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Development of the PC Version of TRAC-M/F77

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Abstract

TRAC-M/F77 computer code is a calculational tool for analyzing pressurized light-water reactors during a loss-of-coolant accident and operational transients. TRAC-M was designed originally for the super computers such as CRAY-1 and CRAY-XMP. Efforts have been made to make the programming as machine-independent as possible. A PC-based version is presented here. The calculational results are compared with those of HP version for the TRAC-M assessment cases.

1. Introduction

The Los Alamos National Laboratory (LANL) has developed the modernized Transient Reactor Analysis Code (TRAC-M) to provide advanced, best-estimate simulations of real and postulated transients in pressurized water reactors (PWRs) and for many related thermal-hydraulic facilities. The code features one and three-dimensional (1D/3D), two-fluid treatment for the thermal hydraulics, together with other necessary modeling capabilities to describe a reactor system.

Due to the complexity of the thermal-hydraulic modeling, the code was originally designed for the super computers such as Cray computers (1, X-MP, Y-MP, 2) using the Cray operating system, UNICOS, or the Cray Timesharing System (CTSS) used at Los Alamos.

Efforts have been made to make the programming as machine independent as possible. Now, the code can be run on IBM mainframe computers using VM or MVS operating systems; Cyber 205, Amdahl, FACOM, and VAX computers; and SUN, HP-RISC, and IBM-RISC workstation computers.

Here is presented a PC-based version of the code. This is to take advantage of rapidly improving PC environments. The calculational results are compared with those of HP version for the TRAC-M developmental assessment cases which were used to assess the 1993 code release, TRAC-PF1/MOD2[1], and the 1998 code release, TRAC-M/F77[2].

2. TRAC Code Structure and Porting Tool from Mainframes to a PC

2.1 History of TRAC Code

The Transient Reactor Analysis Code (TRAC) is an advanced, best-estimate computer program to calculate the transient reactor behavior of a pressurized water reactor (PWR). As such, TRAC incorporates four-component (liquid water, liquid solute, water vapor, and noncondensable gas), two-fluid (liquid and gas) modeling of thermal-hydraulic processes involved in such transients. This complexity of the thermal-hydraulic modeling requires many additional models and correlations to provide closure for the equation set. A model consists of a set of correlations with logic imposed into a coherent description of a phenomenon.

A preliminary TRAC version consisting of only one-dimensional (1D) 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 1D loop-component modules. The first publicly released version, TRAC-P1, was completed in December 1977. The TRAC-P1 program was designed primarily for the analysis of large-break loss-of-coolant accidents (LOCAs) in PWRs. A refined version, TRAC-P1A, was released to the National Energy Software Center (NESC) in March 1979. TRAC-PD2 contains improvements in reflood, heat-transfer models, and numerical solution methods. Although it is a large-break LOCA code, it has been applied successfully to small-break problems and to the Three Mile Island incident. TRAC-PF1, released publicly in July 1981, was designed to improve the ability of TRAC-PD2 to handle small-break LOCAs and other transients. TRAC-PF1/MOD1 maintained the models necessary for applying the code to large-break LOCAs (LBLOCAs) and added or modified models as necessary to enhance the application of the code to small-break LOCAs (SBLOCAs) and operational transients[2].

The TRAC-M/F77 code is the latest released version. This code differs from the last formally released TRAC code in the following major features. First, standard FORTRAN 77 (F77) has been implemented throughout the code with a commensurate increase in portability and maintainability. Second, the platform-dependent binary file named TRCGRF has been replaced by the files XTVGR.b and XTVGR.t, which can be processed by the TRAC visualization and plotting tool, X-TRAC-View[3]. Third, this version contains a newly revised reflood model.

XTV is a simple, intuitive, postprocessing Graphical User Interface (GUI) to the complex database generated by a TRAC calculation. It provides static and animated color-mapped visualizations of both thermal-hydraulic and heat-conduction components in a TRAC model of a nuclear power plant, as well as two-dimensional (2D) plot capabilities. Both plots and color maps can be output to printers in PostScript format. XTV is the successor to TRAP, the former TRAC postprocessor using the proprietary DISSPLA graphics library. XTV requires a UNIX operating system running X Windows.

2.2 Code Structure and Calculational Sequence

In an effort to strive for a code structure that minimizes the problems of maintaining and extending the code, TRAC was developed in a modular fashion. This modularity manifests itself in two important ways. First, because TRAC analyzes nuclear-reactor systems that consist of specific component types, the code is written to utilize subroutines that handle specific component types. Second, the TRAC program is written to be functionally modular; that is, each TRAC subprogram performs a specific function. Some low-level subprograms are used by all components, thereby strengthening this modularity.

Functional modularity within TRAC-M is taken a step further by grouping routines into modules. Figure 1 displays a calling-tree representation of the TRAC modules.

The overall sequence of the calculation is directed by the TRAC main program. Module INPUT always is invoked at the start of each TRAC execution to read control-procedure and component input data. Component data are initialized by the module INIT. A steady-state calculation (if requested) is performed by subroutine STEADY. During a steady-state calculation, the reactor-core power is initially zero and is set to its steady-state power level after fluid flow has been established. A transient calculation (if requested) is performed by subroutine TRANS. Modules EDIT and DUMP are called during a steady-state calculation by subroutine STEADY and during a transient calculation by subroutine TRANS by calling subroutine PSTEPQ to generate current-time output results as user requested. Overlay CLEAN is called to close all output files at the end of the calculation or when a fatal error occurs that aborts the calculation. TRAC calculation flow diagrams are presented in Figure 2 and 3.

2.3 Porting from Mainframes to a PC

The porting of the code from mainframes to a PC has been performed using Cygwin tools. The Cygwin tools are ports of the popular GNU development tools for Windows NT, 95, and 98. The Cygwin library provides the UNIX system calls and environment these programs expect. With these tools installed, it is possible to write Win32 console or GUI applications that make use of the standard Microsoft Win32 API and/or the Cygwin API. As a result, it is possible to port many significant Unix programs without the need for extensive changes to the source code.

Although TRAC-M and XTV are written in clean ANSI C and standard FORTRAN 77, it's not straight forward to port the code directly into a PC, since they use unix-based X Windows libraries, the Xlib library for low-level graphics and the Xt and Motif libraries for implementation of high-level, user-interface, graphical objects.

In order to compile the code properly, some parts of the source are modified. First, the routine that uses POSIX library has been removed, since there is no known stable compilers that support the POSIX library, for now. Fortunately, the routine is only for calculating elapsed CPU time used by the calling process. This routine does not affect the TRAC results and used only for developmental check list that shows the developer the elapsed CPU time for each subroutine call.

Second, since the XTV requires unix-based X Windows libraries, it is necessary to use the proper libraries working on a PC. Here, we used precompiled X libraries, X Windows Version 11 Release 6.4 client libraries compiled with the Cygwin port of gcc to Win32.

With this minimum modification and X Windows libraries, we successfully ported the TRAC-M and XTV to a PC platform.

3. Assessment Cases

The PC version of the TRAC-M was run on a IBM-compatible PC (Pentium-III, 64MB RAM) using Windows98 operating system. The calculational results for assessment cases are then compared with those of HP mainframe.

3.1 Steady-State Conduction Problems : 1D Radial Conduction

The 1D radial steady-state conduction was determined for a generic nuclear fuel rod. The dimensions for the rod are given in Figure 4. For this test problem, the inner material is representative of fuel surrounded by a gap that is surrounded by cladding. The material from $r=0$ to $r=r1$ is a uniform source of 1000 W. From $r=r1$ to $r=r2$, a gap occurs with a gap conductance of 1000 $W \cdot m^{-1} \cdot K^{-1}$. From $r=r2$ to $r=r3$, the conductivity is 13.8 $W \cdot m^{-1} \cdot K^{-1}$. The fluid temperature is 300 K and the surface heat-transfer coefficient is 2836 $W \cdot m^{-2} \cdot K^{-1}$.

A TRAC model using 18 nodes in the radial direction was used to represent the geometry of the test problem described above. The results are given in Table 1.

3.2 Steady-State Conduction Problems : 2D Radial and Axial Conduction

The 2D radial and axial heat-conduction problem is for a solid rod with a constant and uniform heat source, with a constant heat-transfer coefficient in the radial direction, and adiabatic boundary conditions at both ends of the rod (Figure 5). The axial variation in the temperature profile is obtained by having one fluid temperature boundary condition on the lower half of the rod and another fluid temperature boundary condition on the upper half of the rod. The TRAC results of the rod temperatures along the centerline of the rod are given in Table 2.

The results given in Table 2 are with the fine-mesh option on. The TRAC-M/F77 fine-mesh option adds axial levels in regions where the temperature profile is steep in an attempt to reduce the finite-difference error in that region.

3.3 1D Drain and Fill Test Problem

The drain test problem consists of a vertical Pipe component that is partially filled with water, a Fill component, and a Break component as shown in Figure 6. The Break component provides a constant-pressure-boundary condition (1.0e+05 *Pa*) for the top of the pipe. The Fill component slowly drains water from the pipe and then refills the pipe to the original level.

In Figure 7, the pressure in cell 1 is plotted for the drain-fill transient. Again, it shows that the two results are identical.

4. Conclusions

A PC version of the TRAC-M code was presented here. Verification has been performed for typical TRAC assessment cases and the calculational results are compared with those of HP workstation. The two results are identical and we determined that the PC version is as stable and accurate as mainframe versions.

The PC version of the code can be useful for several reasons. One important thing is that we can directly benefit from rapidly improving PC environments. Although it has yet to be approved by USNRC before using its results for nuclear safety analysis, the PC version of TRAC-M can be used as a preliminary testing tool.

References

[1] J. C. Lin, V. Martinez, and J. W. Spore, "TRAC-PF1/MOD2 Developmental Assessment Manual," Los Alamos National Laboratory (1993)

[2] B. E. Boyack, J. F. Lime, D. A. Pimentel, J. W. Spore, and J. L. Steiner, "TRAC-M/F77 Developmental Assessment Manual," Los Alamos National Laboratory (1998)

[3] R. Johns, "Proposed Chaaaaanges to X-TRAC-View and variable additions to TRCGRF Equivalence," Los Alamos National Laboratory (1998)

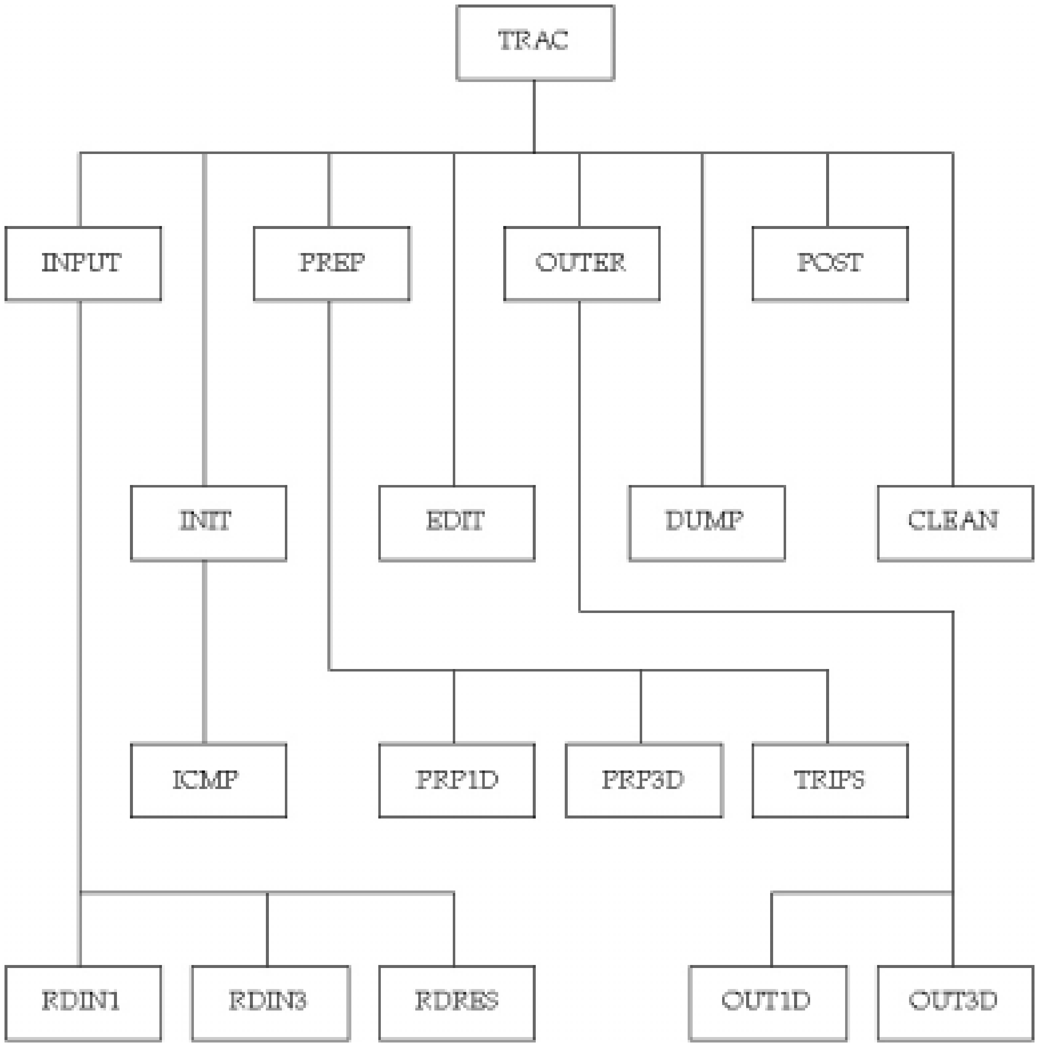

Figure 1. TRAC-M Module Structure

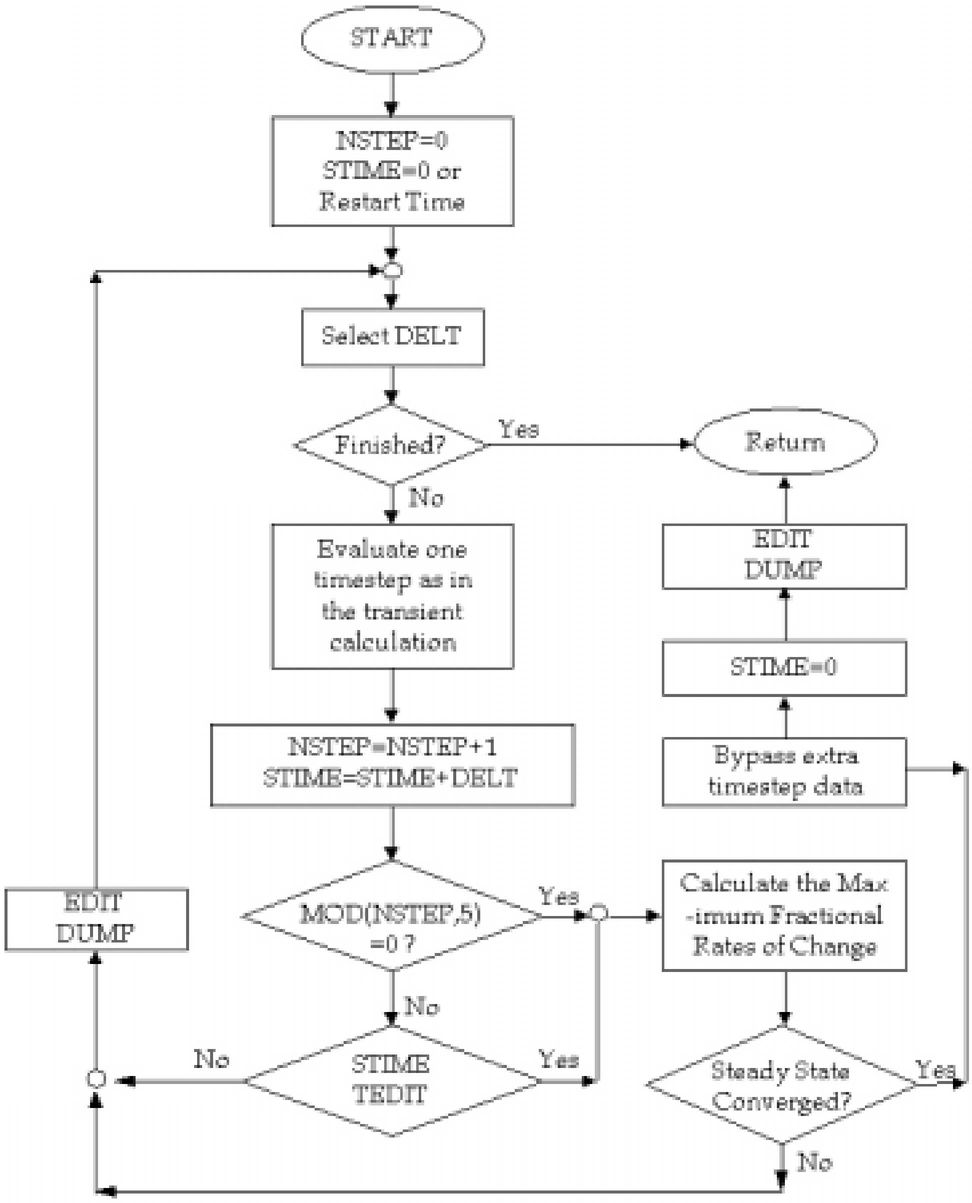

Figure 2. Steady-State Calculation Flow Diagram

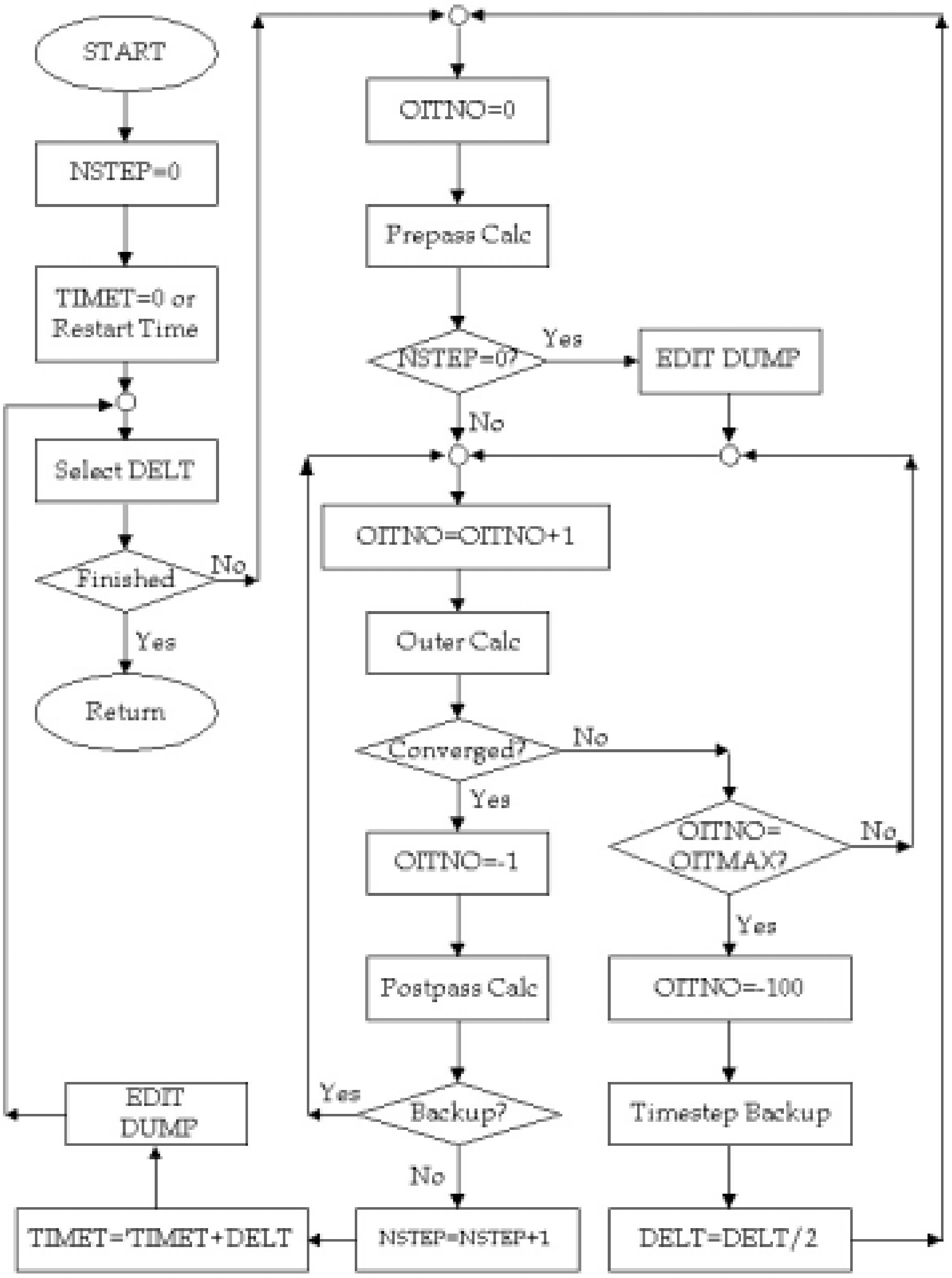

Figure 3. Transiennt Calculation Flow Diagram

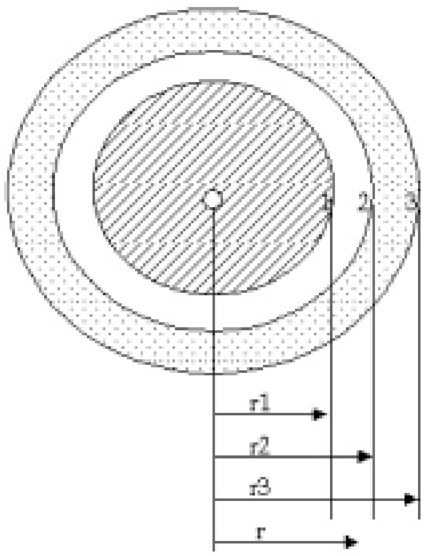

Figure 4. Boundary Conditions of a 1D Heat-Conduction Problem

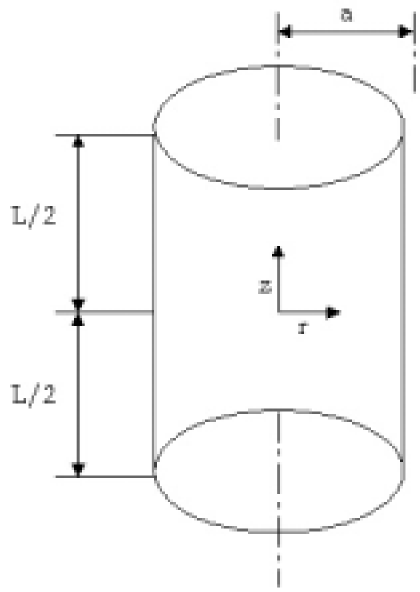

Figure 5. Sketch of the 2D Radial and Axial Heat-Conduction Problem

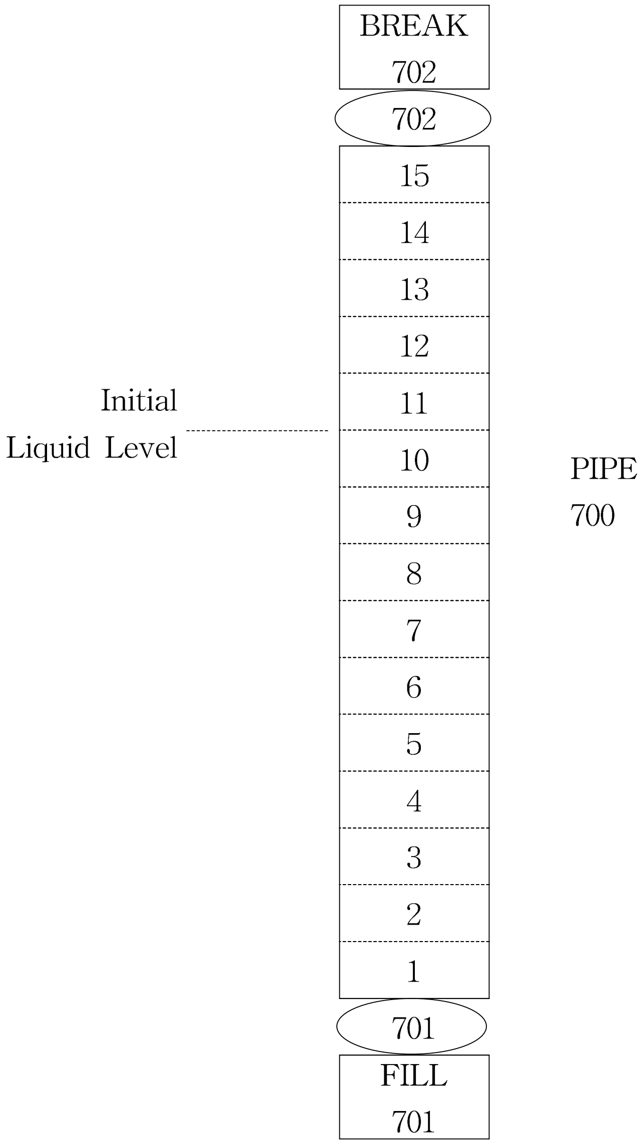

Figure 6. TRAC Model of the Drain and Fill Test Problem

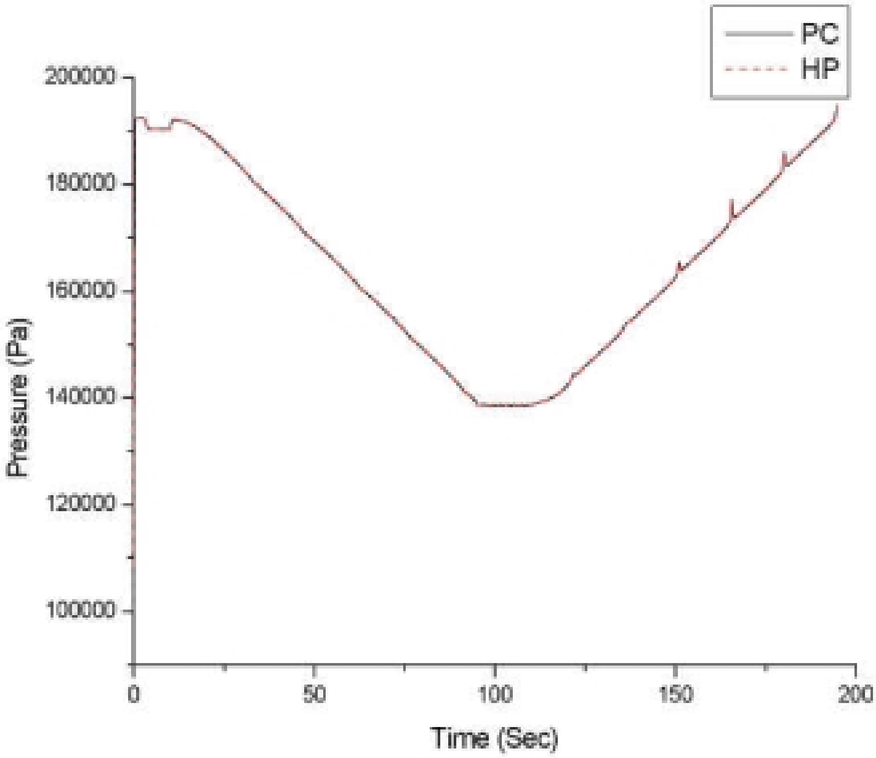

Figure 7. Cell 1 Pressure for the Drain and Fill Test Problem

Node Location (mm)	HP Result (K)	PC Result (K)	Error (K)
0.000	1038.30	1038.30	0.0
1.830	1005.30	1005.30	0.0
2.590	972.10	972.10	0.0
3.175	938.82	938.82	0.0
3.670	905.39	905.39	0.0
4.100	872.42	872.42	0.0
4.490	839.36	839.36	0.0
4.850	806.19	806.19	0.0
5.185	773.01	773.01	0.0
5.500	739.80	739.80	0.0
5.800	706.35	706.35	0.0
6.080	673.53	673.53	0.0
6.350	640.41	640.41	0.0
6.426	391.26	391.26	0.0
6.670	386.96	386.96	0.0
6.840	384.06	384.06	0.0
7.040	380.74	380.74	0.0
7.239	377.52	377.52	0.0

Table 1. Comparison between HP and PC Results for a 1D Heat-Conduction Problem in the Radial Directions at Steady State

Node Location (mm)	HP Result (K)	PC Result (K)	Error (K)
0	658.10	658.10	0.0
10	658.10	658.10	0.0
20	658.10	658.10	0.0
30	658.10	658.10	0.0
40	658.10	658.10	0.0
50	658.10	658.10	0.0
60	658.10	658.10	0.0
70	658.10	658.10	0.0
80	658.25	658.25	0.0
90	662.73	662.73	0.0
100	758.10	758.10	0.0
110	853.47	853.47	0.0
120	857.94	857.94	0.0
130	858.09	858.09	0.0
140	858.10	858.10	0.0
150	858.10	858.10	0.0
160	858.10	858.10	0.0
170	858.10	858.10	0.0
180	858.10	858.10	0.0
190	858.10	858.10	0.0
200	858.10	858.10	0.0

Table 2. Comparison between HP and PC Results along a Center Line for a rod in a 2D Heat-Conduction Problem