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International Agreement Report

The Development and Assessment of TRACE Model for Maanshan Nuclear Power Plant LOCA

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ABSTRACT

The U.S. NRC is developing an advanced thermal hydraulic code named TRACE for safety analyses of nuclear power plants (NPPs). According to TRACE user's manual, 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. SNAP is a program with graphic user interface, which processes the input and output of TRACE. As TRACE user's manual describes, TRACE has a greater simulation capability than the other old codes, especially for events like loss-of-coolant accident (LOCA).

The Maanshan NPP operated by Taiwan Power Company is the only Westinghouse-PWR in Taiwan. The rated core thermal power is 2775 MWt. The reactor coolant system has three loops, each of which includes a reactor coolant pump and a steam generator. The pressurizer is connected to the hot-leg piping in loop 2. The Maanshan NPP TRACE model has been successfully established [1]-[3]. This study focuses on the establishment of the TRACE large break LOCA (LBLOCA) model for Maanshan NPP. Then, the TRACE LBLOCA analysis results compare with the FSAR data [4]. In this study, the LBLOCA is defined as a double-ended guillotine in cold-leg. The break is located in loop 1, which is one of the two loops that don't have a pressurizer. For a LBLOCA analysis, the most important parameter is the peak cladding temperature (PCT). As defined by the 10 CFR 50.46 regulation [5], the PCT does not exceed 1477.6 K (2200℉). In this LBLOCA, the peak cladding temperature of TRACE calculated was 1358.8 K (1986℉).

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 LOCA model of Maanshan NPP has been built. In this report, the LBLOCA transient data of Maanshan NPP is utilized and conducted to confirm the accuracy of the TRACE model.

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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 LOCA model of Maanshan NPP is developed by INER.

According to the TRACE user's manual [6], 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. Therefore, in the future, NRC has ensured that TRACE will be the main code used in thermal hydraulic safety analysis, without further development of other thermal hydraulic codes such as RELAP5 and TRAC. Besides, the 3-D geometry model of reactor vessel is one of the features of TRACE. It can support a more accurate and detailed safety analysis of NPPs. TRACE has a greater simulation capability than the other old codes, especially for events like LOCA.

The Maanshan NPP operated by Taiwan Power Company is the only Westinghouse-PWR in Taiwan. The rated core thermal power is 2775 MWt. The reactor coolant system has three loops, each of which includes a reactor coolant pump and a steam generator. The pressurizer is connected to the hot-leg piping in loop 2. The Maanshan NPP TRACE model has been successfully established [1]-[3]. This research focuses on the establishment of the TRACE LBLOCA model for Maanshan NPP. The codes used in this research are TRACE v 5.0p1 and SNAP v 2.0.3. Then, the TRACE LBLOCA analysis results compare with the FSAR data [4]. The main components of LBLOCA model include the pressure vessel, pressurizer, steam generators, steam piping in the secondary side, the steam dump system, accumulators, and safety injection of emergency core cooling system (ECCS). The TRACE LBLOCA model of Maanshan NPP is a three-loop model and each loop has a feedwater control system. The pressure vessel of the TRACE LBLOCA model is cylindrical. The pressure vessel is divided into 12 levels in the axial direction, two rings in the radial direction (internal and external rings) and six equal azimuthal sectors in the "θ" direction. The control rod conduit connects the 12th and 7th layers of the vessel from end to end. The fuel region is between the third and sixth layers, and heat conductors are added onto these structures to simulate the reactor core. In this study, the LBLOCA is defined as a double-ended guillotine in cold-leg. The break was located in loop 1, which is one of the two loops that don't have a pressurizer. In transient analysis, the TRACE code simulates or calculates the core power by either two methods. One is a constant power or input the power curve by "power table" into the TRACE model. Another is to use "point kinetic" data (e.g., the delay neutron fraction, Doppler reactivity coefficient, and moderator temperature reactivity coefficient) in the TRACE model and let TRACE to calculate the solution of the point kinetic equations for the transient analysis. These point kinetic equations specify the time behavior of the core power with neutronic reactivity (include the sum of programmed reactivity and feedback reactivity). The feedback reactivity calculation of TRACE is based on changes in the core-averaged fuel temperature, coolant temperature, gas volume fraction, and boron concentration. In this research, we use the TRACE point kinetic to calculate the core power, and compare with the FSAR data.

By using SNAP/TRACE, this study establishes the TRACE LBLOCA model of the Maanshan NPP. Analytical results indicate that the Maanshan NPP TRACE LBLOCA model predicts not only the behaviors of important plant parameters in consistent trends with the FSAR data [4], but also provides a greater margin for the PCT evaluation. The TRACE model of Maanshan NPP can be used in future safety analysis with confidence, such as the applications for different break size and other break locations in LOCA. As defined by the 10 CFR 50.46 regulation [5], the PCT does not exceed 1477.6 K (2200℉). In this LBLOCA, the peak cladding temperature of TRACE calculated was 1358.8 K (1986℉).

ABBREVIATIONS

BAF	Bottom of the Active Fuel
CAMP	Code Applications and Maintenance Program
CCFL	Counter Current Flow Limitation
CHF	Critical Heat Flux
ECCS	Emergency Core Cooling System
FSAR	Final safety analysis report
HHSI	High Head Safety Injection
INER	Institute of Nuclear Energy Research Atomic Energy Council, R.O.C.
LBLOCA	Large Break LOCA
LHSI	Low Head Safety Injection
LOCA	Loss Of Coolant Accident
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
PCT	Peak Cladding Temperature
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RCP	Reactor Coolant Pumps
SIS	Safety Injection Signal
SNAP	Symbolic Nuclear Analysis Program
TAF	Top of the Active Fuel
TRACE	TRAC/RELAP Advanced Computational Engine
US	United States

1. INTRODUCTION

The U.S. NRC is developing an advanced thermal hydraulic code named TRACE for safety analyses of NPPs. According to the reference [6], 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. Therefore, in the future, NRC has ensured that TRACE will be the main code used in thermal hydraulic safety analysis, without further development of other thermal hydraulic codes such as RELAP5 and TRAC.

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As defined by the 10 CFR 50.46 regulation [5], the PCT does not exceed 1477.6K (2200℉). In this LBLOCA, the peak cladding temperature of TRACE calculated was 1358.8K (1986℉).

2. Description of the codes and Maanshan TRACE LBLOCA model

2.1 Codes

The codes used in this research are TRACE v 5.0p1 and SNAP v 2.0.3. SNAP is a program with graphic user interface which processes the inputs and outputs of TRACE. 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 NPPs. As the reference [6] describes, TRACE has a greater simulation capability than the other old codes, especially for events like LOCA. Models for multidimensional two-phase flow, non-equilibrium thermo-dynamics, heat transfer, reflood, level tracking, and reactor kinetics are also included in TRACE.

The results of TRACE LBLOCA analysis are compared with the FSAR data of Maanshan NPP. There are four codes used for LBLOCA analysis in FSAR, which are SATAN, BASH, COCO, and LOCBART. SATAN is a one-dimensional nodal network code which models the thermal-hydraulic phenomena during the blowdown depressurization of the reactor coolant system after a postulated large rupture of a primary coolant pipe. The BASH code is used to calculate the refill and reflood portions of the LBLOCA. The COCO code can calculate the pressure and temperature transients inside the containment during the depressurization and post-blowdown phase following a LOCA. The LOCBART code is used to calculate the hot rod temperature during the blowdown, refill, and reflood phases of the LBLOCA.

2.2 Maanshan TRACE LBLOCA model

Fig 2.1 shows the TRACE LBLOCA model of Maanshan NPP. It is a three-loop model and each loop has a feedwater control system. The main structure of this model includes the pressure vessel, pressurizer, steam generators, steam piping at the secondary side, the steam dump system, accumulators, and safety injection of ECCS. The pressure vessels are cylindrical, and its divisions are as shown in Fig 2.1. It is divided into 12 levels in the axial direction, two rings in the radial direction (internal and external rings) and six equal azimuthal sectors in the "θ" direction. The control rod conduit connects the 12th and 7th layers of the vessel from end to end. The fuel region is between the third and sixth layers, and heat conductors were added onto these structures to simulate the reactor core.

Before any transient analysis can begin, a consistent set of parameters used in the TRACE model must be obtained in the process of steady-state initialization. In transient analysis, the TRACE code simulates or calculates the core power by either two methods. One is a constant power or input the power curve by "power table" into the TRACE model. Another is to use "point kinetic" data (e.g., the delay neutron fraction, Doppler reactivity coefficient, and moderator temperature reactivity coefficient) in the TRACE model and let TRACE to calculate the solution of the point kinetic equations for the transient analysis. These point kinetic equations specify the time behavior of the core power with neutronic reactivity (include the sum of programmed reactivity and feedback reactivity). The feedback reactivity calculation of TRACE is based on changes in the core-averaged fuel temperature, coolant temperature, gas volume fraction, and boron concentration. In this research, we use the TRACE point kinetic to calculate the core power, and compare with the FSAR data.

2.2.1 Break's simulation and Choked flow model

In this study, the LBLOCA is defined as a double-ended guillotine in cold-leg. According to FSAR describe, a major pipe break (large break) is defined as a rupture with a total cross sectional area equal to or greater than 1.0 ft^2. In this LBLOCA, the cross sectional area is 4.17 ft^2. Fig 2.2 shows the initial and boundary conditions of break component in the TRACE LBLOCA model. The ECCS is designed to prevent fuel cladding damage. Following a postulated double ended rupture of a reactor coolant pipe, the ECCS limits the clad temperature to well below the melting point and ensures that the reactor core remains intact and in a coolable geometry.

The break mass flow is one of the most important parameters during the simulation of LBLOCA. In this study, the choked flow model is used in the break of Maanshan NPP TRACE LBLOCA model which references to our previous study [7]. In our previous study, the TRACE IIST facility model also used the choked flow mode to simulate the IIST facility 2% cold-leg-break LOCA experiment. The analytical results of TRACE IIST facility models indicate that the TRACE IIST facility models predict not only the behaviors of important parameters in consistent trends with experiments data, but also their numerical values with respectable accuracy. Choked flow occurs when the mass flow in a pipe becomes independent of the downstream conditions [8]. Choked flow can also be defined in single-phase system with sonic velocity, choking velocity equals sonic velocity. This means that pressure signals can't be transmitted to higher pressure upstream anymore, because transmission speed can't exceed sonic velocity. The choked flow model used in TRACE is actually compounded by three different models, which are the subcooled-liquid choked-flow model, the two-phase, two-component choked-flow model, and the single-phase vapor choked-flow model. For subcooled single-phase, TRACE applies a modified form of the Burnell model and is essentially the same as that used in RELAP5. For the two-phase, two-component choked flow model, an extension of a model developed by Ransom and Trapp is used. Finally, the single-phase vapor choked flow model is based on isentropic expansion of an ideal gas. The TRACE model incorporates an additional inertgas component and nonequilibrium effects. In addition, the transition from liquid to two-phase flow, which presents a discontinuity, is handled in TRACE by linear interpolation between the subcooled and the two-phase regimes. The best value for the coefficient of the choked model was 0.5 in this study.

2.2.2 ECCS' simulation
The ECCS includes the accumulators, low head safety injection (LHSI), and high head safety injection (HHSI). Fig 2.3 shows the TRACE model of the ECCS and its control systems for Maanshan NPP. After the break occurs, low pressurizer pressure caused the ECCS injecting water to the reactor coolant system (RCS) cold-leg and preventing excessive clad temperatures. As the reactor coolant system pressure decreased below 4.24MPa, accumulator injection started. The cold water in the accumulator was expelled into the reactor coolant system by nitrogen gas filled in the accumulator. Fig 2.4 shows the simulation of the accumulators by using pipe components. The total volume and height were 41.1m^3 and 5.72m, respectively.

In a LBLOCA of a PWR, most of the initial reactor coolant inventory is rapidly expelled through the break and the pressure of the primary system decreases causing most of the liquid inventory to flash into steam. After the break occurs, the water of ECCS begins to be injected into the reactor coolant system. The purpose of the ECCS injection is to rapidly refill the reactor vessel lower plenum and to reflood the reactor core. When the pressure has decreased below the safety injection setpoint (11.8MPa), LHSI and HHSI begin to be injected into the reactor coolant system with a delay time of 27 sec. Fig 2.5 and Fig 2.6 show the LHSI and HHSI simulation of TRACE LBLOCA model. Fig 2.7 and Fig 2.8 show the fill table of LHSI and HHSI which is the safety injection flow rate correspond to the RCS pressure.

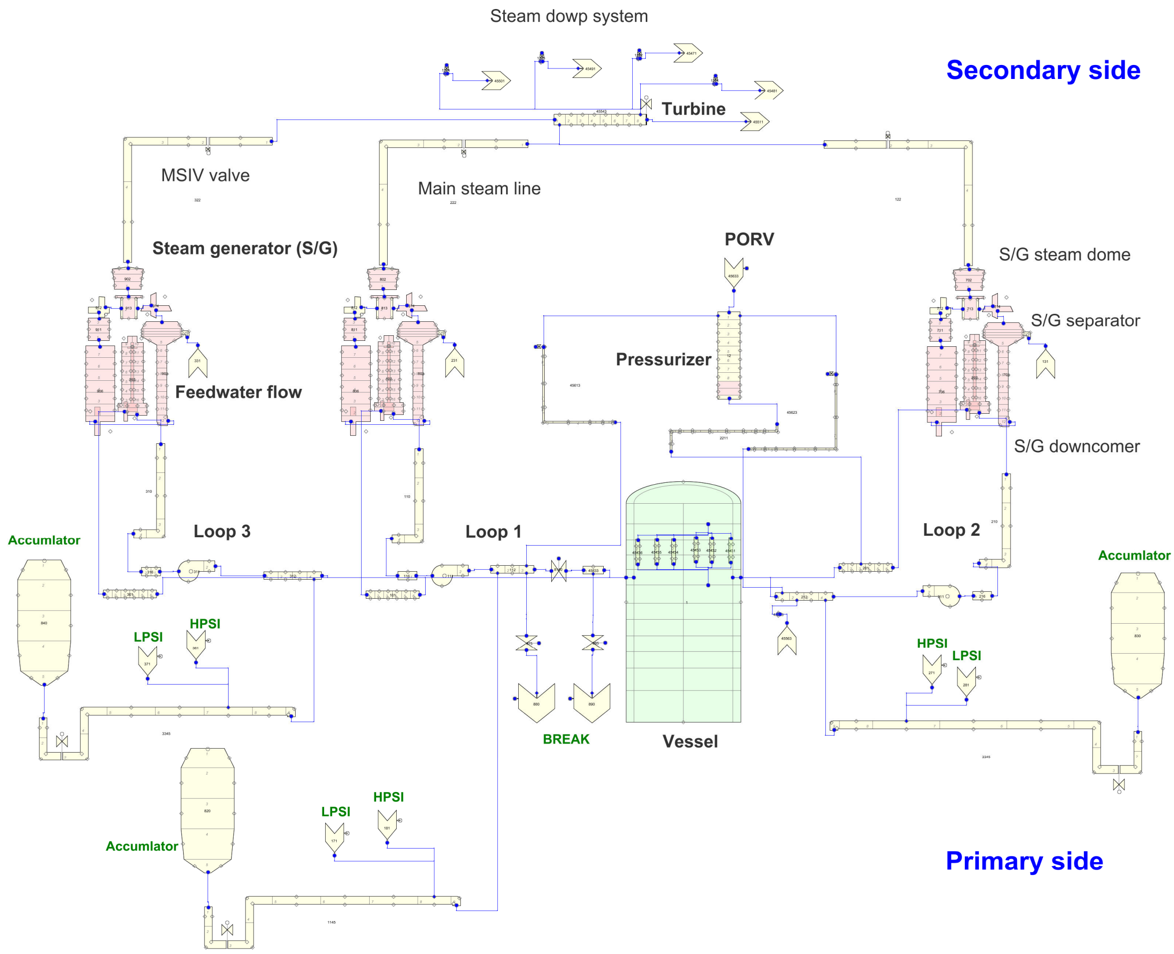
2.2.3 CCFL model
Counter Current Flow Limitation (CCFL) is an important issue related to the safety analysis of PWRs. CCFL may occur in the downcomer, the upper core tie plate, the hot legs, the entrance of the steam generator inlet plenum, and the pressurizer surge line, where the flow direction or

flow area changes. The CCFL correlations can be represented as Wallis type, Kutateladze type, and Bankoff type [8]. In TRACE, the CCFL model basically uses the Bankoff correlation. The Bankoff correlation can revert to the Wallis type or Kutateladze type by setting the interpolation constant β (β=0 is Wallis type; β=1 is Kutateladze type). The Equation of the Bankoff correlation is as follow:

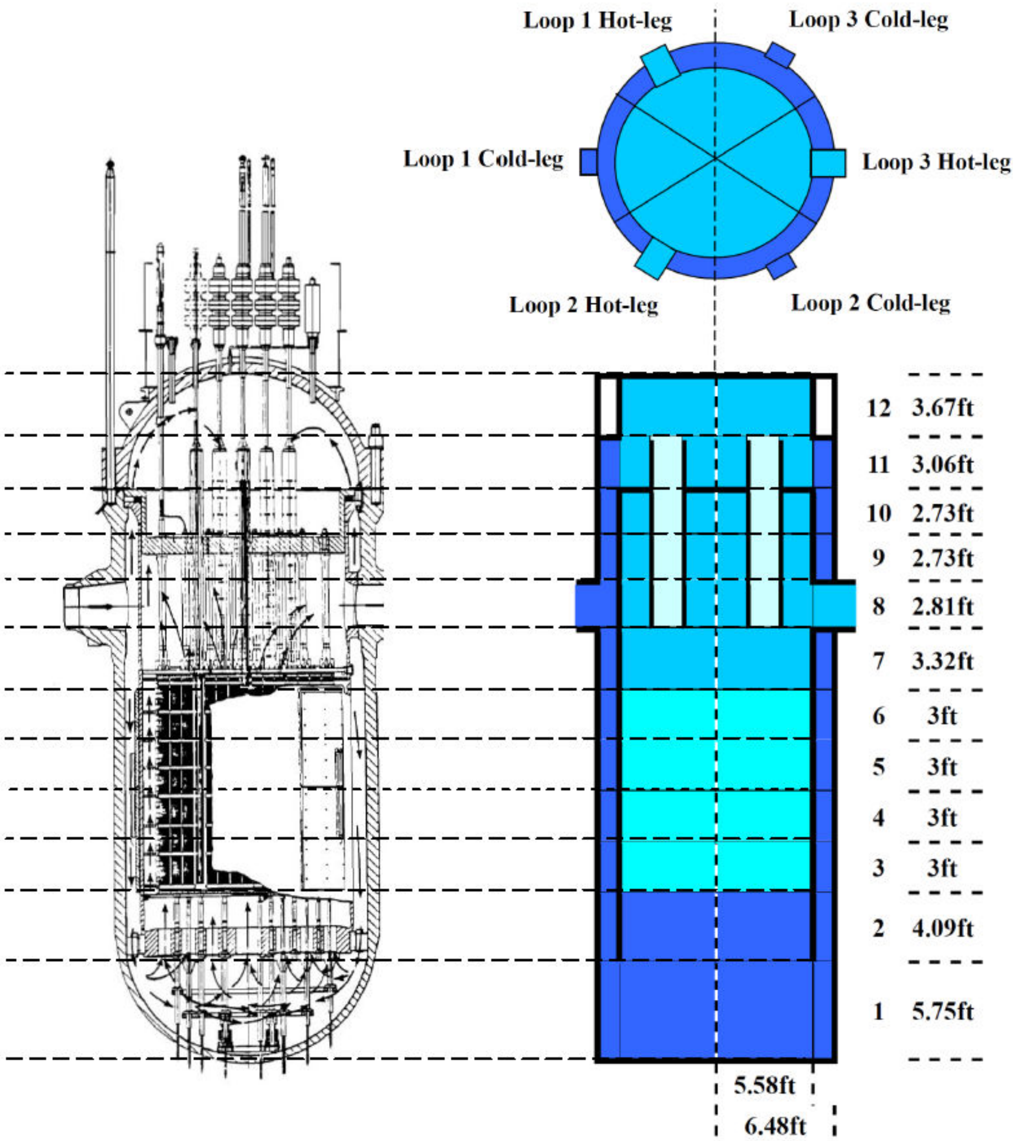
$$H_g^{1/2} + mH_l^{1/2} = C$$

where H_k is dimensionless mass flux (k=gas or liquid), m and C are constants determined from the experiments.

In this study, the CCFL model used the Kutateladze type by setting β = 1. Two correlation constants, m and C, are imported by 1.24 and 1.5, respectively.



(a) Overall region



(b) Vessel region

Fig. 2.1 The LBLOCA TRACE model of Maanshan NPP.

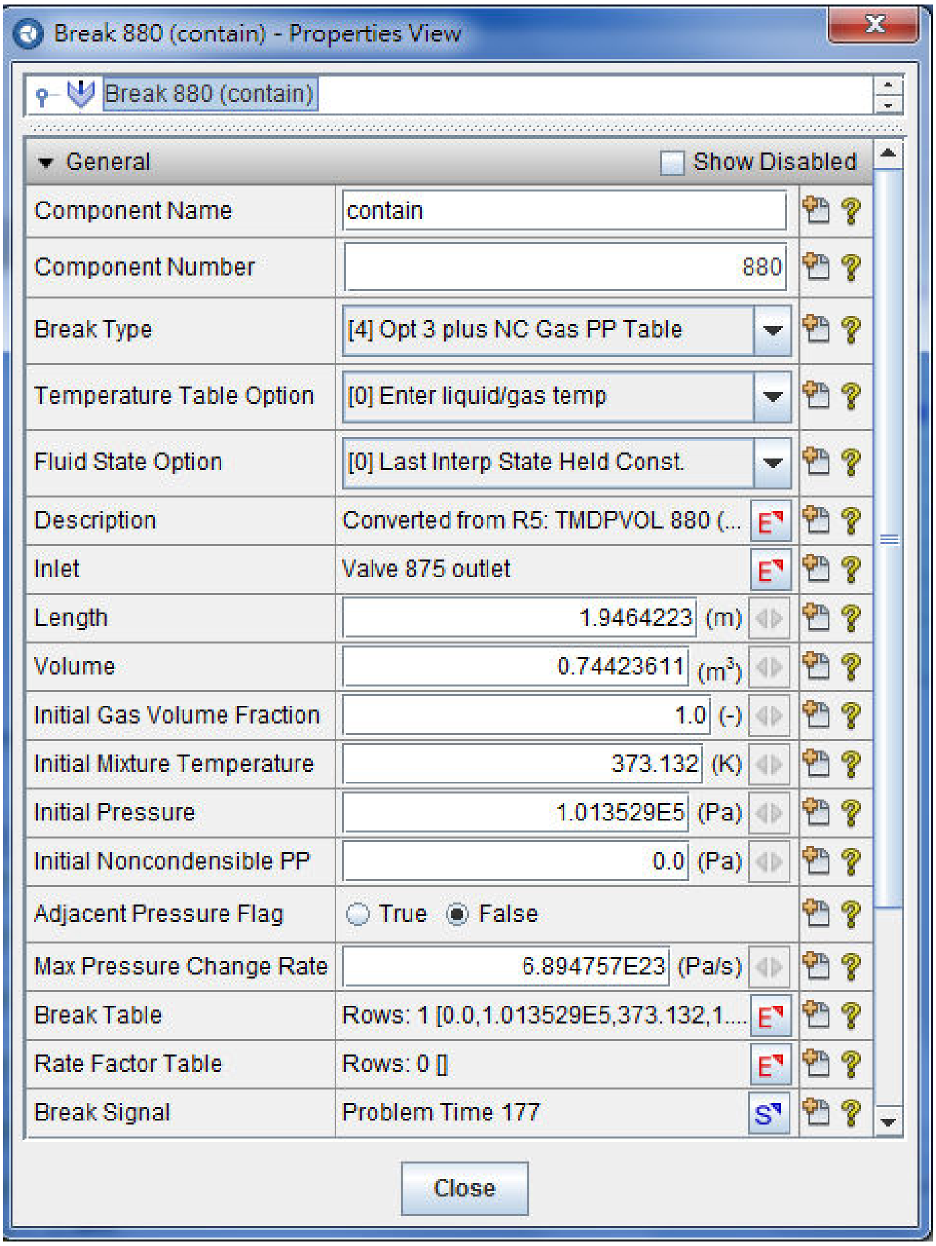


Fig 2.2 The break simulation of TRACE LBLOCA model.

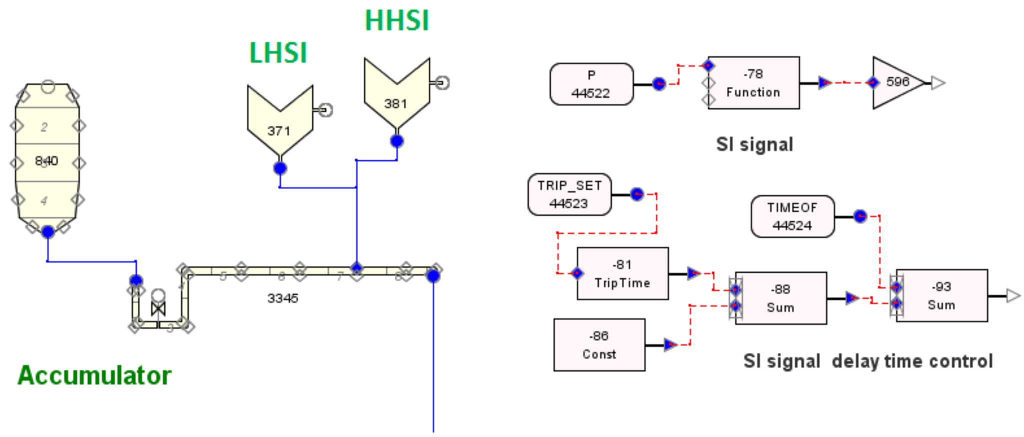
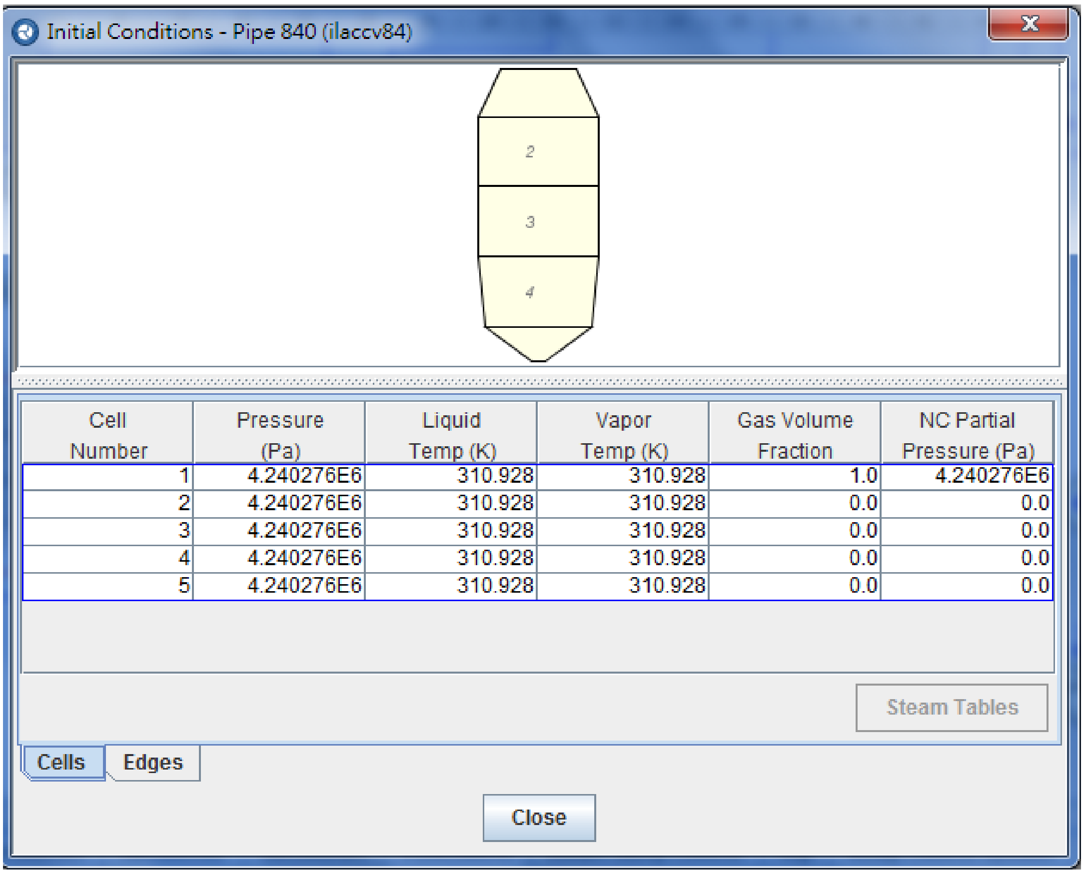


Fig 2.3 The TRACE model of the ECCS control system for Maanshan NPP.



Cell Number	Pressure (Pa)	Liquid Temp (K)	Vapor Temp (K)	Gas Volume Fraction	NC Partial Pressure (Pa)
1	4.240276E6	310.928	310.928	1.0	4.240276E6
2	4.240276E6	310.928	310.928	0.0	0.0
3	4.240276E6	310.928	310.928	0.0	0.0
4	4.240276E6	310.928	310.928	0.0	0.0
5	4.240276E6	310.928	310.928	0.0	0.0

Fig 2.4 The accumulator simulation of TRACE LBLOCA model.

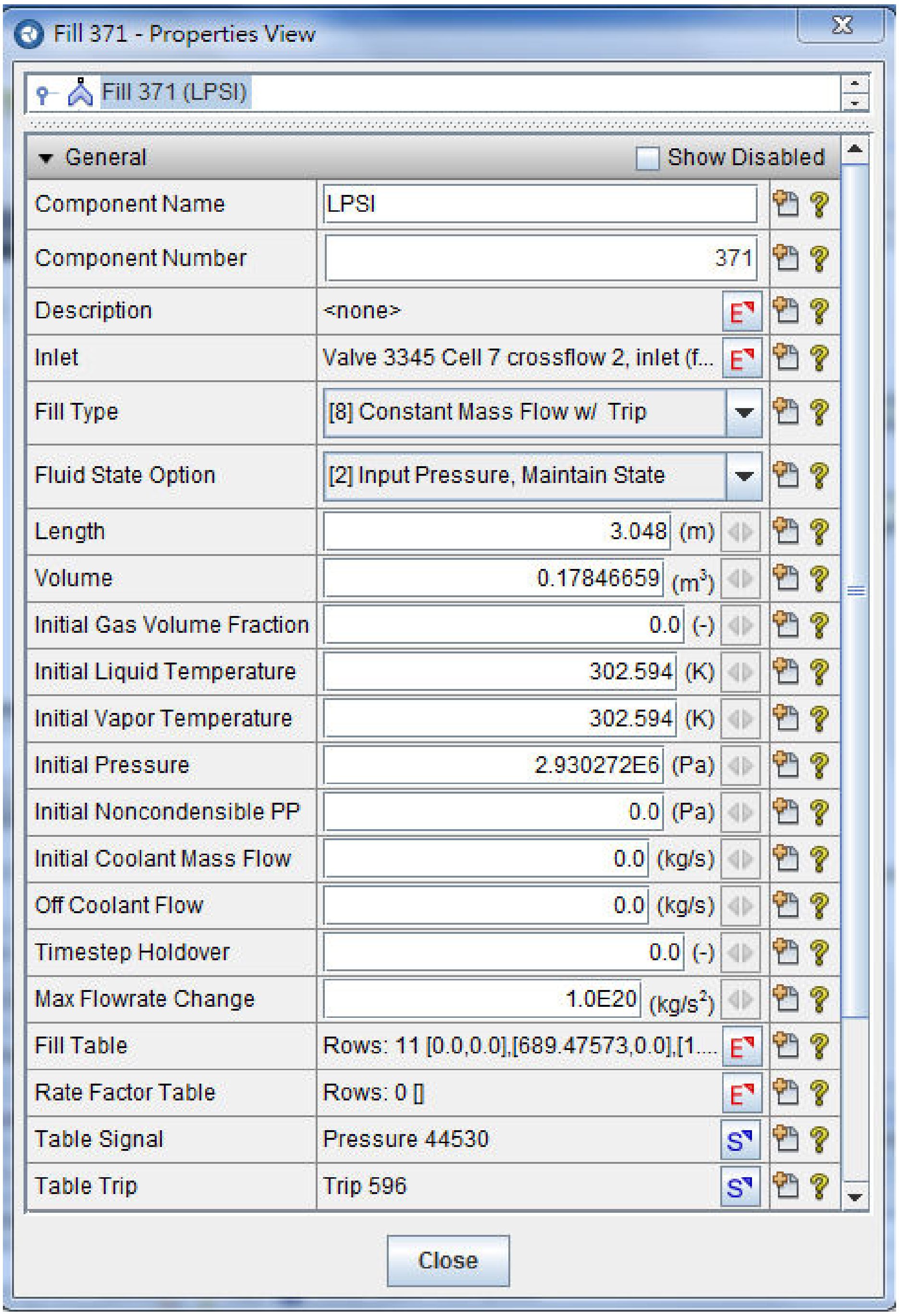


Fig 2.5 The LHSI simulation of TRACE LBLOCA model.

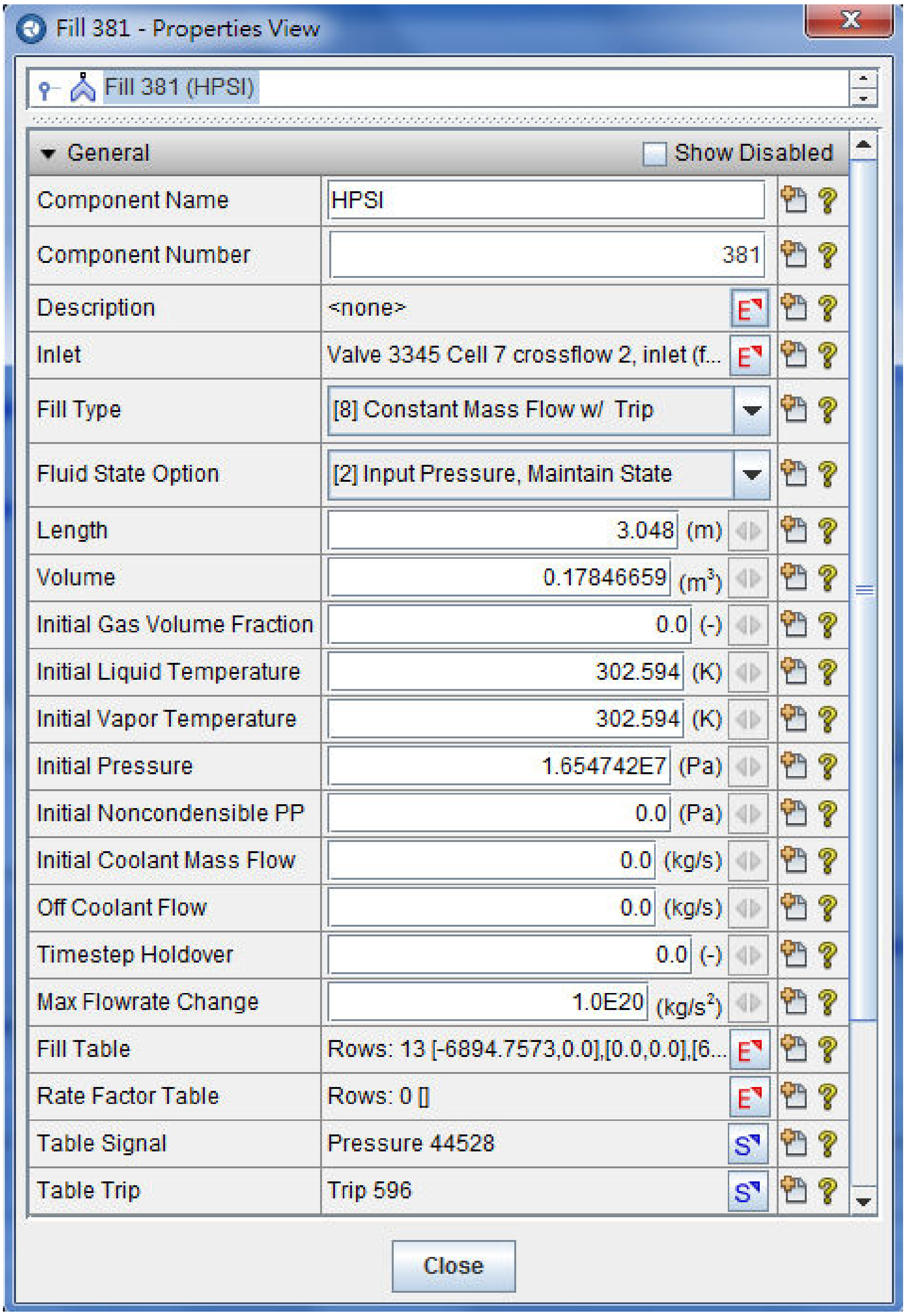


Fig 2.6 The HHSI simulation of TRACE LBLOCA model.

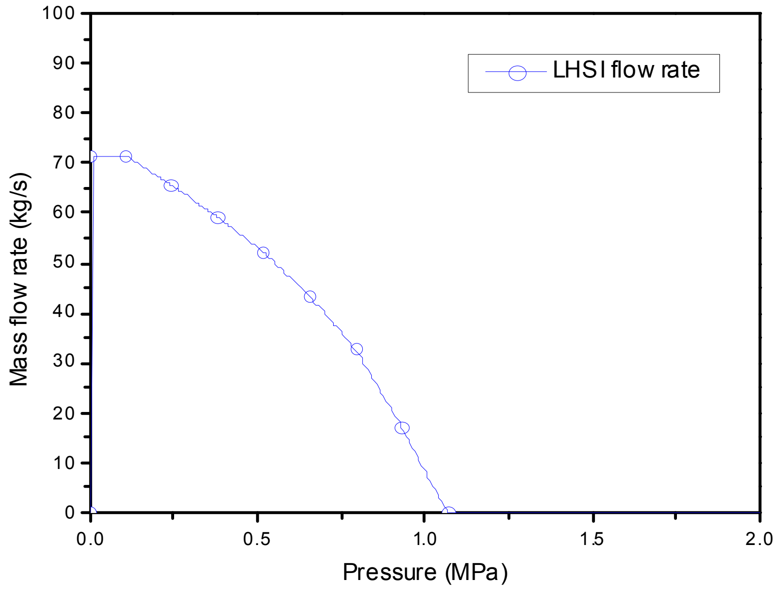


Fig 2.7 The LHSI flow rate correspond to the RCS pressure.

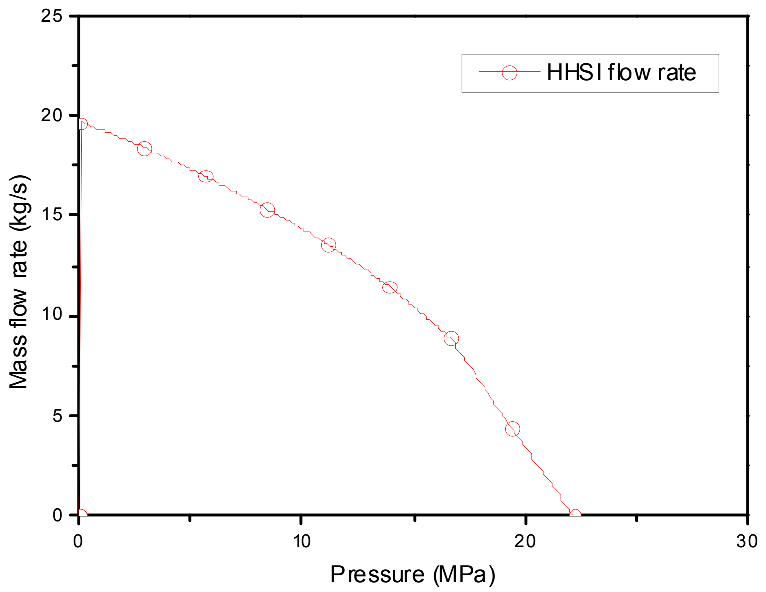


Fig 2.8 The HHSI flow rate correspond to the RCS pressure.

3. Assumptions and description of LBLOCA

By the conservative assumptions of analyzing the LOCA [4], [9]-[10], it must be assumed that the reactor has been operating continuously at a power level at least 1.02 times the licensed power level. Table 3.1 shows the initial input parameters in Maanshan LBLOCA TRACE model.

The analysis of a LBLOCA is divided into three phases: (1) blowdown, (2) refill, and (3) reflood.

3.1 Blowdown

Before the break occurs, the plant is in an equilibrium condition. Should a major break occur, depressurization of the RCS results in a pressure decrease in the pressurizer. The reactor trip signal subsequently occurs when the pressurizer low pressure trip setpoint is reached. During blowdown, heat from fission product decay, hot internals and the vessel continues to be transferred to the reactor coolant. As the core becomes uncovered, both turbulent and laminar forced convection and radiation are considered as core heat transfer mechanisms. Steam water counter-current flow blocks ECC flow in downcomer and turns it towards the broken loop instead of the reactor core (see Fig 3.1). Heat stored in the vessel walls boils ECC water and strengthens the bypass phenomenon. The important parameter of peaking cladding temperature depends on the velocity of blowdown phase in LOCA analysis. The combination of 1D and 3D components in TRACE allows an accurate modeling of complex flow networks as well as local multidimensional flows. This is important in determining of the flow velocity and primary pressure during blowdown.

3.2 Refill

When the RCS pressure is the same with the pressure of the containment, the blowdown phase of the transient terminates. During the refill phase, the mechanisms that are responsible for the bypassing of emergency core cooling water injected into the RCS are calculated not to be effective. At this time refill of the reactor vessel lower plenum begins. Refill is complete when emergency core cooling water has filled the lower plenum of the reactor vessel which is bounded by the bottom of the fuel rods.

3.3 Reflood

The reflood phase of the transient is defined as the time period lasting from the end of refill until the reactor vessel has been filled with water to the extent that the core temperature rise has been terminated. From the later stage of blowdown, and then the beginning of reflood, the safety injection accumulator tanks rapidly discharge borated cooling water into the RCS, contributing to the filling of the reactor vessel downcomer. The downcomer water elevation head provides the driving force required for the reflooding of the reactor core. The low head and high head safety injection pumps aid the filling of the downcomer and subsequently supply water to maintain a full downcomer and complete the reflooding process.

Table 3.1 The initial input parameters in TRACE model.

Input Parameters	Value
Licensed Core Power	102% of total thermal power
Loop Flow (kg/sec)	4331.8
Vessel Average Temperature (K)	584.5
Initial RCS Pressure (MPa)	15.8
Low Pressurizer Pressure Reactor Trip Setpoint (MPa)	12.8
Low Pressurizer Pressure SI Setpoint (MPa)	11.8
Safety Injection Initiation Delay time with loss of offsite power (sec)	27
Accumlator Water Volume (m^3/tank)	27.9
Accumlator Tank Volume (m^3/tank)	41.1
Minimum Accumlator Gas Pressure (MPa)	4.24
Accumlator Water Temperature (K)	311
Nominal RWST Water Temperature (K)	302.6

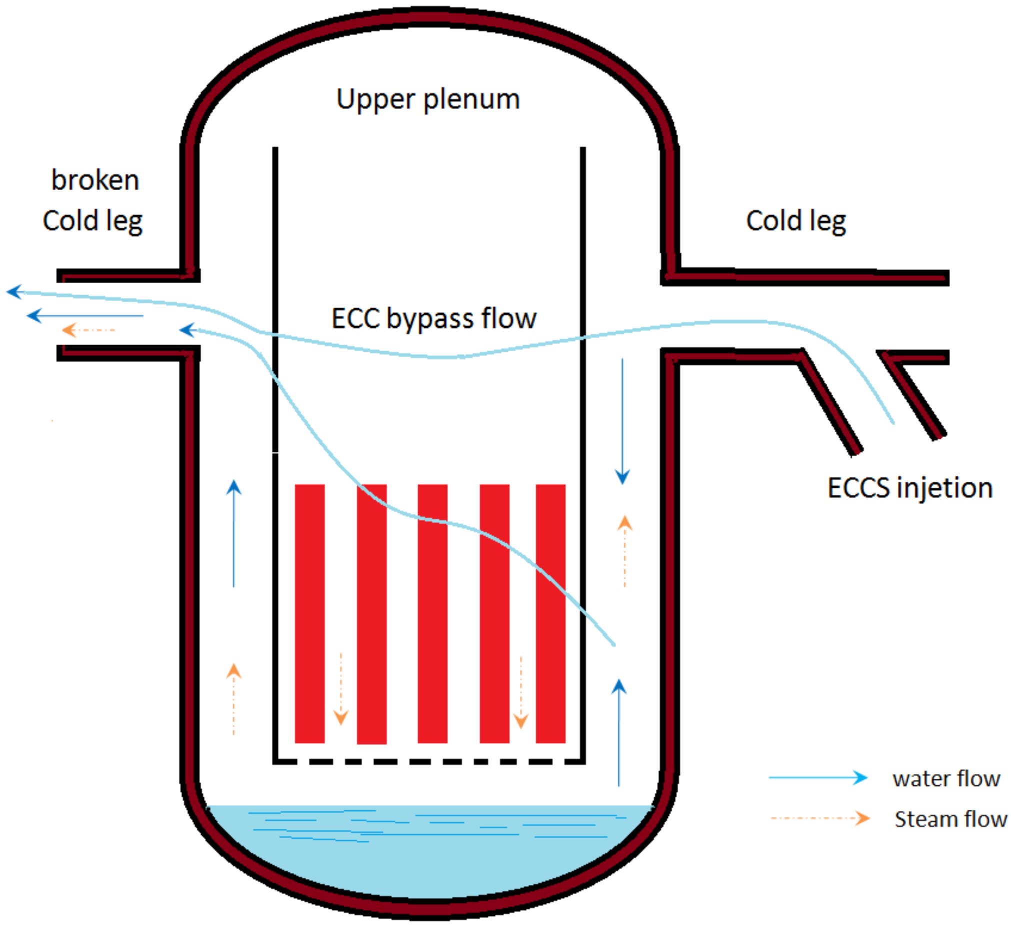


Fig 3.1 The steam and liquid flow phenomena in vessel.

4. Results and discussions

In TRACE, steady-state initialization was performed. The parameters' results such as the power, the pressure of the pressurizer, the Tavg temperature, and the RCS flow rate are compared with FSAR data [4]. Table 4.1 shows the comparison between the steady-state results of the TRACE and FSAR. The results are clearly mutually quite consistent.

4.1 The results of thermal-hydraulic parameters

Following the steady state initialization, the TRACE LBLOCA model's transient predicted results are compared with the FSAR data. Table 4.2 presents the sequence of LBLOCA and the timings of the LBLOCA predicted by TRACE. The sequence of TRACE arose from the actuation of the related control system, which in turn had to be actuated by physical parameter signals. If the parameters predicted by TRACE differ from the FSAR data, then the event sequences will also differ. Such deviations can be observed in the comparisons of transient event analyses.

Fig. 4.1 plots the power curve that calculated from TRACE in the case of LBLOCA, and then compares with the FSAR data. In TRACE, the core power can be calculated using the built-in point kinetics model, and the power calculated includes decay heat. It displays that the power curve of TRACE is almost the same as those of FSAR data. Fig. 4.2 compares the pressures of the vessel and suggests that the pressure calculated by TRACE approximately follows the trend of the FSAR data. Fig. 4.3 compares the break mass flow rate of cold-leg in loop 1. It reveals that break mass flow rate predicted by TRACE agrees closely with the results of the FSAR data. Fig. 4.4 shows the comparisons of accumulator mass flow rate of intact loops between TRACE model and FSAR data. Fig. 4.5 compares the core inlet flow rate, revealing that the flow rate calculated by TRACE is in agreement with the FSAR data except for the period between 6 and 18 sec. It reveals that the flow rate calculated by TRACE is slightly lower between 6 and 18 sec. Fig. 4.6 plots the results for core outlet flow rate. The difference results of core outlet flow before 6 sec are consideration of the nature flow in TRACE. Fig. 4.7 shows TRACE's vessel water level and PCT results. It also reveals the blowdown, refill, and reflood phases of LBLOCA. In the blowdown phase, the vessel water level dropped sharply after the break occurred. The vessel water level was lower than the BAF (Bottom of the Active Fuel). At the same time, due to the vessel water level decreased, the PCT increased. In the refill phase, the vessel water level raised. The Refill phase is complete when the water has filled the lower plenum of the reactor vessel which is bounded by the bottom of the fuel rods. The PCT reached the max. value in the refill phase. As defined by the 10 CFR 50.46 regulation [5], the PCT does not exceed 1477.6 K (2200℉). In this LBLOCA, the peak cladding temperature of TRACE calculated was 1358.8 K (1986℉). Finally, in the reflood phase, the vessel water level was higher than the BAF and the PCT dropped.

Furthermore, the animation of this TRACE LBLOCA model is presented using the animation function of SNAP/TRACE interface with above models and analysis results. The animation model of Maanshan NPP is shown in Fig. 4.8.

4.2 Sensitivity studies for LBLOCA model

The work performed to improve the Maanshan LBLOCA model was focused on following sensitivity studies. The best set of the sensitivity studies have been used in the TRACE model and the analysis results are described in section 4.1.

4.2.1 Accumulators nodalization

In LBLOCA analysis, ECCS play an important role in preventing fuel cladding damage and ensuring the core maintains integrity. In Maanshan NPP, there is one accumulator in each loop. The accumulators provide high flow borated water in a short time after the system pressure drops below 4.24 MPa. The nodalization of the accumulators becomes especially important in this LOCA analysis [11].

The initial nodalization of the accumulator had three cells, simulating nitrogen gas layer, coolant water layer, and exit layer, respectively. In order to enhance the accuracy of TRACE predictions, the number of cells was increased to five cells. The accumulator geometry was still in 41 m^3 of total volume and 5.8 m of height, respectively. The mass flow rate of the accumulator injection is shown in Fig. 4.9. The time of accumulator injection is earlier in the case of three cells because of faster pressure decrease (see Fig. 4.10). Fig 4.9 indicates that accumulator mass flow rates calculated by TRACE in the case with 5 cells and 7 cells approximately follows the trend of the FSAR data. In the PCT's comparison, the 5 cells case is higher than 3 cells case and is roughly the same with 7 cells case. The above results suggest that using 5 cells of accumulator is good enough to predict the trend of accumulator injection.

4.2.2 Pipe nodalization (near the break)

One of the most sensitive parameters during the simulation of a LOCA is certainly the evolution of the break mass flow. In order to determine the velocity and the pressure at the throat of the break, the conditions at the cell-edge, where the choking criterion is applied must be known. The homogeneous equilibrium sound speed is calculated to estimate the corresponding cell-edge conditions, given the conditions at the cell center. The results of predicting for the TRACE choked flow model during the blowdown are presented in Fig 4.11. At approximately 2.7 seconds, the calculated break flow starts to transition from subcooled liquid flow to two-phase flow.

The initial nodalization of the pipe (near the break) had only one cell. In order to enhance the accurately of TRACE predicted, the pipe component was split to two cells. Fig 4.12 shows the mass flow rate of break. There are some significant differences between the 1 cell and 2 cells in TRACE calculation from 9 sec to 15 sec. As for the case with 2 cells, it is seen that the break flow rate from TRACE prediction is in better accuracy, compared with FSAR. The maximum mass flow rate in TRACE prediction is almost the same between the 1 cell and 2 cells. As for the case with 2 cells, it is seen that the break flow rates predicted by TRACE agrees closely with the results of the FSAR data. In the PCT's comparison, the 2 cells case is is roughly the same with 1 cell case. The above results indicate that using 2 cells case is good for the TRACE model.

4.2.3 Critical heat flux calculated in TRACE

Critical heat flux (CHF) is the point where the maximum heat flux occurs in the idealized boiling curve. In TRACE [8], the role of the CHF model is two-fold: 1. Determine the transition point for the heat transfer regime; 2. Serve as the anchor point for the transition boiling wall heat flux. To serve both these roles, the CHF model in TRACE must provide a continuous estimate of the CHF over a wide range of conditions with reasonable accuracy.

According to TRACE manual [8], the 1995 AECL-IPPE CHF look-up table was selected for the default CHF model in TRACE. It is based on an extensive database of CHF values obtained in tubes with a vertical upflow of a steam-water mixture and provides the value of the critical heat flux as a function of the local conditions. This method of determining the value of the critical heat flux was selected for TRACE because of its reasonably good accuracy and wide range of applicability. Two critical quality correlations were available in the TRAC-B code and have been incorporated into TRACE as part of the code consolidation process: the CISE-GE correlation and a model derived from the Biasi CHF correlation. Fig 4.13 shows that sensitivity study of PCT prediction. In LBLOCA analysis, the PCT calculated by AECL-IPPE table with critical quality from CISE-GE correlation shows the highest peak cladding temperature. The temperatures predicted by table and the critical quality from Biasi correlation are almost the same. In this research, the AECL-IPPE table with critical quality from CISE-GE correlation was selected in the TRACE model.

4.2.4 CCFL phenomena in downcomer

In the reactor vessel, CCFL can occur during blowdown as ECC liquid is attempting to fill the downcomer (see fig 3.1). Steam is generated which rises upwards and reduces penetration of ECC fluid to the core. CCFL sets limits for the ECC penetration and determines how effectively the reactor pressure vessel is refilled and how much of the ECC fluid is bypassed directly to the broken loop. As the steam generation decreases the ECC fluid starts to fill the lower plenum (Nuclear Regulatory Commission, 1988). Fig 4.14 indicates that TRACE with CCF model predicted the lower reactor water level between 18 and 30s. The results of peak cladding temperature that analyzed with CCF model could increase for 18K.

Finally, the PCT comparison of the sensitivity studies lists in Table 4.3.

Table 4.1 The comparison between the steady state data in LBLOCA of TRACE and Final safety analysis report (FSAR).

Parameter	FSAR	TRACE	Error (%)
Power (MWt)	2830	2830	0
Tavg * (K)	584.5	584.53	0.0001
Pressurizer pressure (MPa)	15.858	15.859	0.0001
Loop Flow (kg/sec)	4331.8	4347	0.0035

*Tavg = (Hot-leg temperature +Cold-leg temperature)/2

Table 4.2 The LBLOCA sequences of TRACE and FSAR.

LBLOCA	FSAR (sec)	TRACE (sec)
Break began	0.0	0.0
Reactor scram setpoint reached	0.50	0.50
SI signal generated	1.4	1.5
Accumulators Injection	15.0	14.2
Start of Pumped SI	28.4	28.5
Accumulators empty	52.1	59.5

Table 4.3 The PCT comparison of sensitivity studies.

	PCT		
Case	**3 cells**	**5 cells**	**7 cells**
Accumulators nodalization	base	large than 3 cells case	large than 3 cells and roughly the same with 5 cells case
Case	**1 cell**	**2 cells**	
Pipe nodalization (near the break)	base	roughly the same with 1 cell case	
Case	**AECL-IPPE table**	**AECL-IPPE table with Biasi correlation**	**AECL-IPPE table with CISE-GE correlation**
Critical heat flux	base	roughly the same with AECL-IPPE table case	larger than AECL-IPPE table case
Case	**No use CCFL**	**Use CCFL**	
CCFL	base	larger than no use CCEL case	

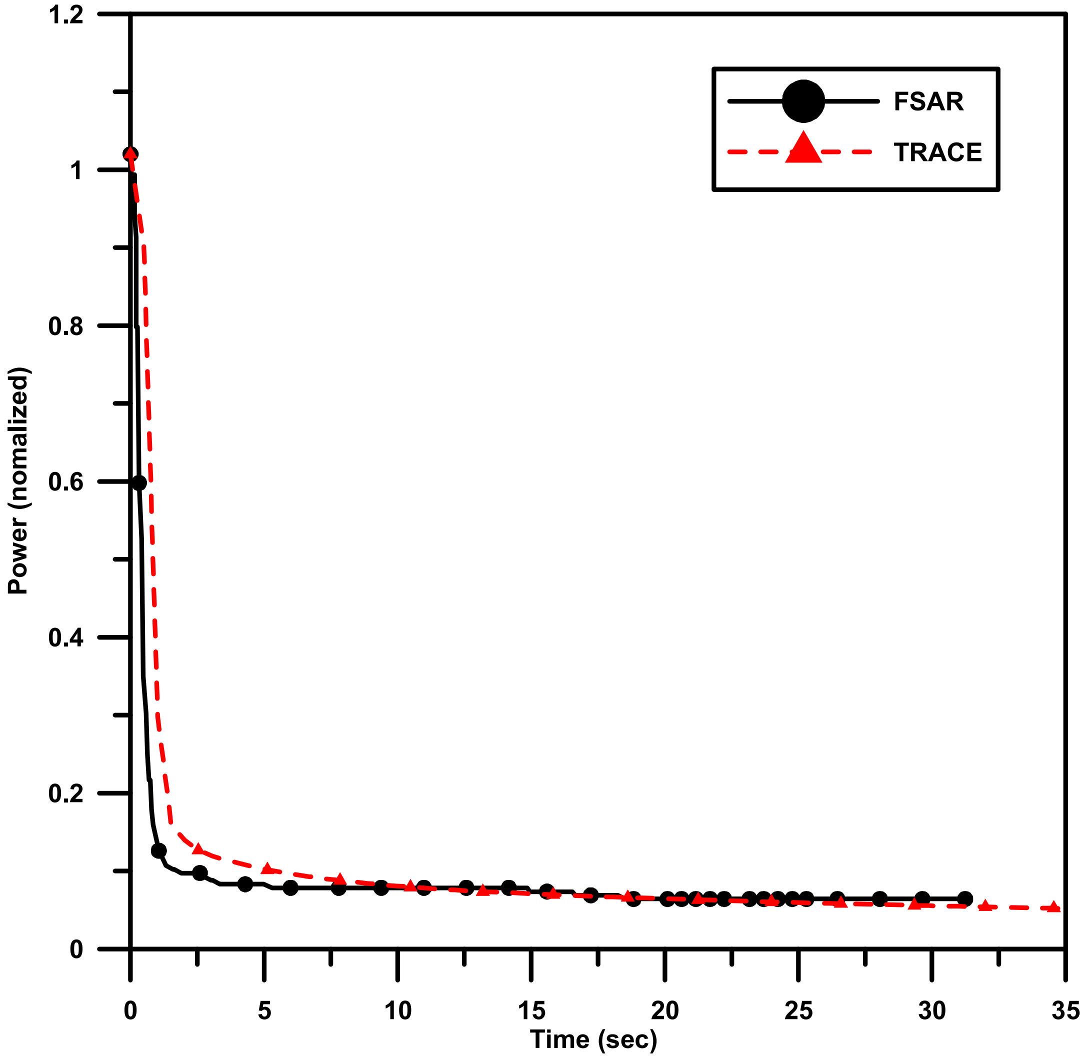


Fig. 4.1 The comparisons of power between TRACE and FSAR data.

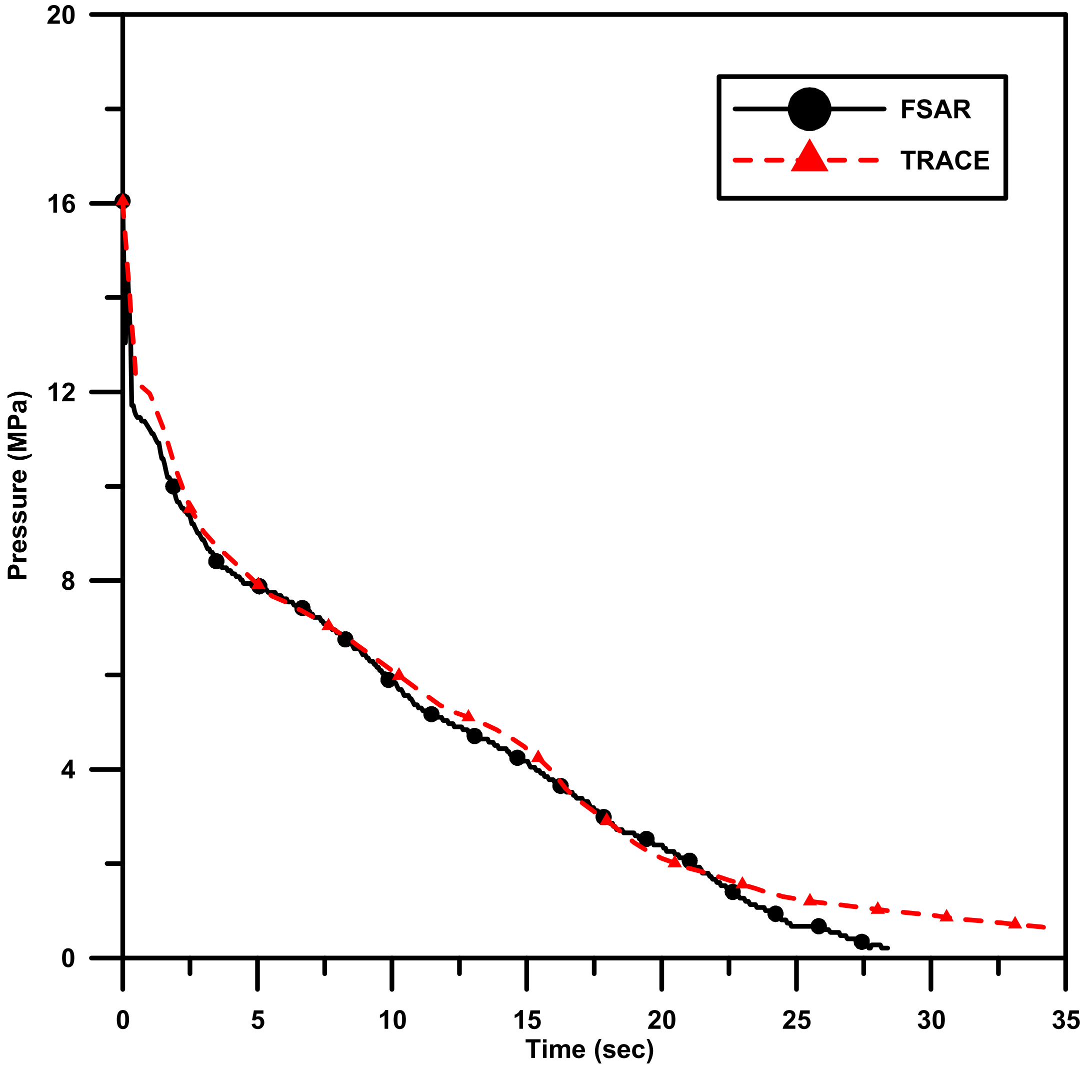


Fig. 4.2 The comparisons of vessel pressure between TRACE and FSAR data.

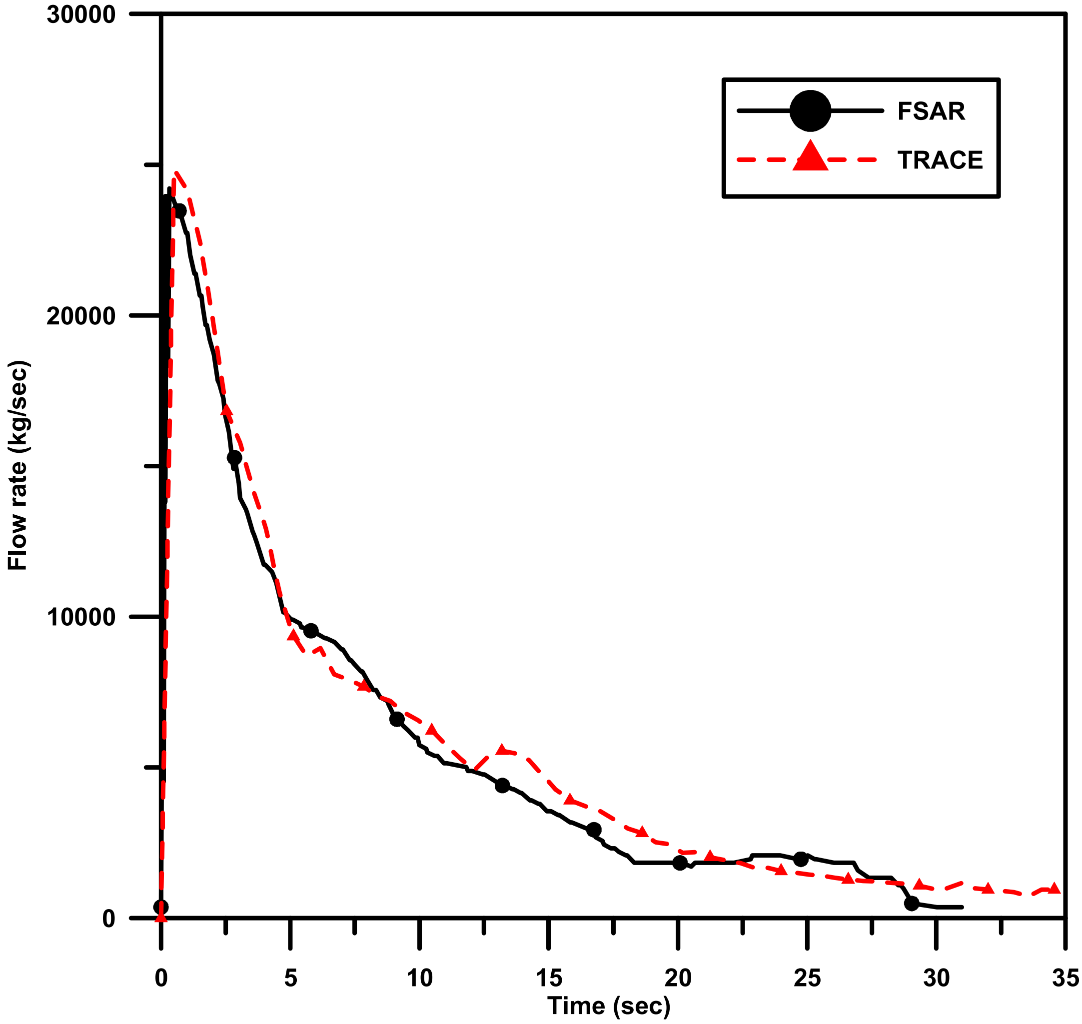


Fig. 4.3 The comparisons of break mass flow rate between TRACE and FSAR data.

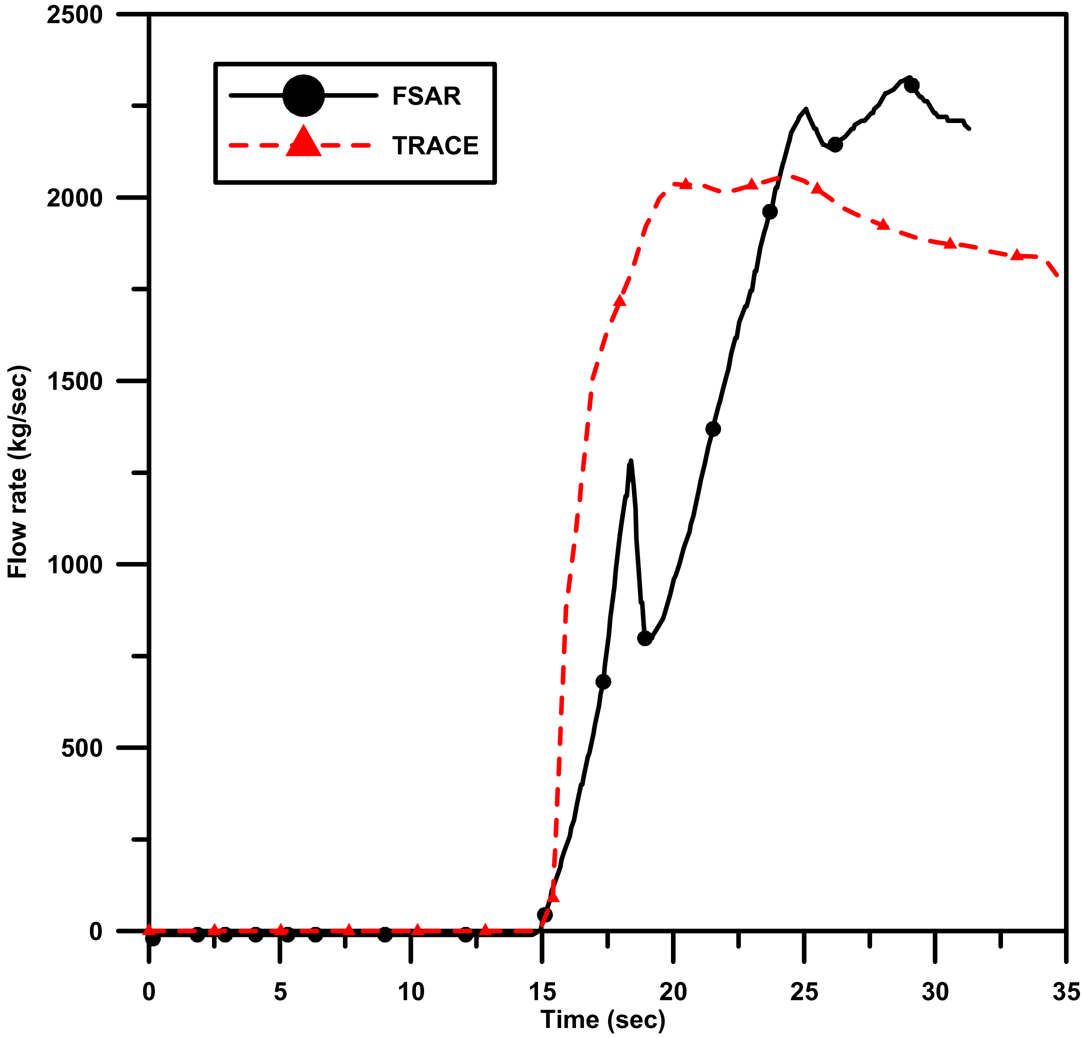


Fig. 4.4 The comparisons of accumlator mass flow rate between TRACE and FSAR data.

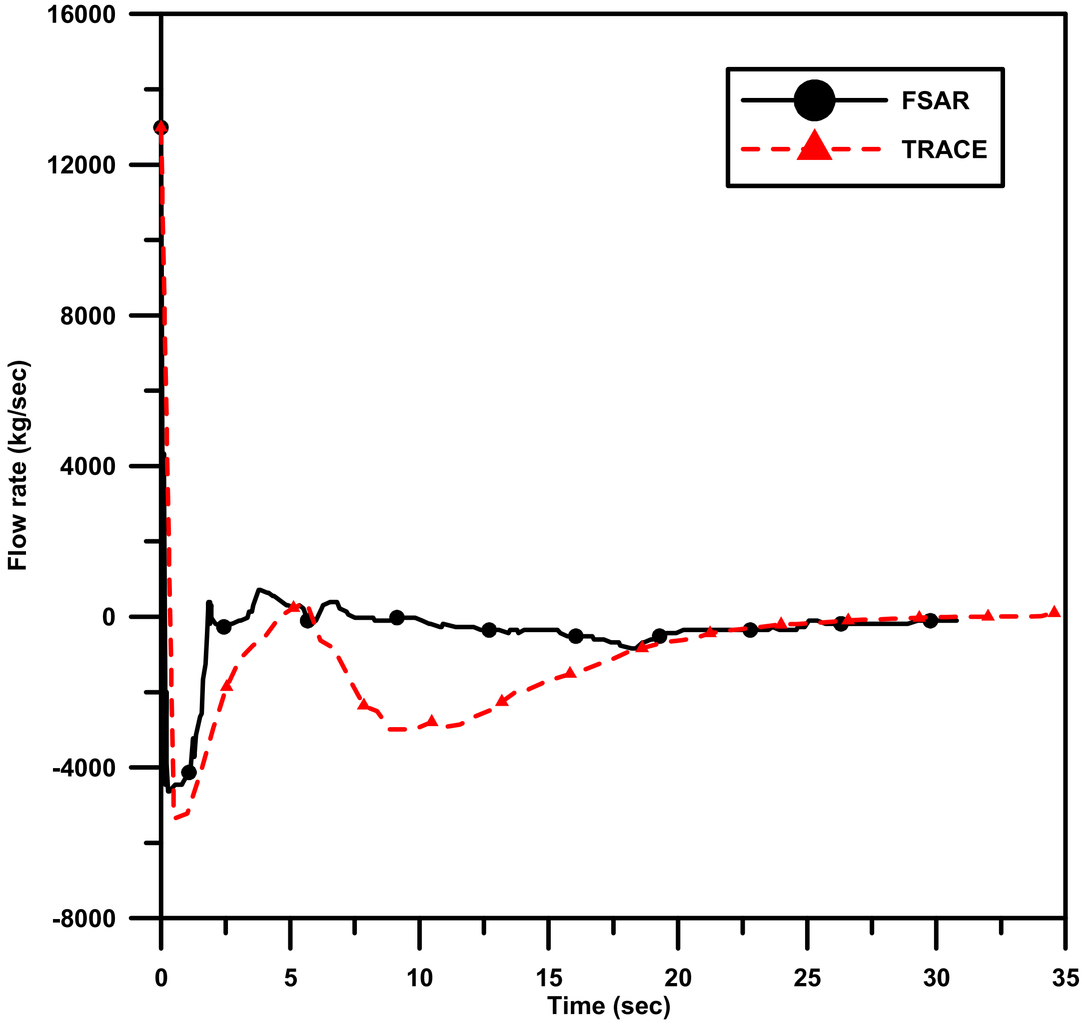


Fig. 4.5 The comparisons of core inlet flow rate between TRACE and FSAR data.

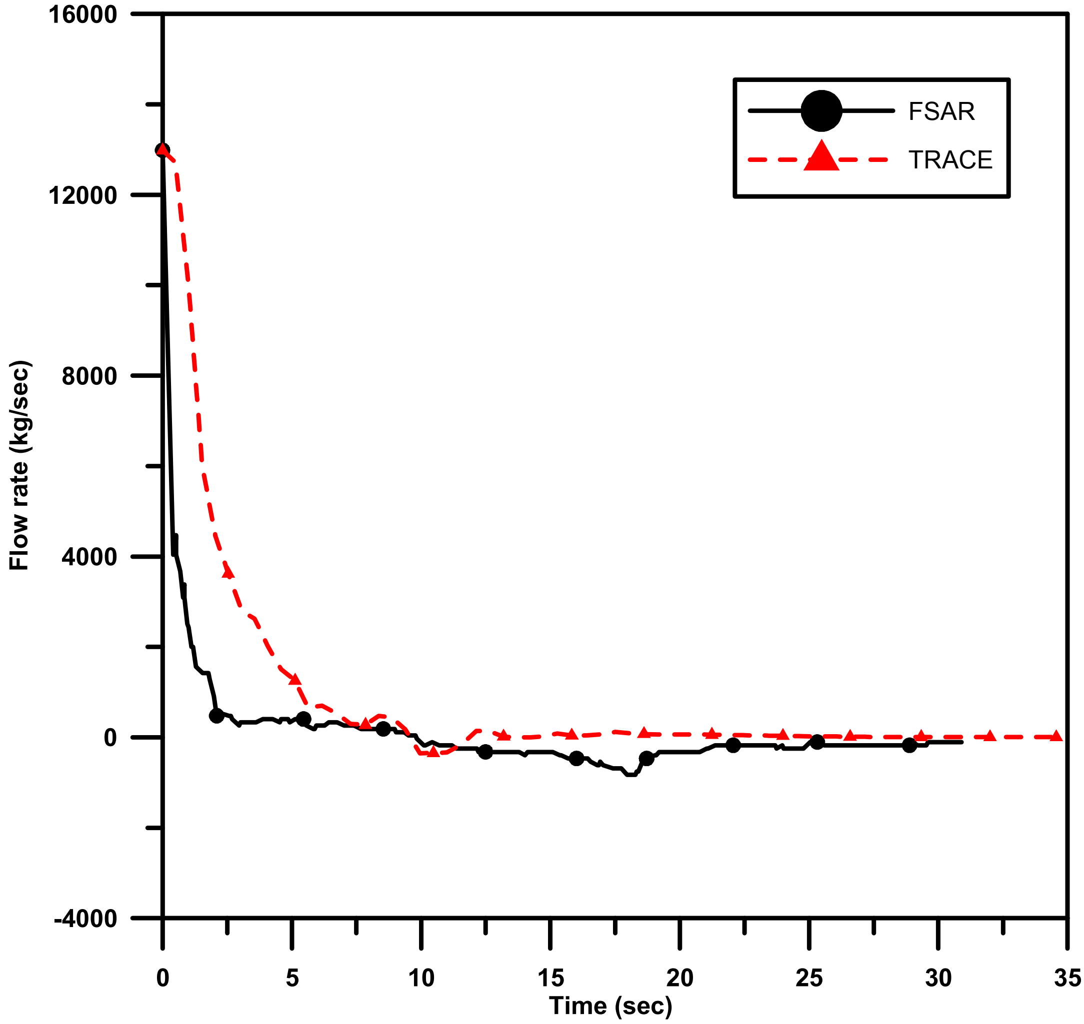


Fig. 4.6 The comparisons of core outlet flow rate between TRACE and FSAR data.

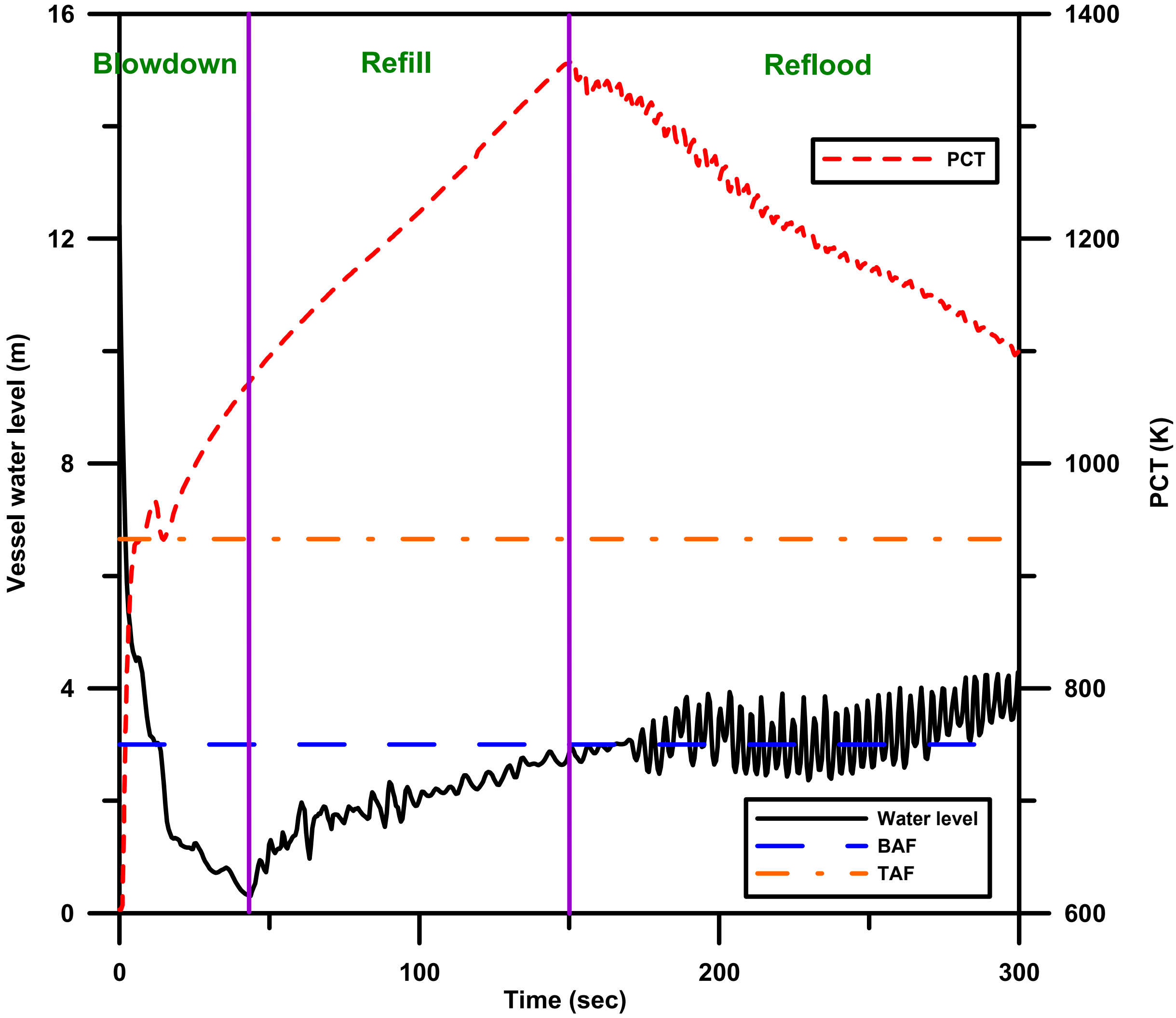


Fig 4.7 The blowdown , refill , and reflood phases of LBLOCA.

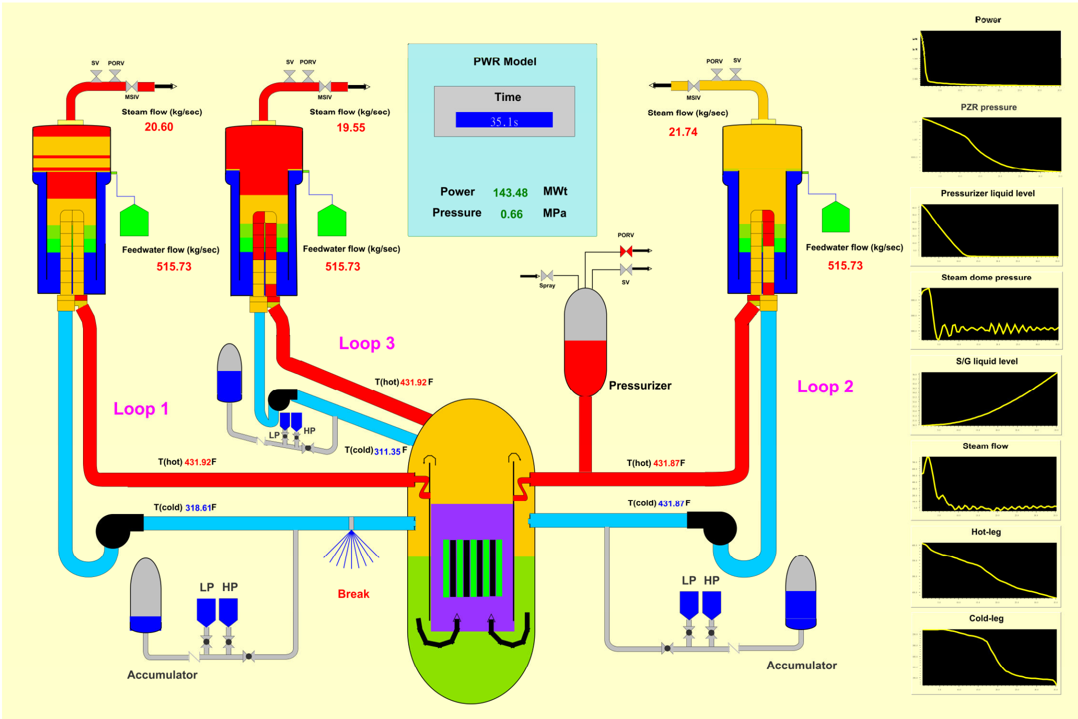


Fig. 4.8 Animation of the TRACE LBLOCA model for Maanshan NPP.

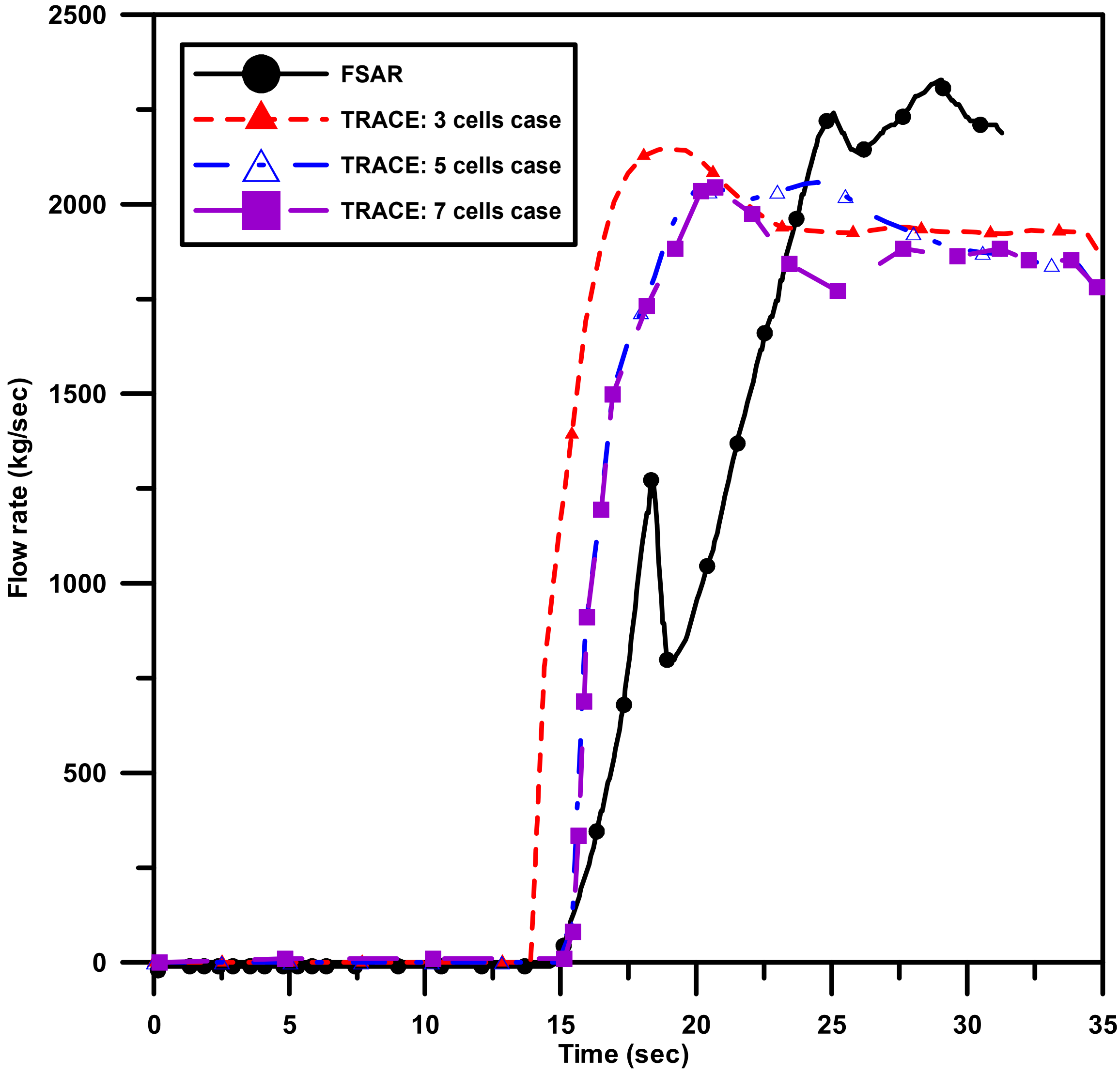


Fig 4.9 The accumulators flow rate results of the accumulators nodalization sensitivity studies.

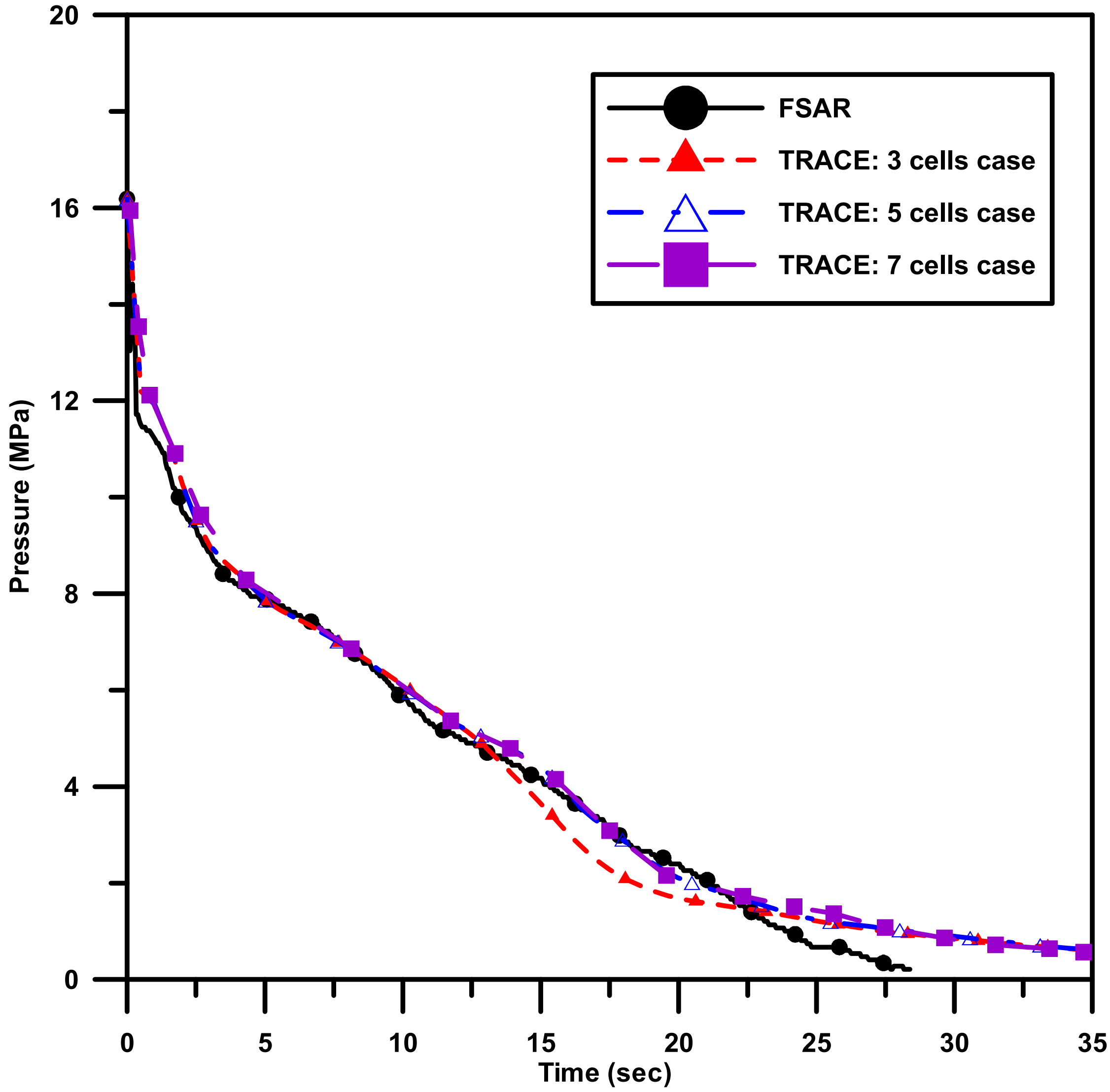


Fig 4.10 The system pressure results of the accumulators nodalization sensitivity studies.

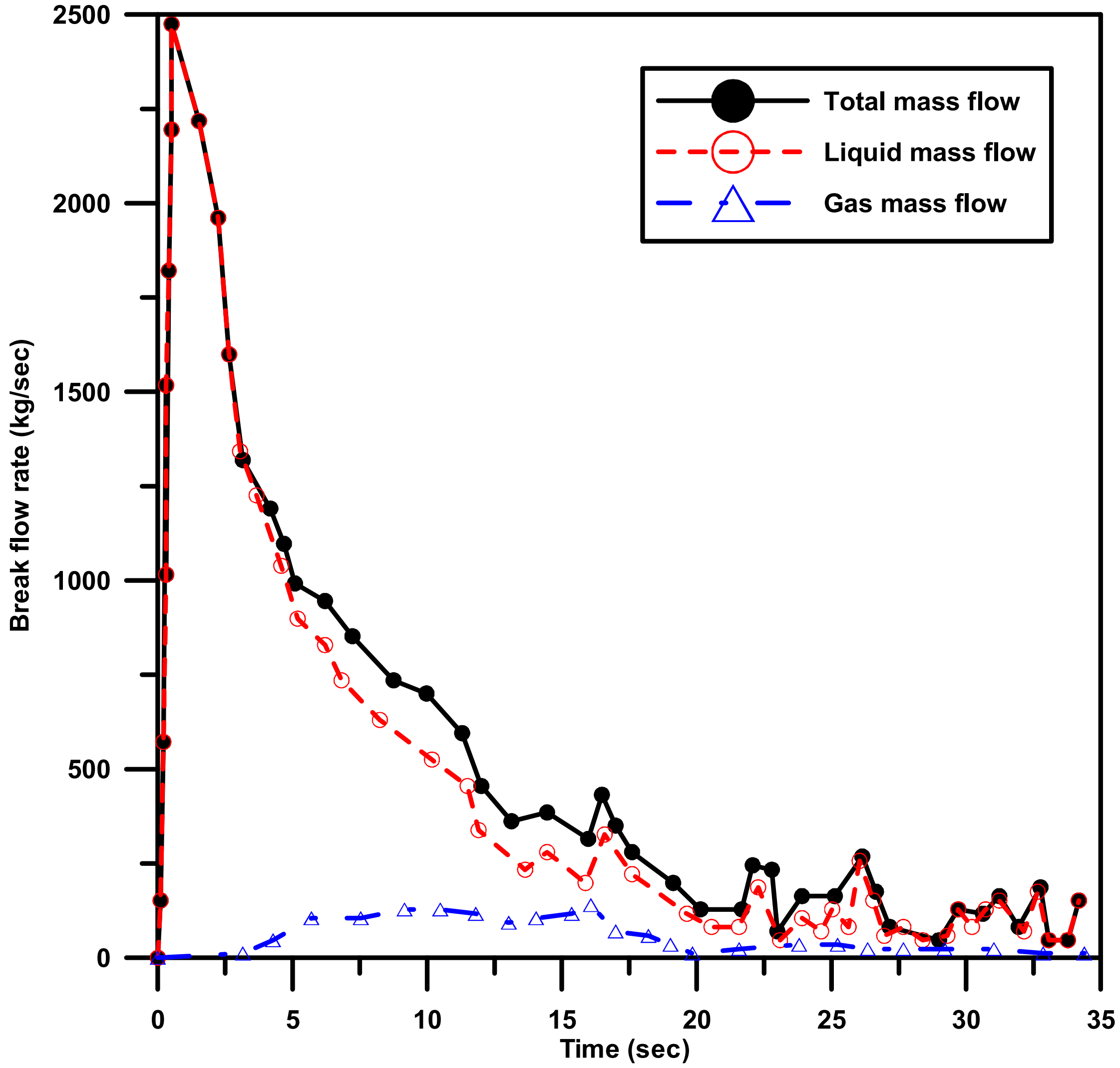


Fig 4.11 The break flow rate result of TRACE.

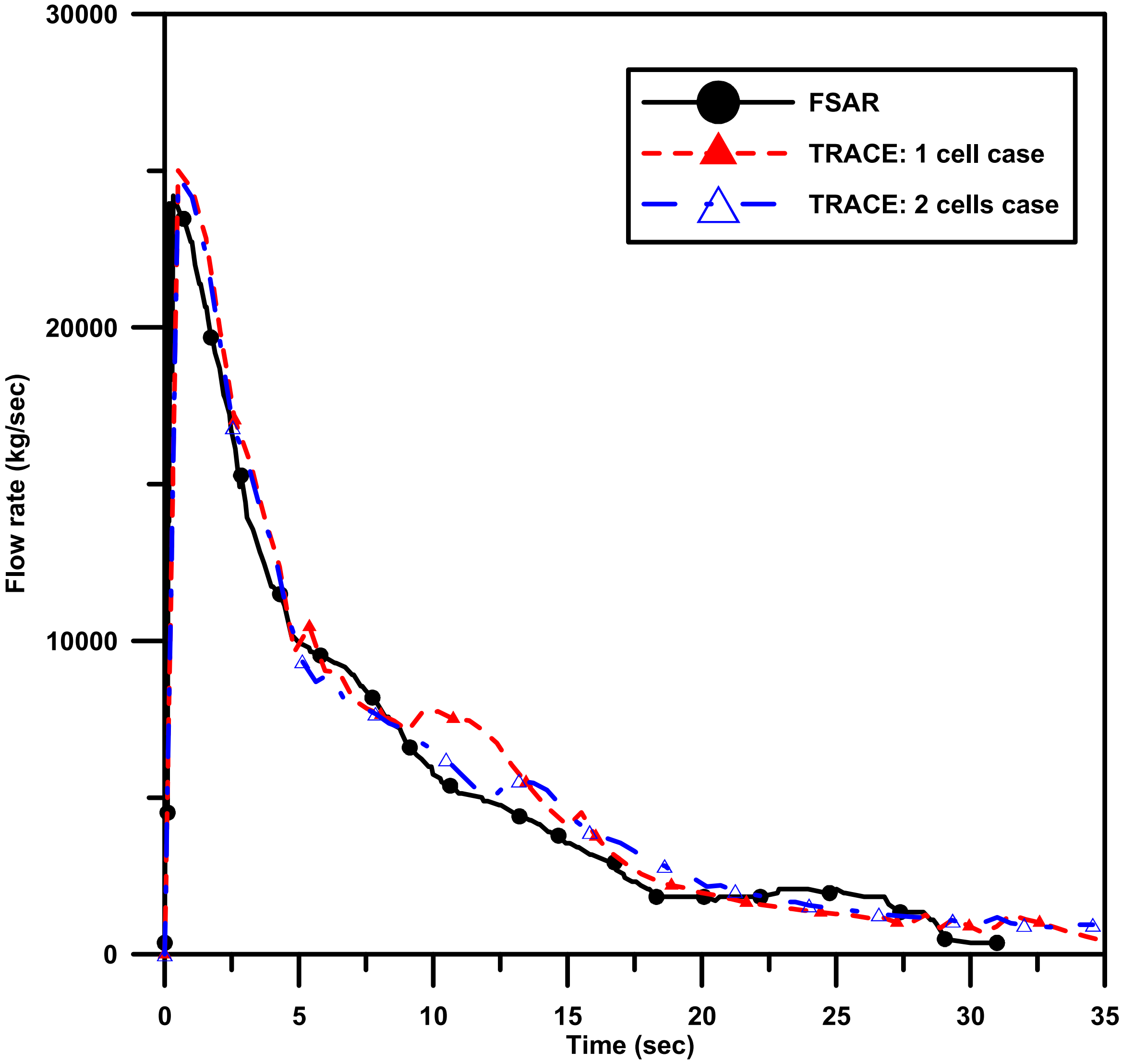


Fig 4.12 The break flow rate results of the pipe nodalization (near the break) sensitivity studies.

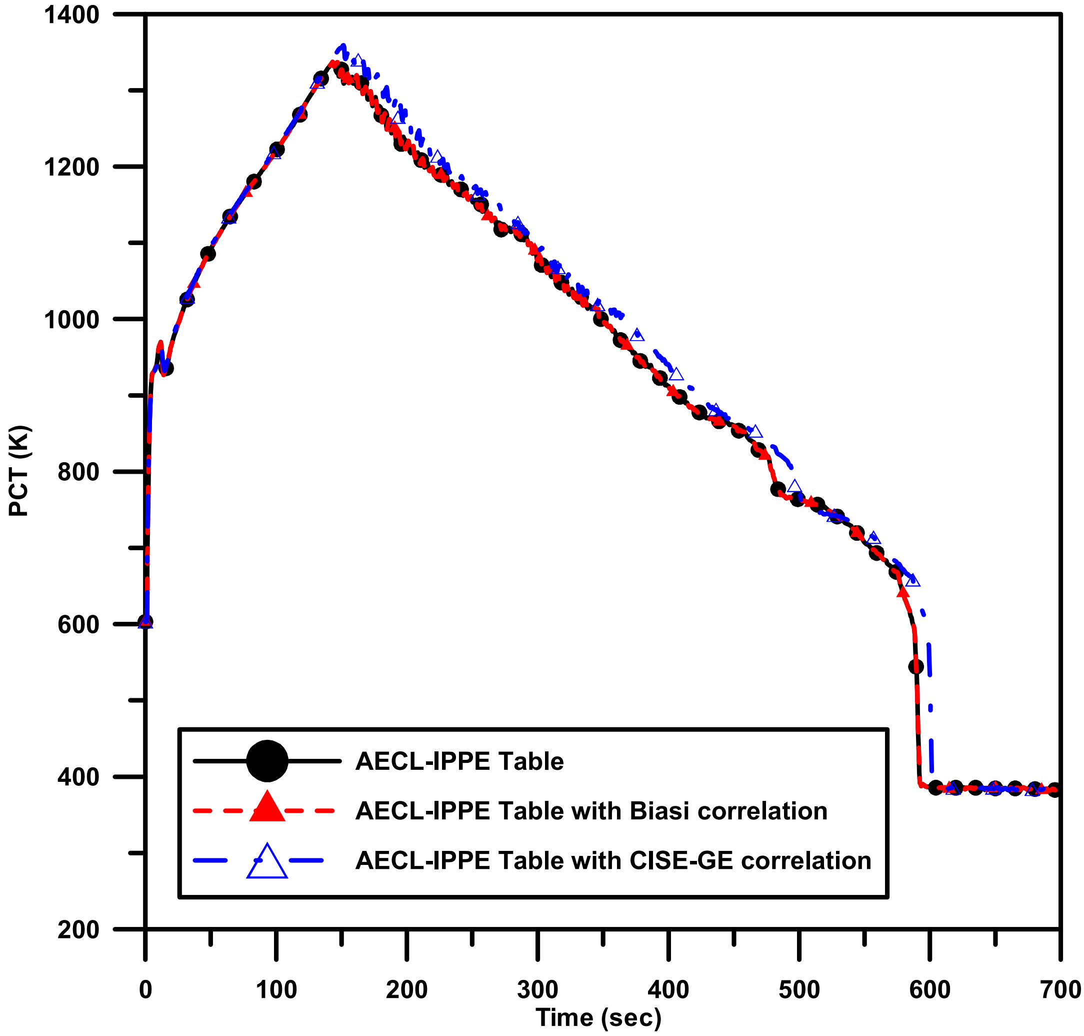


Fig 4.13 The PCT results of the CHF model sensitivity studies.

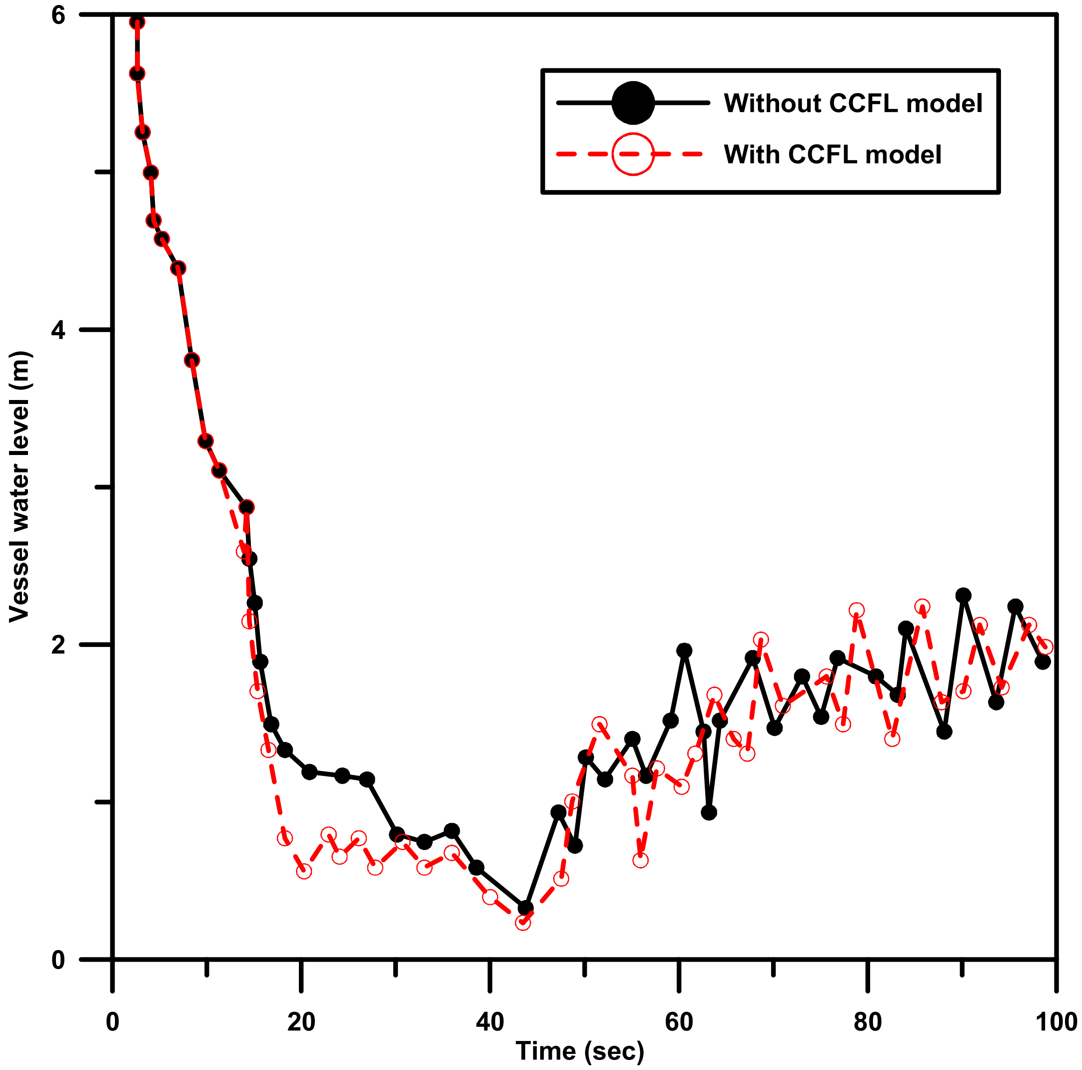


Fig 4.14 The vessel water level results of the CCFL model sensitivity studies.

5. CONCLUSIONS

By using SNAP/TRACE, this study establishes the TRACE LBLOCA model of the Maanshan NPP. Analytical results indicate that the Maanshan NPP TRACE LBLOCA model predicts not only the behaviors of important plant parameters in consistent trends with the FSAR data, but also provides a greater margin for the PCT evaluation. The TRACE model of Maanshan NPP can be used in future safety analysis with confidence, such as the applications for different break size and other break locations in LOCA.

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10. SUPPLEMENTARY NOTES

A. Calvo, NRC Project Manager

11. ABSTRACT *(200 words or less)*

The U.S. NRC is developing an advanced thermal hydraulic code named TRACE for safety analyses of nuclear power plants (NPPs). According to TRACE user's manual, 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. SNAP is a program with graphic user interface, which processes the input and output of TRACE. As TRACE user's manual describes, TRACE has a greater simulation capability than the other old codes, especially for events like loss-of-coolant accident (LOCA).

The Maanshan NPP operated by Taiwan Power Company is the only Westinghouse-PWR in Taiwan. The rated core thermal power is 2775 MWt. The reactor coolant system has three loops, each of which includes a reactor coolant pump and a steam generator. The pressurizer is connected to the hot-leg piping in loop 2. The Maanshan NPP TRACE model has been successfully established [1]-[3]. This study focuses on the establishment of the TRACE large break LOCA (LBLOCA) model for Maanshan NPP. Then, the TRACE LBLOCA analysis results compare with the FSAR data [4]. In this study, the LBLOCA is defined as a double-ended guillotine in cold-leg.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*	13. AVAILABILITY STATEMENT
TRACE (TRAC/RELAP Advanced Computational Engine) models LBLOCA LOCA IIST (Institute of Nuclear Energy Research Integral System Test) INER (Institute of Nuclear Energy Research, Atomic Energy Council, R.O.C.) SNAP (Symbolic Nuclear Analysis Program) Institute of Nuclear Energy Research, Atomic Energy Council, R.O.C. TPC (Taiwan Power Company) Institute of Nuclear Engineering and Science, National Tsing Hua University CAMP (Code Applications and Maintenance Program)	unlimited 14. SECURITY CLASSIFICATION *(This Page)* unclassified *(This Report)* unclassified 15. NUMBER OF PAGES 16. PRICE

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