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LA-UR -88-3846

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LA-UR--88-3846

DE89 003494

TITLE: TRAC-PF1/MOD2 STATUS AND PLANS

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SUBMITTED TO Water Reactor Safety Information Meeting
National Bureau of Standards
Gaithersburg, MD
October 24--27, 1988

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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by

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ABSTRACT

The development of the TRAC-PF1/MOD1 code was completed in July 1988 with the release of Version 14.4. A TRAC-PF1/MOD2 code deveopment plan addresses code deficiencies identified in the MOD1 code in order to provide an accurate and defensible tool that can be used to simulate large-break loss-of-coolant accidents (LOCAs), small-break LOCAs, and operational transients. The MOD2 code development plan is an international cooperative effort that includes contributions from Los Alamos National Laboratory, Idaho National Engineering Laboratory (INEL), Japanese Atomic Energy Research Institute (JAERI), Cray Research, Central Electricity Generating Board (CEGB), and United Kingdom Atomic Energy Authority (UKAEA).

INTRODUCTION

Version 14.4 of the TRAC-PF1/MOD1 code was released as the final version of MOD1 in July 1988. The MOD1 interfacial constitutive package in Version 14.4 was improved to provide accurate predictions of downcomer bypass, emergency core coolant (ECC) penetration, upper-plenum modeling, and hot-leg and cold-leg plugging and oscillations. Developmental assessment calculations were performed with Version 14.4 on the Cylindrical-Core Test Facility (CCTF) Run 14; Akimioto's condensation experiment; Upper-Plenum Test Facility (UPTF) Tests 5, 6, 8, 11, and 12; and Small-Core Test Facility (SCTF) Test 703. The MOD2 code development effort has paced the MOD1 maintenance and completion effort by implementing most of the MOD1 error corrections and code improvements into the MOD2 code.

MOD1 STATUS AND HISTORY

Version 12.1 of the TRAC-PF1/MOD1 code was released in January 1985 as the frozen version for the purpose of independent code assessment. The principal features of the MOD1 code are as follows.

1. A variable-dimension fluid-dynamics model that can analyze three-dimensional (3D) cylindrical geometry flow in the vessel component and one-dimensional (1D) flow in the primary- and secondary-side flow loops. A 1D or two-dimensional (2D) Cartesian-coordinate geometry vessel component can be specified by the user to reduce computational costs.

2. The nonhomogeneous, nonequilibrium, full two-fluid, six-equation hydrodynamics model describes steam-water flow. A horizontal stratified-flow model for 1D flow, a seventh field (mass) equation that evaluates a noncondensable-gas field, and an eighth field equation that tracks solutes in the liquid phase are provided in the TRAC hydrodynamics model.

3. A flow-regime-dependent, constitutive-equation package describes the transfer of mass, momentum, and energy between the steam-water phases and the heat transfer to those fluid phases from the system structure.

4. Flow-regime-dependent wall-to-fluid heat-transfer correlations are obtained from a generalized boiling curve based on local conditions.

5. A two-dimensional, fuel-rod conduction model includes a dynamic fine-mesh rezoning capability that can resolve both bottom-flooding and falling-film quench fronts.

6. Consistent analysis of the entire accident sequence is performed, including initial conditions and blowdown, refill, and reflood phases of a loss-of-coolant accident (LOCA). A complete range of break sizes as well as operational transients can be simulated.

7. Component and functional modularity allow the user to model virtually any PWR design or experimental configuration. There are component models for accumulators, breaks, fills, cores, pipes, pressurizers, pumps, steam generators, tees, turbines, valves, and vessels with associated internals.

8. Signal-variable parameters, control-block function, and action-controlling trips give the TRAC user the flexibility to model virtually any PWR or experimental control and protection system.

Since Version 12.1 was released, additional error-correction/user-convenience update sets have been included. These correction sets contain modifications to the TRAC code that can be grouped into three categories. The first group encompasses error corrections to logic and models less frequently activated by the code or users; the second group addresses user-convenience changes that deal with input and output; and the third group provides new model options that require user input to activate.

One of the updates in the first group is a major error correction that improves the interfacial-condensation model by limiting its rate of change to what is observed experimentally. This replaces the old method of logrithmic-averaging the old- and new-time va..es, which yields time-step-size-dependent results. A major user convenience added to TRAC is the multiple-component connections to a single cell of a vessel component. This allows the user to reduce the vessel noding for transients in which multidimensional flow in the vessel is not significant, thereby saving computational costs. Another significant user convenience is the self-initialization capability. This capability allows the user to input user-desired initial conditions (that is, cold-leg fluid temperature, primary- and secondary-side mass flow rates, pressure upstream of a valve, and so on); built-in controllers applied to user-selected component actions force the TRAC steady-state solution to those user-specified conditions.

A major model improvement added to TRAC that is activated by input is the counter-current flow limiting (CCFL) model. The user is given the option of specifying a flooding curve for any location within the vessel component for which there are experimental data. Because the effective interfacial shear for flooding or the CCFL condition is strongly dependent on geometry, TRAC uses this input-specified flooding curve to infer an effective interfacial shear for those locations where the user has flooding data. If no flooding data are available, TRAC uses its default interfacial-shear package, which will predict a typical flooding curve for a straight pipe. In addition, a new separator model has been implemented into the MOD1 code. This new separator model can simulate a separator with a constant efficiency. It uses the GE mechanistic model or user-specified performance curves to predict the carryunder and carryover.

Version 14.3 of TRAC-PF1/MOD1 was released in August 1987. Version 14.3 was used as the base code on which the code scaling applicability and uncertainty (CSAU)[1] methodology was applied. As data became available from the UPTF, it became apparent that additional work on the TRAC constitutive models would be required for large-scale geometries. It was decided that another version of the MOD1 code would be developed and released that addressed some of the large-scale constitutive-model deficiencies.

Version 14.4 of the TRAC-PF1/MOD1 code was released as the final version of MOD1 in July 1988. In Version 14.4, the MOD1 interfacial constitutive package was improved to provide accurate predictions of downcomer bypass, ECC penetration, upper-plenum modeling, and hot-leg and cold-leg plugging and oscillations. Developmental assessment calculations were performed with Version 14.4 on CCTF Run 14; Akimioto's condensation experiment; UPTF Tests 5, 6, 8, 11, and 12; and SCTF Test 703. A comparsion of the TRAC-PF1/MOD1 calculations for Version 14.3 and 14.4 for one of the UPTF downcomer refill tests is shown in Fig. 1. The improvement in the calculated downcomer-refill is apparent from this figure. The improved model in Version 14.4 forces the interfacial-shear model into the annular-flow regime for the downcomer geometry only. This model is not appropriate for all scales; therefore, additional development is required for a general model that can be applied at all scales for a full range of thermal-hydraulic conditions. The development of a general model for down- comer penetration at all scales and for a full range of thermal-hydraulic conditions is continuing for the MOD2 code.

MOD2 STATUS

In addition to keeping current with the MOD1 changes, the MOD2 develop- ment effort has resulted in unique enhancements and model improvements. The MOD2 code has the following additional improvements that are not available in the MOD1 code.

1. 3D-Two-Step numerics apply the 1D-Two-Step numerics in MOD1 to the 3D hydro- dynamics solution. The 3D-Two-Step numerics allow the 3D-vessel component to take larger time steps during a relatively slow transient (for example, a small- break or operational transient). The MOD1 3D vessel semi-implicit numerics require smaller time steps and thus a longer computation time for relatively slow transients.

2. Partial vectorization of the vessel-component thermal-hydraulic solution allows the TRAC code to take advantage of the vector-mode computation of Cray or Cray-like computers. Preliminary testing indicated a 10-20% speed-up for a large-break LOCA (LBLOCA) calculation resulting from partial vectorization of the 3D solution.

3. Inversion of the vessel data base results in coding for the vessel component that is easier to read and maintain. In addition, it results in arrays that vectorize computation in the axial direction.

4. A generalized heat-structure component allows the user to couple any hydro cell with any other hydro cell in the TRAC model by way of a heat-transfer path. Also, multiple heat-structure components may be coupled to a given hydro cell. This component provides the capability for increased accuracy in modeling steam generators, vessel internal structures, and so on.

5. Implementation of the Electric Power Research Institute (EPRI) drift-flux correlation results in significant improvements in the axial void-fraction profile when compared with the CCTF Run 14 data. Additional testing and development of improved core-reflood heat-transfer models is in progress.

6. During some recent application work, it was found that the MOD1 momentum-flux solution was inaccurate at smooth flow-area changes. A conserving momentum-flux solution[2] has been developed for the the MOD2 code. The capability to convect momentum flux across a plenum-component cell also has been added.

7. As part of the MOD1 Q/A document[3] development, it was found that the 1D and 3D wall-shear models were inaccurate and inconsistent. The MOD2 wall-shear models were made consistent. In addition, the MOD1 wall-shear model was improved in the MOD2 code with fixes to the laminar-flow model, inclusion of the surface-roughness effect in the turbulent regime, and improvements to the two-phase pressure-drop model.

8. The MOD1 valve model for flow resistance through a partially-closed valve is not based on either theory or experimental data. A new MOD2 valve flow-resist- ance model was developed based on experimental data for partially closed globe valves.

9. The Gauss-Seidel numerical solution for the 3D-vessel pressure-matrix equation was observed to be inaccurate for small breaks and operational transients. This inaccuracy typically would be observed as a mass error in the vessel component. This problem was solved in the MOD2 code by eliminating the Gauss-Seidel method and replacing the remaining full-matrix-inversion algorithm with the more efficient Capacitance-Matrix method[4] for solving the vessel pressure- and stabilizer-matrix equations. The Capacitance-Matrix method is 10 times faster than the vectorized full-matrix-inversion algorithm and faster than the Gauss-Seidel method for a 300- to 400-cell vessel.

10. The MOD1 subcooled-boiling model is inaccurate and has a questionable justification. The subcooled-boiling model was replaced in the MOD2 code with the TRAC-BWR subcooled-boiling model,[5] which has been tested to be accurate and is based on published correlations.

11. The capability to input the magnitude and general orientation of the vessel component for the gravitational-acceleration vector was added to the MOD2 code. This option was developed to address horizontal-tube vessel modeling requirements encountered during a recent application of the MOD2 code.

12. A 60-, 120-, or 180-degree rotational symmetry in cylindrical geometry option was added to the MOD2 code. This option was developed to allow for flexible vessel noding and significantly reduced noding if loop and vessel behavior is rotationally symmetric.

A simple 1D-flow test problem that exercises several of the MOD2 code features is given in Fig. 2. The figure shows a series of pipe and vessel components with changing flow area and elevation. The capability to orient the vessel component horizontally is required for this simple test problem to be analyzed. In addition, the multiple-vessel capability is required. The results for pipes replacing the vessels and for three different vessel-component orientations in this geometry are given in Fig. 3 This is a plot of the Bernoulli expression vs cell locations down the flow channel. If all of the flow-area changes are smooth with no irrreversible flow losses and if there is no wall friction (by defining the hydraulic diameter large), then the Bernoulli expression should be constant in value according to Bernoulli's equation[6] for single-phase, 1D flow. The MOD2 code with flow-area ratios applied to the momentum-convection term gives a constant-valued Bernoulli expression, whereas the MOD1 code without flow-area ratios produces significant error and nonconservation of momentum as the flow area and elevation change. This calculation was repeated with the 3D-vessel component modeling 1D flow and oriented in the x, y, and z directions to demonstrate that the solution is the same for the vessel component in all three directions. In addition, the calculation was repeated with the vessel components replaced by pipe components of the same geometry to verify that the vessel-component solution is consistent with the pipe-component solution. Consistency between the solutions from the 3D-vessel component and 1D components is not realized with the MOD1 code. In addition, successful consistency calculations for single-phase flow have been performed between the TRAC- PF1/MOD2 pipe, plenum, tee, and vessel components on another parallel-flow-channel test problem. This was possible for the plenum component by applying the new optional capability for convecting momentum flux across the plenum-component cell.

The CSAU MOD1 input-data file was converted to the slightly modified MOD2 input-data format (with an automatic converter program called GOCVRT) to investigate the calculative speed-up of 3D-Two-Step numerics in the MOD2 code in comparison to the MOD1 code without 3D-Two-Step numerics. The peak-clad temperatures (PCT) for the CSAU nominal LBLOCA calculation is given in Figs. 4 to 6. Version 14.3 tends to calculate a lower blowdown PCT because the Version 14.3 steady-state calculation had a cold-leg temperature that was too high. This high cold-leg temperature resulted in early flashing of the cold-leg fluid which resulted in an early blowdown and cooldown of the core from 4 to 7 s. The Version 14.4 and MOD2 steady-state calculations determined an accurate initial cold-leg temperature that resulted in a less significant core blowdown and cooldown and a slightly higher PCT. Because of the improved down- comer models in Version 14.4 and the MOD2 code, the core reflood starts ~10 s earlier than in the Version 14.3 calculation. Both Version 14.4 and the MOD2 code calcula- tions tend to reflood the core faster than the Version 14.3 calculation. The MOD2 core is essentially quenched at 50 s into the transient.

The CPU times for these three calculations is show in Fig. 7. The MOD2 code runs much faster than either of the MOD1 code versions. The major difference between these calculations is the 3D-Two-Step numerics allowing the time-step size to increase significantly over the material-Courant limit. In this input deck, several very small hydro cells in the vessel component were used to simulate leakage-flow paths between the downcomer and upper-plenum regions. The material-Courant limit in these small hydro cells kept the MOD1 time-step size small, whereas it had no effect on the MOD2 time-step size. The MOD2 time-step size tended to be controlled by how rapidly the LBLOCA transient progressed.

An international cooperative effort to continue development of the MOD2 code through the International Code Assessment and Application Program (ICAP) was started in January 1988. The planned MOD2 development tasks are described in the following section.

PLANNED MOD2-CODE IMPROVEMENTS

The objective of the MOD2 development plan is to address identified significant code deficiencies in the MOD1 code in order to provide an accurate and defensible tool that can be used to simulate large-break LOCAs, small-break LOCAs, and operational transients. The MOD2 code development plan is an international cooperative effort that includes contributions from Los Alamos, INEL, JAERI. Cray Research, CEGB, and UKAEA. The following MOD2 development contributions are planned.

1. Post-CHF Heat Transfer and Quenching

The current TRAC reflood heat-transfer model would be rewritten, removing Forslund-Rohsenow[7] and any nonphysical models or fits. Defensible correlations for inverted annular-film boiling would be included into the TRAC code. These correlations may depend on distance from the quench front or separate thermal-boundary-layer solutions. In addition, improvements in the dispersed-droplet film-boiling heat-transfer regime would be investigated including the possible addition of a cold-surface model. Several organizations currently are developing new TRAC post-CHF models: UKAEA, CEGB, JAERI, and Los Alamos.

2. Interfacial Drag Under Wet-Wall Conditons

The CEGB[8] has recommended a set of correlations for use under wet-wall conditions for high flow rates, low flow rates, upflow, downflow, rod bundles, and small-, intermediate-, and large-diameter pipes. Los Alamos has implemented the CEGB recommendations for rod bundles and large-diameter pipes. The other CEBG recommendations are under investigation.

3. Improved Offtake Model for Horizontal Pipes

The UK has recommended a model for branching flow at tees. The purpose of the model is to determine the amount of vapor pull through or liquid entrainment that occurs in a horizontal pipe that has a smaller pipe or break located on its side, bottom, or top. This model would be included directly into the TRAC tee component. This same model has been implemented into the RELAP5 code and experience from that implementation and assessment will be used.

4. Implicit Axial-Conduction Model

JAERI has agreed to provide to Los Alamos a new fully-implicit axial-conduction model for the MOD2 code. The MOD1 and MOD2 moving-mesh axial-conduction solution is currently explicit. This explicit solution can result in small-time step sizes as the axial-mesh size is reduced in the vicinity of the quench front.

5. Code Speed-Up

JAERI has agreed to investigate various methods for speeding-up the TRAC code calculations. For example, smoothing the constitutive correlations between flow regimes has proven successful in speeding up other thermal-hydraulic codes.

6. Elimination of Nonstandard Fortran

JAERI has agreed to assist in eliminating nonstandard Fortran. Cray Research developed a set of updates for the MOD1 code that eliminated a significant portion of the nonstandard Fortran. Los Alamos has extended those updates to the MOD2 code.

7. Vectorization and Parallelization

Cray Research has agreed to assist in eliminating nonstandard Fortran.

8. Documentation on RELAP5/MOD3 Improvements

INEL will provide Los Alamos with documentation on the RELAP5/MOD3 improvements as they become available.

9. Improved Critical-Flow Model

Los Alamos plans to investigate improvements in the TRAC critical-flow model for nonequilibrium, two-phase flow conditions.

10. Implementation of the ANS 1979 Decay-Heat Standard

Los Alamos plans to develop a simple model for the estimation of nuclear parameters for mixed-oxide fuels. The current model allows for the simulation of power history effects, for the delayed-neutron effect from actinides, and for the recommended decay-heat model. The current model will be modified so that the 1979 standard is the default model.

11. Implementation of the CCFL Model Into the MOD2 Code

Los Alamos plans to implement the MOD1 CCFL model into the MOD2 code.

12. General Model for Interfacial Heat Transfer

Los Alamos plans to develop a general model for interfacial heat transfer for all flow regimes. The Q/A document and the assessment of TRAC-PF1/ MOD1 Version 14.4 indicate that the current correlations can be modified to predict the dominant phenomena for a few geometries and a few flow regimes. However, to be successful for a wide range of geometries and flow regimes, specific models and correlations must be developed and implemented for specific geometries and flow regimes. For example, the current correlation for condensation assuming $St = 0.02$ is adequate for cold-leg condensation at high steam-flow rates. However, at lower steam-flow rates, this correlation tends to predict too much condensation.

13. Improvements in Time-Step Control

Los Alamos plans to develop new algorithms for the adjustment of time-step size. These algorithms would monitor the rate of change with respect to the important independent variables and the number of outer iterations required to converge a given time-step solution.

14. Improved Accumulator Model

Los Alamos plans to set up several test cases for the MOD2 code using the LOFT accumulators and the ROSA-IV separate-effects accumulator tests. Calculations would be performed to determine whether the new models in the MOD2 code still resulted in oscillations and excessive vapor entrainment. It is anticipated that the MOD2 code will not have these same problems; however, if it does, fixes would be proposed.

15. Break-Flow Time-Step Sensitivity

The MOD2 interfacial-shear time averaging already has been changed to reduce time-step size dependency on the results. Los Alamos plans to rerun the UPTF- test sensitivity calculations to determine whether any time-step sensitivity is still pre- sent.

16. Flexible Vessel Noding

The capability to finely node the downcomer and coarsely node the core region is a code improvement that was identified as being important during the CSAU methodology application to the TRAC-PF1/MOD1 code. The MOD2 code currently has that capability with the exception that the plenum component would have to be improved. With the MOD2 code, the downcomer would be modeled as an eight theta-sector vessel component. Each azimuthal theta sector would have a short-pipe connection to the lower plenum that would be modeled with a plenum component. An additional pipe component would be used to model the lower portion of the lower plenum. The core region would be modeled with one or two theta sectors and with one or two radial rings. A generalized heat-structure capability would have to be programmed for the plenum component. A long-term development effort would be to eliminate the short pipes and connect the vessel component directly to the plenum component.

Current plans for MOD2 development include completing the developmental assessment and draft documentation by the end of October 1989.

MOD2 ENHANCEMENTS TO BE CONSIDERED FOR FY 1990

1. Hot-Channel Option

The capability to model through input a hydraulically coupled hot channel would be developed and tested in the MOD2 code.

2. Direct Moderator Heating

The simple model given below would be used to define direct moderator heating as the core-average liquid fraction and fission power change.

$$DMH = a_f \, f_{dmh} \, P_{fp} \, , \qquad (1)$$

where

DMH = direct moderator heating (W),
a_f = core-average liquid fraction,
f_{dmh} = input-specified fraction of the total core fission power that is direct moderator heating when the core has no void, and
P_{fp} = total core fission power (W).

The direct-moderator-heating-energy source term would be included in the liquid-phase energy equation and distributed in the core region according to the power-shape factors that the user inputs.

3. Pump-Energy Source Term

Coding would be developed and tested to include the pump-energy source term directly in the PUMP-component energy equations.

4. Mechanistic Pump Model

A mechanistic pump model similar to the EPRI pump model would be developed and implemented into the TRAC code. The no-slip assumption at the pump exit would be eliminated.

5. Development of a General Model for Downcomer Penetration at All Scales

A general model for predicting the flow regime in the downcomer for both small- and large-scale experiments would be developed and implemented into the TRAC code.

6. Improved Fuel-Rod Model (Including Swelling and Rupture Models)

The generalized heat-structure component in the MOD2 code would be modified to keep track of two different gap widths. One gap width (Dz_{gap}) would be a uniform gap width so that the 2D-conduction solution would continue to be solved on an orthogonal 2D-coordinate geometry. The other gap width would be the axial- and time-varying gap width from which $h_{gap}(r,t)$ would be calculated. The $h_{gap}(r,t)$ would be transformed into an effective gap conductance to be used in the fixed geometry of the 2D-conduction solution:

$$k_{gap}(r,t) = h_{gap}(r,t)\, Dz_{gap} \quad . \tag{2}$$

Using Eq. (2) ensures that the heat flux across the uniform gap width is the same as the heat flux across the axial- and time-varying gap width. The heat flux across the uniform gap width is

$$q_{gap} = k_{gap}(r,t)\, \{T_{fuel} - T_{clad}\} / Dz_{gap} \quad , \tag{3}$$

and the heat flux across the axiall- and time-varying gap width is

$$q_{gap} = h_{gap}(r,t)\, \{T_{fuel} - T_{clad}\} \quad . \tag{4}$$

Simplified models for swelling and rupture would be investigated for inclusion into the TRAC code.

7. **Improved Steam-Generator Heat-Transfer Models [Specifically for Babcock & Wilcox (B&W) Steam Generators]**

Develop and implement a mechanistic model that estimates the surface area wetted by the auxiliary feed for a B&W steam generator and determines the appropriate wall heat-transfer coefficient.

8. **Generalized 1D Component**

A generalized 1D component would be developed that would allow for vectorization of the 1D routines. The 1D data base would be inverted, and the 1D and 3D data bases would be made consistent.

9. **Geometry-Dependent Flow-Regime Map**

As part of the work on TRAC-PF1/MOD1 Version 14.4, geometry-dependent flow-regime maps already have been developed for the downcomer, lower plenum, upper plenum, and hot leg. This work would continue based on available data and the identification of problem areas.

10. **Input Preprocessor**

As part of a small business contract for the NRC, Energy Incorporated (EI) has developed the capability to generate and modify TRAC input-data files using an IBM/PC. This capability has the user-friendly features of inputting data into prepared forms with data descriptions and screen editing existing input data. Preliminary testing indicates that the software is not ready for release and some debugging is necessary. In addi- tion, the software has to be changed to handle the slightly modified input-data format of the MOD2 code. Los Alamos is proposing that EI be subcontracted to complete this work.

11. **Improved CHF Model**

The results of the RELAP5 work on the development and implementation of an Improved CHF model would be used.

12. Complete the Implementation of the TRAC-BWR Separator Model Into the MOD2 Code

INEL, Los Alamos, and UKAEA identified numerical problems with the TRAC-BWR separator model. INEL has developed fixes to address these problems. Los Alamos would implement these fixes and test to verify that the separator model is accurate and robust.

CONCLUSIONS

The list of development tasks described in this presentation will satisfy the objectives of the MOD2 code development plan. Los Alamos is committed to providing a high-quality, accurate, and defensible MOD2 code.

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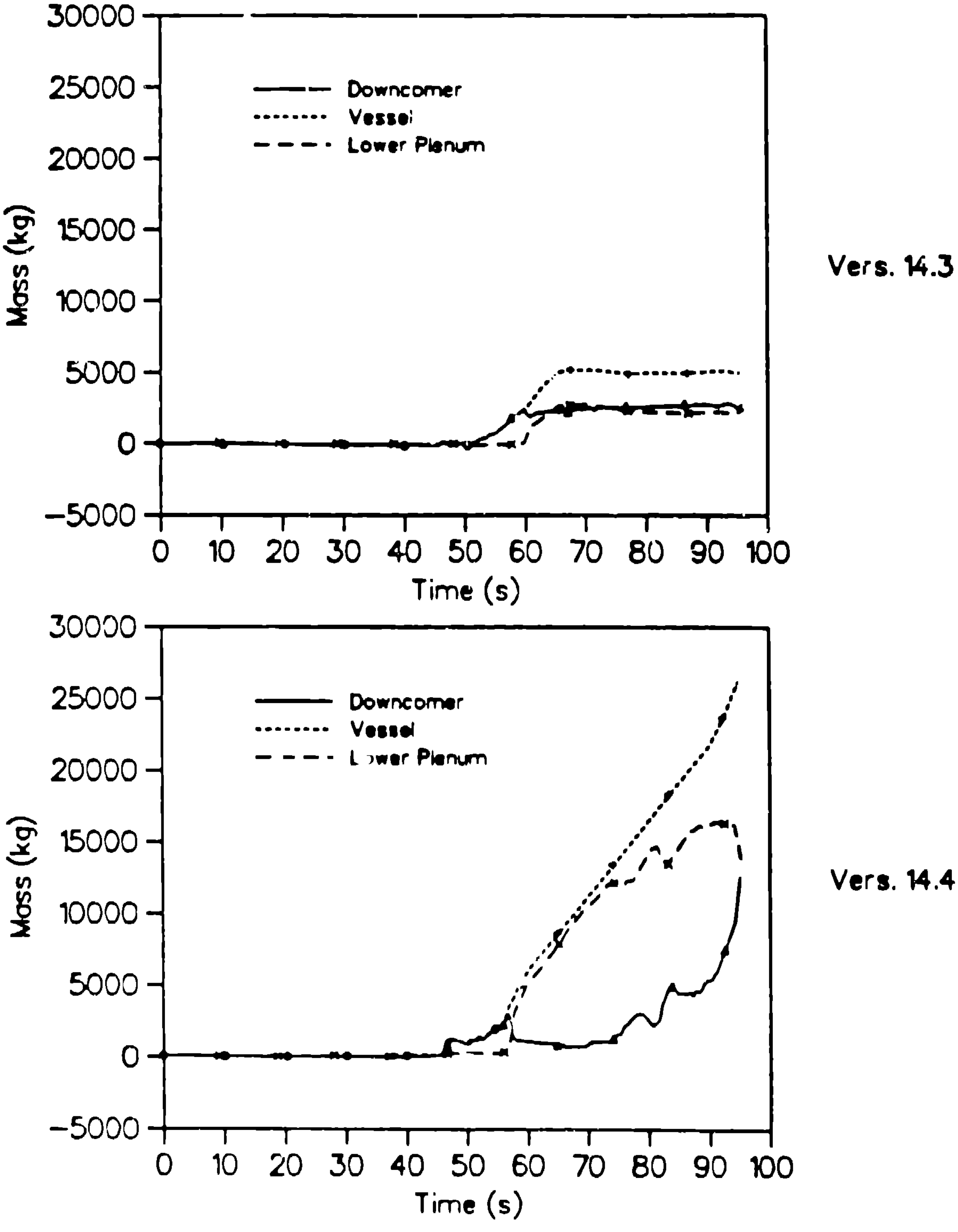

Fig. 1. Comparison of TRAC Versions 14.3 and 14.4 calculations.

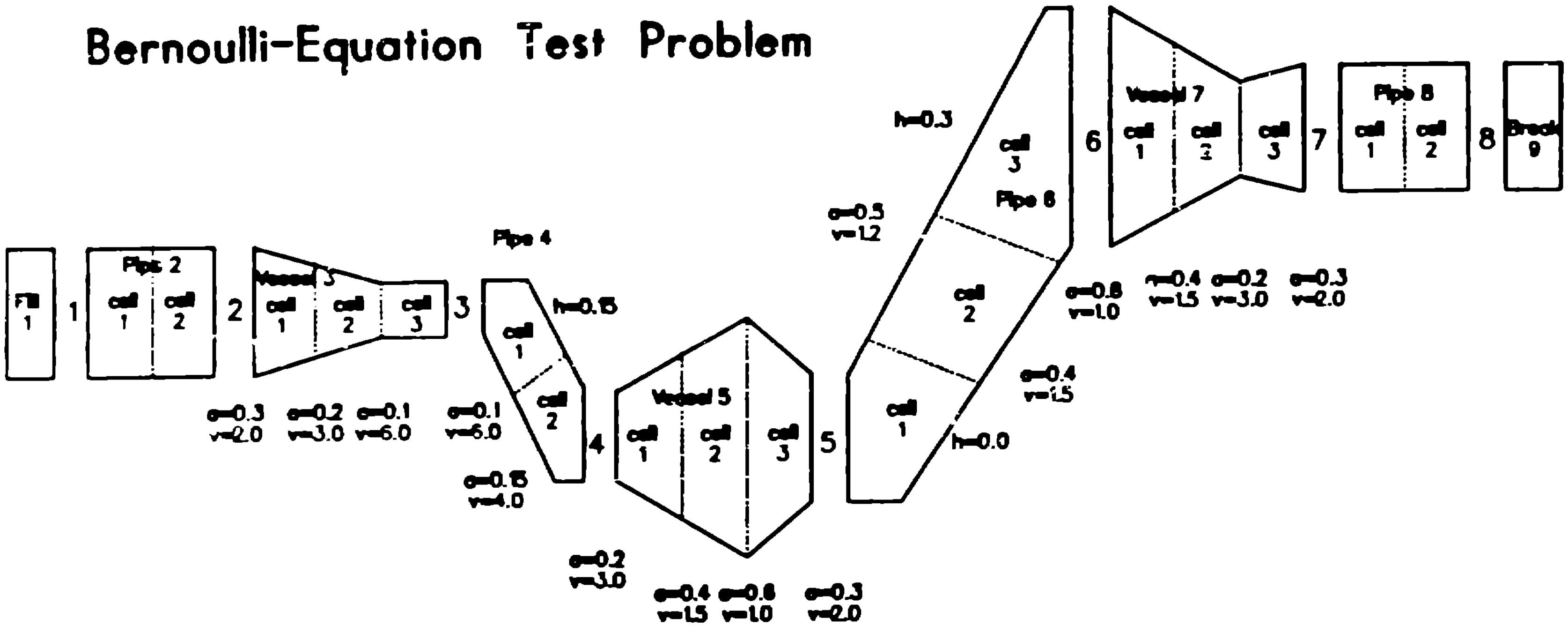

Fig. 2. Simple one-dimensional flow test problem.

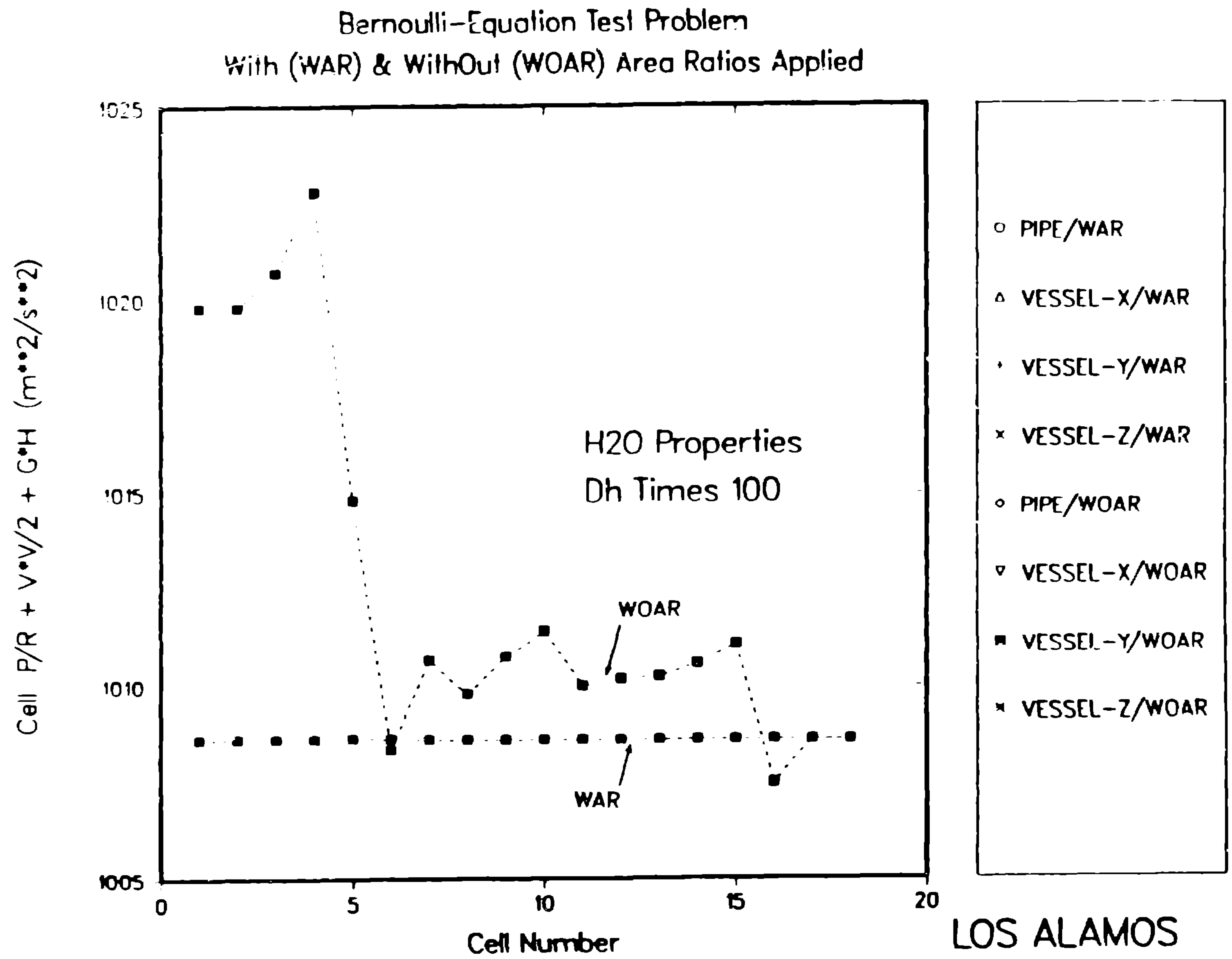

Fig. 3. MOD2 results for simple one-dimensional test problem.

Mod1 Version 14.3

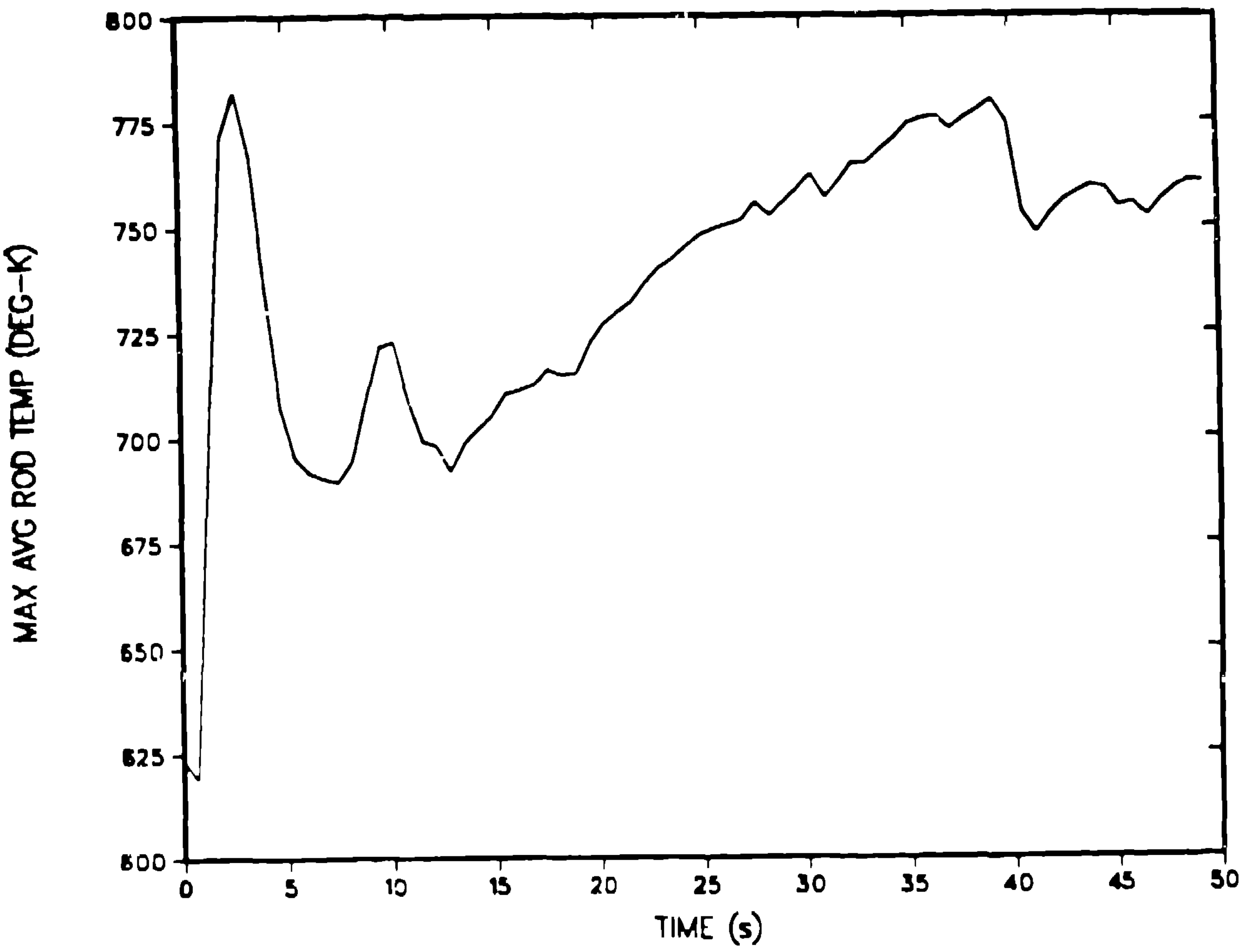

Fig. 4. TRAC-PF1/MOD1 Version 14.3 peak clad temperature for the CSAU LBLOCA calculation

Mod1, Version 14.4

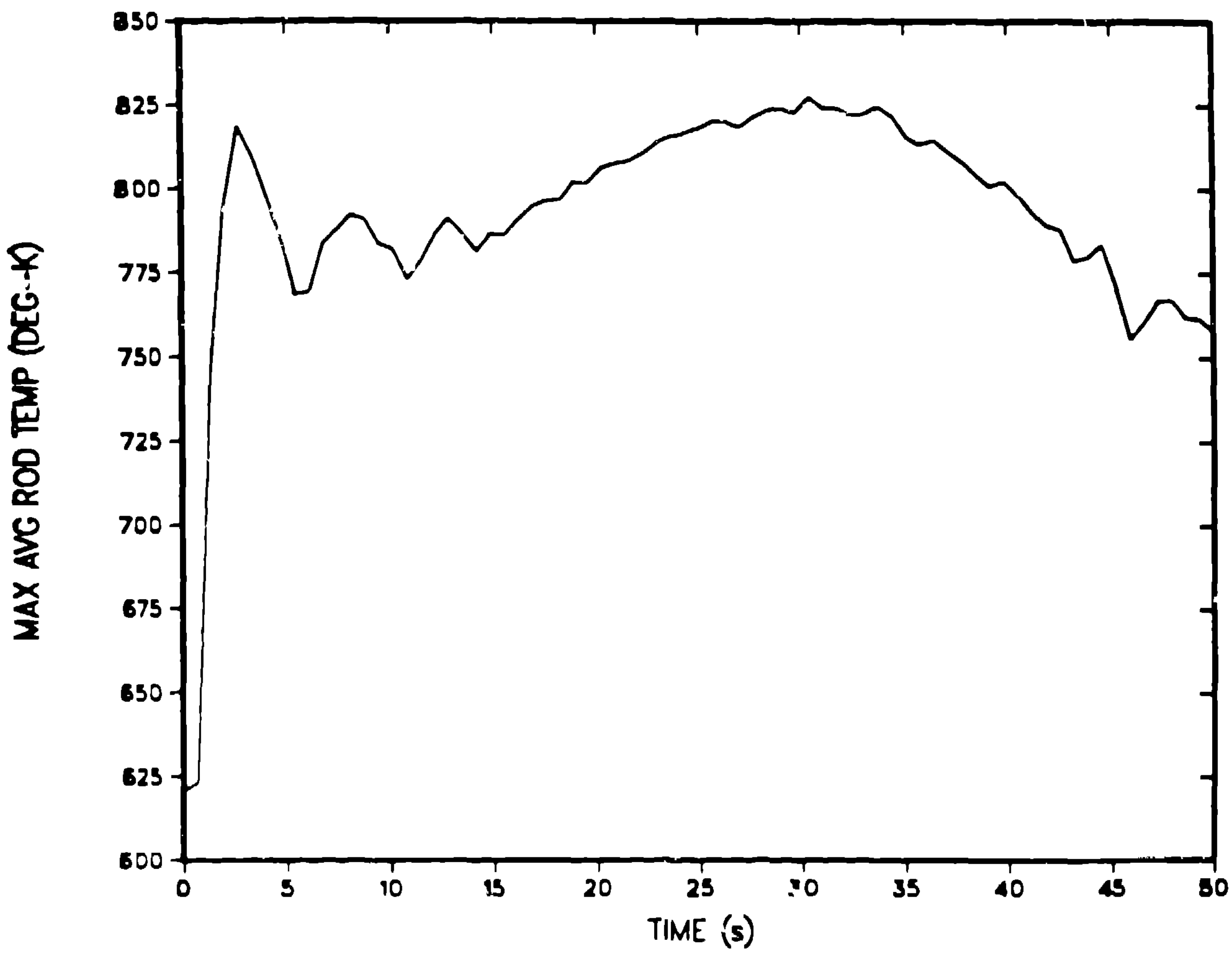

Fig. 5. TRAC-PF1/MOD1 Version 14.4 peak clad temperature for the CSAU LBLOCA calculation.

Mod2, Version 4.2

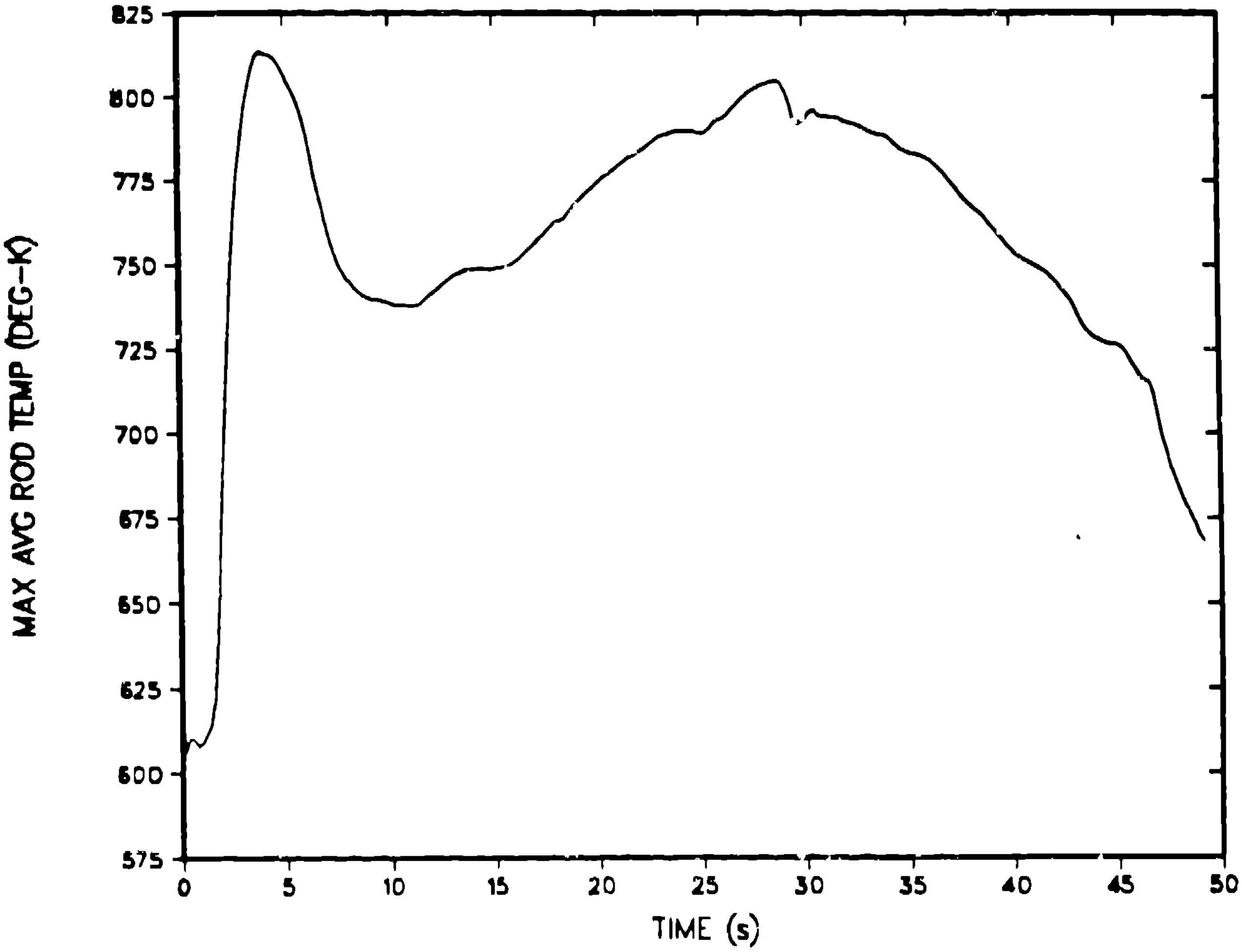

Fig. 6. TRAC-PF1/MOD2 Version 4.1 plus Red Star (~ Version 4.2) peak clad temperatura for the CSAU LBLOCA calculation.

Computer Run Time Comparison

- WPWR LBLOCA, CSAU Input Deck
- 50 Seconds of Transient Time

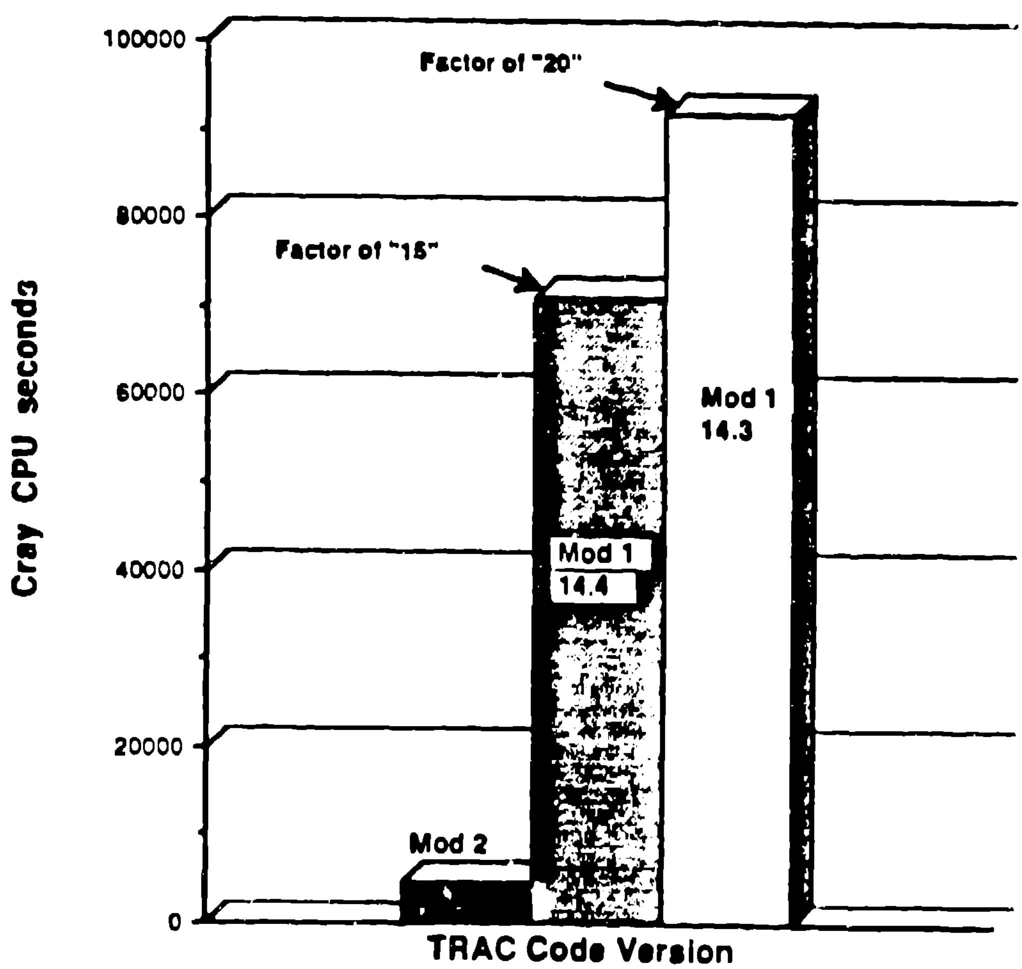

Fig. 7. CPU computer-time comparisons between TRAC-PF1/MOD1 Versions 14.3 and 14.4 and TRAC-PF1/MOD2 Version 4.1.