NUREG/IA-0252

International Agreement Report

The Development and Verification of TRACE Model for IIST Experiments

Prepared by:

Jong-Rong Wang[1]. Hao-Tzu Lin[1],
Chin-Jang Chang[1]
Wei-Xiang Zhuang[2], Chunkuan Shih[2]

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

[2]Institute of Nuclear Engineering and Science
National Tsing Hua University
101 Section 2, Kuang Fu Rd.
HsinChu, TAIWAN

A. Calvo, NRC Project Manager

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

February 2011

Prepared as part of
The Agreement on Research Participation and Technical Exchange
Under the International Code Assessment and Maintenance Program (CAMP)

Published by
U.S. Nuclear Regulatory Commission

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Public Electronic Reading Room at http://www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and *Title 10, Energy*, in the Code of *Federal Regulations* may also be purchased from one of these two sources.

1. The Superintendent of Documents
   U.S. Government Printing Office
   Mail Stop SSOP
   Washington, DC 20402-0001
   Internet: bookstore.gpo.gov
   Telephone: 202-512-1800
   Fax: 202-512-2250
2. The National Technical Information Service
   Springfield, VA 22161-0002
   www.ntis.gov
   1-800-553-6847 or, locally, 703-605-6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: U.S. Nuclear Regulatory Commission
Office of Administration
Publications Branch
Washington, DC 20555-0001
E-mail: DISTRIBUTION.RESOURCE@NRC.GOV
Facsimile: 301-415-2289

Some publications in the NUREG series that are posted at NRC's Web site address http://www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036-8002
www.ansi.org
212-642-4900

Legally binding regulatory requirements are stated only in laws; NRC regulations; licenses, including technical specifications; or orders, not in NUREG-series publications. The views expressed in contractor-prepared publications in this series are not necessarily those of the NRC.

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG-XXXX) or agency contractors (NUREG/CR-XXXX), (2) proceedings of conferences (NUREG/CP-XXXX), (3) reports resulting from international agreements (NUREG/IA-XXXX), (4) brochures (NUREG/BR-XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG-0750).

NUREG/IA-0252

International Agreement Report

The Development and Verification of TRACE Model for IIST Experiments

Prepared by:

Jong-Rong Wang[1]. Hao-Tzu Lin[1],
Chin-Jang Chang[1]
Wei-Xiang Zhuang[2], Chunkuan Shih[2]

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

[2]Institute of Nuclear Engineering and Science
National Tsing Hua University
101 Section 2, Kuang Fu Rd.
HsinChu, TAIWAN

A. Calvo, NRC Project Manager

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

February 2011

Prepared as part of
The Agreement on Research Participation and Technical Exchange
Under the International Code Assessment and Maintenance Program (CAMP)

Published by
U.S. Nuclear Regulatory Commission

ABSTRACT

A RHRP (Reduced-Height and Reduced-Pressure) IIST (Institute of Nuclear Energy Research Integral System Test) facility has been established in 1992 for safety studies of the Westinghouse three-loop PWR (Pressurized Water Reactor) NPP (Nuclear Power Plant). The research purposes of the IIST facility are as follows: (a) to enhance the understanding of thermal hydraulics phenomena during the accidents, (b) to contribute to evaluate and develop the safety computer codes, and (c) to validate the emergency operating procedure (EOP) during the accidents of PWR. The scaling factors of the IIST facility for height and volume of the reactor coolant system (RCS) are approximately 1/4 and 1/400, respectively. The maximum operating pressure of the IIST facility is 2.1 MPa. The IIST facility has three loops as well as all the systems which are about studying Westinghouse PWR plant system transients. The experiment of the IIST facility was finished which simulated a 2% cold-leg-break loss-of-coolant accident (LOCA) with total high-pressure injection (HPI) failure. This break was located in loop 2 of IIST facility, which is one of the two loops that do not have a pressurizer. Besides, three cooldown experiments of IIST facility were also performed. In this research, the IIST facility experiments data and RELAP5 analysis results of IIST facility experiments are used to verify and establish the TRACE (TRAC/RELAP Advanced Computational Engine) IIST facility models. Comparing steady state results, it can be concluded that the steady state results of TRACE calculations are in agreement with those of IIST facility experiments data and RELAP5 analysis results of IIST facility experiments. On the other hand, comparing the transient results, it also indicates that they are in reasonable consistency. The verified results of TRACE IIST facility models reveal that there is respectable accuracy in the analysis of the 2% cold-leg-break LOCA and cooldown experiments.

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 users' experiences of it, and providing suggestions for its development. To meet this responsibility, the TRACE models of IIST facility have been built. In this report, the 2% cold-leg-break LOCA experiment and cooldown experiments data of IIST facility were utilized and conducted to confirm the accuracy of the TRACE models.

CONTENTS

Figures

Tables

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 models of IIST facility were developed by INER.

A RHRP IIST facility has been established for safety studies of the Westinghouse three loops PWR. The research purposes of the IIST facility are as follows: (a) to enhance the understanding of thermal hydraulics phenomena during the accidents[(1)-(3)], (b) to contribute to evaluate and develop the safety computer codes[(4)-(5)], and (c) to validate the EOP during the accidents of PWR[(6)]. The scaling factors of the IIST facility for height and volume in the RCS are approximately 1/4 and 1/400, respectively. The maximum operating pressure of the IIST facility is 2.1 MPa. The IIST facility has three loops as well as all the systems which are about studying Westinghouse PWR plant system transients. An experiment of the IIST facility was finished which simulated a 2% cold-leg-break LOCA with total HPI failure[(7)]. This break was located in loop 2 of IIST facility, which is one of the two loops that do not have a pressurizer. Besides, three cooldown experiments of IIST facility were also performed[(8)].

The codes used in this research are SNAP v 1.1.8 and TRACE v 5.0p1. By referring to the RELAP5 IIST facility model and IIST facility experiments data[(7)-(8)], the TRACE IIST facility model (named model A) was developed. The TRACE IIST facility model has three loops. Each of the three loops includes the simulation of the hot-leg, SG (Steam Generator) inlet plenum, SG U-tubes, SG outlet plenum, crossover leg, reactor coolant pump, and cold-leg. The pressurizer located in loop 1, the break valve located in loop 2, and several pipe components were used to simulate the IIST pressure vessel. The models of the three SG secondaries were identical. The secondary models can be subdivided into the downcomer, boiling section, and steam dome. The feedwater line was simulated using a time-dependent junction. The steam line was simulated by a break component, which simulated the pressure of steam line during the IIST experiment. The break flow area was simulated using a specific valve with the critical flow option. The heat source of IIST facility was simulated by a power component of TRACE, which used the power table option to simulate the power varying during the experiments. Besides, another TRACE IIST facility model (named model B) was developed in order to use the TRACE 3D component-vessel instead of pipe components.

Effectiveness of the proposed models were verified with the IIST facility 2% cold-leg-break LOCA experiment data, IIST facility cooldown experiments data, and the RELAP5 analysis results data of these experiments. 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.

ABBREVIATIONS

CAMP	Code Applications and Maintenance Program
EOP	Emergency Operating Procedure
HPI	High-Pressure Injection
IIST	Institute of Nuclear Energy Research Integral System Test
INER	Institute of Nuclear Energy Research Atomic Energy Council, R.O.C.
LOCA	Loss Of Coolant Accident
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RHRP	Reduced-Height and Reduced-Pressure
RV	Relief Valve
SBLOCA	Small Break LOCA
SG	Steam Generator
SNAP	Symbolic Nuclear Analysis Program
TRACE	TRAC/RELAP Advanced Computational Engine
US	United States

1. INTRODUCTION

The US NRC is developing an advanced thermal hydraulic code named TRACE for safety analyses of NPPs. The development of TRACE is based on TRAC and integrating with RELAP5 and other programs. 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 in the future. SNAP, a program with graphic user interface, which processes the inputs and outputs of TRACE is also underdeveloped. 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. TRACE has a greater simulation capability than the other old codes, especially for events like LOCA.

A RHRP IIST facility has been established for safety studies of the Westinghouse three loops PWR since 1992. The research purposes of the IIST facility are as follows: (a) to enhance the understanding of thermal hydraulics phenomena during the accidents[(1)-(3)], (b) to contribute to evaluate and develop the safety computer codes[(4)-(5)], and (c) to validate the EOP during the accidents of PWR[(6)]. The scaling factors of the IIST facility for height and volume in the RCS are approximately 1/4 and 1/400, respectively. The maximum operating pressure of the IIST facility is 2.1 MPa. The IIST facility has three loops as well as all the systems which are about studying Westinghouse PWR plant system transients. An experiment of the IIST facility was finished which simulated a 2% cold-leg-break LOCA with total HPI failure[(7)]. This break was located in loop 2 of IIST facility, which is one of the two loops that do not have a pressurizer. Besides, three cooldown experiments of IIST facility were also performed[(8)].

In this research, according to the greater LOCA simulation capability of TRACE, the IIST facility TRACE models are established and are verified with the 2% cold-leg-break LOCA experiment data of IIST facility and the RELAP5 analysis results of this experiment[(7)]. Besides, the cooldown experiments data of IIST facility and the RELAP5 analysis results of these experiments are also used to establish and verify the TRACE models[(8)].

2. IIST facility and experiments

Fig. 2.1 shows the schema of the IIST facility. IIST facility is established in order to simulate the thermal hydraulics phenomena of Maanshan NPP which is a Westinghouse three loops PWR. Maanshan NPP is the only Westinghouse-PWR in Taiwan. The rated core thermal power is 2775 MW. The reactor coolant system has three loops, each of which includes a reactor coolant pump and a SG. The pressurizer is connected to the hot-leg piping in loop 2.

The IIST facility consists of a pressure vessel and three loops. Each loop has a SG and a coolant pump. Except that there is a pressurizer in the loop 1, the three loops are identical. The scaling factors of height and volume in the RCS are approximately 1/4 and 1/400, respectively. Scaled safety injection systems (include HPI and accumulators) inject cooling water into the cold-leg of each loop. During the SBLOCA (Small Break LOCA) experiment, a catch tank is simulated to collect and measure the effluent from the simulated break. The comparison of major parameters between IIST facility and the Maanshan NPP is shown in Table 2.1.

The data acquisition system of the IIST facility records data from more than 200 instruments which include K-type thermocouples, venturi flowmeters, pressure transducers, and differential pressure transducers in order to measure temperature, flow rate, pressure, and differential pressure, respectively. The accuracies of the instruments are as follows[7]: (1) Thermocouple accuracies are 2.2 K or 0.75% of the full scale. (2) Venturi flowmeters located in the downflow section of the crossover leg (the loop seals) are used to measure the loop flow rate which the accuracy is 1.66% of the range. (3) Pressure and pressure difference transducers are used to measure the system pressure and the local pressure drop in the loops. The accuracies of pressure and pressure difference are 0.25 and 0.77% of the ranges, respectively. (4) The collapsed liquid levels are calculated based on the differential pressures and temperatures for regions of the system when the local velocities are low. The accuracy of the collapsed liquid level is 1.8% of the range. (5) The break flow is discharged to the catch tank during the simulation of the LOCA experiments. So, the break flow rate is calculated from the multiplication of the liquid level rising rate, flow area, and liquid density in the catch tank. The accuracy of the break flow rate is 1.8% of the range. The detail description of the above instruments are listed in the INER report[9] and Table 2.2 shows some data of instruments which include the calculation range, location, and function.

Besides, there are 50 view ports in the IIST facility in order to see the thermal hydraulics phenomena and thus enhance understanding of two-phase phenomena in the pressure vessel, hot-legs, SG inlet and outlet plenums, SG secondary sides, crossover legs, cold-legs, and pressurizer. However, a total of 13 video cameras are located at selected view ports to record the key thermal hydraulics phenomena during the IIST facility experiments.

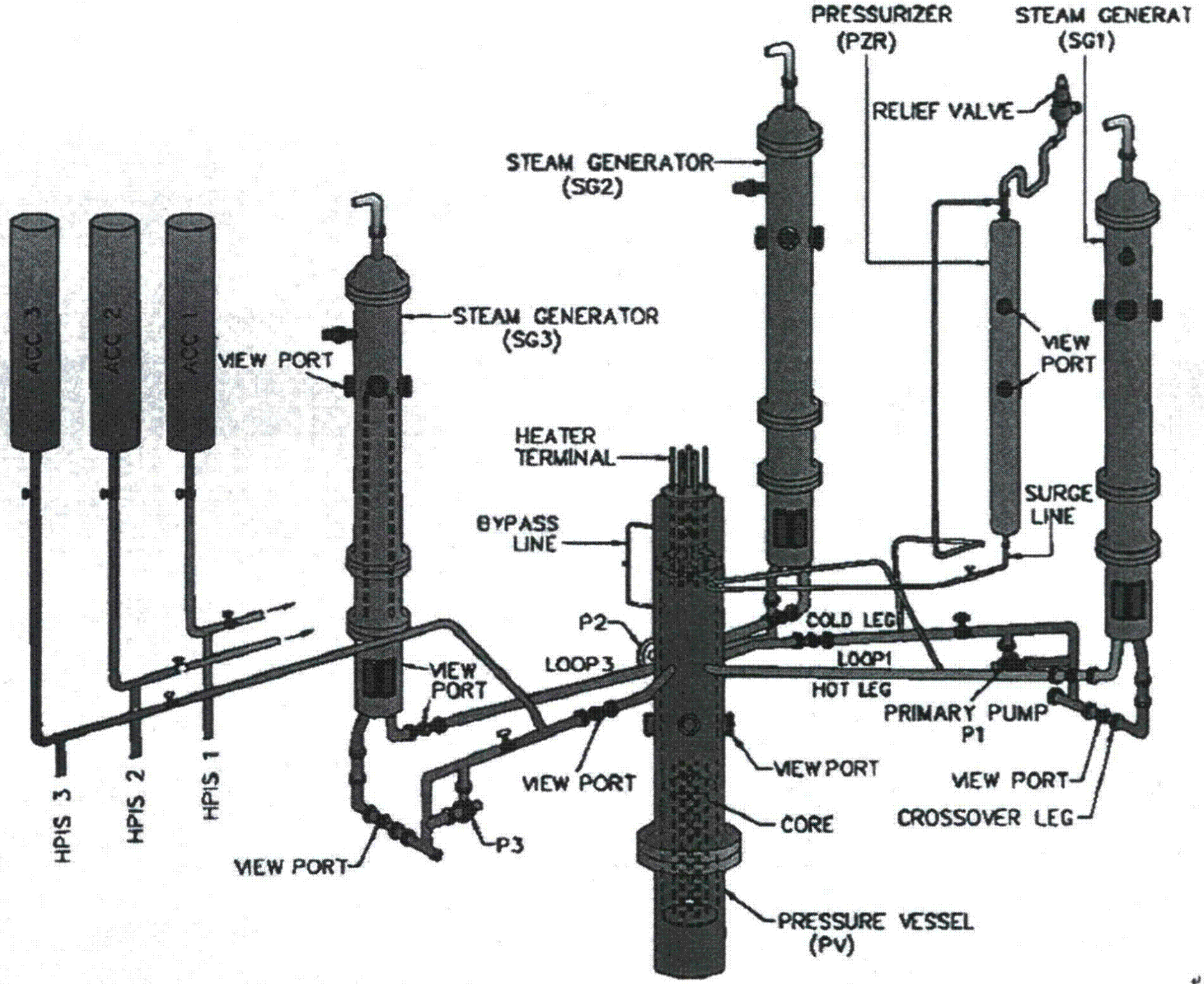


Fig. 2.1 The schema of the IIST facility[7]

Table 2.1 The comparison of major parameters between IIST facility and the Maanshan NPP[7]

Parameter	IIST	Maanshan PWR	IIST/PWR
Design pressure (MPa)	2.1	15.6	1.35×10^{-1}
Maximum core power (MW)	0.45	2775	1.62×10^{-4}
Primary system volume (m^3)	5.37×10^{-1}	2.15×10^{2}	2.50×10^{-3}
Number of loops	3	3	1.0
Core			
Height (m)	1.0	3.6	2.77×10^{-1}
Hydraulic diameter (m)	1.08×10^{-1}	1.22×10^{-2}	8.85
Bypass area (m^2)	7.2×10^{-5}	1.54×10^{-2}	4.67×10^{-3}
Hot leg			
Inner diameter. D (m)	5.25×10^{-2}	7.35×10^{-1}	7.13×10^{-2}
Length. L (m)	2.0	7.28	2.75×10^{-1}
$L/\sqrt{D}$ ($m^{0.5}$)	8.72	8.48	1.03
U-tube in one SG			
Number	30	5626	5.33×10^{-3}
Average length (m)	4.08	16.85	2.24×10^{-1}
Inner diameter (mm)	15.4	15.4	1.0
Volume (m^3)	2.28×10^{-2}	18.44	1.23×10^{-3}
Cold leg			
Inner diameter D (m)	5.25×10^{-2}	7.87×10^{-1}	6.67×10^{-2}
Length L (m)	5.0	15.7	3.18×10^{-1}
$L/\sqrt{D}$ ($m^{0.5}$)	21.8	17.69	1.22
Downcomer			
Flow area (m^2)	0.0185	2.63	7.03×10^{-2}
Hydraulic diameter (m)	4.12×10^{-2}	4.8×10^{-1}	8.58×10^{-2}
Pressurizer			
Volume (m^3)	9.32×10^{-2}	39.64	2.35×10^{-3}
Surge-line flow area (m^2)	3.44×10^{-4}	6.38×10^{-2}	5.39×10^{-3}

Table 2.2 The instruments data of IIST facility[9]

P1

Sensor	Function	Cal. Range	Tap Position (Hi/Lo)	Model	Serial	Spec. Range	TC	Remark
LT-1012	Downcomer level	0~2400 mm	Upper DC/Core Bot (+10cm)	1151dp4j22m1b1(RM)	RS123670	0-25 to 0-150 inH_2O	TE1035A	
LT-1013	Core level-1	0~1900 mm	HL1(NC)/Core Bot(+10 cm)	1151dp4j22m1b1(RM)	RS123672	0-25 to 0-150 inH_2O	TE1033	
LT-1101	Hot leg-1 level	0~80 mm	Top of HL1/Bot of HL1	1151dr2f22m1b1(RM)	1673547	0-0.5 to 0-6 inH_2O	TE1119A	
LT-1102	Inlet plenum level-1	216~271 cm	Bot of IP/Top of IP	1151dp3e22m1b1(RM)	RS137880	0-5 to 0-30 inH_2O	TE1120	
LT-1103	Outlet plenum level-1	0~700 mm	Top of OP/Bot of OP	1151dp4j22b1(RM)	781388	0-25 to 0-150 inH_2O	TE1123	
LT-1104	COL vertical-Venturi	0~1100 mm	OP/Bots of COL				TE1124A	
LT-1105	COL horizontal	0-80 mm	Top of COL/Bot of COL	1151dr2f22m1b1(RM)	1673548	0-0.5 to 0-6 inH_2O	TE1124A	
LT-1106	COL vertical-Pump	104~185 cm	Bot of COL/Top of CL1(FC)	1151hp4e22b1	781025	0-25 to 0-150 inH_2O	TE1124A	
LT-1107	Cold leg-1 level	0~80 mm	Top of CL1/Bot of CL1	1151dr2f22m1b1(RM)	1673549	0-0.5 to 0-6 inH_2O	TE1127A	
PDT-1102	U-tube upflow-Short	-19.18~0 kPa	Top of IP/Top of U-tube				TE3105	
PDT-1104	U-tube downflow-Short	0~19.18 kPa	Top of U-tube/Top of OP				TE3105	
PDT-1105	U-tube inlet/outlet ΔP	-5~6 kPa	Tops of IP/OP	1151hp4e22b1(RM)	781,026	0-25 to 0-150 inH_2O		
PDT-1110	ΔP betw. HL1/CL1	-2.0~3 kPa	CL1(NC)/HL1(NC)	1151hp4e22m2b1(RM)	476,861	0-25 to 0-150 inH_2O		
LT-5101	ACC tank level-1	32~152 cm	ACC bot/ACC top	1151dp4e22m1b1(RM)	1710415	0-25 to 0-150 inH_2O		
LT-1023	Core level-2	0~1900 mm	Core Bot(+10 cm)/HL2(NC)					
LT-1202	Inlet plenum level-2	0~700 mm	Top of IP/Bot of IP	1151dp4j22m1b1(RM)	RS123671	0-25 to 0-150 inH_2O	TE1220	
LT-1203	Outlet plenum level-2	0~700 mm	Top of OP/Bot of OP	E13dm(TH)	4,604,979	-42 ~ 0 inH_2O	TE1223	
LT-1204	COL vertical-Venturi	0~1100 mm	OP/Bot of COL	1151dp4j22b1(RM)	781,384	0-25 to 0-150 inH_2O	TE1218	
LT-1205	COL horizontal	0~80 mm	Top of COL/Bot of COL	1151dr2f22m1b1(RM)	RS130749	0-0.5 to 0-6 inH_2O	TE1218	
LT-1206	COL vertical-Pump	114~205 cm	Bot of COL/Top of CL2(FC)	1151dp4e22m1b1(RM)	117884	0-25 to 0-150 inH_2O	TE1218	
LT-1207	Cold leg-2 level	0~80 mm	Top of CL2/Bot of CL2	1151dr2f22m1b1(RM)	1673546	0-0.5 to 0-6 inH_2O	TE1227A	
PDT-1202	U-tube upflow-Short	-77~0 in H_2O	Top of IP/Top of U-tube	1151hp5e22m2b1(RM)	476,863	0-125 to 0-750 inH_2O	TE3205	
PDT-1204	U-tube downflow-Short	0~19.18 kPa	Tops of U-tube/OP	1151dp4e22m1b1(RM)	RS144683	0-25 to 0-150 inH_2O	TE3205	
PDT-1205	U-tube inlet/outlet ΔP	-5~6 kPa	Tops of IP/OP	1151dp4e22b1(RM)	781,021	0-25 to 0-150 inH_2O		
PDT-1210	ΔP betw. HL2/CL2	-2.0~3 kPa	HL2(NC)/CL2(NC)					
LT-5201	ACC tank level-2	0~1200 mm	ACC bottom/ACC top					

p-2

Sensor	Function	Cal. Range	Tap Position (Hi/Lo)	Model	Serial	Spec. Range	TC	Remark
LT-1033	Core level-3	0~1900 mm	Core Bot(+10 cm)/HL3(NC)					
LT-1301	Hot leg-3 level	0~80 mm	Top of HL3/Bot of HL3/	1151dr2f22m1b1(RM)	RS130748	0~0.5 to 0~6 inH2O	TE1319A	
LT-1302	Inlet plenum level-3	250~308 cm	Bot of IP/Top of IP	1151dp3e22m1b1(RM)	RS137876	0~5 to 0~30 inH2O	TE1320	
LT-1303	Outlet plenum level-3	226~285 cm	Bot of OP/Top of OP	1151dp3e22m1b1(RM)	RS137877	0~5 to 0~30 inH2O	TE1323	
LT-1304	COL vertical-Venturi	129~218 cm	Bots of COL/OP	1151dp4e22m1b1(RM)	RS137881	0~25 to 0~150 inH2O	TE1324A	
LT-1305	COL horizontal	0~80 mm	Top of COL/Bot of COL	1151dr2f22m1b1(RM)	RS130752	0~0.5 to 0~6 inH2O	TE1324A	
LT-1306	COL vertical-Pump	124~206 cm	Bot of COL/Top of CL3(FC)	1151dp4e22m1b1(RM)	1710414	0~25 to 0~150 inH2O	TE1324A	
LT-1307	Cold leg-3 level	0~80 mm	Bot of CL3/Top of CL3	1151dr2f22m1b1(RM)	RS130751	0~0.5 to 0~6 inH2O	TE1328	
PDT-1302	U-tube upflow-Short	-77~0 inch	Tops of IP/U-tube	1151dp4e22m1b1(RM)	476864	0~125 to 0~750 inH2O	TE3305	
PDT-1304	U-tube downflow-Short	0~19.18 kPa	Tops of U-tube/OP	1151dp4e22m1b1(RM)	RS144682	0~25 to 0~150 inH2O	TE3305	
PDT-1305	U-tube inlet/outlet AP	-5~6 kPa	Tops of IP/OP	1151hp4e22b1(RM)	781,022	0~25 to 0~150 inH2O		
PDT-1310	ΔP betw. HL3/CL3	-2.0~3 kPa	HL3(NC)/CL3(NC)					
LT-5301	ACC tank level-3	32~152 mm	ACC bot/ACC top	1151dp4e22m1b1	1710413	0~25 to 0~150 inH2O		
LT-1001	PRV level	48~316 cm	PRV Bot(+115mm)/Top	1151dp4e22m1b1	1710412	0~25 to 0~150 inH2O	TE1033	
LT-2001	PRZ level	37~341 cm	PRZ Bot/Top	1151dp4e22m1b1(RM)	RS123499	0~25 to 0~150 inH2O	TE2012	
LT-3101	SG-1 2nd. level	0~92 inch	Upper tap/Tubesheet/	823dp-i3simn2(FB)	87n21941-13a2	0-1500 mmH2O	TE3100	
LT-3201	SG-2 2nd. level	113~360 cm	Tubesheet/Upper tap	1151dp4e22m1b1(RM)	RS137883	0~25 to 0~150 inH2O	TE3200	
LT-3301	SG-3 2nd. level	0~92 inch	Upper tap/Tubesheet	823dp-i3simn2(FB)	87n21941-13a3	0-1500 mmH2O	TE3300	
LT-4001	SG 2nd. feedwater tank	0~500 mm						
LT-2002	Catch tank level	0~4500 mm	Bot(+5 cm)/Top	1151dp5e22m1b1(RM)	123659	0~125 to 0~750 inH2O	TE2000	

p-3

Sensor	Function	Cal. Range	Tap Position (Hi/Lo)	Model	Serial	Spec. Range	TC	Remark
FT-1104A	Venturi-1 forward flow	0~6 inH2O	Upstream/Center	1151dr2f22m1b1(RM)	RS124858	0~0.5 to 0~6 inH2O	TE1118	
FT-1204A	Venturi-2 forward flow	0~6 inH2O	Upstream/Center	1151dr2f22m1b1(RM)	RS124863	0~0.5 to 0~6 inH2O	TE1218	
FT-1304A	Venturi-3 forward flow	0~6 inH2O	Upstream/Center	1151dr2f22m1b1(RM)	RS124861	0~0.5 to 0~6 inH2O	TE1318	
FT-1104D	Venturi-1 reversed flow	0~6 inH2O	Downstream/Center				TE1118	
FT-1204D	Venturi-2 reversed flow	0~6 inH2O	Downstream/Center				TE1218	
FT-1304D	Venturi-3 reversed flow	0~6 inH2O	Downstream/Center	1151dr2f22m1b1(RM)	RS130750	0~0.5 to 0~6 inH2O	TE1318	
PT-1001A	PRV upper-head AP	0~400 psia	PRV upper-head	1151gp8e22m1b1(RM)	RS124868	0~30 kg/cm^2		
PT-1001	PRV bottom AP	0~400 psia	PRV bottom(+115mm)	1144g0600a22(RM)	777,455	0-400 psia		
PT-1104	CL-1 AP	0~400 psia	CL-1 (FC)	1151gp8e22m1b1(RM)	RS123500	0~30 kg/cm^2		
PT-1204	On/Off signal							
PT-2001	PRZ AP	0~400 psia	Top of PRZ	1151gp8e22m1b1(RM)	RS123663	0~30 kg/cm^2		
PT-3001	SG 2nd. common outlet	0~150 psia	SG 2nd. common outlet	1151gp7e22m1b1(RM)	RS124869	0~10 kg/cm^2		
PT-3101	SG-1 2nd. AP	0~150 psia	Steam dome-1	1151hp7e22b1(RM)	772,096	0~200 psia		
PT-3201	SG-2 2nd. AP	0~150 psia	Steam dome 2	1151hp7e22b1(RM)	772,097	0~200 psia		
PT-3301	SG-3 2nd. Ap	0~150 psia	Steam dome-3	1151hp7e22b1(RM)	766,709	0~200 psia		
PT-5101	ACC-1 tank AP	0~150 psia	Top of ACC tank-1	1151gp8e22m1b1(RM)	RS123661	0~30 kg/cm^2		
PT-5201	ACC-2 tank AP	0~150 psia	Top of ACC tank-2	1151gp8e22m1b1(RM)	RS124865	0-30 kg/cm^2		
PT-5301	ACC-3 tank AP	0~150 psia	Top of ACC tank-3	1151gp8e22m1b1(RM)	RS124867	0-30 kg/cm^2		

Bot - Bottom
CL - Cold Leg
COL - Cross-Over Leg
DC - Downcomer
FB - Foxboro
FC - Far Core
HL - Hot Leg
IP - Inlet Plenum
NC - Near Core
OP - Outlet Plenum
PRV - Pressure Vessel
PRZ - Pressurizer
RM - Rosemount
TC - Temperature Compensation

2.1 IIST facility SBLOCA experiment[7]

The experiment of IIST facility was performed in order to simulate a 2% cold-leg break (the break area is 2% of the scaled cold-leg cross-section area) with total HPI failure. A horizontal break nozzle was installed in the cold-leg of loop 2. In this experiment, the core power decay and pump coastdown during the SBLOCA experiment were not simulated. The initial condition of the experiment is showed in Table 2.3.

The SBLOCA experiment started from the break occurred at time zero, the primary pressure of IIST facility dropped until it became only a little higher than the secondary-side pressure of IIST facility. Besides, the primary pressure decreased slowly because the energy content of the liquid discharged through the break was a little larger than the core energy generation. The air flowed through the hot-leg into the SG-1 U-tubes after emptying of the pressurizer at 128 sec. After 164 sec of the break, the loop 1 flow rate suddenly dropped to near zero, which means the decrease of the heat removal capability of SG-1. The effects of noncondensable air caused obviously slowed the rising temperatures in both the primary and secondary sides of SG-1 and the suddenly decrease of the natural-circulation flow rate in loop 1. An asymmetric coolant inventory distribution was observed in the three SGs during the two-phase natural-circulation and reflux condensation. In SG-1, the liquid holdup in the inlet plenum was not observed because the steam flowed into SG-1 which caused no flooding phenomena occurred during the reflux condensation. However, in SG-2 and SG-3, liquid holdup was shown in the upflow-side U-tubes and the inlet plenum resulting from the occurrence of flooding phenomena at the inlet of the SG U-tubes and hot-legs. The collapsed liquid level of core decreased sharply after the break occurred because of the subcooled liquid discharge in the time period between 0 to 146 sec. Then, the collapsed liquid level of core decreased slowly, when the break flow became a two-phase mixture from 146 to 400 sec. Finally, because of no coolant makeup, the core was uncovered with heatup at 1734 sec.

Table 2.3 The initial condition of the IIST facility SBLOCA experiment[7]

Parameter	IIST test data
Primary coolant system	
Core power (kW)	126
Pressurizer pressure (MPa)	0.958
Pressurizer water level (mm)	1459
Loop flow rate (kg/s)	
Loop1	0.210
Loop2	0.217
Loop3	0.217
Hot-leg temperature (K)	
Loop1	450
Loop2	449
Loop3	451
Cold-leg temperature (K)	
Loop1	409
Loop2	408
Loop3	409
Secondary coolant system	
Secondary-side pressure (MPa)	
SG-1	0.301
SG-2	0.295
SG-3	0.295
Secondary-side fluid temperature (K)	
SG-1	407
SG-2	407
SG-3	407

2.2 IIST facility cooldown experiments[8]

In 1996, a break of pressurizer venting tube occurred at Maanshan NPP, which result in the coolant release to the containment and the action of cooldown and depressurization process in RCS. In this accident, the leakage was estimated that could be greater than 50 gpm. However, the RCS collapsed liquid level shrinks and decreases due to cooldown and depressurization which may lead to overprediction the leakage rate and misjudgment of the proper actions in accident management. Therefore, a series of IIST facility cooldown experiments were performed in order to study the shrink effect in the RCS and the verification of theoretical approach of leakage evaluation model. Besides, the IIST facility cooldown experiments results were also used for the assessment of RELAP5 IIST facility model.

There are three cooldown experiments of IIST facility (C61128, C61210, and C70122) and the initial conditions are listed in Table 2.4. The cooldown experiments were divided two steps. The first step (0~1000 sec) was the intital primary pressure maintaining by regulating the power of the pressurizer heater and the secondary side pressure controlling by adjusting the opening of a control valve (located at the header of steam lines). The second step (after 1000 sec) was the relief valve (RV) of the steam generator which opens at 1000 sec and the core power was adjusted in decreasing rate of 1.75 kW every 50 seconds which resulted in cooldown in the RCS and depressurization in the secondary side. These cooldown experiments were performed with the cooldown rates ranging from 0.9 to 1.2 K/min, which were within the limitation of Maanshan NPP.

Table 2.4 The initial condition of the IIST facility cooldown experiments[8]

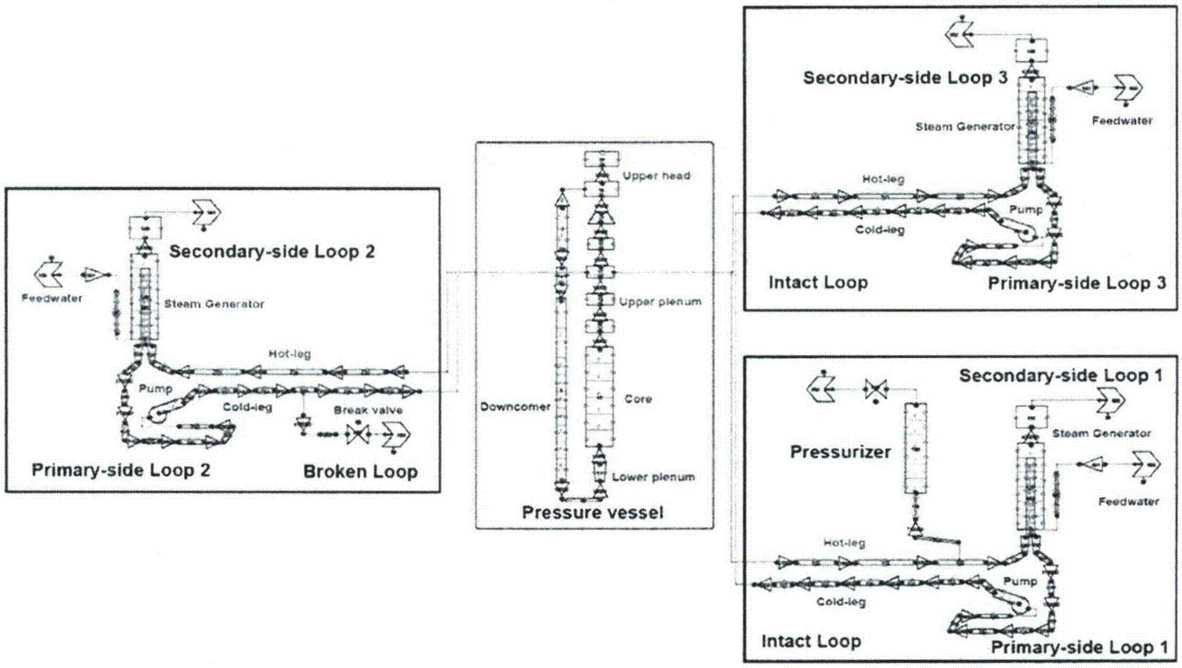
	C61128	C61210	C70122
Pressurizer pressure (MPa)	0.972	0.979	1.82
Pressurizer water level (mm)	1241	1269	1771
Core power (kW)	100.4	120	100.3
Hot-leg temperature (K)	442.1	448.8	468.5
Cold-leg temperature (K)	410.3	412.2	436.1
SG pressure (MPa)	0.286	0.283	0.62
SG water level (mm)	2230	2264	2293
SG fluid temperature (K)	405	0.979	435

3. The RELAP5 and TRACE IIST model description

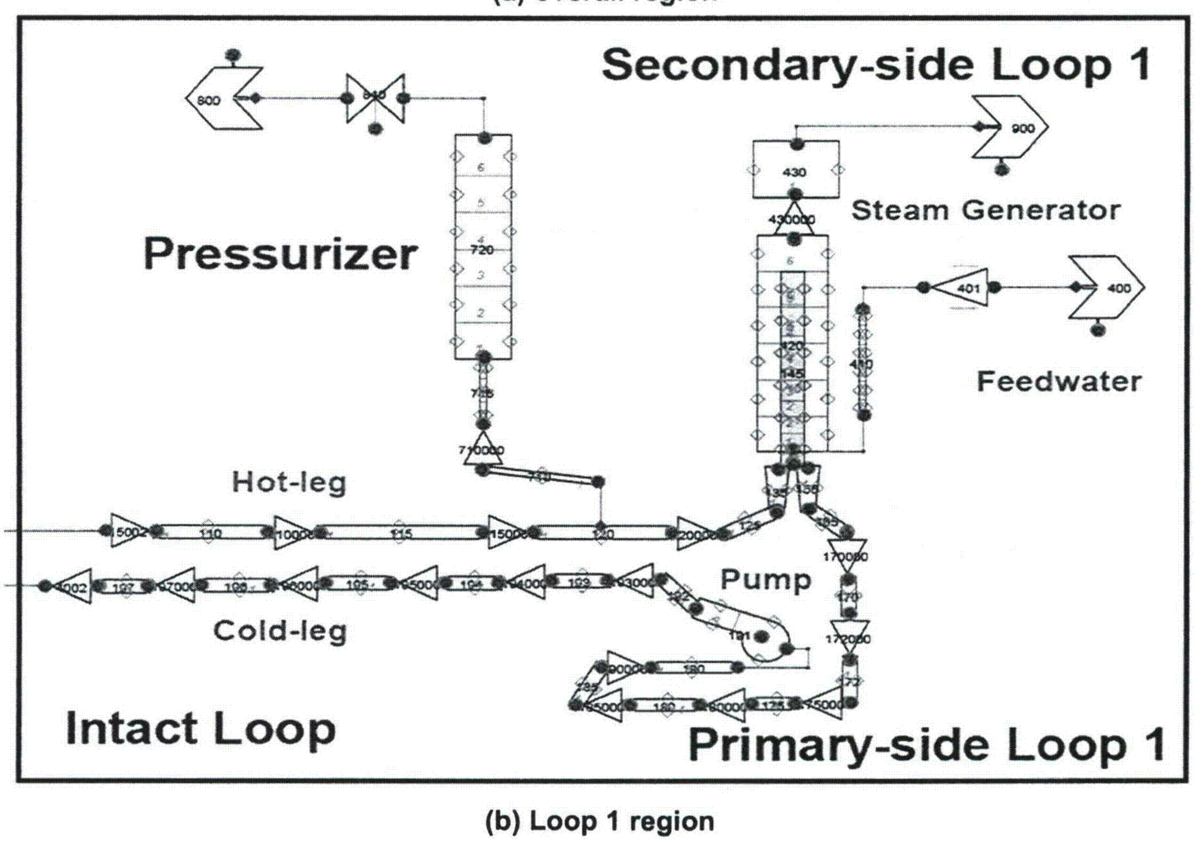
The RELAP5 IIST facility model was including 172 volumes connected by 175 junctions and 141 heat structures, had been developed to simulate the IIST facility. The detail description of RELAP5 IIST facility models were in INER's previous study[(7)-(8)].

By referring to the RELAP5 IIST facility models and IIST experiments data[(7)-(8)], the TRACE IIST facility model was developed. The SNAP v 1.1.8 and TRACE v 5.0p1 were employed in this research. The TRACE IIST facility model (named model A) is showed in Fig. 3.1. It shows that the TRACE IIST facility model has three loops: loop 1 (pipe components 110 to 197, shown in Fig.3.1 (b)), loop 2 (pipe components 210 to 297, shown in Fig.3.1 (c)), and loop 3 (pipe components 310 to 397, shown in Fig.3.1 (d)). Each of the three loops includes the simulation of the hot-leg, SG inlet plenum, SG U-tubes, SG outlet plenum, crossover leg, coolant pump, and cold-leg. The pressurizer (pipe component 720, shown in Fig.3.1 (b)) located in loop 1, the break valve (valve component 805, shown in Fig.3.1 (c)) located in loop 2, and pipe components 3~19 were used to simulate the pressure vessel of IIST facility (shown in Fig.3.1 (e)). The models of the three SG secondaries (pipe components 410 through 430, 510 through 530, and 610 through 630, respectively) were identical. The secondary models can be subdivided into the downcomer, boiling section, and steam dome. The steam line was simulated by a break component, which simulated the pressure of steam line during the IIST facility experiments. The break flow area was simulated using a specific valve with the critical flow option. Besides, another TRACE IIST facility model (named model B) was developed in order to use the TRACE 3D component-vessel instead of pipe 3~19. The TRACE IIST facility model B is shown in Fig. 3.2.

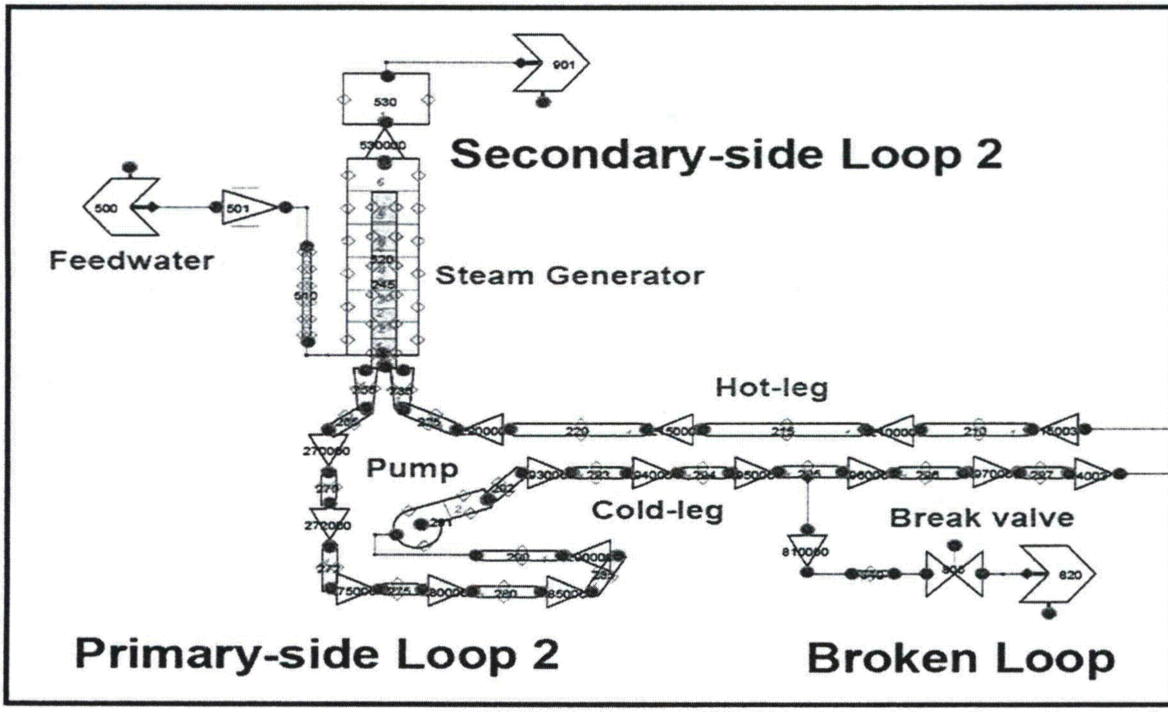
The heat source of IIST facility was simulated by a power component of TRACE (power component 32000), which used the power table (option 6) to simulate the power varying during the experiments, as shown in Fig. 3.3. Besides, the main heat exchange simulation of IIST facility TRACE models were as follows: (1) the heat exchange in the primary-side and the secondary-side of the SGs, shown in Fig. 3.4, (2) the internal heat exchange of the pressure vessel, shown in Fig. 3.5. The feedwater line was simulated using a time-dependent junction, as shown in Fig. 3.6. In all break components of IIST facility TRACE models, the break type used option 4 in order to use the tables to simulate the boundary conditions of IIST facility experiments (shown in Fig. 3.7). Finally, the timestep range ($0.01\sim1\times10^{-8}$ sec) of IIST facility TRACE models were used in the calculation process (shown in Fig. 3.8).



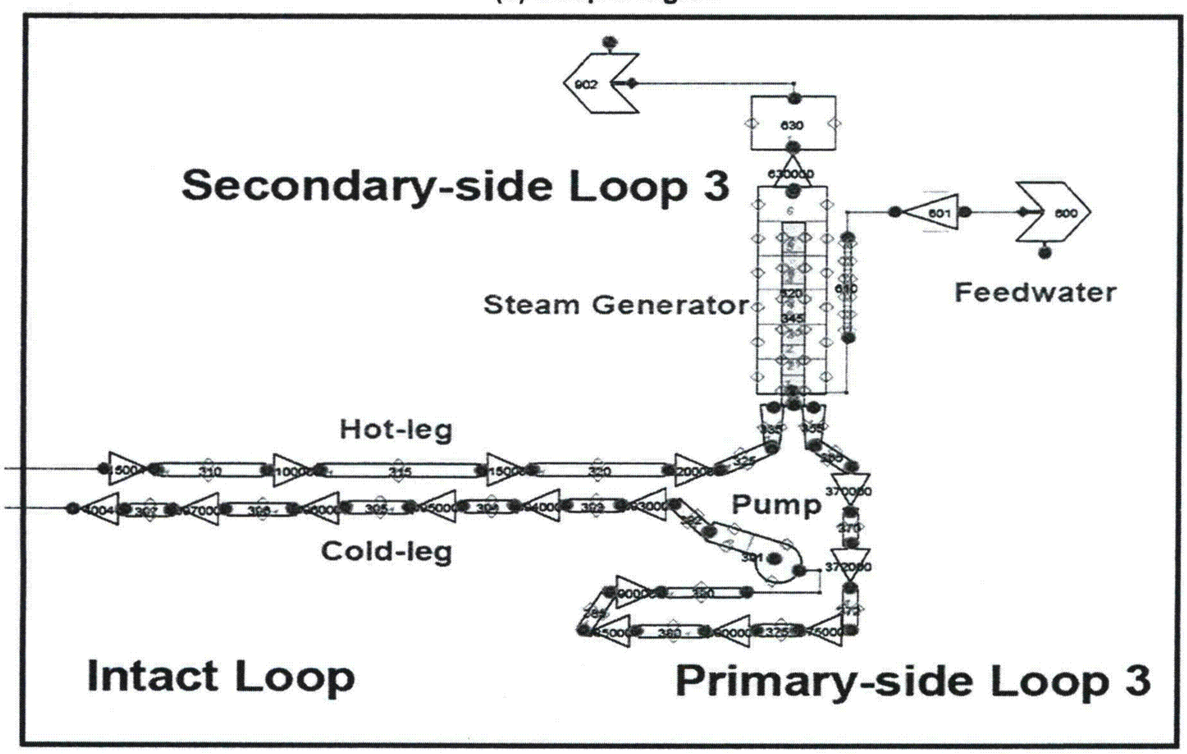
(a) overall region



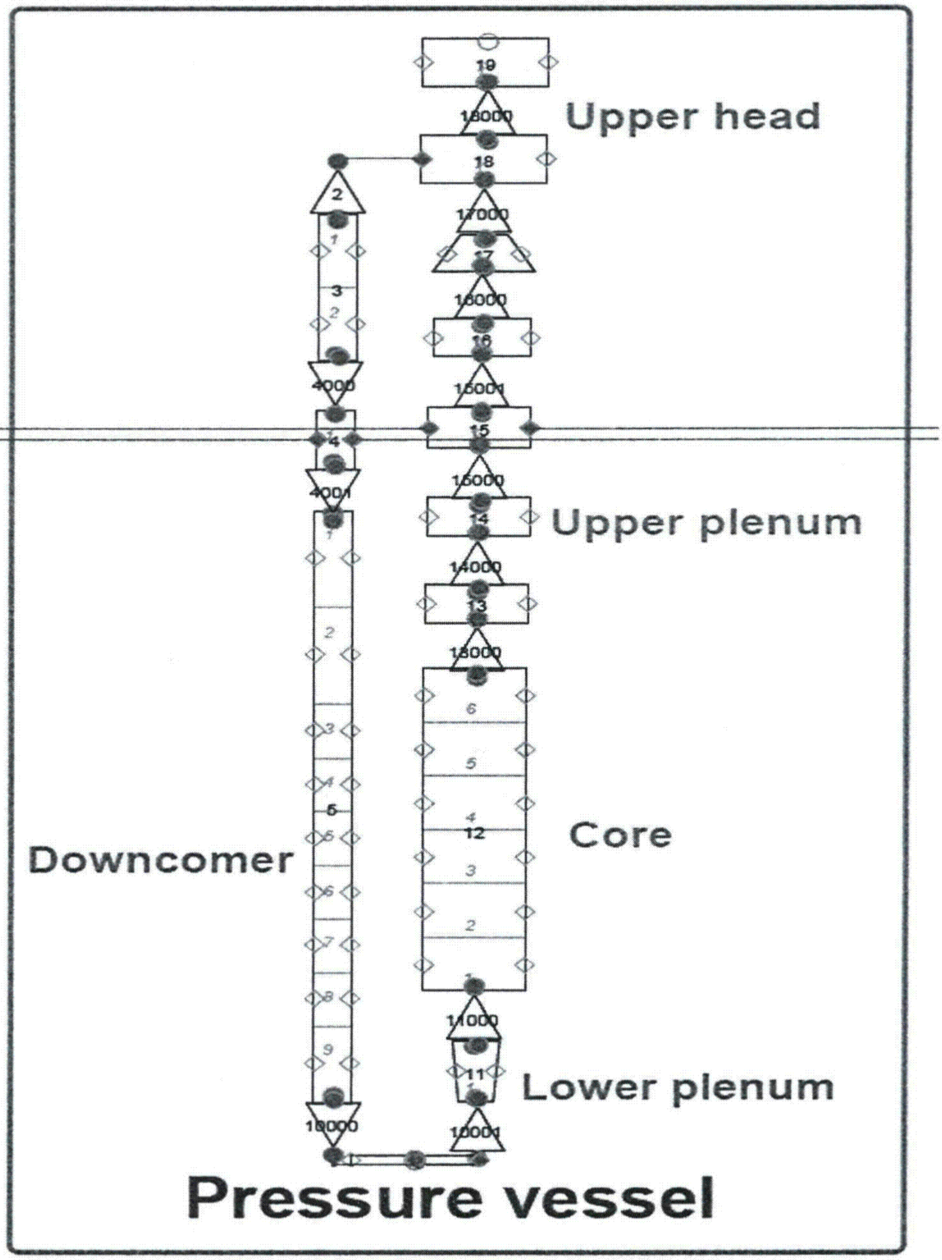
(b) Loop 1 region



(c) Loop 2 region



(d) Loop 3 region



(e) Pressure vessel region
Fig. 3.1 The TRACE IIST facility model (model A)

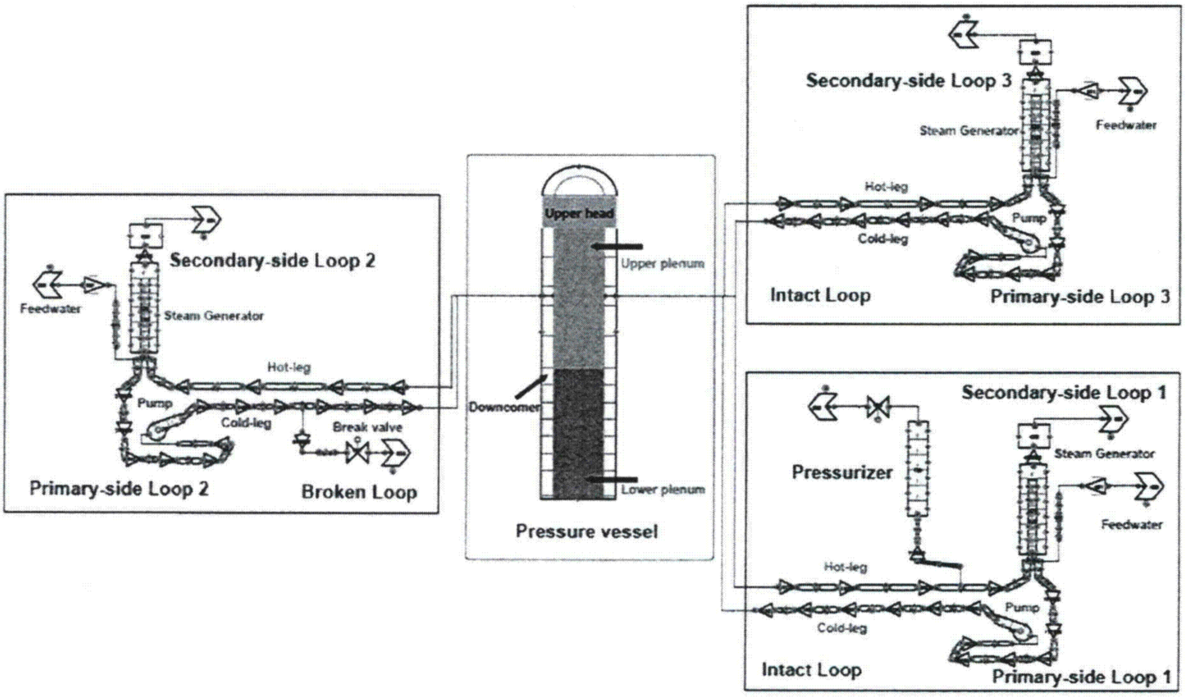


Fig. 3.2 The TRACE IIST facility model (model B)

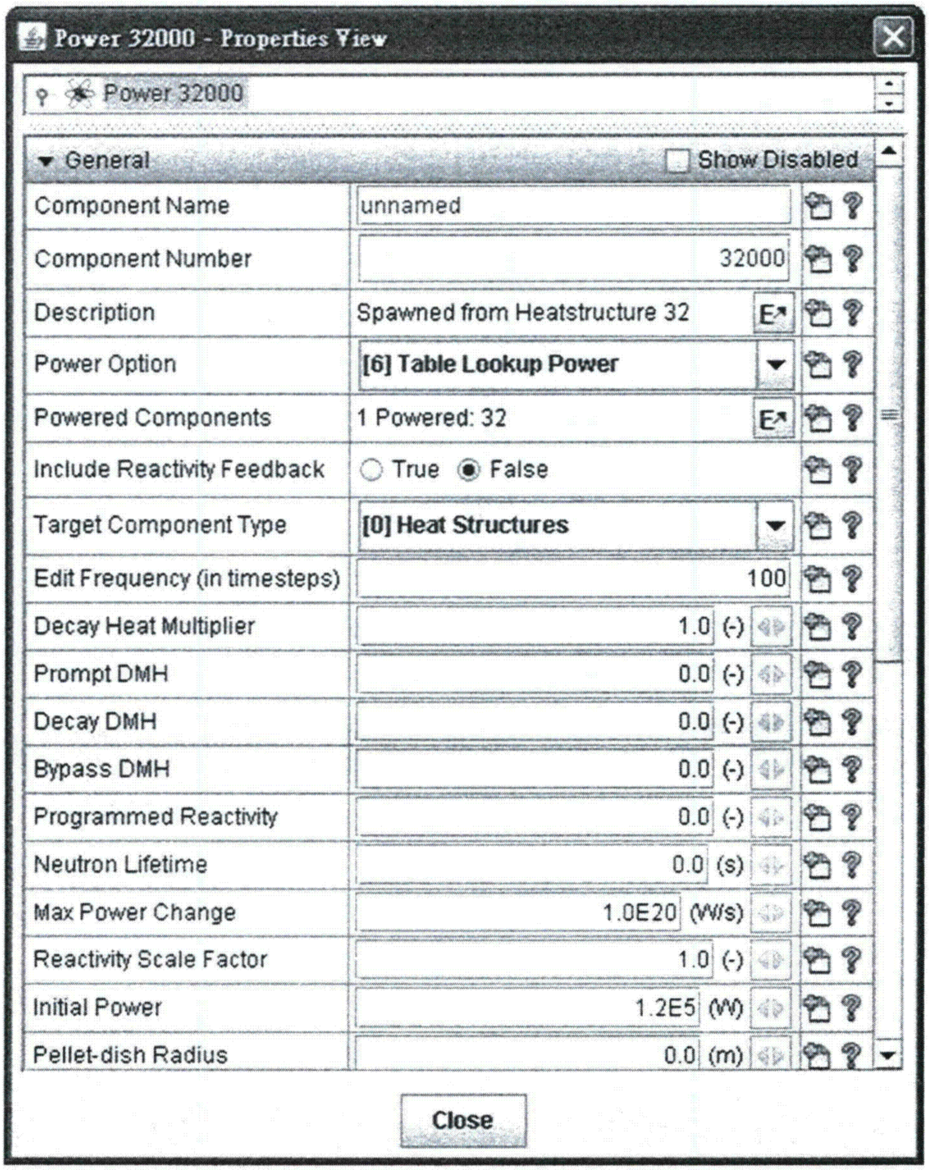
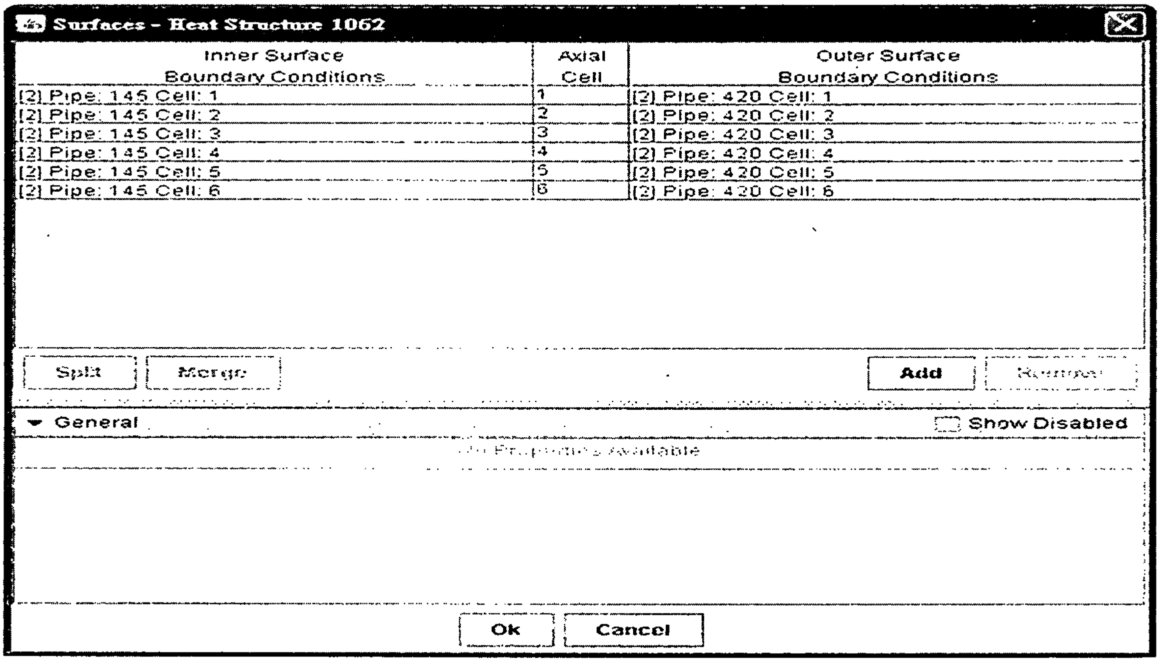
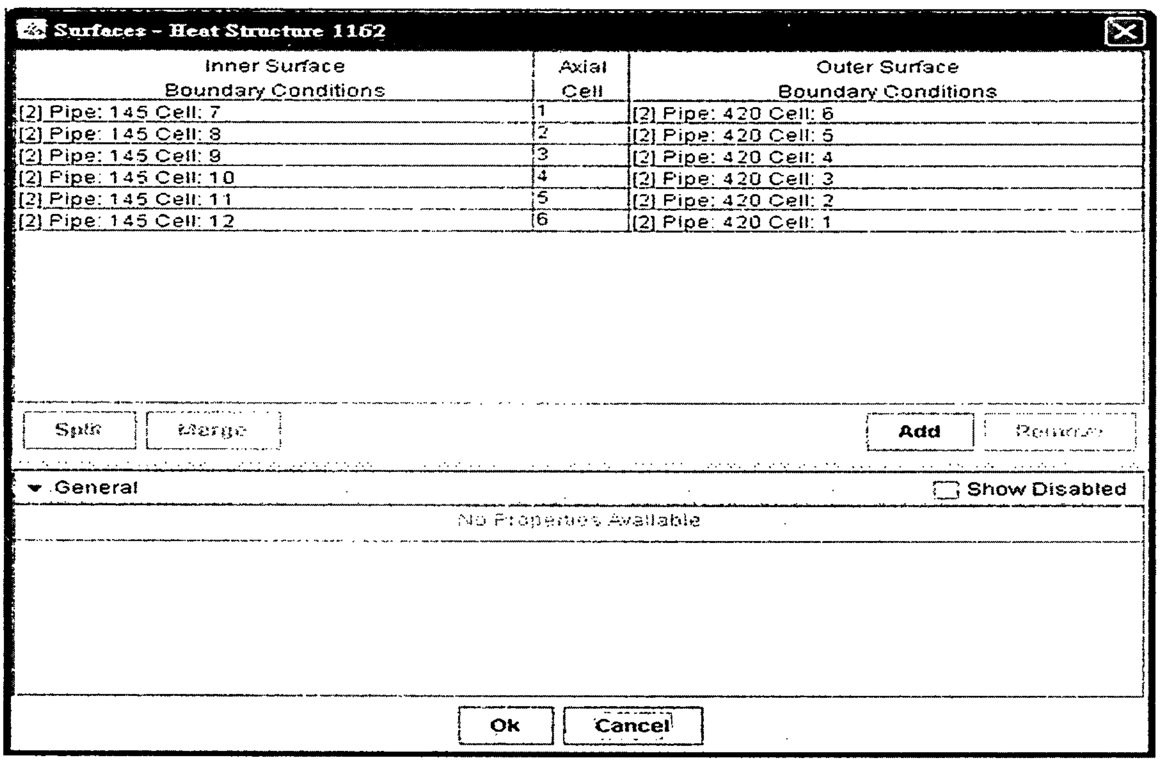


Fig. 3.3 The power component simulation of IIST facility TRACE model

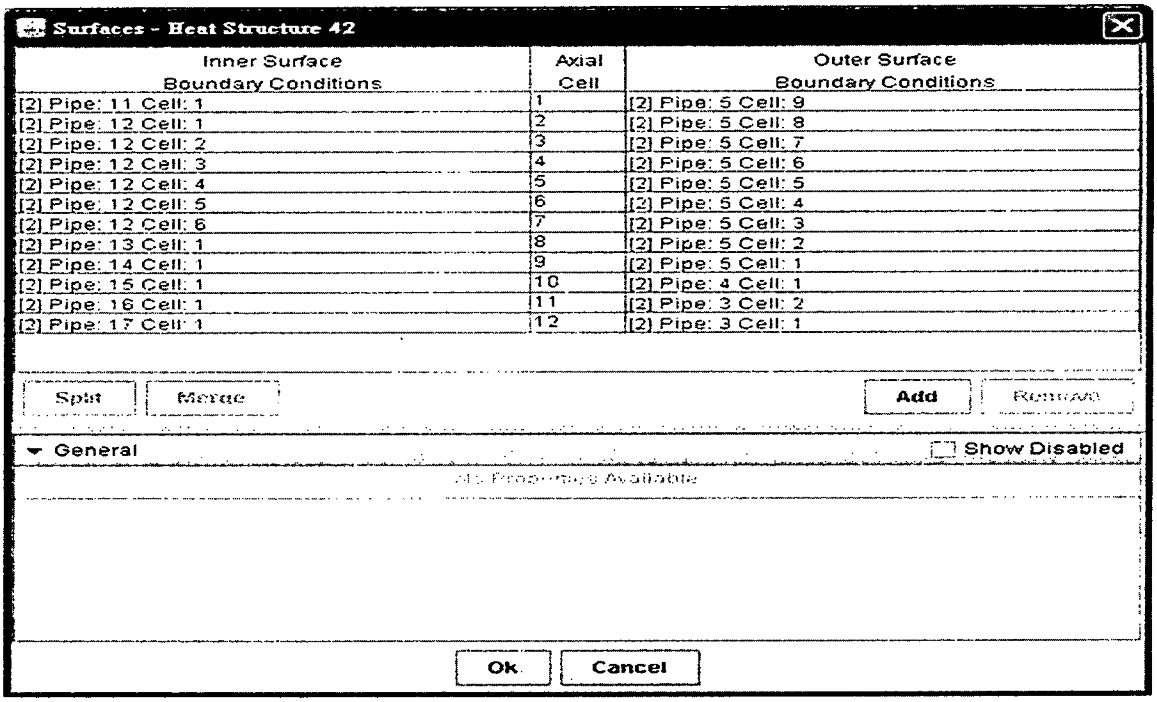


(a) the SG U tube part I (pipe 145 cell 1~6)



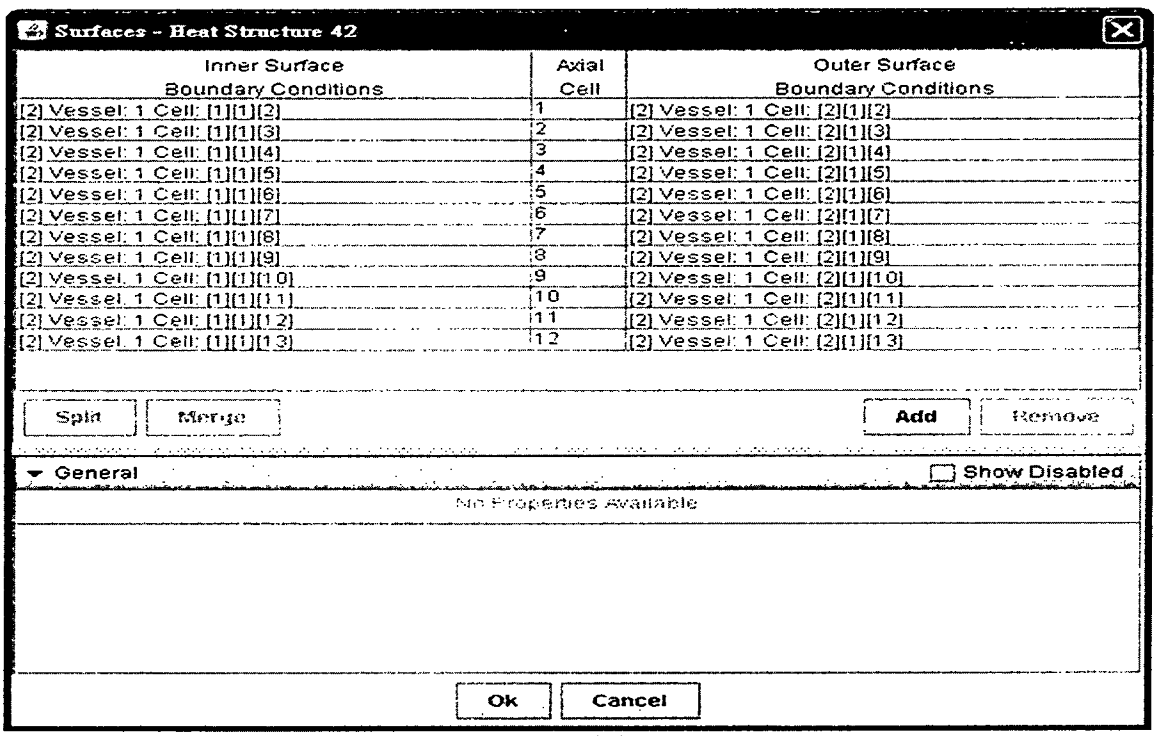
(b) the SG U tube part II (pipe 145 cell 7~12)

Fig. 3.4 The SG heat exchange simulation of IIST facility TRACE model



Inner Surface Boundary Conditions	Axial Cell	Outer Surface Boundary Conditions
[2] Pipe: 11 Cell: 1	1	[2] Pipe: 5 Cell: 9
[2] Pipe: 12 Cell: 1	2	[2] Pipe: 5 Cell: 8
[2] Pipe: 12 Cell: 2	3	[2] Pipe: 5 Cell: 7
[2] Pipe: 12 Cell: 3	4	[2] Pipe: 5 Cell: 6
[2] Pipe: 12 Cell: 4	5	[2] Pipe: 5 Cell: 5
[2] Pipe: 12 Cell: 5	6	[2] Pipe: 5 Cell: 4
[2] Pipe: 12 Cell: 6	7	[2] Pipe: 5 Cell: 3
[2] Pipe: 13 Cell: 1	8	[2] Pipe: 5 Cell: 2
[2] Pipe: 14 Cell: 1	9	[2] Pipe: 5 Cell: 1
[2] Pipe: 15 Cell: 1	10	[2] Pipe: 4 Cell: 1
[2] Pipe: 16 Cell: 1	11	[2] Pipe: 3 Cell: 2
[2] Pipe: 17 Cell: 1	12	[2] Pipe: 3 Cell: 1

(a) model A



Inner Surface Boundary Conditions	Axial Cell	Outer Surface Boundary Conditions
[2] Vessel: 1 Cell: [1][1][2]	1	[2] Vessel: 1 Cell: [2][1][2]
[2] Vessel: 1 Cell: [1][1][3]	2	[2] Vessel: 1 Cell: [2][1][3]
[2] Vessel: 1 Cell: [1][1][4]	3	[2] Vessel: 1 Cell: [2][1][4]
[2] Vessel: 1 Cell: [1][1][5]	4	[2] Vessel: 1 Cell: [2][1][5]
[2] Vessel: 1 Cell: [1][1][6]	5	[2] Vessel: 1 Cell: [2][1][6]
[2] Vessel: 1 Cell: [1][1][7]	6	[2] Vessel: 1 Cell: [2][1][7]
[2] Vessel: 1 Cell: [1][1][8]	7	[2] Vessel: 1 Cell: [2][1][8]
[2] Vessel: 1 Cell: [1][1][9]	8	[2] Vessel: 1 Cell: [2][1][9]
[2] Vessel: 1 Cell: [1][1][10]	9	[2] Vessel: 1 Cell: [2][1][10]
[2] Vessel: 1 Cell: [1][1][11]	10	[2] Vessel: 1 Cell: [2][1][11]
[2] Vessel: 1 Cell: [1][1][12]	11	[2] Vessel: 1 Cell: [2][1][12]
[2] Vessel: 1 Cell: [1][1][13]	12	[2] Vessel: 1 Cell: [2][1][13]

(b) model B

Fig. 3.5 The pressure vessel heat exchange simulation of IIST facility TRACE model

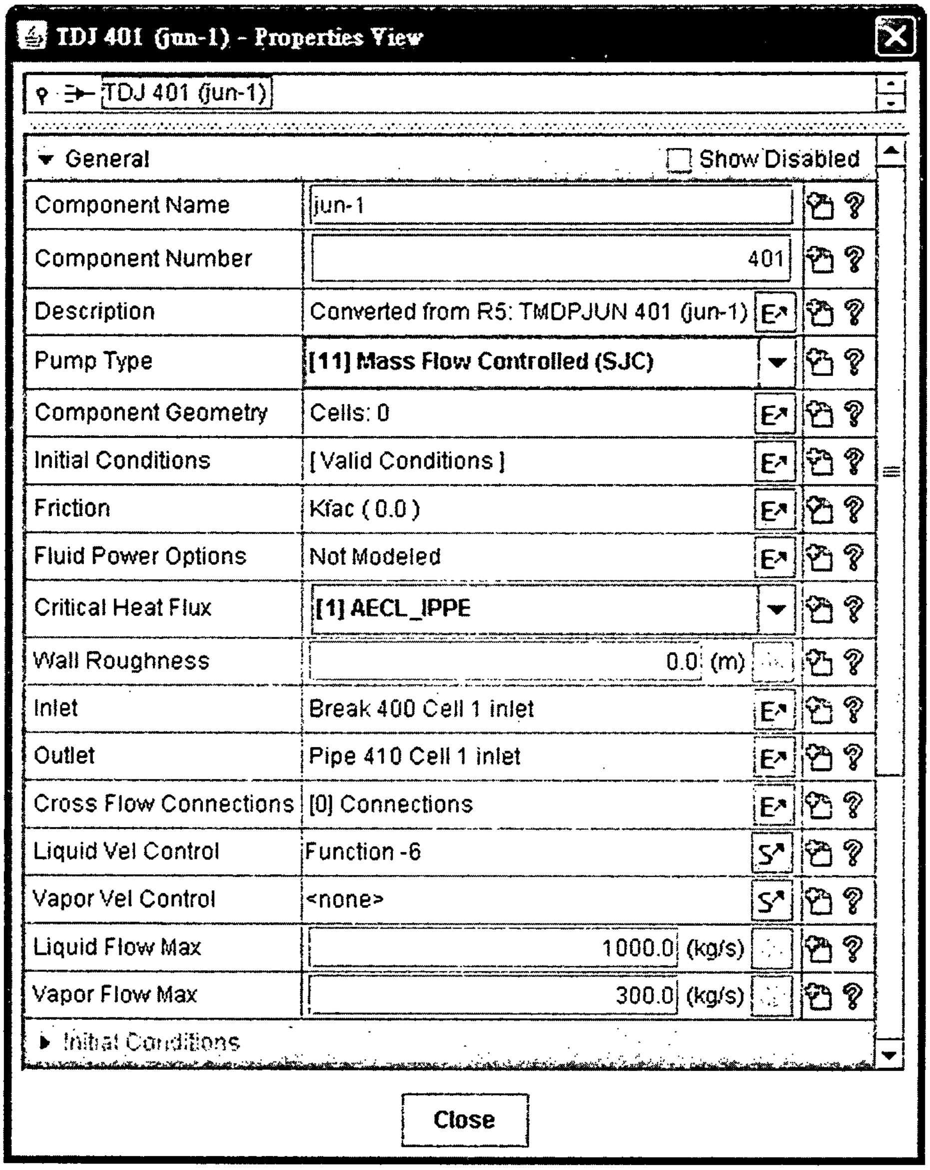


Fig. 3.6 The feedwater simulation of IIST facility TRACE model

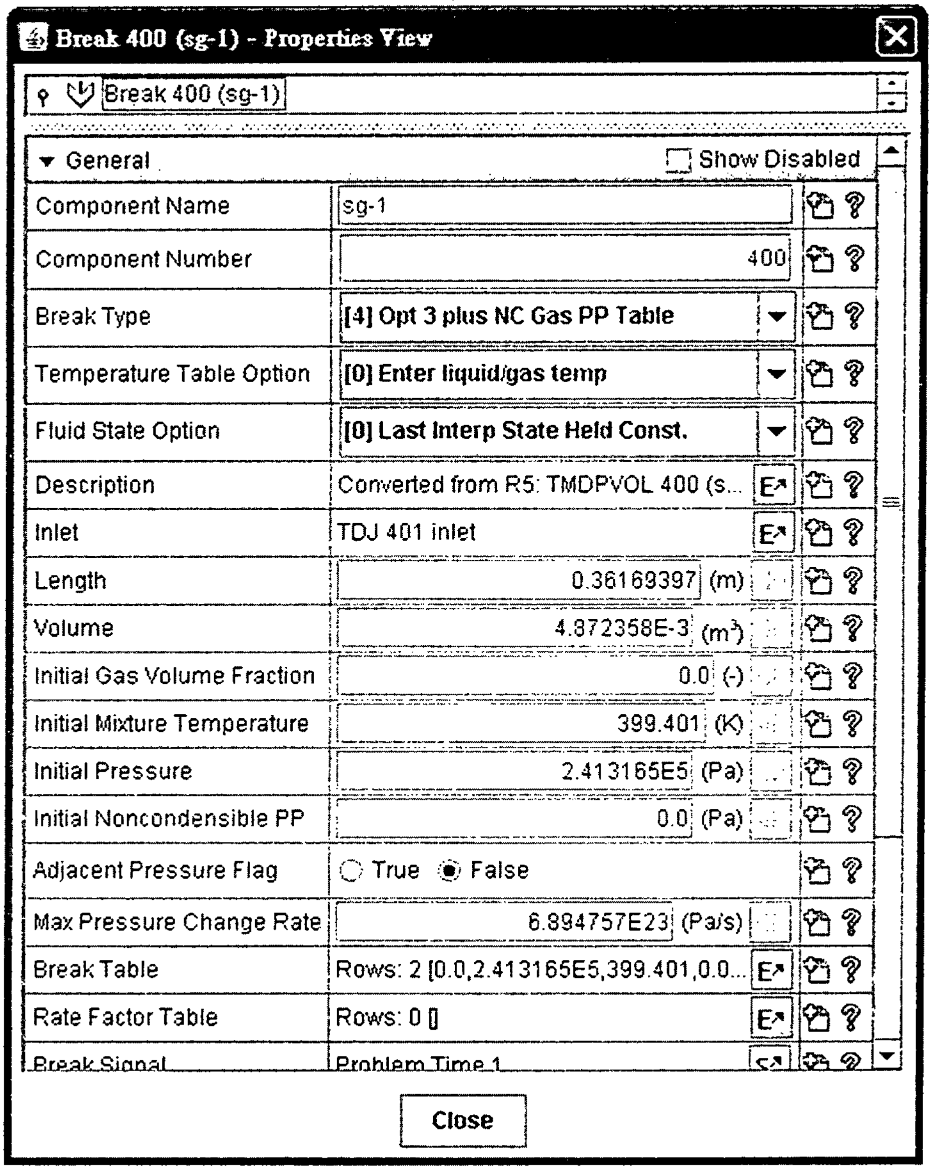
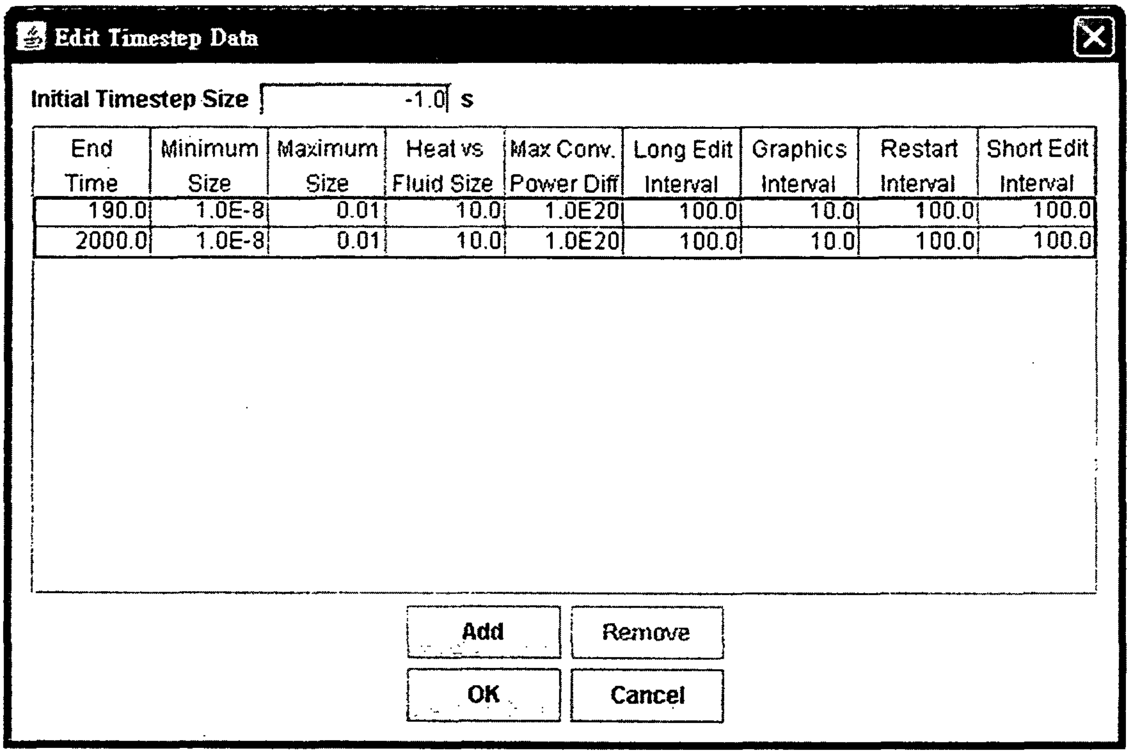


Fig. 3.7 The break simulation of IIST facility TRACE model



End Time	Minimum Size	Maximum Size	Heat vs Fluid Size	Max Conv. Power Diff	Long Edit Interval	Graphics Interval	Restart Interval	Short Edit Interval
190.0	1.0E-8	0.01	10.0	1.0E20	100.0	10.0	100.0	100.0
2000.0	1.0E-8	0.01	10.0	1.0E20	100.0	10.0	100.0	100.0

Fig. 3.8 The timestep data of IIST facility TRACE model

4. Results and discussions

4.1 IIST facility SBLOCA experiment

Table 4.1 shows the comparison of initial condition among IIST facility, RELAP5, TRACE. The TRACE analysis results are in good agreement with the IIST facility and RELAP5 data. Fig. 4.1 shows the comparison of primary system pressure among IIST facility, RELAP5, TRACE. Fig. 4.2 shows the comparison of break flow rate among IIST facility, RELAP5, TRACE. The primary system pressure and break flow rate trends of TRACE are similar with the IIST facility and RELAP5 data. Besides, it also shows that the TRACE model A overpredicted the primary system pressure during 100~600 sec. From the data of IIST facility SBLOCA experiment and RELAP5 analysis[(7)], it shows three periods: (1) subcooled liquid break flow from 0 to 320 sec, (2) low-quality two-phase break flow from 320 to 620 sec, and (3) high-quality two-phase break flow after 620 sec. The above data also described that RELAP5 underpredicted the primary system pressure during the subcooled break flow period, and it overpredicted pressure during the low-quality two-phase break flow period. The differences of the primary system pressure between IIST facility and RELAP5 were caused by overprediction of the subcooled break flow period, underprediction of the low-quality two-phase break flow period, compared with the IIST facility data, as shown in Fig. 4.2. Therefore, the TRACE model A overpredicted the primary system pressure during the subcooled break flow and the low-quality two-phase break flow periods. It was due to underprediction of break flow rate during the subcooled break flow and the low-quality two-phase break flow, compared with the IIST facility data, as shown in Fig. 4.2.

Asymmetric natural-circulation flow rates were observed in the three loops during the IIST facility SBLOCA experiment, but TRACE was unable to simulate these phenomena, which was shown in Fig. 4.3 and Fig. 4.4. According to the previous paper[(7)], the above trend is also observed in the results of RELAP5 (shown in Fig. 4.3 and Fig. 4.4) and this paper described the difference generated from the inadequate simulation of the effect of noncondensable air in RELAP5 after emptying of the pressurizer. Hence, in this parameter analyses, the above results shows that there is the same defect in TRACE.

Fig. 4.5 and Fig. 4.6 show the differential pressures of IIST facility, RELAP5, and TRACE in the upflow and downflow sides of the U-tubes for SG-2. The TRACE model A and RELAP5 predicted more liquid holdup in both sides of the U-tubes. However, the TRACE model B predicted the similar result with the IIST facility data. The main difference in TRACE model A and model B is the simulation of IIST facility pressure vessel. Therefore, it may be the reason which caused the difference between analyses result of TRACE model A and model B in this parameter.

For loop 1, the IIST facility data show the inlet and outlet plenum of SG-1 to empty after 500 sec, as shown in Fig. 4.7 and Fig. 4.8. However, the TRACE and RELAP5 overpredicted liquid holdup in the SG-1 inlet and outlet plenum. The difference among IIST facility, RELAP5, and TRACE were caused by the reason which happened in Fig. 4.3.

Fig. 4.9 shows the comparison of the liquid holdup in the SG-2 inlet plenum among IIST facility, RELAP5, and TRACE. There are the similar trends in this parameter. However, the value of TRACE is lower than IIST facility and RELAP5 after 400 sec. Fig. 4.10 shows the comparison of outlet plenum liquid level of SG-3 among IIST facility, RELAP5, and TRACE. The trends of their curves are generally consistent in 0~1000 sec. For the TRACE model B, it underpredicted after 1000sec. Besides, RELAP5 also underpredicted after 1300sec.

Fig. 4.11 and Fig. 4.12 show the fluid temperatures of the hot-leg and cold-leg in loop 3. The TRACE and RELAP5 predicted the loop 3 fluid temperature to be in good agreement with the IIST facility experiment data.

Fig. 4.13 shows the comparison of the core liquid level among IIST facility, RELAP5, and TRACE. The trends of their curves are the similar. The core liquid level of RELAP5 was slightly lower than IIST facility. However, the TRACE results data are better than RELAP5. Besides, the TRACE and RELAP5 can well predict the time to reach the core uncover which caused the cladding temperature increase, as shown in Fig. 4.14.

Overall, the TRACE analyses results are roughly consistent with the IIST facility and RELAP5 data. Besides, the TRACE model B has better prediction than model A in the primary system pressure, break flow, SG2-inlet tube top differential pressure, and SG2-outlet tube top differential pressure.

Table 4.1 The comparison of SBLOCA experiment initial condition among IIST facility, RELAP5, TRACE

Parameter	IIST facility	RELAP5	TRACE(model A) /error (%)	TRACE(model B) /error (%)
Primary coolant system				
Core power (kW)	126	126	126	126
Pressurizer pressure (MPa)	0.958	0.958	0.964 /0.6	0.964 /0.6
Pressurizer water level (mm)	1459	1413	1463 /0.3	1394 /4.5
Loop flow rate (kg/s)				
Loop1	0.210	0.227	0.219 /4.3	0.204 /2.9
Loop2	0.217	0.227	0.219 /0.9	0.198 /8.8
Loop3	0.217	0.227	0.219 /0.9	0.198 /8.8
Hot-leg temperature (K)				
Loop1	450	445	448.7 /0.3	446.1 /0.9
Loop2	449	445	448.7 /0.1	446.1 /0.6
Loop3	451	445	448.7 /0.5	446.1 /1.1
Cold-leg temperature (K)				
Loop1	409	409	409.5 /0.1	409.5 /0.1
Loop2	408	409	409.5 /0.4	409.5 /0.4
Loop3	409	409	409.5/ 0.1	409.5 /0.1
Secondary coolant system				
Secondary-side pressure (MPa)				
SG-1	0.301	0.301	0.303 /0.7	0.303 /0.7
SG-2	0.295	0.301	0.299 /1.4	0.299 /1.4
SG-3	0.295	0.301	0.299 /1.4	0.299 /1.4
Secondary-side fluid temperature (K)				
SG-1	407	407	406.1 /0.2	406.0 /0.2
SG-2	407	407	405.6 /0.3	405.6 /0.3
SG-3	407	407	405.6 /0.3	405.6 /0.3

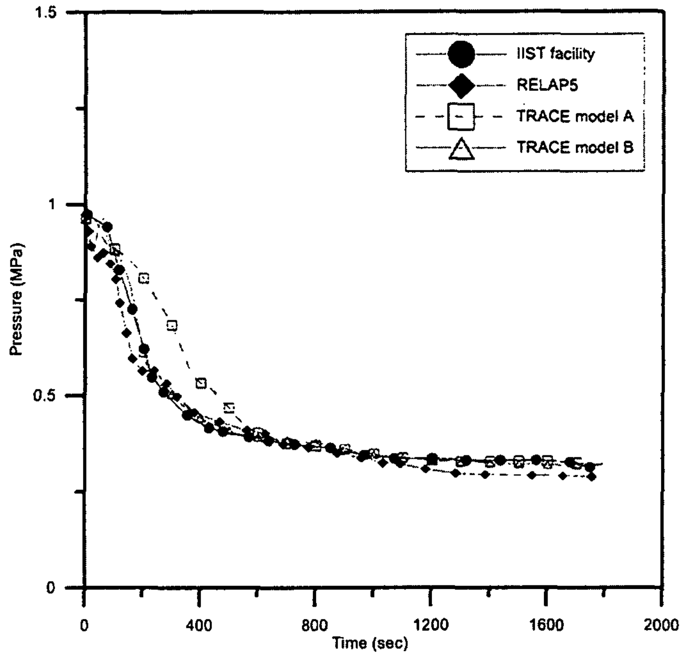


Fig. 4.1 The comparison of primary system pressure among IIST facility, RELAP5, TRACE in the SBLOCA experiment

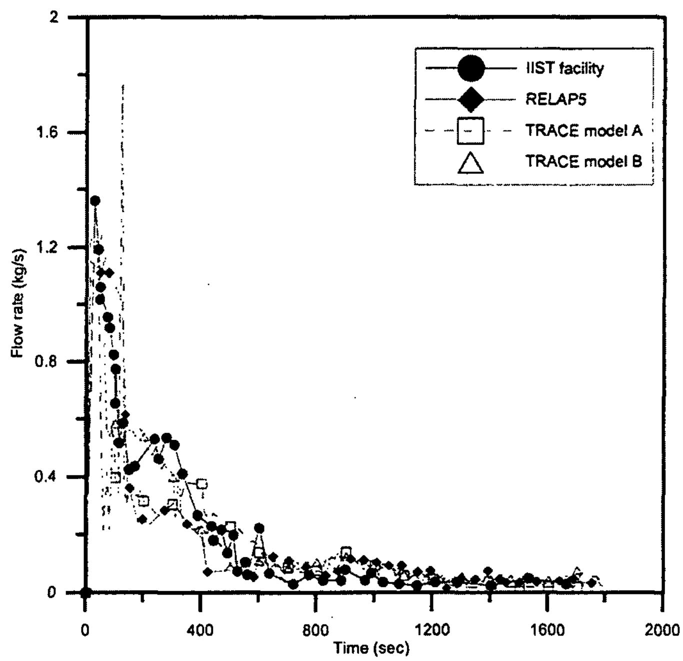


Fig. 4.2 The comparison of break flow rate among IIST facility, RELAP5, TRACE in the SBLOCA experiment

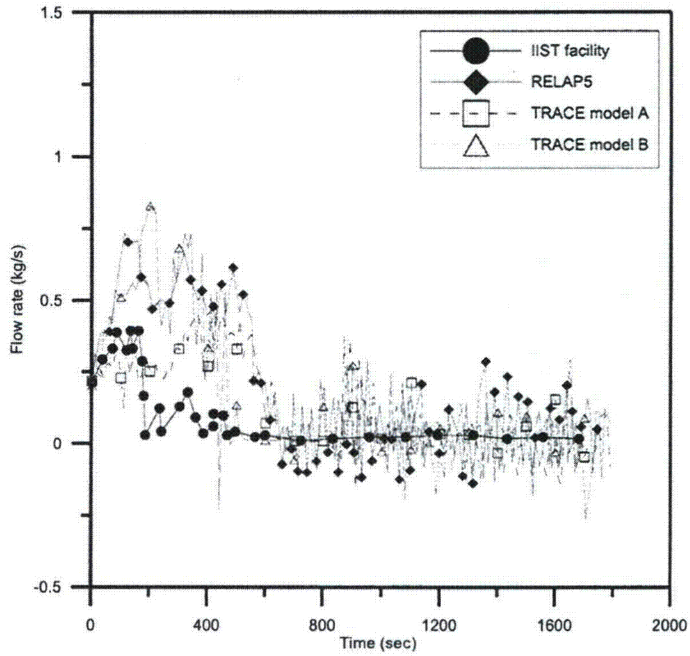


Fig. 4.3 The comparison of loop 1 flow rate among IIST facility, RELAP5, TRACE in the SBLOCA experiment

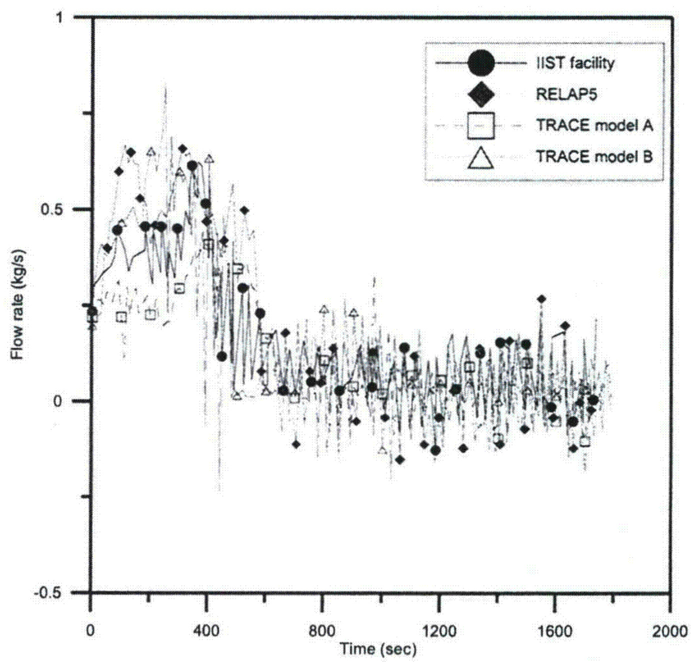


Fig. 4.4 The comparison of loop 3 flow rate among IIST facility, RELAP5, TRACE in the SBLOCA experiment

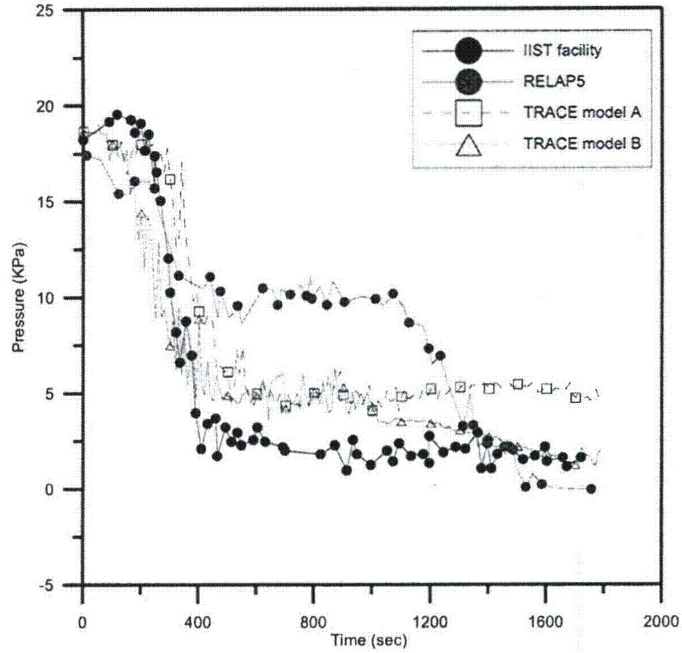


Fig. 4.5 The comparison of SG2-inlet tube top differential pressure among IIST facility, RELAP5, TRACE in the SBLOCA experiment

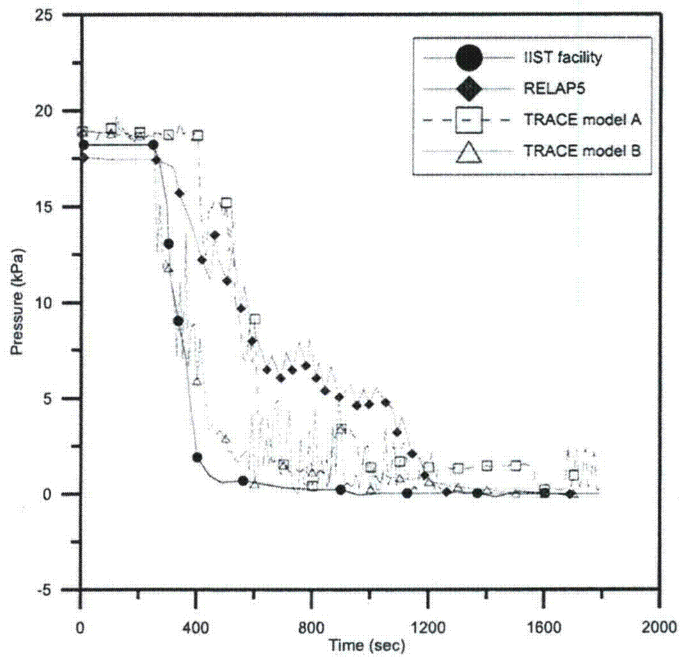


Fig. 4.6 The comparison of SG2-outlet tube top differential pressure among IIST facility, RELAP5, TRACE in the SBLOCA experiment

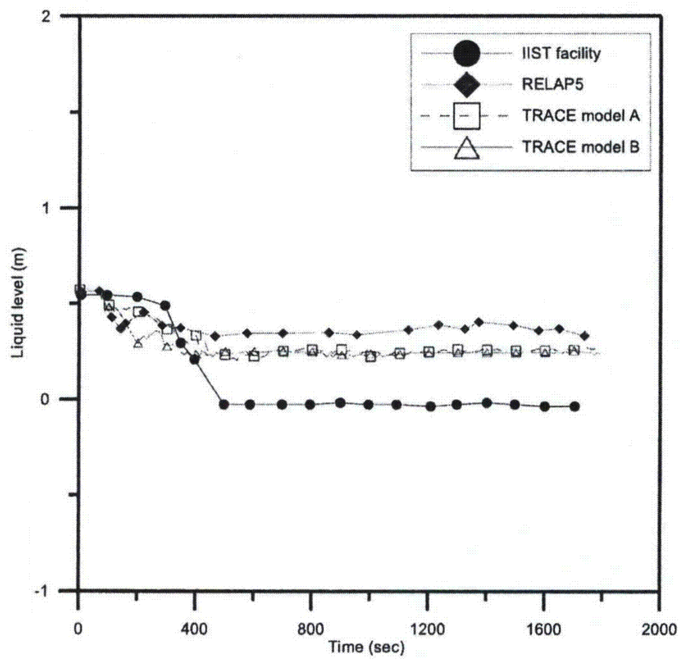


Fig. 4.7 The comparison of SG1-inlet plenum liquid level among IIST facility, RELAP5, TRACE in the SBLOCA experiment

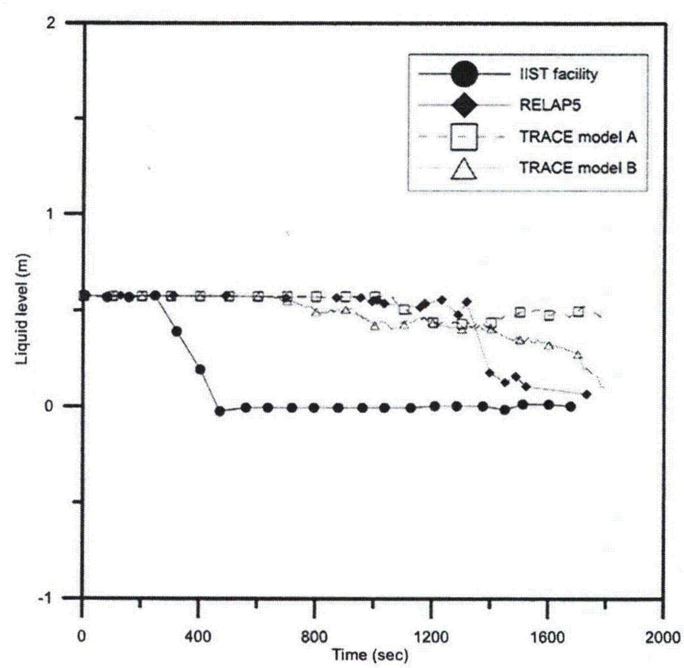


Fig. 4.8 The comparison of SG1-outlet plenum liquid level among IIST facility, RELAP5, TRACE in the SBLOCA experiment

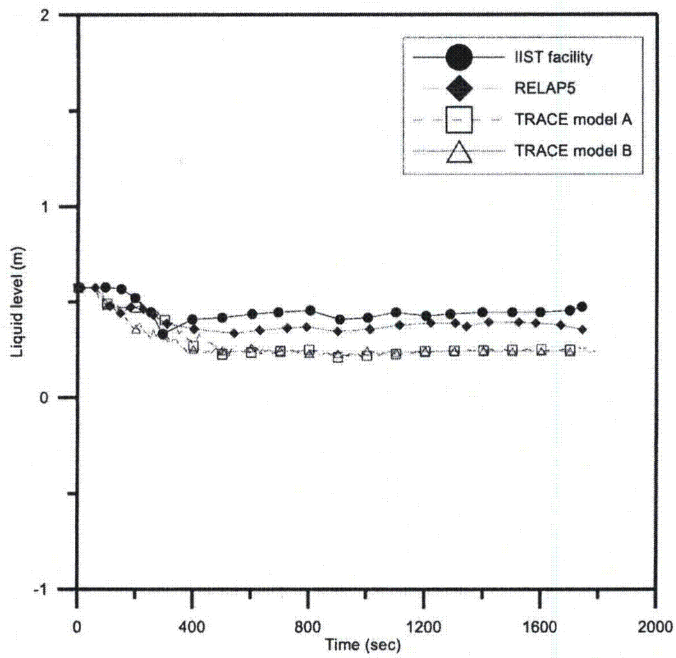


Fig. 4.9 The comparison of SG2-inlet plenum liquid level among IIST facility, RELAP5, TRACE in the SBLOCA experiment

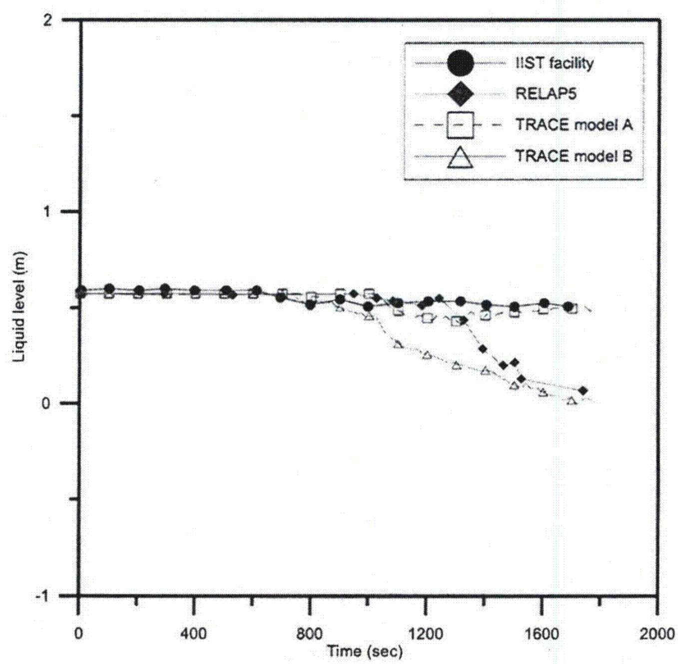


Fig. 4.10 The comparison of SG3-outlet plenum liquid level among IIST facility, RELAP5, TRACE in the SBLOCA experiment

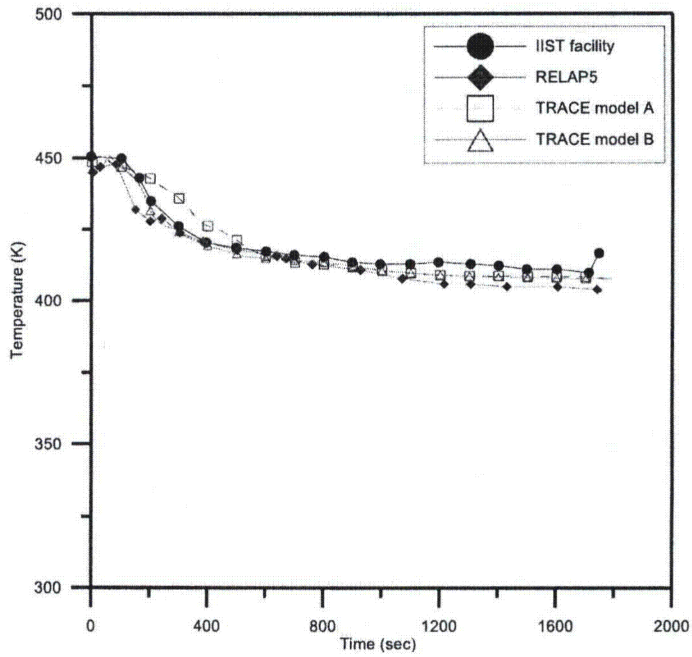


Fig. 4.11 The comparison of loop 3 hot-leg temperature among IIST facility, RELAP5, TRACE in the SBLOCA experiment

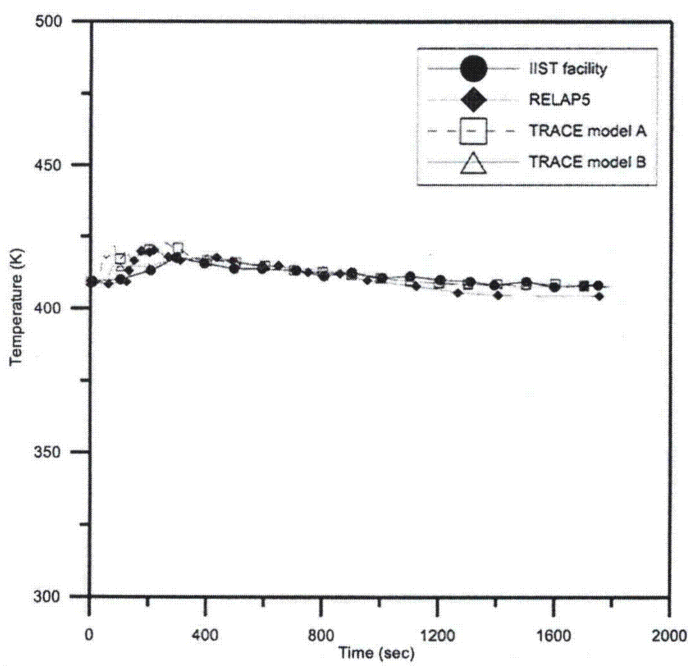


Fig. 4.12 The comparison of loop 3 cold-leg temperature among IIST facility, RELAP5, TRACE in the SBLOCA experiment

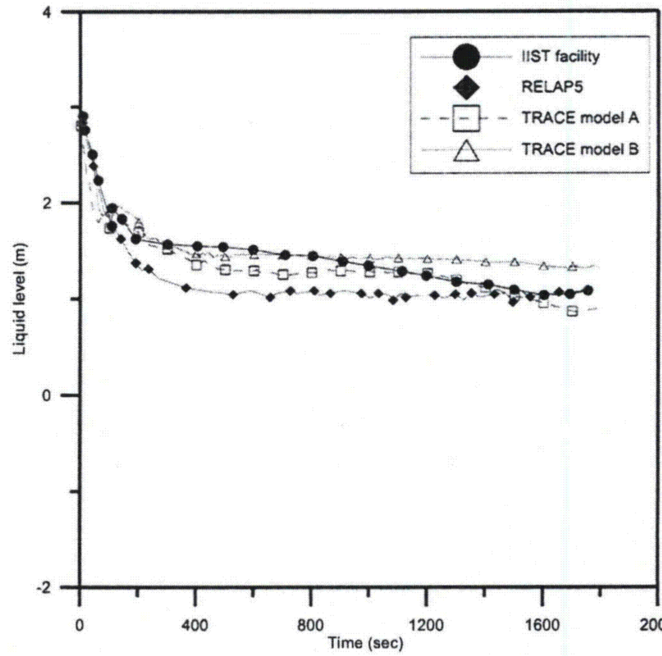


Fig. 4.13 The comparison of core collapsed liquid level among IIST facility, RELAP5, TRACE in the SBLOCA experiment

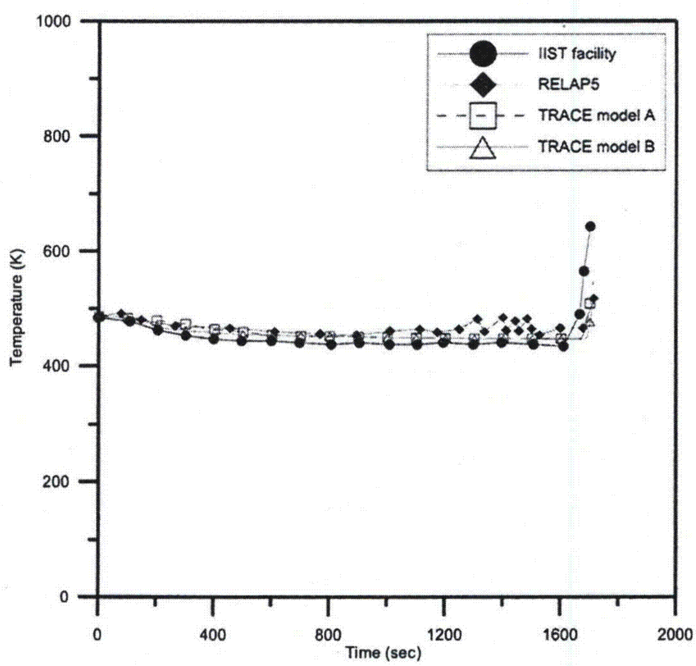


Fig. 4.14 The comparison of Core cladding temperature among IIST facility, RELAP5, TRACE in the SBLOCA experiment

4.2 IIST cooldown experiments

In this section, Table 4.2, Table 4.3, and Table 4.4 show the comparison of initial condition among IIST facility, RELAP5, TRACE for the cooldown experiments(8). The TRACE analysis results are in agreement with the IIST facility and RELAP5 data.

Table 4.2 The comparison of C61128 cooldown experiment initial condition among IIST facility, RELAP5, TRACE(8)

	IIST facility	RELAP5	TRACE (model A) /error(%)	TRACE (model B) /error(%)
Pressurizer pressure (MPa)	0.972	0.953	0.981 /0.9	0.961 /1.1
Pressurizer water level (mm)	1241	1225	1237 /0.3	1277 /2.9
Core power (kW)	100.4	100.4	100.4	100.4
Hot leg temperature (K)	442.1	438.6	444.8 /0.6	440.3/ 0.4
Cold leg temperature (K)	410.3	410.4	411.4 /0.3	411.0 /0.2
SG pressure (MPa)	0.286	0.286	0.281 /1.7	0.286 /0.0
SG water level (mm)	2230	2198	2258 /1.3	2244 /0.6

Table 4.3 The comparison of C61210 cooldown experiment initial condition among IIST facility, RELAP5, TRACE(8)

	IIST facility	RELAP5	TRACE (model A) /error(%)	TRACE (model B) /error(%)
Pressurizer pressure (MPa)	0.979	0.979	0.953 /2.7	0.944 /3.6
Pressurizer water level (mm)	1269	1342	1335 /5.2	1316/3.7
Core power (kW)	120	120	120	120
Hot leg temperature (K)	448.8	444.6	448.7 /0.02	448.1 /0.2
Cold leg temperature (K)	412.2	412.2	411.3 /0.2	412.5 /0.1

SG pressure (MPa)	0.283	0.289	0.287 /1.4	0.286 /1.1
SG water level (mm)	2264	2282	2249 /0.7	2229/1.5

Table 4.4 The comparison of C70122 cooldown experiment initial condition among IIST facility, RELAP5, TRACE[8]

	IIST facility	RELAP5	TRACE (model A) /error(%)	TRACE (model B) /error(%)
Pressurizer pressure (MPa)	1.82	1.82	1.81 /0.5	1.82 /0.0
Pressurizer water level (mm)	1771	1748	1742 /1.6	1800 /1.6
Core power (kW)	100.3	100.3	100.3	100.3
Hot leg temperature (K)	468.5	462.4	466.6 /0.4	468.4 /0.02
Cold leg temperature (K)	436.1	435.7	434.5 /0.4	436.6 /0.1
SG pressure (MPa)	0.62	0.63	0.61 /1.6	0.64 /3.2
SG water level (mm)	2293	2288	2298 /0.2	2388 /4.1

4.2.1 Test C61128

According to the C61128 experiment data[8], it is high inlet subcooling (9.6K) and the cooldown rate is approximately equal to 0.9 K/min within the limitation range (≦ 1.85 K/min) of Maanshan NPP. Fig. 4.15 shows the comparison of Primary system pressure among IIST facility, RELAP5, TRACE. The TRACE was overpredicted in this parameter during 0~1500 and 2500~3800 sec. However, RELAP5 was also overpredicted in this parameter during 0~4000 sec. At 1000 sec, the core power was adjusted in decreasing rate of 1.75 kW every 50 seconds and the RVs of the SGs opened which resulted in cooldown effect in the RCS. Therefore, the trends of curves decreased after 1000 sec. Fig. 4.16 shows the comparison of SG1 secondary side pressure among IIST facility, RELAP5, TRACE. The trends of TRACE were roughly consistent with the IIST facility and RELAP5 data. The SG secondary pressure keeps constant during 0 to 1000 sec. The RVs of SGs opens at 1000 sec and the pressure decreases; finally it remains at atmospheric pressure.

Fig. 4.17, Fig. 4.18, and Fig. 4.19 show that the SG secondary side, pressurizer, and core collapsed liquid levels of TRACE are consistent with the IIST facility and RELAP5 data. As the RVs open at 1000 sec, the collapsed liquid levels of SG secondary side and pressurizer decrease. However, the core collapsed liquid level is nearly the same during the overall time interval.

Fig. 4.20 and 4.21 show the comparison of loop 1 hot-leg and cold-leg temperatures among IIST facility, RELAP5, TRACE. The TRACE predict the hot-leg and cold-leg temperatures in good agreement with the IIST facility experiment and RELAP5 data.

Overall, the TRACE analyses results are roughly consistent with the IIST facility and RELAP5 data. In the comparison of analysis results of the TRACE model A and B, they are similar in all parameters.

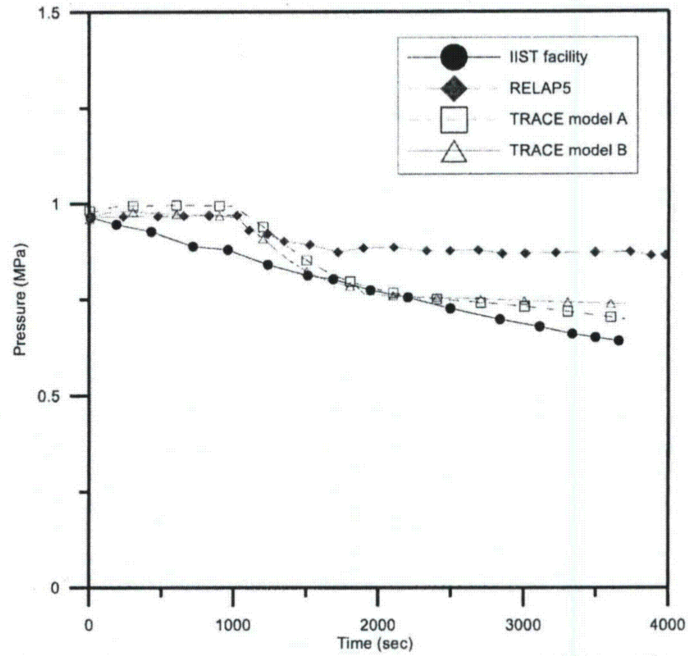


Fig. 4.15 The comparison of Primary system pressure among IIST facility, RELAP5, TRACE in the C61128 experiment

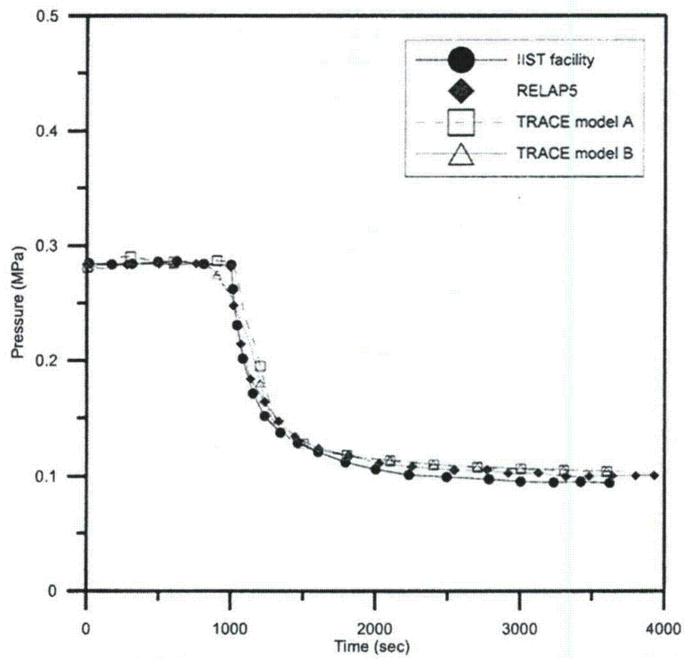


Fig. 4.16 The comparison of SG1 secondary side pressure among IIST facility, RELAP5, TRACE in the C61128 experiment

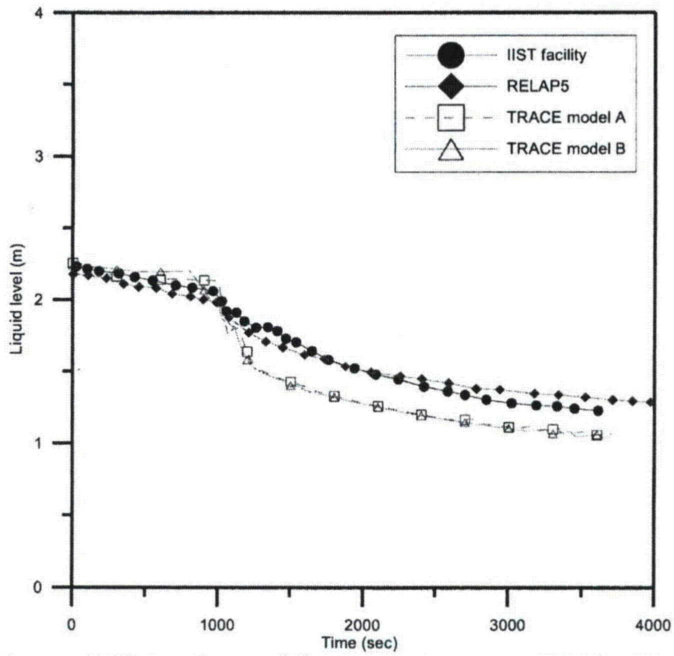


Fig. 4.17 The comparison of SG1 collapsed liquid level among IIST facility, RELAP5, TRACE in the C61128 experiment

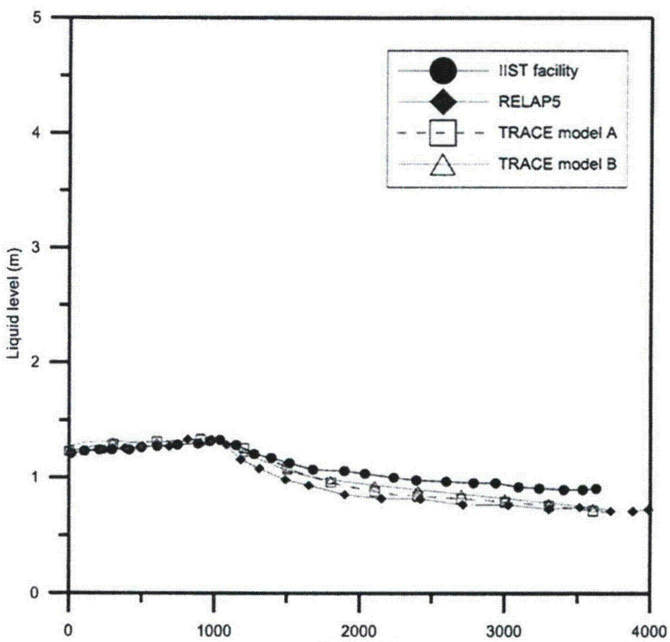


Fig. 4.18 The comparison of pressurizer collapsed liquid level among IIST facility, RELAP5, TRACE in the C61128 experiment

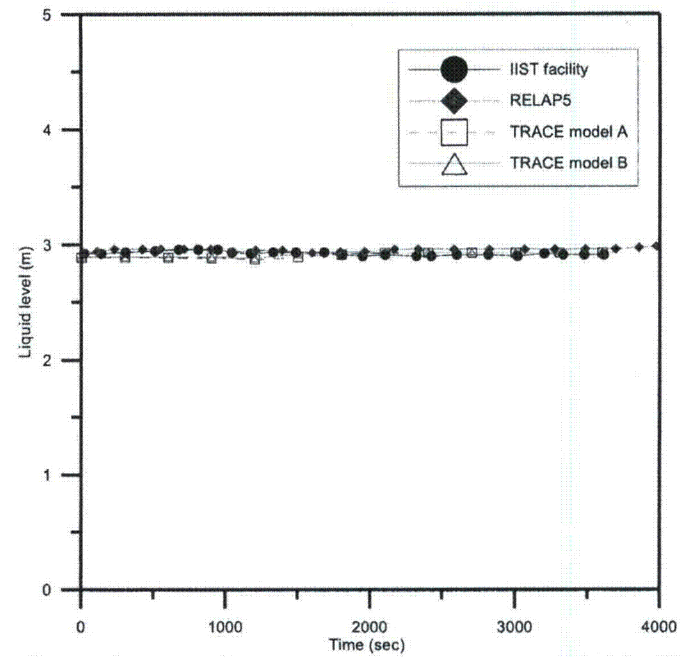


Fig. 4.19 The comparison of core collapsed liquid level among IIST facility, RELAP5, TRACE in the C61128 experiment

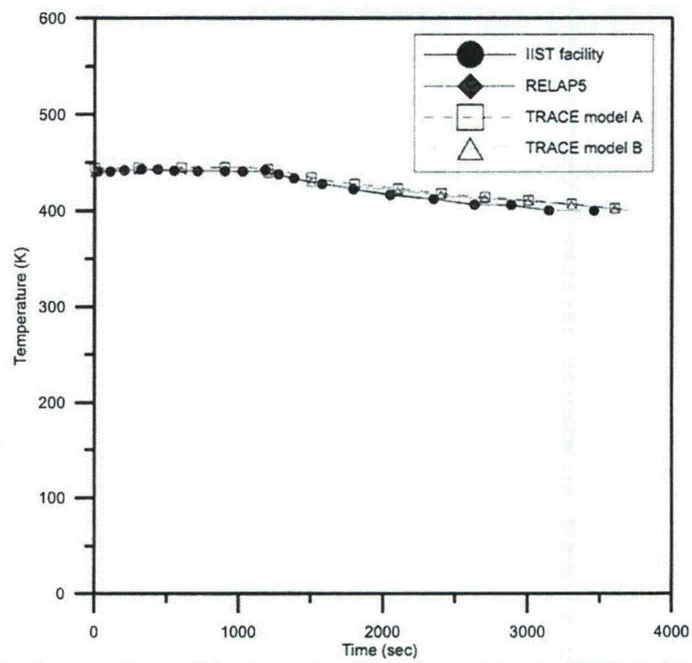


Fig. 4.20 The comparison of loop 1 hot-leg temperature among IIST facility, RELAP5, TRACE in the C61128 experiment

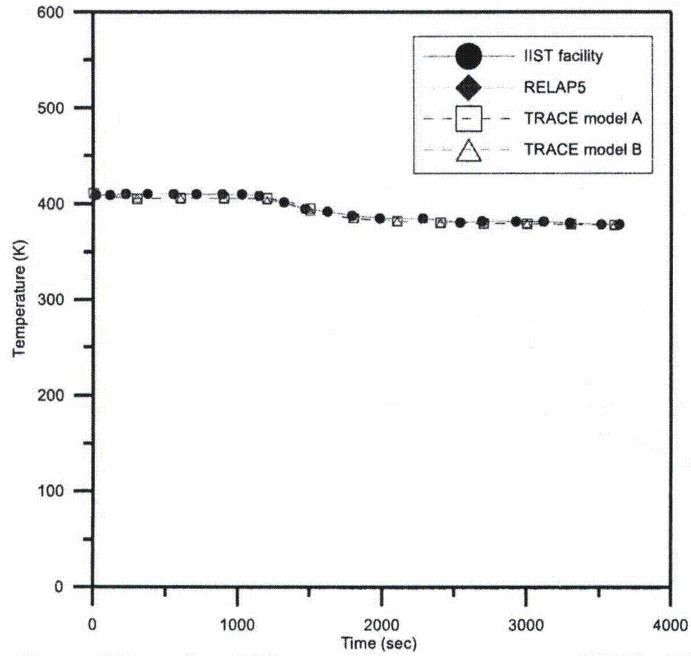


Fig. 4.21 The comparison of loop 1 cold-leg temperature among IIST facility, RELAP5, TRACE in the C61128 experiment

4.2.2 Test C61210

According to the C61210 experiment data[8], it is low inlet subcooling (3K) and the cooldown rate is approximately equal to 1 K/min within the limitation range (≦ 1.85 K/min) of Maanshan NPP. Fig. 4.22 shows the primary system pressures of the IIST facility, RELAP5, TRACE. In this parameter, the trends of TRACE were roughly similar with the IIST facility data. Besides, TRACE was overpredicted in this parameter after 1500 sec. However, RELAP5 was also overpredicted in this parameter during the overall time interval. Besides, the value of RELAP5 was higher than TRACE. At 1000 sec, the core power was adjusted in decreasing rate of 1.75 kW every 50 seconds and the RVs of the SGs opened which resulted in cooldown effect in the RCS. Therefore, the primary system pressures of the IIST facility, RELAP5, and TRACE decreased after 1000 sec. Fig. 4.23 shows the comparison of SG1 secondary side pressure among IIST facility, RELAP5, TRACE. The trends of TRACE were in agreement with the IIST facility and RELAP5 data. The SG secondary pressure keeps constant during 0 to 1000 sec. The RVs of SGs opens at 1000 sec and the pressure decreases; finally it remains at atmospheric pressure.

Fig. 4.24 shows the SG1 secondary side collapsed liquid levels of the IIST facility, RELAP5, TRACE. In this parameter, TRACE was underpredicted after 1000 sec but the trends of TRACE were roughly consistent with the IIST facility and RELAP5 data. Fig. 4.25 and Fig. 4.26 show that the pressurizer and core collapsed liquid levels of TRACE are consistent with the IIST facility and RELAP5 data. Besides, comparing Fig. 4.25 and Fig. 4.26, it can found as the pressurizer collapsed liquid levels of TRACE are lower than IIST facility and RELAP5; the core collapsed liquid levels of TRACE are higher than IIST facility and RELAP5. As the RVs open at 1000 sec, the collapsed liquid levels of SG secondary side and pressurizer decrease. However, the core collapsed liquid level is nearly the same during the overall time interval.

Fig. 4.27 and 4.28 show the loop 1 hot-leg and cold-leg temperatures of IIST facility, RELAP5, TRACE. The hot-leg and cold-leg temperatures prediction of TRACE were the similar with the IIST facility experiment and RELAP5 data.

Overall, the TRACE analyses results are roughly consistent with the IIST facility and RELAP5 data. In the comparison of analysis results of the TRACE model A and B, they are similar in all parameters. However, in primary system pressure, the result of the TRACE model B is better than model A.

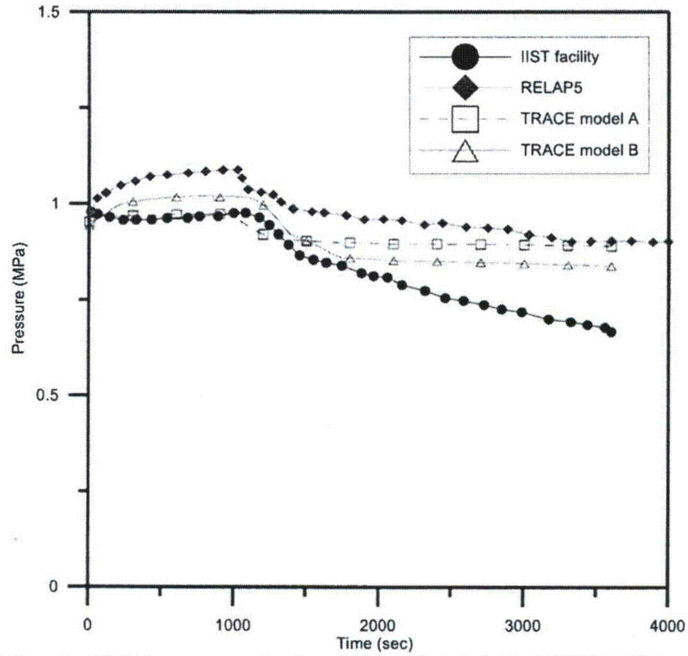


Fig. 4.22 The comparison of Primary system pressure among IIST facility, RELAP5, TRACE in the C61210 experiment

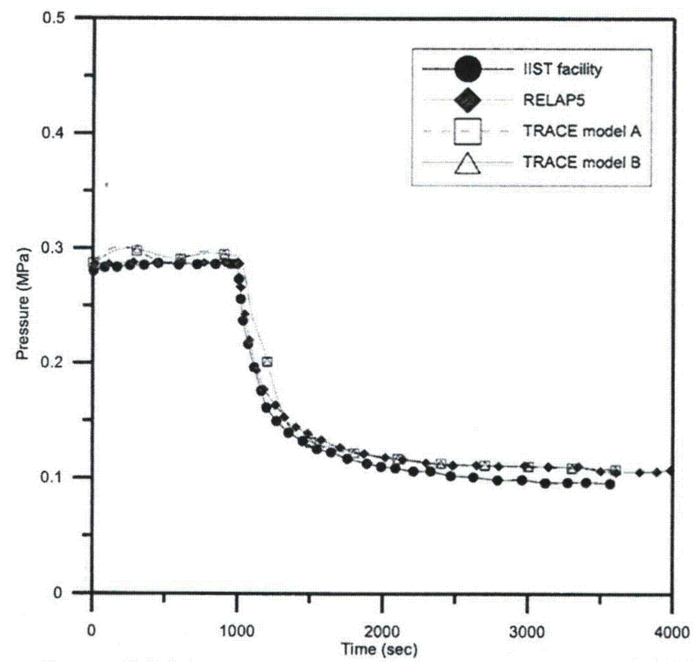


Fig. 4.23 The comparison of SG1 secondary side pressure among IIST facility, RELAP5, TRACE in the C61210 experiment

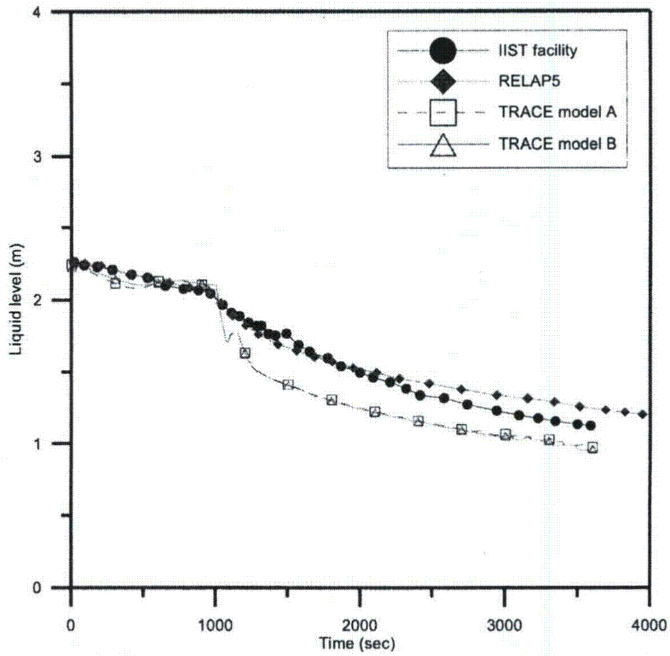


Fig. 4.24 The comparison of SG1 collapsed liquid level among IIST facility, RELAP5, TRACE in the C61210 experiment

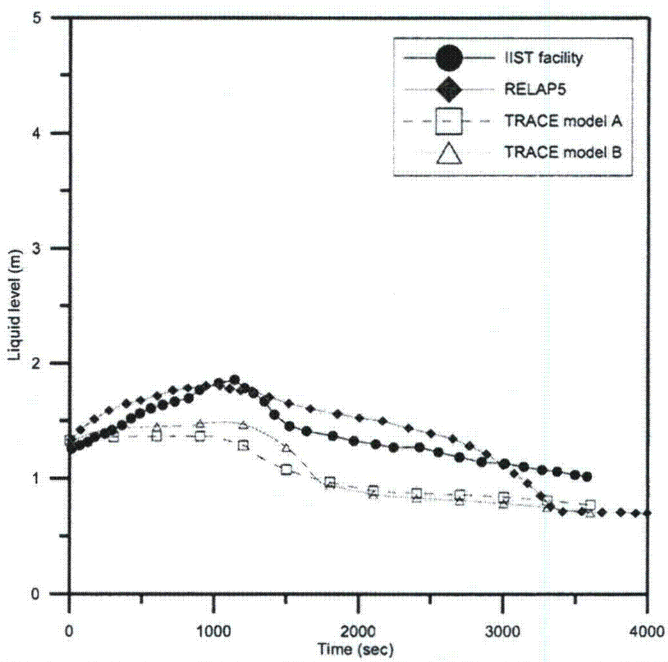


Fig. 4.25 The comparison of pressurizer collapsed liquid level among IIST facility, RELAP5, TRACE in the C61210 experiment

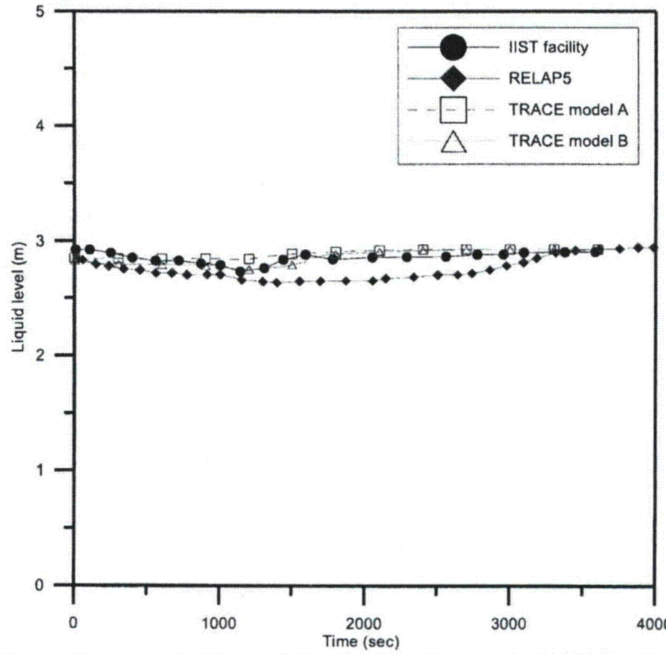


Fig. 4.26 The comparison of core collapsed liquid level among IIST facility, RELAP5, TRACE in the C61210 experiment

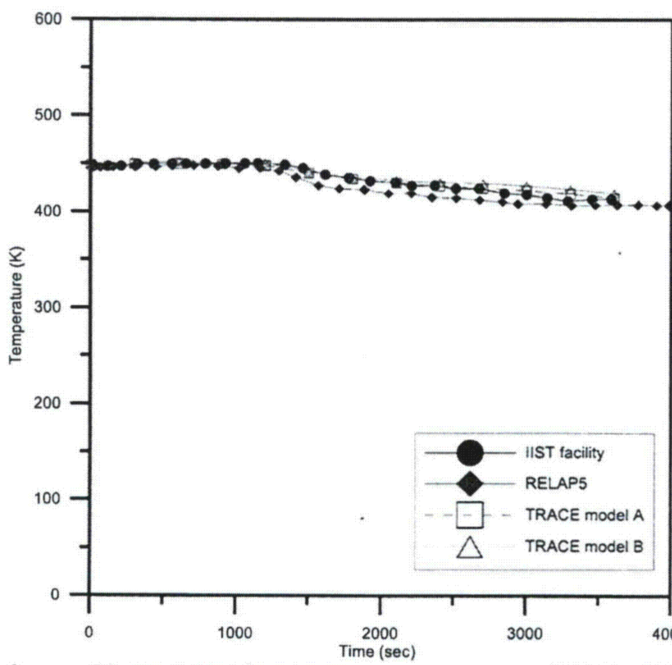


Fig. 4.27 The comparison of loop 1 hot-leg temperature among IIST facility, RELAP5, TRACE in the C61210 experiment

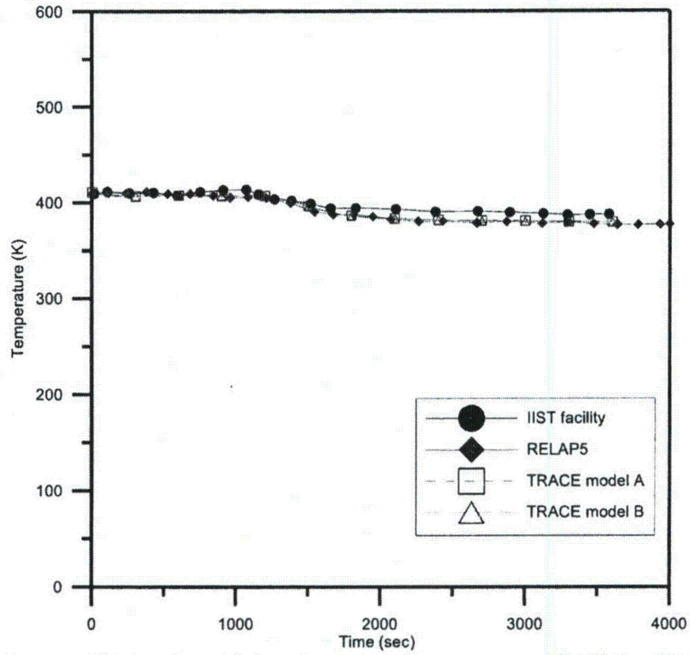


Fig. 4.28 The comparison of loop 1 cold-leg temperature among IIST facility, RELAP5, TRACE in the C61210 experiment

4.2.3 Test C70122

According to the C70122 experiment data[8], it is high inlet subcooling (12.1K) and the cooldown rate is approximately equal to 1.2 K/min within the limitation range (≦ 1.85 K/min) of Maanshan NPP. Fig. 4.29 shows the comparison of primary system pressure among IIST facility, RELAP5, TRACE. The TRACE model A and RELAP5 were overpredicted in this parameter during the overall time interval. Besides, the value of TRACE model A was roughly the similar with RELAP5. However, the result of the TRACE model B is better than TRACE model A and RELAP5. At 1000 sec, the core power was adjusted in decreasing rate of 1.75 kW every 50 seconds and the RVs of the SGs opened which resulted in cooldown effect in the RCS. Therefore, the primary system pressures of the IIST facility, RELAP5, and TRACE decreased after 1000 sec. Fig. 4.30 shows the SG1 secondary side pressures of IIST facility, RELAP5, and TRACE. The trends of TRACE were nearly the same with the IIST facility and RELAP5 data. The SG secondary pressure keeps constant during 0 to 1000 sec. The RVs of SGs opens at 1000 sec and the pressure decreases; finally it remains at atmospheric pressure.

Fig. 4.31 shows the comparison of SG1 secondary side collapsed liquid levels among IIST facility, RELAP5, TRACE. In this parameter, the trends of TRACE were roughly consistent with the IIST facility and RELAP5 data, but the TRACE model B was underpredicted after 1000 sec. Fig. 4.32 shows the pressurizer collapsed liquid levels of the IIST facility, RELAP5, and TRACE. Their trends were roughly the silimar, but the TRACE and RELAP5 were underpredicted after 1000 sec. Fig. 4.33 shows the comparison of the core collapsed liquid levels among IIST facility, RELAP5, TRACE. The TRACE results were in agreement the IIST facility and RELAP5 data. As the RVs open at 1000 sec, the collapsed liquid levels of SG secondary side and pressurizer decrease. However, the core collapsed liquid level is nearly the same during the overall time interval.

Fig. 4.34 and 4.35 show the comparison of loop 1 hot-leg and cold-leg temperatures among IIST facility, RELAP5, and TRACE. The TRACE predict the hot-leg and cold-leg temperatures in good agreement with the IIST facility experiment and RELAP5 data.

Overall, the TRACE analyses results are roughly similar with the IIST facility and RELAP5 data. In the comparison of analysis results of the TRACE model A and B, there are bigger difference in the primary system pressure and SG1 secondary side collapsed liquid level.

Furthermore, the animation of the TRACE model is presented using the animation function of SNAP/TRACE interface with the TRACE analysis results. The animation model of IIST facility is shown in Fig. 4.36.

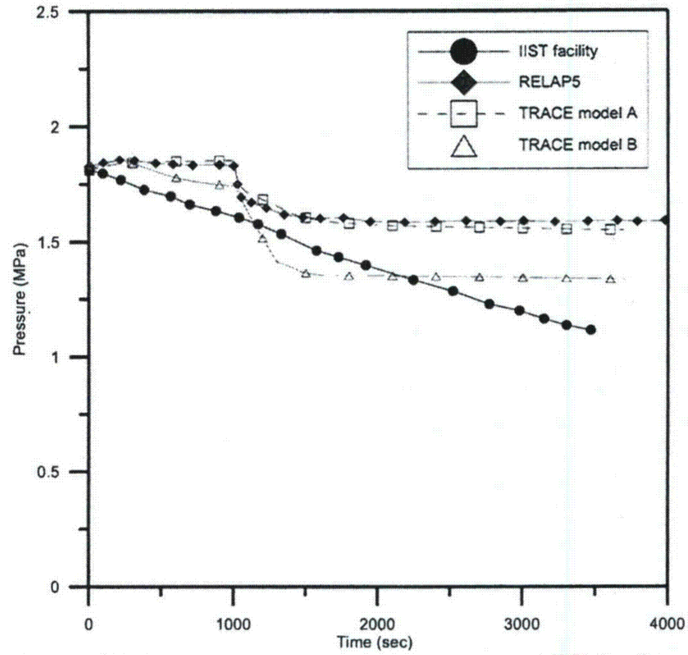


Fig. 4.29 The comparison of Primary system pressure among IIST facility, RELAP5, TRACE in the C70122 experiment

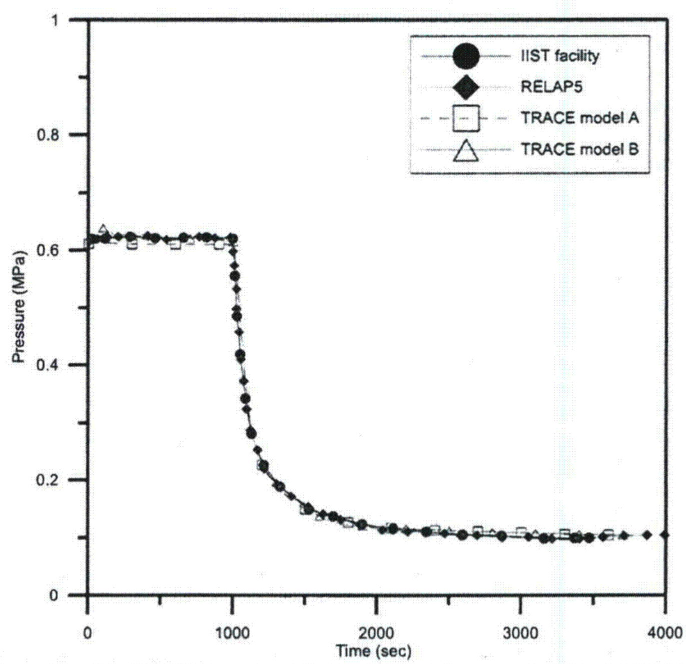


Fig. 4.30 The comparison of SG1 secondary side pressure among IIST facility, RELAP5, TRACE in the C70122 experiment

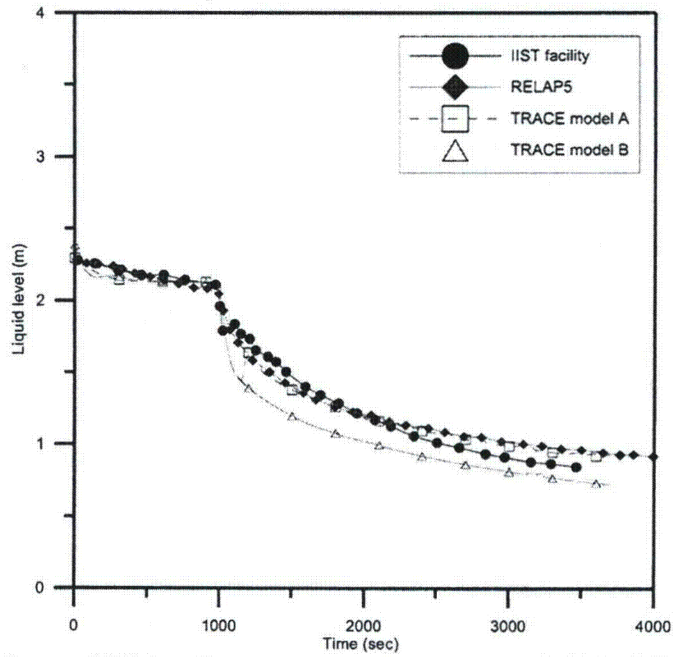


Fig. 4.31 The comparison of SG1 collapsed liquid level among IIST facility, RELAP5, TRACE in the C70122 experiment

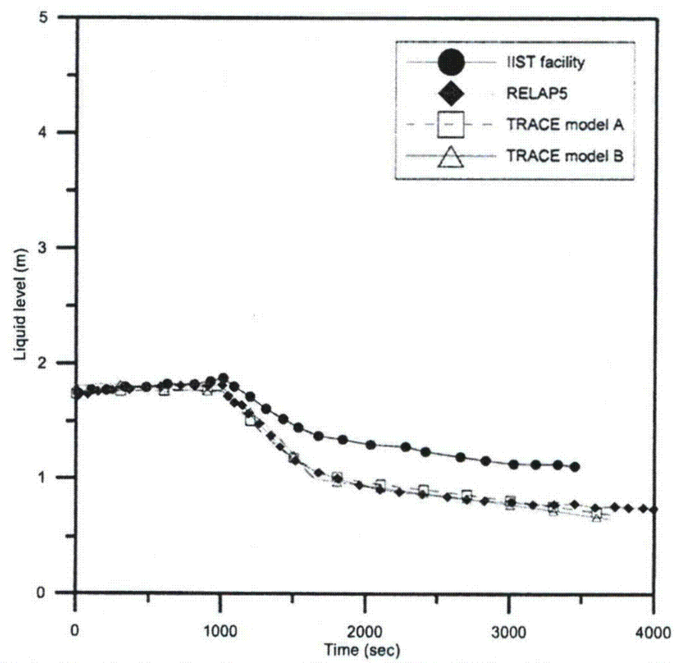


Fig. 4.32 The comparison of pressurizer collapsed liquid level among IIST facility, RELAP5, TRACE in the C70122 experiment

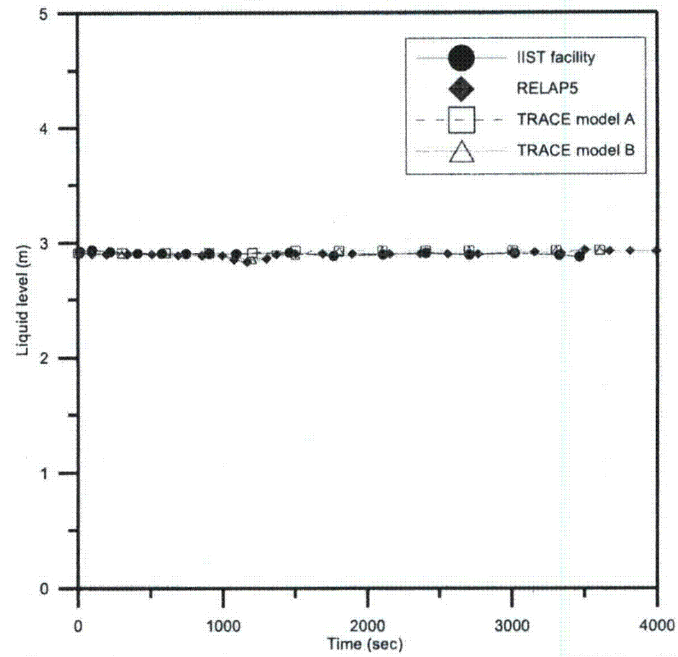


Fig. 4.33 The comparison of core collapsed liquid level among IIST facility, RELAP5, TRACE in the C70122 experiment

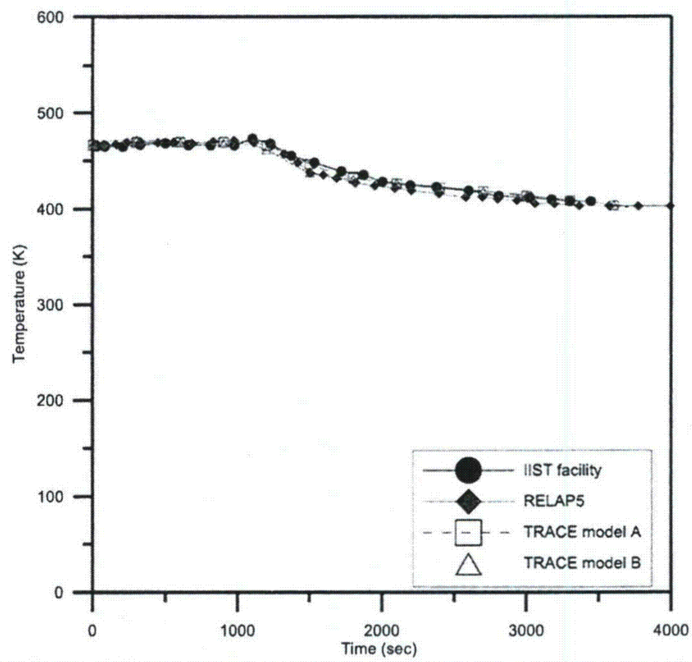


Fig. 4.34 The comparison of loop 1 hot-leg temperature among IIST facility, RELAP5, TRACE in the C70122 experiment

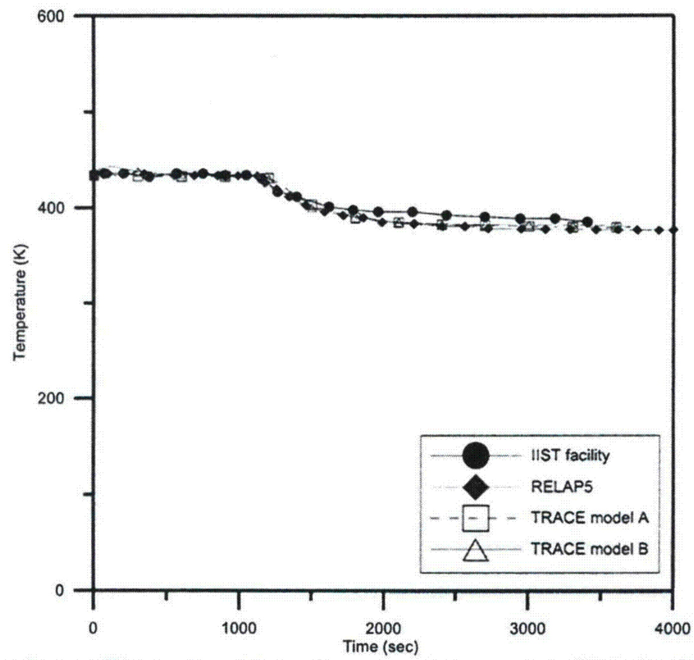


Fig. 4.35 The comparison of loop 1 cold-leg temperature among IIST facility, RELAP5, TRACE in the C70122 experiment

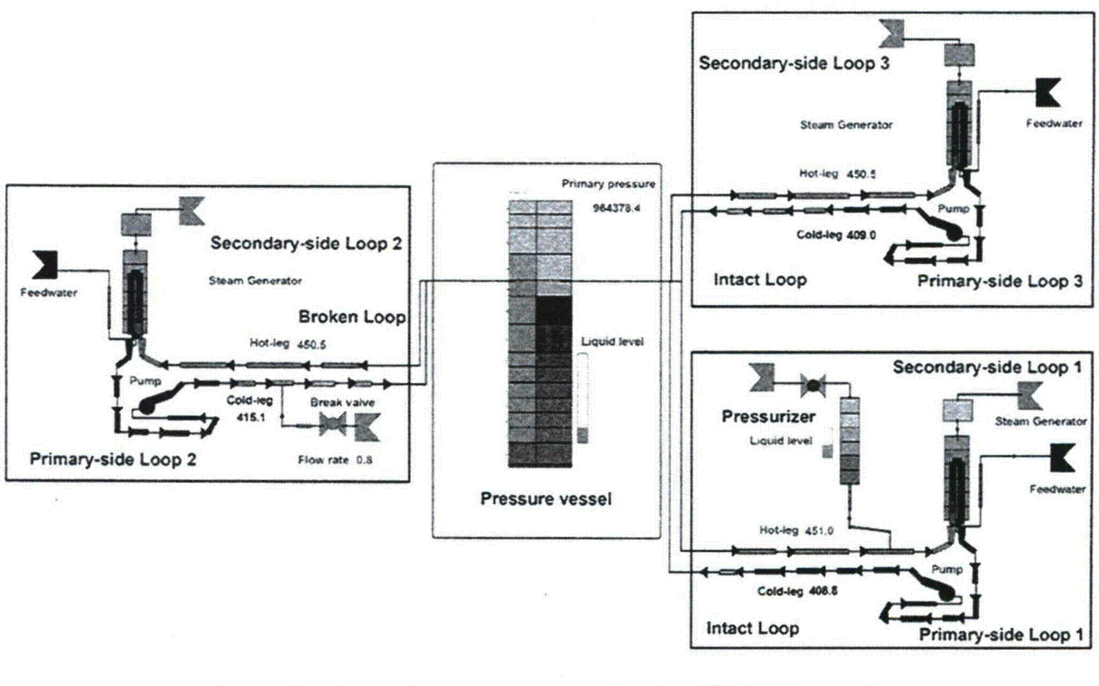


Fig. 4.36 The animation of IIST facility TRACE model

5. CONCLUSIONS

By using SNAP/TRACE, this study developed the TRACE models of the IIST facility. Effectiveness of the proposed models were verified with the 2% cold-leg-break LOCA IIST facility experiment data, IIST facility cooldown experiments data, and the RELAP5 analyses results data. In this research, the following results can be obtained:

1. By referring to the RELAP5 IIST facility models and IIST experiments data[(7)-(8)], two kinds of TRACE IIST facility models were developed success. The main difference in two kinds of TRACE IIST facility models is the simulation of the IIST facility pressure vessel. The TRACE IIST facility model A simulated the IIST facility pressure vessel by pipe components. However, the TRACE IIST facility model B simulated the IIST facility pressure vessel by TRACE 3D component-vessel.
2. In the 2% cold-leg-break LOCA IIST facility experiment, overall, the TRACE analyses results are roughly in agreement with the IIST facility and RELAP5 data. Besides, the TRACE model B has better prediction than model A in the primary system pressure, break flow, SG2-inlet tube top differential pressure, and SG2-outlet tube top differential pressure.
3. In the IIST facility cooldown experiments, the TRACE analyses results are roughly consistent with the IIST facility and RELAP5 data. In the comparison of analysis results of the TRACE model A and B, they are similar in all parameters. However, in primary system pressure, the analysis result of the TRACE model B is better than model A.
4. Finally, 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 experiment data, but also their numerical values with respectable accuracy.

6. REFERENCES

1. Lee, C. H., "INER Integral System Test (IIST) facility for simulating the Maanshan nuclear power plant—Investigation of PWR Natural Circulation", Nucl. Sci. J., Vol.31, 83, 1994.
2. Lee, C. H., Liu, T. J., Hong, W. T., Huang, I. M., Chan, Y. K., and Chang, C. J., "Experimental investigation of PWR small break loss-of-coolant accidents in IIST facility", Nucl. Sci. J., Vol. 33, 251, 1996.
3. Lee, C. H., Liu, T. J., Way., Y. S., and Hsia, D. Y., "Investigation of mid-loop operation with loss of RHR at INER Integral System Test (IIST) facility", Nucl. Eng. Des., Vol. 163, 349, 1996.
4. Ferng, Y. M. and Lee, C. H., "Numerical simulation of atural circulation experiments conducted at IIST facility", Nucl. Eng. Des., Vol. 31, 83, 1994.
5. Ferng, Y. M. and Lee, C. H., "A comparison of the RELAP5/MOD3 code with IIST natural circulation experiments", Nucl. Technol., Vol. 111, 34, 1995.
6. Chang, C. Y., Lee, C. H., Liu, T. J., and Chan, Y. K., "Experimental investigation of loss of feedwater with bleed and feed operation", Nucl. Sci. J. , Vol. 33, 318, 1996.
7. Lee, C. H., Huang, I. M., Chang, C. J., Liu, T. J., and Ferng, Y. M., "Using an IIST SBLOCA experiment to assess RELAP5/MOD3.2", Nucl. Technol., Vol. 126, 48, 1999.
8. Chang, C. J, et al., "Analysis of IIST cooldown and leakage experiments", INER report, INER-1763, 1998.
9. Liu, T. J., et al., "Cold leg small break LOCA simulation tests and code assessments on Maanshan nuclear power station", INER report, INER-1318, 1995.

NRC FORM 335 (9-2004) NRCMD 3.7

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
NUREG/IA-0252

2. TITLE AND SUBTITLE
The Development and Verification of TRACE Model for IIST Experiments

3. DATE REPORT PUBLISHED

MONTH	YEAR
February	2011

4. FIN OR GRANT NUMBER

5. AUTHOR(S)
Jong-Rong Wang, Hao-Tzu Lin, Chin-Jang Chang/Institute of Nuclear Energy Research, Atomic Energy Council
Wei-Xiang Zhuang, Chunkuan Shih/Institute of Nuclear Engineering and Science, National Tsing Hua University

6. TYPE OF REPORT
Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*
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

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*
Division of Systems Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES
A. Calvo, NRC Project Manager

11. ABSTRACT *(200 words or less)*
A RHRP (Reduced-Height and Reduced-Pressure) IIST (Institute of Nuclear Energy Research Integral System Test) facility has been established in 1992 for safety studies of the Westinghouse three-loop PWR (Pressurized Water Reactor) NPP (Nuclear Power Plant). The research purposes of the IIST facility are as follows: (a) to enhance the understanding of thermal hydraulics phenomena during the accidents, (b) to contribute to evaluate and develop the safety computer codes, and (c) to validate the emergency operating procedure (EOP) during the accidents of PWR. The scaling factors of the IIST facility for height and volume of the reactor coolant system (RCS) are approximately 1/4 and 1/400, respectively. The maximum operating pressure of the IIST facility is 2.1 MPa. The IIST facility has three loops as well as all the systems which are about studying Westinghouse PWR plant system transients. The experiment of the IIST facility was finished which simulated a 2% cold-leg-break loss-of-coolant accident (LOCA) with total high-pressure injection (HPI) failure. This break was located in loop 2 of IIST facility, which is one of the two loops that do not have a pressurizer. Besides, three cooldown experiments of IIST facility were also performed. In this research, the IIST facility experiments data and RELAP5 analysis results of IIST facility experiments are used to verify and establish the TRACE (TRAC/RELAP Advanced Computational Engine) IIST facility models. Comparing steady state results, it can be concluded that the steady state results of TRACE calculations are in agreement with those of IIST facility experiments data and RELAP5 analysis results of IIST facility experiments.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*
TRACE (TRAC/RELAP Advanced Computational Engine) models
RHRP (Reduced-Height and Reduced-Pressure)
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)

13. AVAILABILITY STATEMENT
unlimited

14. SECURITY CLASSIFICATION
(This Page)
unclassified
(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS