tee parameters on explicit pass.
ETEE	Evaluates tee parameters on explicit pass.
EVALDF	Evaluates the absolute difference between XOLD and XNEW.
EVFXXX	Evaluates the XXX component-action function.
EVLTAB	Interpolates the function value F from the tabular data based on the value of the table's independent variable: a signal variable (NVAR.GT.0), a control block (NVAR.LT.0), or a trip-signal difference DELSV (NVAR.EQ.0).
EXPAND	Adds rows of conduction nodes within the vessel rods during reflood.
FAXPOS	Evaluates the flow-area fraction, FA, on valve-stem position, XPOS for the VALVE.
FEMOM	Sets up stabilizing momentum equations.
FF3D	Makes final pass update for all variables in three-dimensional VESSEL.

<u>Name</u>	<u>Function</u>
FILL1	Controls FILL prepass.
FILL2	Controls FILL outer iteration.
FILL3	Controls FILL postpass.
FILLX	Evaluates postpass FILL velocity.
FLUX	Calculates mass flow at the boundary of a one-dimensional component for use in mass inventory.
FNMESH	Initializes the supplemental user-specified rows of conduction nodes within the vessel rods at the start of reflood.
FPROP	Calculates values for fluid enthalpy, transport properties, and surface tension.
FROD	Calculates temperature profiles in nuclear or electrically heated fuel rods.
FTHEX	Calculates the fuel linear thermal-expansion coefficient for uranium-dioxide and mixed-oxide fuels.
FWALL	Computes a two-phase friction factor.
GAPHT	Calculates fuel-cladding gap HTC.
GETBIT	Returns value of bit N of word B.
GETCRV	Gets appropriate pump curves from data base.
GRAF	Edits graphics data during transient.
GRFGET	Returns entries in graphics catalog block.
GRFPUT	Places entries in graphics catalog block.
GVSSL1	Calculates integrated vessel parameters for graphics purposes.
GVSSL2	Calculates average values for vessel graphics (integrated values calculated in subroutine GVSSL1).
HEV	Calculates the heat of evaporation of liquid corresponding to a given temperature for low pressures.
HOUT	Controls the outer iteration logic for a complete time step.

<u>Name</u>	<u>Function</u>
HQR	Support subroutine for SGEEV.
HQR2	Support subroutine for SGEEV.
HTCOR	Computes HTC's.
HTIF	Calculates the interphasic heat transfer for the zero-dimensional and one-dimensional components.
HTPIPE	Averages velocities and generates HTC's for one-dimensional components.
HTVSSL	Averages velocities and generates HTC's for the vessel.
HUNTS	Searches character string for specified search string.
HVFILM	Calculates the vapor HTC that is the maximum of the Bromley, natural-convection, and the Dougall-Rohsenow coefficients.
IACCUM	Initializes the accumulator (ACCUM) data arrays that are not input from cards.
IBRK	Initializes the BREAK data arrays that are not input from cards.
ICHL	Returns character at given position in string (left-justified, blank-filled).
ICMP	Overlay controls the initialization of component data.
ICMPR	Logically compares a real variable with an integer variable.
ICOMP	Controls the routines that initialize component data.
ICORE	Initializes the CORE data arrays that are not input from cards.
IDEL	Searches specified substring of string for any one character in a set of specified characters.
IFILL	Initializes the FILL data arrays that are not input from cards.
IGACUM	Supplies accumulator (ACCUM) data for graphics.
IGBRAK	Supplies BREAK data for graphics.

<u>Name</u>	<u>Function</u>
IGCOMP	Supplies graphic output information for most one-dimensional components to the graphics COMMON block.
IGCORE	Specifies graphics data for one-dimensional CORE.
IGFILL	Supplies FILL data for graphics.
IGPIPE	Supplies PIPE data for graphics.
IGPLEN	Outputs FLT and VLT data.
IGPRZR	Supplies pressurizer (PRIZER) data for graphics.
IGPUMP	Supplies PUMP data for graphics.
IGRAF	Initializes graphics variables and writes a header to the graphics file.
IGRF	Controls the creation of the graphics dictionary.
IGSTGN	Supplies steam-generator (STGEN) data for graphics.
IGSVCB	Obtains the signal-variable values.
IGTEE	Supplies TEE data for graphics.
IGTURB	Supplies turbine (TURB) stage data for graphics.
IGVLVE	Supplies VALVE data for graphics.
IGVSS2	Returns the VESSEL variable-length table's variables NASX and LENLD.
IGVSSL	Supplies VESSEL data for graphics.
INDEL	Searches specified substring of string for first nonoccurrence of any one character in a set of specified characters.
INIT	Supplies entry routine for overlay INIT.
INNER	Performs an inner iteration for a one-dimensional component.
INPUT	Supplies entry routine for overlay INPUT.
IOVLY	Initializes overlay bookkeeping.
IPIPE	Initializes the PIPE data arrays that are not input from cards.

<u>Name</u>	<u>Function</u>
IPLN	Loads the PLENUM arrays that are needed, but not input, to start a problem.
IPRIZR	Initializes the pressurizer (PRIZER) data arrays that are not input from cards.
IPROP	Calls subroutines THERMO, FPROP, and MIXPRP for most one-dimensional components.
IPUMP	Initializes the PUMP data arrays that are not input from cards.
ISORT	Sorts a list of integers in ascending order.
ISTGEN	Initializes the steam-generator (STGEN) data arrays that are not input from cards.
ITEE	Initializes the TEE data arrays that are not input from cards.
ITR1	Gives iterative solution of reduced, linearized three-dimensional finite-difference equations.
ITURB	Loads the arrays that are not input but that are needed to start a problem.
IVLVE	Initializes the VALVE data arrays that are not input from cards.
IVSSL	Initializes the VESSEL data arrays that are not input from cards.
J1D	Fills boundary array at component junctions.
JFIND	Locates junctions in junction sequence array.
JUNSOL	Determines junction parameters for connecting and sequencing components.
JVALUE	Converts one character of a string to a binary number; 0-9 returned as binary mode; blank, as binary 0; all others, as less than 0.
LCMOVE	Copies data from one part of LCM to another.
LEVEL	Uses a curve fit to obtain the water level in a cylindrical pipe as a function of the void fraction.
LININT	Performs linear interpolation on arrays.

<u>Name</u>	<u>Function</u>
LINT4D	Linearly interpolates a function table with zero to four independent variables.
LOAD	Reads in specially formatted input data.
LOCF	Locates the variable address.
LOCPMP	Calculates the required relative variable location in a common block for the VALVE.
LOCTEE	Calculates the required relative variable location in a common block for the TEE.
LOCTRB	Calculates the required relative variable location in a common block for the TURB.
LOCVLV	Calculates the required relative variable location in a common block for the VALVE.
MACCUM	Controls modification of accumulator (ACCUM) components.
MANAGE	Performs all level and rod data management operations for the vessel.
MAPIN	Converts data types [for the nuclear plant analyzer (NPA) only].
MBN	Calculates values for electrically heated nuclear fuel-rod insulator properties.
MBREAK	Controls modification of a BREAK.
MCORE	Allows changes to a CORE.
MCTAIN	Allows changes to containment components.
MFILL	Controls modification of a FILL.
MFROD	Orders fuel-rod property selection and evaluates an average temperature for property evaluation.
MFUEL	Calculates values for uranium-dioxide and uranium-plutonium dioxide properties.
MGAP	Calculates values for the thermal conductivity of the gas-gas mixture.
MHTR	Calculates values for electrically heated fuel-rod heater coil properties.

<u>Name</u>	<u>Function</u>
MIXPRP	Calculates mixture properties from those of separate phases.
MODCMP	Controls modification of components.
MODCPV	Allows modification of the control-panel vector specification cards.
MODCTL	Modifies and writes out the main control cards.
MODIFY	Control program for the interactive modification.
MODSV	Allows modification of the signal-variable cards.
MODTRP	Allows modification of the trip data cards.
MPIPE	Controls the modification of a PIPE.
MPLEN	Controls modification of a PLENUM.
MPRIZR	Controls modification of pressurizer (PRIZER) components.
MPROP	Orders structure property selection and evaluates an average temperature for property evaluation.
MPUMP	Controls modification of a PUMP.
MSTGEN	Controls modification of steam-generator (STGEN) components.
MSTRCT	Calculates properties for certain types of steel.
MTEE	Controls modification of a TEE.
MTURB	Controls modification of a turbine (TURB).
MVALVE	Controls modification of a VALVE.
MVSSL	Controls modification of a VESSEL.
MWRX	Calculates the Zircaloy steam reaction in the cladding at high temperatures.
MZIRC	Calculates properties for Zircaloy-4.
NEWDLT	Evaluates prospective new time increment.
NXTCMP	Finds the beginning of data for the next component.

<u>Name</u>	<u>Function</u>
ORDER	Rearranges the signal-variable, control-block, and trip ID numbers in ascending order based on their absolute value and searches for the DO loop index values for each control-parameter evaluation pass through the signal variables, control blocks, and trips.
ORTHES	Support subroutine for SGEEV.
ORTRAN	Support subroutine for SGEEV.
OUT1D	Controls outer calculation for one-dimensional components.
OUT3D	Controls outer calculation for a VESSEL.
OUTER	Controls outer calculation for one time step.
PACKIT	Packs data from one array into another.
PIPE1	Controls pipe prepass.
PIPE1X	Calculates liquid volume discharged (q_{out}), collapsed liquid level (z), and volumetric flow rate (v_{flow}); assumes vertical component with low-numbered cell at top.
PIPE2	Controls PIPE outer iteration.
PIPE3	Controls PIPE postpass.
PLEN1	Performs the prep stage calculation for the PLENUM time-step initialization.
PLEN2	Controls PLENUM outer iteration.
PLEN3	Controls PLENUM postpass.
PMPP	Calculates PUMP enthalpy, pressure, and density.
POST	Controls postpass calculation for one time step.
POST3D	Controls postpass calculation for the VESSEL.
POSTER	Performs postpass calculation for one-dimensional components.
PRCINT	Processes interrupts.
PRCNPA	Processes NPA commands that affect TRAC execution during an NPA simulation.

<u>Name</u>	<u>Function</u>
PREINP	Converts free-format TRACIN deck to format used by TRAC input subroutine.
PREP	Controls prepass calculation for one time step.
PREP1D	Controls the one-pass calculation for one-dimensional components.
PREP3D	Controls prepass calculation for three-dimensional components.
PREPER	Performs prepass calculation for one-dimensional components.
PRIZR1	Controls pressurizer (PRIZER) prepass.
PRIZR2	Controls pressurizer (PRIZER) outer iteration.
PRIZR3	Controls pressurizer (PRIZER) postpass.
PRZR1X	Evaluates pressurizer (PRIZER) water level and heater/-sprayer source.
PRZR3X	Evaluates mass change during steady-state calculation.
PSTEPQ	Controls printing, dumping, and graphing of data at the completion of a time step.
PUMP1	Controls PUMP prepass.
PUMP2	Controls PUMP outer iteration.
PUMP3	Controls PUMP postpass.
PUMPD	Calculates head and torque from PUMP curves.
PUMPI	Supplies built-in PUMP characteristics.
PUMPSR	Evaluates PUMP momentum and energy source.
PUMPX	Calculates PUMP head and torque.
R1MACH	Support subroutine for SGEEV.
RACCUM	Reads accumulator (ACCUM) data input file and creates pointer table for these data.
RBREAK	Reads BREAK data from input file and creates a pointer table for these data.

<u>Name</u>	<u>Function</u>
RCNTL	Reads in signal-variable, trip, and controller input data.
RCOMP	Reads data common to most one-dimensional components from input files and writes these data to output file.
RCORE	Reads CORE data from input file and creates a pointer table for these data.
RCPVEC	Processes the control-panel vector input cards.
RDCOM3	Controls reading of three-dimensional VESSEL data from input file.
RDCOMP	Controls reading of component data from input file.
RDCRDS	Reads time-step cards until DTMIN < 0 is encountered.
RDCRVS	Reads PUMP curves from input file.
RDDIM	Reads number of points on PUMP curves from input file.
RDLCM	Moves data from LCM to SCM.
RDREST	Controls reading of component data from a restart dump file.
REACCM	Reads accumulator (ACCUM) data from a restart dump and creates a pointer table for these data.
READI	Reads integer data in I14 format.
READR	Reads real data in E14.6 format.
REBRK	Reads BREAK data from a restart dump and creates a pointer table for these data.
RECNTL	Reads the signal-variable, trip, and controller data from the restart file.
RECOMP	Reads data from disk common to most one-dimensional components (used by subroutine RESTART).
RECORE	Reads CORE data from a restart dump and creates a pointer table for these data.
RECPV	Adds the restart file control-panel vector data that was not specified on input and prints it out.
REFILL	Reads FILL data from a restart dump and creates a pointer table for these data.

<u>Name</u>	<u>Function</u>
REPIPE	Reads PIPE data from a restart dump and creates a pointer table for these data.
REPLEN	Reads PLENUM data from a restart dump and creates a pointer table for these data.
REPRZR	Reads pressurizer (PRIZER) data from a restart dump and creates a pointer table for these data.
REPUMP))	Reads PUMP data from a restart dump and creates a pointer table for these data.
RESTGN	Reads steam-generator (STGEN) data from a restart dump and creates a pointer table for these data.
RETEE	Reads TEE data from a restart dump and creates a pointer table for these data.
RETURB	Reads turbine (TURB) stage data from a restart dump and creates a pointer table for these data.
REVLVE	Reads VALVE data from a restart dump and creates a pointer table for these data.
REVSSL	Reads VESSEL data from a restart dump and creates a pointer table for these data.
RFDBK	Evaluates the reactor core reactivity feedback caused by changes in the fuel temperature, coolant temperature, and coolant void from the beginning of the previous time step.
RFILL	Reads FILL data from input file and creates a pointer table for these data.
RHOLIQ	Calculates values of liquid density and its derivatives.
RKIN	Integrates the neutron point-kinetics equations.
RODHT	Calculates the fuel-rod temperature field.
RPIPE	Reads PIPE data from the input file and creates a pointer table for these data.
RPLEN	Reads PLENUM data from the input file and creates a pointer table for these data.
RPRIZR	Reads pressurizer (PRIZER) data from input file and sets up a pointer table for these data.

<u>Name</u>	<u>Function</u>
RPUMP	Reads PUMP data from input file and creates a pointer table for these data.
RSTGEN	Reads steam-generator (STGEN) data from input file and creates pointer tables for these data.
RTEE	Reads TEE data from input file and creates a pointer table for these data.
RTURB	Reads turbine (TURB) stage data from input file and creates a pointer table for these data.
RVLVE	Reads VALVE data from input file and creates a pointer table for these data.
RVSSL	Reads VESSEL data from input file and creates a pointer table for these data.
S1DPTR	Sets pointers for one-dimensional components.
SATDER	Calculates the derivative of saturation temperature of vapor with respect to pressure.
SATPRS	Calculates saturation pressure of vapor corresponding to a given temperature.
SATTMP	Calculates saturation temperature of vapor corresponding to a given pressure.
SAVBD	Moves boundary information into component arrays.
SCLTBL	Scales input table according to scale factor passed by input routine.
SCMLCM	Checks for overflow. Transfers fixed-length, variable-length, and pointer tables to LCM. Adjusts pointers.
SCOPY	Support subroutine for SGEEV.
SCOPYM	Support subroutine for SGEEV.
SEDIT	Writes short edit to TRCOUT file.
SETBD	Stores component information in boundary arrays.
SETBRK	Sets special pointers for a break.
SETCMP	Determines the component type and sets the LCM pointer for control-panel vector parameter IPARAM for component ICOMP.

<u>Name</u>	<u>Function</u>
SETCOR	Sets special pointers for a CORE.
SETCPV	Sets up the control-panel vector pointers. All errors encountered by subordinate routines are treated as warning errors. If an error would inhibit further processing, IERRFL is set to 1. At the end of this routine a fatal error is issued if IERRFL is not 0. This allows checking of all parameters in a single pass.
SETEOS	Sets the equation of state constants.
SETFIL	Sets special pointers for a fill.
SETLCM	Monitors use of LCM dynamic area.
SETNET	Provides the information needed to set up the network solution matrices.
SETPMP	Sets the volume flow pointer for a PUMP.
SETPRZ	Sets special pointers for a pressurizer (PRIZER).
SETSCM	Monitors use of SCM dynamic area.
SETVSL	Sets special pointers for a VESSEL.
SGEDI	Computes the determinant of a matrix using the factors computed by SGEFA.
SGEEV	Computes the eigenvalues and eigenvectors of a general real matrix.
SGEFA	Factors a real matrix by Gaussian elimination. SGEFA is usually called by SGEFO, but it can be called directly with a saving in time if RCOND is not needed. (time for SGEFO) = (1 + 9/N) * (time for SGEFA).
SGESL	Solves the real system $A * X = B$ or $TRANS(A) * X = B$ using the factors computed by SGEFO or SGEFA.
SGTBC	Boundary cell calculations for the special case where the TEE junction cell is the first or last cell in a main steam-generator pipe. This logic duplicates the logic in subroutine TEEL after the call to BKMOM.
SHIFTB	Translates the table's abscissa coordinate values so that the function value F in the table corresponds to an abscissa coordinate value of 0.0.

<u>Name</u>	<u>Function</u>
SHRINK	Removes rows of conduction nodes within the VESSEL rods during reflood.
SIGMA	Returns surface tension of water as a function of pressure.
SLABHT	Calculates the slab temperatures.
SMOVE	Moves a character from one string to another.
SMOVEN	Moves a specified number of characters from one string to another.
SOUND	Homogeneous equilibrium sound speed calculation.
SPLIT	Reads appropriate data from PUMP curves.
SRCHCL	Searches the component list for component number ICOMP. It returns the component LCM pointer in IBASE. If the component is not found, it sets IERR to one and returns -1 in IBASE.
SREBAL	Sets up coarse-mesh rebalance in the VESSEL.
SRTLPL	Sorts components into loops and reorders them for the network solution.
STBME	Sets up the stabilizing mass and energy equations.
STBMPL	Sets up the stabilizing mass and energy equations for the PLENUM.
STDIR	Sets up direct inversion of the VESSEL matrix.
STEADY	Generates a steady-state solution.
STGABD	Finds the void fractions in adjacent cells within a steam generator to use in heat-transfer averaging.
STGEN1	Controls steam-generator (STGEN) prepass.
STGEN2	Controls steam-generator (STGEN) outer iteration.
STGEN3	Controls steam-generator (STGEN) postpass.
STGN1X	Evaluates HTCs for steam-generator (STGEN) secondary.
STGN3X	Performs steam-generator (STGEN) heat-transfer calculation.
STGNTX	Computes needed quantities on prepass.

<u>Name</u>	<u>Function</u>
STGPTH	Initializes TRAC communication to the NPA controller.
STPCLS	Closes disk file used for NPA controller communication.
STPMSG	Checks for message from the NPA controller.
STPRD	Reads message from the NPA controller.
STPWRT	Writes message to the NPA controller.
STRLER	Provides error message for NPA controller communication failure (reserved for future use).
SVSET	Evaluates location-independent (0 = ISUN < 17) signal variables.
SVSET1	Evaluates signal variables with locations defined in the one-dimensional components.
SVSET3	Evaluates signal variables with locations defined in the three-dimensional VESSEL.
TEE1	Controls TEE prepass.
TEE1X	Calculates source for TEE side-leg hydrodynamics.
TEE2	Controls TEE outer iteration.
TEE3	Controls TEE postpass.
TF1D	Drives one-dimensional hydrodynamics routines.
TF1DS	Solves the hydrodynamic equations for the one-dimensional two-fluid pipe model.
TF1DS1	Sets up initial velocity approximations and their pressure derivatives for the one-dimensional two-fluid pipe model.
TF1DS3	Performs the backward substitution for the one-dimensional two-fluid pipe model.
TF3DE	Evaluates constitutive relations for interfacial shear and heat transfer; makes an evaluation of new time velocities.
TF3DI	Sets up the linearized three-dimensional finite-difference equations.
TFPLBK	Performs the backward substitution for the basic difference equations for the PLENUM (similar to TF1DS3 for the other one-dimensional components).

<u>Name</u>	<u>Function</u>
TFPLN	Solves the basic hydrodynamic equations for the PLENUM (similar to TFLDS for the other one-dimensional components).
THCL	Returns thermal conductivity of water as a function of pressure and enthalpy.
THCV	Returns thermal conductivity of steam as a function of pressure and enthalpy.
THERMO	Calculates thermodynamic properties of water.
TIMCHK	Checks elapsed time to see whether certain functions should be performed.
TIMSTP	Sets up time-step and time-edit interval times.
TMSFB	Calculates the minimum stable film-boiling temperature (T_{min}).
TRAC	Supplies MAIN program.
TRANS	Controls overall calculation for each time step.
TRANSF	Transfers data from the steam-generator internal network matrix to the loop network matrix.
TRBPOW	Calculates the efficiency and power output of a turbine stage.
TRBPRE	Calculates the data pertaining to the entire turbine-generator set (common/sum all stages) during the prep stage.
TRBPST	Calculates the data pertaining to the entire turbine-generator set (common/sum all stages) during the post stage.
TRIP	Returns status of a trip.
TRIPS	Evaluates the control parameters for the beginning of the time-step system state.
TRISLV	Solves linear system of the form $A * X = B$ where A is tridiagonal.
TRPSET	Sets up trip status flags.
TURB1	Performs the prep stage calculation for the turbine stage component time-step initialization.

<u>Name</u>	<u>Function</u>
TURB2	Controls turbine stage outer iteration.
TURB3	Controls turbine stage postpass.
UNPKIT	Unpacks data packed by subroutine PACKIT.
VALUE	Converts an Ascii string to its binary value.
VELCK	Checks for incorrect donor-celling in subroutine VSSL caused by velocity sign changes.
VISCL	Evaluates viscosity of water as a function of pressure and enthalpy.
VISCV	Evaluates viscosity of steam as a function of pressure and enthalpy.
VLEVEL	Indicates the beginning of a certain level in a VESSEL.
VLVE1	Controls VALVE prepass.
VLVE2	Controls VALVE outer iteration.
VLVE3	Controls VALVE postpass.
VLVEX	Evaluates the value of the flow-area change action.
VOLFA	Calculates cell volume flow areas.
VOLV	Calculates cell-averaged phase velocities for one-dimensional components.
VSLGEO	Writes the geometry cards for the VESSEL on the restart input file.
VSLEEV	Writes the level data cards for the VESSEL on the restart input file.
VSLROD	Writes the rod data cards for the VESSEL to the restart input file.
VSSL1	Performs prepass calculations for VESSEL dynamics.
VSSL2	Performs inner iterations for VESSEL dynamics.
VSSL3	Performs postpass calculations for VESSEL dynamics.
WACCUM	Writes selected accumulator (ACCUM) data to output file TRCOUT.

<u>Name</u>	<u>Function</u>
WARRAY	Writes a real array to output file TRCOUT.
WBREAK	Writes selected BREAK data to output file TRCOUT.
WCOMP	Controls the writing of selected component data to output file TRCOUT.
WCORE	Writes selected CORE data to output file TRCOUT.
WFILL	Writes selected FILL data to output file TRCOUT.
WIARR	Writes an integer array to output file TRCOUT.
WPIPE	Writes selected PIPE data to output file TRCOUT.
WPLEN	Writes selected PLENUM quantities to the printer.
WPRIZR	Writes selected pressurizer (PRIZER) data to output file TRCOUT.
WPUMP	Writes selected PUMP data to output file TRCOUT.
WRCOMP	Writes data common to one-dimensional components to output files.
WRITEE	This subroutine does not combine numbers as does subroutine R. It merely puts an E at the end of the data for a variable to make it compatible with the LOAD subroutine of the TRAC code.
WRITEI	Takes integers and puts them into format compatible with the LOAD subroutine of TRAC.
WRITER	Takes real numbers and puts them into format compatible with the LOAD subroutine of TRAC.
WRLCM	Transfers a given number of words from SCM to LCM.
WSTGEN	Writes selected steam-generator (STGEN) data to output file TRCOUT.
WTEE	Writes selected TEE data to output file TRCOUT.
WTURB	Writes selected quantities to the printer for a turbine (TURB) stage component.
WVLVE	Writes selected VALVE data to output file TRCOUT.
WVSSL	Writes selected VESSEL data to output file TRCOUT.

APPENDIX H

DESCRIPTION OF COMMON-BLOCK VARIABLES

DECK BKCNTL

COMMON/BKCTRL/IPREIT,LBCKV,LREIT,LREITV

INTEGER VARIABLES:

IPREIT: Flag to print messages on forced reiteration.
LBCKV: If .TRUE., then variable forces a time-step back-up.
LREIT: If .TRUE., then variable forces a reiteration.
LREITV: If .TRUE., then variable forces a reiteration.

COMMON/DONR/ITDON,JDONP,NCOMDP

INTEGER VARIABLES:

ITDON: If flow reversals occur for OITNO > ITDON, the time step is backed up.
JDONP: Cell number in NCOMDP.
NCOMDP: Component number of flow reversal forcing back-up.

DECK BKPOST

COMMON/BKPOST/BKPALL,BKPALU,BKPSTA,BKPSTP,BKPSTT

COMMON/BKPOST/IBKPST,JBKPST,LBKPST

REAL VARIABLES:

BKPALL: Maximum lower limits on void fraction such that a back-up is forced if the void fraction lies within these limits.
BKPALU: Maximum upper limits on void fraction such that a back-up is forced if the void fraction lies within these limits.
BKPSTA: Void-fraction variation that is allowed in the POST stage. If the void-fraction change exceeds BKPSTA, back-up is forced.

BKPSTP: Maximum fractional pressure change that is allowed in the POST stage. If the fractional pressure change exceeds BKSTP, back-up is forced.

BKPSTT: Maximum variation in liquid and vapor temperatures that is allowed in the POST stage. If the temperature change exceeds BKPSTT, back-up is forced.

INTEGER VARIABLES:

IBKPST: Component forces back-up.

JBKPST: Cell number.

LBKPST: Logical variable. If .TRUE., then a time-step back-up is forced from POST.

COMDECK BLANKCOM

COMMON A(25000)

A(25000): Dynamic SCM storage area. This array is dimensioned to other sizes or dynamically dimensioned for certain conditional directives imposed during compilation.

COMDECK CDBLKS

COMMON/CODEBK/CBNAM,ILEV,MAX1LV,MAXLEN,MAXLN3,MLNVMT

DIMENSION CBNAM(5)

INTEGER VARIABLES:

CBNAM: Array containing the names of the overlays currently in core.

ILEV: The number of overlays currently in core.

MAX1LV: Maximum amount of SCM storage needed for three-dimensional components when only one level of data is required.

MAXLEN: Maximum amount of SCM storage needed to process any one-dimensional component.

MAXLN3: Maximum amount of SCM storage needed to process any three-dimensional component.

MLNVMT: The amount of SCM space required to solve the vessel matrix.

COMDECK CFLOW

COMMON/CFLOW/CHM1,CHM2,CHMLT1,CHMLT2

COMMON/CFLOW/ICFLOW,IHOR,IHORG

DIMENSION CHM1(5),CHM2(5)

REAL VARIABLES:

CHM1: Array of choked-flow multipliers on the subcooled flow.

CHM2: Array of choked-flow multipliers on the two-phase flow.

CHMLT1: Multiplier on the subcooled flow.

CHMLT2: Multiplier on the two-phase flow.

INTEGER VARIABLES:

ICFLOW: Choked-flow mode controller.
0 = model turned off,
1 = model using default multipliers turned on only for components connected to a BREAK (default condition), or
2 = model using optional multipliers turned on at cell edges indicated in component input (note that this option requires additional array data for all one-dimensional hydrodynamic components).

IHOR: Drag controller.
0 = uses dispersed drag only,
1 = (default) uses stratified drag in one dimension if conditions are met, or
2 = always uses stratified drag.

IHORG: Stratified flow regime controller.
0 = turns off stratified flow regime including head gradient force,
1 = (default) uses normal stratified flow, or
2 = turns off head gradient force.

COMDECK CHECKS

COMMON/CHECKS/DTEND,DTSTRT,HDUMP,HEDIT,HGRAF,HSEDIT

COMMON/CHECKS/NALT,NDID

REAL VARIABLES:

DTEND: Time interval during which the special time-step data are used.

DTSTRT: A constant initially defined to be -1.0 that can be used to force a calculation to begin with a specified time-step size (ΔT_{STRT} when DTSTRT has been set greater than zero).

HDUMP: Saved value of the next restart/dump edit time from the regular time-step data when the special time-step data are used.

HEDIT: Saved value of the next long edit time from the regular time-step data when the special time-step data are used.

HGRAF: Saved value of the next graphics edit time from the regular time-step data when the special time-step data are used.

HSEDIT: Saved value of the next short edit time from the regular time-step data when the special time-step data are used.

INTEGER VARIABLES:

NALT: Constant used to determine if void-fraction adjustments are needed when the interfacial drag is calculated at a one-dimensional junction connected to a BREAK.

NDID: ID number of the special time-step data that are being used.

COMDECK CHGALP

COMMON/CHGALP/DAL,DAU,OAL,OAU,XDAL,XDAU,XOAL,XOAU

COMMON/CHGALP/JDAL,JDAU,JOAL,JOAU,NDAL,NDAU,NOAL,NOAU

REAL VARIABLES:

DAL: Maximum decrease in void fraction.

DAU: Maximum increase in void fraction over the time step.
 OAL: Maximum decrease in void fraction immediately following an increase.
 OAU: Maximum increase in void fraction immediately following a decrease.
 XDAL: Limit on DAL beyond which the time step is reduced.
 XDAU: Limit on DAU beyond which the time step is reduced.
 XOAL: Limit on OAL beyond which the time step is reduced.
 XOAU: Limit on OAU beyond which the time step is reduced.

INTEGER VARIABLES:

JDAL: Cell where DAL occurred.
 JDAU: Cell where DAU occurred.
 JOAL: Cell where OAL occurred.
 JOAU: Cell where OAU occurred.
 NDAL: Component where DAL occurred.
 NDAU: Component where DAU occurred.
 NOAL: Component where OAL occurred.
 NOAU: Component where OAU occurred.

COMDECK COMCOM

COMMON/CC/IMAX,IMIN,JFLAG

INTEGER VARIABLES:

IMAX: Last component (TRAC-assigned component number) in a loop to control the outer calculation for one-dimensional components.
 IMIN: First component (TRAC-assigned component number) in a loop to control the outer calculation for one-dimensional components.
 JFLAG: Flag that indicates an error in the outer calculation.

COMDECK CONSTANT

COMMON/CONST/PI,GC,ZERO,ONE,EPSALP

REAL VARIABLES:

PI: Constant π (3.1415926535898).
GC: Gravitational constant ($9.80665 \text{ m} \cdot \text{s}^{-2}$).
ZERO: Real constant zero.
ONE: Real constant one.
EPSALP: Void-fraction cutoff for thermodynamic vapor properties.

COMDECK CONTRLLR

COMMON/CONTRL/DAMMC,DAMX,DELT,DELTHT,DIFMIN,DPRMX,DTLMX,DTMAX,DTMIN,DTO,
DTRMX,DTSMX,DTVMX,EPS1,EPS2,EPSI,EPSO,EPSP,EPSS,ETIME,
HTLOSI,HTLOSO,ODELT,TEND,TIMEC,TIMET,VARER,VCMN,VCMX,
VMAXO,VMAXT,VMCON,VMNEW,VMOLD

COMMON/CONTRL/DSTEP,IADDED,ICCMX,ICMP,ICP,IEOS,IFPREP,IGEOM3,IITMAX,
IM100,IM100X,IMFR,INVAN,IPAK,IPAKON,IPKPMP,IRSTFL,ISOLUT,
ISSFLG,ISTDY,ISTTC,ITMIN,ITPAKO,KCCMX,LCMPTR,LEVSTG,NCMN,
NCMX,NCRG,NDIA1,NDIA3,NFRC1,NFRC3,NITAV,NITMN,NITMX,
NIVSMN,NIVSMX,NSEND,NSEO,NSMN,NSMX,NSPL,NSPU,NSSO,NSTP,
NSVSMN,NSVSMX,OITMAX,SITMAX,STDYST,TRANSI

REAL VARIABLES:

DAMMC: Maximum void-fraction change during time step.
DAMX: Error caused by relative change in void fraction.
DELT: Current time increment for advancement of finite-difference equations.
DELTHT: Heat-transfer time-step size.
DIFMIN: Minimum diffusion number required for stability of the nod conduction solution.
DPRMX: Maximum pressure change during the current time step.
DTLMX: Maximum liquid-temperature change during time step.
DTMAX: Maximum allowable time-step size for time interval.

DTMIN: Minimum allowable time-step size for time interval.

DTO: Previous time-step size.

DTRMX: Maximum rod-temperature change during time step.

DTSMX: Maximum metal-temperature change during time step.

DTVMX: Maximum vapor-temperature change during time step.

EPS1: The lower-bound criterion for increasing the Kaganove method integration time step for solving the point-kinetics equation.

EPS2: The upper-bound criterion for decreasing the Kaganove method integration time step for solving the point-kinetics equations.

EPSI: Convergence criterion for vessel iteration.

EPSO: Convergence criterion for outer iteration.

EPSP: Convergence criteria for PWR initialization calculation.

EPSS: Convergence criterion for steady-state calculation.

ETIME: Current calculation time used for edits.

HTLOSI: Inside system heat loss for one-dimensional components only (total system heat loss to the inside walls for one-dimensional components only).

HTLOSO: Outside system heat loss for one-dimensional components only (total heat loss from the outside of the heat structures to the surroundings for one-dimensional components only).

ODELT: Time increment for previous time step.

TEND: End of time domain.

TIMEC: Clock time in seconds (s).

TIMET: Current calculation time.

VARER: Variable error.

VCMN: Final convergence for component NCMN at step NSMN.

VCMX: Final convergence for component NCMX at step NSMX.

VMAXO: Maximum Courant number found during time step.
 VMAXT: Maximum Courant number.
 VMCON: Net water mass (liquid plus vapor) convected into vessel during time interval ($t^{n+1} - t^n$).
 VMNEW: Vessel water mass (liquid plus vapor) at (t^{n+1}).
 VMOLD: Vessel water mass (liquid plus vapor) at (t^n).

INTEGER VARIABLES:

DSTEP: Time-step number of dump to be used for restart.
 IADDED: Time-step interval for printing calculation summary to the terminal. (Zero suppresses this print.)
 ICCMX: Component number in the IORDER array with the most severe time-step limit for stability.
 ICMP: Component indicator.
 ICP: Temporary pointer to next free location in the dynamic storage area for component data.
 IEOS: Air-water option flag.
 0 = steam-air-water;
 1 = air-water (no steam present).
 IFPREP: Flag that indicates sections of PREPER to be executed (nonzero only for one-dimensional cores).
 IGEOM3: Vessel geometry flag.
 0 = (default) flow areas between the downcomer and inside of the vessel set to zero;
 1 = flow areas between the downcomer and inside of the vessel maintained at the user input values.
 Note: The vent valve option overrides IGEOM3 = 1 option in cells that have vent valve connections.
 IITMAX: Maximum number of vessel iterations.
 IM100: Flag that indicates if back-up occurred on previous time-step (used for mass check on logic).
 IM100X: Flag that indicates whether previous time step that failed was obtained from a restart.

IMFR: Calculates the theta, axial, and radial mass flows (kg/s) for both liquid and vapor, and adds them to the graphics. This option is invoked by a new NAMELIST variable IMFR.
 1 = (default) one-dimensional vessel mass flow;
 3 = three-dimensional vessel mass flow.

INVAN: Flag to select either T_{CHF} or T_{sat} for control of the inverted annular flow regime.

IPAK: Flag that indicates water-packing option.
 0 = off;
 1 = on.

IPAKON: Flag that indicates if water-packing logic is on during time step.

IPKPMP: Flag that indicates if water-packing corrections are made at a pump source.
 0 = (default) water-packing corrections are not made at a pump source;
 1 = water-packing corrections are made at a pump source.

IRSTFL: Flag to control dump generation in the interactive mode.
 0 = normal operation;
 1 = termination with a dump because the interactive mode is requesting a component modification.

ISOLUT: Flag that turns on solute tracking option.

ISSFLG: Flag that controls editing in steady state.

ISTDY: Flag that indicates type of calculation.
 0 = transient;
 1 = steady state.

ISTTC: Static check flag.
 0 = normal mode;
 1 = a static balance check was requested when $STDYST = 5$ was input.

ITMIN: Minimum stable film-boiling option flag.

ITPAKO: Iteration number for which water packing was detected.

KCCMX: Cell in above component that limits stability.

LCMPTR: Pointer to end of component data for last component read.

LEVSTG: Void-fraction averaging flag.
0 = default, no void-fraction averaging is performed in HTCOR in the steam-generator secondaries;
1 = special void-fraction averaging is performed in HTCOR for steam-generator secondaries.

NCMN: Position in IORDER array for component that was last to converge at step NSMN.

NCMX: Position in IORDER array for component that was last to converge at step NSMX.

NCRG: NAMELIST variable (not documented elsewhere and overwritten to zero) that could be used to force the input of ICRRG (see the VESSEL variable-length table, App. I). Logic is incomplete.

NDIA1: Heat-transfer diameter option for one-dimensional components.
1 = (default) no heat-transfer diameter input for one-dimensional components;
2 = heat-transfer diameter input for one-dimensional components.

NDIA3: Heat-transfer diameter option for three-dimensional components.
1 = (default) no heat-transfer diameter input for three-dimensional components;
3 = heat-transfer diameter input for three-dimensional components.

NFRC1: Set to 2 if forward and reverse loss coefficients are to be input for one-dimensional components.

NFRC3: Set to 2 if forward and reverse loss coefficients are to be input in the vessel.

NITAV: Average number of outer iterations since the last edit.

NITMN: Minimum number of outer iterations since the last edit.

NITMX: Maximum number of outer iterations since the last edit.

NIVSMN: Minimum number of vessel iterations required since the last edit.

NIVSMX: Maximum number of vessel iterations required since the last edit.

NSEND: End the calculation at this time-step number.
 NSEO: Time-step number of last completed edit.
 NSMN: Last time step at which NITMN outer iterations occurred.
 NSMX: Last time step at which NITMX outer iterations occurred.
 NSPL: Print if NSPL < NSTEP < NSPU.
 NSPU: Print if NSPL < NSTEP < NSPU.
 NSSO: Time-step number of last completed short edit.
 NSTP: Number of time steps since the last edit.
 NSVSMN: Last time step at which NIVSMN vessel iterations occurred.
 NSVSMX: Last time step at which NIVSMX vessel iterations occurred.
 OITMAX: Maximum number of outer iterations.
 SITMAX: Maximum number of outer iterations for steady-state calculation.
 STDYST: Steady-state calculation indicator.
 TRANCI: Transient calculation indicator.

COMDECK CPVECT

COMMON/CPVECT/CPVINT,RDIAM,RMASS,RSTMLT,TCPVPR,VCPVLP,VCPVPR

COMMON/CPVECT/IHTRIG,INTFLG,IPRCPV,KFLOW,KLEVEL,KPRESS,KTEMP,LASOG,
LCPVLP,LCPVPR,NCPVP,NORMDP,NORMRS

DIMENSION LCPVLP(4,9),LCPVPR(9),VCPVLP(4,9),VCPVPR(6)

REAL VARIABLES:

CPVINT: Print interval for control-panel vector.
 RDIAM: Refueling storage tank diameter.
 RMASS: Initial refueling storage tank water mass (kg).
 RSTMLT: Multiplier for converting refueling storage tank water mass to water level.

TCPVPR: Time of the last control-panel vector printout.
 VCPVLP: Control-panel vector loop parameter values.
 VCPVPR: Control-panel vector primary parameter values.

INTEGER VARIABLES:

IHTRIG: Terminal (TTY) heading print trigger.
 INTFLG: Flag that indicates an interrupt message has been received.
 IPRCPV: Control-panel vector processing flag.
 0 = control-panel vector processing selected;
 1 = control-panel vector processing not selected.
 KFLOW: Flow output units.
 0 = kg/s;
 1 = lb/s.
 KLEVEL: Level output units.
 0 = m;
 1 = ft.
 KPRESS: Pressure output units.
 0 = MPa;
 1 = psi.
 KTEMP: Temperature output units.
 0 = K;
 1 = °F .
 LASOG: Length of each interactive graphics edit.
 LCPVLP: LCM pointers to variables used in evaluating control-panel vector loop parameters.
 LCPVPR: LCM pointers for variables used in evaluating control-panel vector primary parameters.
 NCPVP: Number of interactive graphic dumps.
 NORMDP: Flag that indicates a dump in the noninteractive mode.
 0 = no dump occurs, default if code is interactive;
 1 = dump occurs.
 NORMRS: Flag that indicates if a restart was obtained from a normal noninteractive TRAC version.
 0 = no restart, default if code is interactive;
 1 = a restart was obtained.

COMDECK CPVINP

COMMON/CPVINP/ICELLS,ICOMPS,JCELL,JCOMPS,JDISCH,LOOPCT,LOOPID,LOOPS

DIMENSION ICELLS(4,8),ICOMPS(4,9),JCELL(3),JCOMPS(4),JDISCH(4),
LOOPID(4),LOOPS(4)

INTEGER VARIABLES:

ICELLS(L,I): Cell number in loop L where the control-panel vector parameter I is located.

I = 1, hot-leg temperature;
= 2, cold-leg temperature;
= 3, primary-liquid mass flow;
= 4, ECCS liquid mass flow;
= 5, steam-generator secondary-side pressure;
= 6, steam-generator secondary-side steam-mass flow;
= 7, steam-generator secondary-side main-feedwater mass flow; and
= 8, steam-generator secondary-side auxiliary-feedwater mass flow.

ICOMPS(L,I): Component number in loop L where the control-panel vector parameter I is located. I = 1 through 8 defined in ICELLS(L,I).

I = 9, steam-generator secondary-side water level.

JCELL(I): Cell number where the control-panel vector global parameter I is located.

I = 2, primary pressure; and
= 3, containment pressure and temperature.

JCOMPS(I): Component number where the control-panel vector global parameter I is located. I = 2 and 3 defined in JCELL(I).

I = 1, reactor power; and
= 4, pressurizer water level.

JDISCH(L): Component number for refueling storage tank discharge in loop L (should be a FILL).

LOOPCT: Number of loops in this model ($1 \leq \text{LOOPCT} \leq 4$).

LOOPID(L): Loop identification for loop L.

LOOPS(L): Number of physical loops in loop L.

COMDECK DEFVAL

COMMON/DEFVAL/ALPQ,HSTNQ,PQ,PAQ,QPPPQ,TLQ,TVQ,TWQ,VLQ,VVQ

COMMON/DEFVAL/ISTOPT

REAL VARIABLES:

ALPQ: Default value for initial void fractions input through NAMELIST and used to specify void fractions when ISTOPT = 1 or 2.

HSTNQ: Default value for initial VESSEL heat-slab temperatures input through NAMELIST and used to specify the VESSEL heat-slab temperatures when ISTOPT = 1 or 2.

PQ: Default value for initial pressures input through NAMELIST and used to specify pressures when ISTOPT = 1 or 2.

PAQ: Default value for initial air partial pressures input through NAMELIST and used to specify air partial pressures when ISTOPT = 1 or 2.

QPPPQ: Default value for initial volumetric heat sources in pipe walls input through NAMELIST and used to specify volumetric heat sources when ISTOPT = 1 or 2.

TLQ: Default value for initial liquid temperatures input through NAMELIST and used to specify liquid temperatures when ISTOPT = 1 or 2.

TVQ: Default value for initial vapor temperatures input through NAMELIST and used to specify vapor temperatures when ISTOPT = 1 or 2.

TWQ: Default value for initial wall temperatures input through NAMELIST and used to specify wall temperatures when ISTOPT = 1 or 2.

VLQ: Default value for initial liquid velocities input through NAMELIST and used to specify liquid velocities when ISTOPT = 1 or 2.

VVQ: Default value for initial vapor velocities input through NAMELIST and used to specify vapor velocities when ISTOPT = 1 or 2.

INTEGER VARIABLE:

ISTOPT: Default-value input option.

COMDECK DF1DC

COMMON/DF1DC/A11111,C1A,C1AV,C2A,C2AV,CT,CTP,DVJP,FL1,FL2,FV1,FV2,
HAVLV,QTP,R1L,R1V,R2L,R2V,S01,S02,SALT,SAVT,SSAC,SSE,
SSMC,SSMOM,SSVC,SSVE,VJS,ZZZZZZ

COMMON/DF1DC/IO1,IO2,IO3,IACC2,IBKS,ICLFLG,ICME,ICORL,ICORU,IIO1,IIO2,
IIO3,IL,ISFLG,ISLB,ISRB,IVPVLV,JSTART,LPINDX,MSC,NC2,NJN,
NSTG,NTEE

REAL VARIABLES:

A11111: Dummy variable that provides a known start to the
COMMON block.

C1A: Fraction of liquid velocity at the left face of the
tee junction cell that contributes to the momentum
transfer into the tee side leg.

C1AV: Vapor velocity fraction at the left face of the tee
junction cell that contributes to the momentum trans-
fer into the tee side leg.

C2A: Fraction of liquid velocity at the right face of the
tee junction cell that contributes to the momentum
transfer into the tee side leg.

C2AV: Vapor velocity fraction at the right face of the tee
junction cell that contributes to the momentum trans-
fer into the tee side leg.

CT: Momentum source coefficient.

CTP: Momentum source coefficient.

DVJP: Pressure derivative of source velocity.

FL1: Temporary storage for liquid mass-flow corrections for
mass conservation checks at low-numbered cell face.

FL2: Temporary storage for liquid mass-flow corrections for
mass conservation checks at high-numbered cell face.

FV1: Temporary storage for vapor mass-flow corrections for
mass conservation checks at low-numbered cell face.

FV2: Temporary storage for vapor mass-flow corrections for
mass conservation checks at high-numbered cell face.

HAVLV: Temporary storage for the hydraulic diameter when the valve is open.
 QTP: Total direct power input.
 R1L: Coefficient for the liquid momentum source term at the left edge of the tee junction cell.
 R1V: Coefficient for the vapor momentum source term at the left edge of the tee junction cell.
 R2L: Coefficient for the liquid momentum source term at the right edge of the tee junction cell.
 R2V: Coefficient for the vapor momentum source term at the right edge of the tee junction cell.
 S01: Sign of IOU(1,current component).
 S02: Sign of IOU(2,current component).
 SALT: Source term to liquid for compressible work.
 SAVT: Source term to vapor for compressible work.
 SSAC: Air source.
 SSE: Energy source.
 SSMC: Mass source.
 SSMOM: Momentum source to left-hand cell boundary.
 SSVC: Vapor mass source.
 SSVE: Vapor energy source.
 VJS: Source velocity.
 ZZZZZ: Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES:

IO1: ABS(IOU(1,current component)).
 IO2: ABS(IOU(2,current component)).
 IO3: IOU(3,current component) [always positive].
 IACC2: Flag for pipe used to model accumulator.

IBKS:	Indicator for network solution.
ICLFLG:	Flag used by the steam-generator component in the postpass to instruct the numerical stabilizer whether or not the second junction of a secondary component is connected to an external component.
ICME:	Component index for referencing IOU array.
ICORL:	Core lower boundary.
ICORU:	Core upper boundary.
II01:	IO1 plus a displacement for the current loop.
II02:	IO2 plus a loop displacement.
II03:	IO3 plus a loop displacement.
IL:	Loop number index.
ISFLG:	Flag that indicates if the calculations are being performed for a steam-generator component.
ISLB:	Left-hand boundary switch.
ISRB:	Right-hand boundary switch.
JSTART:	Cell number at left end of one-dimensional segment.
LPINDX:	Loop index that indicates the loop in the system.
MSC:	Cell number for source terms.
NC2:	Cell number that begins a tee and steam-generator tee secondary.
NJN:	Number of network matrix junctions.
NSTG:	Counter for steam generators.
NTEE:	Counter for tees.

COMDECK DIDDLE

COMMON/DIDDLE/AFCT,ALPBCT,ALPCC,ALPLVL,ALPLVU,ALPSHL,ALPSHU,CALV2,CBMIN,
ENCUT,ENFAC1,ENFAC2,ENMIN,FAREA1,FAREAH,FAREAV,FMD1,FMD2,
FSE5,VDRPF,SCINAN,VDRPMX,VECLCT,VECVCT,VINTF,VLVCMX,
VRBCUT,VRTCUT

COMMON/DIDDLE/NIFSLB

REAL VARIABLES:

AFCT: Area scaling for waves on inverted annular interface.

ALPBCT: Lower bound on bubble void fraction used to compute interfacial heat-transfer rates (and resulting Γ) when boiling.

ALPCC: Void fraction that gives the minimum value for the bubble condensation rate.

ALPLVL: Lowest value of the maximum adjacent void fraction allowed for calculating a plug interfacial area.

ALPLVU: Highest value of the minimum adjacent void fraction allowed for calculating a plug interfacial area.

ALPSHL: Void below which the interface sharpener is off.

ALPSHU: Void above which the interface sharpener is completely on.

CALV2: The constant a in Eq. (82), the liquid-side HTC for superheated drops.

CBMIN: Minimum allowed mean bubble diameter.

ENCUT: Minimum droplet entrainment fraction.

ENFAC1: Scaling factor for minimum entrainment velocity.

ENFAC2: Scaling factor for entrainment correlation exponent.

ENMIN: Variable not implemented.

FAREA1: Scale factor for one-dimensional plug flow condensation area.

FAREAH: Scale factor for three-dimensional separated plug flow horizontal condensation area.

FAREAV: Scale factor for three-dimensional separated plug flow vertical condensation area.

FMD1: Factor scaling the gravity void-fraction adjustment.
If both are zero, there is no manometer damping.

FMD2: Factor scaling the gravity void-fraction adjustment.
If both are zero, there is no manometer damping.

FSE5: Scale factor for pool entrainment.

SCINAN: Scale factor for inverted annular drag.

VDRPF: Scale factor in the expression for the limiting
circulation velocity in a drop.

VDRPMX: Maximum allowed internal circulation velocity in a
drop.

VECLCT: Lowest allowed liquid speed when computing interfacial
coefficients.

VECVCT: Lowest allowed vapor speed when computing interfacial
coefficients.

VINTF: Factor in expression for mean circulation speed in a
moving drop.

VLVCMX: Maximum liquid velocity used for the condensation ALV
correlation.

VRBCUT: Minimum allowed relative velocity for computing ALV
during boiling.

VRTCUT: Minimum allowed relative speed for computing inter-
facial coefficients (except during boiling).

INTEGER VARIABLES:

NIFSLB: If nonzero, then slabs should be used to test for
inverted annular flow.

COMDECK DIDDLH

COMMON/DIDDLH/AFLML,AFLMU,ALP2,ALP3,ALPBR,ALPCUT,ALOW,AUP,FDFHL,HGF,HGVMN

COMMON/DIDDLH/IHTAV,IHTCN,NSHTCN

REAL VARIABLES:

AFLML: Void fraction below which Bromley film boiling
contributes fully to the liquid.

AFLMU: Void fraction above which no Bromley coefficient is
added to the liquid.

ALP2: Void above which vapor is in forced convection.

ALP3: Void above which there is no liquid heat transfer.

ALPBR: Void above which liquid convection is linearly faired off and vapor connection is faired on.

ALPCUT: Void above which nucleate boiling is not permitted (if other criteria are met).

ALOW: Lowest value of α in adjacent cells.

AUP: Highest value of α in adjacent cells.

FDFHL: A scaling factor for the wall to droplet heat-transfer correlation.

HGF: Function of nucleate-boiling heat transfer, which contributed to subcooled boiling.

HGVMN: Cutoff velocity for condensation used to suppress subcooled nucleate boiling.

INTEGER VARIABLES:

IHTAV: Variable is normally 1. If IHTAV is 0, then there is no time averaging of HTC's.

IHTCN: Variable is normally 0. If set to 1, then HTC's are forced to remain constant.

NSHTCN: Variable is normally 10 000 000. If NSTEP > NSHTCN, then IHTCH is set to 1 (for debugging only).

COMDECK DIMENSION

COMMON/DIMEN/IFREE,JNVSSL,LAST,LENBD,LENDIM,LENTBL,LFREE,LLAST,LVER,NCOMP,
NCOMPT,NJNMX,NJNT,NJUN,NLOOPS,NMVSSL,NPX,NSTGJ,NTHM,NTHM1D,
NTHM3D,NUMTCR,NVCON

INTEGER VARIABLES:

IFREE: First free word in the dynamic storage area.

JNVSSL: Maximum number of vessel junctions in a loop.

LAST: Last word in the dynamic storage area.

LENBD: Length of boundary data array for each junction.

LENDIM: Variable that dimensions the component variable-length tables.

LENTBL:	Length of fixed-length table.
LFREE:	First free location in LCM.
LLAST:	Last location in LCM.
LVER:	Location in LCM of version information data.
NCOMP:	Number of components (each STGEN component counts as a single component).
NCOMPT:	Total number of components, including the secondary components defined as parts of the STGEN components.
NJNMX:	Maximum number of network junctions.
NJNT:	Total number of network junctions for all loops.
NJUN:	Number of junctions.
NLOOPS:	Number of one-dimensional loops in the system.
NMVSSL:	Number of vessels.
NPX:	Number of pointers in the PTRS COMMON block.
NSTGJ:	Number of internal junctions in a steam generator.
NTHM:	Number of elements per cell in the DRIV array.
NTHM1D:	Length of the data stored per cell in the DRIV array (mostly thermodynamic derivatives) in one-dimensional components.
NTHM3D:	Length of the data stored per cell in the DRIV array (mostly thermodynamic derivatives) in three-dimensional components.
NUMTCR:	Number of title cards.
NVCON:	Total number of vessel connections.

COMDECK DLIMIT

COMMON/DLIM/DELAMX, DELCMX, DELDMX, DELEMX, DELPMX, DELRMX, DELVMX, DELXMX,
DTBKUP, FPMAX, FXMAX, GXMAX

COMMON/DLIM/NLIM

DIMENSION NLIM(8)

REAL VARIABLES:

DELAMX:	Time-step limit caused by void-fraction change.
DELCMX:	Time-step limit caused by maximum changes in pressures and temperatures.
DELDMX:	Time-step limit caused by numerical considerations in the rod heat transfer.
DELEMX:	Time-step limit caused by vessel mass errors.
DELPMPX:	Estimated time-step size that results in a 20% change in core power.
DELRMX:	Time-step limit caused by final value of the percentage variation in pressure from iteration to iteration.
DELVMX:	Material Courant stability limit (computed only in vessels).
DELXMX:	The maximum time-step size permitted for adjustment of VALVE components.
DTBKUP:	Desired time-step size for repeating a time step when the back-up is detected by subroutine HOUT.
FPMAX:	Maximum fractional change (0.2) in core power per time step.
FXMAX:	Valve adjustment algorithm parameter (0.4).
GXMAX:	Maximum limit on the change in the VALVE flow-area fraction over a time step.

INTEGER VARIABLES:

NLIM(8):	Array that stores the number of times each of the time-step limits controls the time-step size since the last major edit.
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COMDECK DMPCTRL

COMMON/CTRLDP/DMPFLG,DMPINT,LTDUMP,TDUMP

COMMON/CTRLDP/ICTRLD,NSDO

DIMENSION ICTRLD(8)

REAL VARIABLES:

DMPINT: Dump interval for time domain.

LTDUMP: CPU time when last dump was taken.

TDUMP: Calculation time when next dump will be taken.

INTEGER VARIABLES:

DMPFLG: Flag that signals whether the dump output file has
been initialized.
0 = uninitialized;
1 = initialized.

ICTRLD(8): Array that contains buffering information about the
dump output file.

NSDO: Time-step number of last completed dump.

COMDECK ELVKF

COMMON/ELVKF/IELV,IINL,IKFAC

INTEGER VARIABLES:

IELV: Input option switch that allows user to input cell-
centered elevations for gravity term.

IINL: Index for the two passes through INIT.

IKFAC: Input option switch that allows user to input K
factors for additive loss coefficients.

COMDECK ERRCON

COMMON/ERRCON/DARA,DARL,DARV,DDVL,DDVV,DTLL,DTLLM,DTLU,DTLUM,DTVLM,DTVLM,
DTVU,DTVUM,TIMDL,TIMDU

COMMON/ERRCON/ICHGA,IDARA,IDARL,IDARV,IDDVL,DDVV,DTLL,DTLU,DTVLM,
IDTVU,ILREIT,IPTEST,JDARA,JDARL,JDARV,JDDVL,JDDVV,JDTLL,
JDTLU,JDTVLM,JDTVU,JPTTEST,NSDL,NSDU

REAL VARIABLES:

DARA:	Maximum change in αp_a .
DARL:	Measure of the maximum difference in $(1 - \alpha) p_g$ between the basic and stabilizer steps.
DARV:	Measure of the maximum difference in αp_g between the basic and stabilizer steps.
DDVL:	Measure of the maximum difference in V_l between the basic and stabilizer steps.
DDVV:	Measure of the maximum difference in V_g between the basic and stabilizer steps.
DTLL:	Largest decrease in T_l for current iteration.
DTLLM:	DTVLM and DTLLM are limits on DTVL and DTLL beyond which another iteration must be performed.
DTLU:	Largest increase in T_l for current iteration.
DTLUM:	DTVLM and DTLLM are limits on DTVL and DTLL beyond which another iteration must be performed.
DTVLM:	Largest decrease in vapor temperature in a given iteration.
DTVLM:	DTVLM and DTLLM are limits on DTVL and DTLL beyond which another iteration must be performed.
DTVU:	Largest increase in T_g for current iteration.
DTVUM:	DTVLM and DTLLM are limits on DTVL and DTLL beyond which another iteration must be performed.
TIMDL:	If $TIMDL \leq TIMET \leq TIMDU$, details of DARV, etc., should be printed.
TIMDU:	If $TIMDL \leq TIMET \leq TIMDU$, details of DARV, etc., should be printed.

INTEGER VARIABLES:

ICHGA:	Flag to print maximum void-fraction changes to the message file.
IDARA:	Component where DARA occurred.
IDARL:	Component where DARL occurred.
IDARV:	Component where DARV occurred.
IDDVL:	Component where DDVL occurred.
DDVV:	Component where DDVV occurred.
IDTLL:	Component where DTLL occurred.
IDTLU:	Component where DTLU occurred.
IDTVL:	Component where DTVL occurred.
IDTVU:	Component where DTVU occurred.
ILREIT:	Flag that allows reiteration messages when equation set changes.
IPTEST:	Component with maximum $ \delta p/p $.
JDARA:	Cell where DARA occurred.
JDARL:	Cell where DARL occurred.
JDARV:	Cell where DARV occurred.
JDDVL:	Cell where DDVL occurred.
JDDVV:	Cell where DDVV occurred.
JDTLL:	Cell where DTLL occurred.
JDTLU:	Cell where DTLU occurred.
JDTVL:	Cell where DTVL occurred.
JDTVU:	Cell where DTVU occurred.
JPTEST:	Cell with maximum $ \delta p/p $.
NSDL:	If $NSDL \leq NSTEP \leq NSDU$, a detailed diagnostic of DARV, etc., should be printed to TRCMSG.

NSDU: If $NSDL \leq NSTEP \leq NSDU$, a detailed diagnostic of DARV, etc., should be printed to TRCMSG.

FIXED-LENGTH TABLES

The structure of the fixed-length data tables is shown below and is identical for all TRAC components. Refer to Sec. VI for a detailed discussion of the TRAC data base.

COMDECK FIXEDLT

COMMON/FLTAB/HTLSCI,HTLSCO

COMMON/FLTAB/CTITLE,ICFLG,ID,IREST,LENARR,LENFV,LENFV2,LENPTR,LENVLT,
LEXTRA,LFV,LFVN,NCELLT,NODES,NRVLT,NUM,NUMBM1,NUMBM2,
NUMBM3,NUMBN1,NUMBN2,NUMBN3,TYPE //

DIMENSION CTITLE(3)

REAL VARIABLES:

HTLSCI: Inside component heat loss.

HTLSCO: Outside component heat loss.

INTEGER VARIABLES:

CTITLE(3): Component description.

ICFLG: Cell-edge choked-flow model options.

ID: Component identification.

IREST: Component restart indicator.

LENARR: Length of array block.

LENFV: Length of fundamental variables.

LENFV2: Length of fundamental variables for which old time and new time values are the same at the start of the OUTER code block.

LENPTR: Length of pointer table.

LENVLT: Length of variable-length table.

LEXTRA: Length of nonstandard dump for components.

LFV: Relative position of old fundamental variables.

LFVN: Relative position of new fundamental variables.

NCELLT: Total number of cells.

NODES: Number of heat-transfer nodes.

NRVLT: Number of real variables in each component VLT COMMON block.

NUM: Component number.

NUMBM1: Indices to access large numerals for printing component NUM and IORDER.

NUMBM2: Indices to access large numerals for printing component NUM and IORDER.

NUMBM3: Indices to access large numerals for printing component NUM and IORDER.

NUMBN1: Indices to access large numerals for printing component NUM and IORDER.

NUMBN2: Indices to access large numerals for printing component NUM and IORDER.

NUMBN3: Indices to access large numerals for printing component NUM and IORDER.

TYPE: Component type.

COMDECK FIXUM

COMMON/FIXUM/NOAIR,NSMEC,NTHRMC,NVTC

INTEGER VARIABLES:

NOAIR: Variable that turns off air field calculations.

NSMEC: Variable that turns off stabilizer mass and energy equations.

NTHRMC: Variable that turns off (debugs) basic equation set.

NVTC: Variable that turns off stabilizer motion equations.

COMDECK GRAPHICS

COMMON/GRAPH/EDINT,GFINT,SEDINT,TEDIT,TGRAF,TSEDIT

COMMON/GRAPH/IBUFF,ICTRLG,IPKG,KP,LCAT,LCMGCT,LENCAT,NCTX,NSGO,NWTX

[NUCLEAR PLANT ANALYZER (NPA) VARIABLES LISTED BELOW CURRENTLY ARE
INTENDED ONLY FOR IN-HOUSE LOS ALAMOS USE.]

COMMON/GRAPH/EDTBLK,NBLKOUT,IGROUT,IBLK

DIMENSION ICTRLG(8)

REAL VARIABLES:

EDINT: Print edit interval for time domain.
GFINT: Graphics edit interval for time domain.
SEDINT: Interval for short edits.
TEDIT: Time of next print edit.
TGRAF: Time of next graphics edit.
TSEDIT: Time for next short edit.

INTEGER VARIABLES:

IBLK: Counter for number of data-edit blocks.
IBUFF: Length of graphics buffer.
ICTRLG(8): Array that contains buffering information about the
 graphics output file.
IGROUT: Controller that maintains the address for NPA random
 disk writes.
IPKG: Graphics file packing density.
KP: Pointer in graphics catalog block.
LCAT: Address of graphics catalog in SCM.
LCMGCT: Address of graphics catalog in LCM.
LENCAT: Number of words in each catalog entry.
NBLKOUT: Counter for the number of words written to buffer in
 current graphics data edit.

NCTX: Number of graphics catalog entries.
NSGO: Time-step number of last completed graphics edit.
NWTX: Number of words written to disk per graphics edit.

LOGICAL VARIABLE:

EDTBLK: Flag that is set to TRUE when graphics file is written
 to start of the first data edit.

COMDECK HOLLERITH

COMMON/HOLL/ACCUMH,BREAKH,COREH,CTAINH,FILLH,PIPEH,PLENH,PRIZRH,PUMPH,
 STGENH,TEEH,TURBH,VALVEH,VSSLH

INTEGER VARIABLES:

ACCUMH: Hollerith representation of word "ACCUM."
BREAKH: Hollerith representation of word "BREAK."
COREH: Hollerith representation of word "CORE."
CTAINH: Hollerith representation of word "CTAIN."
FILLH: Hollerith representation of word "FILL."
PIPEH: Hollerith representation of word "PIPE."
PLENH: Hollerith representation of word "PLENUM."
PRIZRH: Hollerith representation of word "PRIZER."
PUMPH: Hollerith representation of word "PUMP."
STGENH: Hollerith representation of word "STGEN."
TEEH: Hollerith representation of word "TEE."
TURBH: Hollerith representation of word "TURB."
VALVEH: Hollerith representation of word "VALVE."
VSSLH: Hollerith representation of word "VESSEL."

COMDECK HOLLR

COMMON/HOLLR/HPLEN,HPRIZR,VSS

REAL VARIABLES:

HPLEN: Real Hollerith PLENUM component name.
HPRIZR: Real Hollerith PRIZER component name.
VSS: Real Hollerith VESSEL component name.

COMDECK IOUNITS

COMMON/UNITS/CARD,IBFADD,IBFADG,IBFADR,IBFLND,IBFLNG,IBFLNR,IDOUT,IGOUT,
IMOUT,IN,INPROC,IODONE,IOERR,IOSKIP,IOUT,IRSTRT,ITTY,LCMCPD

INTEGER VARIABLES:

CARD(9): Variable that contains the current input card in character format.
IBFADD: Pointer to beginning of dump LCM buffer.
IBFADG: Pointer to beginning of graphics LCM buffer.
IBFADR: Pointer to beginning of restart LCM buffer.
IBFLND: Length of dump buffer.
IBFLNG: Length of graphics buffer.
IBFLNR: Length of restart buffer.
IDOUT: I/O unit number for dump output file (currently set to unit 12).
IGOUT: I/O unit number for graphics output file (currently set to unit 11).
IMOUT: I/O unit number for warning messages (currently set to unit 7).
IN: I/O unit number for input to TRAC (initially set to unit 5 to point to file TRCINP; if the input does not invoke free format, IN is changed to 1 to point to file TRACIN).
INPROC: Flag used during input that indicates whether component data is being processed.

IODONE: Flag that indicates if the current input card has been read.
 IOERR: Input error flag.
 IOSKIP: Flag that turns input processing off and on.
 IOUT: I/O unit number for printed output file (currently set to unit 6).
 IRSTRT: I/O unit number for restart input file (currently set to unit 13).
 ITTY: I/O unit number for terminal output (currently set to unit 59).
 LCMCPD: Storage for the beginning address for reading from or writing to LCM with calls to subroutines RDLCM and WRLCM.

COMDECK ITERSTAT

COMMON/ISTAT/VARERM,VERR

COMMON/ISTAT/IIBIG,IIFAIL,IITNO,IITV,IOTT,NSTEP,OITNO

REAL VARIABLES:

VARERM: Maximum variable error.
 VERR: Velocity error at component junction.

INTEGER VARIABLES:

IIBIG: Maximum number of inner iterations per outer iteration.
 IIFAIL: Flag that indicates failure of hydrodynamics to converge.
 IITNO: Inner iteration number.
 IITV: Variable that passes the vessel inner iteration count.
 IOTT: Temporary storage for IITNO.
 NSTEP: Number of time steps taken.
 OITNO: Outer iteration number.

COMDECK JUNCTION

COMMON/JUNCT/JMATCH,JPTR

INTEGER VARIABLES:

JMATCH: Counts the number of bad junction numbers detected during the network trace in SRTLTP.

JPTR: Number of junction-component pairs.

COMDECK LCMSPACE

COMMON/LCMSP/ALCM(131071)

ALCM(131071): Dynamic LCM storage area.

COMDECK MDFCOM

COMMON/MDFCOM/ICLIST(100),INPT,INRST

DIMENSION ICLIST(100)

INTEGER VARIABLES:

ICLIST(100): Component number list that is used during interactive deck modifications.

INPT: Unit number for the input deck that is to be interactively modified.

INRST: Unit number for the restart input deck, which contains interactively modified components.

COMDECK MEMORY

COMMON/TIMER/ADATE,ATIME,CPTIME,CPUT,SYSTM,TIMEI,TIMIO,TLTSS

COMMON/TIMER/NSTEPT

REAL VARIABLES:

ADATE: Storage for the date obtained from a call to the system routine DATE.

ATIME: Storage for the time obtained from a call to the system routine DATE.

CPTIME: Storage for the CPU time obtained from a call to the system routine TIMING.

CPUT: Storage for the cumulative CPU time from previous jobs in a linked series of calculations; CPUT is set to 0.0 at time 0.0.

SYSTM: Storage for the system time obtained from a call to the system routine TIMING.

TIMEI: Storage for the time limit of the current job and obtained from a call to the system routine GETJTL.

TIMIO: Storage for the I/O time obtained from a call to the system routine TIMING.

TLTSS: Storage for the charge time obtained from a call to the system routine SECOND.

INTEGER VARIABLE:

NSTEPT: Storage for the cumulative number of time steps from previous jobs in a linked series of calculations; NSTEPT is set to 0 at time 0.0.

COMDECK NMFAIL

COMMON/NMFAIL/S3

COMMON/NMFAIL/IFTP,ITFL1,NFL1,NFL3

REAL VARIABLE:

S3: Offset on liquid super heat used in interfacial area adjustment.

INTEGER VARIABLES:

IFTP: Flag that prevents thermal failure messages if a message has come from TF1SD3 or FF3D.

ITFL1: Iteration number of the last TF1DS3 failure.

NFL1: Total number of TF1DS3 failures in the current time step.

NFL3: Total number of FF3D failures in the current time step.

COMDECK NPA

[NUCLEAR PLANT ANALYZER (NPA) VARIABLES LISTED BELOW CURRENTLY ARE INTENDED ONLY FOR IN-HOUSE LOS ALAMOS USE.]

COMMON/NPA/CONNPA,DTDUMP,DTEDIT,DTNPA,SRATIO,TGEDIT,TIMNPA,TPAUSE,TPDUMP,
TRCNPA,TSTOP,VALNPA,ZNAME

COMMON/NPA/IACT,IFD,NACT,NFNPA,NPACOM,NTSNPA

DIMENSION TIMNPA(100),VALNPA(100),ZNAME(6),NAPCOM(100)

REAL VARIABLES:

CONNPA:	Hollerith data name for the NPA executive "master" program connected to the process-to-process (PTP) data path.
DTDUMP:	Time edit, defined interactively by the the NPA user, between dump (restart) edits to file TRCDMP.
DTEDIT:	Time interval, defined interactively by the NPA user, between large edits to file TRCOUT.
DTNPA:	Time error (0.1 s) allowed to implement an NPA user command before the user is prompted by the system to decide if a back-up procedure should be performed to implement the command action at the correct problem time.
SRATIO:	Maximum speed ratio of the problem time-step size to the computer time required to evaluate the time step.
TGEDIT:	Problem time after which the next NPA user-defined graphics edit to file TRCGRF will occur.
TIMNPA(100):	Array that defines the problem time when a pending NPA user-defined action will be implemented.
TPAUSE:	Problem time when the next NPA user-defined pause in the TRAC calculation will occur.
TPDUMP:	Problem time after which the next NPA user-defined dump (restart) edit to file TRCDMP will occur.
TRCNPA:	Hollerith data name for the TRAC "slave" program connected to the PTP data path.
TSTOP:	Problem time specified by the NPA user after which the TRAC calculation will terminate.

VALNPA(100): Array that defines the desired value of an NPA user-controlled action that is pending at time TIMNPA.

ZNAME(6): Array containing a Hollerith data message that communicates NPA user commands to TRAC or TRAC warning messages to the NPA executive program.

INTEGER VARIABLES:

IACT: Flag that is changed from 0 to 1 when an additional graphics edit and dump (restart) edit will be performed before an NPA user-defined component-action adjustment is performed.

IFD: Number of PTP data paths.

NACT: Number of pending NPA user-defined commands stored in arrays TIMNPA, VALNPA, and NPACOM.

NFNPA: Flag that is changed from 0 to 1 when file PTPDSK will not be destroyed at the end of the TRAC run.

NPACOM(100): Array that defines the component number to which a pending NPA user-defined action will be applied at time TIMNPA.

NTSNPA: Number of TRAC time steps (2) between TRAC status messages that are being sent to the NPA executive program.

COMDECK PIPEPT

COMMON/PTAB/LPOWRF,LPOWTB,LQP3RF,LQP3TB,PTDUM

INTEGER VARIABLES:

LPOWRF: A-array pointer variable for the rate-factor table that is applied to the independent variable of the reactivity/power table.

LPOWTB: A-array pointer variable for the reactivity/power definition table.

LQP3RF: A-array pointer variable for the rate-factor table that is applied to the independent variable for the q''' source table.

LQP3TB: A-array pointer variable for the q''' source table.

PTDUM: Dummy array that accounts for the remaining unused variables in the PTAB COMMON block.

COMDECK POINTERS

-----GENERAL POINTERS-----

```
COMMON/PTRS/I11111,LBD,LCNTL,LCOMPT,LDRA,LDRC,LIITNO,LIJVS,LILCMP,LIOU,  
LISVF,LIVCON,LIVLJN,LJOUT,LJSEQ,LJUN,LLCON,LLOOPN,LMATB,  
LMCMSh,LMsCT,LNBR,LNjN,LNSIG,LNSIGP,LNVCNL.LORDER,LPRPTB,  
LPTBLN,LTITLE,LVSI
```

-----NETWORK SOLUTION POINTERS-----

```
COMMON/PTRS/JAOL,JAov,JDRa,JDRc,JdREL,JdREV,JdRL,JdRV,JNJUN,JOD,LAOL,  
LAOU,LAov,LDPVC,LDPVCV,LdREL,LdREV,LdRL,LdRV,LdVB,LIDPCV,  
LOD,LVRH
```

-----COMBINATION OF UNSHIFTED POINTERS AND ARRAY LENGTHS-----

```
COMMON/PTRS/LENFXD,LFXD,LVMAT,LVSSC,LVSSIP,NMAT,NVCELL,NZZZZZ
```

```
DIMENSION IPT(62)
```

GENERAL POINTERS:

I11111:	Dummy variable that provides a known start to the COMMON block.
LBD:	Boundary data array, described in Table XX of Sec. VI.
LCNTL:	Signal-variable, trip, and controller data array described in Fig. 52 of Sec. VI.
LCOMPT:	Component LCM pointers stored in the order used for iteration.
LDRA:	Storage for right-hand side of the air stabilizer equation.
LDRC:	Pointers for network variables for the solute tracking option.
LIITNO:	Number of inner iterations during the last outer iteration for each component (in the order used for iteration).
LIJVS:	Pointer for a temporary array that contains a list of all junction numbers that link to a vessel.
LILCMP:	Component LCM pointers stored in the order in which components were read.
LIOU:	Network junction numbers for the junctions of all components excluding BREAKs and FILLs.

LISVF: Pointer to an array of flags indicating whether or not a particular component is used to evaluate one or more signal variables (-1, no signal variable; +1, signal variable). This array uses the same order in which the component data are processed.

LIVCON: Pointer to network junction numbers that connect to a vessel.

LIVLJN: IVLJN(I) is the vessel junction number that corresponds to the network junction number given by IVCON(I).

LJOUT: Storage area for pointers that locate the beginning of each system loop within data for IOU.

LJSEQ: Junction numbers in the order in which junctions occur in the junction-component array.

LJUN: Junction-component pair array, described in Table XIX.

LLCON: Number of times each component was the last to converge since last edit.

LLOOPN: IA(LLOOPN+IL-1) gives the element of the IORDER array that begins the ILth loop.

LMATB: Pointer for additional material-property ID number.

LMCMSh: Storage for number of coarse-mesh vessel source cells or absolute cell index if direct vessel solution is used.

LMSCT: Temporary storage for vessel pressure changes adjacent to sources.

LNBR: Component numbers stored in the order in which components were read.

LNJN: NJN(IL) is the number of network junctions in loop IL.

LNSIG: NSIG(IL) is the total number of components excluding BREAKs and FILLs in a loop.

LNSIGP: NSIGP(IL) is NSIG(IL) plus the number of steam generators (STGENs) in loop IL.

LNVCNL: IA(LNVCNL+IL-1) points to the elements of IVCON and IVLJN that begin the ILth loop.

LORDER: Component numbers stored in the order used for iteration.

LPRPTB: Pointer to user-defined material-property tables.

LPTBLN: Pointer for the number of entry groups in the user-defined material-property table.

LTITLE: Problem title and version information (stored using only the first four bytes of each word).

LVSI: Junction flow reversal indicators in the order in which junctions occur in the junction-component array.

NETWORK SOLUTION POINTERS:

LAOL: Variable to rework solution of ARL, AREL, and VLT (contains rework matrix).

LAOU: Network junction coefficient matrix.

LAOV: Variable to rework solution of ARV, AREV, and VVT (contains rework matrix).

LDPVC: Locator that shows the beginning of coefficients to evaluate the derivatives of junction velocities with respect to vessel pressures.

LDPVCV: Pointer for reordered coupling coefficients between the vessel and the one-dimensional network solution.

LDREL: Storage for right-hand side of the liquid stabilizer equation.

LDREV: Storage for right-hand side of the vapor stabilizer equation.

LDRL: Variable to rework solution of ARL and VLT (contains right-hand side of linear equations).

LDRV: Variable to rework solution of ARV and VVT (contains right-hand side of linear equations).

LDVB: Storage for the right-hand side of the network junction equations or the changes in junction velocities.

LIDPCV: Pointers to coefficients stored in DPCV.

LOD: Temporary storage for intercomponent coupling information.

LVRH: Storage for explicit information to evaluate equations of motion at network junctions.

JAOL: Pointer for steam-generator internal network solution matrix.

JAOV: Pointer for steam-generator internal network solution matrix.

JDRA: Pointer for steam-generator internal network solution vector.

JDRC: Pointer for steam-generator internal network solution vector.

JDREL: Pointer for steam-generator internal network solution vector.

JDREV: Network vector internal to the steam generator.

JDRL: Pointer for steam-generator internal network solution vector.

JDRV: Pointer for steam-generator internal network solution vector.

JNJUN: Temporary storage location used to define the number of junctions in the current network solution procedure.

JOD: Pointer for steam-generator internal network solution matrix.

COMBINATION OF UNSHIFTED POINTERS AND ARRAY LENGTHS:

LENFXD: Length of data that always remains in the SCM array A.

LFXD: First word address in the A array of the data defined by LENFXD.

LVMAT: Vessel matrix storage for coarse-mesh rebalance or direct inversion.

LVSSC: Right-hand side of equation associated with LVMAT.

LVSSIP: Pivoting information for LVMAT.

NMAT: Number of additional material-property tables provided by the user.

NVCELL: Total number of coarse regions when iteration is used on the vessel or total number of cells in all vessels if direct solution is used.

NZZZZZ: Dummy integer that provides a known end to the COMMON block.

COMDECK PSE

COMMON/PSE/NPICMP,NPSE,NPSE1,NPSE3,NPSIZ,NPSJ,NPSK,NPSV1

INTEGER VARIABLES:

NPICMP: Component number in TF1DS (pause) if NSTEP = NPSE1.

NPSE: Pause in TRANS if NSTEP = NPSE.

NPSE1: Pause in TF1DS if NSTEP = NPSE1. The cell number is NPSJ, and the component number is NPICMP.

NPSE3: Pause in TF3DI if NSTEP = NPSE3. The cell index K is NPSK, and the second level is NPSIZ.

NPSIZ: Level in TF3DI (pause) if NSTEP = NPSE3.

NPSJ: Cell number in TF1DS (pause) if NSTEP = NPSE1.

NPSK: Cell index in TF3DI (pause) if NSTEP = NPSE3.

NPSV1: Pause in TF1DS1 if NSTEP = NPSE1. The cell number is NPSJ, and the component number is NPICMP.

COMDECK RESTART

COMMON/RSTART/DDATE,DDTIME

COMMON/RSTART/DLNFLT,DNCOMP,ICTRLR

DIMENSION ICTRLR(8)

REAL VARIABLES:

DDATE: Date restart file was created.

DDTIME: Time restart file was created.

INTEGER VARIABLES:

DLNFLT: Length of fixed-length tables read from restart file.

DNCOMP: Number of components in the restart file.

ICTRLR(8): Array that contains buffering information about the restart file.

COMDECK SIGNAL

COMMON/SIGNAL/CPV,DSV

DIMENSION CPV(42),DSV(2)

REAL VARIABLES:

CPV(42): Control-panel vector for storing the values of signal-variable parameter numbers 1 through 6 for the global parameters and 7 through 15 for up to four coolant loops.

DSV(2): Dummy signal-variable vector for storing the values of signal-variable parameter numbers 16 and 17.

COMDECK SOLCON

COMMON/SOLCON/CNC,CNMAX,CNMIN,CNT,CNTLMN,CNTLMX

REAL VARIABLES:

CNC: Constant term (kg solute/kg liquid) in linear fit to solubility.

CNMAX: Solubility (kg solute/kg liquid) when liquid temperature is at or above CNTLMX.

CNMIN: Solubility (kg solute/kg liquid) when liquid temperature is at or below CNTLMN.

CNT: Coefficient of liquid temperature (kg solute/kg liquid K) in linear fit.

CNTLMN: Minimum liquid temperature (K) to use linear fit.

CNTLMX: Maximum liquid temperature (K) to use linear fit.

COMDECK STDYERR

COMMON/SSCON/EPS,EPSPOW,FMAX,FMXLVZ,MAXFLN,MINVEL,RTWFP,STIME,TPOWR

COMMON/SSCON/IPOVEL,IPOWR,LOK,NCORES,NEF

DIMENSION FMAX(7),LOK(7,2)

REAL VARIABLES:

EPS: Band on steady-state time for editing and terminating the problem.

EPSPOW: Core power to be initialized when the liquid velocity steady-state change ratio is less than or equal to EPSPOW.
 FMAX(7): Maximum normalized errors.
 FMXLVZ: Maximum normalized rate of change for axial vessel velocities.
 MAXFLN: Maximum one-dimensional mass flow at this steady-state convergence test.
 MINVEL: Minimum liquid velocity for initializing core power.
 RTWFP: Ratio of heat-transfer to fluid-dynamics time-step sizes.
 STIME: Current calculation time for steady state.
 TPOWR: Steady-state time (s) when the rod power should be turned on.

INTEGER VARIABLES:

IPOVEL: Flag that initializes core power based on liquid velocity in core.
 0 = liquid velocity in core less than or equal to MINVEL;
 1 = liquid velocity in core greater than MINVEL.
 IPOWR: Flag that turns on the power in steady state.
 LOK(7,2): Location of maximum normalized errors.
 NCORES: Total number of core and vessel components.
 NEF: Number of time steps between steady-state checks.

COMDECK SYSSUM

COMMON/SYSSUM/ALQCOR,ALQPRZ,ALQUP,CORWM,PMX,TLMX,TLNCOR,TRODMX,TSHCOR,
 TSNCOR,TVMX,VOLCOR,XLQCOR,XTSHCR

COMMON/SYSSUM/JPMX,JTLMX,JTVMX,NPMX,NTLMX,NTVMX

REAL VARIABLES:

ALQCOR: Mean core liquid fraction.
 ALQPRZ: Mean pressure liquid fraction.

ALQUP: Upper-plenum liquid fraction. (Calculated only for three-dimensional vessel.)

CORWM: Core water mass.

PMX: Maximum pressure.

TLMX: Maximum liquid temperature.

TLNCOR: Mean core liquid temperature.

TRODMX: Maximum rod temperature.

TSHCOR: Mean core super heat.

TSNCOR: Mean core saturation temperature.

TVMX: Maximum vapor temperature.

VOLCOR: Core volume.

XLQCOR: Minimum core liquid fraction.

XTSHCR: Maximum core super heat.

INTEGER VARIABLES:

JPMX: Cell number for the maximum pressure.

JTLMX: Cell number for the maximum liquid temperature.

JTVMX: Cell number for the maximum vapor temperature.

NPMX: Component number for the maximum pressure.

NTLMX: Component number for the maximum liquid temperature.

NTVMX: Component number for the maximum vapor temperature.

COMDECK TF3DC

COMMON/TF3DC/INSCT, IZ, KABS0, KCMSH, KL, KU, ORG

INTEGER VARIABLES:

INSCT: Variable used to obtain a displacement into network arrays involving vessel junctions when there is more than one vessel.

IZ: Vessel level number currently being used.

KABSO: Storage offset to obtain an absolute cell number when multiple vessels are used.

KCMSh: Offset for coarse-mesh indexing with multiple vessels.

KL: Displacement of level (IZ-1) from level (IZ) in A3D array.

KU: Displacement of level (IZ+1) from level (IZ) in A3D array.

ORG: Origin of level (IZ) data A3D array.

COMDECK TOTALS

COMMON/TOTALS/TLEN,TVOL

TLEN: Total length of a component section.

TVOL: Total volume of a component section.

COMDECK TSATCN

COMMON/TSATCN/AEOS14,CEOS1,CEOS2,CEOS3,CEOSLP

COMMON/TSATCN/IGAS,ILIQ

DIMENSION CEOSLP(40)

REAL VARIABLES:

AEOS14: Constant in expression for saturation temperature calculation for intermediate pressures.

CEOS1: Constant in expression for saturation temperature, set in routine THERMO, calculation for the intermediate pressures.

CEOS2: Constant in expression for saturation temperature, calculation for the intermediate pressures.

CEOS3: Constant in expression for saturation temperature, calculation for intermediate pressures.

CEOSLP(40): Equation-of-state array for low pressures. Defined in subroutine SETEOS.

INTEGER VARIABLES:

IGAS: Flag for noncondensable gas.
 1 = air;
 2 = hydrogen.

ILIQ: Variable not implemented.

COMDECK TWOSTEP

COMMON/TWOSTP/NPSFE,NPSME,NTSPRN

INTEGER VARIABLES:

NPSFE: Pause in FEMOM if NSTEP = NPSEL. The cell number is
 NPSJ, and the component number is NPICMP.

NPSME: Pause in STBME if NSTEP = NPSEL. The cell number is
 NPSJ, and the component number is NPICMP.

NTSPRN: Flag for printing extra stabilizer step information to
 TRCOUT.

COMDECK VCKDAT

COMMON/VCKDAT/DONTOL

COMMON/VCKDAT/IPRVCK,ISKIP,ITVKMX

REAL VARIABLES:

DONTOL: Tolerance for density difference requiring re-donor-
 celling in VESSEL.

INTEGER VARIABLES:

IPRVCK: Flag to print information about re-donor-celling in
 VESSEL (normally set to 0 for no print).

ISKIP: Flag to skip re-donor-cell logic in VESSEL component
 (normally set to 0 for no skip).

ITVKMX: Maximum iteration count to check for need to re-donor-
 cell in VESSEL.

COMDECK WEBNUM

COMMON/WEBNUM/ALVFCP,ALVFCS,BMIN,CHTFCP,CHTFCS,CHTIBC,CHTIBH,CNDFC,DMIN,
PENTL,PENTU,VLSPR,VVLOW,VVUP,WEB,WED,WEDU

COMMON/WEBNUM/ICHVOL

REAL VARIABLES:

ALVFCP: Multiplier on ALV for low-velocity vertical components.

ALVFCS: Multiplier on ALV under spray conditions.

BMIN: Minimum allowed bubble size.

CHTFCP: Multiplier on CHTI for low-velocity vertical components. //

CHTFCS: Multiplier on CHTI under spray conditions.

CHTIBC: Vapor bubble interfacial HTC when $TV > TSAT$.

CHTIBH: Vapor bubble interfacial HTC when $TV < TSAT$.

CNDFC: Condensation rate scaling factor.

DMIN: Minimum allowed drop size.

PENTL: Lower bound on entrained α .

PENTU: Upper bound on entrained α .

VLSPR: Lower limit on quantity $(1 - \alpha)V_{\ell}$ at the top of the cell above which spray condition is assumed to exist.

VVLOW: Lower limit on vapor velocity for special condensation model for low-velocity vertical components.

VVUP: Upper limit on vapor velocity for special condensation for low-velocity vertical components. Note: For liquid velocity greater than VLUP, regular condensation model is used. For liquid velocity less than VLOW, the special condensation model is used. For liquid velocity between VLOW and VLUP, a linear interpolation between the two models is used. //

WEB: Bubble Weber number.

WED: Droplet Weber number.

WEDU: Droplet Weber number during core upflow (not implemented).

INTEGER VARIABLES:

ICHVOL: Flag that invokes a minimum value on the interface HTC.
0 = has no effect, normal;
1 = sets the minimum to the cell volume times 1.0×10^7 .

COMDECK XVAR

COMMON/XVAR/NX1,NX4,NX5

INTEGER VARIABLES:

NX1: The SX1-NX5 variables are reserved for code testing purposes.
NX4: The SX1-NX5 variables are reserved for code testing purposes.
NX5: Variable set to 1 to bypass coarse-mesh rebalance in the VESSEL.

COMDECK XVOL

COMMON/XVOL/BGSS,DAWL,DAXVL,DAXVU,DGSS,FREV

COMMON/XVOL/IFVT,IFVTU,LDAX

REAL VARIABLES:

BGSS: Limits or special void-fraction prediction logic.
DAWL: Weighting factors in special TFIDS flux logic.
DAXVL: Bypass switches on special TFIDS flux logic.
DAXVU: Bypass switches on special TFIDS flux logic.
DGSS: Limits on special void-fraction prediction logic.
FREV: Sensitivity level for reiteration on flow reversal.

INTEGER VARIABLES:

IFVT: Flag for setting velocities passed to TFIDS for special flux logic.

IFVTU: Time velocity controller.
0 = the XVSET logic uses the old time velocity;
1 = the XVSET logic uses the the new time velocity.

LDAX: Bypass switches on special TFIDS flux logic.

APPENDIX I
COMPONENT DATA TABLES

I. GENERAL POINTER TABLES

The pointer tables for one-dimensional components (described below) use four general sets of pointers DUALPT, HYDROPT, INTPT, and HEATPT.

A. DUALPT

These pointers refer to variables whose values are stored at both old and new time values.

INTEGER VARIABLES

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1	LALP	ALP	NCELLS	Old vapor fractions.
2	LALPD	ALPD	0	Variable not currently implemented.
3	LALPDN	ALPDN	0	Variable not currently implemented.
4	LALPN	ALPN	NCELLS	New vapor fraction.
5	LALV	ALV	NCELLS	Old value of liquid-to-interface HTC times interfacial area (ALV).
6	LALVN	ALVN	NCELLS	New value of liquid-to-interface HTC times interfacial area (ALV).
7	LARA	ARA	NCELLS	Old stabilizer value for αp_a .
8	LARAN	ARAN	NCELLS	New stabilizer value for αp_a .
9	LAREL	AREL	NCELLS	Old stabilizer value for $(1 - \alpha) \rho_l e_l$.
10	LARELN	ARELN	NCELLS	New stabilizer value for $(1 - \alpha) \rho_l e_l$.
11	LAREV	AREV	NCELLS	Old stabilizer value for $\alpha p_v e_v$.
12	LAREVN	AREVN	NCELLS	New stabilizer value for $\alpha p_v e_v$.
13	LARL	ARL	NCELLS	Old stabilizer value for $(1 - \alpha) \rho_l$.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
14	LARLN	ARLN	NCELLS	New stabilizer value for $(1 - \alpha)\rho_g$.
15	LARV	ARV	NCELLS	Old stabilizer value for $\alpha\rho_v$.
16	LARVN	ARVN	NCELLS	New stabilizer value for $\alpha\rho_v$.
17	LBIT	BIT	NCELLS+1	Bit flags from previous time step.
18	LBITN	BITN	NCELLS+1	Bit flags for current time step.
19	LCIF	CIF	2(NCELLS+1)	Old interfacial drag coefficients.
20	LCIFN	CIFN	2(NCELLS+1)	New interfacial drag coefficients.
21	LCONC	CONC	NCELLS*ISOLUT	Old boron mass to coolant mass ratio. ISOLUT = 0 or 1.
22	LCONCN	CONC	NCELLS*ISOLUT	New boron mass to coolant mass ratio. ISOLUT = 0 or 1.
23-25	LD(3)	D	0	Variable not currently implemented.
26-28	LDN(3)	DN	0	Variable not currently implemented.
29	LEA	EA	NCELLS	Old air internal energy.
30	LEAN	EAN	NCELLS	New air internal energy.
31	LEL	EL	NCELLS	Old liquid internal energy.
32	LELN	ELN	NCELLS	New liquid internal energy.
33	LEV	EV	NCELLS	Old vapor internal energy.
34	LEVN	EVN	NCELLS	New vapor internal energy.
35	LGAM	GAM	NCELLS	Old vapor generation rate per unit volume.
36	LGAMN	GAMN	NCELLS (ρ_g)	New vapor generation rate per unit volume.
37	LHIL	HIL	NCELLS	New HTC between inside wall and liquid.
38	LHILO	HILO	NCELLS	Old HTC between inside wall and liquid.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
39	LHIV	HIV	NCELLS	New HTC between inside wall and vapor.
40	LHIVO	HIVO	NCELLS	Old HTC between inside wall and vapor.
41	LHLV	HLV	NCELLS	Old value of vapor-to-interface HTC times interfacial area (CHTI).
42	LHLVN	HLVN	NCELLS	New value of vapor-to-interface HTC times interfacial area (CHTI).
43	LP	P	NCELLS	Old pressure.
44	LPA	PA	NCELLS	Old air partial pressure.
45	LPAN	PAN	NCELLS	New air partial pressure.
46	LPN	PN	NCELLS	New pressure.
47	LROA	ROA	NCELLS	Old air densities.
48	LROAN	ROAN	NCELLS	New air density.
49	LROL	ROL	NCELLS	Old liquid densities.
50	LROLN	ROLN	NCELLS	New liquid density.
51	LROV	ROV	NCELLS	Old vapor densities.
52	LROVN	ROVN	NCELLS	New vapor density.
53	LS	S	NCELLS*ISOLUT	Old boron solute mass plated on structure surface. ISOLUT = 0 or 1.
54	LSN	SN	NCELLS*ISOLUT	New boron solute mass plated on structure surface. ISOLUT = 0 or 1.
55	LTD	TD	0	Variable not currently implemented.
56	LTDN	TDN	0	Variable not currently implemented.
57	LTL	TL	NCELLS	Old liquid temperature.
58	LTLN	TLN	NCELLS	New liquid temperature.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
59	LTV	TV	NCELLS	Old vapor temperature.
60	LTVN	TVN	NCELLS	New vapor temperature.
61	LTW	TW	NCELLS*NODES	Old wall temperatures.
62	LTVN	TVN	NCELLS*NODES	New wall temperatures.
63	LVL	VL	NCELLS+1	Old liquid velocities.
64	LVLN	VLN	NCELLS+1	New liquid velocities.
65	LVLT	VLT	NCELLS+1	New stabilizer liquid velocity ($\tilde{V}_e^{n+1}$).
66	LVLTO	VLTO	NCELLS+1	Old stabilizer liquid velocity ($\tilde{V}_e^n$).
67	LVM	VM	NCELLS+1	Initial mixture velocities.
68	LVMN	VMN	NCELLS+1	New mixture velocity.
69	LVV	VV	NCELLS+1	Old vapor velocities.
70	LVVN	VVN	NCELLS+1	New vapor velocities.
71	LVVT	VVT	NCELLS+1	New stabilizer vapor velocity ($\tilde{V}_g^{n+1}$).
72	LVVTO	VVTO	NCELLS+1	Old stabilizer vapor velocity ($\tilde{V}_g$).

B. HYDROPT

These pointers refer to variables associated with the hydrodynamic calculations.

INTEGER VARIABLES

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1	LALPMN	ALPMN	NCELLS	Minimum value of void fraction among a cell and all its neighbors.
2	LALPMX	ALPMX	NCELLS	Maximum value of void fraction among a cell and all its neighbors.
3	LALPO	ALPO	NCELLS	Void fraction from previous step (α^{n-1}).
4	LAM	AM	NCELLS	New pointer for air mass.
5	LARC	ARC	NCELLS*ISOLUT	Density of solute in cell, $c(1 - \alpha)\rho_g$. ISOLUT = 0 or 1.
6	LB	B	0	Variable not currently implemented.
7	LCFZ	CFZ	0	Variable not currently implemented.
8	LCL	CL	NCELLS	Liquid conductivity.
9	LCPL	CPL	NCELLS	Liquid specific heat at constant pressure.
10	LCPV	CPV	NCELLS	Vapor specific heat at constant pressure.
11	LCV	CV	NCELLS	Vapor conductivity.
12	LDALVA	DALVA	NCELLS	Derivative of ALV with respect to α .
13	LDFLDP	DFLDP	NCELLS+1	Derivative of liquid velocity with respect to pressure.
14	LDFVDP	DFVDP	NCELLS+1	Derivative of vapor velocity with respect to pressure.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
15	LDRIV	DRIV1	19*(NCELLS+1)	Storage array for thermodynamic derivatives and enthalpies.
16	LDX	DX	NCELLS	Cell length in flow direction.
17	LELEV	ELEV	NCELLS*IELV	The pointer for the array containing cell-centered elevations. It is used only if IELV is set to 1 in the NAMELIST input.
18	LFA	FA	NCELLS+1	Cell-edge flow area.
19	FAVOL	FAVOL	NCELLS	Cell flow area used in choked-flow model.
20	LFINAN	FINAN	NCELLS	Inverted annular regime factor.
21	LFRIC	FRIC	(NCELLS+1) *NFRCL	Additive friction factors.
22	LFSMLT	FSMLT	NCELLS	Interphasic area multiplier during condensation.
23	LGRAV	GRAV1	NCELLS+1	Gravitation terms (cosine theta).
24	LGRVOL	GRAV1	NCELLS	Cell-averaged GRAV.
25	LH(1)	WFHF	NCELLS+1	Weighting factor for stratified-flow regime.
26	LH(2)	SI*DX	NCELLS+1	Stratified interfacial area.
27	LH(3)	DHLDZ	NCELLS+1	Gravitational head force caused by alpha gradient.
28	LHD	HD	(NCELLS+1) *NDIAL	Hydraulic diameters.
29	LHFG	HFG	NCELLS	Latent heat of vaporization.
30	LHGAM	HGAM	NCELLS	Continuation of heat transfer to subcooled boiling.
31	LHLA	HLA	NCELLS	Sum of all products of liquid HTC with heat-transfer area.
32	HLATW	HLATW	NCELLS	Similar to LHLA except that the product includes wall temperature.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
33	LHVA	HVA	NCELLS	Sum of all products of vapor HTC with heat-transfer area (similar to LHVA).
34	LHVATW	HVATW	NCELLS	Similar to LHVA except that the product includes wall temperature.
35	LQP3F	QP3F	NCELLS	QPPP factor applied to the wall heat source.
36	LQPPP	QPPP	NODES*NCELLS	Wall heat source.
37	LRHS	RHS	NCELLS	Right-hand side of the vapor continuity and energy equations.
38	LRMEM	RMEM	0	Variable not currently implemented.
39	LRMVM	RMVM	NCELLS+1	Mixture density times mixture velocity.
40	LROM	ROM	NCELLS	Mixture density.
41	LRVMF	RVMF	NCELLS+1	Pointer for vapor mass flow. //
42	LSIG	SIG	NCELLS	Surface tension.
43	LTRID	TRID	6*(NCELLS+1)	Storage for stabilizer linear system.
44	LTSAT	TSAT	NCELLS	Saturation temperature.
45	LTSSN	TSSN	NCELLS	Saturation temperature for steam pressure.
46 ¹⁵	LVISL	VISL	NCELLS	Liquid viscosity.
47	LVISV	VISV	NCELLS	Vapor viscosity.
48	LVLALP	VLALP	NCELLS	Liquid mass flux that enters the cell from the cell edges located above the cell.
49	LVLVC	VLVC	NCELLS	Liquid velocity at a neighboring cell edge where the donor-celled liquid fraction is maximum.
50	LVLVOL	VLVOL	NCELLS	Cell liquid velocity used in choked-flow model.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
51	LVLX	VLX	0	Variable not currently implemented.
52	LVOL	VOL	NCELLS	Cell volumes.
53	LVR	VR	NCELLS+1	Relative velocity.
54	LVVOL	VVOL	NCELLS	Cell vapor velocity used in choked-flow model.
55	LVVX	VVX	0	Variable not currently implemented.
56	LWA	WA	NCELLS	Wall areas.
57	LWAT	WAT	NCELLS	Total heat-transfer area.
58	LWFL	WFL	NCELLS+1	Wall friction factor for liquid.
59	LWV	WV	NCELLS+1	Wall friction factor for vapor.

C. INTPT

These pointers refer to variables with integer values.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1	LIDR	IDR	NCELLS	Heat-transfer regime.
2	LMATID	MATID	NODES-1	Material identifications.
3	LNFF	NFF	NCELLT+1	Friction-correlation options.

D. HEATPT

These pointers refer to variables associated with the wall heat-transfer calculations.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1	LCPW	CPW	(NODES-1) *NCELLS	Specific heat of wall.
2	LCW	CW	(NODES-1) *NCELLS	Wall conductivity.
3	LDR	DR	NODES-1	Radial mesh size.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
4	LEMIS	EMIS	NCELLS	Wall emissivity.
5	LHOL	HOL	NCELLS	HTC between outside wall and liquid.
6	LHOV	HOV	NCELLS	HTC between outside wall and vapor.
7	LQPPC	QPPC	NCELLS	Critical heat flux.
8	LRN	RN	NODES	Radii at nodes.
9	LRN2	RN2	NODES-1	Radii at node centers.
10	LOW	ROW	(NODES-1) *NCELLS	Wall density.
11	LTOL	TOL	NCELLS	Liquid temperature outside wall.
12	LTOV	TOV	NCELLS	Vapor temperature outside wall.

II. ACCUMULATOR MODULE

A. ACCUMVLT--ACCUM Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	BSMASS	Time-integrated mass flow from component.
3-4	FL(2)	Liquid mass-flow corrections for mass-conservation checks.
5	FLOW	Volume flow rate at discharge.
6-7	FV(2)	Vapor mass-flow corrections for mass-conservation checks.
8	QINT	Initial water volume in accumulator.
9	QOUT	Volume of liquid that has been discharged from the accumulator.
10	Z	Water height above discharge.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
11	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

12	IA1111	Dummy variable that provides a known start to the COMMON block.
13	ICJ	Iteration index of adjacent component.
14	ICONC	Indicator for presence of boron in the coolant.
15	ISTOP	Indicator that accumulator has emptied.
16	IUV1	Indicator for velocity update at JUN1 (equal to zero).
17	IUV2	Indicator for velocity update at JUN2.
18	JS2	Junction sequence number at cell NCELLS of the accumulator.
19	JUN2	Junction number of the junction at cell NCELLS.
20	NCELLS	Number of fluid cells.
21	TYPE2	Type of adjacent component at JUN2.
22	Z11111	Dummy variable that provides a known end to the COMMON block.

B. ACCUMPT--ACCUM Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135	LBD1	BD1	LENBD	Dummy BD1 array.
136	LQPPL	QPPL	NCELLT	Heat flux from wall to liquid.
137-317	PTDUM	--	--	Dummy variable.

C. ACCDATA--ACCUM Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; ACCUMVLT, defined in Sec. II.A; and ACCUMPT, defined in Sec. II.B.

III. BREAK MODULE

A. BREAKVLT--BREAK Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	ALPOFF	Coolant void fraction when the trip is OFF after it was ON.
3	BSA	Total air from break.
4	BSMASS	Time-integrated mass flow from break.
5	BXA	Air mass flow from break.
6	BXMASS	Current mass flow from break.
7	CONOFF	Ratio of boron mass to coolant mass when the trip is OFF after it was ON.
8	PAOFF	Air partial pressure when the trip is OFF after it was ON.
9	POFF	Coolant pressure when the trip is OFF after it was ON.
10	RBMX	Maximum rate of change of pressure at the break.
11	TIN	Fluid temperature at the break.
12	TLOFF	Liquid temperature when the trip is OFF after it was ON.
13	TVOFF	Vapor temperature when the trip is OFF after it was ON.
14	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
15	IA1111	Dummy variable that provides a known start to the COMMON block.
16	IBF	Last interpolated interval in the rate-factor table.
17	IBP	Last interpolated interval in the break composition parameter tables.
18	IBSV	Break-table abscissa-coordinate variable ID number.
19	IBTR	Trip ID number that controls evaluation of the break tables.
20	IBTY	Break-table input option.
21	ICJ	Iteration index of adjacent component.
22	INEXTI	Implicitness level of adjacent component.
23	IOFF	Fluid-state option when the trip is OFF after it was ON.
24	IONOFF	Number of time steps the trip is ON.
25	ISAT	Break-table use option.
26	JS1	Junction sequence number.
27	JUN1	Junction number where break is located.
28	NBRF	Number of pairs in the rate-factor table.
29	NBSV	Rate-factor table's abscissa-coordinate variable ID number.
30	NBTB	Number of pairs for each break table.
31	TYPE1	Type of adjacent component at JUN1.
32	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. BREAKPT--BREAK Pointer Table (For BREAKS, NCELLS = 1)

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132	LALPTB	ALPTB	NBTB *2	Void fraction table.
133	LCONTB	CONTB	NBTB *2	Ratio of boron mass to coolant mass table.
134	LPATB	PTAB	NBTB *2	Air partial pressure table.
135	LPTB	PTB	NBTB *2	Pressure table.
136	LRFTB	RFTB	NBRF *2	Rate-factor table.
137	LTLTB	TLTB	NBTB *2	Liquid temperature table.
138	LTVTB	TVTB	NBTB *2	Vapor temperature table.
139-317	PTDUM	--	--	Dummy variable.

C. BRKDATA--BREAK Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; BREAKVLT, defined in Sec. III.A; and BREAKPT, defined in Sec. III.B.

IV. CORE MODULE

A. COREVLT--CORE Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	AMH2	Hydrogen mass generated from metal-water reaction.
3	BCRO	Zero-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of control-rod pin boron.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
4	BCR1	First-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of control-rod pin boron.
5	BEFF	Total delayed neutron fraction.
6	BPP0	Zero-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of burnable-poison pin boron.
7	BPP1	First-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of burnable-poison pin boron.
8	BSMASS	Total fluid mass for core.
9	DRFB	Reactivity-feedback change in K over last time step.
10	DRI	Estimated change in reactivity over the previous time step.
11	DRIO	Old value of DRI equals the old value of the power or reactivity-estimate correction.
12-13	DTNHT(2)	Delta temperature minimums used in reflood calculation.
14	DTPK	The Kaganove-method integration time step for solving the point-kinetics equations.
15-16	DTXHT(2)	Delta temperature maximums used in reflood calculation.
17	DZNHT	Delta $Z_{\min}$ used in reflood calculation.
18	ENEFF	Total decay heat fraction.
19	EXTSOU	Thermal power (W) produced by external source neutrons in the reactor core.
20-21	FL(2)	Liquid mass-flow corrections for mass conservation checks.
22	FUCRAC	Fraction of uncracked fuel.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
23-24	FV(2)	Vapor mass-flow corrections for mass conservation checks.
25	HGAPO	Rod gap-conductance coefficient (MATRD = 3).
26	HOUTL	HTC between outer boundary of core wall and liquid.
27	HOUTV	HTC between outer boundary of core wall and vapor.
28	PDRAT	Rod pitch-to-diameter ratio.
29	PLDR	Pellet dish radius. (PLDR = 0.0, no calculation of pellet dishing.)
30	POWEXP	Exponent value to which the power distribution is raised and that defines the weighting function for averaging the reactivity-feedback parameters over the core volume.
31	QP3IN	Initial QPPP factor.
32	QRDTOT	Total rod heat flux.
33	QSLTOT	Total slab heat flux.
34	RADIN	Inner radius of core wall.
35	REAC	Reactivity feedback at the beginning of the previous time step.
36	REACN	Reactivity-feedback estimate at the end of the present time step.
37	REACT	Total reactivity at the beginning time of the present time step.
38	RMCK	Reactor multiplication constant at the beginning time of the present time step.
39	RMCKN	Reactor multiplication constant estimate at the ending time of the present time step.
40	RPOWPF	The prompt fission power.
41	RPOWR	Old reactor power.
42	RPOWRI	Initial reactor power.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
43	RPOWRN	New reactor power.
44	RPOWRO	Old reactor power in the previous time step.
45	RPWOFF	Programmed reactivity or reactor power when the controlling trip is OFF after it was ON.
46	RRPWMX	Maximum rate of change of programmed reactivity or reactor power.
47	RZPWMX	Maximum rate of change of the axial power shape.
48	SDT	The time interval (s) since the last reactivity change printout.
49	STIMET	The problem time (s) at which the last reactivity change was summed to variable storage for late printout.
50	TH	Thickness of core wall.
51	TNEUT	Neutron generation time.
52	TOUTL	Liquid temperature outside core.
53	TOUTV	Vapor temperature outside core.
54	TRAMAX	Average-rod peak-cladding temperature.
55	TRHMAX	Maximum supplemental rod temperature.
56	ZPWIN	Axial power shape table's abscissa-coordinate variable value corresponding to the initial axial power shape.
57	ZPWOFF	Axial power shape table's abscissa-coordinate variable value corresponding to the axial power shape to use when the controlling trip is OFF after it was ON.
58	Z11111	Dummy variable that provides a known end to the COMMON block.
INTEGER VARIABLES		
59	IA1111	Dummy variable that provides a known start to the COMMON block.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
60-63	IBU(4)	Boron-unit flag for the Jth reactivity coefficient.
64	ICHF	CHF calculation option.
65	ICJ1	Iteration index of adjacent component at JUN1.
66	ICJ2	Iteration index of adjacent component at JUN2.
67	ICONC	Indicator for presence of boron in the coolant.
68	ICRL	Core lower-boundary segment number, Z(ICRL).
69	ICRU	Core upper-boundary segment number, Z(ICRU).
70	IONOFF	Number of time steps the reactivity-power table's controlling trip has been ON.
71-74	IRC(4)	Number of values that defines the argument-number reactivity-coefficient table.
75-78	IRCJFM(4)	Reactivity-coefficient form number for the argument-number reactivity-feedback parameter.
79-94	IRCJTB(4,4)	The number of first argument reactivity-feedback parameter-value entries for the second argument reactivity-coefficient table.
95	IRF	Last interpolated interval number in the rate-factor table for the reactivity-power table.
96	IRFTR	Trip ID number that controls evaluation with the reflood axial fine mesh in the fuel rod.
97	IRP	Last interpolated interval number in the reactivity-power table.
98	IRPWSV	The signal-variable ID number that defines the power or reactivity table's independent variable.
99	IRPWTR	Reactor-kinetics trip ID number.
100	IRPWTY	Reactor-kinetics option flag.
101	ISNOTB	A flag variable that is defined if the solute is boron for the reactivity-feedback calculation. 0 = solute is boron, 1 = solute is not boron.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
102	ISOLLB	Indicator for velocity update at JUN1.
103	ISOLRB	Indicator for velocity update at JUN2.
104	IZF	Last interpolated interval number in the rate-factor table for the axial power-shape table.
105	IZP	Last interpolated interval number in the axial power-shape table.
106	IZPWSV	Axial power-shape table's abscissa-coordinate variable ID number.
107	IZPWTR	Trip ID number that controls evaluation of the axial power-shape table.
108	JS1	Junction sequence number at cell 1 of the core.
109	JS2	Junction sequence number at cell NCELLS of the core.
110	JUN1	Junction number of the junction at cell 1.
111	JUN2	Junction number of the junction at cell NCELLS.
112	LENFVG	Length of power data stored at both the old and new times.
113	LENGEN	Length of the general data.
114	LENRD	Length of the rod data.
115	LFVG	Relative position of old-time power data.
116	LFVGN	Relative position of new-time power data.
117	LFVR	Relative position of old-time rod data.
118	LFVRN	Relative position of new-time rod data.
119	LNFVR	Length of rod data stored at both old and new times.
120	LNPTRR	Number of rod-data pointers.
121	MAT	Material identification.
122	NCELLS	Total number of fluid cells.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
123	NCRZ	Number of axial mesh cells.
124	NDGX	Number of delayed neutron groups.
125	NDHX	Number of decay heat groups.
126	NDRDS	Number of rod heat-transfer nodes.
127	NDSLb	Number of slab heat-transfer nodes (unused).
128	NFBPWT	Flag that defines the spatial distribution used to weight the averaging of the reactivity-feedback parameters over the reactor-core volume.
129	NFCI	Fuel-cladding interaction (FCI) flag. 0 = no calculation, 1 = calculation.
130	NFCIL	Upper limit on number of FCI calculations per time step.
131	NFUEL	Number of nodes in fuel pellet.
132	NINT	Number of interfaces between dissimilar materials in rods.
133	NMWRX	Metal-water reaction flag. 0 = no calculation, 1 = calculation.
134	NONOFF	The number of time steps the trip-controlling evaluation of the axial power-shape table has been ON.
135	NRAMAX	Cell number of the average-rod peak-cladding temperature (always 1).
136	NRFD	Reflood flag. 0 = takes no action, 1 = turns on fine-mesh flag.
137	NRUMAX	Cell number of the supplemental rod peak-cladding temperature.
138	NRODS	Number of computational rods.
139	NRPWRF	The number of power reactivity rate-factor table entries.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
140	NRPWSV	Reactivity-power rate-factor table's abscissa-coordinate variable ID number.
141	NRPWTB	Number of entry pairs in the reactivity-power table.
142	NRTS	The number of time steps the programmed-reactivity and reactivity-feedback changes are summed for printout.
143	NSET	The previous reflood fine-mesh trip set position status value.
144	NSLBS	Number of computational slabs (unused).
145	NZMAX	Maximum number of rows of heat-transfer nodes used in reflood calculation.
146	NZPWRF	Number of entry pairs in the axial power-shape rate-factor table.
147	NZPWSV	Axial power-shape rate-factor table's abscissa-coordinate variable ID number.
148	NZPWTB	Number of axial power shapes in the axial power-shape table.
149	TYPE1	Type of adjacent component at JUN1.
150	TYPE2	Type of adjacent component at JUN2.
151	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. COREPT--CORE Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.
GLOBAL DATA POINTERS				
147	LBETA	BETA	NDGX	Delayed neutron group fraction.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
148	LCDG	CDG	NDGX	Old concentration of delayed neutron groups.
149	LCDGN	CDGN	NDGX	New concentration of delayed neutron groups.
150	LCDH	CDH	NDHX	Old concentration of decay heat groups.
151	LCDHN	CDHN	NDHX	New concentration of decay heat groups.
152	LCLN	CLEN	1	Old total cladding length.
153	LCLN	CLENN	1	New total cladding length.
154	LCPOWR	CPOWR	1	Relative rod power density.
155	LEDH	EDH	NDHX	Energy yield fraction of decay heat groups.
156	LFPUO2	FPUO2	1	Fraction of plutonium oxide in mixed-oxide fuel fraction.
157	LFTD	FTD	1	Fuel theoretical density.
158	LGMIX	GMIX	7	Mole fraction of gap-gas constituents.
159	LGMLES	GMLES	1	Moles of gap gas.
160	LLAMDA	LAMDA	NDGX	Delay constant of neutron delayed groups.
161	LLAMDH	LAMDH	NDHX	Delay constant of decay heat groups.
162	LMATRD	MATRD	NDM1	Rod material identification.
163	LNFA	NFA	NCRZ	Rod fine-mesh nodding factor.
164	LNRD	NRD	1	Number of rods in volume.
165	LPGAPT	PGAPT	1	Gap total gas pressure.
166	LPLVOL	PLVOL	1	Rod plenum volume.
167	LPSLEN	PSLEN	1	Pellet stack length.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
168	LRADRD	RADRD	NDRDS	Rod node radius (cold).
169	LRCAL	RCAL	$\Sigma \text{IRCJTB}(i,3) + \pi_i \text{IRCJTB}(i,3)$	Coolant void-fraction reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
170	LRCBM	RCBM	$\Sigma \text{IRCJTB}(i,4) + \pi_i \text{IRCJTB}(i,4)$	Boron reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
171	LRCN	RCN	4	Reactivity-coefficient values at the beginning of the previous time step.
172	LRCTC	RCTC	$\Sigma \text{IRCJTB}(i,2) + \pi_i \text{IRCJTB}(i,2)$	Coolant temperature reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
173	LRCTF	RCTF	$\Sigma \text{IRCJTB}(i,1) + \pi_i \text{IRCJTB}(i,1)$	Fuel temperature reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
174	LRDPWR	RDPWR	NDRDS	Rod relative radial power density.
175	LRPKF	RPKF	NRODS	Rod power peaking factor.
176	LRPWRF	RPWRF	NRPWRF *2	Rate-factor table for the power or reactivity table.
177	LRPWTB	RPWTB	NRPWTB *2	Reactivity power table.
178	LRS	RS	NDRDS*MOD (NFBPWT,2)	Pointer variable for the fuel-rod radial shape weight function used to average reactivity-feedback parameters over the core volume. [MOD(N,2) = N - (N/2)*2]
179	LSRP	SRP	15	Summed programmed and feedback-reactivity changes.
180	LXN	XN	4	New reactivity-feedback parameter values.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
181	LXO	XO	4	Old reactivity-feedback parameter values.
182	LZ	Z	NCELLS	Axial segment upper elevation.
183	LZPW	ZPW	ICRU-ICRL+1	Last interpolated axial power shape.
184	LZPWR	ZPWR	NZPWR *2	Axial power-shape rate-factor table.
185	LZPWTB	ZPWTB	NZPWTB ((ICRU-ICRL)+2)	Relative axial power-shape table.
186	LZS	ZS	((ICRU-ICRL) +1)*(NFBPWT/2)	Pointer variable for the axial shape.

ROD DATA POINTERS

187	LBURN	BURN	NCRZ+1	Fuel burnup.
188	LCND	CND	NDRDS* (NCRZ+1)	Rod conductivity.
189	LCNDR	CNDR	NINT* (NCRZ+1)	Rod heat conductivity at right of interface.
190	LCPDR	CPDR	NINT* (NCRZ+1)	Rod heat capacity at specific heat.
191	LCPND	CPND	NDRDS* (NCRZ+1)	Rod specific heat.
192	LDRLDT	DRLDT	NCRZ	Derivative of liquid density with respect to liquid temperature.
193	LDRVDT	DRVDT	NCRZ	Derivative of vapor density with respect to vapor temperature.
194	LDRZ	DRZ	NCRZ+1	Old zirconium dioxide reaction depth.
195	LDRZN	DRZN	NCRZ+1	New zirconium dioxide reaction depth.
196	LEMISR	EMISR	NDRDS* (NCRZ+1)	Rod emissivity.
197	LHDR	HDR	NCRZ	Rod bundle hydraulic diameter.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
198	LHGAP	HGAP	NCRZ+1	Gap conductance.
199	LHLVR	HLVR	NCRZ	Interfacial HTC.
200	LHRFL	HRFL	NZMAX	Fine-mesh liquid HTC.
201	LHRFV	HRFV	NZMAX	Fine-mesh vapor HTC.
202	LHRLI	HRLI	NCRZ+1	Liquid HTC.
203	LHRLV	HRLV	NCRZ+1	Vapor HTC.
204	LIDHT	IDHT	NZMAX	Heat-transfer cell identifier.
205	LIDRGR	IDRGR	NCRZ+2	Flow regime flag.
206	LIHTF	IHTF	NXMAX	Fine-mesh heat-transfer regime flag.
207	LNOHT	NOHT	1	Number of rows of heat-transfer nodes for each rod.
208	LPGAP	PGAP	NCRZ+1	Gap local gas pressure.
209	LPINT	PINT	NCRZ+1	Pellet-cladding contact pressure.
210	LPLDV	PLDV	NCRZ	Pellet dish volume.
211	LQWRX	QWRX	NCRZ+1	Metal-water reaction heat source.
212	LRADR	RADR	NDRDS* (NCRZ+1)	Old radial node positions.
213	LRDHLO	RDHLO	NCRZ	Variable not currently implemented.
214	LRDHLR	RDHLR	NCRZ	Liquid HTC.
215	LRDHVO	RDHVO	NCRZ	Variable not currently implemented.
216	LRDHVR	RDHVR	NCRZ	Vapor HTC.
217	LRDTLR	RDTLR	NCRZ	Average-rod wall temperature seen by liquid.
218	LRDTVR	RDTV	NCRZ	Average-rod wall temperature seen by vapor.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
219	LRFT	RFT	NDRDS* NZMAX	Old fine-mesh rod temperature.
220	LRFTN	RFTN	NDRDS* NZMAX	New fine-mesh rod temperature.
221	LRND	RND	NDRDS* (NCRZ+1)	Rod density.
222	LRNDR	RNDR	NINT* (NCRZ+1)-1	Rod density at right of interface.
223	LRPOWF	RPOWF	NDRDS	Rod power density.
224	LTCHFF	TCHFF	NZMAX	Fine-mesh wall temperature at CHF point.
225	LTCHFR	TCHFR	NCELLS	Wall temperature at CHF point.
226	LTLID	TLEID	NZMAX	Leidenfrost temperature.
227	LZHT	ZHT	NZMAX	Axial location of heat-transfer node.
228-307	PTDUM	--	--	Dummy variable.

C. COREDATA--CORE Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; COREVLT, defined in Sec. IV.A; and COREPT, defined in Sec. IV.B.

V. FILL MODULE

A. FILLVLT--FILL Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	ALPOFF	Coolant void fraction when the trip is OFF after it was ON.
3	CONOFF	Ratio of boron mass to coolant mass when the trip is OFF after it was ON.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
4	FLOWIN	Initial mass flow into or from adjacent component.
5	FLWOFF	Coolant mass flow when the trip is OFF after it was ON.
6	FSMASS	Time-integrated mass-flow rate out of fill.
7	FXMASS	Current mass-flow rate out of fill.
8	PAOFF	Air partial pressure when the trip is OFF after it was ON.
9	POFF	Coolant pressure when the trip is OFF after it was ON.
10	RFMX	Maximum rate of change of fill velocity or mass flow.
11	TLOFF	Liquid temperature when the trip is OFF after it was ON.
12	TVOFF	Vapor temperature when the trip is OFF after it was ON.
13	TWTOLD	The fraction of a previous fill fluid dynamic-state parameter that is averaged with the fill table's defined parameter and that defines the fill parameter value for this time step ($0.0 \leq \text{TWTOLD} < 1.0$).
14	VLOFF	Liquid velocity when the trip is OFF after it was ON.
15	VVOFF	Vapor velocity when the trip is OFF after it was ON.
16	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

17	IA1111	Dummy variable that provides a known start to the COMMON block.
18	ICJ	Iteration index of adjacent component.
19	IFF	Last interpolated interval in the rate-factor table.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
20	IFP	Last interpolated interval in the fill table.
21	IFSV	The signal-variable ID number, which defines the fill table's independent variable.
22	IFTR	Fill trip number.
23	IFTY	Fill type.
24	INEXTI	Implicitness level of adjacent component.
25	IOFF	Fill fluid-state option when the trip is OFF after it was ON.
26	IONOFF	The number of time steps the trip has been ON.
27	JS1	Junction sequence number at JUN1.
28	JUN1	Junction number where fill is located.
29	NFRF	Number of rate-factor table pairs whose rate factor is applied to the fill table's independent variable.
30	NFSV	Rate-factor table's abscissa-coordinate variable ID number.
31	NFTB	Number of pairs in the fill table.
32	TYPE1	Type of adjacent component at JUN1.
33	Z11111	Dummy variable that provides a known end to the COMMON block.

B. FILLPT--FILL Pointer Table (For FILLS, NCELLS = 1)

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132	LALPTB	ALPTB	NFTB *2	Void fraction table.
133	LCONTB	CONTB	NFTB *2	Ratio of boron mass to coolant mass.
134	LPATB	PATB	NFTB *2	Air partial pressure table.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
135	LPTB	PTB	NFTB *2	Pressure table.
136	LRFTB	RFTB	NFRF *2	The pointer for the fill rate-factor table.
137	LTLTB	TLTB	NFTB *2	Liquid temperature table.
138	LTVTB	TVTB	NFTB *2	Vapor temperature table.
139	LVMTB	VMTB	NFTB *2	Liquid velocity table.
140	LVVTB	VVTB	NFTB *2	Vapor velocity table.
141-317	PTDUM	--	--	Dummy variable.

C. FILLDATA--FILL Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; FILLVLT, defined in Sec. V.A; and FILLPT, defined in Sec. V.B.

VI. PIPE MODULE

A. PIPEVLT--PIPE Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	BSMASS	Time-integrated mass flow from pipe.
3	CPOW	Special pipe power input.
4	ENINP	Total (time-integrated) energy directly input to the pipe.
5-6	FL(2)	Liquid mass-flow corrections for mass conservation checks.
7-8	FV(2)	Vapor mass-flow corrections for mass conservation checks.
9	HOUTL	HTC between outer boundary of pipe wall and liquid.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
10	HOUTV	HTC between outer boundary of pipe wall and vapor.
11	PLENT	Total length of the pipe.
12	POWIN	Initial power deposited in the liquid.
13	POWOFF	Power deposited in the liquid when the trip is OFF after it was ON.
14	QINT	Initial water volume in pipe.
15	QOUT	Volume of liquid that has been discharged from pipe used as accumulator.
16	QP3IN	Initial QPPP factor.
17	QP3OFF	QPPP factor when its trip is OFF after it was ON.
18	RADIN	Inner radius of pipe wall.
19	RPOWMX	Maximum rate of change of power deposited in the coolant.
20	RQP3MX	Maximum rate of change of the QPPP factor.
21	TH	Thickness of pipe wall.
22	TOUTL	Liquid temperature outside pipe.
23	TOUTV	Vapor temperature outside pipe.
24	VFLOW	Volume flow rate at discharge from pipe used as accumulator.
25	Z	Water height above discharge.
26	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
27	IA1111	Dummy variable that provides a known start to the COMMON block.
28	IACC	Pipe accumulator option switch.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
29	ICHF	CHF calculation option.
30	ICJ1	Iteration index of adjacent component at JUN1.
31	ICJ2	Iteration index of adjacent component at JUN2.
32	ICONC	Indicator for presence of boron in the coolant.
33	IONOFF	Number of time steps the power deposited in the coolant trip has been ON.
34	IPF	Last interpolated interval in the power deposited in the coolant's rate-factor table.
35	IPOW	Indicator for presence of power deposited in the coolant.
36	IPOWSV	Power deposited in the coolant table's abscissa-coordinate variable ID number.
37	IPOWTR	Trip ID number that controls evaluation of the power deposited in the coolant table.
38	IPP	Last interpolated interval in the power deposited in the coolant table.
39	IQF	Last interpolated interval in the QPPP factor table's rate-factor table.
40	IQP	Last interpolated interval in the QPPP factor table.
41	IQP3SV	QPPP factor table's abscissa-coordinate variable ID number.
42	IQP3TR	Trip ID number that controls evaluation of the QPPP factor table.
43	ISOLLB	Indicator for velocity update at JUN1.
44	ISOLRB	Indicator for velocity update at JUN2.
45	JS1	Junction sequence number at cell 1 of the pipe.
46	JS2	Junction sequence number at cell NCELLS of the pipe.
47	JUN1	Junction number of the junction at cell 1.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
48	JUN2	Junction number of the junction at cell NCELLS.
49	MAT	Material identification.
50 "	NCELLS	Number of fluid cells.
51	NONOFF	Number of time steps the QPPP factor table's controlling trip has been ON.
52	NPOWRF	Number of pairs in the power deposited in the coolant table's rate-factor table.
53	NPOWSV	Power deposited in the coolant rate-factor table's abscissa-coordinate variable ID number.
54	NPOWTB	Length of pipe power table.
55	NQP3RF	Number of pairs in the QPPP factor table's rate-factor table.
56//	NQP3SV	QPPP factor rate-factor table's abscissa-coordinate variable ID number.
57	NQP3TB	Number of pairs in the QPPP factor table.
58	TYPE1	Type of adjacent component at JUN1.
59	TYPE2	Type of adjacent component at JUN2.
60	Z1111	Dummy variable that provides a known end to the COMMON block.

B. PIPEPT--PIPE Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.
147	LPOWRF	POWRF	NPOWRF *2	Rate-factor tables for the power deposited in the coolant tables.
148	LPOWTB	POWTB	NPOWTB *2	Power deposited in the coolant table.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
149	LQP3RF	QP3RF	NQP3RF *2	Rate-factor table for the QPPP factor tables.
150	LQP3TB	QP3TB	NQP3TB *2	QPPP factor tables.
151-317	PTDUM	--	--	Dummy variable.

C. PIPEDATA--PIPE Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; PIPEVLT, defined in Sec. VI.A; and PIPEPT, defined in Sec. VI.B.

VII. PLENUM MODULE

The plenum data are all contained in the PLENDATA COMMON block that consists of the following COMMON blocks: DIMNSION, IOUNITS, JUNCTION, FIXEDLT, and BLANKCOM, all defined in App. H; VLTAB, defined in Sec. VII.A; and PTAB, defined in Sec. VII.B.

A. VLTAB--PLENUM Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	BL	Temporary storage for liquid mass conservation checks.
3	BSMASS	Time-integrated mass flow from plenum.
4	BV	Temporary storage for liquid mass conservation checks.
5	FLXA	Total air mass flow into the plenum during a time step.
6	FLXAL	Total liquid volumetric flow into the plenum during a time step.
7	FLXAV	Total vapor (gas phase) volumetric flow into the plenum during a time step.
8	FLXC	Total solute mass flow into the plenum during a time step.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
9	FLXEL	Total liquid internal energy flow into the plenum during a time step.
10	FLXEV	Total vapor internal energy flow into the plenum during a time step.
11	FLXL	Total liquid mass flow into the plenum during a time step.
12	FLXV	Total vapor mass flow into the plenum during a time step.
13	RXCL	Temporary storage for the right-hand side of the liquid stabilizer mass and energy equations.
14	RXCV	Temporary storage for the right-hand side of the vapor stabilizer mass and energy equations.
15	XL	Gross total liquid volumetric flow from the plenum during a time step.
16	XV	Gross total vapor volumetric flow from the plenum during a time step.
17	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

18	IA1111	Dummy variable that provides a known start to the COMMON block.
19	K	Address location that designates the location of the array data variables.
20	ICONC	Indicator for the presence of boron in the coolant.
21	IPOW	Indicator for the presence of power deposited in the coolant.
22	LENAAR	Lengths of the array data that are referenced using pointers.
23	NPLJN	Number of plenum junctions.
24	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. PTAB--PLENUM Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1	L11111	--	1	Dummy variable that provides a known start to the COMMON block.
2	LALW	ALW	NPLJN	Temporary storage for the right-hand side of the liquid stabilizer mass and energy equations.
3	LAVW	AVW	NPLJN	Temporary storage for the right-hand side of the vapor stabilizer mass and energy equations.
4	LDBND	DBND	5*NPLJN	Donor-cell quantities $\alpha \rho_v$, $(1 - \alpha) \rho_l$, $\alpha \rho_v e_v$, $(1 - \alpha) \rho_l e_l$, and $\alpha \rho_a$.
5	LDFLDP	DFLDP	NPLJN	Derivative of the liquid velocity with respect to pressure.
6	LDFVDP	DFVDP	NPLJN	Derivative of the vapor velocity with respect to pressure.
7	LDNFL	DONFL	NPLJN	Donor-cell flag for liquid. 0.0 = indicates flow into the plenum, 1.0 = indicates flow from the plenum.
8	LDNFV	DONFV	NPLJN	Donor-cell flag for vapor. 0.0 = indicates flow into the plenum, 1.0 = indicates flow from the plenum.
9	LDX	DX	NPLJN	Effective plenum-side cell lengths for junctions connected to the plenum (required in the solution of the momentum equations).
10	LFAVOL	FAVOL	NPLJN	Cell flow area used in the choked-flow model.
11	LGRAV	GRAV	NPLJN	Gravitational terms (cosine theta).
12	LIOJ	IOJ	NPLJN	Network junction numbers.
13	LJUNJ	JUNJ	NPLJN	Plenum junction numbers.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
14	LJSN	JSN	NPLJN	Plenum junction sequence numbers.
15	LPAK	PAK	NPLJN	BIT array for the plenum junctions; however, it is used only for storing the water packing and stretching bits.
16	LSGN	SGN	NPLJN	Junction flow-reversal indicators.
17	LVLVOL	VLVOL	NPLJN	Effective liquid velocity used in the choked-flow model.
18	LVVVOL	VVVOL	NPLJN	Effective vapor velocity used in the choked-flow model.
19	LZZZZZ	--	1	Dummy variable that provides a known end to the COMMON block.

C. Equivalences Defined for BLANKCOM

<u>Mnemonic</u>	<u>Variable</u>	<u>Description</u>
ALP(1)	A(01)	Old void fraction.
ALPMN(1)	A(74)	Minimum value of void fraction among the plenum and all its neighbors.
ALPMX(1)	A(75)	Maximum value of void fraction among the plenum and all its neighbors.
ALPN(1)	A(25)	New void fraction.
ALPO(1)	A(53)	Void fraction from previous time step (α^{n-1}).
ALV(1)	A(02)	Old value of liquid-to-interface HTC times the interfacial area.
ALVN(1)	A(26)	New value of liquid-to-interface HTC times the interfacial area.
AM(1)	A(54)	Air mass.
ARA(1)	A(03)	Old stabilizer value for α_a .
ARAN(1)	A(27)	New stabilizer value for α_a .
ARC(1)	A(55)	Solute density.
AREL(1)	A(04)	Old stabilizer value for $(1 - \alpha) \rho_l e_l$.

<u>Mnemonic</u>	<u>Variable</u>	<u>Description</u>
ARELN(1)	A(28)	New stabilizer value for $(1 - \alpha)\rho_l e_l$.
AREV(1)	A(05)	Old stabilizer value for $\alpha\rho_v e_v$.
AREVN(1)	A(29)	New stabilizer value for $\alpha\rho_v e_v$.
ARL(1)	A(06)	Old stabilizer value for $(1 - \alpha)\rho_l$.
ARLN(1)	A(30)	New stabilizer value for $(1 - \alpha)\rho_l$.
ARV(1)	A(07)	Old stabilizer value for $\alpha\rho_v$.
ARVN(1)	A(31)	New stabilizer value for $\alpha\rho_v$.
BIT(1)	A(22)	Old bit flag.
BITN(1)	A(46)	New bit flag.
BOR(1)	A(08)	Old boron-to-coolant mass ratio.
BORN(1)	A(32)	New boron-to-coolant mass ratio.
CHTI(1)	A(12)	Old value of vapor-to-interface HTC times the interfacial area.
CHTIN(1)	A(36)	New value of vapor-to-interface HTC times the interfacial area.
CL(1)	A(49)	Liquid conductivity.
CPL(1)	A(50)	Liquid specific heat at constant pressure.
CPV(1)	A(51)	Liquid specific heat at constant volume.
CV(1)	A(52)	Vapor conductivity.
DALP(1)	A(57)	Weighting factor XVSET.
DALVA(1)	A(68)	Derivative of ALV with respect to α .
DELDP(1)	A(80)	Derivative of the liquid internal energy with respect to pressure at constant temperature.
DELDT(1)	A(82)	Derivative of the liquid internal energy with respect to temperature at constant pressure.
DEVAP(1)	A(94)	Derivative of air internal energy with respect to pressure at constant temperature.

<u>Mnemonic</u>	<u>Variable</u>	<u>Description</u>
DEVAT(1)	A(93)	Derivative of air internal energy with respect to temperature at constant pressure.
DEVDP(1)	A(81)	Derivative of the steam internal energy with respect to pressure at constant temperature.
DEVDT(1)	A(83)	Derivative of the steam internal energy with respect to temperature at constant pressure.
DHLSP(1)	A(91)	Derivative of HLST with respect to pressure.
DHVSP(1)	A(90)	Derivative of HVST with respect to pressure.
DROLP(1)	A(84)	Derivative of the liquid density with respect to pressure at constant temperature.
DROLT(1)	A(86)	Derivative of the liquid density with respect to temperature at constant pressure.
DROVP(1)	A(85)	Derivative of the steam density with respect to pressure at constant temperature.
DROVT(1)	A(87)	Derivative of the steam density with respect to temperature at constant pressure.
DRVAP(1)	A(95)	Derivative of air density with respect to pressure at constant temperature.
DRVAT(1)	A(96)	Derivative of air density with respect to temperature at constant pressure.
DTSDP(1)	A(79)	Derivative of TSAT with respect to pressure.
DTSSP(1)	A(92)	Derivative of TSSN with respect to pressure.
DXVOL(1)	A(69)	Plenum average length.
EL(1)	A(10)	Old liquid internal energy.
ELEV(1)	A(66)	Plenum center elevation. This is used only if IELV is set to 1 in the NAMELIST input.
ELN(1)	A(34)	New liquid internal energy.
EV(1)	A(11)	Old vapor internal energy.
EVA(1)	A(09)	Old air internal energy.
EVAN(1)	A(33)	New air internal energy.

<u>Mnemonic</u>	<u>Variable</u>	<u>Description</u>
EVN(1)	A(35)	New vapor internal energy.
FASMLT(1)	A(77)	Interphase area multiplier during condensation.
FAVOL(1)	A(70)	Plenum average flow area.
GAM(1)	A(13)	Old vapor generation rate per unit volume.
GAMN(1)	A(37)	New vapor generation rate per unit volume.
GRAVOL(1)	A(73)	Plenum average GRAV.
HFG(1)	A(56)	Latent heat of vaporization.
HIL(1)	A(23)	Old HTC between inside wall and liquid.
HILN(1)	A(47)	New HTC between inside wall and liquid.
HIV(1)	A(24)	Old HTC between inside wall and vapor.
HIVN(1)	A(48)	New HTC between inside wall and vapor.
HLST(1)	A(89)	Saturated liquid enthalpy (at TSSN and total pressure).
HVST(1)	A(88)	Saturated steam enthalpy (at TSSN and steam partial pressure).
P(1)	A(14)	Old pressure.
PA(1)	A(15)	Old air partial pressure.
PAN(1)	A(39)	New air partial pressure.
PN(1)	A(38)	New pressure.
QP3F(1)	A(67)	QPPP factor applied to the wall heat source.
ROL(1)	A(17)	Old liquid density.
ROLN(1)	A(41)	New liquid density.
ROM(1)	A(58)	Mixture density.
ROV(1)	A(18)	Old vapor density.
ROVA(1)	A(16)	Old air density.
ROVAN(1)	A(40)	New air density.

<u>Mnemonic</u>	<u>Variable</u>	<u>Description</u>
ROVN(1)	A(42)	New vapor density.
SIG(1)	A(59)	Surface tension.
SOLID(1)	A(19)	Old boron solute mass plated on structure surface.
SOLIDN(1)	A(43)	New boron solute mass plated on structure surface.
TL(1)	A(20)	Old liquid temperature.
TLN(1)	A(44)	New liquid temperature.
TSAT(1)	A(60)	Saturation temperature corresponding to total vapor pressure.
TSSN(1)	A(61)	Saturation temperature corresponding to steam partial pressure.
TV(1)	A(21)	Old vapor temperature.
TVN(1)	A(45)	New vapor temperature.
VISL(1)	A(62)	Liquid viscosity.
VISV(1)	A(63)	Vapor viscosity.
VLALP(1)	A(78)	Maximum value of the liquid mass flux entering the plenum from junctions located above the plenum.
VLVC(1)	A(76)	Absolute value of the liquid velocity at a junction where the donor-celled liquid fraction is maximum.
VLVOL(1)	A(71)	Plenum average liquid velocity.
VOL(1)	A(64)	Plenum volume.
VVOL(1)	A(72)	Plenum average vapor velocity.
WA(1)	A(65)	Wall area.

VIII. PRESSURIZER MODULE

A. PRIZEVLT--PRIZER Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	BSMASS	Time-integrated mass flow from pressurizer.
3	BSMSSP	Current mass-flow rate during transient.
4	BXMASS	Current mass-flow rate during steady state.
5	DPMAX	Differential pressure at which heaters have maximum power.
6-7	FL(2)	Liquid mass-flow corrections for mass conservation checks.
8	FLOW	Volume flow rate at discharge.
9-10	FV(2)	Vapor mass-flow corrections for mass conservation checks.
11	HOUTL	HTC between outer boundary of pressurizer wall and liquid.
12	HOUTV	HTC between outer boundary of pressurizer wall and vapor.
13	PSET	Pressurizer pressure set point for heater-spray control.
14	QHEAT	Total heater power.
15 //	QIN	Heater power being input to water.
16	QINT	Initial water volume in pressurizer.
17	QOUT	Volume of liquid that has discharged from the pressurizer.
18	QP3IN	Initial QPPP factor.
19	RADIN	Inner radius of pressurizer wall.
20	TH	Thickness of pressurizer wall.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
21	TOUTL	Liquid temperature outside pressurizer.
22	TOUTV	Vapor temperature outside pressurizer.
23	Z	Water height above discharge.
24	ZHTR	Water height for heater cutoff.
25	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

26	IA1111	Dummy variable that provides a known start to the COMMON block.
27	ICHF	CHF calculation option.
28	ICJ	Iteration index of adjacent component.
29	ICONC	Indicator for presence of boron in the coolant.
30	ICT1	The sequence number (position in the IORDER array) of the component next to the junction of the pressurizer. This variable is computed but not used.
31	IUV1	Indicator for velocity update at JUN1 (equal to zero).
32	IUV2	Indicator for velocity update at JUN2.
33	JS1	Junction sequence number at cell 1 of the pressurizer.
34	JS2	Junction sequence number at cell NCELLS of the pressurizer.
35	JUN1	Junction number of the junction at cell 1.
36	JUN2	Junction number of the junction at cell NCELLS.
37	MAT	Material ID number of the pressurizer wall.
38	NCELLS	Number of fluid cells.
39	TYPE1	Type of adjacent component at JUN1.
40	TYPE2	Type of component adjacent at JUN2.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
41	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. PRIZEPT--PRIZER Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.

C. PRZDATA--PRIZER Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; PRIZEVLT, defined in Sec. VIII.A; and PRIZEPT, defined in Sec. VIII.B.

IX. PUMP MODULE

A. PUMPVLT--PUMP Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	AEFFMI	The coefficient for the (OMEGA/ROMEGA)**2 term in the calculation of the variable moment of inertia ($\text{kg} \cdot \text{m}^2$).
3	ALPHA	Pump void fraction.
4	ALPHAO	Void fraction used on previous time step for pump head calculation.
5	BEFFMI	The coefficient for the (OMEGA/ROMEGA) term in the calculation of the variable moment of inertia ($\text{kg} \cdot \text{m}^2$).
6	BSMASS	Time-integrated mass flow from pump.
7	CEFFMI	The constant term in the calculation of the variable moment of inertia ($\text{kg} \cdot \text{m}^2$).

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
8	DELP	Delta P across pump.
9	DSMOM	Derivative of pump head with velocity.
10	EFFMI	Moment of inertia.
11	EFFMI1	The alternate effective moment of inertia.
12-13	FL(2)	Liquid mass-flow corrections for mass conservation checks.
14	FLOW	Pump volumetric flow rate.
15-16	FV(2)	Vapor mass-flow corrections for mass conservation checks.
17	HEAD	Pump head.
18	HOUTL	HTC between outer boundary of pump wall and liquid.
19	HOUTV	HTC between outer boundary of pump wall and vapor.
20	MFLOW	Pump mass-flow rate.
21	OMEGA	Angular velocity at old time.
22	OMEGAN	Angular velocity at new time.
23	OMGOFF	Pump rotational speed when its controlling trip is OFF after it was ON.
24	OMTEST	The PUMP speed below which EFFMI1 (the alternate effective moment of inertia) is used ($\text{rad} \cdot \text{s}^{-1}$).
25	QP3IN	Initial QPPP factor.
26	QP3OFF	QPPP factor when its controlling trip is OFF after it was ON.
27	RADIN	Inner radius of wall.
28	RFLOW	Rated flow.
29	RHEAD	Rated head.
30	RHO	Pump mixture density.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
31	ROMEGA	Rated angular velocity.
32	ROMGMX	Maximum rate of change of the pump rotational speed.
33	RQP3MX	Maximum rate of change of the QPPP factor.
34	RRHO	Rated density.
35	RTORK	Rated torque.
36	SMOM	Momentum source.
37	TFR1	Frictional torque constant 1.
38	TFR2	Frictional torque constant 2.
39	TH	Wall thickness.
40	TORQUE	Pump torque.
41	TOUTL	Liquid temperature outside wall.
42	TOUTV	Vapor temperature outside wall.
43	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

44	IA1111	Dummy variable that provides a known start to the COMMON block.
45	ICHF	CHF calculation option.
46	ICJ1	Iteration index of adjacent component at JUN1.
47	ICJ2	Iteration index of adjacent component at JUN2.
48	ICONC	Indicator for presence of boron in the coolant.
49	INDXHM	Index on head degradation multiplier curve.
50	INDXTM	Index on torque degradation multiplier curve.
51	IONOFF	Number of time steps the pump-speed controlling trip has been ON.
52	IPF	Last interpolated interval in the pump-speed table's rate-factor table.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
53	IPM	Two-phase indicator. 0 = use single-phase curves, 1 = use two-phase curves.
54	IPMPS	Flag that indicates whether or not the pump speed previously has dropped below OMTEST. 0 = pump speed always has been greater than OMTEST, 1 = pump speed has dropped below OMTEST at some time.
55	IPMPS2	Flag that indicates the use of the variable pump inertia; set in subroutine RPUMP.
56	IPMPSV	Signal-variable ID number that defines the pump-speed table's independent variable.
57	IPMPTR	Pump trip identification.
58	IPMPTY	Pump type (1 or 2).
59	IPP	Last interpolated interval in the pump-speed table.
60	IQF	Last interpolated interval in the QPPP factor table's rate-factor table.
61	IQP	Last interpolated interval in the QPPP factor table.
62	IQP3SV	QPPP factor rate-factor table's abscissa-coordinate variable ID number.
63	IQP3TR	Trip ID number that controls evaluation of the QPPP factor table.
64	IRP	Reverse speed indicator. 0 = reverse not allowed, 1 = reverse allowed.
65	ISOL1	Indicator for velocity update at JUN1.
66	ISOL2	Indicator for velocity update at JUN2.
67	JS1	Junction sequence number at cell 1 of the pump.
68	JS2	Junction sequence number at cell NCELLS of the pump.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
69	JUN1	Junction number of the junction at cell 1.
70	JUN2	Junction number of the junction at cell NCELLS.
71	MAT	Wall material ID number.
72	NCELLS	Number of fluid cells.
73	NDMAX	Size of scratch storage array.
74	NHDM	Number of points on the head degradation multiplier curve.
75	NONOFF	Number of time steps the QPPP factor table's controlling trip has been ON.
76	NPMPRF	The number of rate-factor table pairs whose rate factor is applied to the pump-speed table's independent variable.
77	NPMPSD	Signal-variable or control-block ID number that defines the pump rotational speed when the pump-speed controlling trip is initially OFF.
78	NPMPSV	Pump-speed rate-factor table's abscissa-coordinate variable ID number.
79	NPMPTB	Number of pairs in the pump-speed table.
80	NQP3RF	Number of pairs in the QPPP factor table's rate-factor table.
81	NQP3SV	QPPP factor rate-factor table's abscissa-coordinate variable ID number.
82	NQP3TB	Number of pairs in the QPPP factor table.
83	NTDM	Number of points on the torque degradation multiplier curve.
84	OPTION	Pump curve option.
85	TYPE1	Type of adjacent component at JUN1.
86	TYPE2	Type of adjacent component at JUN2.
87	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. PUMPPT--PUMP Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.
HEAD AND TORQUE TABLE				
147	LHSP1	HSP1	2*NDATA(1)	Single-phase head curve 1.
148	LHSP2	HSP2	2*NDATA(2)	Single-phase head curve 2.
149	LHSP3	HSP3	2*NDATA(3)	Single-phase head curve 3.
150	LHSP4	HSP4	2*NDATA(4)	Single-phase head curve 4.
151	LHTP1	HTP1	2*NDATA(5)	Two-phase head curve 1.
152	LHTP2	HTP2	2*NDATA(6)	Two-phase head curve 2.
153	LHTP3	HTP3	2*NDATA(7)	Two-phase head curve 3.
154	LHTP4	HTP4	2*NDATA(8)	Two-phase head curve 4.
155	LTSP1	TSP1	2*NDATA(9)	Single-phase torque curve 1.
156	LTSP2	TSP2	2*NDATA(10)	Single-phase torque curve 2.
157	LTSP3	TSP3	2*NDATA(11)	Single-phase torque curve 3.
158	LTSP4	TSP4	2*NDATA(12)	Single-phase torque curve 4.
159	LTP1	TTP1	2*NDATA(13)	Two-phase torque curve 1.
160	LTP2	TTP2	2*NDATA(14)	Two-phase torque curve 2.
161	LTP3	TTP3	2*NDATA(15)	Two-phase torque curve 3.
162	LTP4	TTP4	2*NDATA(16)	Two-phase torque curve 4.
MISCELLANEOUS TABLE				
163	LBD4	BD4	LENBD	Dummy variable.
164	LHDM	HDM	2*NHDM	Head degradation multiplier curve.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
165	LIDXCS	IDXCS	16	Curve set index array.
166	LNDATA	NDATA	16	Number of sets of points in head and torque curves.
167	LPMPRF	PMPRF	NPMPRF *2	Rate-factor table for the pump-speed table.
168	LPMPTB	PMPTB	NPMPTB *2	Pump rotational speed table.
169	LQP3RF	QP3RF	NQP3RF *2	Rate-factor table for the QPPP factor table.
170	LQP3TB	QP3TB	NQP3TB *2	QPPP factor table.
171	LTDM	TDM	2*NTDM	Torque degradation multiplier curve.
172-317	PTDUM	--	--	Dummy variable.

C. PUMPDATA--PUMP Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; PUMPVLT, defined in Sec. IX.A; and PUMPPT, defined in Sec. IX.B.

X. STEAM-GENERATOR MODULE

A. STGENVLT--STGEN Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	BSMSS1	Time-integrated mass flow from primary side.
3	BSMSS2	Time-integrated mass flow from secondary side.
4	CA1P	Fraction of liquid velocity at the right face of the primary tee junction cell that contributes to the momentum transfer into the primary tee side leg.
5	CA1VP	Fraction of vapor velocity at the right face of the primary tee junction cell that contributes to the momentum transfer into the primary tee side leg.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
6	CAP	Fraction of liquid velocity at the left face of the primary tee junction cell that contributes to the momentum transfer into the tee side leg.
7	CAVP	Fraction of vapor velocity at the left face of the primary tee junction cell that contributes to the momentum transfer into the primary tee side leg.
8	COSP	Cosine of the angle measured from the low-numbered side of the primary tube to the primary tee tube.
9-12	FL(4)	Liquid mass-flow corrections for mass conservation checks.
13-16	FV(4)	Vapor mass-flow corrections for mass conservation checks.
17	HTLSGI	Heat loss on the inside of a general surface (HAAT).
18	HTLSGO	Heat loss on the outside of a general surface (HAAT).
19	QPP3IN	Initial QPPP factor.
20	RADIN	Inner radius of a tube wall.
21	RT1LP	Coefficient for the liquid momentum source term at the left edge of the primary junction cell.
22	RT2LP	Coefficient for the liquid momentum source term at the right edge of the primary tee junction cell.
23	RT1VP	Coefficient for the vapor momentum source term at the left edge of the primary tee junction cell.
24	RT2VP	Coefficient for the upper momentum source term at the right edge of the primary tee junction.
25	TH	Tube wall thickness.
26	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
27	IA1111	Dummy variable that provides a known start to the COMMON block.
28	ICHF1	Indicator for a CHF calculation on the primary side. 0 = no CHF calculation, 1 = CHF calculation.
29	ICHF2	Indicator for a CHF calculation on the secondary side. 0 = no CHF calculation, 1 = CHF calculation.
30	ICNC2	Presence of boron in the secondary flag. 0 = no boron present, 1 = boron present.
31	ICONC	Presence of boron in the primary flag 0 = no boron present, 1 = boron present.
32	ISOLP	Indicator for velocity update at JUNP.
33	ISVLB1	Indicator for velocity update at JUN11.
34	ISVLB2	Indicator for velocity update at JUN21.
35	ISVRB1	Indicator for velocity update at JUN12.
36	ISVRB2	Indicator for velocity update at JUN22.
37	JCLP	Junction cell index of a primary tee connection.
38	JINL	Junction cell index for the secondary inlet junction.
39	JOTL	Junction cell index for the secondary outlet junction.
40	JS11	Junction sequence number at JUN1.
41	JS12	Junction sequence number at JUN2.
42	JSP	Junction sequence number at JUNP.
43	JUN11	Junction number adjacent to cell 1 on primary side.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
44	JUN12	Junction number adjacent to cell NCELL1 on primary side.
45	JUNP	Junction number of the high-numbered-cell end of a primary tee.
46	LGHT	Location in the pointer table of the old time generalized heat-transfer variables.
47	LGHTN	Location in the pointer table of the new time generalized heat-transfer variables.
48	LNGHT	Length of the variables of the generalized heat-transfer information for which old and new time values are stored.
49	MAT	Material identification for tubes.
50	NCELL1	Number of fluid cells on tube side (primary side) excluding the side leg if the primary component is a tee.
51	NCELL2	Number of fluid cells on shell side (secondary side).
52	NCELLS	Total number of fluid cells (NCELL1 + NCELL2 + 1) excluding, if the primary component is a tee, the cells on the primary tee side leg.
53	NCLP	Number of cells on the primary tee.
54-63	NCLS(10)	Number of cells on the primary side of a secondary component.
64-73	NCLT(10)	Number of cells on the side leg of a secondary component (a TEE).
74	NDHT	Number of nodes used in the second set of heat conduction paths.
75	NGHT	Number of heat conduction paths used to model structures in the second set of generalized heat-transfer volumes.
76	NITJN	Number of junctions internal to the secondary flow path (includes the junctions).
77	NODMX	Maximum number of nodes for heat conduction paths (maximum of NODES and NOHT).

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
78	NOTEET	Number of tees used to construct the secondary flow path.
79	NSCMP	Number of components used to construct the secondary flow path.
80	NSJNE	Total number of junctions in the secondary flow path (includes tee junctions and external connections).
81	NSJUN	On input, the total number of junctions in the secondary flow path. This number then is reduced by the number of fills or breaks that are connected to the secondary external connections.
82	NSTJN	Number of external connections on secondary steam generator.
83	NTUBE	The number of conduction paths used to model the first set of generalized heat-transfer volumes.
84-93	STYPE(10)	The component types (PIPEs or TEEs) used to construct the secondary flow path.
94	TYPE11	Type of adjacent component at JUN11.
95	TYPE12	Type of adjacent component at JUN12.
96	TYPEP	Type of adjacent component at JUNP.
97	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. STGENPT--STGEN Pointer Table (For STGEN, NCELLS = NCELL1 + NCELL2 + NCELL3 + NCELL4 + 3NCELLT = NCELL1 + NCELL2 + 1

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
147	LQPPL	QPPL	NCELLS-1	Heat flux ($W \cdot m^{-3}$) from wall to liquid.
148	LQPPV	QPPV	NCELLS-1	Heat flux ($W \cdot m^{-3}$) from wall to vapor.
COMPONENT POINTERS				
149	LCAS	CAS	NSCMP	Source term for a fluid cell containing a side tee junction.
150	LCA1S	CA1S	NSCMP	Source term for a fluid cell that contains a side tee junction.
151	LCA1VS	CA1VS	NSCMP	Source term for a fluid cell that contains a side tee junction.
152	LCAVS	CAVS	NSCMP	Source term for a fluid cell that contains a side tee junction.
153	LCOSS	COSS	NSCMP	Cosine of the angle measured from the low-numbered side of the primary tube to the side tube for a secondary TEE component.
154	LFLS	FLS	4*NSCMP	Liquid volumetric flow rate.
155	LFVS	FVS	4*NSCMP	Vapor volumetric flow rate.
156	LJCLSC	JCLSC	NSJUN	Secondary cell where secondary junction is located.
157	LJCLT	JCLT	NSCMP	Fluid cell number that contains a side-leg tee connection.
158	LJNPOS	JNPOS	NSJUN	Junction location parameter (inflow, outflow, or tee).
159	LJNS	JNS	3*NSCMP	Junction numbers for components that compose the steam-generator secondary side.
160	LJNSC	JNSC	NSJUN	Secondary external junction number (from input).
161	LJSINT	JSINT	4*NSCMP	Sequence numbers for the junctions that compose the steam-generator secondary-side flow path.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
162	LJSSN	JSSN	NSJUN	BD array for the external junction.
163	LJUNS	JUNS	8*(NSJUN -NOTEE)	An array that contains junction information for the components that compose the steam-generator secondary-side flow path.
164	LNCMSC	NCMSC	NSJUN	Secondary component number that contains the junction.
165	LNCTS	NCTS	NSJUN	A vector that contains the junction numbers for the components that comprise the steam-generator secondary side.
166	LNSOL	NSOL	4*NSCMP	An array that contains information about the method of connecting secondary-side steam-generator components.
167	LNUMS	NUMS	NSCMP	User-specified steam-generator secondary-side component numbers.
168	LRT1LS	RT1LS	NSCMP	A source term for a fluid cell that contains a side tee junction.
169	LRT2LS	RT2LS	NSCMP	A source term for a fluid cell that contains a side tee junction.
170	LRT1VS	RT1VS	NSCMP	A source term for a fluid cell that contains a side tee junction.
171	LRT2VS	RT2VS	NSCMP	A source term for a fluid cell that contains a side tee junction.
172	LVSS	VSS	NSJUN	An array that contains information about the method of connecting secondary-side steam-generator components.

HEAT-TRANSFER POINTERS

173	LCPWG	CPWG	NGHT*NDHM1	Wall specific heat ($J \cdot kg^{-1} \cdot K^{-1}$).
174	LCWG	CWG	NGHT*NDHM1	Wall conductivity ($W \cdot m^{-1} \cdot K^{-1}$).
175	LDRG	DRG	NGHT*NDHM1	Internodal spacing (Δr in m) between nodes in the wall.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
176	LEMSG	EMSG	NGHT	Wall emissivity.
177	LHILG	HHILG	NGHT	HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the liquid on the interior of a wall.
178	LHILGN	HILGN	NGHT	New time HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the liquid on the interior of a wall.
179	LHIVG	HIVG	NGHT	HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the vapor on the interior of a wall.
180	LHIVGN	HIVGN	NGHT	New time HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the vapor on the interior of a wall.
181	LHOLG	HOLG	NGHT	HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the liquid on the exterior of a wall.
182	LHOLGN	HOLGN	NGHT	New time HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the liquid on the exterior of a wall.
183	LHOVG	HOVG	NGHT	HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the vapor on the exterior of a wall.
184	LHOVGN	HOVGN	NGHT	New time HTC ($W \cdot m^{-2} \cdot K^{-1}$) to the vapor on the exterior of a wall.
185	LIDGHI	IDGHI	NGHT	Heat-transfer regime flag for the interior of a wall.
186	LIDGHO	IDGHO	NGHT	Heat-transfer regime flag for the exterior of a wall.
187	LIDGI	IDGI	NGHT	Fluid cell identifier for heat transfer with the interior of a wall.
188	LIDGO	IDGO	NGHT	Fluid cell identifier for heat transfer with the exterior of a wall.
189	LMATG	MATG	NGHT*NDHML	Wall material identifier.
190	LQPPG	QPPG	NGHT*NODMX	Wall volumetric heat flux distribution ($W \cdot m^{-3}$).

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
191	LRADIG	RADIG	NGHT	Wall interior radius (m).
192	LRNG	RNG	NGHT*NODMX	Radial locations (m) of the wall heat-transfer nodes.
193	LRN2G	RN2G	NGHT*NDHML	Radial locations (m) of the heat conduction cell edges.
194	LROWG	ROWG	NGHT*NDHML	Wall density ($\text{kg} \cdot \text{m}^{-3}$).
195	LTHG	THG	NGHT	Wall thickness (m).
196	LTILG	TILG	NGHT	Liquid temperature (K) of the fluid interior to the wall.
197	LTIVG	TIVG	NGHT	Vapor temperature (K) of the fluid interior to the wall.
198	LTOLG	TOLG	NGHT	Liquid temperature (K) of the fluid exterior to the wall.
199	LTOVG	TOVG	NGHT	Vapor temperature (K) of the fluid exterior to the wall.
200	LTWG	TWG	NGHT*NODMX	Wall temperature distribution (K).
201	LTWGN	TWGN	NGHT*NODMX	New time wall temperature distribution (K).
202	LWAIG	WAIG	NGHT	Interior wall surface area (m^2).
203	LWAOG	WAOG	NGHT	Exterior wall surface area (m^2).
NETWORK POINTERS				
204	LAOLS	AOLS	NSJUN* (NSJUN+1)	Steam-generator network matrix.
205	LAOUS	AOUS	NSJUN*NSJUN	Steam-generator network matrix.
206	LAOVS	AOVS	NSJUN*NSJUN	Steam-generator network matrix.
207	LBDP	BDP	LENBD	Boundary array for the primary tee connection.
208	LBDS	BDS	NSJUN*LENBD	Boundary arrays for the steam-generator secondary components.
209	LDRAS	DRAS	NSJUN	Steam-generator network vector.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
210	LDRCS	DRCS	NSJUN	Steam-generator network vector.
211	LDRELS	DRELS	NSJUN	Steam-generator network vector.
212	LDREVS	DREVS	NSJUN	Steam-generator network vector.
213	LDRLS	DRLS	NSJUN	Steam-generator network vector.
214	LDRVS	DRVS	NSJUN	Steam-generator network vector.
215	LDVBS	DVBS	NSJUN	Steam-generator network vector.
216	LIOJS	IIOJS	NSJUN	Vector that contains information regarding the association of the steam-generator junctions and the external network matrix.
217	LIOUS	IOUS	NSJUN	Vector that contains information regarding the sequence numbers of the steam-generator secondary junctions.
218	LODS	ODS	4*NSJUN	Steam-generator network matrix.
219	LVRHS	VRHS	NSJUN	Steam-generator network matrix.
220-308	PTDUM	--	--	Dummy variable.

C. STGNDATA--STGEN Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; STGENVLT, defined in Sec. X.A; and STGENPT, defined in Sec. X.B.

XI. TEE MODULE

A. TEEVLT--Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	BSMASS	Time-integrated mass flow from tee.
3	CA	Fraction of liquid velocity at the left face of the tee junction cell that contributes to the momentum transfer into the tee side leg.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
4	CA1	Fraction of liquid velocity at the right face of the tee junction cell that contributes to the momentum transfer into the side leg.
5	CA1V	Fraction of vapor velocity at the right face of the tee junction cell that contributes to the momentum transfer into the tee side leg.
6	CAV	Fraction of vapor velocity at the left face of the tee junction cell that contributes to the momentum transfer into the tee side leg.
7	COST	Cosine of the angle from the low-numbered segment to the secondary tube.
8	ENIN1	Total (time-integrated) energy directly input to the primary.
9	ENIN2	Total (time-integrated) energy directly input to the secondary.
10-13	FL(4)	Liquid mass-flow corrections for mass conservation checks.
14-17	FV(4)	Vapor mass-flow corrections for mass conservation checks.
18	HOUTL1	HTC to liquid at the outer boundary of the primary tube wall.
19	HOUTL2	HTC to liquid at the outer boundary of the secondary tube wall.
20	HOUTV1	HTC to vapor at the outer boundary of the primary tube wall.
21	HOUTV2	HTC to vapor at the outer boundary of the secondary tube wall.
22	POWR1	Power per length added to the tee primary.
23	POWR2	Power per length added to the tee secondary.
24	PWIN1	Initial power deposited in the coolant of the tee primary tube.
25	PWIN2	Initial power deposited in the coolant of the tee secondary tube.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
26	PWOFF1	Power deposited in the coolant of the tee primary tube when its controlling trip is OFF after it was ON.
27	PWOFF2	Power deposited in the coolant of the tee secondary tube when its controlling trip is OFF after it was ON.
28	QPIN1	Initial QPPP factor in the tee primary tube.
29	QPIN2	Initial QPPP factor in the tee secondary tube.
30	QPOFF1	QPPP factor for the tee primary tube when its controlling trip is OFF after it was ON.
31	QPOFF2	QPPP factor for the tee secondary tube when its controlling trip is OFF after it was ON.
32	RADIN1	Inner radius of the primary tube.
33	RADIN2	Inner radius of the secondary tube.
34	RPWMX1	Maximum rate of change of power deposited in the coolant for the tee primary tube.
35	RPWMX2	Maximum rate of change of power deposited in the coolant for the tee secondary tube.
36	RQPMX1	Maximum rate of change of the QPPP factor for the tee secondary tube.
37	RQPMX2	Maximum rate of change of the QPPP factor for the tee secondary tube.
38	RT1L	Coefficient for the liquid momentum source term at the left edge of the junction cell.
39	RT1V	Coefficient for the vapor momentum source term at the left edge of the tee junction cell.
40	RT2L	Coefficient for the liquid momentum source term at the right edge of the tee junction cell.
41	RT2V	Coefficient for the upper momentum source term at the right edge of the tee junction.
42	TH1	Wall thickness of the primary tube.
43	TH2	Wall thickness of the secondary tube.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
44	TLEN1	Length of the primary.
45	TLEN2	Length of the secondary.
46	TOUTL1	Temperature of liquid outside the primary tube wall.
47	TOUTL2	Temperature of liquid outside the secondary tube wall.
48	TOUTV1	Temperature of vapor outside the primary tube wall.
49	TOUTV2	Temperature of vapor outside the secondary tube wall.
50	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

51	IA1111	Dummy variable that provides a known start to the COMMON block.
52	ICHF	CHF calculation option.
53	ICJ1	Iteration index of adjacent component to tee at JUN1.
54	ICJ2	Iteration index of adjacent component to tee at JUN2.
55	ICJ3	Iteration index of adjacent component to tee at JUN3.
56	ICONC1	Indicator for presence of boron in the coolant of the tee primary tube.
57	ICONC2	Indicator for presence of boron in the coolant of the tee secondary tube.
58	IONOF1	Number of time steps the power deposited in the coolant table for the tee primary tube's controlling trip has been ON.
59	IONOF2	Number of time steps the power deposited in the coolant table for the tee secondary tube's controlling trip has been ON.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
60	IPF1	Last interpolated interval number of the rate-factor table for the power deposited in the coolant of the tee primary tube.
61	IPF2	Last interpolated interval number of the rate-factor table for the power deposited in the coolant of the tee secondary tube.
62	IPOW1	Indicator for presence of power deposited in the coolant of the tee primary tube.
63	IPOW2	Indicator for presence of power deposited in the coolant of the tee secondary tube.
64	IPP1	Last interpolated interval number of the power deposited in the coolant table for the tee primary tube.
65	IPP2	Last interpolated interval number of the power deposited in the coolant table for the tee secondary tube.
66	IPWSV1	Power deposited in the coolant table's abscissa-coordinate variable ID number for the tee primary tube.
67	IPWSV2	Power deposited in the coolant table's abscissa-coordinate variable ID number for the tee secondary tube.
68	IPWTR1	Trip ID number that controls evaluation of the power deposited in the coolant table for the tee primary tube.
69	IPWTR2	Trip ID number that controls evaluation of the power deposited in the coolant table for the tee secondary tube.
70	IQF1	Last interpolated interval number of the rate-factor table for the QPPP factor table of the tee primary tube.
71	IQF2	Last interpolated interval number of the rate-factor table for the QPPP factor of the tee secondary tube.
72	IQP1	Last interpolated interval number of the QPPP factor table for the tee primary tube.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
73	IQP2	Last interpolated interval number of the QPPP factor table for the tee secondary tube.
74	IQPSV1	QPPP factor table's abscissa-coordinate variable ID number for the tee primary tube.
75	IQPSV2	QPPP factor table's abscissa-coordinate variable ID number for the tee secondary tube.
76	IQPTR1	Trip ID number that controls evaluation of the QPPP factor table for the tee primary tube.
77	IQPTR2	Trip ID number that controls evaluation of the QPPP factor table for the tee secondary tube.
78	ISOL1	Indicator for velocity update at JUN1.
79	ISOL2	Indicator for velocity update at JUN2.
80	ISOL3	Indicator for velocity update at JUN3.
81	JCELL	Index of the junction cell within the primary tube.
82	JS1	Junction sequence number at cell 1 of the primary tube.
83	JS2	Junction sequence number at cell NCELL1 of the primary tube.
84	JS3	Junction sequence number at cell NCELL2 of the side tube.
85	JUN1	Junction number of the junction at cell 1 of the primary tube.
86	JUN2	Junction number of the junction at cell NCELL1 of the primary tube.
87	JUN3	Junction number of the junction at cell NCELL2 of the side tube.
88	MAT	Wall material ID numbers.
89	NCELL1	Number of fluid cells in the primary tube of the tee.
90	NCELL2	Number of fluid cells in the side tube of the tee.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
91	NCELLS	$NCELL1 + NCELL2 + 1$.
92	NONOF1	Number of time steps the QPPP factor table for the tee primary tube's controlling trip has been ON.
93	NONOF2	Number of time steps the QPPP factor table for the tee secondary tube's controlling trip has been ON.
94	NPWRF1	Number of pairs in the rate-factor table for the power deposited in the coolant table of the tee primary tube.
95	NPWRF2	Number of pairs in the rate-factor table for the power deposited in the coolant table of the tee secondary tube.
96	NPWSV1	Rate-factor table's abscissa-coordinate variable ID number for the power deposited in the coolant table of the tee primary tube.
97	NPWSV2	Rate-factor table's abscissa-coordinate variable ID number for the power deposited in the coolant table of the tee secondary tube.
98	NPWTB1	Number of pairs in the power deposited in the coolant table for the tee primary tube.
99	NPWTB2	Number of pairs in the power deposited in the coolant table for the tee secondary tube.
100	NQPRF1	Number of pairs in the rate-factor table for the QPPP factor table of the tee primary tube.
101	NQPRF2	Number of pairs in the rate-factor table for the QPPP factor table of the tee secondary tube.
102	NQPSV1	Rate-factor table's abscissa-coordinate variable ID number for the QPPP factor table of the tee primary tube.
103	NQPSV2	Rate-factor table's abscissa-coordinate variable ID number for the QPPP factor table of the tee secondary tube.
104	NQPTB1	Number of pairs in the QPPP factor table for the tee primary tube.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
105	NQPTB2	Number of pairs in the QPPP factor table for the tee secondary tube.
106	TYPE1	Type of adjacent component at JUN1.
107	TYPE2	Type of adjacent component at JUN2.
108	TYPE3	Type of adjacent component at JUN3.
109	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. TEEPT--TEE Pointer Table (For TEE, NCELLS = NCELL1 + NCELL2 + 1)

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.
147	LBD4	BD4	LENBD	Dummy BD4 array.
148	LPOWRF	POWRF	(NPWRF1 + NPWRF2)*2	Rate-factor tables for the power deposited in the coolant tables.
149	LPOWTB	POWTB	(NPWTB1 + NPWTB2)*2	Power deposited in the coolant table.
150	LQP3RF	QP3RF	(NQPRF1 + NQPRF2)*2	Rate-factor table for the QPPP factor tables.
151	LQP3TB	QP3TB	(NQPTB1 + NQPTB2)*2	QPPP factor tables.
152-317	PTDUM	--	--	Dummy variable.

C. TEEDATA--TEE Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; TEEVLT, defined in Sec. XI.A; and TEEPT, defined in Sec. XI.B.

XII. TURBINE MODULE

A. TURBNVLT--TURB Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	ALPHA1	Upstream void fraction.
3	ALPHA2	Downstream void fraction.
4	AR	Area ratio (bucket exit area/nozzle exit area).
5	BSMASS	Time-integrated mass flow from turbine.
6	COEF1	Nozzle coefficient.
7	COEF2	Bucket coefficient.
8	COF3SQ	Fraction of reaction energy actually delivered in the stage.
9	CP	Specific heat at constant pressure.
10	CPOW	Special turbine input.
11	DIA	Bucket centerline diameter.
12	DSMOM	Derivative of SMOM with respect to velocity.
13	EFFDSN	Stage efficiency at design conditions.
14	EFFSTG	Stage efficiency.
15	ENINP	Total (time-integrated) energy directly input to the turbine.
16-17	FL(2)	Liquid mass-flow corrections for mass conservation checks.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
18	FLODIR	Flow direction flag. -1.0 = indicates normal flow direction is from JUN2 to JUN1, 1.0 = indicates normal flow direction is from JUN1 to JUN2.
19	FLOW	Mass-flow rate.
20-21	FV(2)	Vapor mass-flow corrections for mass conserva- tion checks.
22	GAMMA	Isentropic exponent of expansion.
23	PHIREM	Remaining losses (rotation or diaphragm- packing).
24	PLENT	Total length of the turbine stage.
25	POWIN	Initial power in the coolant.
26	POWDSN	Stage power output at design conditions.
27	POWOFF	Power in the coolant when the controlling trip is OFF after it was ON.
28	POWSTG	Stage power output.
29	PRES1	Upstream pressure.
30	PRES2	Downstream pressure.
31	QUALTY	Thermodynamic quality of steam.
32	REACTN	Degree of reaction at design conditions.
33	RHOL1	Upstream liquid density.
34	RHOL2	Downstream liquid density.
35	RHOM1	Upstream mixture density.
36	RHOM2	Downstream mixture density.
37	RHOV1	Upstream steam density.
38	RHOV2	Downstream steam density.
39	RPOWMX	Maximum rate of change of the power deposited in the coolant.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
40	SMOM	Source term in the momentum equation (head gain).
41	SUPRHT	Upstream degree of superheat of steam.
42	TEMPL1	Upstream liquid temperature.
43	TEMPL2	Downstream liquid temperature.
44	TEMPV1	Upstream steam temperature.
45	TEMPV2	Downstream steam temperature.
46	VELL1	Upstream liquid velocity.
47	VELL2	Downstream liquid velocity.
48	VELM1	Upstream mixture velocity.
49	VELM2	Downstream mixture velocity.
50	VELV1	Upstream steam velocity.
51	VELV2	Downstream steam velocity.
52	VSTAG	Stagnation velocity.
53	Z11111	Dummy variable that provides a known end to the COMMON block.
INTEGER VARIABLES		
54	IA1111	Dummy variable that provides a known start to the COMMON block.
55	ICJ1	Iteration index of adjacent component at JUN1.
56	ICJ2	Iteration index of adjacent component at JUN2.
57	ICONC	Presence of boron dissolved in the liquid coolant flag.
58	IONOFF	Number of time steps the power deposited in the coolant trip has been ON.
59	IPF	Power deposited in the coolant table's rate-factor table interval last interpolated.
60	IPOW	Presence of power in the coolant flag.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
61	IPOWSV	Power deposited in the coolant table's abscissa-coordinate variable ID number.
62	IPOWTR	Trip ID number that controls power deposited in the coolant table evaluation.
63	IPP	Power deposited in the coolant table interval last interpolated.
64	ISOLLB	Indicator for velocity update at JUN1.
65	ISOLRB	Indicator for velocity update at JUN2.
66	ISTG	Stage number.
67	JS1	Junction sequence number at cell 1 of the turbine.
68	JS2	Junction sequence number at cell NCELLS of the turbine.
69	JUN1	Junction number of the junction at cell 1.
70	JUN2	Junction number of the junction at cell NCELLS.
71	LENTTB	Length of the turbine block in array data (information pertaining to the entire turbine-generator assembly, that is, the sum over all stages).
72	NCELLS	Number of fluid calculation cells in the turbine component.
73	NEFCON	Turbine efficiency. 0 = stage efficiency to be computed at off-design conditions, 1 = constant efficiency.
74	NPOWRF	Number of entry pairs in the power deposited in the coolant table's rate-factor table.
75	NPOWSV	Power deposited in the coolant table's rate-factor table's abscissa-coordinate variable ID number.
76	NPOWTB	Number of entry pairs in the power deposited in the coolant table.
77	NROWS	Number of rows of moving blades.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
78	TYPE1	Type of adjacent component at JUN1.
79	TYPE2	Type of adjacent component at JUN2.
80	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. TURBPT--TURB Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.
147	LANGL	ANGL	NROWS2	Pointer for blade angles.
148	LPOWRF	POWRF	NPOWRF *2	Pointer variable address for the power deposited in the coolant table's rate-factor table.
149	LPOWTB	POWTB	NPOWTB *2	Pointer variable address for the power deposited in the coolant table.
150	LTURB	TURB	-1	Absolute LCM address for the turbine data common among all stages.
151-314	PTDUM	--	--	Dummy variable.

C. TURBDATA--TURB Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; TURBNVLT, defined in Sec. XII.A; and TURBPT, defined in Sec. XII.B.

XIII. VALVE MODULE

A. VALVEVLT--VALVE Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	AVLVE	Valve open flow area.
3	BSMASS	Time-integrated mass flow from the valve.
4	FAVLVE	Fraction of the fully open flow area AVLVE to which the adjustable valve cross section is set.
5-6	FL(2)	Liquid mass-flow corrections for mass conservation checks.
7	FMAXOV	Maximum flow area fraction or relative valve stem position during valve adjustment by the overriding trip.
8	FMINOV	Minimum flow area fraction or relative valve stem position during valve adjustment by the overriding trip.
9-10	FV(2)	Vapor mass-flow corrections for mass conservation checks.
11	HOUTL	HTC between outer boundary of valve wall and liquid.
12	HOUTV	HTC between outer boundary of valve wall and vapor.
13	HVLVE	Valve open hydraulic diameter.
14	QP3IN	Initial QPPP factor.
15	QP3OFF	QPPP factor when the controlling trip is OFF after it was ON.
16	RADIN	Inner radius of pipe wall.
17	RQP3MX	Maximum allowed rate of change of the QPPP factor(s).

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
18	RVMX	Maximum rate of change of valve flow area fraction or relative valve stem position.
19	RVOV	Rate of change of valve flow area fraction or relative valve stem position when controlled by the overriding trip being ON.
20	TH	Thickness of pipe wall.
21	TOUTL	Liquid temperature outside valve.
22	TOUTV	Vapor temperature outside valve.
23	XPOS	Variable flag for valve operation in progress. 0 = no movement, 1 = opening movement.
24	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

25	IA1111	Dummy variable that provides a known start to the COMMON block.
26	ICHF	CHF calculation option.
27	ICJ1	Iteration index of adjacent component at JUN1.
28	ICJ2	Iteration index of adjacent component at JUN2.
29	ICONC	Indicator for presence of boron in the coolant.
30	IONOFF	Number of time steps the valve table's controlling trip has been ON.
31	IQF	Last interpolated interval number in the rate-factor table for the QPPP factor table.
32	IQP	Last interpolated interval number in the QPPP factor table.
33	IQP3SV	QPPP factor table's abscissa-coordinate variable ID number.
34	IQP3TR	Trip ID number that controls evaluation of the QPPP factor table.
35	ISOLLB	Indicator for velocity update at JUN1.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
36	ISOLRB	Indicator for velocity update at JUN2.
37	IVF	Last interpolated interval number in the rate-factor table for the valve adjustment table.
38	IVP1	// Last interpolated interval number in the first valve adjustment table.
39	IVP2	Last interpolated interval number in the second valve adjustment table.
40	IVPS	Adjustable valve interface position.
41	IVSV	Signal-variable ID number that defines the valve table's independent variable.
42	IVTR	Trip ID number that controls evaluation of the valve adjustment table(s).
43	IVTROV	Trip ID number that overrides trip IVTR control of the adjustable valve.
44	IVTY	Valve type option indicator.
45	IVTYOV	Type of valve flow adjustment by the overriding trip IVTROV.
46	JS1	Junction sequence number at cell 1 of the valve.
47	JS2	Junction sequence number at cell NCELLS of the valve.
48	JUN1	Junction number of the junction at cell 1.
49	JUN2	Junction number of the junction at cell NCELLS.
50	MAT	Wall material ID number.
51	MODE	Indicator for valve movement over the previous time step. -1 = closing, 0 = no movement, or 1 = opening.
52	NCELLS	Number of fluid cells.
53	NONOFF	Number of time steps the QPPP factor table's controlling trip has been ON.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
54	NQP3RF	Number of pairs in the rate-factor table for the QPPP factor table.
55	NQP3SV	Rate-factor table's abscissa-coordinate variable ID number for the QPPP factor table.
56	NQP3TB	Number of pairs in the QPPP factor table.
57	NVRF	Number of rate-factor table pairs whose rate factor is applied to the valve table's independent variable.
58	NVSV	Rate-factor table's abscissa-coordinate variable ID number for the valve adjustment table(s).
59	NVTB1	Number of pairs in the first valve adjustment table.
60	NVTB2	Number of pairs in the second valve adjustment table.
61	TYPE1	Type of adjacent component at JUN1.
62	TYPE2	Type of adjacent component at JUN2.
63	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. VLVEPT--VALVE Pointer Table

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1-72	DUALPT	--	--	General pointer table.
73-131	HYDROPT	--	--	General pointer table.
132-134	INTPT	--	--	General pointer table.
135-146	HEATPT	--	--	General pointer table.
147	LQP3RF	QP3RF	NQP3RF *2	Rate-factor table for the QPPP factor table.
148	LQP3TB	QP3TB	NQP3TB *2	QPPP factor table.
149	LVRF	VRF	NVRF *2	Rate-factor table for the valve adjustment table(s).

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
150	LVTB1	VTB1	NVTB1 *2	First valve adjustment table.
151	LVTB2	VTB2	NVTB2 *2	Second valve adjustment table.
152-317	PTDUM	--	--	Dummy variable.

C. VLVEDATA--VALVE Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; VALVEVLT, defined in Sec. XIII.A; and VLVEPT, defined in Sec. XIII.B.

XIV. VESSEL MODULE

A. VSSELVLT--VESSEL Variable-Length Table

REAL VARIABLES

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
1	AA1111	Dummy variable that provides a known start to the COMMON block.
2	AMH2	Hydrogen mass generated from metal-water reaction.
3	BCR0	Zero-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of control-rod pin boron.
4	BCR1	First-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of control-rod pin boron.
5	BEFF	Total delayed neutron fraction.
6	BPP0	Zero-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of burnable-poison pin boron.
7	BPP1	First-order coefficient of the first-order polynomial that defines the effective core-averaged concentration of burnable-poison pin boron.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
8	BSMASS	Integrated fluid flow from vessel at start of time step.
9	BSMSSN	Integrated fluid flow from vessel at end of time step.
10	CIMFR	Core inlet mass-flow rate.
11	CIMFRL	Core inlet liquid mass-flow rate.
12	CIMFRV	Core liquid volume fraction.
13	COMFR	Core outlet mass-flow rate.
14	COMFRL	Core outlet liquid mass-flow rate.
15	COMFRV	Core outlet vapor pressure mass-flow rate.
16	CORELQ	Core liquid volume fraction.
17	DCFLOW	Downcomer mass-flow rate.
18	DCLQVL	Downcomer liquid volume fraction.
19	DRFB	Reactivity-feedback change in K over last time step.
20	DRI	Estimated change in reactivity over the previous time step.
21	DRIO	Old value of DRI equals the old value of the power or reactivity-estimate correction.
22-23	DTNHT(2)	Delta temperature minimums used in reflood calculation.
24	DTPK	Kaganove-method integration time step for solving the point-kinetics equations.
25-26	DTXHT(2)	Delta temperature maximums used in reflood calculation.
27	DZNHT	Delta Z_{min} .
28	ENEFF	Total decay heat fraction.
29	EXTSOU	Thermal power (W) produced by external source neutrons in the reactor core.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
30	FUCRAC	Fraction of uncracked fuel.
31	HGAPO	Rod gap-conductance coefficient (MATRD = 3).
32	PCORE	Average core pressure.
33	PDC	Downcomer average pressure.
34	PDRAT	Rod pitch-to-diameter ratio.
35	PLDR	Pellet dish radius. 0.0 = no pellet-dish calculation, 1.0 = pellet-dish calculation.
36	PLP	Lower-plenum average pressure.
37	POWEXP	Exponent value to which the power distribution is raised to define the weighting function for averaging the reactivity-feedback parameters over the core volume.
38	PUP	Upper-plenum average pressure.
39	QRDTOT	Total rod heat flux.
40	QSLTOT	Total slab heat flux.
41	REAC	Reactivity feedback at the beginning of the previous time step.
42	REACN	Reactivity-feedback estimate at the end of the present time step.
43	REACT	Total reactivity at the beginning of the present time step.
44	RMCK	Reactor multiplication constant at the beginning of the present time step.
45	RMCKN	Reactor multiplication constant estimate at the end of the present time step.
46	RPOWPF	Prompt fission power.
47	RPOWR	Old reactor power.
48	RPOWRI	Initial reactor power.
49	RPOWRN	New reactor power.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
50	RPOWRO	Old reactor power of the previous time step.
51	RPWOFF	Programmed reactivity or reactor power when the controlling trip is OFF after it was ON.
52	RRPWMX	Maximum rate of change of programmed reactivity or reactor power.
53	RZPWMX	Maximum rate of change of the axial power shape.
54	SDT	Time interval (s) since the last reactivity change printout.
55	SHELV	Addition to the input vessel Z coordinates to get elevations for computing GRAV in one dimension.
56	STIMET	Problem time (s) at which the last reactivity change was summed to variable storage for later printout.
57	TCILMF	Integrated core inlet liquid mass flow (kg).
58	TCIVMF	Integrated core inlet vapor mass flow (kg).
59	TCOLMF	Integrated core outlet liquid mass flow (kg).
60	TCORE	Average core temperature.
61	TCOVMF	Integrated core outlet vapor mass flow (kg).
62	TDC	Downcomer average liquid temperature.
63	TLP	Lower-plenum average temperature.
64	TNEUT	Neutron generation time.
65	TRAMAX	Average-rod peak-cladding temperature.
66	TRHMAX	Maximum supplemental rod temperature.
67	TSCORE	Average core saturation temperature.
68	TSDC	Downcomer average saturation temperature.
69	TSLP	Lower-plenum average saturation temperature.
70	TSUP	Upper-plenum average liquid temperature.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
71	TUP	Upper-plenum average liquid temperature.
72	VBMASS	Mass counter for internal break sources.
73	VBSSN	Mass counter for internal break sources.
74	VCORE	Total liquid mass in the core.
75	VDCLQ	Total liquid mass in the downcomer.
76	VFMASS	Mass counter for internal fill source.
77	VFSSN	Mass counter for internal fill source.
78	VLCORE	Core liquid mass.
79	VLPLIQ	Lower-plenum liquid volume fraction.
80	VLPLM	Lower-plenum liquid mass.
81	VLPLQ	Total liquid mass in the lower plenum.
82	VLQMSS	Total liquid mass in the vessel.
83	VOLDC	Downcomer volume.
84	VOLLP	Lower-plenum volume.
85	VOLUP	Upper-plenum volume.
86	VSFLOW	Vessel mass flow.
87	VUPLIQ	Upper-plenum liquid volume fraction.
88	VUPLM	Upper-plenum liquid mass.
89	ZPWIN	Axial power-shape table's abscissa-coordinate variable value corresponding to the initial axial power shape.
90	ZPWOFF	Axial power-shape table's abscissa-coordinate variable value that corresponds to the axial power shape that is used when the controlling trip is OFF after it was ON.
91	Z11111	Dummy variable that provides a known end to the COMMON block.

INTEGER VARIABLES

92	IA1111	Dummy variable that provides a known start to the COMMON block.
93-96	IBU(4)	Boron-unit flag for the Jth reactivity coefficient.
97	ICONC	Presence of boron in the coolant flag.
98	ICRL	Core lower-boundary segment number, Z(ICRL).
99	ICRR	Core outer radial-boundary segment number, RAD(ICRR).
100	ICRRG	Outermost radial ring in the core. Currently defaults to ICRR.
101	ICRU	Core upper-boundary segment number, Z(ICRU).
102	IDCL	Downcomer lower-boundary segment number, Z(IDCL).
103	IDCR	Downcomer radial-boundary segment number, RAD(IDCR).
104	IDCU	Downcomer upper-boundary segment number, Z(IDCUC).
105	IITOT	Inner iteration counter.
106	ILCSP	Lower-core support-plate axial segment number.
107	INHSMX	Number of interfaces between dissimilar materials in the vessel slabs.
108	IONOFF	Number of time steps the reactivity-power table's controlling trip has been ON.
109-112	IRC(4)	Number of values that defines the argument number reactivity-coefficient table.
113-116	IRCJFM(4)	Form number of the reactivity coefficient for the argument number reactivity-feedback parameter.
117-132	IRCJTB(4,4)	Number of first argument reactivity-feedback parameter value entries for the second argument reactivity-coefficient table.
133	IRF	Last interpolated interval number in the rate-factor table for the reactivity-power table.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
134	IRFTR	Trip ID number that controls evaluation with the reflod axial fine mesh in the fuel rod.
135	IRP	Last interpolated interval number in the reactivity-power table.
136	IRPWSV	Reactivity-power table's abscissa-coordinate variable ID number.
137	IRPWTR	Trip ID number that controls evaluation of the reactivity-power table.
138	IRPWTY	Reactor-kinetics option indicator.
139	ISNOTB	A flag variable that is defined if the solute is boron for the reactivity-feedback calculation. 0 = solute is boron, 1 = solute is not boron.
140	IUCSP	Upper-core support-plate axial segment number.
141	IUHP	Upper head-plate axial segment number.
142	IVSSBF	Internal vessel boundary condition. 0 = no internal boundaries (default); 2 = first axial level acts like a fill, last axial level acts like a break; 20 = first axial level acts like a break, last axial level acts like a fill; 22 = both the first and last axial levels act like breaks.
143	IZBK	Switch for backup on water pack.
144	IZBK2	Switch for re-donor-cell logic.
145	IZNX	Variable used in water-packing logic.
146	IZF	Last interpolated interval number in the rate-factor table for the axial power-shape table.
147	IZP	Last interpolated interval number in the axial power-shape table.
148	IZPWSV	Axial power-shape table's abscissa-coordinate variable ID number.
149	IZPWTR	Trip ID number that controls evaluation of the axial power-shape table.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
150	LENLD	Length of level data.
151	LENRD	Length of rod data.
152	LFVL	Relative position of old fundamental variables of level data.
153	LFVNL	Relative position of new fundamental variables of level data.
154	LFVNR	Relative position of new fundamental variables of rod data.
155	LFVR	Relative position of old fundamental variables of rod data.
156	LNFVL	Length of fundamental variables of level data.
157	LNFVR	Length of fundamental variables of rod length.
158	LNPTL	Number of level data pointers.
159	LNPTRR	Number of pointers of rod data.
160	NASX	Number of axial segments (levels).
161	NCELLS	Total number of fluid cells.
162	NCLX	Number of fluid cells per level.
163	NCRX	Maximum number of core volumes per level.
164	NCRXX	Total number of core volumes.
165	NCRZ	Number of core levels.
166	NCSK	Number of cell sources (connections).
167	NDGX	Number of delayed neutron groups.
168	NDHX	Number of decay heat groups.
169	NFBPWT	Flag that defines the spatial distribution used to weight the averaging of the reactivity-feed-back parameters over the reactor-vessel volume.
170	NFCI	FCI flag. 0 = no calculation, 1 = calculation.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
171	NFCIL	Limit on FCI calculations per time step.
172	NFFA	Axial friction-factor correlation option.
173	NFFR	Radial friction-factor correlation option.
174	NFFT	Theta friction-factor correlation option.
175	NFUEL	Number of nodes in fuel pellet.
176	NINT	Number of interfaces between dissimilar materials in rods.
177	NMWRX	Metal-water reaction flag. 0 = no calculation, 1 = calculation.
178	NODHS	Number of nodes in the heat slab.
179	NONOFF	Number of time steps the trip-controlling evaluation of the axial power-shape table has been ON.
180	NRAMAX	Location of average-rod peak-cladding temperature used in reflood calculation.
181	NRFD	Reflood flag. 0 = takes no action, 1 = turns on fine-mesh flag if it is off.
182	NRHMAX	Location of supplemental rod peak-cladding temperature.
183	NRODS	Number of computational rods.
184	NRPWRF	Number of rate-factor table pairs whose rate factor is applied to the power or reactivity table's independent variable.
185	NRPWSV	Reactivity-power rate-factor table's abscissa-coordinate variable ID number.
186	NRPWTB	Number of entry pairs in the reactivity-power table.
187	NRSX	Number of radial segments.
188	NRTS	Number of time steps over which the programmed reactivity and reactivity-feedback changes are summed for printout.

<u>Position(s)</u>	<u>Parameter</u>	<u>Description</u>
189	NSET	Absolute value of the reflood fine axial mesh trip set-status number during the previous time step.
190	NTSX	Number of theta segments.
191	NVENT	Number of cells with vent valves in outer radial surface.
192	NZMAX	Maximum number of rows of heat-transfer nodes used in reflood calculation.
193	NZPWRF	Number of entry pairs in the axial power-shape rate-factor table.
194	NZPWSV	Axial power-shape rate-factor table's abscissa-coordinate variable ID number.
195	NZPWTB	Number of axial power shapes in the axial power-shape table.
196	ZI1111	Dummy variable that provides a known end to the COMMON block.

B. VSSLPT--VESSEL Pointer Table

COMMON DATA POINTERS

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
1	LAVENT	AVENT	NVENT	Pointer for vent valve AEARS.
2	LBETA	BETA	NDGX	Delayed neutron group fraction.
3	LCDG	CDG	NDGX	Old concentration of delayed neutron groups.
4	LCDGN	CDGN	NDGX	New concentration of delayed neutron groups.
5	LCDH	CDH	NDHX	Old concentration of decay heat groups.
6	LCDHN	CDHN	NDHX	New concentration of decay heat groups.
7	LCLEN	CLEN	NCRX	Old total cladding length.
8	LCLENN	CLENN	NCRX-1	New total cladding length.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
9	LCPOWR	CPOWR	NCRX	Relative power per rod.
10	LDPCVN	DPCVN	NVENT	Pointer for vent valve maximum ΔP to be closed.
11	LDPOVN	DPOVN	NVENT	Pointer for vent valve minimum ΔP to be open.
12	LDR	DR	NRSX	Radial segment lengths (delta R).
13	LDTH	DTH	NTSX	Theta segment length (delta theta).
14	LDVLDP	DVLDP	NCSR	Derivative of liquid source velocity with respect to pressure.
15	LDVVDP	DVVDP	NCSR	Derivative of vapor source velocity with respect to pressure.
16	LDZ	DZ	NASX	Axial segment lengths (delta Z).
17	LEDH	EDH	NDHX	Energy yield fraction of decay heat groups.
18	LFPUO2	FPUO2	NCRX	Fraction of plutonium oxide in mixed-oxide fuel fraction.
19	LFRCVN	FRCVN	NVENT	Pointer for vent valve FRIC value when closed.
20	LFROVN	FROVN	NVENT	Pointer for vent valve FRIC value when open.
21	LFTD	FTD	NCRX	Fuel density (fraction of theoretical).
22	LGMIX	GMIX	NCRX*7	Mole fraction of gap-gas constituents.
23	LGMLES	GMLES	NCRX	Moles of gap gas.
24	LHS	HS	NCRX* (NFBPWT/4)	Pointer variable for the horizontal plane shape weight function used.
25	LICJ	ICJ	NCSR	Adjacent component associated with source.
26	LIDROD	IDROD	NRODS	Cell identifier for rods.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
27	LISOLB	ISOLB	NCSR	Indicator for velocity update.
28	LISRC	ISRC	NCSR	Relative cell number associated with source.
29	LISRF	ISRF	NCSR	Face number associated with source.
30	LISRL	ISRL	NCSR	Level number associated with source.
31	LIZREP	IZREP	NASX	Indicator for levels to be re-donor-celled.
32	LJSN	JSN	NCSR	Junction sequence number associated with source.
33	LJUNS	JUNS	NCSR	Junction number associated with source.
34	LLAMDA	LAMDA	NDGX	Decay constant of delayed groups.
35	LLAMDH	LAMDH	NDHX	Decay constant of decay heat groups.
36	LLOCVN	LOCVN	NVENT	Pointer for vent valve location.
37	LMATRD	MATRD	NODES-1	Rod material identification.
38	LMSC	MSC	NCSR	Absolute cell number of source.
39	LN ⁵ FAX	NFAX	NCRZ	Rod fine-mesh nodding factor.
40	LNRDX	NRDX	NCRX	Number of rods in volume.
41	LNSRL	NSRL	NASX	Number of sources on level.
42	LPGAPT	PGAPT	NCRX	Gap total gas pressure.
43	LPLVOL	PLVOL	NCRX	Rod plenum volume.
44	LPSLEN	PSLEN	NCRX	Pellet stack length.
45	LPSNEW	PSNEW	NCSR	New source pressure.
46	LPSOLD	PSOLD	NCSR	Old source pressure.
47	LRAD	RAD	NRSX	Radial segment outer radii.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
48	LRADRD	RADRD	NODES	Rod node radius (cold).
49	LRCAL	RCAL	$\Sigma \text{IRCJTB}(i,3) + \pi_i \text{IRCJTB}(i,3)$	Coolant void-fraction reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
50	LRCBM	RCBM	$\Sigma \text{IRCJTB}(i,4) + \pi_i \text{IRCJTB}(i,4)$	Boron reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
51	LRCN	RCN	4	Reactivity-coefficient values at the beginning of the previous time step.
52	LRCTC	RCTC	$\Sigma \text{IRCJTB}(i,2) + \pi_i \text{IRCJTB}(i,2)$	Coolant temperature reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
53	LRCTF	RCTF	$\Sigma \text{IRCJTB}(i,1) + \pi_i \text{IRCJTB}(i,1)$	Fuel temperature reactivity-coefficient table. The symbol π_i indicates the product of the following variable taken over the i subscript.
54	LRDPWR	RDPWR	NODES	Rod relative radial power density.
55	LRPKF	RPKF	NRODS	Rod power peaking factor.
56	LRPWRF	RPWRF	$ \text{NRPWRF} *2$	Rate-factor table for the power or reactivity table.
57	LRPWTB	RPWTB	$ \text{NRPWTB} *2$	Power or reactivity table.
58	LRS	RS	$\text{NODES}*\text{MOD}(\text{NFBPWT},2)$	Pointer variable for the fuel-rod radial shape weight function used to average reactivity-feedback parameters over the core volume. [MOD(N,2) = N - (N/2)*2]
59	LSAC	SAC	NCSR*2	Air continuity source.
60	LSCC	SCC	NCSR*ISOLUT	Pointer for solute concentration source terms. ISOLUT = 0 or 1.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
61	LSLC	SLC	NCSR*2	Liquid continuity source.
62	LSLE	SLE	NCSR*2	Liquid energy source.
63	LSMOML	SMOML	NCSR*6	Liquid momentum source.
64	LSMOMV	SMOMV	NCSR*6	Vapor momentum source.
65	LSRP	SRP	15	Summed programmed and feedback-reactivity changes.
66	LSVC	SVC	NCSR*2	Vapor continuity source.
67	LSVE	SVE	NCSR*2	Vapor energy source.
68	LTH	TH	NTSX	Theta segment angle.
69	LVELSL	VELSL	NCSR	Liquid source velocity.
70	LVELSV	VELSV	NCSR	Vapor source velocity.
71	LXN	XN	4	New reactivity-feedback parameter values.
72	LXO	XO	4	Old reactivity-feedback parameter values.
73	LZ	Z	NASX	Axial segment upper elevation.
74	LZPW	ZPW	NCRZP1	Last interpolated axial power shape.
75	LZPWRF	ZPWRF	NZPWRF *2	Axial power-shape rate-factor table.
76	LZPWTB	ZPWTB	NZPWTB * NCRZP2	Relative axial power-shape table.
77	LZS	ZS	NCRZP1*(MOD (NFBPWT,4)/2)	Pointer variable for the axial-direction shape. [MOD(N,2) = N - (N/2)*2]
LEVEL DATA POINTERS				
78	LAID1	AID1	NCLX*IDROP	Variable not currently implemented.
79	LAID1N	AID1N	NCLX*IDROP	Variable not currently implemented.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
80	LAID2	AID2	NCLX*IDROP	Variable not currently implemented.
81	LAID2N	AID2N	NCLX*IDROP	Variable not currently implemented.
82	LALD1	ALD1	NCLX*IDROP	Variable not currently implemented.
83	LALD1N	ALD1N	NCLX*IDROP	Variable not currently implemented.
84	LALD2	ALD2	NCLX*IDROP	Variable not currently implemented.
85	LALD2N	ALD2N	NCLX*IDROP	Variable not currently implemented.
86	LALP	ALP	NCLX	Old vapor fraction.
87	LALPN	ALPN	NCLX	New vapor fraction.
88	LALV	ALV	NCLX	Old interfacial area.
89	LALVN	ALVN	NCLX	New interfacial area.
90	LAM	AM	NCLX	Storage for Γ .
91	LAND	AND	NCLX	Variable reserved for a droplet field.
92	LANDN	ANDN	NCLX	Variable reserved for a droplet field.
93	LARC	ARC	NCLX*ISOLUT	Pointer for cellular solute density. ISOLUT = 0 or 1.
94	LARV	ARV	NCLX	Product of void fraction and vapor density.
95	LBIT	BIT	NCLX	Bit flag.
96	LBITN	BITN	NCLX	Bit flag.
97	LCFZL	CFZL	NCLX*3* NFR3	Total friction factors (liquid).
98	LCFZV	CFZV	NCLX*3* *NFR3	Total friction factors (vapor).

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
99	LCL	CL	NCLX	Liquid conductivity.
100	LCNHS	CNHS	NCLX*NODHS	Slab conductivities.
101	LCNHSN	CNHSN	INHSMX*NCLX	Slab conductivities at a material interface.
102	LCONC	CONC	NCLX*ISOLUT	New ratio of boron mass to coolant mass. ISOLUT = 0 or 1.
103	LCONCO	CONCO	NCLX*ISOLUT	Old ratio of boron mass to coolant mass. ISOLUT = 0 or 1.
104	LCPHS	CPHS	NCLX*NODHS	Slab specific heats.
105	LCPHSN	CPHSN	INHSMX*NCLX	Slab specific heat at a material interface.
106	LCPL	CPL	NCLX	Liquid specific heat at constant pressure.
107	LCPV	CPV	NCLX	Vapor specific heat at constant pressure.
108	LCV	CV	NCLX	Vapor conductivity.
109	LDLL	DLL	NCLX*3	Derivative used in momentum update (vapor).
110	LDRIV	DRIV	NTHM3D*NCLX	Variable array for thermodynamic derivatives, enthalpies, and temporary storage for matrix inversions.
111	LDROP	DROP	NCLX*4	Droplet field storage area.
112	LDVD1	DVD1	NCLX*3>IDROP	Variable not currently implemented.
113	LDVD2	DVD2	NCLX*3>IDROP	Variable not currently implemented.
114	LDVV	DVV	NCLX*3	Derivative used in momentum update (liquid).
115	LEA	EA	NCLX	Old air energy.
116	LEAN	EAN	NCLX	New air energy.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
117	LEL	EL	NCLX	Old liquid internal energy.
118	LELN	ELN	NCLX	New liquid internal energy.
119	LEMHS	EMHS	NCLX*NODHS	Slab emissivities.
120	LEV	EV	NCLX	Old vapor internal energy.
121	LEVN	EVN	NCLX	New vapor internal energy.
122	LFA	FA	NCLX*3	Cell-edge fluid areas.
123	LFAG	FAG	NCLX*3	Cell-edge geometric areas.
124	LFINAN	FINAN	NCLX	Inverted annular regime factor.
125	LFRCIN	FRCIN	NCLX*3	New interfacial friction factors.
126	LFRICI	FRICI	NCLX*3	Old interfacial friction factors.
127	LFRICL	FRICL	NCLX*3	Friction multipliers (liquid).
128	LFRICV	FRICV	NCLX*3	Friction multipliers (vapor).
129	LGAM	GAM	NCLX	Storage for Γ .
130	LGAMN	GAMN	NCLX	Storage for Γ .
131	LGCOND	GCOND	NCLX	Vapor condensation rate.
132	LHLA	HLA	NCLX	Sum of all products of liquid HTC with heat-transfer area.
133	LHLATW	HLATW	NCLX	Similar to LHLA except that the product includes wall temperature.
134	LGEVAP	GEVAP	NCLX	Liquid evaporation rate.
135	LGRAV	GRAV	NCLX	Gravitation terms.
--ITEMS BELOW ARE REPEATED FOR EACH LEVEL--				
136	LHD	HD	NCLX*3* NDIA3	Hydraulic diameters.
137	LHFG	HFG	NCLX	Latent heat of vaporization.
138	LHGAM	HGAM	NCLX	Storage for the subcooled boiling.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
139	LHLV	HLV	NCLX	Old interfacial HTC.
140	LHLVN	HLVN	NCLX	New interfacial HTC.
141	LHSA	HSA	NCLX	Heat-slab area.
142	LHSHL	HSHL	NCLX	Slab HTC (liquid).
143	LHSHLO	HSHLO	NCLX	Variable not currently implemented.
144	LHSHV	HSHV	NCLX	Slab HTC (vapor).
145	LHSHVO	HSHVO	NCLX	Variable not currently implemented.
146	LHST	HST	NCLX*NODHS	Old heat-slab temperatures.
147	LHSTN	HSTN	NCLX*NODHS	New heat-slab temperatures.
148	LHSX	HSX	NCLX*NODHS	Spacing of heat-transfer nodes in the slabs.
149	LHVA	HVA	NCLX	Sum of all products of vapor HTC with heat-transfer area (similar to LHVA).
150	LHVATW	HVATW	NCLX	Similar to LHVA except that the product includes wall temperature.
151	LICMSH	ICMSH	NCLX	Index to associated coarse-mesh region.
152	LIDRGS	IDRGS	NCLX	Slab heat-transfer regime flag.
153	LIHSN	IHSN	NCLX	Heat-slab number.
154	LISRN	ISRN	NCSR	Source numbers on level.
155	LMATHS	MATHS	NCLX*NHSM1	Slab material ID numbers.
156	LMFRL	MFRL	NCLX*IMFR	Liquid mass flow.
157	LMFRV	MFRV	NCLX*IMFR	Vapor mass flow.
158	LP	P	NCLX	Old pressure.
159	LPA	PA	NCLX	Old air partial pressure.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
160	LPAN	PAN	NCLX	New air partial pressure.
161	LPN	PN	NCLX-1	New pressure.
162	LQRD	QRD	NCLX	Rod heat flux.
163	LQSL	QSL	NCLX	Slab heat flux.
164	LQVD1	QVD1	NCLX*IDROP	Variable not currently implemented.
165	LQVD2	QVD2	NCLX*IDROP	Variable not currently implemented.
166	LRMEM	RMEM	NCLX	Mixture internal energy.
167	LROA	ROA	NCLX	Old air density.
168	LROAN	ROAN	NCLX	New air density.
169	LROHS	ROHS	NCLX*NODHS	Slab densities.
170	LROHSN	ROHSN	INHSMX*NCLX	Slab density at a material interface.
171	LROL	ROL	NCLX	Old liquid density.
172	LROLN	ROLN	NCLX	New liquid density.
173	LROM	ROM	NCLX	Mixture density.
174	LROV	ROV	NCLX	Old vapor density.
175	LROVN	ROVN	NCLX	New vapor density.
176	LS	S	NCLX*ISOLUT	Boron mass plated on structure. ISOLUT = 0 or 1.
177	LS1	S1	NCLX*IDROP	Variable not currently implemented.
178	LS2	S2	NCLX*IDROP	Variable not currently implemented.
179	LSIG	SIG	NCLX	Surface tension.
180	LSN	SN	NCLX*ISOLUT	Pointer for new time value for solid solute in cell (kg solid). ISOLUT = 0 or 1.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
181	LST	ST	NCLX*IDROP	Variable not currently implemented.
182	LTCHFS	TCHF	NCLX	Rod critical temperature.
183	LTL	TL	NCLX	Old liquid temperature.
184	LTLN	TLN	NCLX	New liquid temperature.
185	LTSAT	TSAT	NCLX	Saturation temperature.
186	LTSSN	TSSN	NCLX	Saturation temperature corresponding to steam partial pressure.
187	LTV	TV	NCLX	Old vapor temperature.
188	LTVN	TVN	NCLX	New vapor temperature.
189	LVD1	VD1	NCLX*3*IDROP	Variable not currently implemented.
190	LVD1N	VD1N	NCLX*3*IDROP	Variable not currently implemented.
191	LVD2	VD2	NCLX*3*IDROP	Variable not currently implemented.
192	LVD2N	VD2N	NCLX*3*IDROP	Variable not currently implemented.
193	LVISL	VISL	NCLX	Liquid viscosity.
194	LVISV	VISV	NCLX	Vapor viscosity.
195	LVL	VL	NCLX*3	Old liquid velocity.
196	LVLC	VLC	NCLX	Liquid cross-flow velocity.
197	LVLN	VLN	NCLX*3	New liquid velocity.
198	LVM	VM	NCLX*3	Mixture velocity.
199	LVOL	VOL	NCLX	Cell fluid volumes.
200	LVOLG	VOLG	NCLX	Cell geometric volumes.
201	LVV	VV	NCLX*3	Old vapor velocity.
202	LVVC	VVC	NCLX	Vapor cross-flow velocity.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
203	LVVN	VVN	NCLX*3	New vapor velocity.
204	LWAT	WAT	NCLX	Total heat-transfer area.
205	LXA	XA	NCLX*IDROP	Variable reserved for a droplet field.
ROD DATA POINTERS				
206	LALPR	ALPR	NCRZ+2	Vapor fraction.
207	LALVR	ALVR	NCRZ+2	Interfacial area.
208	LBITR	BITR	0	Variable not currently implemented.
209	LBITRN	BITRN	0	Variable not currently implemented.
210	LBURN	BURN	NCRZ+1	Fuel burnup.
211	LCLR	CLR	NCRZ+2	Liquid conductivity.
212	LCND	CND	NODES* (NCRZ+1)	Rod conductivity.
213	LCNDR	CNDR	NINT* (NCRZ+1)	Rod heat conductivity at right of interface.
214	LCONCR	CONCR	NCRZ+2	Mass concentration of dissolved boron in the coolant (kg boron/kg water).
215	LCPDR	CPDR	NINT* (NCRZ+1)	Rod heat capacity at specific heat.
216	LCPLR	CPLR	NCRZ+2	Liquid specific heat.
217	LCPND	CPND	NODES* (NCRZ+1)	Rod specific heat.
218	LCPVR	CPVR	NCRZ+2	Vapor specific heat.
219	LCVR	CVR	NCRZ+2	Vapor conductivity.
220	LDRLDT	DRLDT	NCRZ+2	Derivative of liquid density with respect to liquid temperature.
221	LDRVDT	DRVDT	NCRZ+2	Derivative of vapor density with respect to vapor temperature.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
222	LDRZ	DRZ	NCRZ+1	Old zirconium dioxide reaction depth.
223	LDRZN	DRZN	NCRZ+1	New zirconium dioxide reaction depth.
224	LEAR	EAR	NCRZ+2	Specific internal energy of the noncondensable gas component.
225	LELR	ELR	NCRZ+2	Old liquid internal energy.
226	LEMIS	EMIS	NODES* (NCRZ+1)	Rod emissivity.
227	LEVR	EVR	NCRZ+2	Old vapor internal energy.
228	LFINAR	FINAR	NCRZ	Old vapor internal energy.
229	LHDR	HDR	NCRZ+2	Rod-bundle hydraulic diameter.
230	LHFGR	HFGR	NCRZ+2	Latent heat of vaporization.
231	LHGAMR	HGAMR	NCRZ	Fine-mesh contribution to sub-cooled boiling.
232	LHGAP	HGAP	NCRZ+1	Gap conductance.
233	LHLAR	HLAR	NCRZ	Sum of all products of the liquid HTC and the heat-transfer area.
234	LHLATR	HLATR	NCRZ	Sum of all products of the liquid HTC, the heat-transfer area, and the wall temperature.
235	LHLSR	HLSR	NCRZ+2	Specific enthalpy of the liquid phase at saturation (corresponding to saturation temperature at partial pressure of steam.
236	LHLVR	HLVR	NCRZ+2	Interfacial HTC.
237	LHRFL	HRFL	NZMAX	Fine-mesh liquid HTC.
238	LHRFV	HRFV	NZMAX	Fine-mesh vapor HTC.
239	LHRLI	HRLI	NCRZ+1	Liquid HTC.
240	LHRLV	HRLV	NCRZ+1	Vapor HTC.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
241	LHVAR	HVAR	NCRZ	Sum of all products of the vapor HTC and the heat-transfer area.
242	LHVATR	HVATR	NCRZ	Sum of all products of the vapor HTC, the heat-transfer area, and the wall temperature.
243	LHVSF	HVSF	NCRZ+2	Specific enthalpy of the steam (not gas) at saturation (at partial pressure of steam and saturation temperature).
244	LIDHT	IDHT	NZMAX	Heat-transfer cell identifier.
245	LIDRGR	IDRGR	NCRZ+2	Flow-regime flag.
246	LIHTF	IHTF	NZMAX	Fine-mesh heat-transfer regime flag.
247	LNOHT	NOHT	1	Number of rows of heat-transfer nodes for each rod.
248	LPAR	PAR	NCRZ+2	Partial pressure of the noncondensable gas component.
249	LPGAP	PGAP	NCRZ+1	Gap local gas pressure.
250	LPINT	PINT	NCRZ+1	Pellet-cladding contact pressure.
251	LPLDV	PLDV	NCRZ	Pellet dish volume.
252	LPR	PR	NCRZ+2	Coolant pressure.
253	LQWRX	QWRX	NCRZ+1	Metal-water reaction heat source.
254	LRADR	RADR	NODES* (NCRZ+1)	Old radial node positions.
255	LRADRN	RADRN	NODES* (NCRZ+1)	New radial node positions.
256	LRDHLO	RDHLO	NCRZ	Variable not currently implemented.
257	LRDHLR	RDHLR	NCRZ	Liquid HTC.
258	LRDHVO	RDHVO	NCRZ	Variable not currently implemented.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
259	LRDHVR	RDHVR	NCRZ	Vapor HTC.
260	LRDTLR	RDTLR	NCRZ	Average-rod wall temperature seen by liquid.
261	LRDTVR	RDTV	NCRZ	Average-rod wall temperature seen by vapor.
262	LRFT	RFT	NODES*NZMAX	Old fine-mesh rod temperatures.
263	LRFTN	RFTN	NODES*NZMAX	New fine-mesh rod temperatures.
264	LRND	RND	NODES* (NCRZ+1)	Rod density.
265	LRNDR	RNDR	NINT* (NCRZ+1)-1	Rod density at right of interface.
266	LROAR	ROAR	NCRZ+2	Density of the noncondensable gas component.
267	LROLR	ROLR	NCRZ+2	Liquid density.
268	LROMR	ROMR	NCRZ+2	Mixture density.
269	LROVR	ROVR	NCRZ+2	Vapor density.
270	LRPOWF	RPOWF	NODES	Rod power density.
271	LSIGR	SIGR	NCRZ+2	Surface tension.
272	LSR	SR	NCRZ+2	Amount of plated out boron in cell (kg boron $\cdot$ m ⁻³).
273	LTCHFF	TCHFF	NZMAX	Fine-mesh wall temperature at CHF point.
274	LTCHFR	TCHFR	NCRZ	Wall temperature at CHF point.
275	LTLR	TLR	NCRZ+2	Liquid temperature.
276	LTSATR	TSATR	NCRZ+2	Saturation temperature.
277	LTSSNR	TSSNR	NCRZ+2	Saturation temperature corresponding to partial pressure of steam.
278	LTVR	TVR	NCRZ+2	Vapor temperature.

<u>Word(s)</u>	<u>Name</u>	<u>Array</u>	<u>Dimension</u>	<u>Description</u>
279	LVISLR	VISLR	NCRZ+2	Liquid viscosity.
280	LVISVR	VISVR	NCRZ+2	Vapor viscosity.
281	LVLCR	VLGR	NCRZ+2	Liquid cross-flow velocity.
282	LVLZR	VLZR	NCRZ+2	Axial liquid velocity.
283	LVMZR	VMZR	NCRZ+2	Axial mixture velocity.
284	LVOLR	VOLR	NCRZ+2	Pointer variable for the fluid volume in axial mesh cells associated with the fuel rod.
285	LVVCR	VVCR	NCRZ+2	Vapor cross-flow velocity.
286	LVVZR	VVZR	NCRZ+2	Axial vapor velocity.
287	LWATR	WATR	NCRZ	Total rod heat-transfer area.
288	LZHT	ZHT	NZMAX	Axial location of heat-transfer node.
289-300	PTDUM	--	--	Dummy variable.

C. VSSLDATA--VESSEL Data Table

This data table includes the following COMMON blocks: BLANKCOM and FIXEDLT, both defined in App. H; VSSELVLT, defined in Sec. XIV.A; and VSSLPT, defined in Sec. XIV.B.

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13 ABSTRACT (200 words or less) <p>The Los Alamos National Laboratory is developing the Transient Reactor Analysis Code (TRAC) to provide advanced best-estimate predictions of postulated accidents in light-water reactors. The TRAC-PF1/MOD1 program provides this capability for pressurized water reactors and for many thermal-hydraulic test facilities. The code features either a one- or a three-dimensional treatment of the pressure vessel and its associated internals, a two-fluid nonequilibrium hydrodynamics model with a noncondensable gas field and solute tracking, flow-regime-dependent constitutive equation treatment, optional reflood tracking capability for bottom-flood and falling-film quench fronts, and consistent treatment of entire accident sequences including the generation of consistent initial conditions.</p> <p>In addition to the components contained in previous TRAC versions, TRAC-PF1/MOD1 includes an improved steam-generator model, a turbine component, and a control system together with modified constitutive relations to model the balance of plant on the secondary side and to extend the applications to transients without loss of coolant. This report describes the thermal-hydraulic models and the numerical solution methods used in the code. Detailed programming and user information are provided.</p>			
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