UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Harold Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER - 92 - TRAC-P1A

1. INTRODUCTION

A. Need for a Best-Estimate Code

The NRC development of a best-estimate (BE) computer code for analysis of reactor transients and accidents, such as TRAC-P1A (Ref. 1), fulfills three related needs. The first is to provide a firm numerical and physical basis for the margin of safety built into the conservative, or Evaluation Model (EM) computer codes. These conservative codes (Ref. 2) are used extensively in the licensing process and are developed under the philosophy that if one doesn't know for sure how to accurately calculate a complicated physical process, one should use a conservative bounding approximation for that process. For example, since there is some justifiable uncertainty as to exactly how much ECC water bypasses out the broken cold-leg during the depressurization period, the EM model assumes that all the water leaves the system during this 10 to 15 second time period. The TRAC-P1A BE code, on the other hand, treats this same partial bypass period as a complicated two-phase flow process to be calculated with a multidimensional code that has been assessed against bypass data in several scaled experimental facilities. This need to establish the margin of safety in conservative calculations was recognized by NRR (Ref. 3), the American Physical Society (Ref. 4) and the ACRS (Ref. 5) who all requested development of a BE code to fill this need.

The second need for a BE code is to predict, analyze and comprehend data from scaled experimental facilities. These test facilities investigate both integral system and separate effects phenomena for various LOCA conditions, as well as for non-LOCA conditions. This second need is central to the NRC/RES program, which supports a coordinated research effort of both analysis and experiment on safety-related issues. Both the American Physical Society (Ref. 4) and the ACRS (Ref. 5) support the requirement for this combined effort and, thus, recognize this second need for a BE code, like TRAC-P1A, which can assimilate all this experimental data into a comprehensive model of a reactor.

This leads to the third and most important need for a BE code: the need to analyze and predict consequences for both real and postulated accidents in full-scale LWR's. This last need permeates all activities in BE code development and assessment. The TRAC code is being developed to include all major phenomena expected to occur during a severe accident in a LWR, in sufficient detail to provide as accurate a calculation as presently possible. The development is being assessed against scaled data to provide confidence in its extrapolation to full-scale LWR's.

B. TRAC-P1A vs. RELAP-4

RELAP-4 is a BE code which has been used extensively to calculate transient behavior in full-scale LWR's. Its well-known modeling deficiencies (one-dimensional flow geometry, homogeneous equilibrium flow) have been overcome by the development of special global modeling based on experience and engineering judgment. TRAC-P1A was developed as a conscious attempt to improve the RELAP-4 modeling deficiencies. TRAC would then provide an alternate, and advanced, BE code to analyze full-scale LWR's which would be based more on local physical models rather than on global engineering models.

TRAC-P1A provides an advanced analysis capability for pressurized-water reactors. The advanced features of TRAC-P1A include nonhomogeneous, nonequilibrium and multidimensional hydrodynamics with flow-regime-dependent constitutive relations; quench-front tracking capability for both bottom flood and falling films; consistent treatment of entire accident sequences, including the generation of initial steady-state conditions; and modular design which allows representation of a wide variety of experimental configurations, ranging from single components to multiloop systems. Further details of the TRAC-P1A capabilities are described in Appendix I and in Reference 1.

C. TRAC-P1A vs. Future TRAC Versions

TRAC-P1A has been tested against an initial set of separate- and integral-effects experiments. Further assessment of the code through pretest and post-test predictions of other experiments has also occurred.

These testing and assessment activities have been quite successful, but have also pointed out areas where improvements, described below, are required in future versions of the TRAC code. These improvements are based on the experience of several laboratories which have used TRAC-P1A over the past year. They are being incorporated into the next version, TRAC-PD2, which will be ready for release in the summer of 1980.

II. RESULTS

The details of the assessment of TRAC-P1A predictive capabilities are covered in Appendix II and in Reference 6. The results can be summarized as follows:

1. Hydrodynamics

Blowdown Phase

Large Break (~100%)

Very good for a wide range of experiments. Characteristic dimensions range from 0.02m to 0.5m. Fluid conditions range from highly subcooled liquid to two-phase mixture, to saturated and superheated vapor. It is important to note, however, that TRAC underpredicted the flow in the short nozzle Marviken tests, where nonequilibrium effects were important. Experimental facilities: Edwards, CISE, Marviken, Semiscale, LOFT.

Small Break

Very good for single phase flow. Insufficient data comparisons for two-phase flows. Closely coupled to calculate inlet fluid conditions for vertically oriented nozzles (e.g. due to level swell). TRAC underpredicted cold-leg break flow during first 5 seconds of L2-3 (large-break) and the first 150 seconds of L3-1 (small-break). The cause for both disagreements with data was too much local void generation. Experimental facilities: CISE, LOFT, Analytical.

Refill/Bypass Phase

Downcomer (3-D calculation)

Excellent for small scales (1/15-3/15). Insufficient data comparisons at full scale. Wide range of ECC subcoolings and injection rates. Tends to slightly overpredict delivery. Experimental facilities: Creare, Battelle, LOFT.

Pipes (1-D Calculation)

Poor for all flow regimes except dispersed flow. Tends to underpredict penetration in countercurrent flow. Insufficient data for large (~.5m) pipes. Experimental facilities: Semiscale Mod-3, INEL Air/Water Tests, Dartmouth.

Reflood Phase

Strongly coupled to heat transfer. Very good results for high flooding rates; poor results for low flooding rates and lower

plenum ECC injection. Underpredicts liquid carryover and precursory cooling. Numerical pressure spikes caused by too much vapor generation during a time-step within a given control volume. Experimental facilities: FLECHT-SET, FLECHT-SEASET, UCB, LOFT.

2. Heat Transfer

Blowdown Phase

Nucleate boiling regime accurately modeled: Time to DNB very good for a wide range of geometries and fluid conditions. Peak clad temperature normally occurs during this phase - generally very good agreement with data. Rod rewets in LOFT are accurately modeled using Iloeje T_{min}. Experimental facilities: CISE, Semiscale, LOFT.

Refill/Bypass Phase

Heat transfer coefficients between rods and fluid calculated accurately for film boiling and superheated vapor. Underpredicts precursory cooling due to entrained liquid and sputtering on clad. Experimental facilities: Semiscale, LOFT.

Reflood Phase

Core conditions at the beginning of reflood may be considerably different than previously thought due to early rod rewets. Thus, PCT may not occur during reflood.

Reflooding rate generally underpredicted by a substantial amount for cold leg ECC; steam generation due to requenching tends to expel liquid from the core. Nuclear fuel rod model needs to include dynamic fuel gap dimension. Experimental facilities: FLECHT-SET, FLECHT-SEASET, U.C. Berkeley, Semiscale, LOFT.

3. Identified Needs for Improvement

a) The numerical techniques need to be improved to tighten up mass conservation and to decrease the computer running time

b) More mechanistic treatment of the reflood process is needed to allow automatic calculation of the quench front

c) A more realistic model of fuel gap conductance

d) Improved heat transfer correlations

e) Improved flow regime recognition criteria

f) Additional models need to be incorporated to handle counter-current flow of liquid and vapor in a horizontal pipe, as occurring in the "reflux boiler" process during small break LOCA.

Other areas in need of improvement are identified in Section III below and in Appendix II.

III. RECOMMENDATIONS

TRAC-P1A has been designed and tested for analysis of large-break LOCA's in PWR's. The major processes it calculates include: the blowdown process, including choked flow from pipes; ECC bypass and lower plenum refill; and reflooding of the core by the ECC.

PWR calculations with TRAC-P1A, which is a BE code, have shown that the peak clad temperature occurs early in the transient during the blowdown period. This contrasts with conservative EM codes which calculate peak clad temperature much later in time during the reflood period. This is despite the fact that TRAC-P1A overpredicts clad temperature for low flooding rate tests in FLECHT, due to under-prediction of precooling by entrained drops in the upflowing core steam.

One reason why TRAC-P1A calculates lower reflood temperatures than conservative codes is because of its multidimensional BE model for downcomer flow during the ECC bypass period; a model that does well against Creare and BCL downcomer data. Although the code calculates some ECC bypass, it allows much more water to remain in the vessel than do conservative licensing calculations. It should be pointed out that TRAC-P1A does include heat transfer from the downcomer walls.

Initial PWR calculations with TRAC-P1A used between 400 and 600 computational nodes in order to get a reliable base-case indication of the codes' capabilities for the entire LOCA transient. This led to long computer run time - about 15 to 20 hours of CPU time on a CDC-7600 computer. Subsequent noding studies showed that fewer nodes could be used and still get a reliable PWR simulation. One successful study with about 150 nodes gave a running time for the entire LOCA (blowdown through reflood) of about 5 CPU hours. Even this running time is recognized as being too long for many applications, and a fast-running version of TRAC is currently being developed.

There is no kinetics feedback modeled in TRAC-P1A, so this version of the code cannot be used for such problems as ATWS and RIA; a future version of TRAC will include models for these problems.

When the code was applied to small-break tests, its choked flow model was found to overpredict void formation near the break and thus underpredict break mass flow rate. This is being corrected for later versions of TRAC which will be more applicable to small-break analysis.

The code can conceptually handle natural circulation and, in fact, did calculate natural circulation conditions for the TMI accident. However, the accuracy of its natural circulation predictions has not yet been tested against data.

Robert J. Budnitz, Director
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Enclosures:
1. Appendix I,"Description of TRAC-P1A Capabilities - Summary"
2. Appendix II,"TRAC-P1A Developmental Assessment - Summary"

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APPENDIX I

DESCRIPTION OF TRAC-P1A CAPABILITIES - SUMMARY

A. General

TRAC can be characterized as an advanced, best-estimate LWR systems computer program. Within limitations imposed by computer running time, it incorporates state-of-the-art methods and models. The models in TRAC are designed to yield realistic solutions as opposed to conservative evaluation models used in licensing codes. TRAC mainly differs from other existing LWR systems codes (e.g., RELAP-4 code) in its more detailed geometrical models of system components and its more basic treatment of two-phase thermal hydraulics.

User-selected options are minimized in the basic fluid dynamics and heat transfer modeling. This approach, as opposed to that which allows modeling options, places great demands on the basic thermal-hydraulic modeling because the code must determine local flow topology and supply appropriate constitutive relations. Thus, the development of accurate flow-regime-dependent constitutive relations is vital to the TRAC effort. The ultimate goal of the TRAC effort is to produce computer programs that have a demonstrated capability to adequately predict the results of a broad range of experiments with no tuning of basic physical models from one test to another.

Because of the advanced features of TRAC, most of the physical phenomena that are important in LOCA analysis can be treated.

The code can be used to obtain steady-state solutions to provide self-consistent initial conditions for subsequent transient calculations. Both a steady-state and transient calculation can be performed in the same run if desired. Efficient solution strategies, ranging from semi-implicit to fully implicit, are used.

An important characteristic of TRAC is the ability to address the entire LOCA (blowdown, bypass, refill and reflood) in one continuous and consistent calculation. This eliminates the need to interface and combine calculations performed with different codes for each major accident phase. Trips can be specified to simulate protective system actions or operational procedures (e.g., opening or closing of a valve).

A sophisticated graphics package, including movie generation capability, is available to help analyze and digest the large amount of output information generated during a TRAC run. A dump restart feature allows the user to restart a calculation from any point in a transient. This feature is very useful in performing parametric studies and in minimizing loss of computer time due to hardware failure or input studies.

TRAC is designed to run on a CDC 7600 computer, but standard programming techniques are being used to ease its conversion to other computers. ORNL has recently converted TRAC-P1A to the IBM computer. All storage arrays are dynamically allocated so that the only limit on problem size is the available core memory. A capacity of 60,000 words of small-core memory and 220,000 words of large-core memory is sufficient to handle most problems of interest.

B. Component and Functional Modularity

TRAC is completely modular by component and by function. Component modules, which consist of subroutines or sets of subroutines, are available to model vessels (with associated internals), steam generators, pressurizers, etc. Component modules currently available in TRAC are described in Table I. The user can construct a wide variety of configurations by connecting an arbitrary number of these components in a meaningful way. Thus, the user can solve problems ranging from a simple pipe blowdown to a LOCA in a multiloop PWR. Component modularity allows component models to be improved, modified, or added without disturbing the rest of the code.

Functional modules, which also consist of subroutines or sets of subroutines, are available for the multidimensional two-fluid hydrodynamics, one-dimensional drift-flux hydrodynamics, thermodynamic and transport properties, wall heat transfer, etc. These functional modules are described in Table 2. Functional modularity allows the code to be easily upgraded as improved correlations and experimental information become available.

C. Multidimensional Fluid Mechanics

A three-dimensional cylindrical (r-θ-z) or two-dimensional Cartesian (x-y) hydrodynamic calculation can be performed within the reactor vessel. Components outside the vessel are treated in one-dimensional geometry. A typical arrangement of components and mesh cells for one loop of a PWR is shown in Fig. 1.

The vessel module is used to model all regions inside the pressure vessel, including the downcomer, lower plenum, core, upper plenum and upper head. It is in these regions of the reactor system that significant multidimensional effects are likely to occur during a LOCA and other postulated accidents. Examples are two-dimensional and countercurrent steam water flow patterns in the downcomer during the blowdown and refill periods and preferential rewetting of the cooler fuel rods in the core during reflood.

Table 1 TRAC Component Modules

Module	Description
VESSEL	Models a PWR vessel and associated internals using either a three-dimensional (r-θ-z) or two-dimensional (x-y) geometrical representation and a six-equation two-fluid model to evaluate fluid flows within the vessel. VESSEL includes rod heat transfer with reflood dynamics in one-dimensional and cylindrical geometry, slab heat transfer from structure, and point-reactor kinetics with decay heat.
PIPE	Models thermal-hydraulic flow in a one-dimensional duct or pipe using the five-equation drift-flux model. PIPE can treat area changes, wall heat sources, wall friction, and heat transfer across the inner and outer wall surfaces. Both semi-implicit and fully implicit solution algorithms are available in this module. The area change correlations do not change with flow direction.
PRIZER	Simulates a pressurizer using the one-dimensional drift-flux model with drift velocities specified to produce a sharp liquid-vapor interface during discharge. The pressurizer walls are adiabatic, but energy transfer from a heater/sprayer system is simulated.
PUMP	Describes the interaction of the two-phase fluid with a centrifugal pump using the PIPE capabilities and pump correlations for the source of mixture momentum.
ACCUM	Simulates an accumulator filled with ECC water and pressurized with nitrogen gas using the one-dimensional drift-flux model. The vapor-phase properties are those for nitrogen gas and drift velocities are specified to produce a sharp liquid vapor interface during discharge. Nitrogen is not allowed to discharge from the accumulator because a noncondensible field is not yet available in the basic hydrodynamics model.
STGEN	Models either a U-tube or once-through steam generator using the one-dimensional drift-flux model. Primary- and secondary-side hydrodynamics are treated separately with coupling through wall heat transfer.
TEE	Models the thermal-hydraulics of three piping branches (two of which lie along a common line with the third entering at an arbitrary angle) using essentially two pipes. The momentum source modeling is improved in the PD2 version of TRAC.
VALVE	Models the thermal-hydraulic flow in a valve using the basic PIPE capabilities. Valve action is modeled by controlling the flow area and hydraulic diameter between the two fluid cells.

Table 1 Continued

Module	Description
BREAK	Imposes a fixed or time-dependent pressure boundary condition one cell away from its adjacent component. BREAK is not actually a system component module but is treated as such with respect to input, initialization and identification procedures.
FILL	Imposes fixed or time-dependent velocity boundary conditions at the junction with its adjacent component. FILL is not actually a system component module but is treated as such with respect to input, initialization and identification procedures. The user supplies the temperature and void function for the FILL input.

Table 2 TRAC Functional Modules

Module	Description
DFID	Solves the finite-difference equations for the one-dimensional drift-flux model using either a semi-implicit or fully implicit algorithm.
TF3D	Solves the finite-difference equations for the multidimensional two-fluid model using a semi-implicit algorithm. TF3D includes a constitutive package to provide wall and interfacial shears and interfacial mass and heat transfer.
THERMO	Provides thermodynamic properties of water and steam.
FWALL	Computes two-phase wall friction factors; also calculates loss coefficients associated with abrupt area changes.
SLIP	Calculates relative velocities between vapor and liquid phases for the one-dimensional drift-flux model. The procedure is based on a flow regime map similar to that used in the three-dimensional vessel hydrodynamics.
RODHT	Solves the one-dimensional (cylindrical) finite-difference thermal-conduction equations in the fuel rod including pellet, gap and cladding regions.
SLABHT	Solves for the lumped-parameter temperature of a slab of arbitrary configuration.
CYLHT	Solves the one-dimensional (cylindrical), finite-difference thermal-conduction equations in pipe walls.
HTCOR	Provides heat transfer coefficients from wall to fluid based on local conditions.

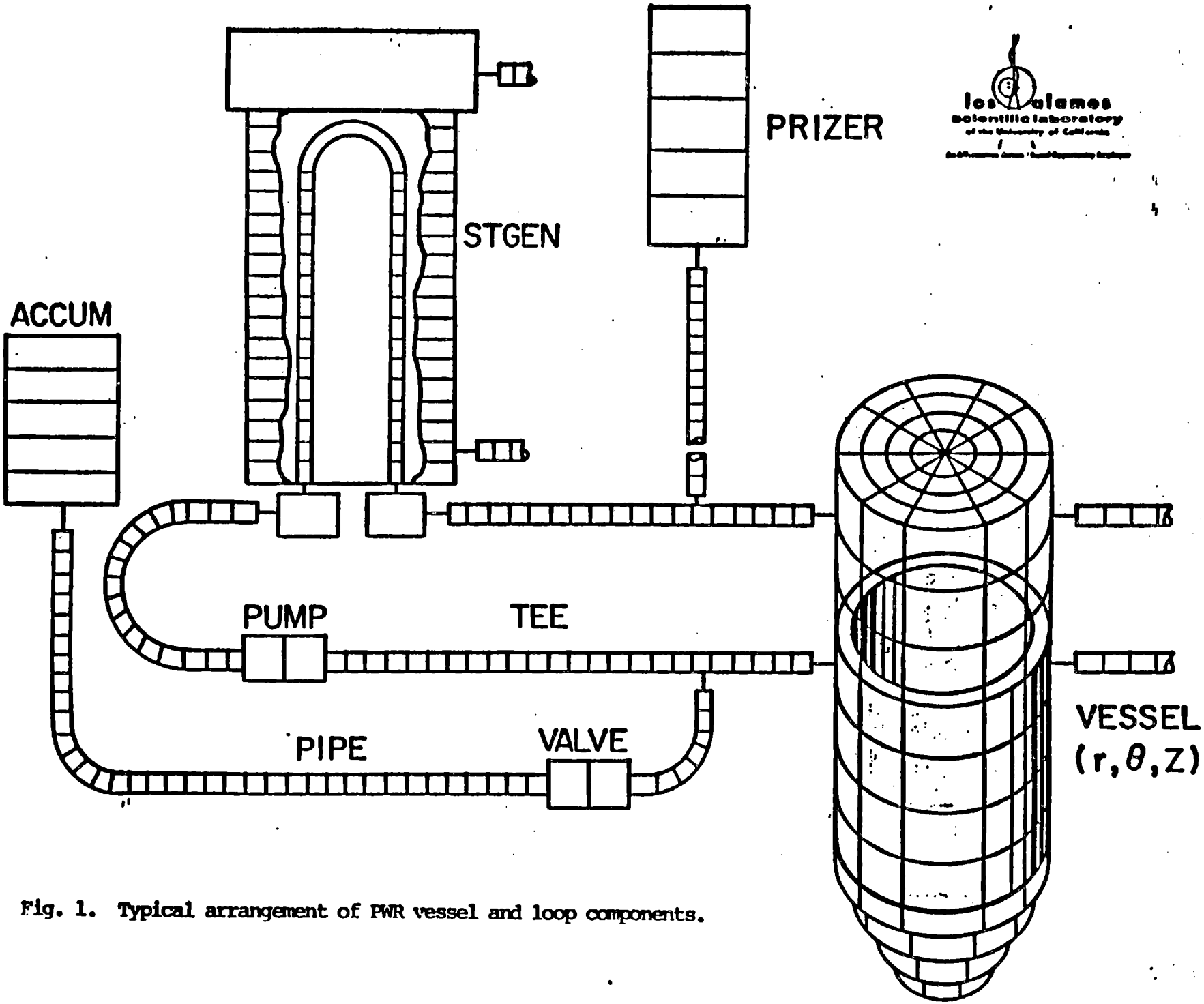

Fig. 1. Typical arrangement of PWR vessel and loop components.

D. Nonhomogeneous, Nonequilibrium Hydrodynamics

Two-phase flow in the various TRAC components is treated using nonhomogeneous, nonequilibrium models; that is, liquid and vapor velocities are not assumed to be equal, and furthermore liquid and vapor temperatures are in general unequal with neither phase assumed to be at saturation conditions.

A two-fluid six-equation model is used to describe the liquid-vapor flow field within the reactor vessel. These equations are based on conservation of mass, momentum and energy for the separate liquid and vapor fields. Supplementing these field equations are so-called constitutive relations or closure equations that specify (1) the transfer of mass, energy and momentum between the liquid and vapor phases and (2) the interaction of these phases with the system structure. The nature of these interfacial transfers and interactions is dependent on flow topology, and therefore a flow-regime-dependent constitutive equation package is included in TRAC.

The flow in the one-dimensional loop components is described by a five-equation drift-flux model. These equations are based on conservation of mass, energy and momentum for the mixture and conservation of mass and energy for the vapor. Liquid and vapor velocities are not assumed to be equal but are expressed in terms of a relative velocity which is dependent on flow topology. More details can be found in Refs. (1a) and (7).

E. Comprehensive Heat Transfer

Heat transfer models in TRAC include (1) conduction models to calculate temperature fields in structural materials and fuel rods and (2) convection models to provide heat transfer between structure and coolant. Heat transfer to the two-phase fluid is calculated using a generalized boiling curve constructed from a library of heat transfer correlations based on local surface and fluid conditions.

Conduction models are available for obtaining temperature fields in one-dimensional (cylindrical) pipe walls, lumped-parameter slabs, and one-dimensional (cylindrical) fuel rod geometries. Pipe wall conduction is used in the components outside the vessel, whereas the slab and fuel rod conduction models are used in the vessel module. The fuel rod conduction analysis accounts for gap conductivity changes due to temperature effects, but not due to geometry effects, metal-water reaction, and quenching phenomena. A fine-mesh axial renoding capability is available for fuel rods to permit more detailed modeling of reflood heat transfer and tracking of quench fronts due to bottom flooding and falling films. Precooling effects and consistency between quench-front propagation and stored energy considerations are included in the reflood heat transfer methodology.

The TRAC library of heat transfer correlations includes data for the following heat transfer regimes: laminar and turbulent forced convection to a single-phase liquid or vapor and to a two-phase mixture; nucleate boiling and forced convection vaporization; pool boiling and high-flow critical heat flux (CHF); transition boiling; minimum stable film boiling; film boiling including subcooling and radiation effects; and horizontal, vertical, and turbulent film condensation.

There is no special treatment for heat transfer in any particular component, all use the same boiling curve and heat transfer coefficients.

In the case of reflood, there are specialized heat transfer coefficients used for the core only, which are differentiated for falling film quench fronts and bottom reflood quench fronts.

F. Solution Strategies

The system of field and constitutive equations in TRAC is solved by standard spatial finite-difference techniques. A semi-implicit time-differencing technique is normally used in most components. This technique is subject to the Courant stability limitation, which restricts the size of the time step in regions of high-speed flow. A fully implicit time-differencing option is available for the fluid dynamics in most of the one-dimensional components. This option allows fine spatial resolution in regions of high velocity (e.g., in a nozzle) without restricting the time step size.

The description of numerical procedures given here is necessarily limited. More detailed descriptions can be found in Refs. 1a, 8 and 9.

Computer running time is highly problem-dependent. It is a function of the total mesh cells in the problem and the maximum allowable time step size. The total run time for a given transient can be estimated from a unit run time of 2 to 3 ms per mesh cell per time step and an average time step size of 5 ms.

The TRAC steady-state capability is designed to provide time-dependent solutions which may be of interest in their own right or as initial conditions for transient calculations. Two distinct calculations are available within the steady-state capability: (1) a generalized steady-state calculation and (2) a PWR initialization calculation. The first is used to find steady-state conditions for a system of arbitrary configuration. The second is applicable only for configurations

typical of current PWR systems and is used to adjust certain loop parameters to match a set of userspecified flow conditions. Both calculations utilize the transient fluid dynamics and heat transfer routines to search for steady-state conditions. The search is terminated when the normalized rates of change of fluid and thermal variables are reduced below a userspecified criterion throughout the system. Generally, for a given problem, much less computer time is used for steady-state calculations than for transient calculations.

APPENDIX II

TRAC-P1A DEVELOPMENTAL ASSESSMENT - SUMMARY

A. Introduction

Experiments selected for developmental assessment of TRAC-P1A, and the more important thermal-hydraulic effects occurring during these tests are given in Table 3. Note that the first five analyses use only the one-dimensional capability in TRAC whereas the remainder involve the multidimensional capability as well. Tests selected for developmental assessment include separate effects (tests involving basically only one component), synergistic effects (several coupled components but only one LOCA phase), and integral effects (several components and more than one LOCA phase).

Detailed comparisons between code results and experimental measurements for the tests in Table 3 are reported in Ref. 6. Therefore, only brief summaries and typical comparisons are given below for selected tests.

B. Edwards, CISE and Marviken Blowdown Tests

The Edwards experiment, (10) referred to as Standard Problem 1, was the depressurization of a straight horizontal pipe (0.073 m ID x 4.1 m long) initially filled with subcooled water at approximately isothermal conditions. A glass rupture disk at one end of the pipe was broken to initiate the blowdown. TRAC best-estimate calculations are in reasonable agreement with available experimental measurements of fluid pressures and temperatures and with the single density measurement.

In the CISE (Centro Informazoni Studi Esperienze) experiments, (11) subcooled water was circulated through a vertical tubular test section. TRAC calculations of the CISE tests are in good overall agreement with the measured data, including fluid pressure and temperature at several locations in the test section, pipe wall temperature in the heater section, and mass holdup measurements.

The Marviken critical flow tests (12) are designed to determine how well code models that were developed using small-scale experiments actually apply to full-scale systems. These tests involve the blowdown of a large (5.2 m ID x 21.5 m high) pressure vessel through a discharge pipe (0.75 m ID x 6.3 long) which protrudes 0.74 m into the bottom of the vessel. In

Table 3 TRAC-P1A Developmental Assessment Analyses

Experiment	Thermal-Hydraulic Effects
1. Edwards horizontal pipe blowdown (Standard Problem 1)	Separate effects, one-dimensional critical flow, phase change, slip, wall friction
2. CISE unheated pipe blowdown (Test 4)	Same as No. 1 plus pipe wall heat transfer, flow area changes, and gravitational effects
3. CISE heated pipe blowdown (Test R)	Same as No. 2 plus critical heat flux
4. Marviken full-scale vessel blowdown (Test 4)	Same as No. 1 plus full-scale effects
5. Semiscale 1 1/2 loop isothermal blowdown (Test 1011, Standard Problem 5)	Synergistic and system effects, one-dimensional flow, phase change, slip, wall friction, critical nozzle flow
6. Semiscale Mod-1 heated loop blowdown (Test S-02-8, Standard Problem 5)	Same as No. 5 plus 3-dimensional vessel model with rod heat transfer including nucleate boiling, departure from nucleate boiling (DNB), and post-DNB
7. Creare quasi-steady downcomer/ECC bypass experiments	Separate effects, countercurrent flow, interfacial drag and heat transfer, condensation
8. FLECHT forced-flooding tests	Separate effects, reflood heat transfer, quench-front propagation, liquid entrainment and carryover
9. Non-nuclear LOFT blowdown with cold-leg injection (Test L1-4, Standard Problem 7)	Integral effects during blowdown and refill, scale midway between Semiscale and full-scale PWR

Test 4 a nozzle with a minimum diameter of 0.51 m was attached to the bottom of the discharge pipe. The blowdown is initiated by overpressurizing the gap between two rupture disks at the downstream end of the nozzle.

TRAC best-estimate results for Marviken Test 4 are in very good overall agreement with fluid pressure and temperature measurements at various locations and with mass fluxes derived from differential pressure and Pitot tube measurements. The mass flux from the break in Marviken Test 4 are shown in Fig. 2.

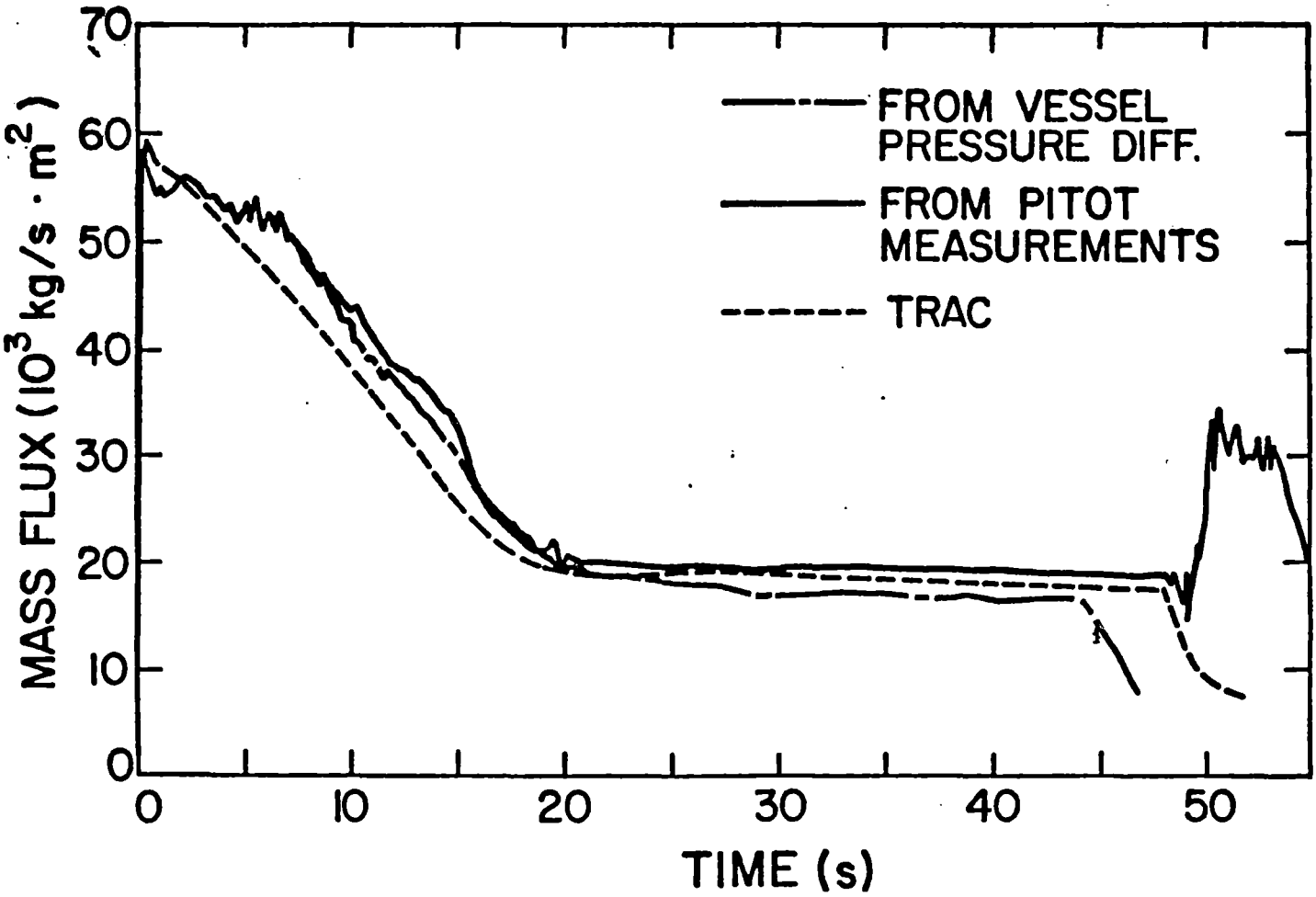

Fig. 2. Mass flux for Marviken blowdown experiment (Test 4).

C. Semiscale Blowdown Tests

Tests in the Semiscale 1 1/2 Loop Isothermal Test Facility (13) provided the first system-effects hydraulic data from a multiloop system. TRAC analysis of Test 1011 included a steady-state calculation to provide self-consistent initial conditions for the blowdown transient and a transient calculation utilizing the restart-dump from the steady-state calculation. Calculated steady-state initial conditions for Test 1011 agree well with measurements of the vessel outlet temperature, intact-loop volumetric flow rate, pump differential pressure, system pressures, etc. Agreement between calculated and experimental results for the blowdown transient was generally very good for all system variables that were compared. These included mass flow rates, system pressures, fluid densities and temperatures, and differential pressures. The comparison for the lower plenum pressure is given in Fig. 3. Test 1011 represents the first developmental assessment problem involving a large variety of components arranged in a multiloop configuration. It is encouraging that the one-dimensional TRAC model is adequate, since the experiment was designed to minimize multidimensional effects. With a TRAC model containing 122 fluid cells, the steady-state and transient calculations required 0.5 and 19 min of CPU time, respectively.

The Semiscale Mod-1 system (14) was very similar to the 1 1/2 loop configuration described previously. However, the Mod-1 vessel contained 39 electrically heated rods (which could be programmed to simulate the surface heat flux of a nuclear rod) and a 0.011-m downcomer gap. Test S-02-8 consisted of a 200 percent double-ended cold-leg break with a programmed power decay curve to simulate decay heat in a nuclear core. The transient was initiated from a steady-state temperature distribution in the core and loop at a power level of 1.6 MW.

The best-estimate TRAC model of Test S-02-8 contains a total of 263 fluid cells, including 152 cells in the three-dimensional vessel model. Although multidimensional effects are not too significant in this facility, the three-dimensional vessel module was used because fuel rod heat transfer is not available in the one-dimensional pipe module. As was the case for Test 1011, calculated steady-state initial conditions and transient results for Test S-02-8 agree well with measurements of system variables. The calculated cladding temperature in the high-power zone is compared in Fig. 4 with the band of temperatures measured in the same zone. Although the overall agreement in cladding temperature response is good, some detailed features were not predicted by TRAC. These include what appear to be random variations in the time to CHF and rewetting of some rods after the initial dryout. Running times for the steady-state and blowdown calculations were 50 min and 120 min, respectively.

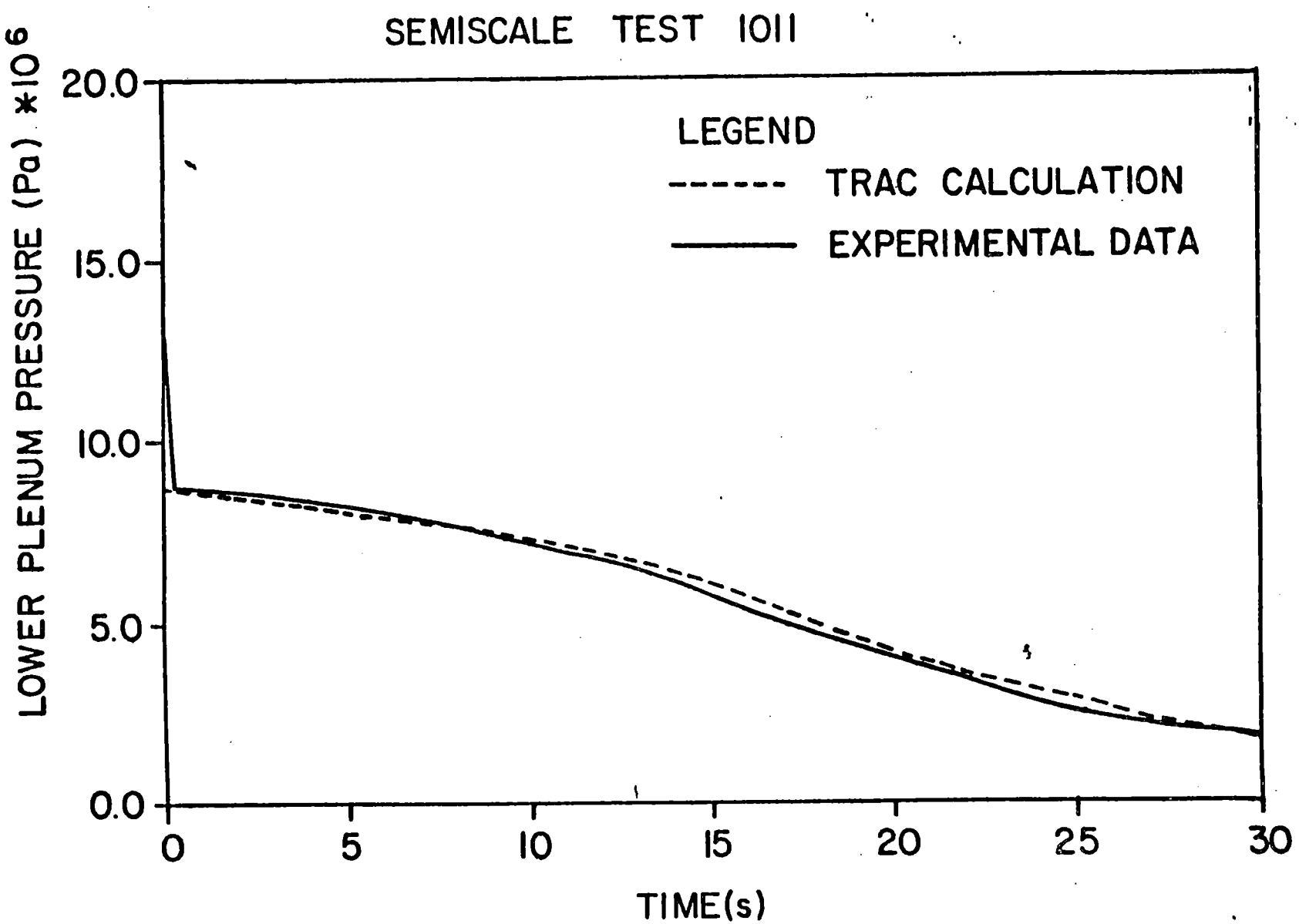

Fig. 3 Lower plenum pressure for Semiscale isothermal blowdown (Test 1011).

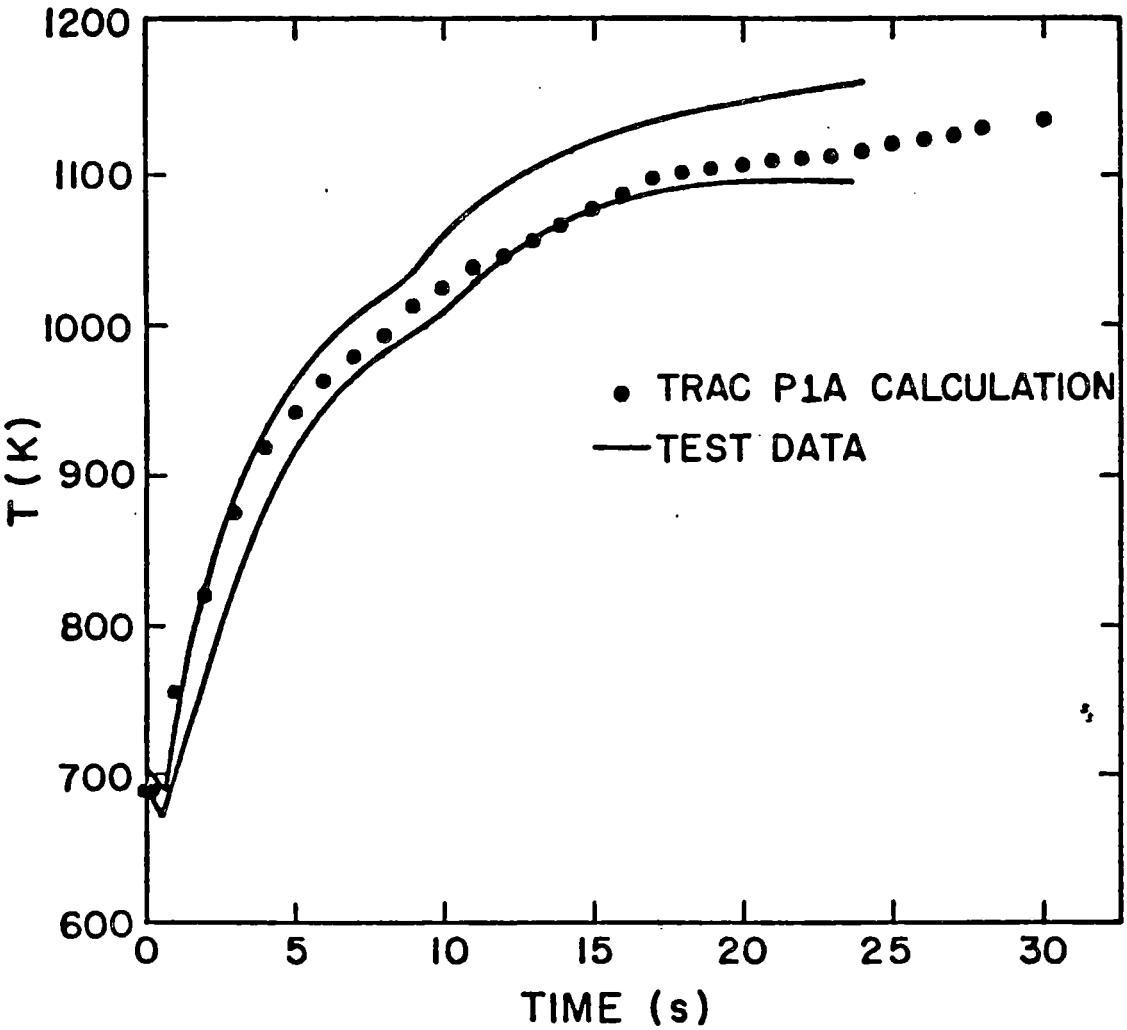

Fig. 4 Cladding temperature in high-power zone for Semiscale Test S-02-8.

D. Creare ECC-Bypass Tests

The primary purpose of the 1/15-scale downcomer experiments at Creare (15) was to study the effect of countercurrent steam flow rate, ECC water subcooling, and downcomer wall superheat on the delivery of ECC water from the downcomer to the lower plenum.

The TRAC best-estimate model for the Creare experiments consists of a three-dimensional vessel containing 112 fluid cells and one-dimensional piping connections for the injection and break ports. The calculational procedure closely parallels the experimental procedure. Results of the Creare calculations are in excellent overall agreement with experimental flooding curves for a wide range of ECC injection rates and subcoolings. This is shown in Fig. 5, which presents the flooding curve for high subcooling. The complete bypass and complete delivery points on the curves are well predicted by TRAC for low- and high-subcooling cases. Computed results for the Battelle Columbus Laboratory (BCL) 2/15-scale facility (16) are similarly in good agreement with the data, indicating that scale effects in this range are properly treated.

E. FLECHT Reflood Tests

Assessment of the reflood heat transfer and quench-front propagation models in TRAC has to date focused on the forced-bottom-flooding experiments in the PWR Full-Length Emergency Cooling Heat Transfer Facility (FLECHT) (17).

The single-channel geometry of these experiments lends itself very well to the use of the slab vessel option in TRAC. As a matter of fact, a one-dimensional representation was obtained by using only one cell per axial level. The base-case model contained nine axial levels in the core, with each of these levels containing five fine-mesh axial intervals for the reflood heat transfer calculation. Conduction in the electrically heated rod was represented with eight radial nodes. Test conditions for the three cases calculated are given in Table 4, and a summary of the calculated and measured results is given in Table 5. TRAC-P1A predicts the maximum temperature (and hence the temperature rise) quite well for all three tests. For the high-flooding-rate case (Test 03541), the calculated turnaround time and quench time also agree very well with the data. This is not the case, however, for the low-flooding-rate tests where the code predicts early turnaround and quenching. Underprediction of the carryover rates results in water remaining within the test vessel and, hence, a rapid refill of the core region which partially accounts for early quenching. TRAC-P1A does not contain an explicit entrainment model. This capability, along with a better definition of a rewetting criterion, should significantly improve the code results for low flooding rates. The ratio of CPU time to transient time is about 25 for the FLECHT calculations.

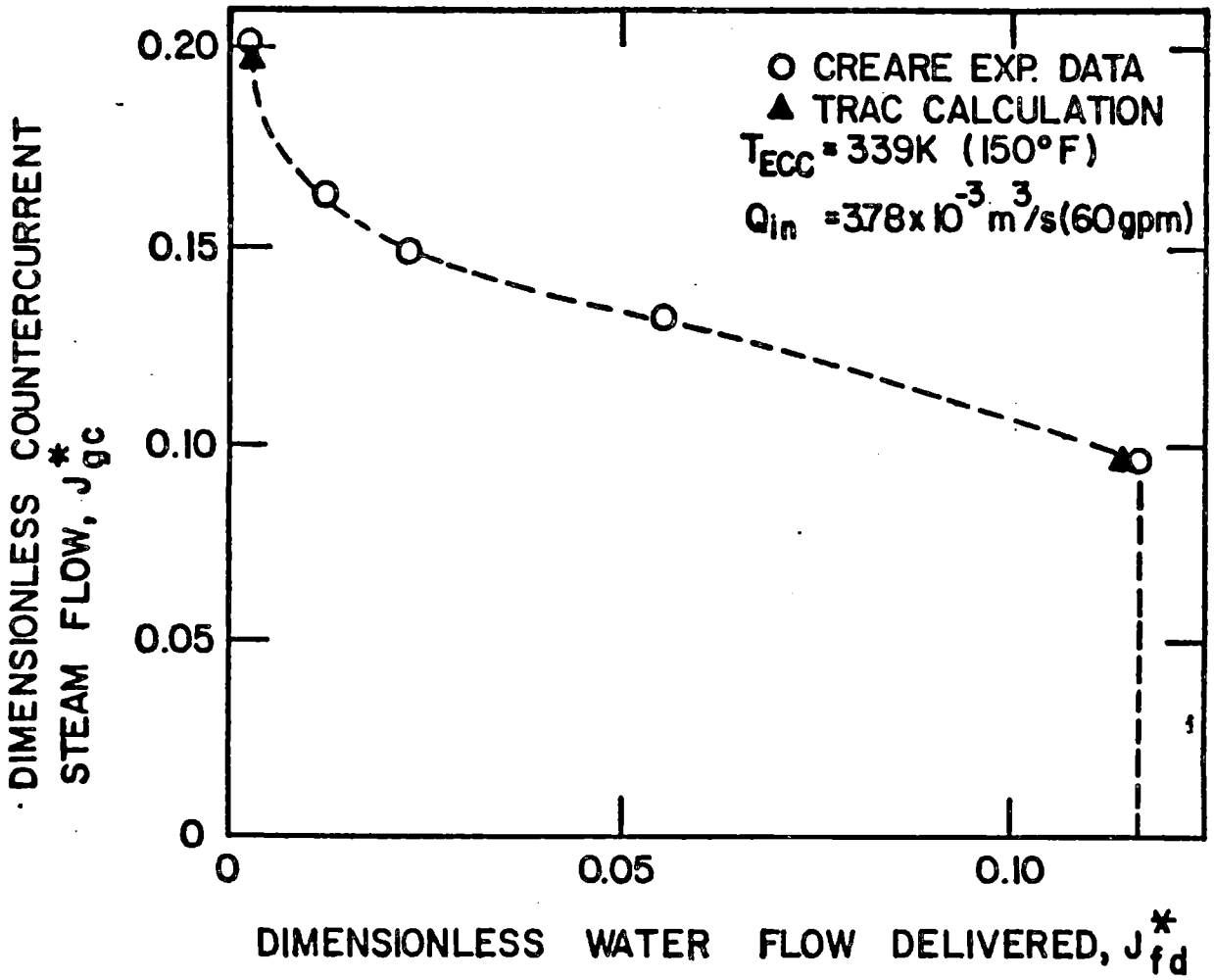

Fig. 5. Flooding curve for Creare high-subcooling tests.

Table 4 FLECHT Experimental Test Conditions for TRAC Calculations

Test No.	Pressure, MPa	Inlet fluid temperature, K	Flooding rate, m/s	Peak power, kW/m
03541	0.39	337.6	0.25	4.07
04831	0.28	324.8	0.04	3.12
02414	0.28	327.1	0.02	2.76

Table 5 Summary of Calculated and Measured Results at the FLECHT Bundle Midheight

	Test 03541		Test 04831		Test 02414	
	Experiment	TRAC	Experiment	TRAC	Experiment	TRAC
Initial temperature, K	1143	1144	1144	1144	1144	1144
Maximum temperature, K	1193	1190	1333	1333	1453	1449
Temperature rise, K	50	46	189	189	308	305
Turnaround time, s	8	6	74	40	96	80
Quench time, s	71	72	219	170	345	210

F. LOFT-Isothermal Blowdown with ECC Injection

The Loss-of-Fluid Test Facility (LOFT), (18) at Idaho National Engineering Laboratory (INEL) is a scale model of a large PWR with volume scaling of about 1:60. Test L1-4 was the fourth in a series of five isothermal blowdown tests in the nonnuclear LOFT program.

Test L1-4 was modeled with 26 TRAC components containing a total of 215 fluid cells, 72 of which were used in the three-dimensional vessel model. Calculated initial steady-state conditions were within 2 percent of the experimental values. The blowdown calculation was started from these initial conditions using the dump restart feature of TRAC. Calculated transient results are in good overall agreement with the experimental measurements, including mass flow rates, fluid temperatures, densities, and pressures throughout the system. The reactor vessel liquid mass is shown in Fig. 6. Effects resulting from the delayed ECC injection appear to be properly represented by the models in TRAC. Results for Test L1-4 indicate that TRAC provides a good representation of integral effects in LOFT during the blowdown and refill phases of a LOCA. The computer CPU times on the CDC 7600 were 40 s for the steady-state calculation and 40 min for the transient calculation.

In addition to LOFT Test L1-4, TRAC has been used to analyze Test L1-5. This test was also an isothermal blowdown experiment but with the nuclear core in place and in a shutdown state. The agreement between the code results and experimental measurements is similar to that for Test L1-4.

Post-test analyses have been performed for other experiments using earlier versions of TRAC. The most noteworthy of these were Semiscale Mod-1 integral tests S-06-3 (Standard Problem 8) and S-02-6 (Standard Problem 6). Test S-06-3 was a single-ended small-break experiment. Coarse mesh models were used in these analyses to evaluate the accuracy of fast-running TRAC computations. Overall results of these computations were quite good, particularly for the large-break test, and are reported in Refs. 19 and 20. The large-break integral test required 169 min of CPU time for the 250 s transient. For the small-break test, 85 min of CPU time were required for the 500 s transient.

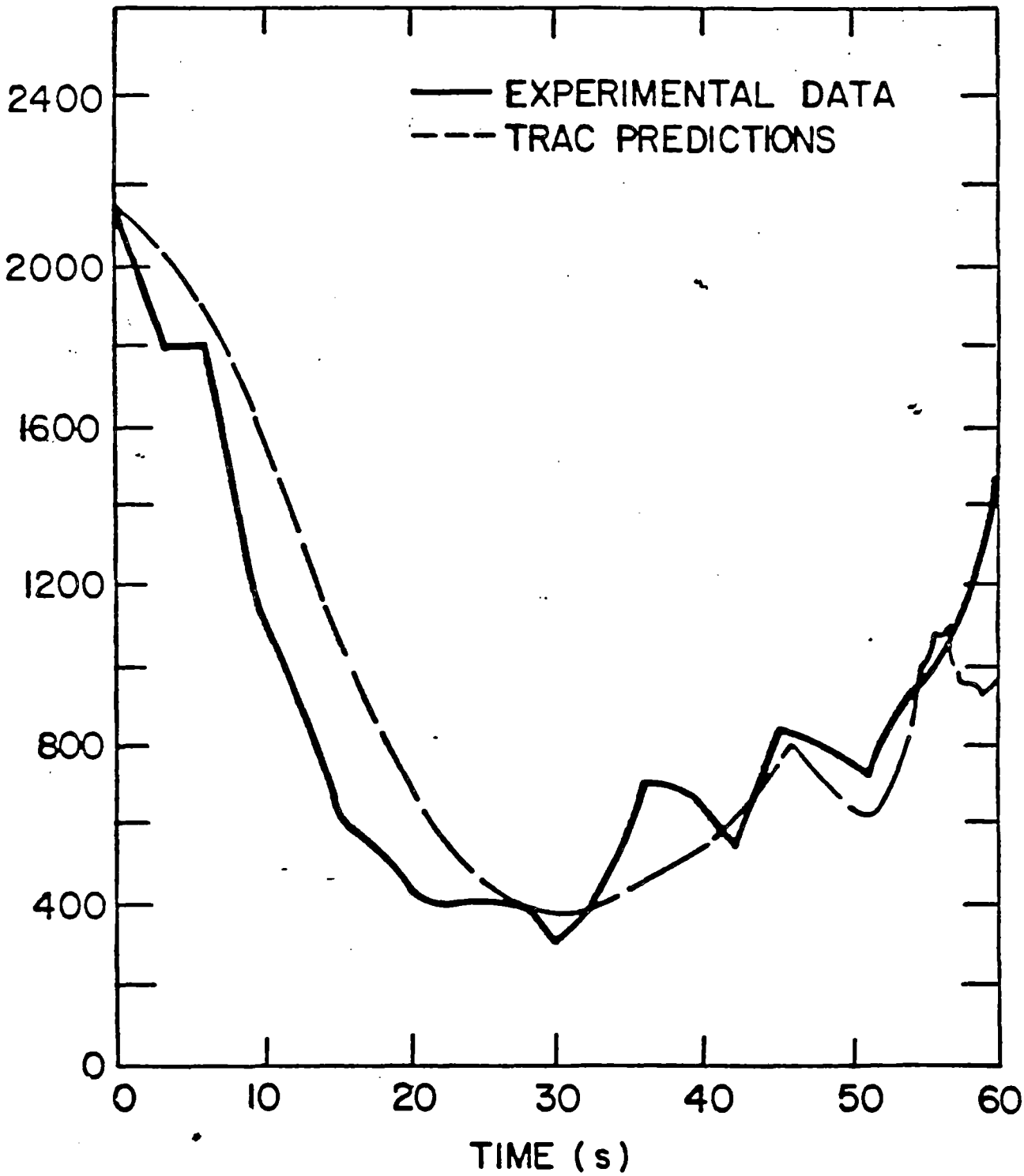

Fig. 6 . Reactor vessel liquid mass for LOFT Test L1-4.

When the code was applied to small-break tests, its choked flow model was found to overpredict void formation near the break and thus underpredict break mass flow rate. This is being corrected for later versions of TRAC which will be more applicable to small-break analysis.

The code can conceptually handle natural circulation and, in fact, did calculate natural circulation conditions for the TMI accident. However, the accuracy of its natural circulation predictions has not yet been tested against data.

Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Appendix I "Description of TRAC-P1A Capabilities - Summary"
2. Appendix II "TRAC-P1A Developmental Assessment - Summary"
3. "TRAC-P1A, An Advanced Best-Estimate Computer Program for PWR LOCA Analysis," Safety Code Developmental Group, Energy Division, Los Alamos Scientific Laboratory, NUREG/CR-0665, LA-7777-MS, May 1979.
4. "TRAC-P1A Assessment," J. Vigil, K. Williams, et al, Energy Division, Los Alamos Scientific Laboratory, NUREG/CR-1059, LA-8056-MS, October 1979.

cc w/encls:
D. F. Ross, NRR
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RECORD NOTE:
To meet the new requirement of the 4/10/80 Budnitz memo of holding a meeting with the user office before a RIL is issued, a meeting was held on 5/14/80 between L. Shotkin of RES and T. Speis, N. Lauben and W. Jensen of NRR. NRR agreed that the research results for TRAC-P1A development merited preparation of a RIL. They suggested that a paragraph be added to note that improvements to TRAC-P1A have already been incorporated in the next version, TRAC-PD2, which will be released shortly. This is added in Section I C of the transmittal letter.

OFFICE	WRSR:ADB	WRSR:ADB	WRSR	RSR	RES	RES
SURNAME	L.Shotkin/bts	S. Fabic	Johnson/Tong	T.E.Murley	J. Larkins	R. Budnitz
DATE	5/20/80	5/20/80	5/22/80	/ /80	6/17/80	/ /80

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Research Request No. (RR-NRR-77-5)

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DATE ►	5/23/80	5/23/80	5/27/80	6/2/80	/ /80	6/18 /80