Report of the fifth International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2013)

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Abstract: The 5th International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2013) was held in Beijing, China in November 22-24, 2013, with the main objective for the nuclear power of international arena to overcome the Fukushima Daiichi accident towards more symbiotic nuclear power for post-Fukushima era. There were seventeen invited presentations and ca. seventy technical papers at the ISSNP2013, the subject of which were mostly related with (i)lessens from Fukushima Daiichi accident, (ii)severe accident, (iii)digital I&C systems, (iv) human-machine interface, and (v) human factors engineering. This article provides the overview of the ISSNP2013 with giving condensed summaries of major invited presentations given by international experts.

Keywords: Fukushima Daiichi accident; severe accident; digital I&C systems; human-machine interface; human factors engineering

1 Introduction

In the 21st century with worsening of environmental pollution and high demands for securing energy resource, the utilization of nuclear energy is developing rapidly. The International Symposium of Symbiotic Nuclear Power Systems for 21st Century (ISSNP) is focused on nuclear power in harmony with human, society, and environment by exploring advanced nuclear technologies for attaining higher safety in nuclear power operation. The ISSNP first held in 2007 in Tsuruga, Japan, and then in 2008 and 2010 both in Harbin, China, and in 2011 in Taejon, Korea, has become a unique and meaningful international conference by the researchers, engineers and industrial practitioners in nuclear developing countries.

In March 2011, the accident at Fukushima Daiichi nuclear power station in Japan sent a shock wave throughout nuclear developing countries who enjoy optimistic mood of nuclear renaissance around the world. Therefore, the concept of symbiotic nuclear power systems which emphasizes truly harmonious relationship in which nuclear powers live together with human and environment should fulfill the need of safety together with economy in post-Fukushima world. China, the new pace maker of nuclear development in the post-Fukushima era, has 17 nuclear power reactors in operation and 28 reactors under construction. China is also becoming self-sufficient largely in reactor design and construction, as well as other aspects of nuclear fuel cycle.

The fifth ISSNP2013 was held in Beijing, China in November 22-24, 2013. It was hosted by Tsinghua University, with the co-organizers of Harbin Engineering University and China Nuclear Power Engineering Corporation (CNPEC) and Design Institute of CNPEC (CNPDC), both of which belong to China Guangdong Nuclear (CGN). The ISSNP2013 was sponsored and supported by State Nuclear Power Technology Corporation (SNPTC), China University of Petroleum Beijing (CUP) and China Techenergy Co. ltd (CTEC).

Received date: December 15, 2013
(Revised date: December 24, 2013)

In ISSNP2013 with the main theme of symbiotic nuclear power systems for post-Fukushima era, there were many technical presentations and discussions by ca. 100 participants from eight countries (China, Japan, Korea, France, USA, Switzerland, Denmark, and Germany) in the technical areas of (i) nuclear power operation and simulation, (ii) nuclear safety, (iii) human-machine interface, (iv) methods to develop proper symbiosis between human, machine and environment. This report gives the overview and summaries of the presentations and the discussions at the ISSNP2013, as described in the subsequent parts of this paper.

2 Overview of conference program

The conference program of ISSNP2013 is as shown in Table 1. The conference was initiated by the opening ceremony at 8:15 am of November 22 in the conference room 6 of Xijiao Hotel, Beijing, by the chair of Prof. Zhou Zhiwei, Tsinghua University, and TPC Chair of ISSNP2013.

Table 1. Time table of ISSNP2013 conference

Day	Time	Items	Notes
November 22, Friday			
	Morning	Opening ceremony Keynote speech I Keynote speech II	 Three speeches Three speeches
	Afternoon	Keynote speech III Facility visit	Two demonstrations CTEC
	Evening	Welcome dinner	
November 23, Saturday			
	Morning	Parallel technical sessions	Three rooms
	Afternoon	Do	Do
November 24, Sunday			
	Morning	Special session I	Five presentations
	Afternoon	Special session II	Five presentations
	Evening	Farewell dinner	
November 25, Monday			
	Morning	Technical tour	HTR-10 facility

Fig. 1 Group photo of all participants of ISSNP2013.

Table 2. Summary of technical papers presented at ISSNP2013

No.	Subjective area (Number of papers)	Major topics of papers
1	Reactor experiment and simulation (12)	Bubbly flow instability in narrow channel; Safety-critical software test method; Monte Carlo code benchmarking; Turbine speed control; Passive residual heat removal; flow instability in rolling motion; SG assembly analysis; LabView for test design; RELAP 5 analysis of AP1000 passive heat removal; Wet steam turbine model, *etc.*
2	Nuclear safety technology (25)	Boron meter improvement; Radwater filter; MFM application for supervisory control; Molten core discharge in fast reactor accident; Reliability analysis of ADS in AP1000; System function test of reactor protection system; FCI in molten fuel pool; Pressurized thermal shock evaluation; Fragmentation of molten core material; MFM application for digital I&C reliability evaluation; I&C security validation test; removal of cobalt ion from rad water; Combustion Hydrogen monitoring system; 3D analysis of locked motor; Mechanical damage estimation by Remanent magnetic field; GO FLOW application for risk monitor; Software reliability evaluation for safety-class digital I&C; Dynamic film module simulation in passive containment cooling; PSA for loss of spent fuel cooling; FPGA application for diversity actuation system; HCR/THERP application, *etc.*
3	NPIC+HMIT technology (16)	Functional modeling for risk monitor; Equipment qualification standard for digital I&C; Seismic qualification test of DCS equipment; Computerized procedure for US-APWR; HRA method implementation; 3d module design system; V&V for digital I&C; Human-machine system design of digital I&C; delivery security of engineering documents; Environmental design of main control room; *etc.*
4	Construction, operation and maintenance technology (15)	Daily load follow operation; Modular construction of containment steel liner; Nuclear power for low carbon smart electric system; Equipment qualification standard digital I&C system; Reliability-centered maintenance; Condition-based monitoring for pipe wall thinning; Optimized plant construction; Human error analysis in maintenance; Security analysis of digital control system; Online outage operation activity flowchart; Equipment health monitoring by wireless sensor network; Anti-seismic DCS cabinet; Periodic testing of safety DCS; Economic analysis of multi-module high temperature gas reactor, *etc.*
5	Advanced nuclear reactor technology (6)	Breed-and-burn operation of PWR spent fuel in fast reactor; Passive safety featured containment; Marine nuclear fuel battery, Long-term cooling capability of AP1000; Lithium-Bismuth target design of Chinese ADS, *etc.*

Prof. Jiang Shengyao, vice president of Tsinghua University, delivered his opening address by representing Host University. Then Prof. Zhang Zhijian, Dean of College of Nuclear Science and Technology, Harbin Engineering University, Prof. Dong Yujie of Institute of Nuclear and New Energy Technology, Tsinghua University, and Dr. Fen Gao, China Nuclear Power Engineering Corporation delivered their greeting words to represent the co-organizers of ISSNP2013.The group photo of all

participants at ISSNP2013 are shown in Fig. 1.
The main body of the program was composed by 17 invited speeches, 73 technical paper presentations and two technical tours as shown in Table 1.
The seven invited speeches as divided into keynote speeches I, II, and III, were given in the first day of the conference, while the ten invited speeches were given in special sessions I and II in the third day of the conference as shown in Table 1. The summaries of those invited presentations are given in the subsequent sections 3 and 3, respectively.
All the technical paper presentations of 74 papers were all made in the second day of the conference, in three separate rooms in parallel. The summaries of technical paper presentations are given in Table 2 with respect to the subjective areas and the number of papers, and major topics of the papers in individual areas.

With regards to the two technical tours, the first tour to the I&C development and production facilities of CTEC was conducted in the afternoon of the first day of the conference after the keynote session III. The second tour was conducted in the morning of November 24, Monday, to visit Tsinghua University's HTR-10 experimental facility.

3 Synopsis of keynote speeches

The contents of the six keynote speeches are briefly introduced in the following.

3.1 DUCG: Intelligent system for fault diagnosis of NPPs to increase safety and availability

Prof. Zhang Qin (Tsinghua University, China) introduced his involved national project of Dynamic Uncertainty Causality Graph (DUCG). DUCG describes various knowledge of engineers in designing. Prof. Zhang Qin stressed in his presentation that the DUCG methodology has more functions than FT/ET used in PRA in both the efficiency and explaining ability of the reasoning, monitoring, prediction, planning and decision making.

3.2 Overview of Fukushima Daiichi accident with its present state

Prof. Sugiyama Ken-ichiro (Hokkaido University, Japan) first reviewed the historical change of nuclear safety concept with the experiences of big nuclear accidents around the world, where he stressed that the significance of Fukushima Daiichi accident is the importance of preparing for uncertain big hazards caused by natural and man-made disasters such as earthquakes, tsunamis, and terrorist attacks. He then reported the present preparatory works at destroyed Fukushima Daiichi plant for the final disassembling the plant facilities such as clean up the rubbles, transfer of fuels from the spent fuel pool in the unit 4, monitoring the damage of reactor vessel, *etc.*

3.3 Recent developments and issues on Korean nuclear industry

Prof. Poong Hyun Seong (KAIST, Korea) looked back the steady development of APR1400 notwithstanding the Korean IMF crisis in 1997. The APR1400 by Korean nuclear industry succeeded nowadays as its export to UAE shows. Korean nuclear power will expand to 34 units in 2024 from the present state of 23 units in 4 sites. He also introduced major nuclear research projects in Korea ranging from APR+ and SMART to future nuclear energy systems (such as thermal reactor, fast reactor and nuclear fusion reactor), nuclear fuel cycle technology (U-TRU-Zr fuel and pyro-process of spent fuel) in the present Korean nuclear research program including TWR.

3.4 Project status of China high temperature gas-cooled reactor demonstration power plant (HTR-PM)

Prof. Dong Yujie (Tsinghua University) first introduced the special characters of high temperature gas-cooled reactors (HTGR) of either pebble-bed or prismatic core which use helium gas as reactor coolant with the outlet temperature greater than 700 degree C. He stressed the inherent safety of modular HTGR reactor (HTR-TM), because of the passive decay heat removal, negative reactivity coefficient, and large heat capacity being no fuel melting in any type of reactor accident. He then introduced the progress of HTR-PM which is the successor of early design of HTR of constructing two reactor-steam turbine module in Shangdong province by the cooperation of Tsinghua University with two nuclear power companies. He also stated that the introduction of reactor cavity cooling system to maintain the integrity of concrete structure can simplify the off-site emergency planning, in addition to the inherent safety of HTR-PM.

3.5 Safety improvement of CNPEC after Fukushima nuclear accident

In his presentation of Mr. Mao Qin (China Nuclear Power Engineering Co. ltd), he mainly explained how the China National Nuclear Safety Administration (NNSA) responded to Fukushima nuclear accident, in order to enhance the safety of all nuclear power plants in China both in operation and under construction. Promptly after Fukushima accident, the NNSA issued 14 requirements of improvement to all the plants in operation and under construction, and then implemented them into the 12th five years plan of nuclear power construction and the 2020 year vision of nuclear safety and radioactive contamination prevention. He also stressed the enforcement of nuclear safety goal as CDF less than 10^{-5} /reactor-year and LRF less than 10^{-6} /reactor-year for ACPR1000 (Chinese localized PWR) while 10^{-6}/reactor-year and 10^{-7}/reactor-year for CDF and LRF, respectively for ACPR1000+(Chinese generation III+ PWR) by further safety enforcement including the adoption of double containment.

3.6 Development and qualification of FirmSys – a safety-classified nuclear DCS platform

Mr. Bai Tao (China Techenergy Co. ltd) introduced the description, qualification, and application of FirmSys, a general DCS platform for nuclear safety class functions such as reactor protection system (RPS), engineered safety facility system (ESFAS), *etc.* According to Mr. Bai Tao, the FirmSys fully follows Chinese nuclear safety law and regulation guides, follows USNRC's regulation guides, IEC and IEEE standards with respect to software design, hardware design, V&V, and qualification. The products of FirmSys are hardware products (processors and communication, IO, conditioning and power, monitoring and switch), structure products (chassis and cabinet), and software products of engineering software and embedded software. The equipment qualification will be made by various analyses ranging from documentation requirement, applicable standards, stress analyses, environmental condition, EMC, and seismic analyses. The FirmSys has been applied for several nuclear power plants in China including HTR-10 of Tsinghua University.

4 Synopsis of plenary speeches

The plenary speeches in the third day of ISSNP2013 were organized by Harbin Engineering University as the 16th International Workshop of Nuclear Safety and Simulation Technology (IWNSST16). Nine invited speeches of IWNSST16 will be briefly introduced in this section.

4.1 Vision of safe nuclear power plants: towards sustainable reduction of human errors

According to a report by Institute of Nuclear Power Operation (INPO), ca. 48 % of the total events in NPPs in the two years (2010 and 2011) were caused by human error, while according to a Korean database called Operation Performance Information System (OPIS), more than 20% of total events in Korean NPPs during ten years between 2003 and 2012 were also by human error. Prof. Poong Hyun Seong (KAIST, Korea) discussed on the effective methodology of human error reduction from the five aspects of (i) automation, (ii) human-machine interface, (iii) procedure, (iv) education and training, and (v) safety culture. He concluded that the acceleration of automation both in operation and maintenance can easily contribute to the reduction of human error with proposing his future image of safety improvement by digitalization.

4.2 Lessons learned from the Fukushima Daiichi nuclear power plant accident

Prof. Narabayashi Tadashi (Hokkaido University, Japan) discussed on the lessons which contribute to improve the nuclear power safety, by reviewing the technical activities in Japan to understand the states and conditions of the Fukushima Daiichi reactors which had committed severe accident. He pointed out first that isolation valve, isolation condenser (IC), and reactor core isolation cooling (RCIC) steam turbine were not designed as fail-safe for the case of loss-of external electric power. He then discussed on the effectiveness of introducing those facilities and systems such as filtered venting system, emergency heat transfer removal system, varieties of back-up electric power sources, and water-proof measures, all of which had not been equipped in all NPPs in Japan before Fukushima accident.

For further details of his presentation, see his paper in this issue. [1]

4.3 Perspectives on phenomenology and

simulation of severe accident in light water reactors

Prof. Sugimoto Jun (Kyoto University, Japan) presented a comprehensive review and perspectives on phenomenology and simulation of severe accident in LWR, with emphasis of insights obtained after the review of Fukushima accident.

Severe accident phenomena in LWR are generally characterized by their physically and chemically complex processes involved with high temperature core melt, multi-component and multi-phase flows, transport of radioactive materials and sometimes highly non-equilibrium state. Severe accident phenomenology can be generally categorized into five phases: (i) in-vessel core degradation, (ii) early containment failure, (iii) late containment failure, (iv) fission product behavior, and (v) severe accident management, which can be further expanded in Table 3.

Table 3. Classification of severe accident phenomenology

Categories	Sub-categories
1. In-vessel core degradation	
2. Early containment failure	2.1 Hydrogen behavior and control 2.2 Direct containment heating 2.3 Steam explosion
3. Late containment failure	3.1 Debris formation and coolability 3.2 Corium spreading 3.3 Molten core concrete interaction
4. Fission product behavior	4.1 In-vessel fission product release 4.2 Fission product transport in reactor coolant system 4.3 Containment bypass 4.4 Ex-vessel fission product release 4.5 Fission product transport in containment
5. Severe accident management	

With regards to simulation of severe accident, some integral analytical codes have been developed in USA, EU, and Japan such as MAAP, MELCORE, ASTEC, THALES, and SAMPSON.

After Fukushima accident, review of severe accident research issues has been conducted, and several issues have been pointed out for further investigation. They are such as effect of BWR-specific core degradation behaviors, sea water injection, pool scrabbling under rapid depressurization, containment failure and leakage, and re-criticality. Some new experimental and analytical efforts have been started in Japan after the Fukushima accident.

Further details are described in his paper in this issue. [2]

4.4 Development of advanced nuclear safety program and numerical nuclear reactor

Dr. Long Pengchang (Institute of Nuclear Energy Safety Technology, China Academy of Sciences) introduced the advanced nuclear safety program by his institute which aims at integrating advanced nuclear software with information technology for fission, fusion reactors and ADS. He also introduced various safety software such as tritium safety analysis, risk analysis for fast reactor, nuclear data library system, experimental platform of software validation, and numerical reactor as the concrete examples of safety software under development.

4.5 Importance of modern instrumentation and control systems in nuclear power plants

The digital I&Cs have been traditionally deemed by regulators as difficult to confirm its reliability by various common cause factors. This is because the digital systems are more complex than analog ones and the performance of the digital systems depends on software, and the rightness of software depends on human programing which is difficult to confirm its rightness. Therefore, the digital I&C systems have been traditionally designed by the principle of diversity and redundancy by human and by function, to assure its reliability.

In his presentation, Dr. Glockler Oszvald (SunPort SA, Switzerland) especially advocated the superiority of using FPGAs which have no software like OS and can be configured by Hardware Description Language (HDL) to be compared with micro-processor based digital systems. He also introduced his international enlightening activities of digital I&C technologies at IAEA and other organizations by himself.

For the details of his presentation, see the paper of Dr. Glockler in this issue [3]

4.6 R&D proposals to improve outage operation – methods, practice and tools

Mr. Dionis Francois (EDF-R&D, France) presented his practical R&D experiences to improve outage operation in nuclear power plant. According to him, it offers a number of tracks on the interactions between operation activities and maintenance, with a methodological perspective and proposals by the usage of information system. On the methodological point of view, modeling a smart plant system allows representing the needed characteristics in order to optimize tagouts, alignment procedures and the related schedule. Tools should take into account new tagout practices such as tags sharing. It is possible to take advantage of 2d drawing integrated into the information system in order to improve the data controls and to visualize operations should allow field operators to join the information system for a better and safer performance.

Concerning concrete examples of the related tool development, see the paper of Mr. Dionis in this issue.[4]

4.7 Hybrid diagnostic system for nuclear power plants

Prof. Gofuku Akio (Okayama University, Japan) presented the results of a development project of a hybrid diagnostic system which can give better diagnostic result by integrating the results of various subsystems of diagnosis by different methodologies. According to Prof. Gofuku, the developed hybrid diagnostic system was targeted for Japanese fast breeder reactor Monju, and it is composed of the following four diagnostic software agents: (i) estimation agent for overall heat transfer coefficients of evaporator and super-heater, (ii)state identification agent based on support vector machine (SVM), (iii)anomaly detection agent by wavelet transformation (WT), and (iv) case base reasoning (CBR) agent using several attributes in both time and frequency domains.

In Prof. Gofuku's presentation, he concentrated on the two issues about how to configure effective hybrid diagnostic system. The one is how to endow "trust values" for individual agents which have individual "confident values" by the agents, while the other is related with the method of proper combination of process signals from the target plant on the basis of the performance of the diagnostic system.

The more detailed discussions on the methodology of the proposed hybrid system and the experimental validation by using Monju plant data, are described in Prof. Gofuku's paper in this issue.[5]

4.8 Human-in-the loop simulation in support of long-term sustainability of light water reactor

According to USDOE, it is the basic notion of nuclear power operation in US that life extension of LWRs over forty years operation is fitted to the national interest that can sustain the low cost and low carbon emission of electric generation over 20 years. In order to satisfy the simultaneous improvement of performance, economy and safety of light water reactors, the Idaho National Laboratory (INL) initiated the project of long-term sustainability of light water reactor by the following three approaches: (i) promoting the study of material degradation mechanism, (ii) confirmation of safety margin by risk information, and (iii) developing new technologies for Intelligent I&C (II&C) architecture.

In his presentation, Dr. Hallbert Bruce (INL, USA) listed up several themes of high priority for II&C areas until 2025, such as (i) performance improvement of nuclear personnel, (ii) improvement of safety and efficiency during plant outages, (iii) online monitoring, (iv)integrated operation, (v) automated plant, and (vi) hybrid control room.

He then introduced the research activities now conducted at INL such as human system simulation lab., computerized operation procedure, safety and efficiency improvement during plant outage, and online monitoring methods.

For the details of his presentation, see the paper of Dr. Hallbert in this issue[6]

4.9 Research on the digitalization of safety information and control system of CPR1000 NPP

Mr. Tan Ke (China Nuclear Power Engineering Corporation, China) introduced the developmental experience of safety information and control system (SICS), which is the backup system for main computerized control means (MCM) for CPR1000. He presented the overviews of the related safety analysis of the target, layout of main control room, plant function analysis and allocation, balance evaluation between conventional control and computerized operation, urgency operation, requirement of regulatory and the related codes, avoidance of common mode failure and application of human factors engineering methods, to be considered for the realization of digitalized SICS.

5 Concluding remarks

The fifth International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2013) was held in Beijing, China in November 22-24, 2013, with the main objective for the nuclear power of international arena to overcome the Fukushima Daiichi accident towards more symbiotic nuclear power for post-Fukushima era. There were seventeen invited presentations and ca. seventy technical papers at the ISSNP2013, the subject of which were mostly related with (i)Fukushima Daiichi accident, (ii)severe accident, (iii)digital I&C systems, (iv) human-machine interface, and (v) human factors engineering. The overview of the ISSNP2013 was given in this report, and the condensed summaries of major invited presentations by international experts were included as the introduction to the readers who would like to know what would be important subjects for nuclear safety after Fukushima Daiichi accident in Japan.

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