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THE DEVELOPMENT AND ASSESSMENT OF TRACE MODEL FOR MAANSHAN PWR

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Abstract

Maanshan nuclear power plant (NPP) is the first PWR in Taiwan. Its reactor is made by Westinghouse Company and has the rated power of 2775 MWt. The Maanshan NPP TRACE model is developed by Institute of Nuclear Energy Research (INER), and National Tsing Hua University (NTHU). The Maanshan NPP TRACE model assessment is performed by Partial Loss of Flow (PLOF) and Complete Loss of Flow (CLOF) of FSAR data and large-load reduction of startup test data. In summary, TRACE analysis results are consistent with FSAR and startup test data.

Introduction

Maanshan NPP's reactor is made by Westinghouse Company and has the rated power of 2775MWt (this value is the original rated power of Maanshan). The reactor coolant system has three loops and each loop has a reactor coolant pump (RCP) and a steam generator (S/G). Besides, the pressurizer is connected with the hot-leg piping in loop 2.

The US NRC has developed an advanced thermal hydraulic code with some basic neutronic capablities named TRACE (TRAC/RELAP Advanced Computational Engine) for nuclear power plant safety analysis. The development of TRACE is based on TRAC, integrating RELAP5 and other programs. According to the reference [1], it 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. A graphic user interface program, SNAP, which processes inputs and outputs for TRACE as well as other analytical codes has also been developed. 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. 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 is the organization in Taiwan that is responsible for the application of TRACE in thermal hydraulic safety analysis, for recording users' experiences of it, and providing suggestions for its development. To meet this responsibility, it has built a TRACE model of TPC (Taiwan Power Company) Maanshan PWR NPP. In Maanshan NPP TRACE model, components or control systems such as pressurizer, steam generators, feedwater control system and steam dump control system, were developed.

In this research, FSAR and startup test data of Maanshan NPP were utilized to confirm the accuracy the TRACE model. PLOF and CLOF of FSAR data were used to assess Maanshan NPP TRACE model. Additionally, large-load reduction of startup test data was also used to estimate the TRACE model.

1. Methodology

The code versions adopted in this research are SNAP v 1.1.8 and TRACE v 5.0p1, and the complete process is presented in Fig. 1. First, FSAR and startup tests data of Maanshan NPP [2]-[7] were collected. Second, the Maanshan NPP TRACE model was developed. It is a three loop model, and every loop has a feedwater control system. The main structures of this model include the vessel, pressurizer, steam generators, steam piping in the secondary side (including four sets of steam dump and vent valves) and the steam dump system. The vessel is cylindrical, and is divided into 12 levels in the axial direction, two rings in the "r" direction (internal and external rings) and six equal azimuthal sectors in the "θ" direction. The control rod conduit connects the 12th and 7th layer of the vessel from end to end. The fuel region is between the third and sixth layer, heat conductors were added onto the structures to simulate the reactor core. Finally, FSAR and startup tests data of Maanshan were used to assess the accuracies of the TRACE model under the steady state and transient conditions. The TRACE model of Maanshan NPP was presented in Fig. 2.

In Maanshan NPP TRACE model, there are two methods to simulate or calculate power in Maanshan NPP TRACE model. One is to use "point kinetics" data (e.g., the delay neutron fraction, Doppler reactivity coefficient, and moderator temperature reactivity coefficient) in the Maanshan NPP TRACE model and let TRACE calculate the power for the transient analysis. . Another is to input the power curve by "power table" into the TRACE model of Maanshan NPP. The first method is used in PLOF and CLOF transients and the second method in large-load reduction transient.

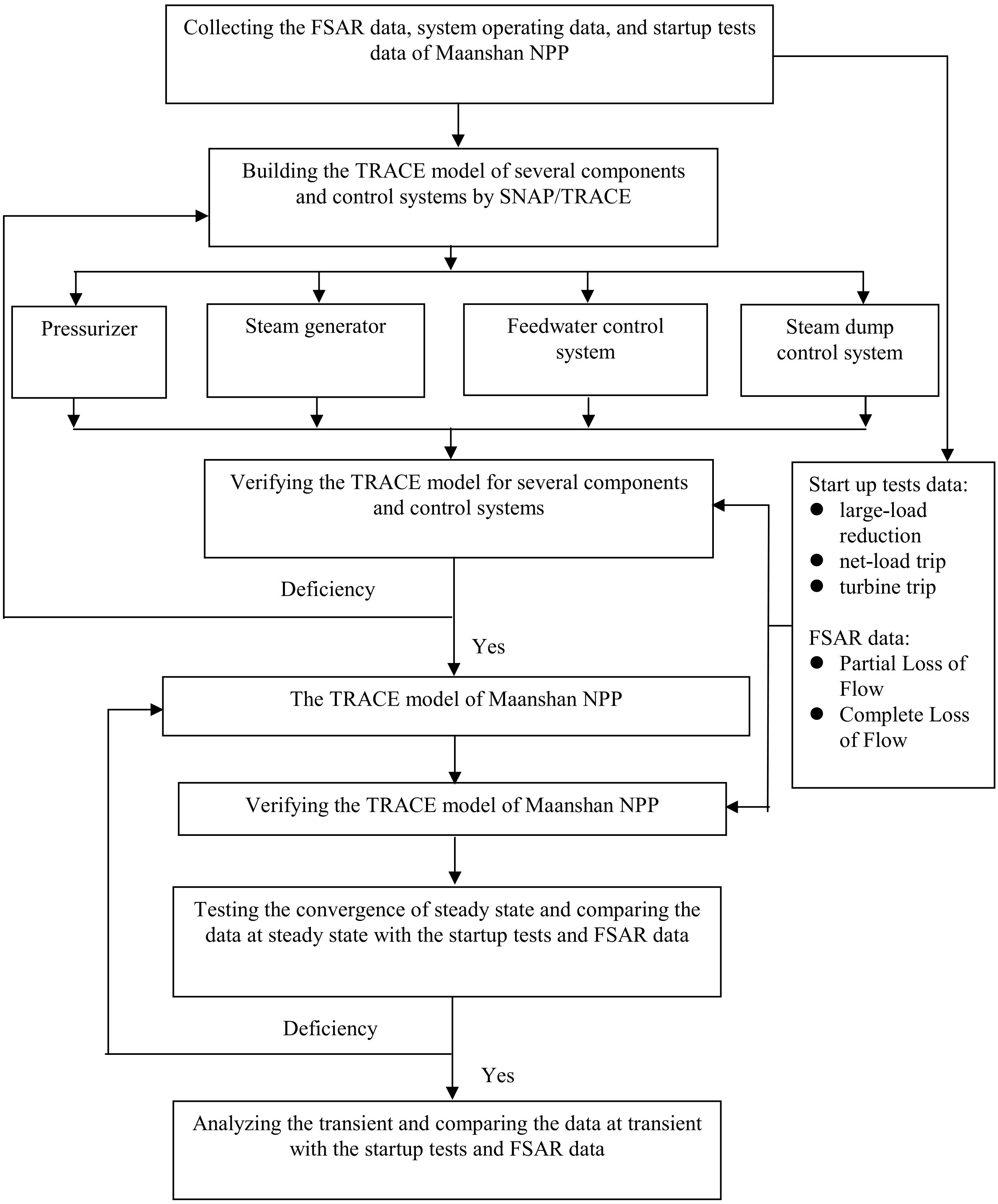

Figure 1 The flow chart of establishing and verifying the TRACE model of Maanshan NPP.

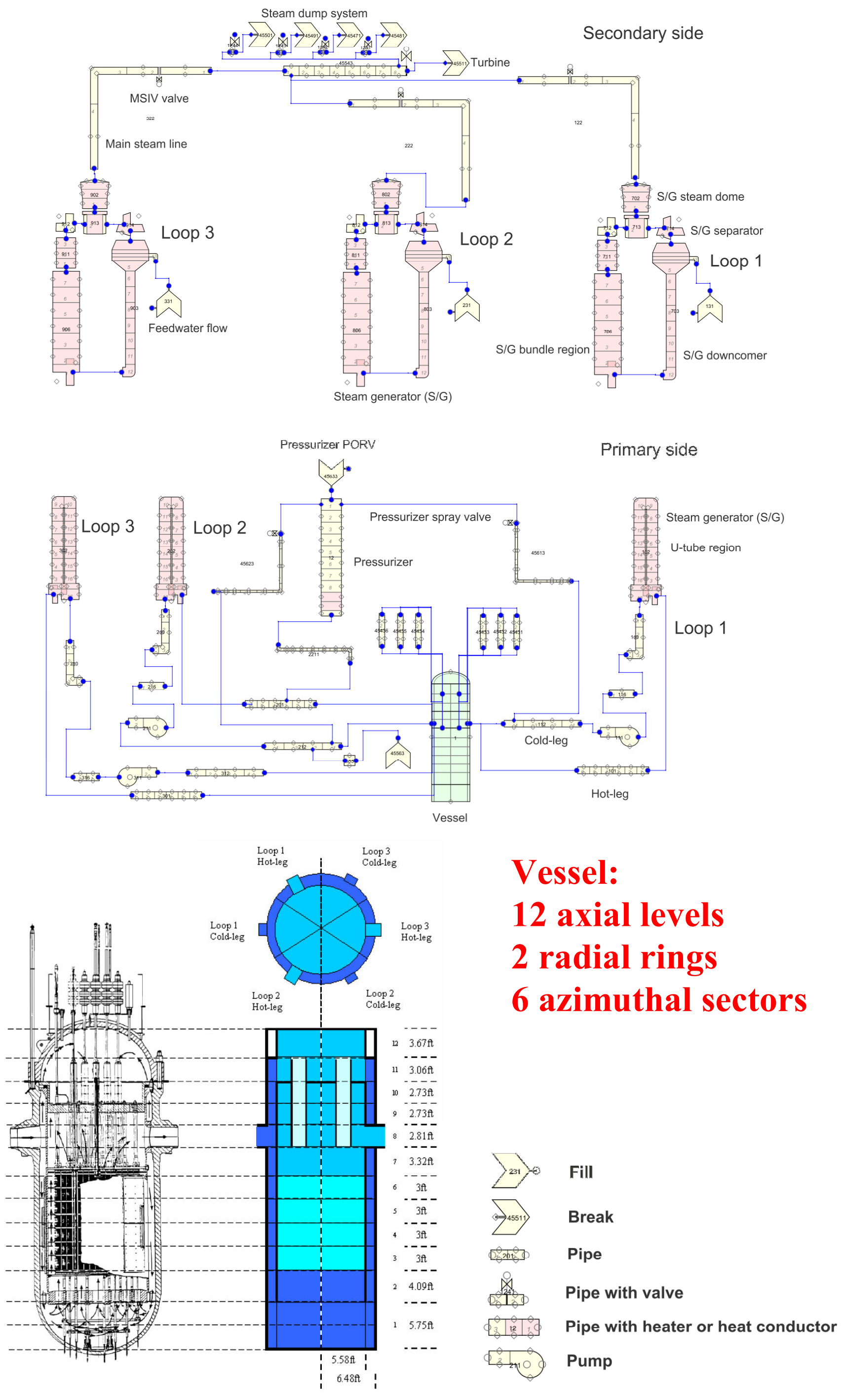

Figure 2 The TRACE model of Maanshan NPP.

2. Results and discussions

Before any transient analysis can begin in Maanshan NPP TRACE model, a consistent set of parameters used in TRACE must be obtained in the process of steady-state initialization. The steady-state initialization of the TRACE model was performed. The resultant calculated parameters such as the feedwater and steam flows of the steam generators, the water level of the steam generators and the pressurizer, the pressure of the pressurizer, and the hot-leg temperatures were compared with data from FSAR and startup tests data [2]-[7]. Comparison of several parameters shows TRACE results to be consistent with FSAR and startup tests data.

Following the steady state initialization, the TRACE model of Maanshan NPP was verified using three cases –PLOF, CLOF, and large-load reduction. Table 1~3 present the Maanshan NPP sequence of transients and those predicted by TRACE. The above results indicate that they are approximately the same.

2.1 Partial Loss of Flow (PLOF)

Fig. 3 compares the power of FSAR and TRACE. In this case, TRACE used "point kinetics" to calculate the power and it displays that the power curve of TRACE is similar with FSAR data. One RCP coast down began in 0 sec. After the low flow scram setpoint was reached, the reactor was tripped in about 2.5 sec. So the power decreased after 2.5 sec. Fig.4 shows the core flow results of TRACE and FSAR. In TRACE's result, the core flow decreased after one RCP coastdown. It also shows that the core flow curve of TRACE approximately follows the trend of FSAR. The comparison of the pressurizer pressure of FSAR and TRACE is present in Fig. 5 and their trends are also similar. Furthermore, the animation of the TRACE model is presented using the animation function of SNAP/TRACE interface with the above model and analysis results. The animation model of Maanshan NPP is shown in Fig. 6.

2.2 Complete Loss of Flow (CLOF)

In this case, TRACE also used "point kinetics" to calculate the power and Fig. 7 shows the power plots of FSAR and TRACE. The TRACE power curve is roughly similar with FSAR's curve. All RCPs coastdown began in 0 sec and the scram was tripped in 1.5 sec. So the power decreased after 1.5 sec. In Fig. 8, it reveals that the core flow curve of TRACE is approximately the same with the curve of FSAR. Due to all RCPs coastdown, the core flow reduced little by little. Fig. 9 compares the pressurizer pressures results of FSAR and TRACE. The pressure curve of TRACE generally follows the trend of FSAR.

2.3 Large-load reduction

In the large-load reduction transient, TRACE used a "power table" function to make simulated power match startup test data (shown in Fig. 10). The purpose of large-load reduction test is to demonstrate the response capability of the Maanshan NPP which is no trip in the reactor and turbine when the power reduces from 100% to 50%. In this case, the criteria are as follows: (1) no trip in the reactor and turbine; (2) the safety valves in the pressurizer and S/Gs do not open during the transient. The results of startup test data and TRACE for large-load reduction are present in Fig. 11~16. The above results indicate that they comply with the criteria of this test. Fig. 11 plots the result of S/G steam flow and their trends are consistent. The oscillation of the steam flow is caused by the oscillation of the power. So the oscillation of the steam flow curve is following the oscillation of the power curve.

Feedwater flow is controlled by a three-element feedwater control system. The main function of the feedwater control system is to maintain a fixed water level of the S/G at the secondary side when it is operating normally. The feedwater control system controls the main feedwater control valve using three signals including the water level error signal, the steam flow signal, and the feedwater flow signal. The water level error signal is calculated as the difference between the actual water level and the preset water level (typically 50%). Another value is calculated as the difference between the steam flow and the feedwater flow. These two differences are taken as the control signals of feedwater valve. Therefore, the above oscillation of the S/G steam flow also has the influence in the feedwater flow and S/G water level (shown in Fig. 12 and 13). Fig. 12 and 13 also show the trends of TRACE similar with the startup test data.

Fig. 14 compares the T_{avg} of startup test data and TRACE (T_{avg} = (Hot-leg temperature +Cold-leg temperature)/2). The temperatures calculated by TRACE roughly similar with the measured values in Maanshan NPP. The oscillation of T_{avg} is also following the oscillation of power. Fig. 15 compares the pressures of pressurize of startup test data and TRACE. The pressure calculated using TRACE also has similar consistent trend with plant data.

The steam dump control system of Maanshan NPP is composed of ten atmospheric venting valves, six turbine bypass valves and the associated piping control apparatus. The ten atmospheric venting valves and six turbine by-pass valves are grouped into four sets in this model. Three turbine bypass valves comprise the first set and the other three as the second set. Five atmospheric venting valves are considered as the third set and the rest as the fourth set. Fig. 16 shows the steam dump system (first set) result of startup test data and TRACE. It is seen that the result of TRACE for steam dump system is consistent with startup test data. The other sets are also similar with startup test data.

Table 1 The sequences of PLOF in FSAR and TRACE

	FSAR time (sec)	TRACE time (sec)
One RCP coastdown begins	0	0
Low flow scram setpoint reached	1.4	1.68
Rods begin to drop (scram)	2.4	2.68

Table 2 The sequences of CLOF in FSAR and TRACE

	FSAR time (sec)	TRACE time (sec)
All RCPs coastdown begins	0	0
Undervoltage scram signal	0	0
Rods begin to drop(scram)	1.5	1.5

Table 3 The large load reduction sequences in TRACE model and Maanshan NPP

Large load reduction *	Plant data Time(sec)	TRACE Time(sec)
Initial load reduction to 50%	10.0	10.0
T/B bypass valves fully open	20.0	19.2

***On steady status at first 10sec**

3. Conclusion

By using SNAP/TRACE, this study developed a TRACE model of the Maanshan NPP. Effectiveness of the proposed model was verified with FSAR and startup test data. Analytical results indicate that the Maanshan NPP TRACE model predicts not only the behaviors of important plant parameters in consistent trends with FSAR and startup test data, but also their numerical values with respectable accuracy. The TRACE model of Maanshan NPP may be used in future safety analysis with confidence, such as applications for power uprating, life extensions, and design modifications.

4. References

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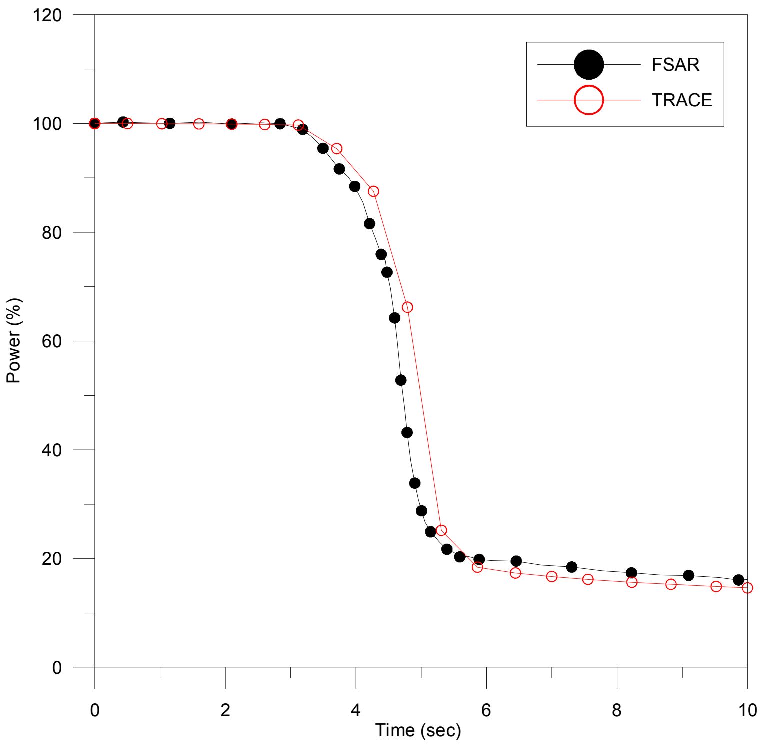

Figure 3 The power comparison between FSAR and TRACE for PLOF transient.

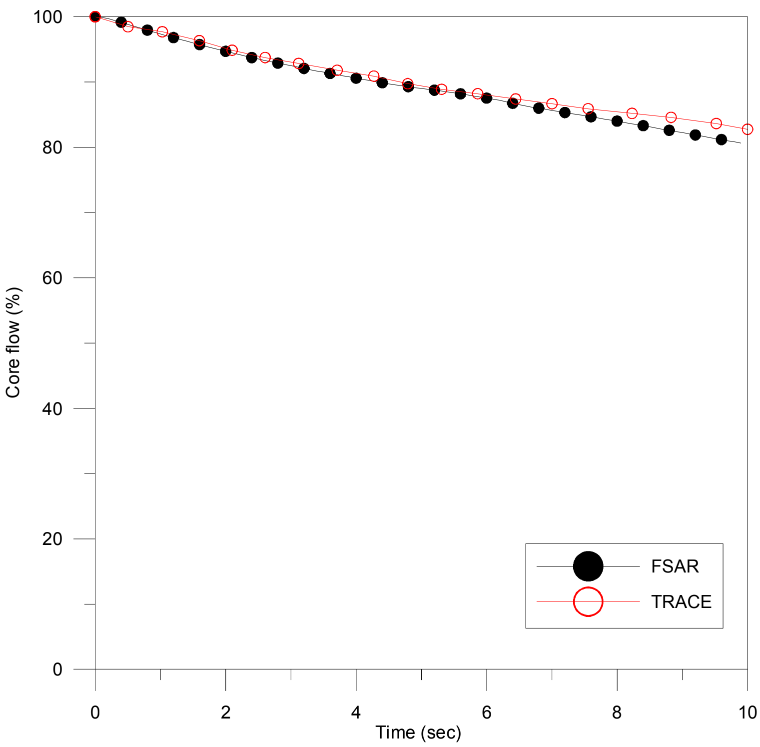

Figure 4 The core flow comparison between FSAR and TRACE for PLOF transient.

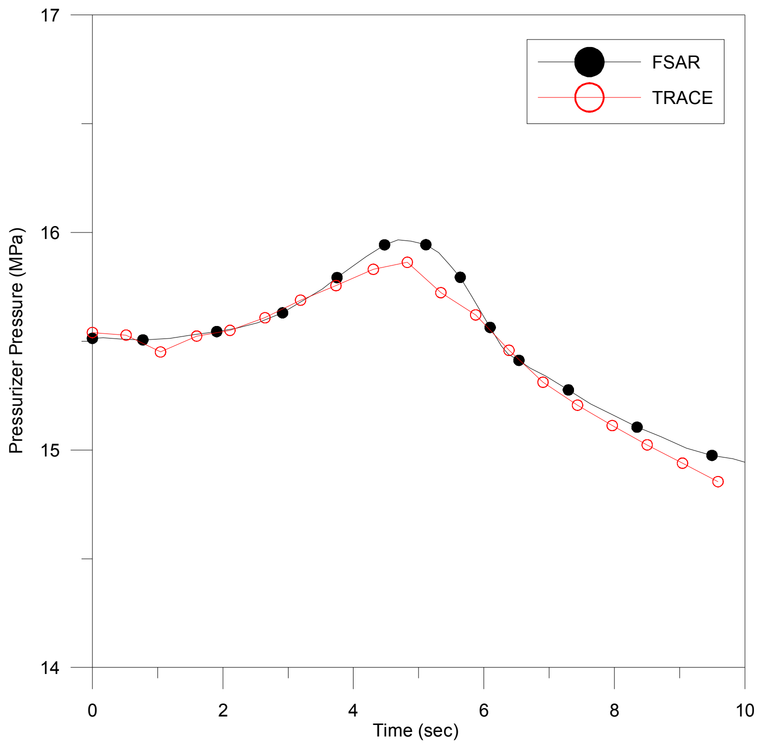

Figure 5 The pressurizer pressure comparison between FSAR and TRACE for PLOF transient.

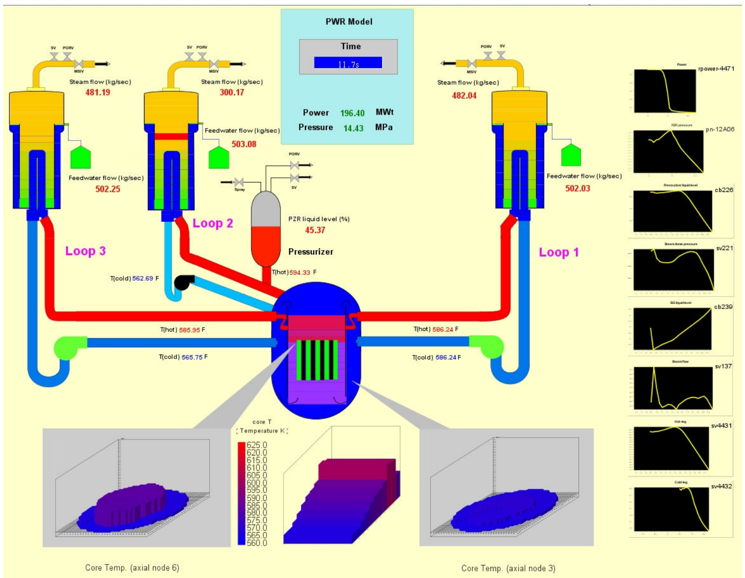

Figure 6 The animation model of Maanshan NPP.

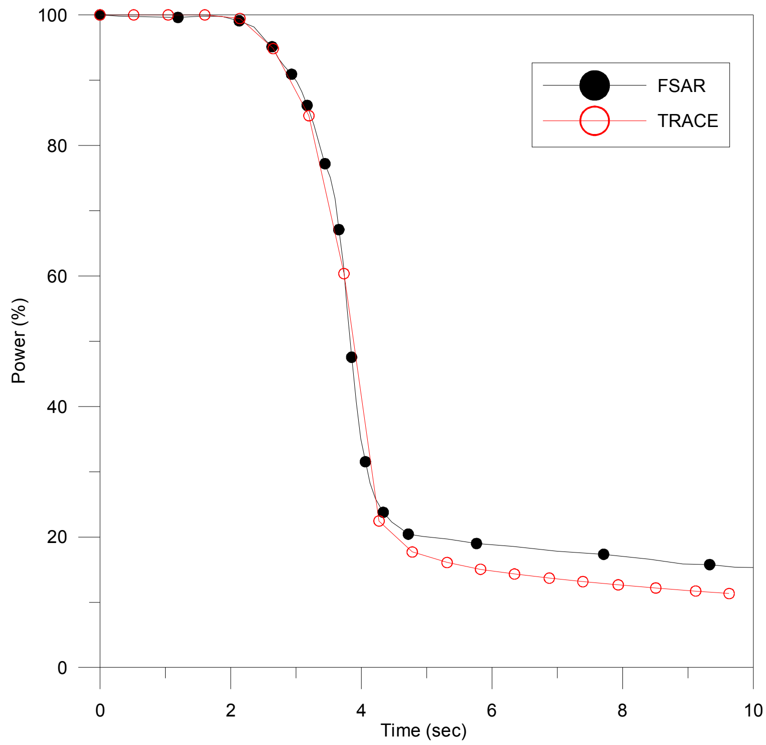

Figure 7 The power comparison between FSAR and TRACE for CLOF transient.

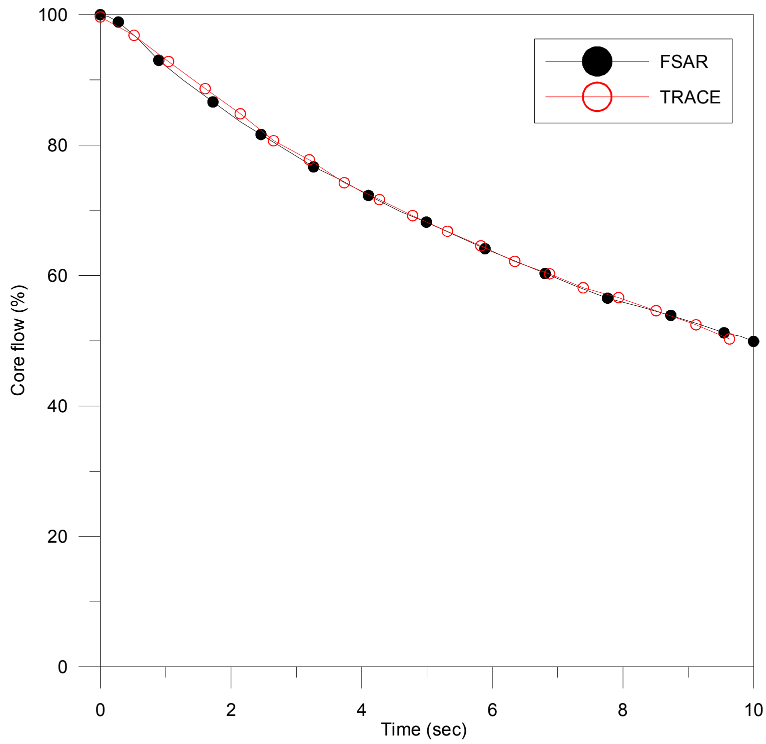

Figure 8 The core flow comparison between FSAR and TRACE for CLOF transient.

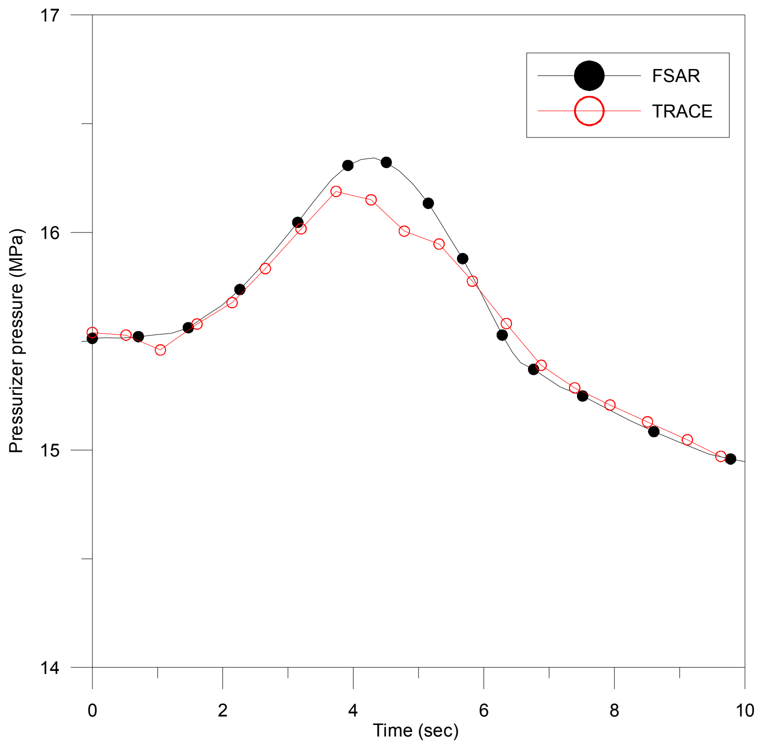

Figure 9 The pressurizer pressure comparison between FSAR and TRACE for CLOF transient.

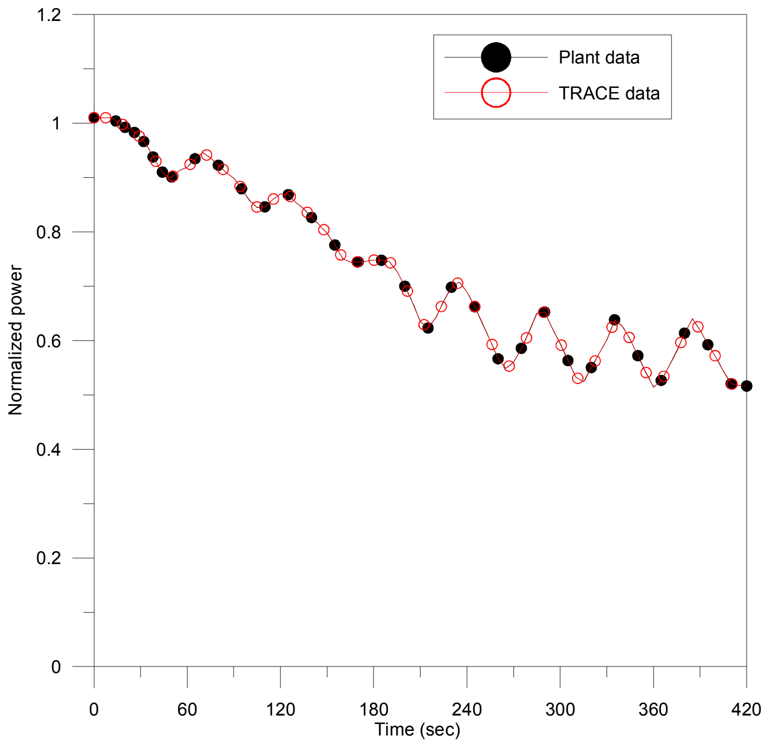

Figure 10 The power of large load reduction transient.

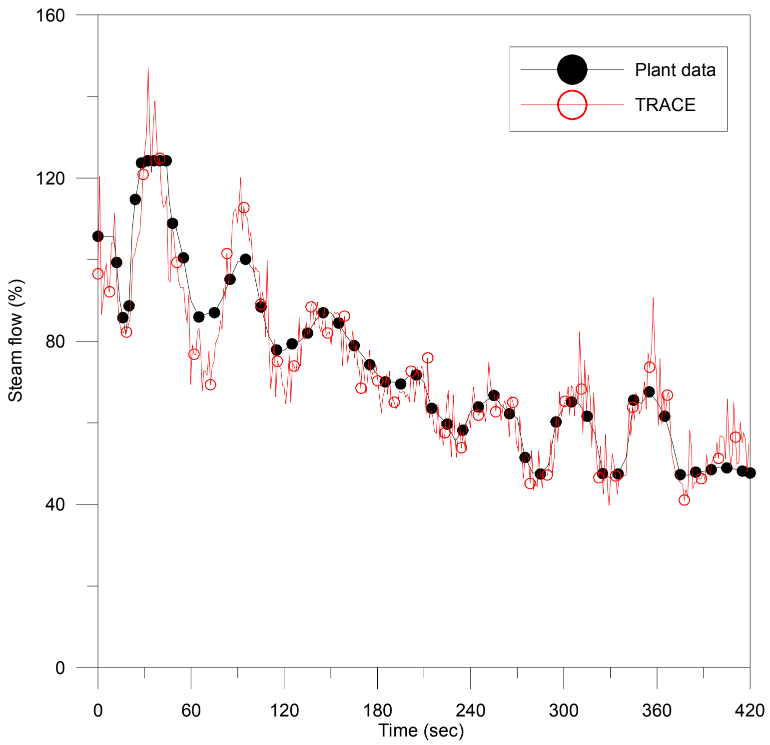

Figure 11 The S/G steam flow comparison between startup test data and TRACE for large load reduction transient.

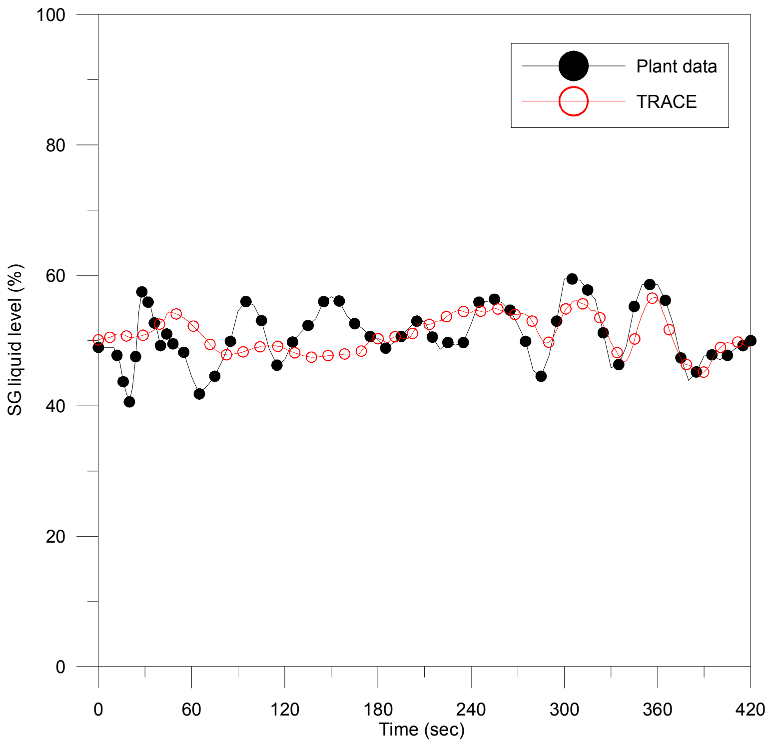

Figure 12 The SG liquid level comparison between startup test data and TRACE for large load reduction transient.

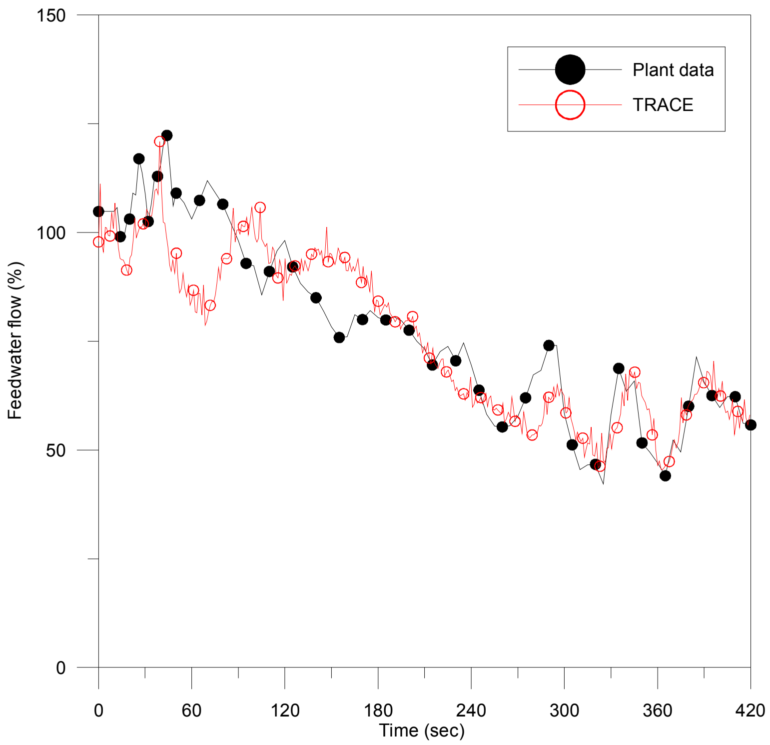

Figure 13 The feedwater flow comparison between startup test data and TRACE for large load reduction transient.

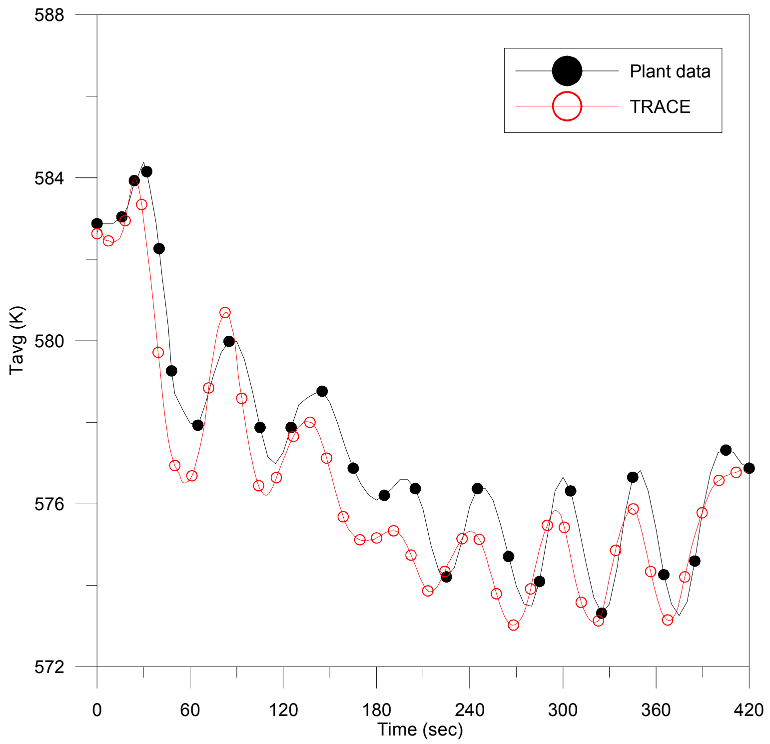

Figure 14 The T_{avg} comparison between startup test data and TRACE for large load reduction transient.

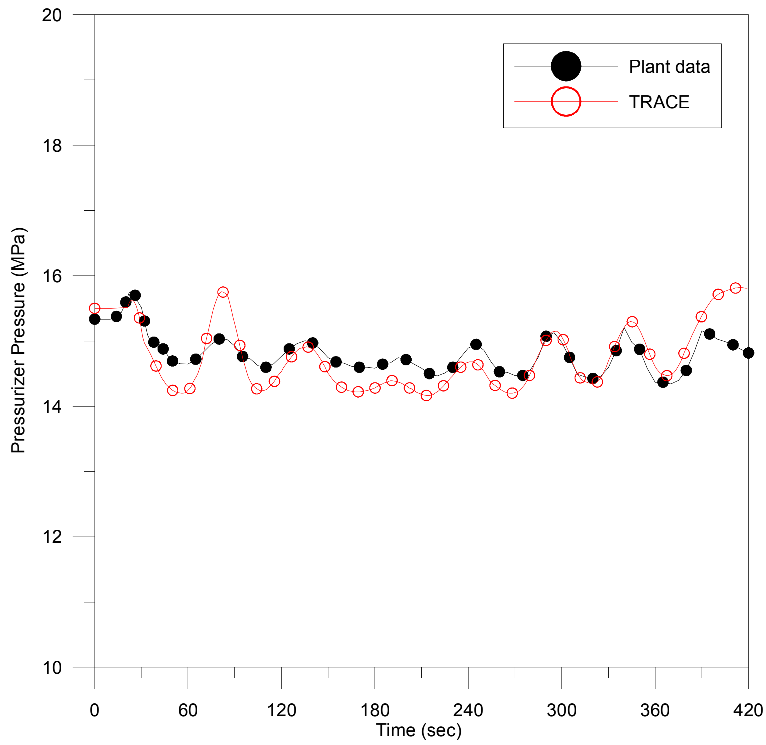

Figure 15 The pressurizer pressure comparison between startup test data and TRACE for large load reduction transient.

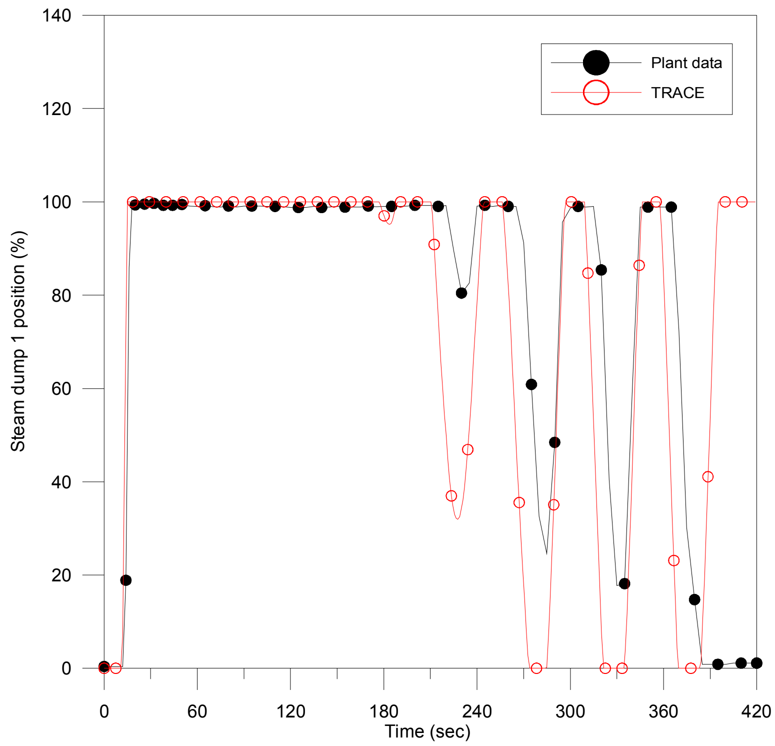

Figure 16 The steam dump 1 position comparison between startup test data and TRACE for large load reduction transient.