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The FSAR Transients Analysis of Lungmen ABWR Using TRACE/PARCS

Prepared by:
Jong-Rong Wang, Hao-Tzu Lin, Chia-Ying Chang*, Chunkuan Shih*

Institute of Nuclear Energy Research, Atomic Energy Council, R.O.C.
1000, Wenhua Rd., Chiaan Village, Lungtan, Taoyuan, 325, TAIWAN

*Institute of Nuclear Engineering and Science, National Tsing Hua University,
101 Section 2, Kuang Fu Rd., Hsinchu, TAIWAN

K. Tien, NRC Project Manager

Division of Systems Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
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ABSTRACT

This study consists of two steps. The first step is the development of a TRACE (TRAC/RELAP Advanced Computational Engine)/PARCS(Purdue Advanced Reactor Core Simulator) model of Lungmen nuclear power plant (NPP) which includes the vessel, reactor internal pumps (RIPs), main steam lines, and important control systems (such as the feedwater control system, steam bypass & pressure control system, and recirculation flow control system), etc.. Key parameters are identified to refine the TRACE/PARCS model further in the frame of a steady state analysis. The second step is the performance of Lungmen NPP TRACE/PARCS model transient analyses. The transient data of Final Safety Analysis Report (FSAR) chapter 15th are used to compare with the analysis results of the Lungmen NPP TRACE/PARCS model. The trends of TRACE/PARCS analysis results are consistent with the FSAR data for the important parameters. However, there are some difference in their bypass valve flow response, scram reactivity and void reactivity.

FOREWORD

The US NRC (United States Nuclear Regulatory Commission) is developing an advanced thermal hydraulic code named TRACE for nuclear power plant safety analysis. The development of TRACE is based on TRAC, integrating RELAP5 and other programs. NRC has determined that in the future, TRACE will be the main code used in thermal hydraulic safety analysis, and no further development of other thermal hydraulic codes such as RELAP5 and TRAC will be continued. A graphic user interface program, SNAP (Symbolic Nuclear Analysis Program) which processes inputs and outputs for TRACE is also under development. One of the features of TRACE is its capacity to model the reactor vessel with 3-D geometry. It can support a more accurate and detailed safety analysis of nuclear power plants. TRACE has a greater simulation capability than the other old codes, especially for events like LOCA.

Taiwan and the United States have signed an agreement on CAMP (Code Applications and Maintenance Program) which includes the development and maintenance of TRACE. INER (Institute of Nuclear Energy Research, Atomic Energy Council, R.O.C.) is the organization in Taiwan responsible for the application of TRACE in thermal hydraulic safety analysis, for recording user’s experiences of it, and providing suggestions for its development. To meet this responsibility, the TRACE/PARCS model of Lungmen NPP has been built. In this report, the FSAR transient data of Lungmen NPP is utilized and conducted to confirm the accuracy of the TRACE/PARCS model.

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FIGURES
(Continued)

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EXECUTIVE SUMMARY

An agreement in 2004 which includes the development and maintenance of TRACE has been signed between Taiwan and USA on CAMP. INER is the organization in Taiwan responsible for applying TRACE to thermal hydraulic safety analysis in order to provide users' experiences and development suggestions. To fulfill this responsibility, the TRACE/PARCS model of Lungmen NPP is developed by INER.

According to the user manual, TRACE is the product of a long term effort to combine the capabilities of the NRC's four main systems codes (TRAC-P, TRAC-B, RELAP5 and RAMONA) into one modernized computational tool. NRC has ensured that TRACE will be the main code used in thermal hydraulic safety analysis in the future without further development of other thermal hydraulic codes, such as RELAP5 and TRAC. Besides, the 3-D geometry model of reactor vessel, which is one of the representative features of TRACE, can support a more accurate and detailed safety analysis of NPPs. On the whole TRACE provides greater simulation capability than the previous codes, especially for events like LOCA.

PARCS is a multi-dimensional reactor core simulator which involves a 3-D calculation model for the realistic representation of the physical reactor while 1-D modeling features are also available. PARCS is capable of coupling the thermal-hydraulics system codes such as TRACE directly, which provide the temperature and flow field data for PARCS during the calculations.

Lungmen NPP is the first ABWR plant in Taiwan and still under construction. It has two identical units with 3,926 MWt rated thermal power each and 52.2×10^6 kg/hr rated core flow. The core has 872 bundles of GE14 fuel, and the steam flow is 7.637×10^6 kg/hr at rated power. There are 10 RIPs in the reactor vessel, providing 111% rated core flow at the nominal operating speed of 151.84 rad/sec. This research focuses on the development of the Lungmen NPP TRACE/PARCS model. The transient data from FSAR have been used to compare with the analysis results of the Lungmen NPP TRACE/PARCS model. The trends of TRACE/PARCS analysis results are similar to the FSAR data for the important parameters. However, there are some difference in their bypass valve flow response, scram reactivity and void reactivity. Therefore, the above difference will be checked with the startup tests data. The startup tests of Lungmen NPP will be performed in 2014 and the measured data of Lungmen NPP will be used to estimate and modify the TRACE/PARCS model of Lungmen NPP in the future.

ABBREVIATIONS

CAMP	Code Applications and Maintenance Program
FSAR	Final safety analysis report
INER	Institute of Nuclear Energy Research Atomic Energy Council, R.O.C.
LOCA	Loss Of Coolant Accident
LOFW	Loss of Feedwater Flow Transient
LRNB	Load Rejection with Failure of All Bypass Valves transient
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRWL	Narrow Range Water Level
RIPs	Reactor Internal Pumps
SNAP	Symbolic Nuclear Analysis Program
TCVs	Turbine Control Valves
TPC	Taiwan Power Company
TRACE	TRAC/RELAP Advanced Computational Engine
TTNB	Turbine Trip with failure of all Bypass valve transient
TTWB	Turbine Trip with Bypass valve transient
US	United States

1. INTRODUCTION

The safety analysis of the NPP is very important work. After the Fukushima NPP event occurred, further concerns over the safety of the NPPs in the world have been raised. The development of computer programs related to NPP safety analysis is one of the main research and development work in the nuclear engineering. One of the advanced thermal hydraulic codes named TRACE has been developed by U.S. NRC for NPP safety analysis. The development of TRACE is based on TRAC, combining with the capabilities of RELAP5 and other programs. In the future, TRACE will be the main code used in thermal hydraulic safety analysis and will replace NRC's present four main systems codes (TRAC-P, TRAC-B, RELAP5 and RAMONA) [1]. Besides, a graphic user interface program, SNAP, which processes inputs, outputs, and the animation model for TRACE, has also been developing. One of the features of TRACE is its capacity to model the reactor vessel with 3-D geometry. It could support a more accurate and detailed safety analysis for nuclear power plants. PARCS is a multi-dimensional reactor core simulator which involves a 3-D calculation model for the realistic representation of the physical reactor while 1-D modeling features are also available. PARCS is capable of coupling the thermal-hydraulics system codes such as TRACE directly, which provide the temperature and flow field data for PARCS during the calculations.

An increasing number of researchers are using TRACE code to analyze the transients of facilities and NPPs. In 2008, Barten et al. published the paper [2] which described the development of a TRACE model for the UMSICHT water hammer experiments. Their TRACE model analysis results showed agreement with experimental data. Xu et al. [3] used TRACE/PARCS to perform the validation work of the stability analysis of Ringhals. Their results showed agreement with the Ringhals data. Gallardo et al. [4] established the TRACE model of a Large-Scale Test Facility, and confirmed its accuracy against data on small-break loss of coolant accidents.

In 2004, the authorities of Taiwan and the United States signed an agreement on CAMP which included the development and maintenance of TRACE. INER is the organization in Taiwan in charge of the application of TRACE in thermal hydraulic safety analysis, including collecting users' experiences and providing suggestions for future improvement of TRACE. To meet this responsibility INER built the TRACE model of TPC (Taiwan Power Company) Maanshan PWR NPP in 2008. The detailed model description and verification can be found in INER report [5]-[7]. In previous research, the actual startup test data of Maanshan NPP were used to establish and verify the Maanshan NPP TRACE model. The results of verification demonstrate that the model has quite good accuracy. Subsequently, based on the successful experience from Maanshan TRACE model, the Lungmen TRACE/PARCS model was established by referring to the FSAR data of Lungmen NPP.

Lungmen NPP is the first ABWR in Taiwan and still under construction. It has two identical units with 3,926 MWt rated thermal power each and 52.2×10^6 kg/hr rated core flow. The core has 872 bundles of GE14 fuel, and the steam flow is 7.637×10^6 kg/hr at rated power. There are 10 RIPs in the reactor vessel, providing 111% rated core flow at the nominal operating speed of 151.84 rad/sec. This research focuses on the development of the Lungmen NPP TRACE/PARCS model. The transient data from FSAR [8] have been used to compare the analysis results of Lungmen NPP TRACE/PARCS model.

2. METHODOLOGY

SNAP v 2.0.6, TRACE v 5.0p2 and PARCS 3.0 are used in this research. The research process is shown in Figure 1. First, the system and operating data [8]-[14] for the FSAR cases of Lungmen NPP are collected. Second, several important control systems such as RIPs control system, steam bypass and pressure control system and feedwater control system etc. are established by SNAP and TRACE. Third, other necessary components (e.g., reactor pressure vessel and main steam piping) are added into the TRACE model to complete the TRACE model for Lungmen NPP. Fourth, CASMO-4 is used to carry out the lattice calculations. CASMO-4 data are employed to establish the PARCS model. Then, the Lungmen TRACE model is coupling with the PARCS model. Finally, the analysis results of the Lungmen TRACE/PARCS model are compared by the FSAR data under the steady state and transient conditions. Additionally, the startup tests of Lungmen NPP will be performed in 2014 and the measured data of Lungmen NPP will be used to estimate and modify the TRACE/PARCS model of Lungmen NPP.

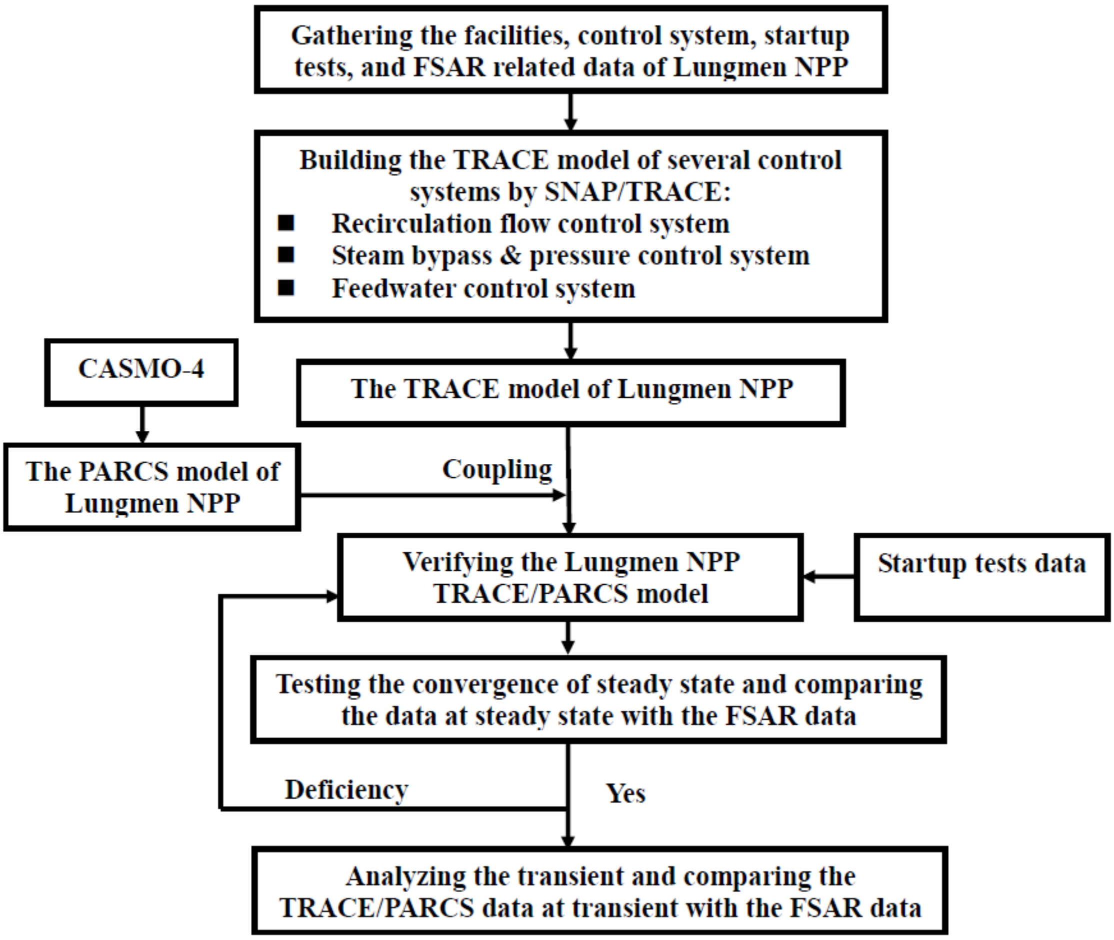


Figure 1   The methodology of Lungmen NPP TRACE/PARCS model

3. TRACE/PARCS MODELING OF LUNGMEN NPP

The TRACE/PARCS model of Lungmen NPP is shown in Figure 2. In this model, the vessel is divided into 11 axial levels, four radial rings, and six azimuthal sectors (separated 36°, 36°, 108°, 36°, 36°, and 108° apart), and connected with four steam lines (connected to the 36° azimuthal sector of the vessel), six feedwater lines (connected to six azimuthal sectors separately, one for each sector), 18 channels which are used to simulate the fuel region (one for each azimuthal sector in three inner radial rings), and 10 RIPs (connected to six azimuthal sectors separately, one for every 36°). The water rods and partial leng th rods are also simulated in the channels (shown in Figure 3) and each channel component multiple some bundles (30 bundles × 6 + 40 bundles × 6 + 75 bundles × 4 + 76 bundles × 2 = 872 bundles). Besides, each steam line has one MSIV and several SRVs. The 10 RIPs are classified into three groups, three RIPs for the first group, another three for the second, and the remaining four RIPs for the third group. The RIPs in the third group are not connected to the motor generator (M/G) set while the other six RIPs are connected to the M/G set.

Before the transient calculation of Lungmen TRACE/PARCS model begins, it is necessary to carry out the steady state calculation to make sure that the system parameters are consistent with those from FSAR [8]-[9]. These system parameters include feedwater flow rates, steam flow rates, NRWL (Narrow Range Water Level), vessel dome pressure, etc. Table 1 shows the comparison of steady state simulations between the results from FSAR and TRACE. It can be seen that the TRACE/PARCS results agree well with FSAR data. The differences of the steady state results between TRACE/PARCS and FSAR are caused by the different calculation procedures, phenomenological modelings, and nodalizations.

ODYN is the GE transient analysis tool which is used in the FSAR, where the one-dimensional neutron kinetics and thermal hydraulic simulation of the reactor core are performed. The overall ODYN model consists of one reactor vessel, one steamline, RIP control system, feedwater control system, and liquid control system, etc.

A comparison of TRACE/PARCS and ODYN models of Lungmen NPP shows that the main differences among simulations of TRACE/PARCS and FSAR are in the RPV and main steam lines (shown in Table 2). The RPV of Lungmen NPP TRACE/PARCS model is composed of only one component (vessel, 3-D component). However, only one one-dimensional vessel component is used to simulate the RPV of Lungmen NPP ODYN model, considering the axial direction of the RPV only. As for steam lines, there are four separate steam lines in Lungmen NPP TRACE model, which is identical to those in Lungmen NPP. However, these four steam lines are lumped to one steam line in Lungmen NPP ODYN models.

Besides, a one-dimensional kinetic model and neutronics data are used for power calculations in Lungmen NPP ODYN model, while in Lungmen NPP TRACE/PARCS model, the neutronics model is three-dimensional model. The TRACE/PARCS neutronics model is comprised of 872 assemblies with a rated power of 3926 MWt, and 205 control rods are simulated as well. Each fuel assembly is represented by a single neutronics node. Figure 4 shows the assembly rotations map in the PARCS model. The control rod pattern is divided into four groups as shown in Figure 5.

In addition, the animation of Lungmen NPP TRACE/PARCS model is presented using the animation function of SNAP/TRACE/PARCS with above models and TRACE/PARCS analysis results. The Lungmen NPP animation model is shown in Figure 6.

Table 1 The comparison of initial conditions between FSAR and TRACE/PARCS

Parameters	FSAR	TRACE /PARCS	Difference (%)
Power (Mwt)	3926	3926	0
Dome pressure (MPa)	7.1705	7.1244	-0.65
Narrow range water level (m)	1.19	1.19	0
Steam flow (kg/sec)	2122	2113	-0.4
Feedwater flow (kg/sec)	2122	2113	-0.4
Core flow(kg/sec)	12314.8	12343.6	0.2

Table 2 The comparison of Lungmen NPP ODYN model and TRACE/PARCS model

	ODYN model	TRACE/PARCS model
The simulation of RPV	One 1-D vessel component (axial)	One 3-D vessel component
The simulation of main steam lines	Four main steam lines lumped to one main steam line	Four main steam lines
Lattice code	TGBLA	CASMO-4
The calculation of power	One-dimensional kinetic model	3-D kinetic model
Fluid field equations	Five equations	Six equations
Animation function	No	Yes

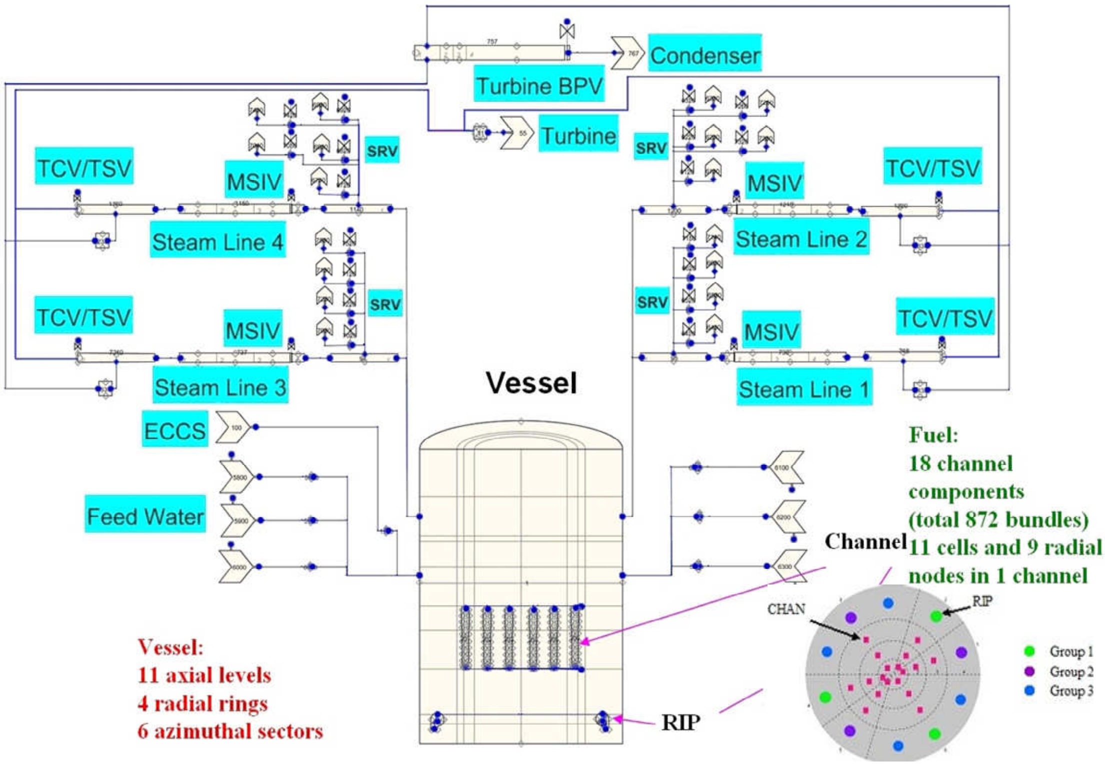


Figure 2 The TRACE/PARCS model of Lungmen NPP

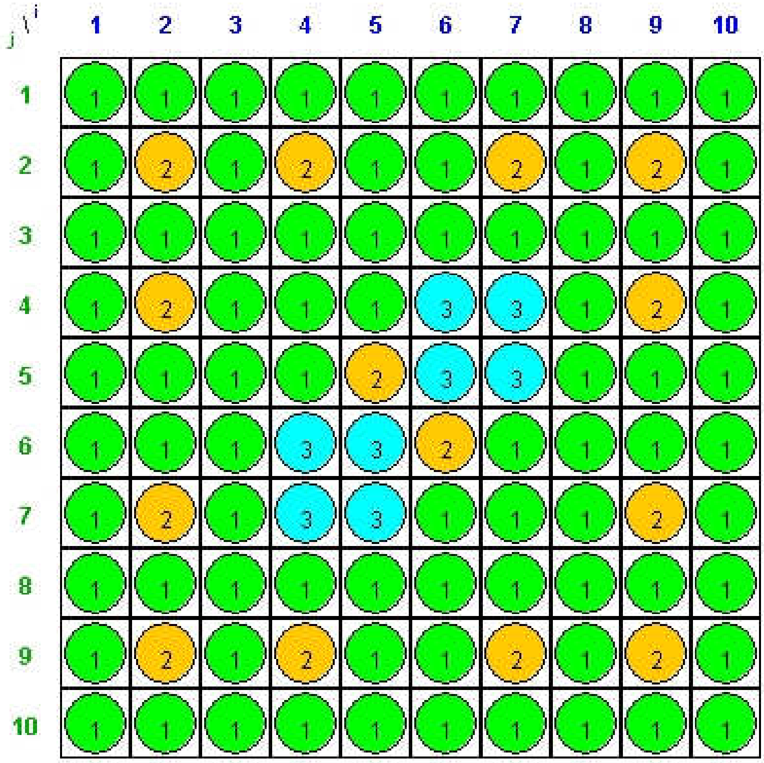
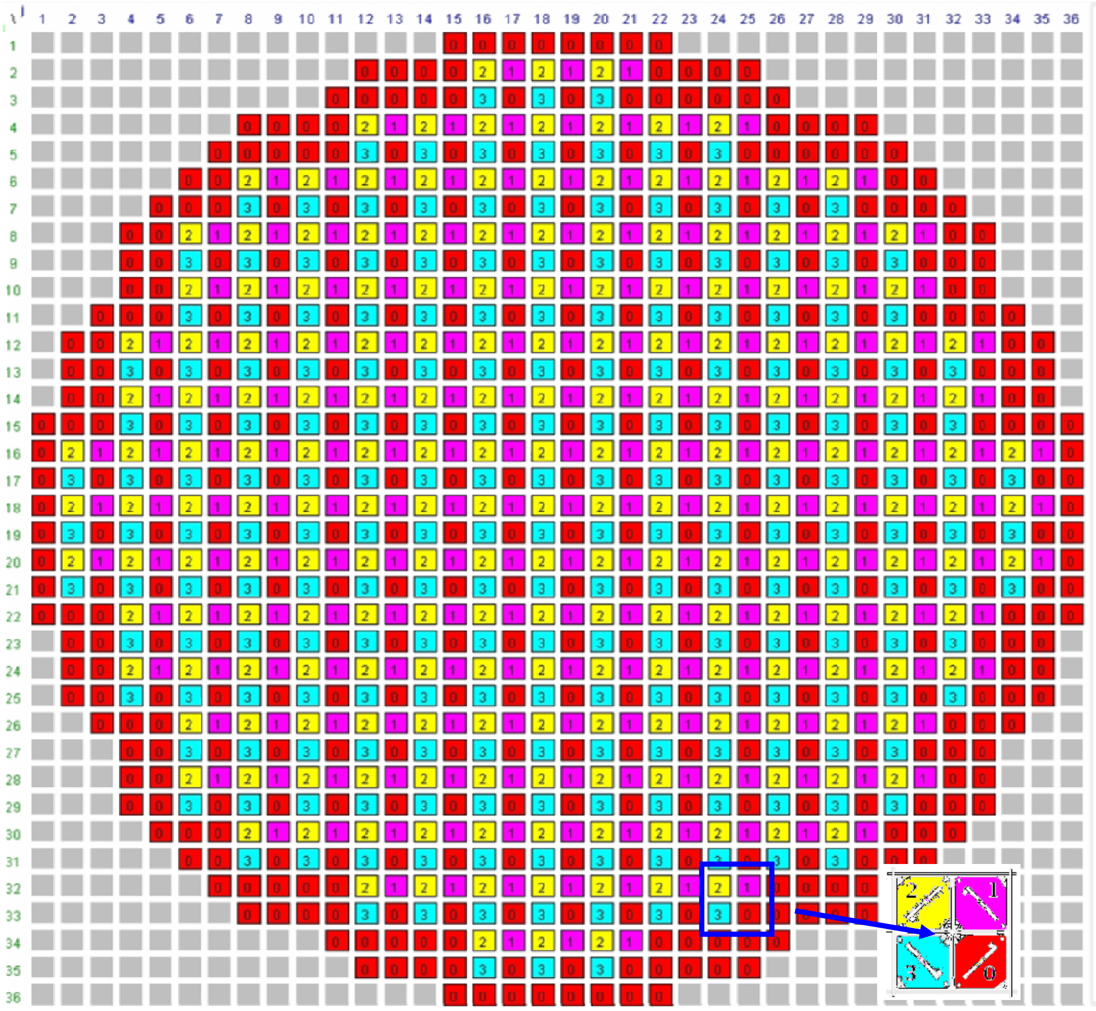
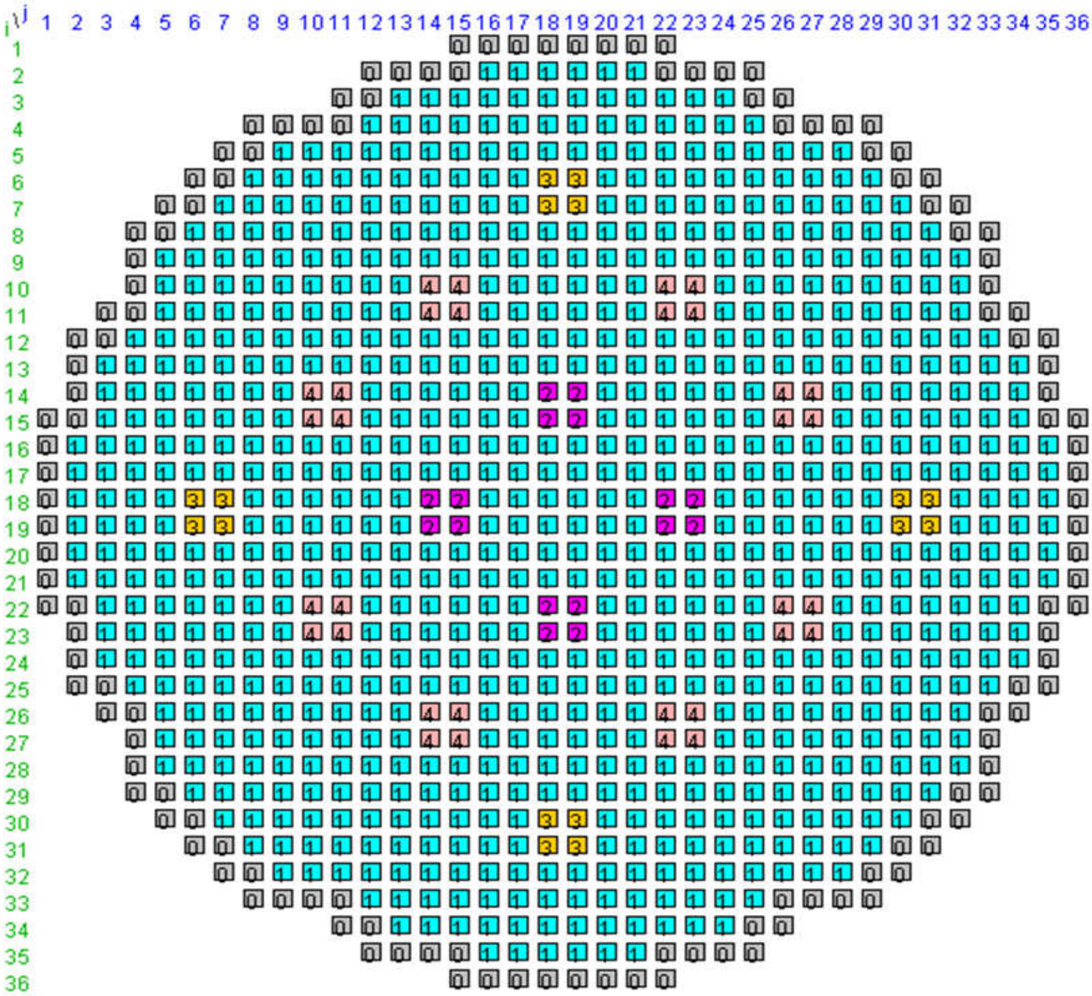


Figure 3 The simulation of the TRACE Channel component (cross-section):
1. full length fuel rod, 2. partial length fuel rod, 3. water rod



Group	assembly rotations
0	rotate assembly 0° anti-clock wise
1	rotate assembly 90° anti-clock wise
2	rotate assembly 180° anti-clock wise
3	rotate assembly 270° anti-clock wise

Figure 4 The assembly rotations map in the PARCS model



Group	Control rod bank (steps)
1	200
2	58
3	117
4	83

0: one control rod all in

200: one control rod all out

0	Reflector region

Figure 5 The control rod map in the PARCS model

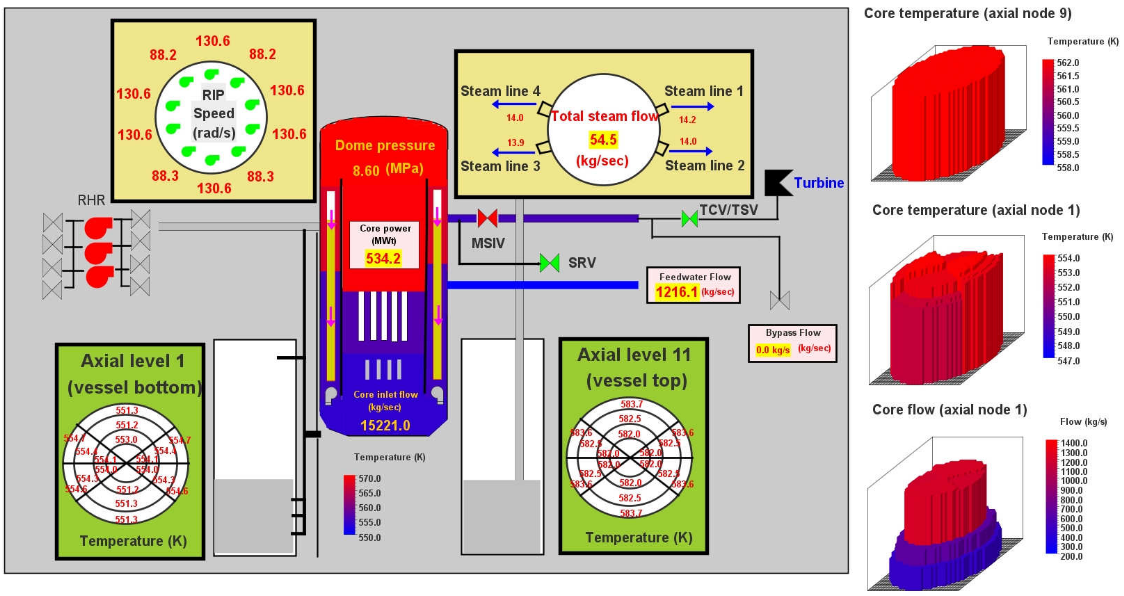


Figure 6 The animation model of Lungmen NPP

4. RESULTS AND DISCUSSIONS

4.1. Turbine Trip with Bypass Valve Transient (TTWB)

In order to verify the dynamic response of the Lungmen NPP TRACE/PARCS model and demonstrate the bypass valve capability of this model to withstand a turbine trip without scram, the TTWB is chosen to check this model. In this transient, turbine stop valve (TSV) closure initiates signals for a reactor scram and four RIPs trip via TSV position signals. However, these signals are purposely delayed to allow time for bypass valve operation verification. Verification of fast opening of all bypass valves inhibits reactor scram and four RIPs trip. The initial condition of TTWB transient is 100% rated power/100% rated core flow.

Table 3 shows the TTWB sequences of FSAR and TRACE/PARCS. Their time series are the same. When Main turbine stop valves reach 85% open position, bypass operation signal is verified. Then, the reactor scram and four RIPs trip are inhibited. Figure 7 depicts the neutron flux curves of FSAR and TRACE/PARCS. The result of TRACE/PARCS is consistent with FSAR data. Figure 8 compares the steam dome pressure rise of FSAR and TRACE/PARCS. The trends of the curves are approximately in agreement. Figure 7 and 8 also shows the peaks of TRACE/PARCS are higher than FSAR. It may be caused by the difference of the bypass valve flow and steam flow between the TRACE/PARCS and FSAR (see Figure 9 and 10). Both the bypass valve flow and steam flow of TRACE/PARCS are smaller than FSAR's results before 1 sec; therefore, the dome pressure of TRACE/ PARCS is higher than FSAR's data. Due to the higher dome pressure in the TRACE/PARCS result, it indicates that the core void fraction of TRACE/PARCS is smaller than FSAR. The smaller core void fraction results in the neutron flux of TRACE/PARCS higher than FSAR. By comparing the above Figures, it also depicts that there are some oscillations in the FSAR's results, which indicates that the system response of the TRACE/PARCS model is less sensitive than FSAR. On the comparison of the other parameters (such as the feedwater flow, core flow, narrow range water level, etc.), the trends of FSAR and TRACE/PARCS are also similar. In summary, the bypass valve performance and important parameters (eq. dome pressurs, steam flow, feedwater flow, etc.) can be observed at a satisfactory value in the TRACE/PARCS model. It indicates that there is the reasonable dynamic response of the Lungmen NPP TRACE/PARCS model in the TTWB.

4.2. Turbine Trip with Failure of All Bypass Valve Transient (TTNB)

In order to demonstrate the scram, relief valves and RIPs trip capability of this model, the TTNB is chosen to check this model. The initial condition of TTNB transient is 100% rated power / 85% rated core flow. In this transient, the TSV closure initiates signals for a reactor scram and four RIPs trip via TSV position signals. Subsequently, the relief valves are activated.

Table 4 compares the TTNB sequences of FSAR with TRACE/PARCS. Their sequences approximately are the same. Figure 11 shows the neutron flux curves of FSAR and TRACE/PARCS. The result of TRACE/PARCS is similar to FSAR's result. The increase of the neutron flux is caused by the TSVs closing. The TSVs closing decreases the reactor's void which generates the positive reactivity. Then, the scram initiates and the neutron flux drops. Figure 11 also depicts the time of TRACE/PARCS in the neutron flux dropped earlier than FSAR data, which may result from the difference of the scram reactivity between TRACE/PARCS and FSAR. Figure 12 shows the scram reactivity results of FSAR and TRACE/PARCS. FSAR may be using different insertion deep of control rod motion speed; nevertheless, TRACE/PARCS is using a fixed motion speed of the control rod insertion. TRACE/PARCS scram curve may not be totally consistent with FSAR data. The Doppler reactivity is shown in Figure 13. The trend of

TRACE/PARCS curve is similar to FSAR curve. However, in the void reactivity, their curves are not in agreement (see Figure 14). The difference on the calculation of void fraction of TRACE/PARCS and FSAR may result in the difference of void reactivity. Figure 15 compares the steam dome pressure of FSAR and TRACE/PARCS. The trends of the curves are approximately in agreement. The TSV closing causes the dome pressure to rise. Then, relief valves open and lead to the decline of dome pressure. The dome pressure of TRACE/PARCS is smaller than FSAR data after 3 sec. The above result is caused by the difference of the neutron flux between TRACE/PARCS and FSAR. The neutron flux of TRACE/PARCS drops earlier than FSAR data. It indicates that the steam generated amount of TRACE/PARCS is less than of FSAR, which makes the dome pressure of TRACE/PARCS smaller than FSAR data after 3 sec. Besides, the dome pressure decreases after 3 sec which indicates that the core void fraction may increase. However, the feedwater flow also increases at this time which results in the larger cooler water into the core. It indicates that the core void fraction may decrease. Combining the above effects, we think that the core void fraction still decrease slower after 3 sec which cause the void reactivity also rises slower. The TRACE/PARCS result is consistent with this phenomenon (see Figure 14). Figure 16 shows the core inlet flow of FSAR and TRACE/PARCS. Due to the dome pressure increase, it results in the core inlet flow rising before 0.46 sec. Then, four RIPs trip causes the core inlet flow drop. On the comparison of the other parameters (such as the feedwater flow, steam flow, narrow range water level, etc.), the trends of FSAR and TRACE/PARCS are also in agreement. In summary, the scram, relief valves, and RIPs trip performance can be observed in the TRACE/PARCS model. It also indicates that there is reasonable response of the Lungmen NPP TRACE/PARCS model in the TTNB.

4.3. Load Rejection with Failure of All Bypass Valves Transient (LRNB)

In order to demonstrate the turbine control valves (TCVs) capability and the system response of this model, the LRNB is used to check this model. The initial condition of LRNB transient is 100% rated power / 85% rated core flow. In this transient, fast closure of the TCVs is initiated whenever electrical grid disturbances which result in significant loss of electrical load on the generator occur. The TCVs are required to be closed as soon as possible to prevent the excessive overspeed of the turbine-generator (T-G) rotor from happening. The closure of the main TCVs may cause a sudden reduction in turbine steam flow, which results in an increase in system pressure if bypass valves fail to open. Then, in order to protect the reactor, the reactor scram and four RIPs trip occur due to the failure of all bypass valves.

Table 5 shows the LRNB sequences of FSAR with TRACE/PARCS. The TRACE/PARCS sequence is consistent with the FSAR data. Figure 17 ~ Figure 22 show the comparisons of TRACE/PARCS and FSAR data. Figure 17 depicts the neutron flux results of FSAR and TRACE/PARCS. The curve of TRACE/PARCS is similar to FSAR’s result. The TCVs closing causes the neutron flux rise and the reactor’s void drop, then the positive reactivity generates thereby. Subsequently, the scram initiates and the neutron flux decreases. The neutron flux dropped time of the TRACE/PARCS is earlier than FSAR, which is also observed in Figure 17. The difference of the scram reactivity between TRACE/PARCS and FSAR may be the reason for the above results. Figure 18 shows the scram reactivity curves of FSAR and TRACE/PARCS. TRACE/PARCS scram curve would not be totally consistent with FSAR data due to the different motion speed of the control rod insertion between TRACE/PARCS and FSAR. Figure 19 compares the Doppler reactivity of the TRACE/PARCS and FSAR. The trend of TRACE/PARCS result is similar to the FSAR data. But their curves are not in agreement in the void reactivity (see Figure 20). The difference on the calculation of void fraction of TRACE/PARCS and FSAR may cause the different void reactivity. The steam dome pressure of FSAR and TRACE/PARCS is shown in Figure 21. Their curves are approximately in agreement. The TCVs closing makes the increase of dome pressure. Subsequently, relief valves open and lead to the decline of dome pressure. The dome pressure of TRACE/PARCS is smaller than FSAR data after 3 sec. The dome pressure decreases after 3 sec which indicates that the core void fraction may rise. But the feedwater flow also increases at this time which leads the larger cooler water into the core. It indicates that the core void fraction may decrease. Combining the above effects, we think that the core void fraction still decrease slower after 3 sec which cause the void reactivity also rises slower. The TRACE/PARCS result is similar to this phenomenon (see Figure 20). Figure 22 shows the core inlet flow curves of TRACE/PARCS and FSAR. Due to the dome pressure rise, it causes the core inlet flow rising before 0.49 sec. Then, four RIPs trip results in the decrease of the core inlet flow. On the comparison of the other parameters (such as the feedwater flow, steam flow, narrow range water level, etc.), the results of FSAR and TRACE/PARCS are also in agreement. In summary, the TCVs capability and the system response of TRACE/PARCS model can be observed in this transient. It also indicates that there is reasonable response of the Lungmen NPP TRACE/PARCS model in the LRNB.

4.4. Loss of Feedwater Flow Transient (LOFW)

A loss of feedwater flow could occur from pump failures, loss of off site power, operator errors, or reactor system variables such as a high vessel water level (L8) trip signal. The feedwater flow reduces to zero flow in 5 sec after the feedwater pumps trip. When the NRWL reaches L3, the reactor scram and four RIPs trip initiate. The initial condition of LOFW transient is 100% rated power/100% rated core flow. Besides, for the conservative consideration, the NRWL initial value of FSAR in LOFW is lower than the value (1.19 m) of the steady state (shown in Figure 23 and Table 1).

Table 6 shows the LOFW sequences of FSAR and TRACE/PARCS. The time series of their sequences are roughly similar, but the “action 3” times of TRACE/PARCS are later than that of FSAR. The NRWL initial value of TRACE/PARCS in LOFW is 1.19m. However, the NRWL initial value of FSAR in LOFW is lower than this value. Therefore, it takes longer time to reach L3 water level for TRACE/PARCS. Figure 23 also shows the NRWL dropping rate of TRACE/PARCS is consistent with the FSAR data. After the feedwater pump trip, the NRWL decreases to L3 which results in the reactor scram and the trip of four RIPs. When the water level of reactor vessel descends to L2, it causes the other six RIPs to trip (see Figure 24). Figure 25 compares the core inlet flows between FSAR and TRACE/PARCS. The trends of the curves are generally consistent, but the value of FSAR is lower than those of TRACE/PARCS due to the fact that the RIPs trip of FSAR occurred earlier. Figure 26 compares the neutron flux curves between FSAR and TRACE/PARCS. The trends of their curves are generally in agreement, but the scram of FSAR is earlier than those of TRACE/PARCS. The similar responses of TRACE/PARCS and FSAR on other parameters also can be observed in Figure 27~30. In summary, the difference of the initial NRWL value between FSAR and TRACE/PARCS causes the response time of TRACE/PARCS later than FSAR data. However, it also shows that the parameters trends of the TRACE/PARCS are similar to the FSAR data for the above results.

Table 3 The TTWB sequences of FSAR and TRACE/PARCS

Action	Time (s)	
	FSAR	TRACE/PARCS
Turbine trip initiates closure of main stop valves	0.0	0.0
Main turbine stop valves reach 85% open position	0.015	0.015
Turbine bypass valves start to open	0.02	0.02
Turbine stop valves are closed	0.1	0.1
Bypass operation signal is verified. Scram and four RIPs trip are inhibited.	Yes	Yes

Table 4 The TTNB sequences of FSAR and TRACE/PARCS

Action	Time (sec)	
	FSAR	TRACE/PARCS
Turbine trip initiated the closure of main stop valves	0	0
Turbine stop valves closed.	0.10	0.10
Scram initiated	0.175	0.175
Four RIPs tripped	0.46	0.46
Safety/relief valves opened due to high pressure	2.6	2.57

Table 5 The LRNB sequences of FSAR and TRACE/PARCS

Action	Time (sec)	
	FSAR	TRACE/PARCS
Generator Load Rejection with Failure of All Bypass Valves	0	0
Turbine control valves closed	0.076	0.076
Scram initiated	0.40	0.40
4 RIPs tripped	0.49	0.49
Safety/relief valves opened due to high pressure	2.6	2.56

Table 6 The LOFW sequences of FSAR and TRACE/PARCS

	Action	Time (sec)	
		FSAR	**TRACE/PARCS**
1	**Two feedwater pumps under normal operation trip, and Loss of Feedwater Flow event occurs.**	0.00	0.00
2	**Feedwater Flow drops thoroughly**	5.00	5.00
3	**The water level of reactor vessel descends to L3 lower level setting point, and it results in the reactor vessel scram and trip signals of four RIPs which were not connected to the M/G set**	7.53	13.23
4	**The water level of reactor vessel descends to L2 lower level setting point, and it causes the other six RIPs to trip**	18.28	17.35

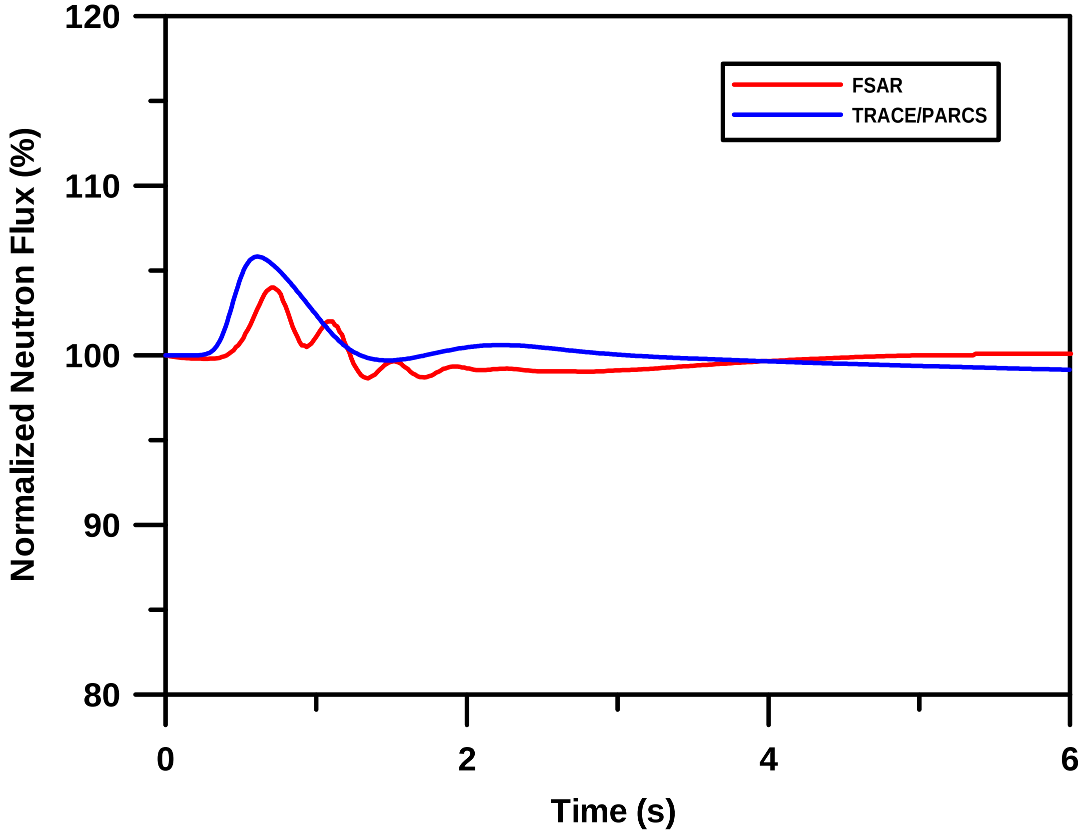


Figure 7 The comparison of neutron flux between FSAR and TRACE/PARCS for TTWB

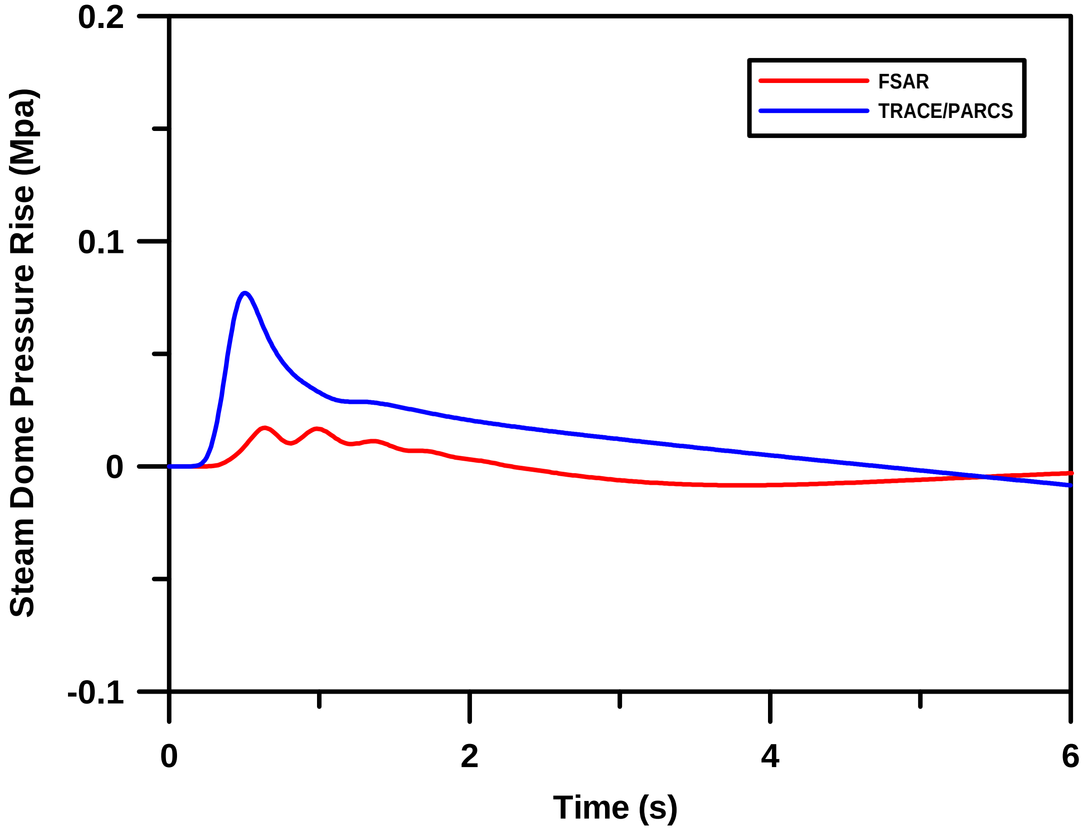


Figure 8 The comparison of steam dome pressure rise between FSAR and TRACE/PARCS for TTWB

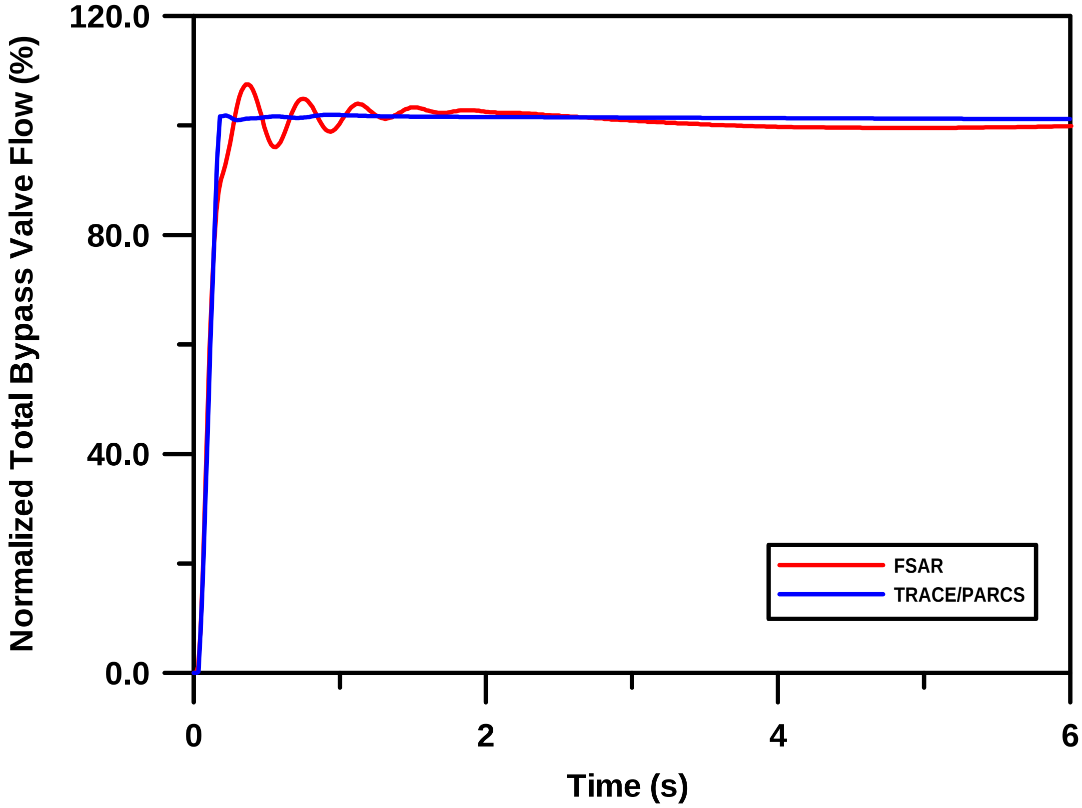


Figure 9 The comparison of total bypass valve flow between FSAR and TRACE/PARCS for TTWB

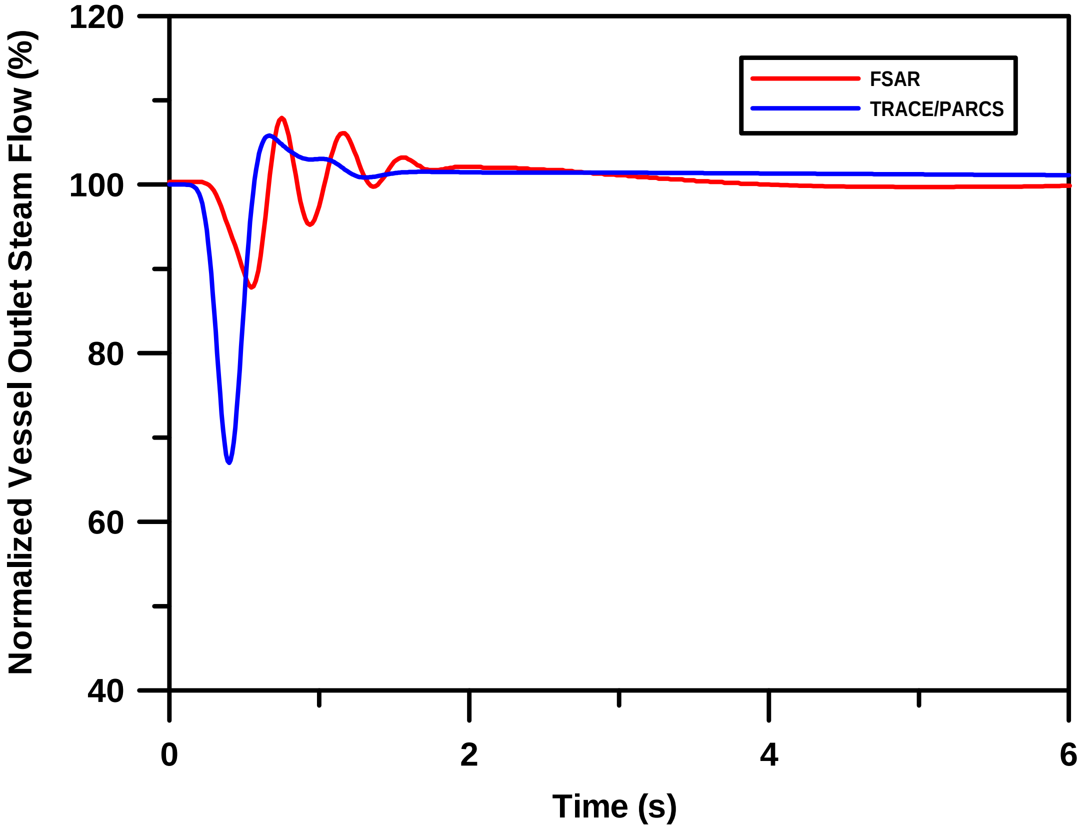


Figure 10 The comparison of vessel outlet steam flow between FSAR and TRACE/PARCS for TTWB

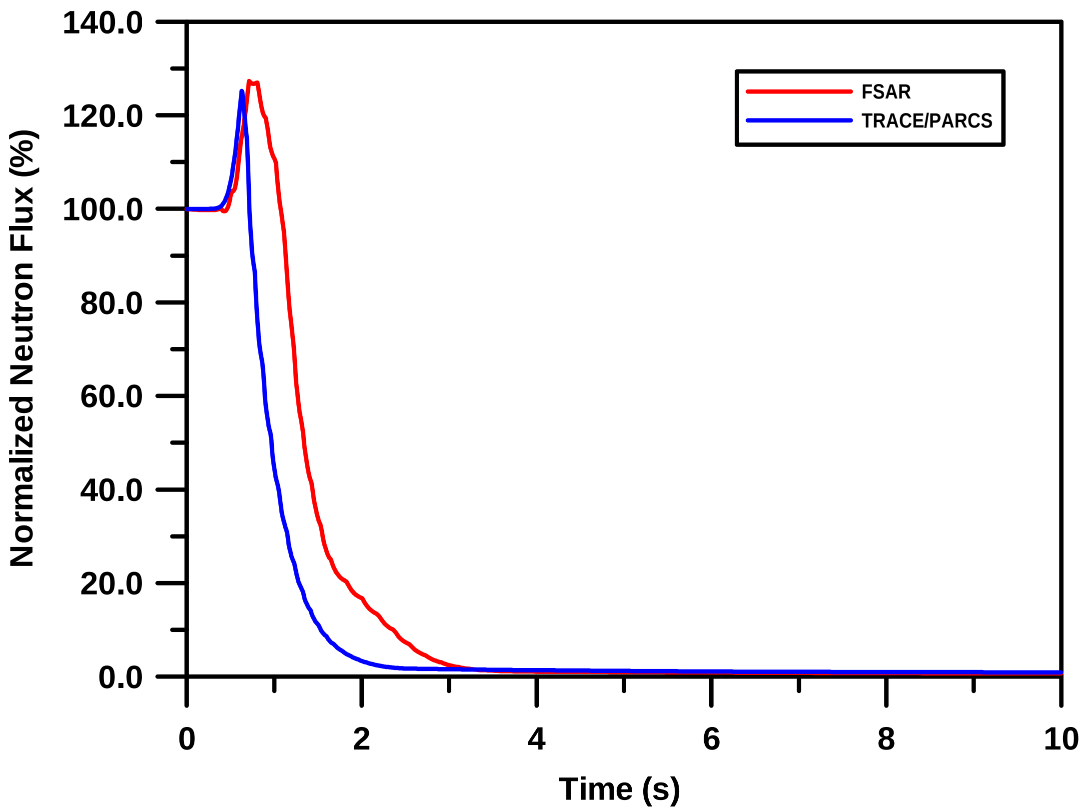


Figure 11 The comparison of neutron flux between FSAR and TRACE/PARCS for TTNB

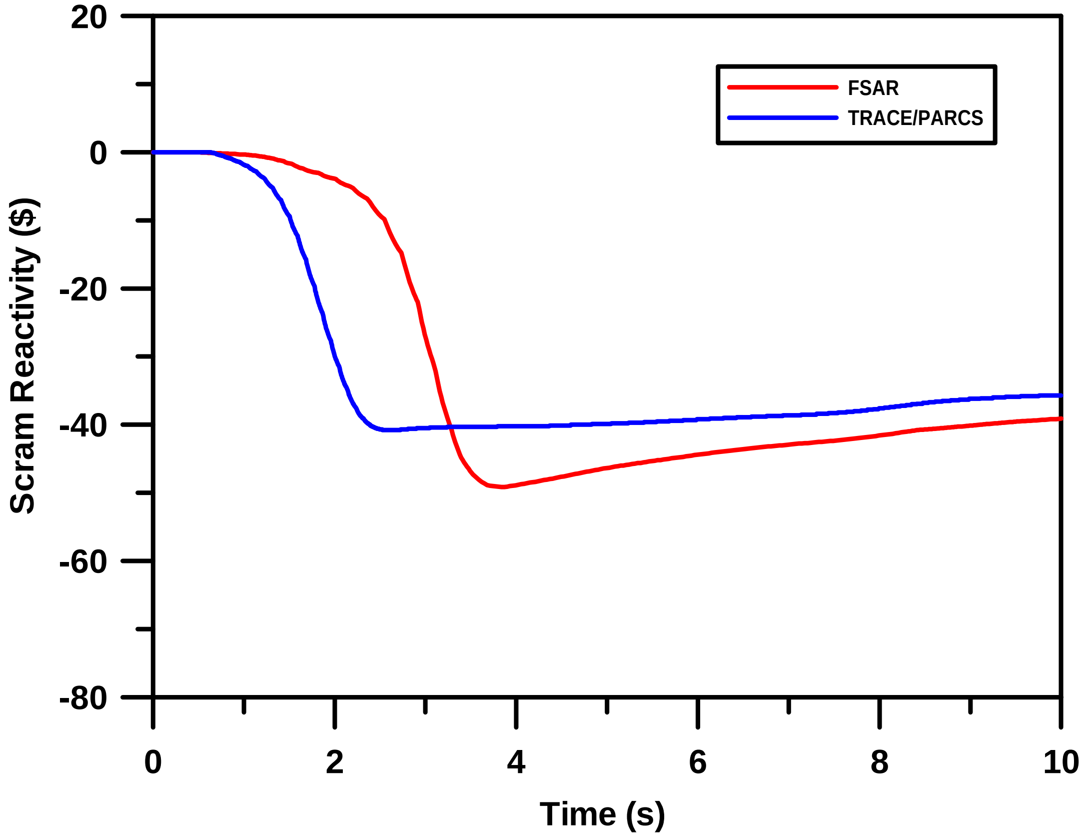


Figure 12 The comparison of scram reactivity between FSAR and TRACE/PARCS for TTNB

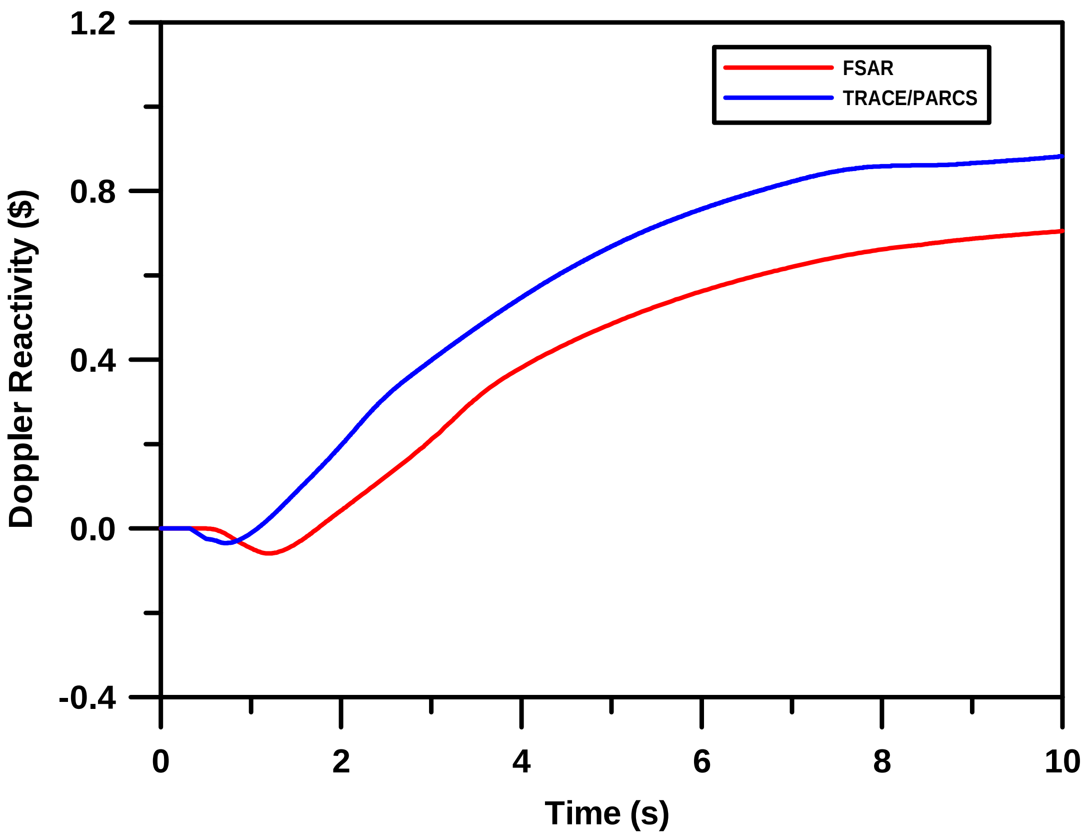


Figure 13 The comparison of Doppler reactivity between FSAR and TRACE/PARCS for TTNB

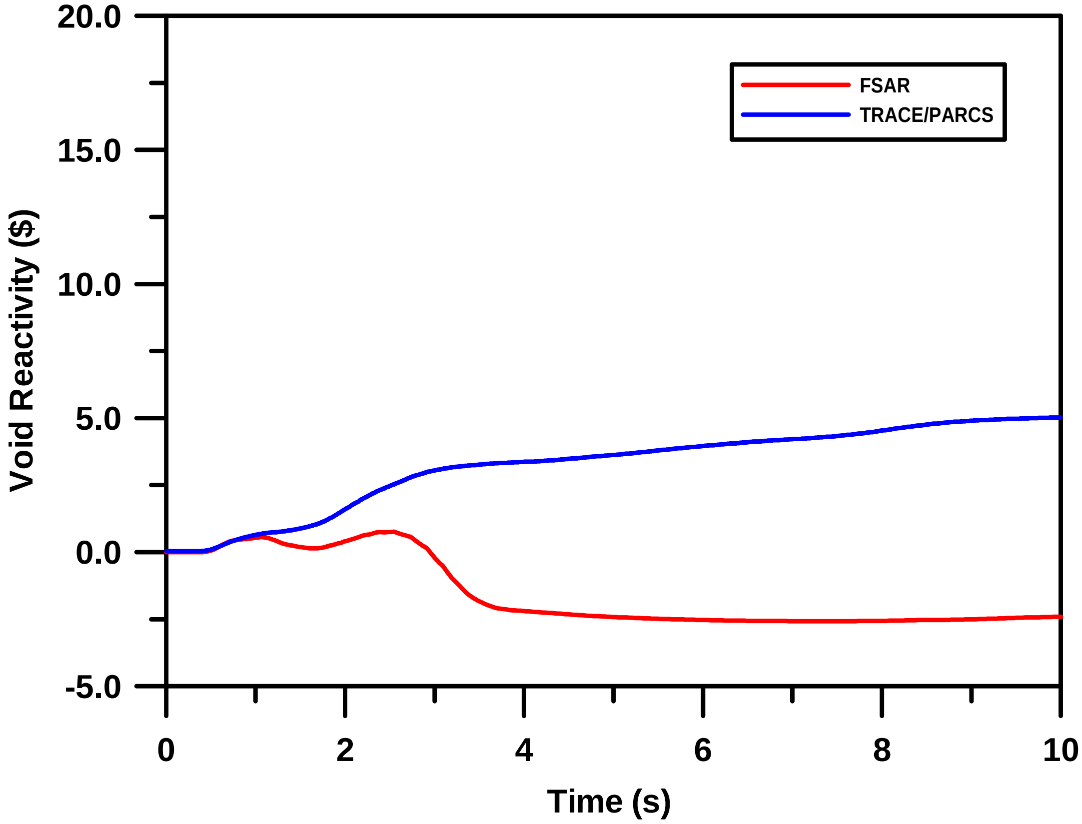


Figure 14 The comparison of void reactivity between FSAR and TRACE/PARCS for TTNB

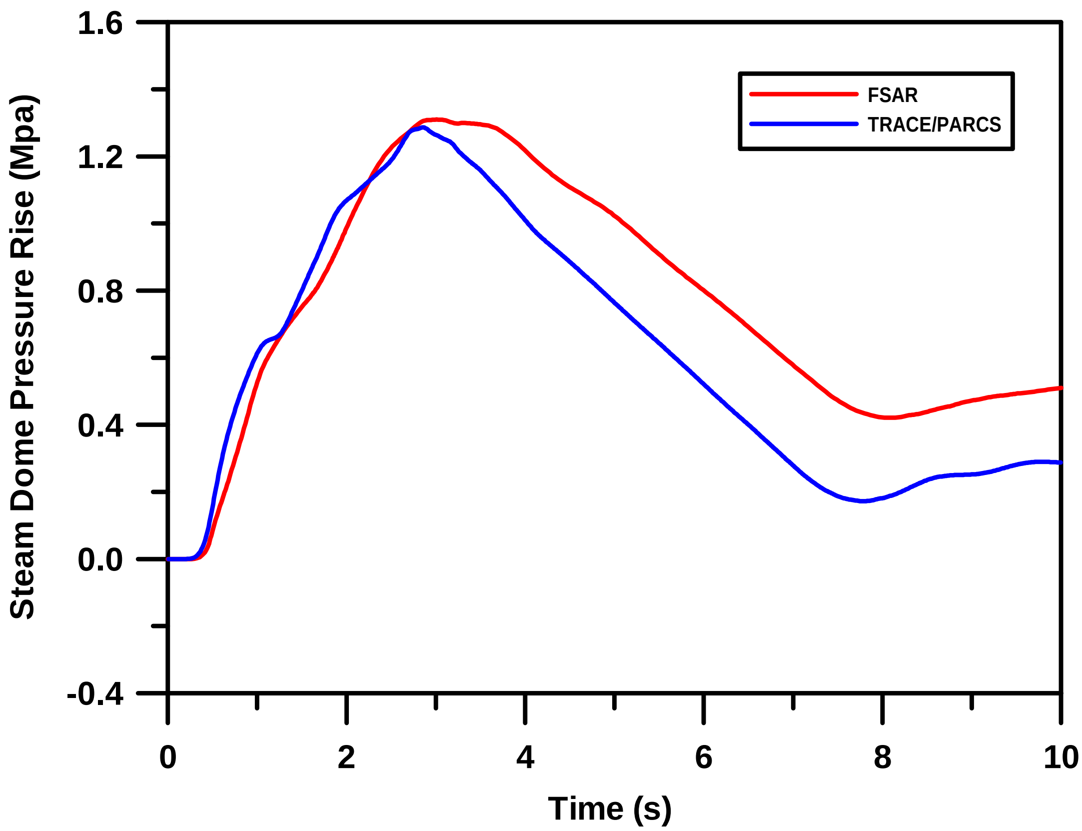


Figure 15 The comparison of steam dome pressure rise between FSAR and TRACE/PARCS for TTNB.

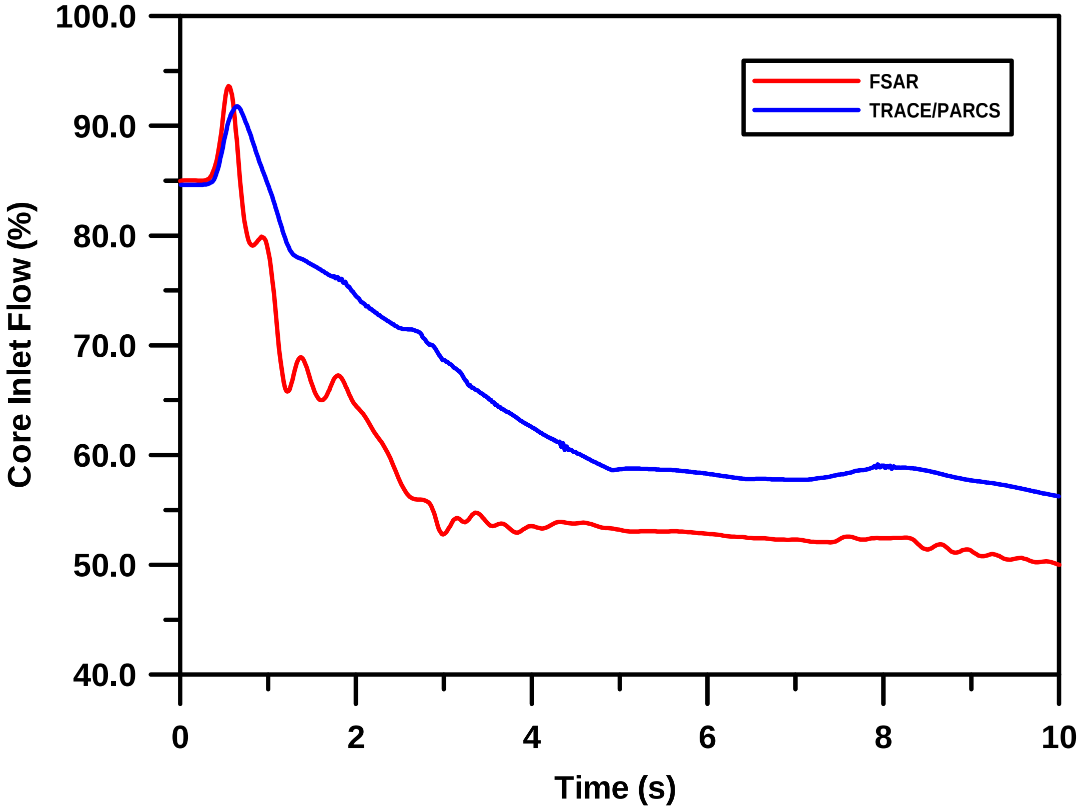


Figure 16 The comparison of core inlet flow between FSAR and TRACE/PARCS for TTNB

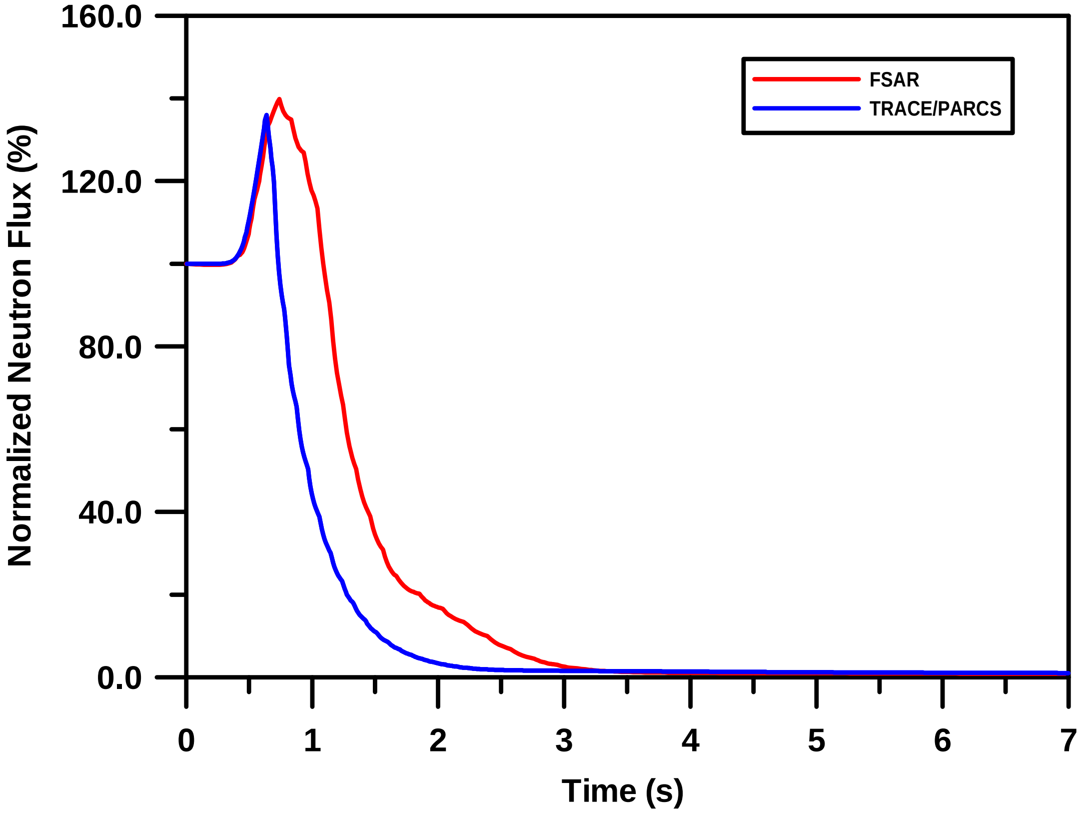


Figure 17 The comparison of neutron flux between FSAR and TRACE/PARCS for LRNB

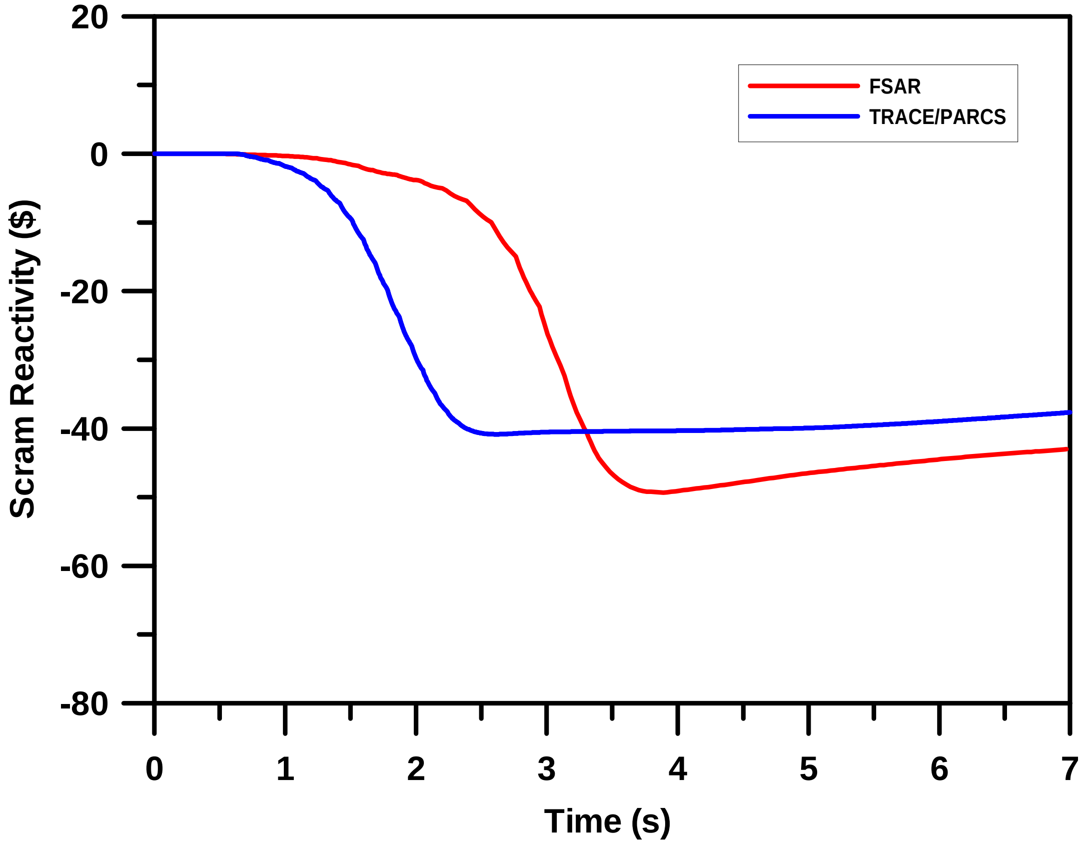


Figure 18 The comparison of scram reactivity between FSAR and TRACE/PARCS for LRNB

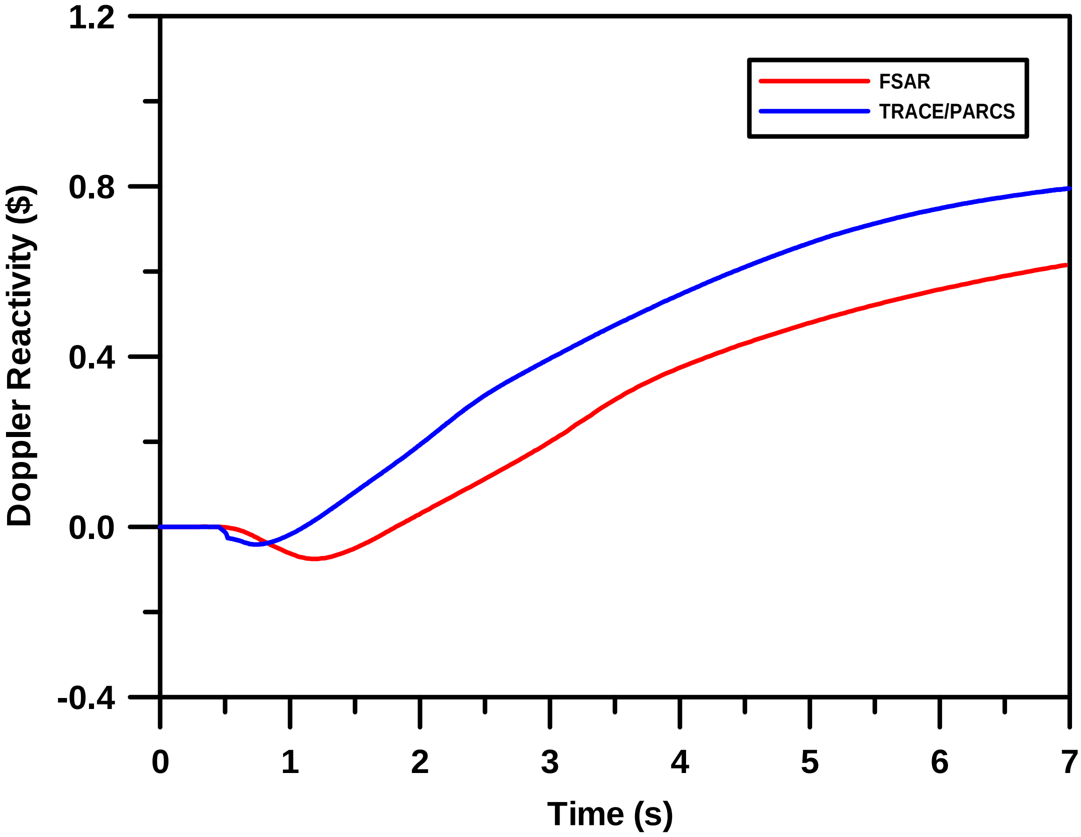


Figure 19 The comparison of Doppler reactivity between FSAR and TRACE/PARCS for LRNB

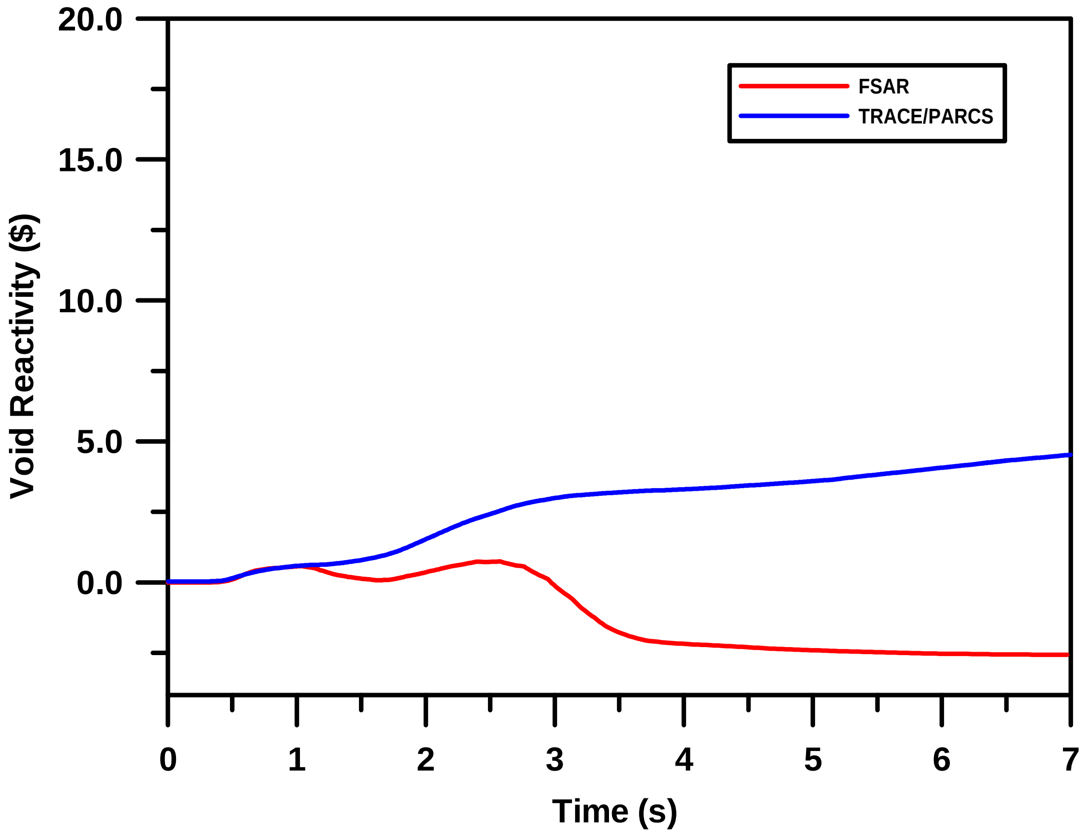


Figure 20 The comparison of void reactivity between FSAR and TRACE/PARCS for LRNB

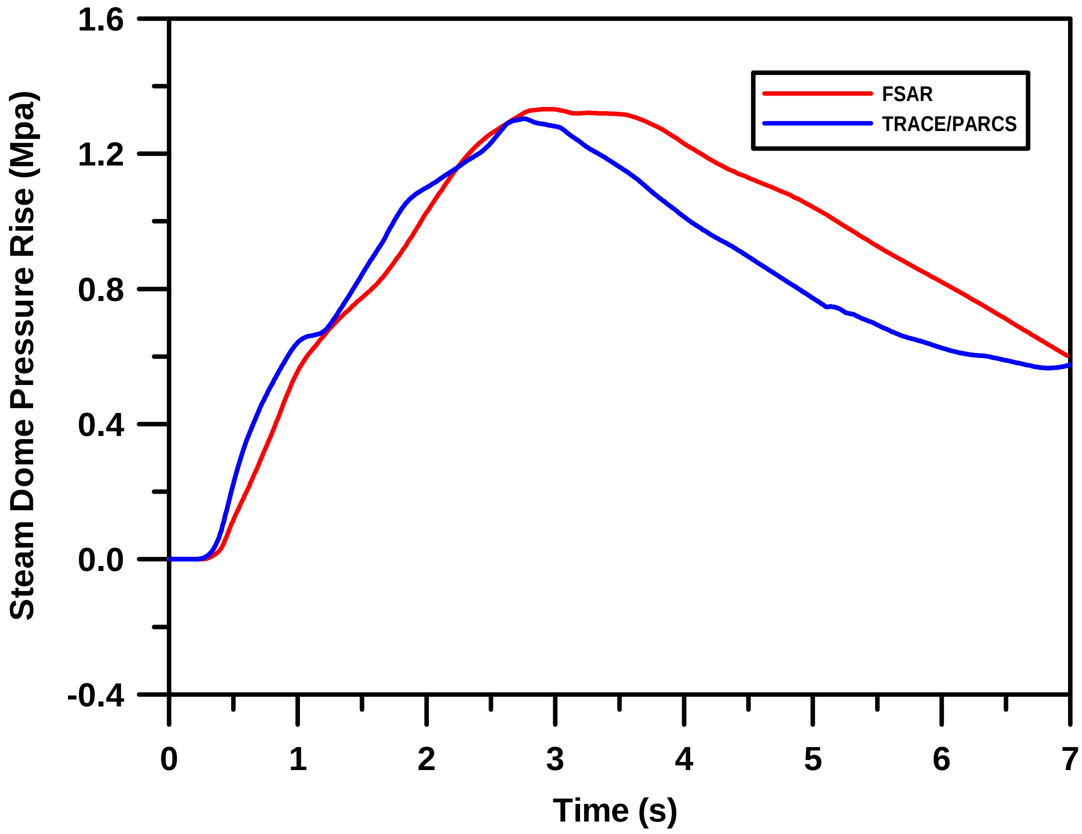


Figure 21 The comparison of steam dome pressure rise between FSAR and TRACE/PARCS for LRNB

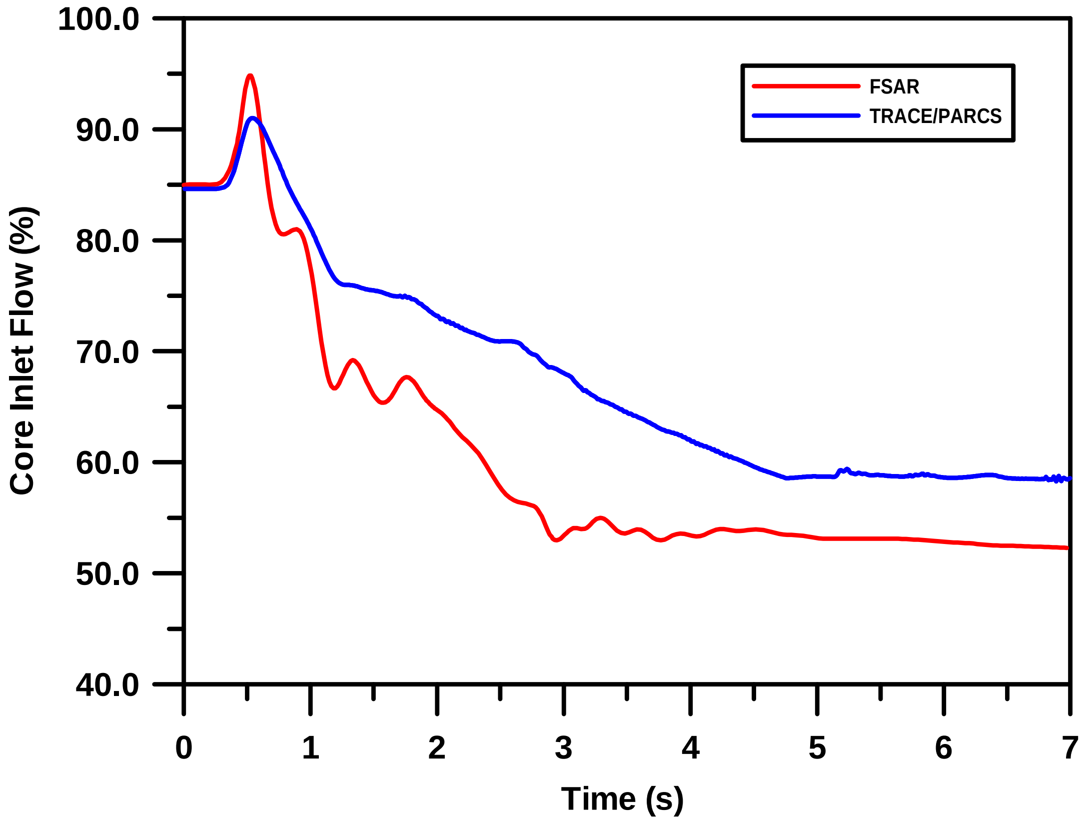


Figure 22 The comparison of core inlet flow between FSAR and TRACE/PARCS for LRNB

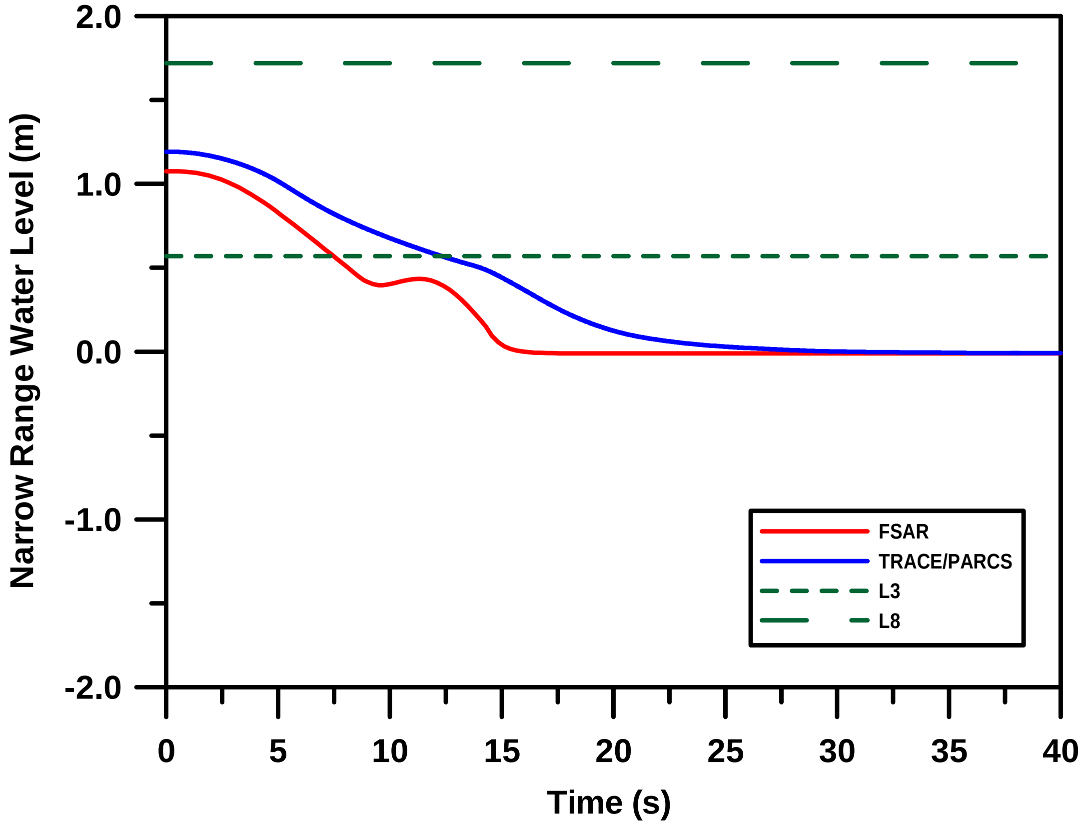


Figure 23 The comparison of narrow water level between FSAR and TRACE/PARCS for LOFW

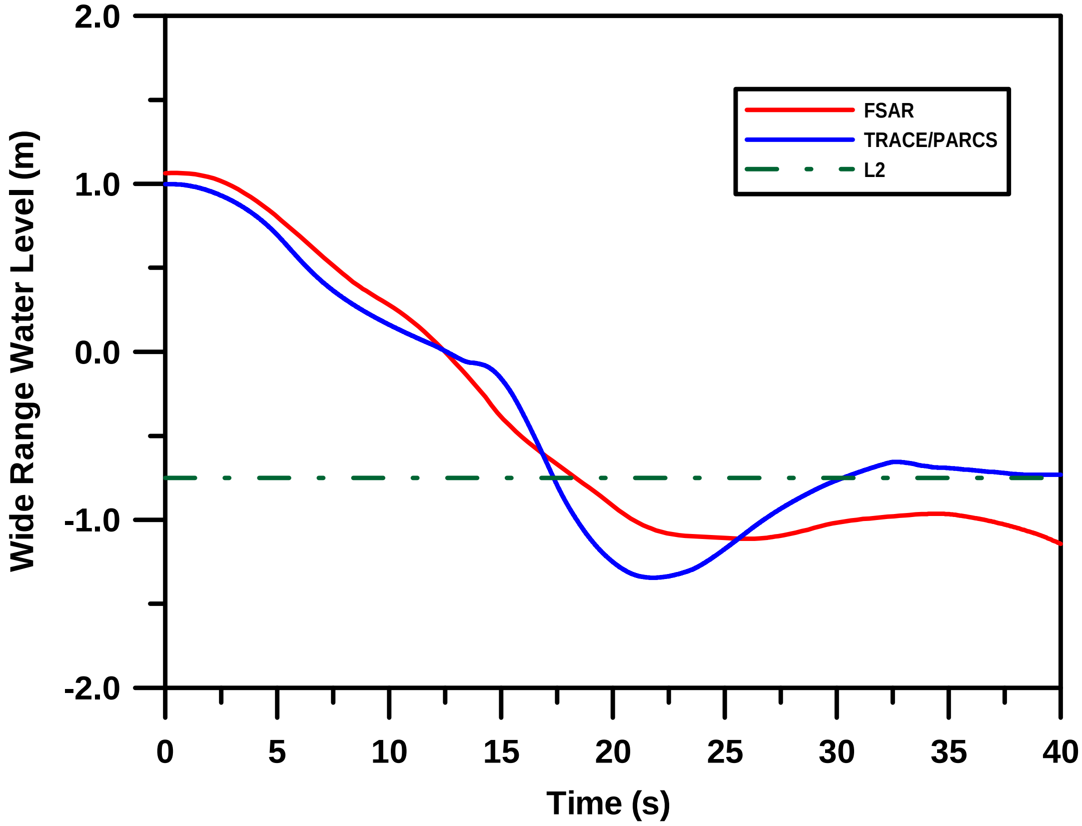


Figure 24 The comparison of wide water level between FSAR and TRACE/PARCS for LOFW

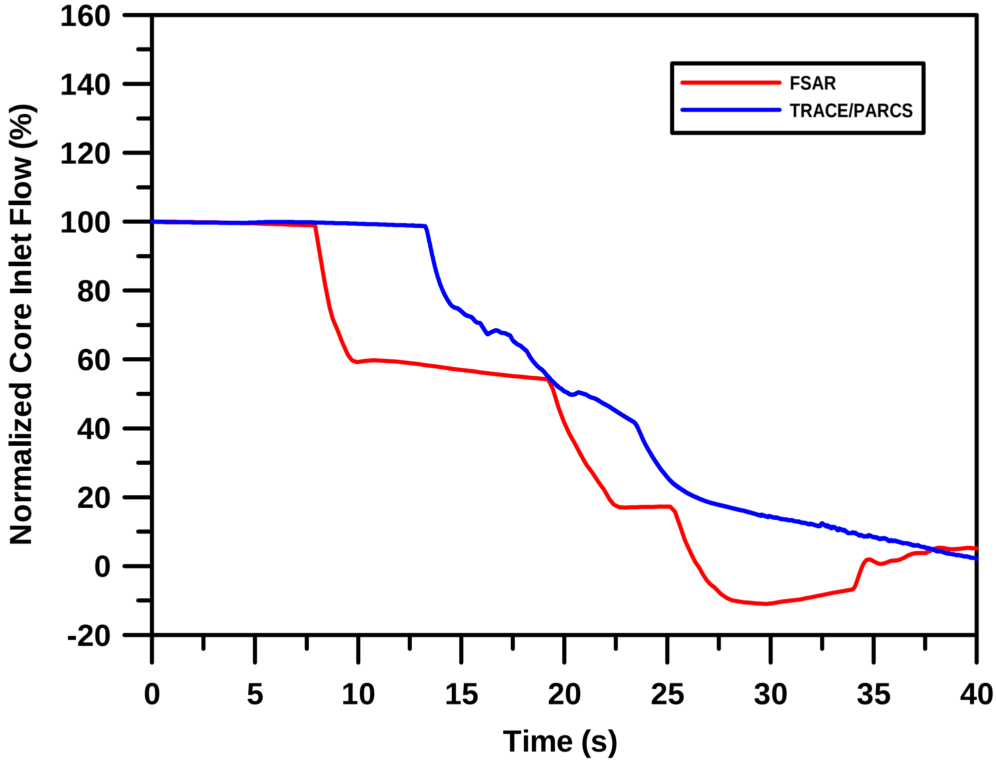


Figure 25 The comparison of core inlet flow between FSAR and TRACE/PARCS for LOFW

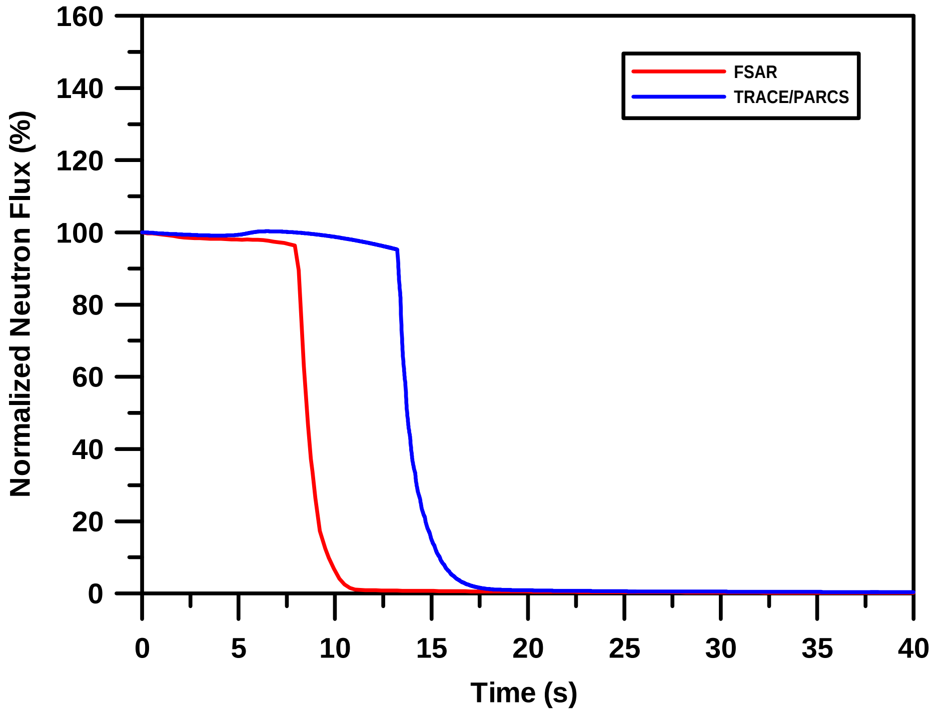


Figure 26 The comparison of neutron flux between FSAR and TRACE/PARCS for LOFW

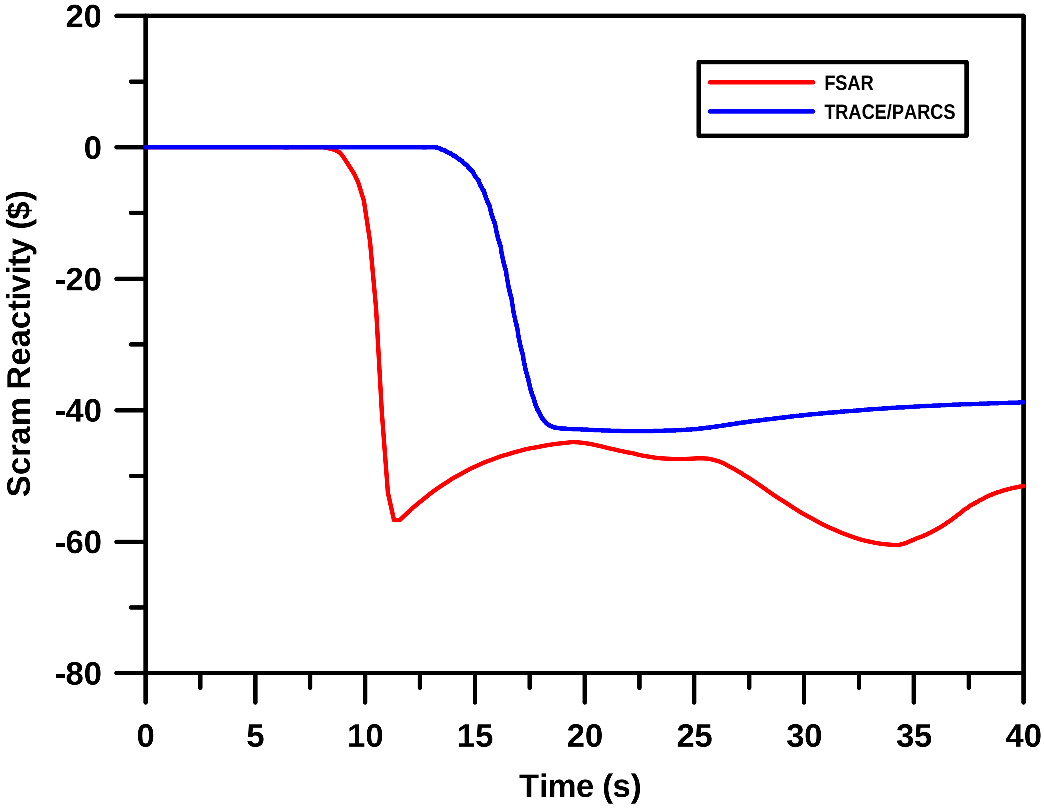


Figure 27 The comparison of scram reactivity between FSAR and TRACE/PARCS for LOFW

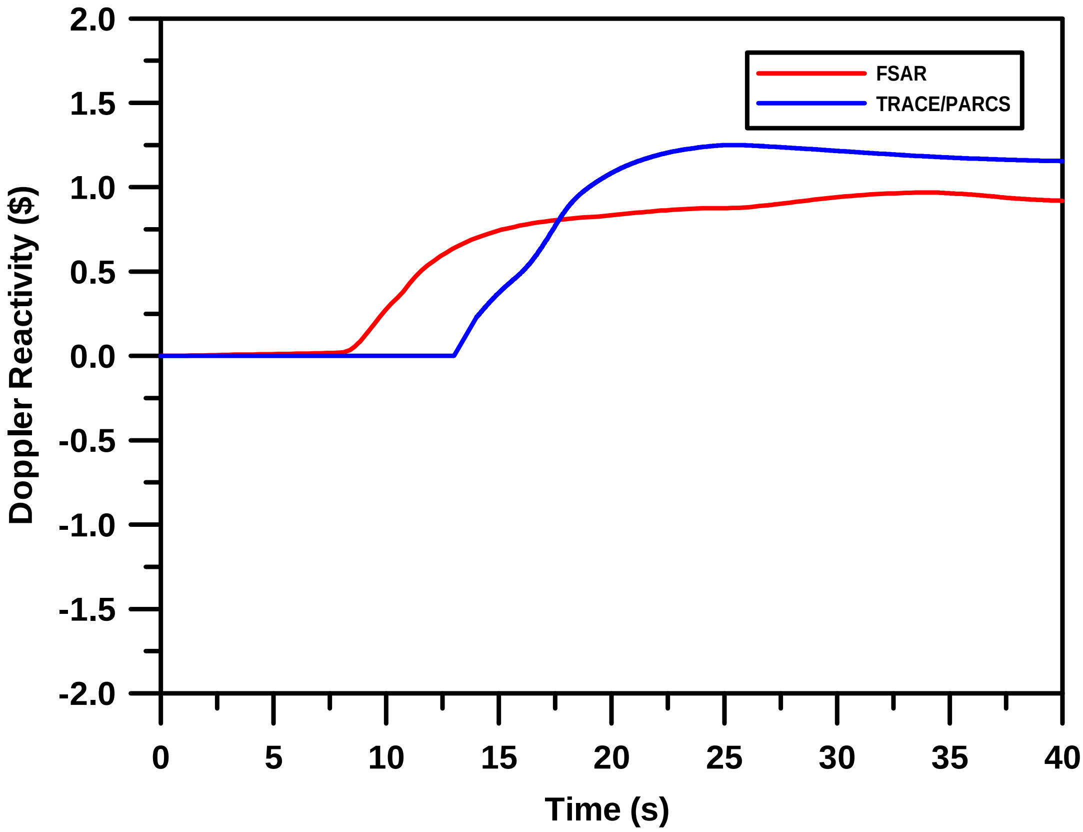


Figure 28 The comparison of Doppler reactivity between FSAR and TRACE/PARCS for LOFW

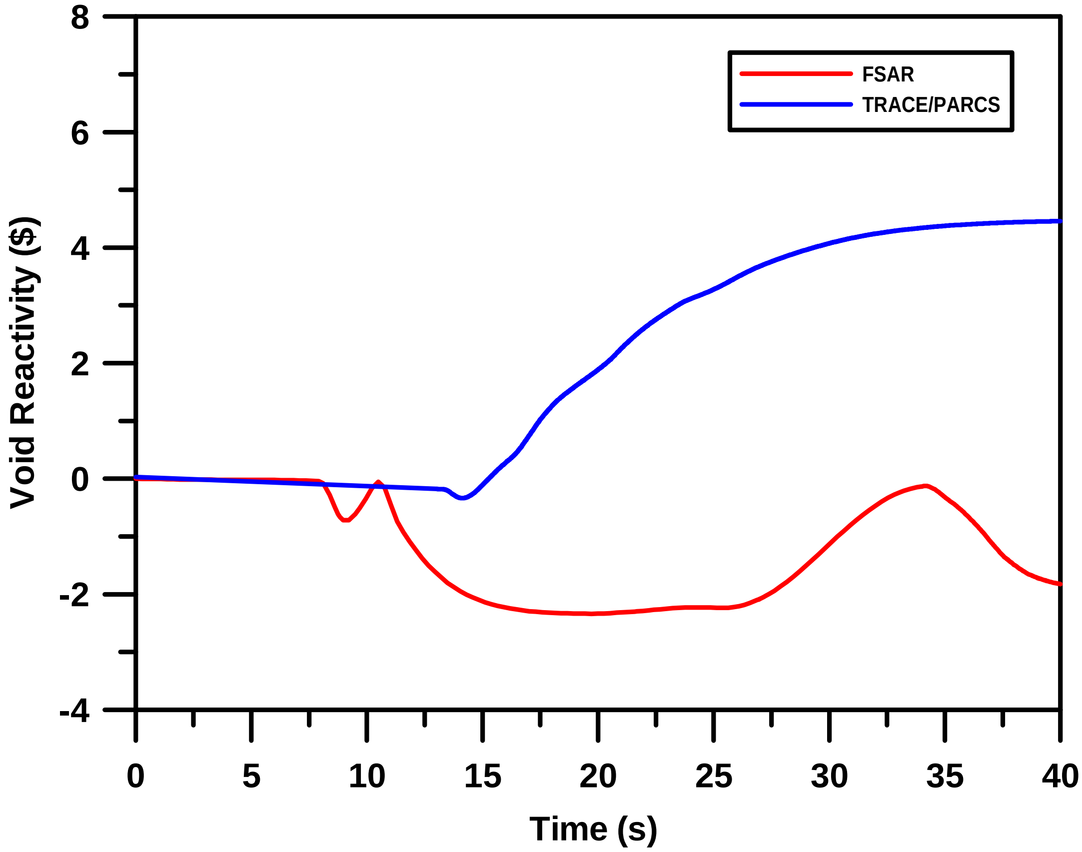


Figure 29 The comparison of void reactivity between FSAR and TRACE/PARCS for LOFW

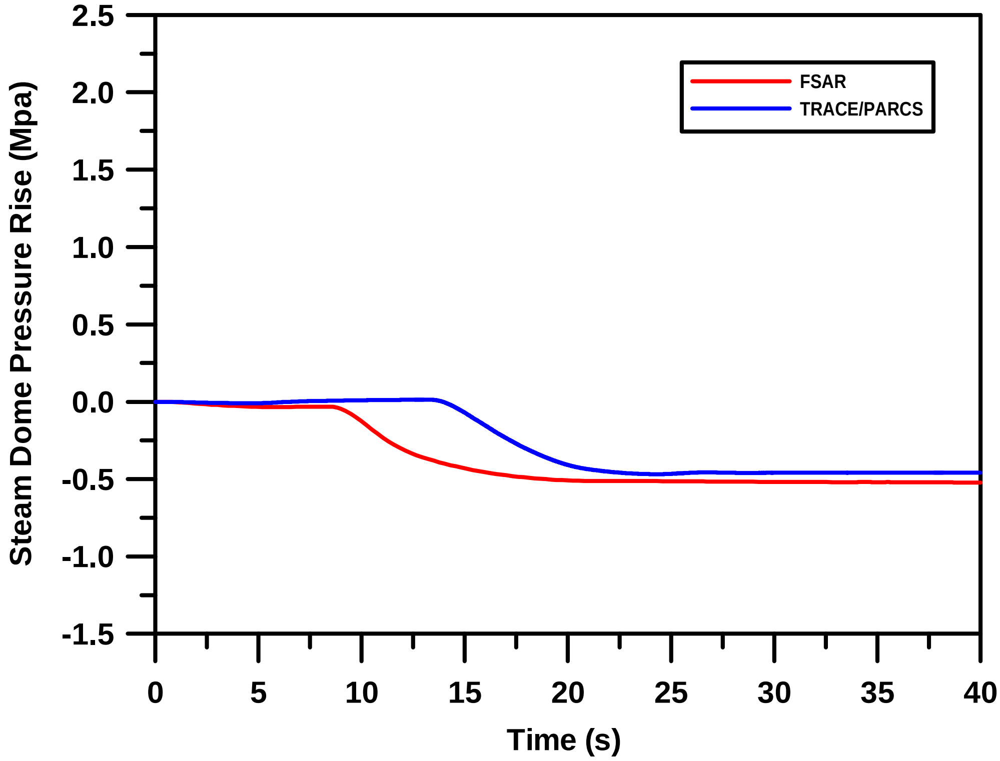


Figure 30 The comparison of steam dome pressure rise between FSAR and TRACE/PARCS for LOFW

5. CONCLUSIONS

By using SNAP/TRACE/PARCS, this study has developed the TRACE/PARCS model of the Lungmen NPP. The proposed TRACE/PARCS model analyzed the cases of FSAR chapter 15^{th}. Analytical results indicate that the Lungmen NPP TRACE/PARCS model can predict the behaviors of important plant parameters reflecting consistent trends with FSAR data. However, some parameters have less difference, as follows:

- In TTWB transient, the response difference of the bypass valve flow between the TRACE/PARCS and FSAR affects their dome pressure and neutron flux.
- In TTNB and LRNB transients, the difference of the scram curve between TRACE/PARCS and FSAR leads the different neutron flux.
- In TTNB and LRNB transients, the difference on the calculation of void fraction of TRACE/PARCS and FSAR results in the difference of void reactivity.
- In LOFW transients, the difference of the initial NRWL value between FSAR and TRACE/PARCS causes the response time of TRACE/PARCS later than FSAR data.

Therefore, the above difference will be checked with the startup tests data. The startup tests of Lungmen NPP may be performed in 2014. The measured data of startup tests will be used to estimate and modify the TRACE/PARCS model of Lungmen NPP.

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1000, Wenhua Rd., Chiaan Village, Lungtan, Taoyuan, 325
Taiwan

*Institute of Nuclear Engineering and Science
National Tsing Hua University
101 Section 2, Kuang Fu Rd., HsinChu
Taiwan

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10. SUPPLEMENTARY NOTES
K. Tien, NRC Project Manager

11. ABSTRACT *(200 words or less)*
This study consists of two steps. The first step is the development of a TRACE (TRAC/RELAP Advanced Computational Engine)/PARCS(Purdue Advanced Reactor Core Simulator) model of Lungmen nuclear power plant (NPP) which includes the vessel, reactor internal pumps (RIPs), main steam lines, and important control systems (such as the feedwater control system, steam bypass & pressure control system, and recirculation flow control system), etc.. Key parameters are identified to refine the TRACE/PARCS model further in the frame of a steady state analysis. The second step is the performance of Lungmen NPP TRACE/PARCS model transient analyses. The transient data of Final Safety Analysis Report (FSAR) chapter 15th are used to compare with the analysis results of the Lungmen NPP TRACE/PARCS model. The trends of TRACE/PARCS analysis results are consistent with the FSAR data for the important parameters. However, there are some difference in their bypass valve flow response, scram reactivity and void reactivity.

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