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ANALYSIS OF THE OECD PEACH BOTTOM TURBINE TRIP 2 TRANSIENT BENCHMARK WITH THE COUPLED NEUTRONIC AND THERMAL-HYDRAULICS CODE TRAC-M/PARCS

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ABSTRACT

An analysis of the Peach Bottom Unit 2 Turbine Trip 2 (TT2) experiment has been performed using the U.S. NRC coupled thermal-hydraulics and neutronics code TRAC-M/PARCS. The objective of the analysis was to assess the performance of TRAC-M/PARCS on a BWR transient with significance in two phase flow and spatial variations of the neutron flux. TRAC-M/PARCS results are found to be in good agreement with measured plant data for both steady state and transient phases of the benchmark.

1. INTRODUCTION

The U.S. NRC 3D neutron kinetics code PARCS (Purdue Advanced Reactor Core Simulator) [Joo, 1998] has been coupled with the U.S. NRC consolidated thermal-hydraulics code TRAC-M [Miller, 1999]. Incorporation of full three-dimensional neutronics models of the reactor core into system transient codes allows for a best-estimate calculation of interactions between the core behavior and plant dynamics. The NEA, OECD has specified coupled code transient benchmarks in order to verify the capability of coupled codes to analyze complex transients with coupled core-plant interactions. The first step in this effort was the development of a PWR Main Steam Line Break (MSLB) Benchmark [Ivanov, 1997], which was then successfully analyzed with TRAC-M/PARCS [Miller, 2000].

The next step in this effort was the development of a BWR coupled code problem. The Peach Bottom turbine trip experiment was well suited for this purpose because it is a pressurization event in which the coupling between core phenomena and system dynamics plays an important role in predicting the plant response and because high quality plant data was available from the tests which were performed in 1977. Three turbine trip tests [Carmichael, 1978] were performed at Peach Bottom Unit 2 at the end of Cycle 2 [Larsen, 1978] in April 1977. The main focus of these tests was to investigate the neutron kinetic and thermal-hydraulic effect of pressurization transients following turbine trips in boiling water reactors. The tests were set up to measure the major system variables such as neutron flux and pressures at selected system locations. Therefore the tests provide verification data for BWR safety analysis methods and benchmark problem [Solis, 2001].

There have been several previous efforts to perform analysis of the Peach Bottom turbine trip transients [Hornyik, 1979] [Moberg, 1981]. The current work is innovative because it is utilizing a next generation coupled system thermal-hydraulic/three-dimensional neutronics code, TRAC-M/PARCS. It provides also a rigorous and consistent prediction of plant behavior in order to achieve "best estimate" analysis of reactor systems.

2. PEACH BOTTOM TURBINE TRIP 2 BENCHMARK

The second test of the Peach Bottom experiment was selected for the OECD/NRC benchmark problem in order to investigate the effect of a pressurization transient on the neutron flux in the reactor core. The actual plant data was collected, including a compilation of reactor design and operating data for Cycles 1 and 2 of Peach Bottom, as well as the actual plant transient experimental data. The Turbine Trip transient begins with a sudden closure of the turbine stop valve. The pressure oscillation generated in the main steam piping propagates with relatively little attenuation into the reactor core. The induced core pressure oscillation results in significant changes of the core void distribution and fluid flow. The magnitude of the neutron flux transient taking place in the BWR core is strongly affected by the initial rate of pressure rise caused by pressure oscillation and has a strong spatial variation. The correct simulation of the power response to the pressure pulse and subsequent void collapse requires a 3-D core modeling supplemented by a one-dimensional simulation of the remainder of the reactor coolant system. Test initial conditions are shown in Table 1.

Table 1. Peach Bottom Turbine Trip 2 Initial Conditions

Core thermal power, MWt	2030
Initial power level, % of rated	61.65
Gross power output, MWe	625.1
Feedwater flow, kg/s	980.26
Reactor pressure, Pa	6798470.0
Total core flow, kg/s	10445.0
Core inlet subcooling, J/kg	48005.291
Core pressure drop (calculated), Pa	113560.7
Core pressure drop (measured), Pa	83567.4
Jet pump driving flow, kg/s	2871.24
Core average exit quality, fraction	0.097
Core average void fraction, fraction	0.304
Core average power density, kW/l	31.28
Control density, fraction	0.159

The benchmark specifications consisted of three separate exercises. Exercise 1 was a power vs. time plant system simulation with fixed axial power profile table. The purpose of exercise 1 was to test the thermal-hydraulic system model. Exercise 2 was a coupled 3-D kinetics/core thermal-hydraulic boundary condition model or a 1D kinetics/core thermal-hydraulic boundary condition model. Exercise 3 is the best-estimate coupled 3D core with a complete thermal-hydraulic system model. Only the results of exercise 3 are reported in this paper.

3. PEACH BOTTOM MODEL DESCRIPTION

3.1 TRAC-M THERMAL-HYDRAULICS MODEL

The TRAC-M Peach Bottom model used here consisted of 67 components. The reactor was modeled using the vessel component with 4 radial rings and 14 axial levels. Fuel assemblies were mapped into 33 thermal-hydraulic channels as shown in the Figure 1 in which the numbers indicate channel number assignments of the fuel assemblies and ‘0’ corresponds to the reflector region. A thermal-hydraulic channel was not assigned to the reflector so that fixed reflector properties were used as provided in the final specifications. The vessel model also used 3 SEPD components using the TRAC-BF1 mechanistic separator option. The steam line was modeled using 2 TEE components and 3 VALVE components.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
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Figure 1. Thermal Hydraulic Channel Mapping for PBTT

3.2 PARCS NEUTRONICS MODEL

The neutronics core model used in this benchmark is based on the end-of-cycle state of the Peach Bottom Unit 2. This is a BWR/4 consisting of 764 fuel assemblies and 185 control rods. At the time of the TT2 test, there were 576 7x7 and 188 8x8 fuel assembly types. All fuel assemblies have Gadolinium as a burnable poison. The PARCS model represents each of the 764 fuel assemblies as a single neutronics node. The active core height is 365.76 cm, which is modeled in PARCS with 24 axial layers. The thickness of the axial layers is 15.24 cm. At the top and bottom of the active core, there exist 15.24 cm-thick axial reflector regions. Afull core geometry was modeled for the benchmark because the core is not symmetric.

The benchmark specifications provided for 432 sets of cross sections in the fuel region and 3 sets for reflector region (bottom, top, and radial reflector). The group constants for each set consist of two kinds of macroscopic cross section data, one for rodded and one for unrodded fuel assemblies. The group constant data were provided as two data files, the first file is for unrodded compositions while the second one is for rodded compositions. Peach Bottom Unit 2 is equipped with local power range monitors (LPRM). Forty-three detector strings are provided for the in-core instrumentation with each string containing four LPRM located at four axial elevations in the core. In the cross section library, the microscopic fission cross sections are provided for the fissile material of the fission chambers, as well as the assembly detector factors, which are the ratio between the flux in the detector location and the average flux of the neutronic cell. An LPRM model was developed and implemented in PARCS to compare the calculations with the measured incore detector signals.

3.3 TRAC-M/PARCS COUPLING

TRAC-M/PARCS coupling is performed using a General Interface [Barber, 1998] which was implemented using Parallel Virtual Machine [Geist, 1994]. Overall controls of the coupled transient such as convergence checks and trip initiation are handled by TRAC-M. For fast steady state initialization, a neutronic calculation skipping strategy is used, i.e., PARCS calculation was done only once per every 20 time advances in TRAC-M. In this benchmark, the reflector nodes in PARCS are not mapped to thermal-hydraulic channels since the reflector thermal-hydraulic properties are fixed. Minor modifications were made to the GI module in order to treat the fixed reflector nodes, as well as to handle the method specified for treating the moderator bypass density correction.

4. RESULTS AND ANALYSIS

4.1 STEADY STATE RESULTS

The steady state condition was initialized with an effective multiplication factor of 1.00545. A comparison of the steady-state results predicted by TRAC-M/PARCS with measured plant data is shown in Table 2 and Figure 2. As indicated, the predicted and measured results are generally in good agreement.

A comparison of the steady-state void distribution predicted by TRAC-M/PARCS and the EPRI code RETRAN [Hornyik, 1979] is shown in Figure 3. As indicated, there is good agreement between the two results.

Table 2. Comparison of Steady-State Results with Measured Plant Data

Parameter	Measurement	TRACM/PARCS
Core Thermal Power (MWt)	2028	2028
Core Flow (kg/s)	10446	10499.7
Core Bypass Flow (kg/s)	841.68	846.5
Feedwater Flow (kg/s)	-	1009.1
Feedwater Temperature (K)	442.3	442.3
Core Inlet Enthalpy (kJ/kg)	1209	1205
Recirculation Flow (kg/s)	2871.24	2897
Steam Flow (kg/s)	-	1009.1
Core Inlet Pressure (MPa)	-	6.94
Core Outlet Pressure (MPa)	-	6.83
Core Pressure Drop (MPa)	-	0.11
Steam Dome Pressure (MPa)	6.80	6.80
Average Core Exit Void Fraction	-	65.2
Core Average Void Fraction	-	32.0
Subcooling (K)	9.86	10.24
Core Exit Quality	0.097	0.0985
Keff	-	1.00545

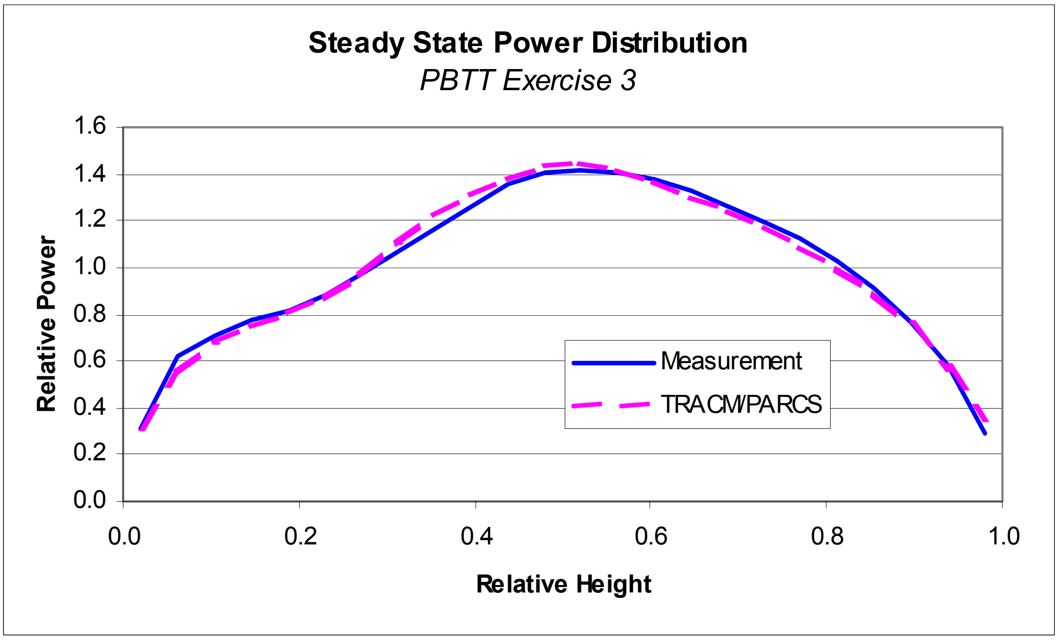

Figure 2. Comparison of Measured and Predicted Axial Power Distribution

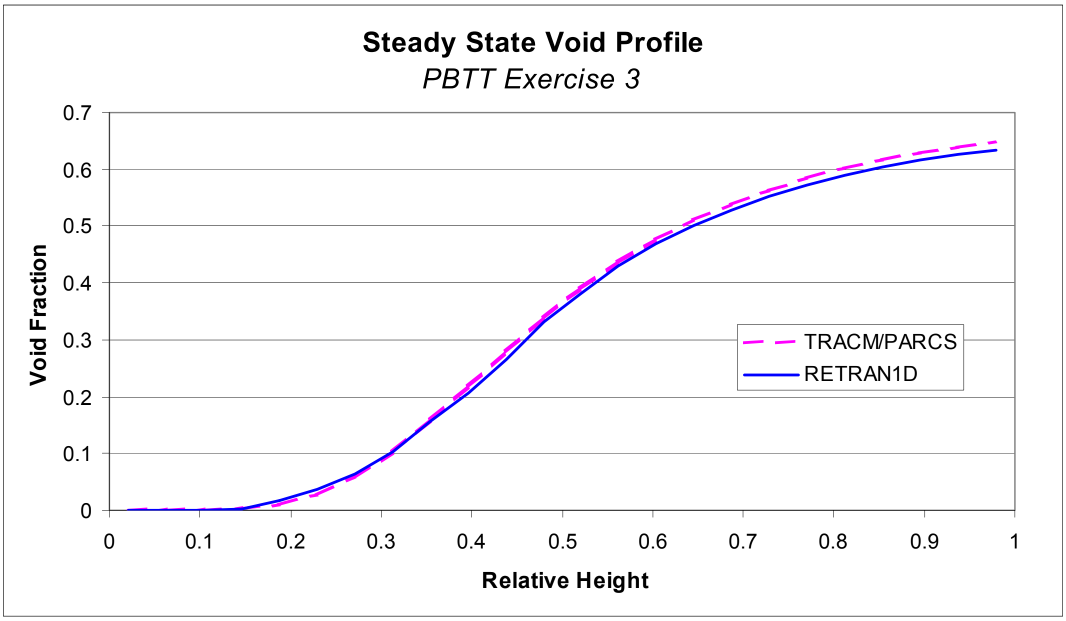

Figure 3. Comparison of Void Distribution Predicted by TRAC-M/PARCS and RETRAN

4.2 TRANSIENT RESULTS

The timing of the transient events predicted by TRAC-M/PARCS is compared to the reported timing of the events in Table 3. The prediction of the dome and core exit response in TRAC-M/PARCS is well matched with the measurements.

Table 3. Comparison of Predicted and Measured Time of Transient Events

Events	TRACM/PARCS	Measured
Turbine Stop Valve	0.090	0.096
Bypass Valve Beginning to Open	0.060	0.060
Bypass Valve Full Open	0.846	0.846
Dome Initial Response	0.444	0.432
Core Exit Inittial Response	0.490	0.486

The steam dome pressure predicted by TRAC-M during the transient is compared to the measured pressure in Figure 4. After a slight delay the pressure wave reaches the core and results in a decrease in the core average void fraction from 32% to 29% as shown in Figure 5. The void collapse in the core leads to an axial redistribution of the power as shown in Figure 6.

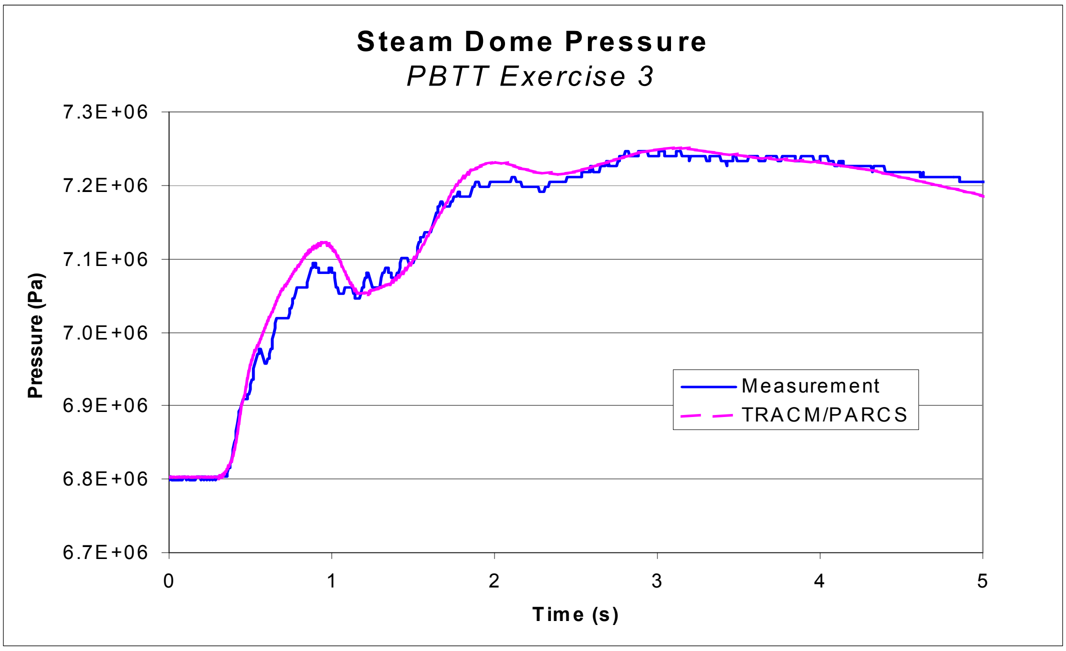

Figure 4. Comparison of Predicted and Measured Steam Dome Pressure During the Transient

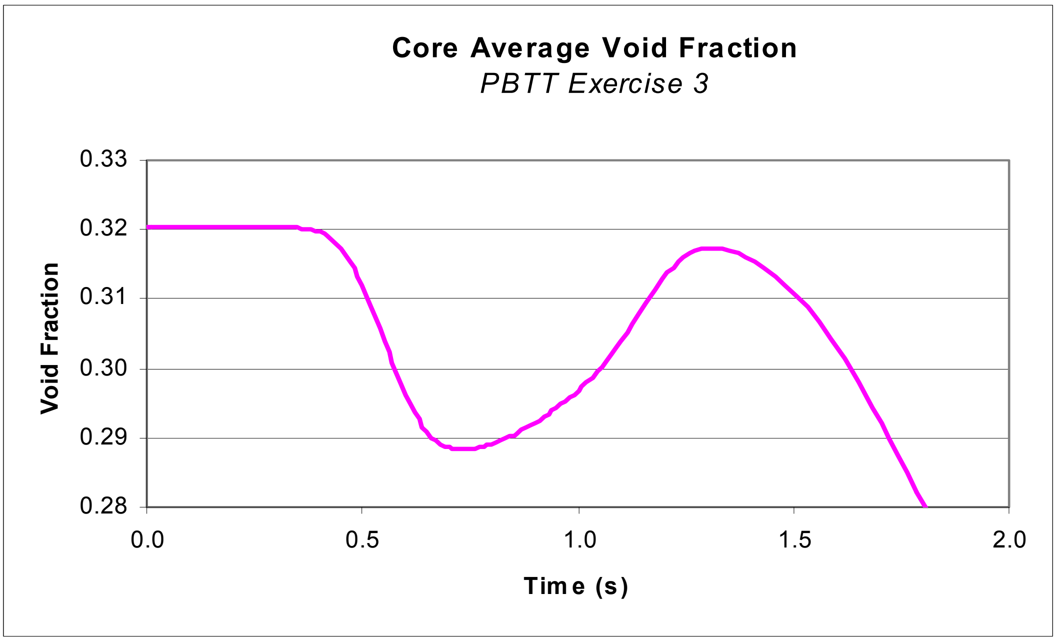

Figure 5. Core Average Void Fraction During the Transient Predicted by TRAC-M/PARCS

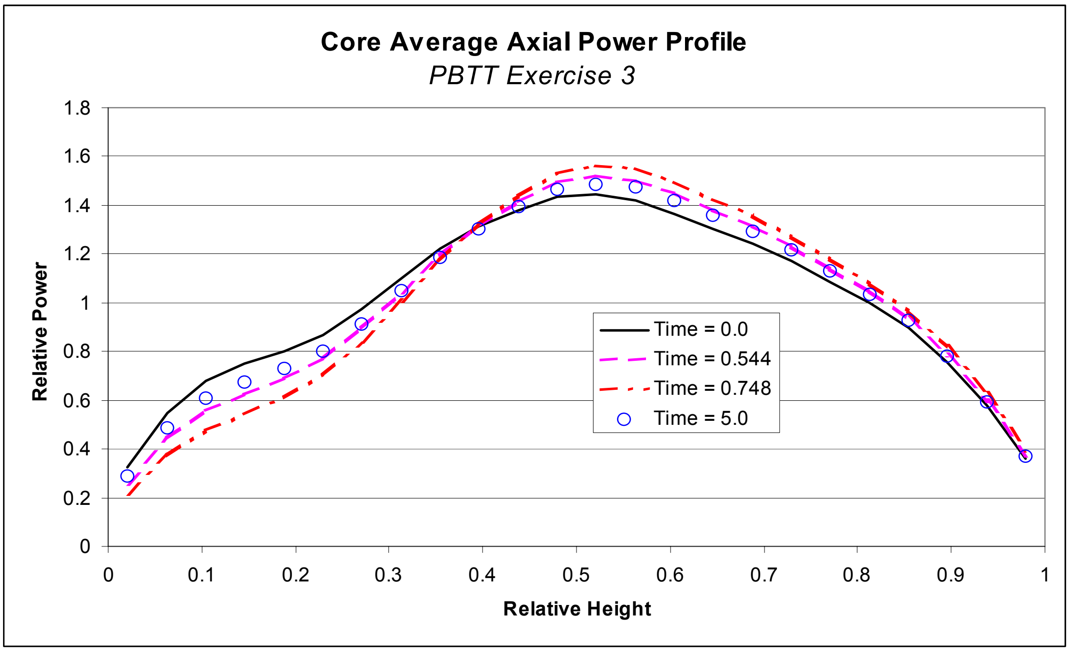

Figure 6. Core Average Axial Power Predicted by TRAC-M/PARCS During the Transient

The core void collapse results in a positive reactivity insertion as shown in Figure 7. The power increase resulting from the positive void reactivity results in an instantaneous negative reactivity from the Doppler reactivity feedback. The transient is terminated with the insertion of the control rods at about 0.8 seconds as shown in Figure 7. The total reactivity predicted by TRAC-M/PARCS is compared to the measured core reactivity in Figure 8.

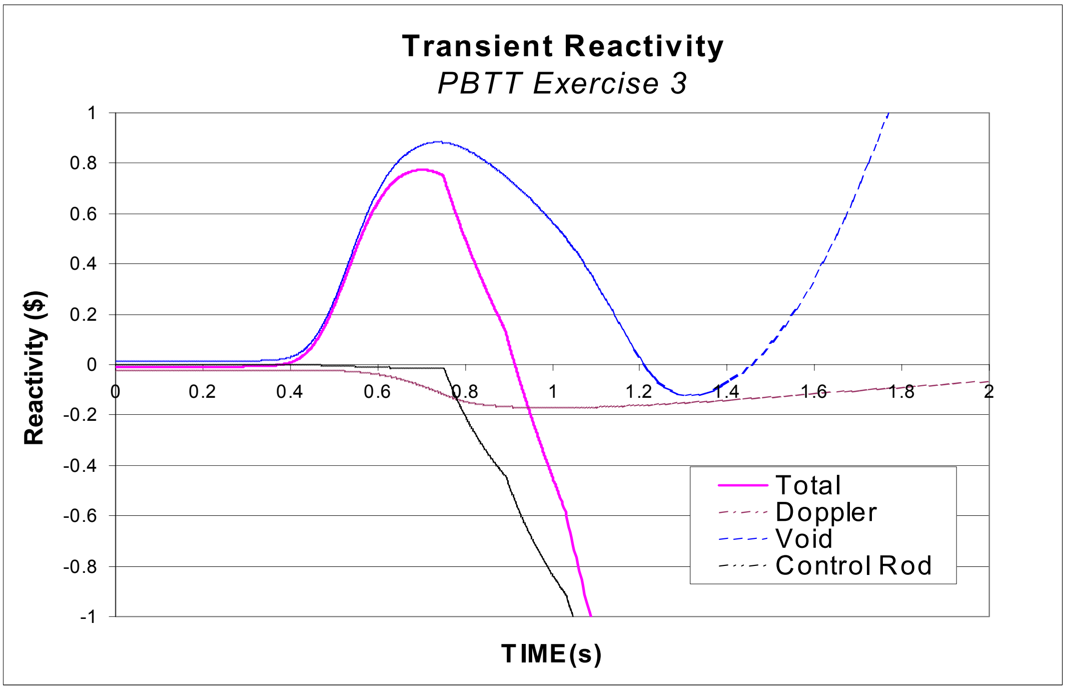

Figure 7. Components of Core Reactivity Predicted by TRAC-M/PARCS

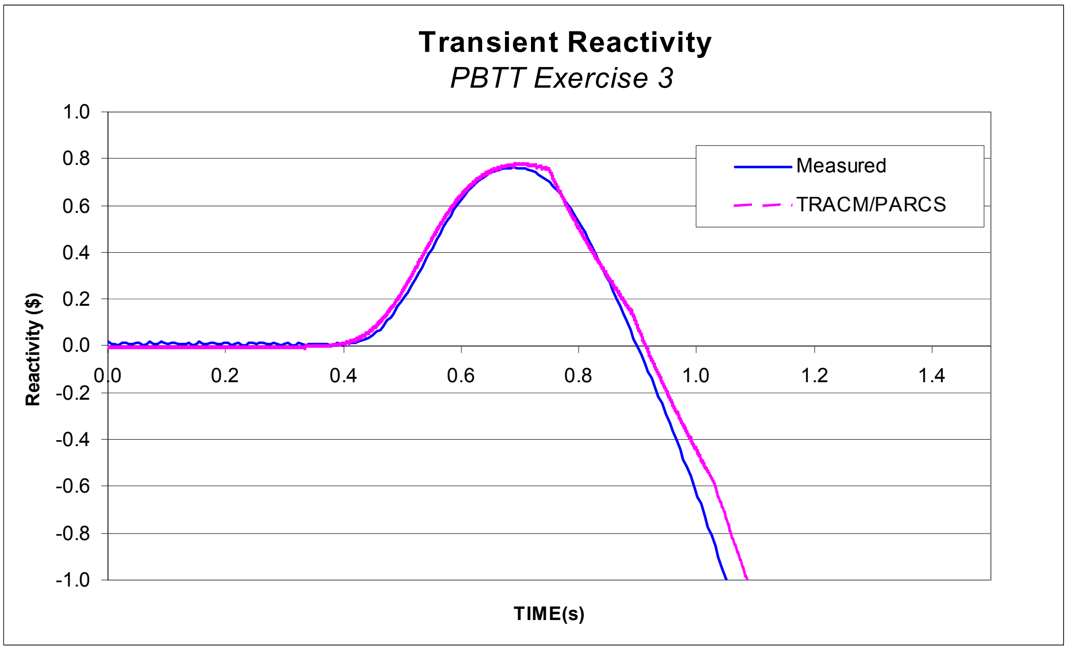

Figure 8. Comparison of Measured and Predicted Total Core Reactivity

The core power response predicted by TRAC-M/PARCS during the transient is compared to the measured power in Figure 8. As indicated, the predicted power response is slightly higher and slightly delayed (22ms) compared to the measured values.

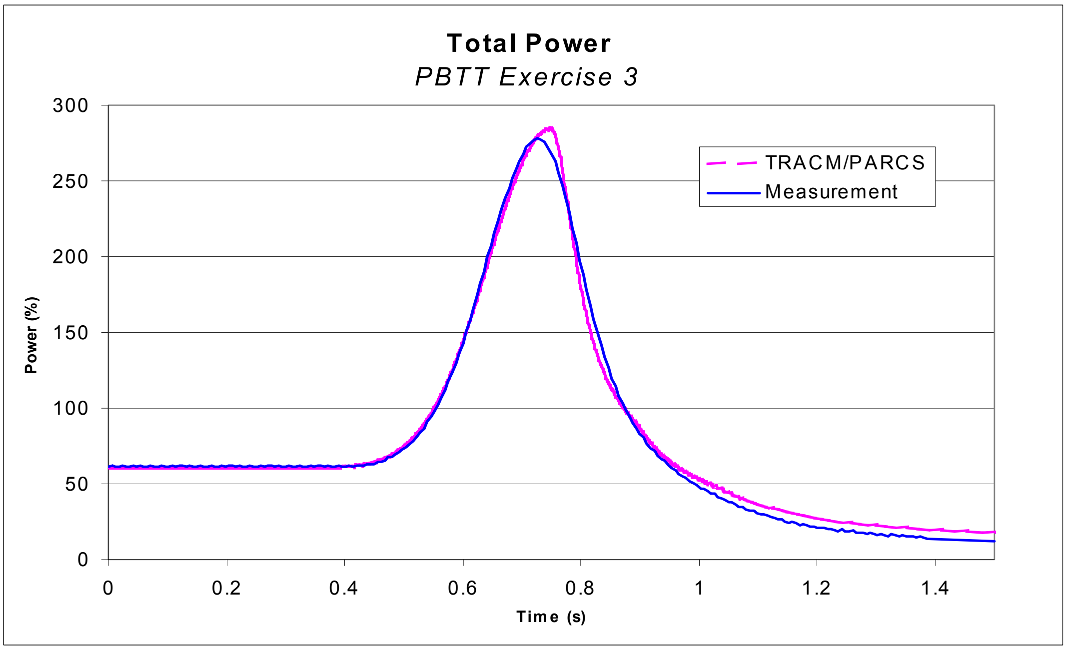

Figure 9. Comparison of Measured and Predicted Total Core Power

The measured data is provided by the core LPRM detectors which are placed at four axial locations A, B, C, and D corresponding to 18, 54, 90, and 126 inches above the bottom of the fuel assembly, respectively. During the turbine trip experiment, there were 20 LPRMs at each axial level and a total of 80 operational LPRMs in the core. The LPRM response was simulated in TRAC-M/PARCS using the predicted thermal flux at the corner of the four fuel assemblies in the LPRM location. The predicted and measured LPRM responses are summarized in Table 4 and Figure 10. As indicated in the Table, there is a slight delay in the time of the peak power at each axial location predicted by TRAC-M/PARCS which corresponds to the propagation of the pressure wave through the core.

Table 4. Summary of Predicted and Measured LPRM Responses at the Peak Power

LPRM		Core Average	Level A	Level B	Level C	Level D
Measurement	Peak	278.2	94.7	182.8	207.2	130.5
	Time (s)	0.726	0.727	0.727	0.727	0.727
TRACM/PARCS	Peak	284.3	93.1	212.0	224.7	130.3
	Time (s)	0.748	0.750	0.749	0.747	0.745

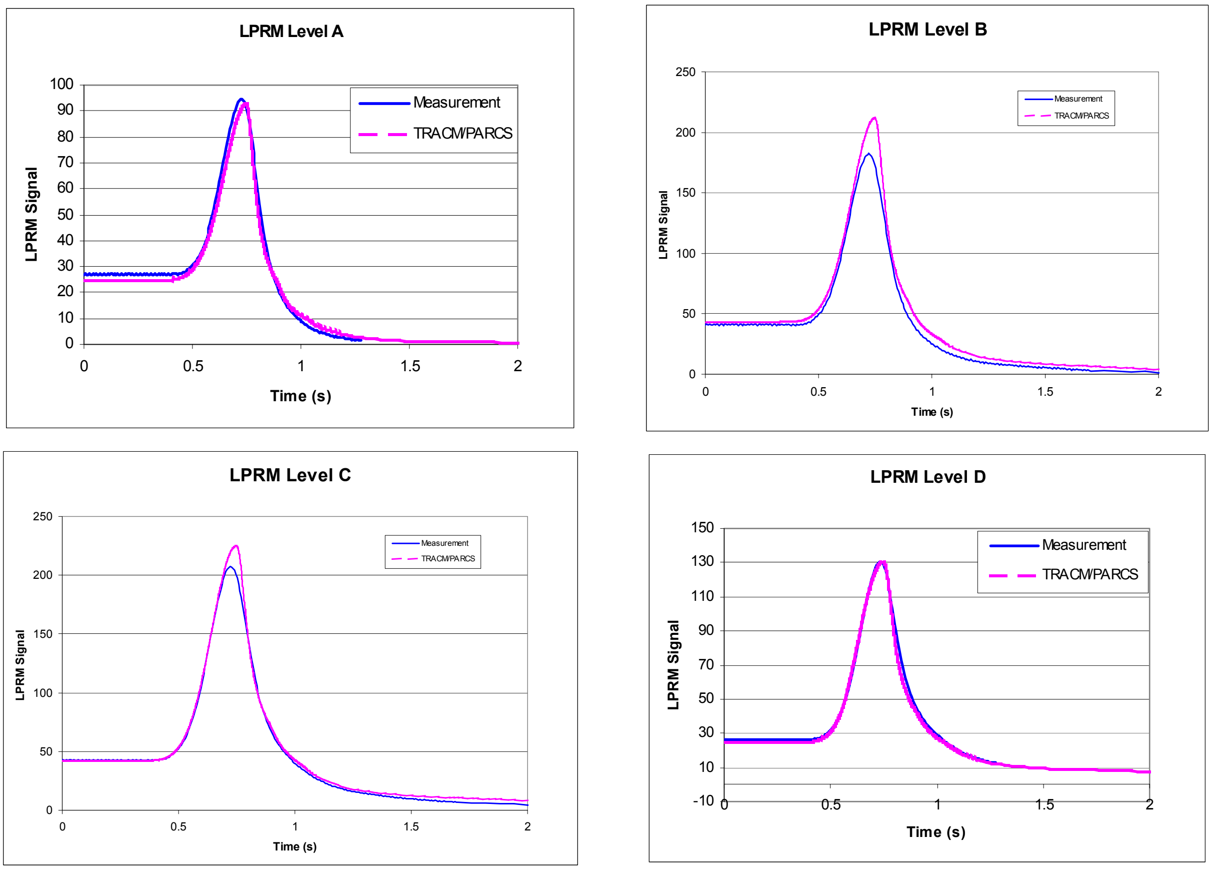

Figure 10. Comparison of Measured and Predicted LPRM Responses at Each Axial Core Location

4.3 EXTREME SCENARIO: NO BYPASS VALVE OPENING AND NO SCRAM

The specifications of the Peach Bottom Turbine Trip Benchmark provided for “extreme scenarios” which went beyond the actual experimental data. These scenarios provided a basis for Code to Code comparisons in more extreme transient conditions. The results shown here are for the extreme scenario in which the bypass valve was not opened after the turbine trip and the reactor was not scrammed. The peak reactivity during the extreme scenario increased to 0.915\$ and the peak core power response increased to about 550% as shown in Figure 11.

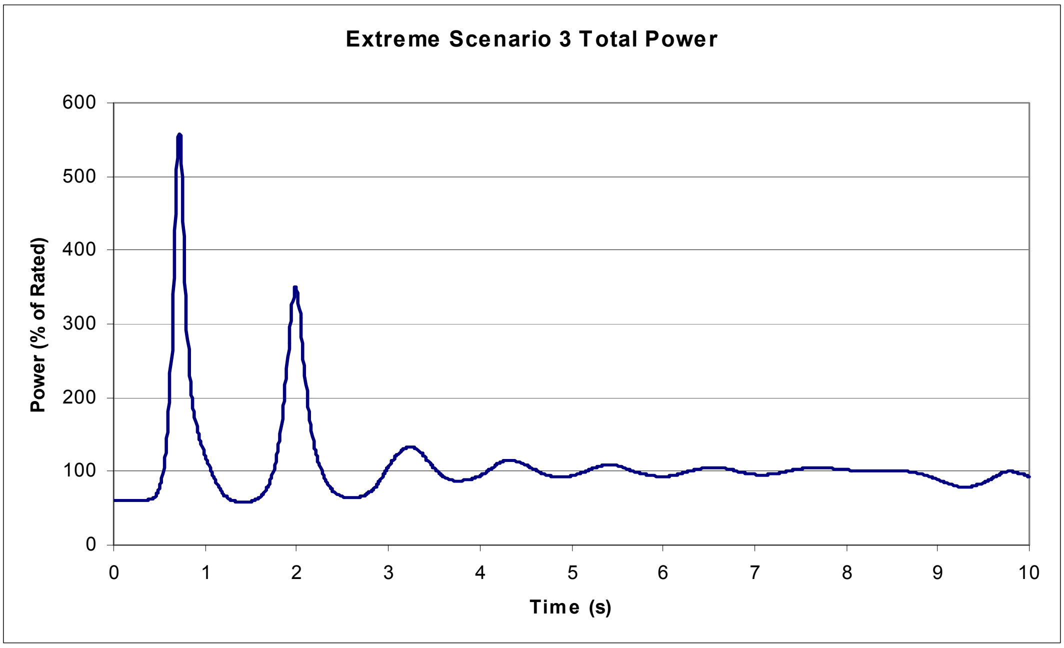

Figure 11 Predicted Core Power Response for Extreme Scenario 3

5. SUMMARY AND CONCLUSIONS

An analysis of the Peach Bottom Turbine Trip 2 experiment using TRAC-M/PARCS was presented in this paper. A PARCS neutronics model and a TRAC-M thermal–hydraulics model were developed to model the Peach Bottom reactor and applied to the turbine trip experiment using the benchmark specifications. Overall, the TRAC-M/PARCS results agreed well with both static and transient core data. Some model deficiencies were identified during the course of this work in both TRAC-M and PARCS which will require continuing work. These include the Steam Separator, Critical Flow, and Level Tracking models in TRAC-M, as well as some of the numerical convergence models in PARCS. Future work will include both neutronics and thermal-hydraulics sensitivity studies.

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