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THE TRAC-PF1/MOD1 COMPUTER CODE*

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INTRODUCTION

The Transient Reactor Analysis Code (TRAC) is an advanced best-estimate systems code for analyzing light-water reactor (LWR) accidents. It 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. This version was not released publicly nor formally documented. However, it was used in the TRAC-P1 development and formed the basis for the one-dimensional loop component modules. The first publicly released version was TRAC-P1, completed in December 1977. It is described in the Los Alamos report LA-7279-MS.

The TRAC-P1 program was designed primarily for the analysis of large-break loss-of-coolant accidents (LOCAs) in pressurized water reactors (PWRs). Because of its versatility, however, it can be applied directly to many analyses ranging from blowdowns in simple pipes to integral LOCA tests in multiloop facilities. A refined version, called TRAC-P1A, was released to the National Energy Software Center (NESC) in March 1979. It is described in the Los Alamos report LA-7777-MS. 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 improved reflood and heat-transfer models and improvements in the numerical solution methods. Although a large 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 but, in addition, 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 previously used. The two-step numerics allow large time steps to be taken for slow transients. A one-dimensional core component

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permitted calculations to be made with reduced dimensionality although the three-dimensional vessel option was retained. A noncondensable gas field was added to both the one-dimensional and three-dimensional hydrodynamics. Significant improvements were made to both the trip logic and the input. TRAC-PF1 was publicly released in July 1981. PF1 and PD2 have been sent out to over 60 organizations worldwide and are being used for a very wide variety of applications.

TRAC-PF1/MOD1 was designed to provide full balance-of-plant modeling capabilities. This required addition of a general capability for modeling plant control systems. The steam generator model was replaced to allow a wider variety of feedwater connections and better modeling of steam tube ruptures. A special turbine component also has been added, but new components were not required for adequate modeling of condensers, heaters, and pumps in the secondary system.

In addition to the expanded capabilities just mentioned, MOD1 contains a number of changes in physical models. The most significant of these is the condensation model. During condensation, the liquid-side interfacial heat-transfer coefficient is now sensitive to flow regime and includes a special model for thermally stratified configurations. Wall heat transfer has been improved in the condensation and film-boiling regimes. The motion equations have been expanded to include momentum transport from phase change, and their momentum flux terms have been changed substantially in the three-dimensional flow equations. This latter change substantially alters the computed pressure drop across a vessel from previous codes. These model changes, along with several small changes, make TRAC-PF1/MOD1 not only a superior code for small-break and operational transients, but also the best version of TRAC to use for large-break analysis. Reflood analyses, for example, generally run noticeably faster with MOD1 as a result of these improvements.

TRAC CHARACTERISTICS

Some distinguishing characteristics of TRAC-PF1/MOD1 are summarized below. Within restrictions imposed by computer running times, attempts are being made to incorporate state-of-the-art technology in two-phase thermal hydraulics.

Variable-Dimensional Fluid Dynamics

A full three-dimensional (r,θ,z) flow calculation can be used within the reactor vessel; the flow within the loop components is treated one dimensionally. This allows 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 transients to be calculated very quickly because the usual time-step restrictions are removed by the special stabilizing numerical treatment.

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, solutes moving with the liquid.

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 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.

Comprehensive Heat-Transfer Capability

The TRAC-PF1 program incorporates a detailed heat-transfer analysis capability for both 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 heat-transfer coefficients obtained from a generalized boiling curve based on local conditions.

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.

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. This gives TRAC great versatility in the possible range of applications. It also allows component modules to be improved, modified, or added without disturbing the remainder of the code. TRAC component modules currently include accumulators, pipes, plena, 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, heat-transfer coefficient 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 experimental information become available.

PHYSICAL PHENOMENA TREATED

Because of the detailed modeling in TRAC, most of the physical phenomena important in both large- and small-break LOCA analysis can be treated. Included are

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 the requirement for artificial mixing zones;
11. critical flow (choking);
12. liquid carryover during reflood;
13. metal-water reaction;
14. water-hammer effects;
15. wall friction losses;
16. horizontally stratified flow;
17. boron injection; and
18. noncondensable gases.

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 the final version in the TRAC series although the code will be maintained and some modest improvements will be added.

Work is progressing on planned post critical heat-flux heat-transfer improvements. A users' workshop was held in August and some of the suggested user-convenience improvements will be incorporated into PF1/MOD1 as time and funding permit.

ASSESSMENT OF PF1/MOD1

Before its release, PF1/MOD1 had undergone developmental assessment. The following Loss-of-Fluid Test (LOFT) and Semiscale experiments have been modeled:

LOFT:	L6-1
	L6-2
	L6-3
Semiscale:	S-UT-6
	S-UT-7
	S-NC-6

These tests emphasize operational transients, small-break LOCAs, and natural-circulation/reflux cooling. In addition, MOD1 has been compared with some Creare downcomer data, a test from the Japanese Cylindrical Core Test Facility, and the large-break LOFT L2-3. No results will be shown in this paper although a document with the test results will be published.

During fiscal year 1985, PF1/MOD1 will be independently assessed by Sandia against a variety of separate-effects and integral-system tests. The results will be used to guide model improvements for updated versions of MOD1.

SUMMARY

TRAC-PF1/MOD1 is the latest and last in a series of advanced best-estimate computer codes. MOD1 can model both primary and secondary loops in a PWR and has noncondensable and boron fields. A full set of trips and controllers allows most transients of interest to be run with this new version. The one-dimensional numerics can permit very large time steps to be taken for slow transients, yet the three-dimensional vessel capability is available if multidimensional effects are deemed important. The result is a very versatile, well-assessed tool for LWR analysis.