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Using TRACE and SNAP Codes to Establish the Model of Maanshan PWR for SBO Accident

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***Abstract*—**In this research, TRACE code with the interface code-SNAP was used to simulate and analyze the SBO (station blackout) accident which occurred in Maanshan PWR (pressurized water reactor) nuclear power plant (NPP). There are four main steps in this research. First, the SBO accident data of Maanshan NPP were collected. Second, the TRACE/SNAP model of Maanshan NPP was established by using these data. Third, this TRACE/SNAP model was used to perform the simulation and analysis of SBO accident. Finally, the simulation and analysis of SBO with mitigation equipments was performed. The analysis results of TRACE are consistent with the data of Maanshan NPP. The mitigation equipments of Maanshan can maintain the safety of Maanshan in the SBO according to the TRACE predictions.

***Keywords*—**PWR, TRACE, SBO, Maanshan.

I. Introduction

TAIWAN has four NPPs. Hence, people in Taiwan concern the safety of NPPs. To use computer codes to analyze transients of NPP can increase and maintain the NPP safety. TRACE is an advanced thermal hydraulic code for safety analysis [1]. One feature for TRACE is a 3-D geometry reactor vessel. This can support a more accurate and detailed safety analysis. In addition, SNAP is a graphic interface code and can process inputs, outputs, and animation models for TRACE [2]. Taiwan and the United States have signed an agreement on CAMP (Code Applications and Maintenance Program). The purpose of CAMP is to develop and update TRACE and SNAP. In addition, U.S. NRC leads CAMP. Therefore, our group can get TRACE and SNAP from U.S. NRC. And we use TRACE and SNAP codes to perform transient analysis and studies for NPPs safety.

Maanshan NPP is the third plant. Additionally, Maanshan is a Westinghouse three-loop PWR plant. The SBO accident of Maanshan NPP occurred on 18 March, 2001 [3]. According to the data of Maanshan NPP [3]-[5], an analysis methodology was established in this research by using TRACE and SNAP codes. Three main steps are in this research. First, the data of SBO accident for Maanshan NPP were collected. Second, the model of TRACE/SNAP was established and developed by using the above data. Third, the simulation and analysis of SBO accident was performed by using the TRACE/SNAP model. Finally, the TRACE/SNAP model was used to perform the simulation and analysis of SBO with mitigation equipments. Hence, this analysis methodology and TRACE/SNAP model can increase and maintain effectively the safety of Maanshan NPP.

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II. The Description of TRACE/SNAP Model

In our previous study, the TRACE/SNAP model of Maanshan PWR which used the older version TRACE and SNAP was established [6]. Fig. 1 shows the new TRACE/SNAP model of Maanshan PWR which was established by using the new version TRACE, SNAP, and Maanshan data [1]-[3]. The TRACE/SNAP model contains 136 hydraulic components, 34 heat structures, 682 control blocks, and 2 power components. The main components including one 3-D vessel, one pressurizer, three RCS loops, three steam generators and basic control systems such as 3-element feedwater control, pressurizer level and heater control, pressurizer spray and steam dump control.

The 3-D vessel component contains two radial rings, six azimuthal sectors, and 12 axial levels. The inner radial ring from axial level 3 to axial level 6 is the core of the reactor. The downcomer region is simulated in the outer radial ring region. The core region connects six control rod guide tubes. The fuels are simulated by six heat structures. Each reactor coolant system (RCS) loop contains steam generator U-tube, hot leg piping, cold leg piping, crossover piping, reactor coolant pump, accumulator tank and accumulator check valve. The pressurizer and pressurizer surge line are connected on RCS loop number 2. The initial condition data calculated by TRACE steady-state calculation are listed in Table I. Table I also shows the predictions of TRACE are similar with the data of Maanshan NPP. In addition, this model was verified with the startup-tests data of Maanshan [7]. The comparison results show that the TRACE/SNAP model has a respectable accuracy.

TABLE I
THE INITIAL CONDITION FOR STEADY-STATE

	TRACE data	NPP data	Difference (%)
Core thermal power (MW)	2822	2822	0
RCS pressure (MPa)	15.518	15.513	0.03
Total RCS flow (Mkg/hr)	49.57	49.59	0.04
Pressurizer liquid volume (m^3)	23.786	23.79	0.017
Hot-leg Temperature (K)	601.7	599.75	0.33
Cold-leg Temperature (K)	566.57	565.35	0.22
Steam generator pressure (MPa)	6.91	6.74	2.5
Steam temperature (K)	558.09	555.45	0.48
Steam generator narrow range water level (%)	50	50	0

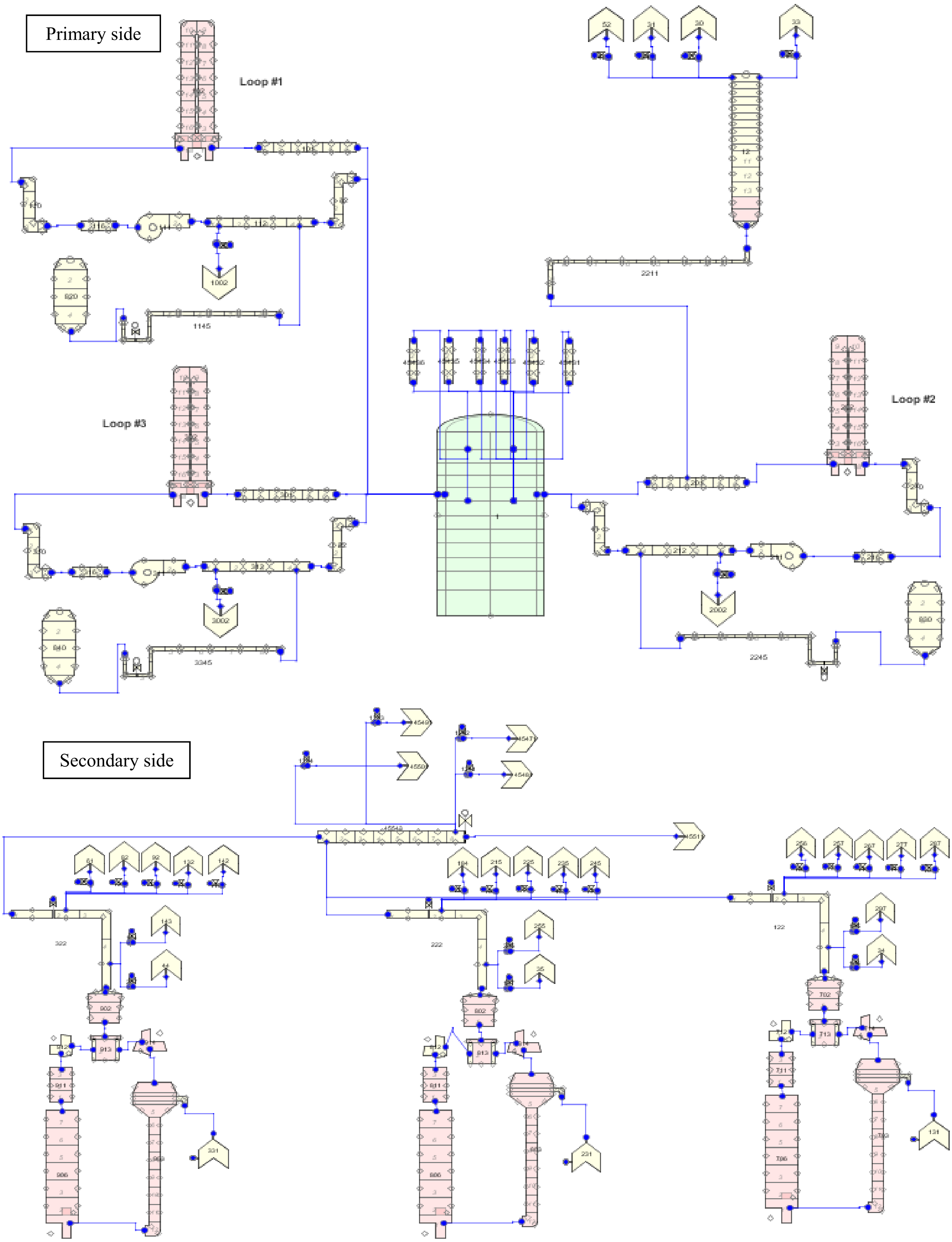

Fig. 1 The TRACE/SNAP model of Maanshan PWR

III. The Description of SBO Accident

Salty wind from the ocean can demote the insulation of power transmission line and resulting in the instability of off-site power in nearby NPP during spring season in Taiwan. The 345 kV off-site power line was lost because of salty wind and 161 kV off-site power was still available on March 17th, 2001, 3:23 am. The Unit 1 of Maanshan NPP tripped and was maintained at hot standby condition by operators.

The malfunctioned breaker in on-site AC power electric system accidentally grounded at 0:46 am, March 18th, which generated electric arc to damage other electric systems. The emergency 4.16 kV bus train A and B were both loss of power supply which is a SBO. The turbine driven auxiliary feedwater system began automatically to provide cold water into steam generators at 0:57am.

The operators began to initiate the EOP (emergency operating procedure) to depressurize the steam generators at 0:58 am. The steam generator pressure and water level and auxiliary feedwater flow rate were controlled and maintained manually by the operators. The emergency diesel generator successfully supplied AC power to emergency 4.16 kV bus B at 2:54 am. Therefore, SBO situation was terminated.

Duration of SBO is about two hours which began from 0:46 am to 2:54 am, March 18th. Additionally, the temperature and pressure of the reactor decreased from 564 K/ 15.3 MPa to 472 K/4.2 MPa. The fuels were covered with water, and no radioactive materials were released during the SBO. The simulation of SBO accident is performed by using Maanshan TRACE/SNAP model. This simulation is from 0:30 am to 3:30 am, March 18th. In addition, the results of TRACE were compared with the plant data to confirm the accuracy of TRACE/SNAP model.

IV. Results

So far, many versions of TRACE and SNAP are used in all kinds of studies and analysis. Therefore, two versions of TRACE and SNAP were used in this research. That is TRACE V5.0p3 / SNAP V2.2.1 (older version) and TRACE V5.0p4 / SNAP V2.5.1 (new version). The analysis results of TRACE are shown in Figs. 2-5.

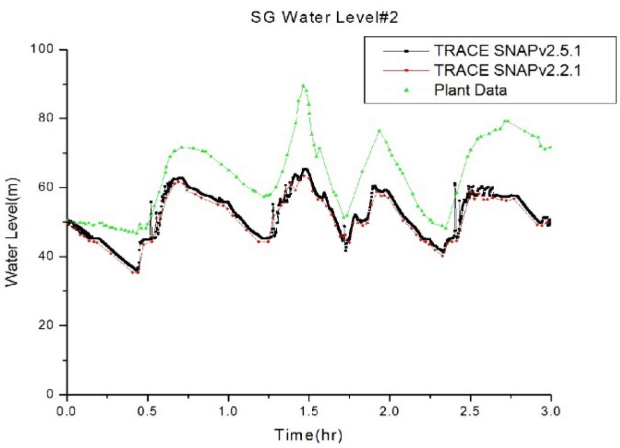

Fig. 2 The narrow range water level of steam generator #2

According to Table II, the SBO occurred at 16 minutes after the simulation began. The turbine driven auxiliary feedwater system (TDAFW) automatically started at 0.45 hour. Operators control the flow rate of auxiliary feedwater via regulating the throttling valve to keep the water levels of steam generators. Because TDAFW system injects water to steam generators, the water level is above 50% most of the time. The TRACE result is like the plant data (see Fig. 2).

The operators started to initiate EOP to decrease the steam generator pressure by opening steam line PORV at 0.46 hour. In TRACE/SNAP model, the PORVs are controlled based on the steam pressure data of Maanshan NPP. Therefore, the TRACE results are the same with the plant data (shown in Fig. 3). The depressurization of steam generator can effectively remove residual heat from the reactor coolant system. Hence, the coolant temperature and pressure decrease (see Figs. 4 and 5). According to above figures, the TRACE results are consistent with the plant data. In addition, the results of TRACE V5.0p4/SNAP V2.5.1 are nearly the same with TRACE V5.0p3/SNAP V2.2.1. This indicates that the effect of version of TRACE and SNAP is very small in this case.

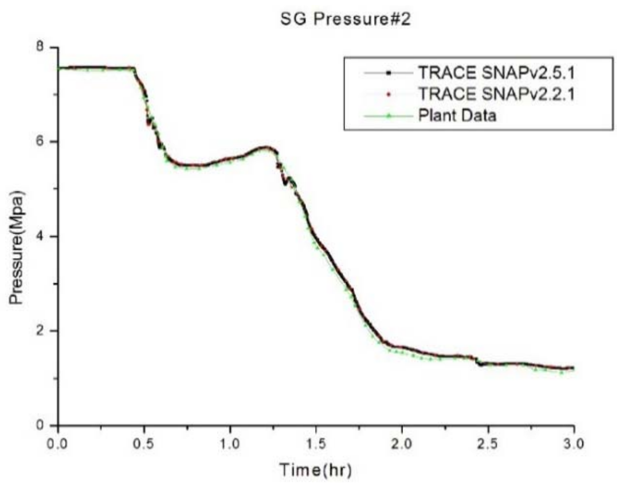

Fig. 3 The pressure of steam generator #2

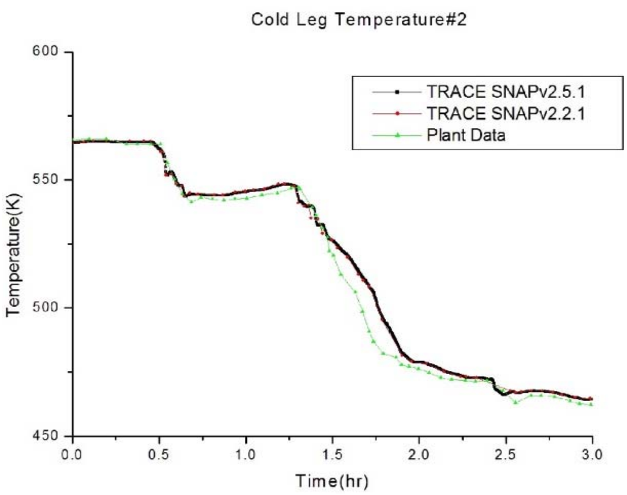

Fig. 4 The liquid temperature of cold leg #2

TABLE II
THE SCENARIO OF MAANSHAN NPP SBO ACCIDENT

Simulation Time (hr)	Accident
--	345 kV off-site power lost Reactor trip
0	Simulation start with hot standby condition
0.26	Breaker failure (SBO)
0.45	Turbine driven auxiliary feedwater (TDAFW) start
0.46	Initiate EOP (SG & RCS cooling)
2.4	SBO terminated
3	End of simulation

TABLE III
THE SCENARIO FOR SBO WITH MITIGATION EQUIPMENTS

Simulation Time (min)	Action
0	Start of simulation
1	The SBO, reactor scram, turbine trip, MSIV closure, RCP trip, feedwater trip, and seal leakage occur TDAFW on Seal leakage rate is 21 gpm/loop Control depressurization, SG pressure depressurize to 21 kg/cm² (300 psia)
480(8hr)	Emergency depressurization, SG pressure depressurize to 3 kg/cm²
480(8hr)	TDAFP off Fire pump 800 gpm (35.704 kg/s) to SG Hydro-Test pump 25 gpm (1.14 g/s) to RPV
4800(80hr)	End of simulation

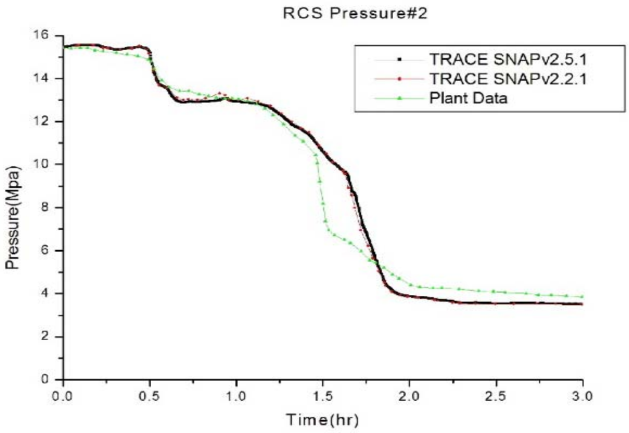

Fig. 5 The pressure of reactor coolant system

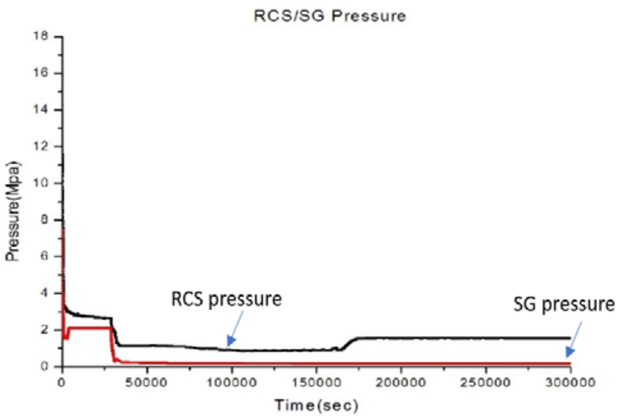

Fig. 6 The pressure of reactor coolant system

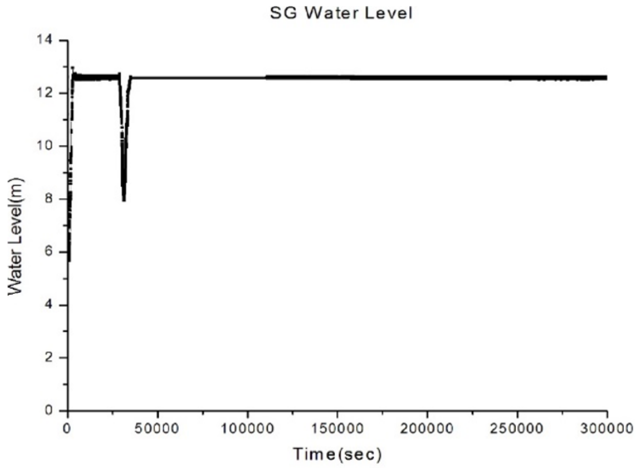

Fig. 7 The pressure of reactor coolant system

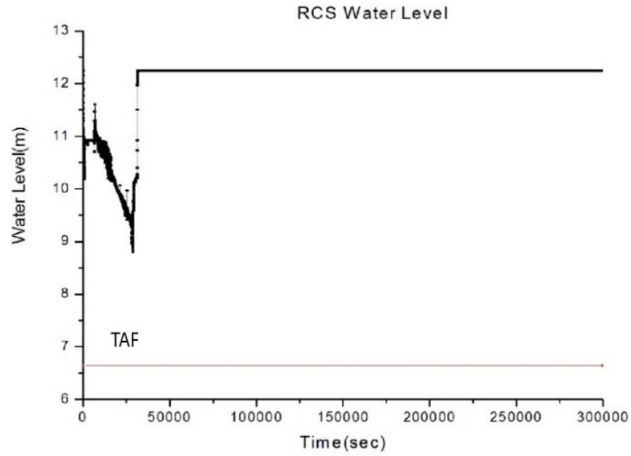

Fig. 8 The pressure of reactor coolant system

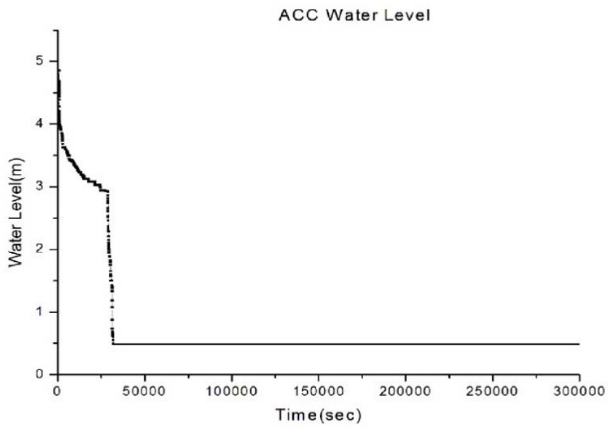

Fig. 9 The pressure of reactor coolant system

In addition, Maanshan NPP adds some mitigation equipments after Fukushima accident which includes fire pump, hydro-test pump, accumulator (ACC), etc. In this study, the TRACE/SNAP model was also used to perform the analysis and simulation of SBO with mitigation equipments. Table III shows the scenario for SBO with mitigation equipments. The TRACE results are shown in Figs. 6-10. The control and emergency depressurizations are performed in this case. In addition, the water injection of fire and Hydro-test pumps are also performed in this case. The SBO occurred at 1 minute first. Subsequently, the reactor scram and control depressurization occurred which resulted in the RCS and SG pressures dropping (see Fig. 6). The RCS and SG pressures decreased again due to the emergency depressurization after 8 hr. The SG water level was kept at full water level since TDAFW was available (see Fig. 7) for 0 minute~8 hr. After 8hr, the fire pump injected water to SGs and Hydro-Test pump injected water to RPV. Therefore, the SG water level kept at full water level and RCS water level increased after 8 hr (shown in Figs. 7 and 8). Fig. 9 shows the water level of the accumulator. The accumulator started to inject water at about 0.2 hr. The PCT is always under 1088.7 K because the RCS water level is above the TAF (see Fig. 10). According to the above results, the mitigation equipment of Maanshan can maintain the safety of Maanshan in the SBO.

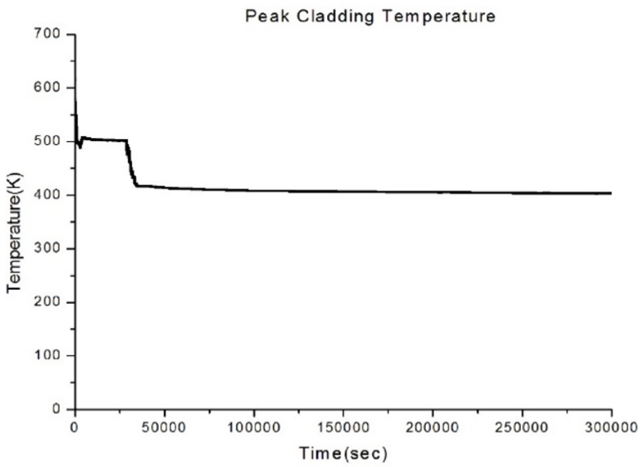

Fig. 10 The pressure of reactor coolant system

V. Conclusion

By using TRACE and SNAP codes, an analysis methodology was established to simulate and analyze the SBO accident of Maanshan PWR in this research. The predictions of TRACE are consistent with the data of Maanshan SBO accident. This implies that the TRACE/SNAP model of Maanshan PWR has a respectable accuracy for SBO. Therefore, this TRACE/SNAP model can be used to perform SBO or Fukushima-like transient for NPP safety. Additionally, the TRACE predictions present that the mitigation equipment of Maanshan can maintain the safety of Maanshan in the SBO. In addition, TRACE V5.0p3 / SNAP V2.2.1 (older version) and TRACE V5.0p4 / SNAP V2.5.1 (new version) were used in this research. However, the analysis results present that the effect of version of TRACE and SNAP is very small.

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