Report of the Eighth International Symposium on Symbiotic Nuclear Power Systems for 21st century (ISSNP2016)

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Abstract: The 8th International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2016) was held in Chengdu, China in September 26-28, 2016. There were ten invited presentations and one hundred and forty-seven technical papers at the ISSNP2016, the subject of which were mostly related with reactor physics, safety analysis, I&C, equipment, nuclear safety, nuclear fuel, thermal hydraulic, advanced reactor, simulation and modeling, experiment and severe accident. The overview of the ISSNP2016 was given in this report, and the condensed summaries of major keynote presentations by international experts were included.

Keyword: advanced reactor; nuclear safety; simulation; thermal hydraulic; I&C

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, and in 2013 in Beijing, China, and in 2014 in Jeju, Korea, and in 2015 in Kyoto, Japan, 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 that 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 8th ISSNP was held in Chengdu, China in September 26-28, 2016. The ISSNP2016 is organized to promote academic exchanges of symbiosis of technology in nuclear industries. It was hosted by Nuclear Power Institute of China, organized by Science and Technology on Reactor System Design Technology Laboratory, with the co-organizers of Harbin Engineering University, cooperated by China Nuclear Society, Korea Nuclear Society, Japan Society of Maintenology, Symbio Community Forum.

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In ISSNP2016 with the main theme of symbiotic nuclear power systems. The conference has fifteen international advisors, and there were ten keynote presentations and discussions by about 160 participants from different countries (China, USA, Japan, France, Korea, Pakistani) in the technical areas of reactor physics, safety analysis, I&C, equipment, nuclear safety, nuclear fuel, thermal hydraulic, advanced reactor, simulation and modeling, experiment and severe accident. This report gives the overview and summaries of the presentations and the discussions at the ISSNP2016, as described in the subsequent parts of this report.

2 Overview of conference program

The conference program of ISSNP2016 is as shown in Table 1. The conference was initiated by the opening ceremony at 8:30 am of September 26 in the Conference Room Yue Jing of Minyue Hotel, Chengdu, by the chair of Prof. YU Hongxing, Nuclear Power Institute of China, delivered his opening address by the committee. Then the foreign guest Hidekazu Yoshikawa, Symbio Community Forum, Japan, Prof. Puzhen Gao, Harbin Engineering University， delivered their greeting words to represent the co-organizers of ISSNP2016. The group photo of all participants at ISSNP2016 are shown in Fig.1.

The main body of the program was composed by 10 keynote speeches, 147 technical paper presentations and a technical tour as shown in Table 1. The ten keynote speeches were divided into Keynote speeches I, II, which were given in the morning of the first two days. The technical paper presentations were made in September 26, 27, and 28 respectively. The summaries of those speeches are given in Table 2.

The best student paper awards were given to nine students at the closing session of the third day as shown in Fig. 2 and the list of receivers as listed in Table 2.

The technical tour to Nuclear Power Institute of China was conducted in the afternoon of September 28. With the technical tour, ISSNP2016 came to a successful end.

Table 1. Time table of ISSNP2016 conference

Day	Time	Items	Notes
September 26, Monday			
	Morning	Opening Ceremony Keynote speech Ⅰ	 Five speeches
	Afternoon	Technique Sessions Ⅰ Technique Sessions Ⅱ	Twenty four presentations in four rooms Twenty four presentations in four rooms
September 27, Tuesday			
	Morning	Keynote speech Ⅱ Technique Sessions Ⅲ	Six speeches Fifteen presentations in four rooms
	Afternoon	Technique Sessions Ⅳ Technique Sessions Ⅴ	Twenty four presentations in four rooms Twenty three presentations in four rooms
September 28, Wednesday			
	Morning	Technique Sessions Ⅵ Technique Sessions Ⅶ Awarding	Twenty three presentations in four rooms Twelve presentations in four rooms
	Afternoon	Technique Tour	

Fig. 1 Group photo of all participants of ISSNP2016.

Table 2. List of best student papers

Subjects	Paper No.	Best student papers	Country
Reactor Physics	ISSNP 2016-033	Capability of Sensitivity Coefficients with regard to Legendre Scattering Moments implemented in RMC *QiuYishu, Wang Zijie, Aufiero Manuele, Fratoni Massimiliano， Wang Kan*	China
	ISSNP 2016-087	A Variational Nodal 2D/1D Approach to Pin Resolved Neutron Transport *ZHANG Tengfei, WU Hongchun, CAO Liangzhi, LEWIS Elmer-E, SMITH Micheal-A， YANG Won Sik*	China
I&C	ISSNP 2016-002	A Technique to Prioritize Plausible Counter Operation Procedures in an Accidental Situation of Plants *INOUE Takahisa, GOFUKU Akio*	Japan
	ISSNP 2016-004	Identification of the Risk Induced by Malicious Attack on the NPP HMI System *KIM Hee Eun, SON Han Seong, KIM Jonghyun, and KANG Hyun Gook*	Korea
Equipment	ISSNP 2016-094	Development of GaN Radiation Detectors for Use in the Current Mode *LIU Yang, LI Liansen*	China
	ISSNP 2016-139	Modeling and Simulation on the Steady-state Performance of Liquid Jet Pumps for Pressurized Water Reactor *Wenjie ZENG， Xi CHEN，Hui CHEN， Dongnan ZHANG，Tao YU*	China
Nuclear Safety	ISSNP 2016-118	The Validation for Transient Heat Transfer Behavior from Supercritical to Subcritical Pressure *SONG Meiqi, LIU Xiaojing; CHEN Xu*	China
Nuclear Fuel	ISSNP 2016-105	Numerical Simulation of Different Sizes Missing Pellet Surface Effects on Thermal-mechanical Behaviors in Nuclear Fuel Rods *TANG Changbin, JIAO Yongjun, CEHN Ping, CHEN Liang*	China
Thermal Hydraulics	ISSNP 2016-057	Flow and Heat Transfer Characteristics in a Vertical Narrow Rectangular Channel under Natural Circulation TIAN Chun-ping, CAO Xia-xin, YAN Chang-qi, XIONG Kun	China

Fig. 2 Group photo of attendants of the best student paper award giving ceremony.

Table 3. Summary of technical papers presented at ISSNP2016

No.	Subjective area (Number of papers)	Major topics of papers
1	Reactor physics (25)	Burnup computations of online refueling process ; Poisoning reactivity; Few-group constant generation; Capability of sensitivity coefficients, Monte Carlo full core critical boron concentration search; Neutron diffusion equation in non-homogenous material; Testing adequacy criterion of reactor physics code of NESTOR; Implementation of layer parallelism in RMC code; Primary knock-on atoms; Produce Co-60 in PWR; Analyze nuclear data in the core critical calculation of Qin Shan Ⅱ; Activation features of the FLiBe coolant; 2D MOC transport calculation; Assembly few-group homogenized cross-section sensitivity and uncertainty; Pn-FEM for solving first-order neutron transport equation; A 3-D nodal SN code for small critical facilities; Neutronics/Thermal-hydraulics coupling with RMC and CTF; Full-core detailed burnup simulations; Periodically Reloading analysis, *etc*.
2	Safety analysis (12)	Severe accidents initiated by LB LOCA; SB-LOCA in AP1000; Small and medium sized reactors; Steam transport and condensation characteristics in steel containment vessel wall; Laminar film condensation outside a horizontal tube; Integrated pressurized water reactor IP200; Severe accident simulator; Passive heat removal capability of FHR; SBLOCA with and without reactor SCRAM; Bottom reflooding analysis; Fire scenario and effect in diesel generator building, *etc*.
3	I & C (16)	Prioritizing plausible counter operation procedures; The risk induced by Malicious attack on the NPP HMI system; Computer-based emergency operating procedure; Power system analysis of ACP1000; Advanced HIS design method; TRICON TMR programmable logic controller; Steam generator water level control system; PWR DI&C software system; Sliding mode power-level control; Fault diagnosis method; A three- region pressurizer; Typical reactor power control system for ASPWR; The site testing of DCS; I&C algorithm configuration based on SCADE platform, *etc*.

4	Equipment (10)	A swirl steam separator with air-water; Materials corrosion inside RCS; CARR safety rod drive mechanism; ring cavity structure pressure vessel of ADS; GaN radiation detectors; Seismic-induced fire of diesel generator building; Recirculation steam generator; Liquid jet pumps, *etc*.
5	Nuclear safety (24)	Debris bed formation behavior; Filtered containment venting system; Released radioactive material during maritime spent fuel transportation; Core damage evaluation software; Thermal-hydraulic passive systems in advanced reactors; Integrity safety for SMR CPR50S; Wire-mesh sensors; Steam generator tube rupture accident for CPR1000; High-performance annular fuel for LWRs; the Dual-functional lithium-lead test blanket module; Natural circulation phenomenon; Sub-channel local heat transfer; Heterogeneous bubble nucleation; Pressure drops through local-generated debris; Composite Shielding Material; Flow instability in the natural circulation; Safety management mode; Hydrogen mitigation measures; BWR spent fuel storage racks; ECC condensation in T-junction; Transient heat transfer behavior; Optimization of monitoring parameters; DEC of emergency operation procedures and software for NPPs; Transportable fluoride-salt-cooled high temperature reactor, *etc*.
6	Nuclear fuel (8)	Local fuel-coolant interactions in a simulated molten fuel pool; Effects of temperature and irradiation on delayed hydride cracking velocity; Specific heat capacity measurement on irradiated Zr-4 alloy; Different sizes missing pellet surface effects; Core heat-up for ATFs under accident conditions; Irradiation growth behavior; FCM fuel thermal-mechanical performance; M5 zirconium alloy tubes, *etc*.
7	Thermal hydraulic (22)	Two-phase flow instability in vertical narrow annulus; Uncertainty analysis methods of thermal–hydraulic simulation; Coolant mixing process during emergency core cooling injection; Virtual mass force and interfacial pressure; Pressure wave propagation problem; Single phase reversed flow; Void fraction in two-phase flow system; Heat transfer scaling distortion; Natural-Convection and Pool- Boiling, Spiral-Spacer Rods Assembly; Electric Heating Tube of AP1000 Pressurizer, *etc*.
8	Advanced reactor (6)	Thimble type heat transfer element in the drain tank of molten salt reactor; Molten lead-bismuth eutectic systems; Natural circulation in molten salt reactor; Heat transfer of supercritical water in reactor core; Radioactive effect in a Molten Salt Reactor; The wetting behavior of LBE and AISI 316L.
9	Simulation and modeling (13)	Prediction of detonation cell width; CHF in lower plenum channel; Mixing at an oblique branch; Thermal behaviors in corium melt pool; Lift force in two phase; MPS Method; micro-scale semicircular flow, *etc*.
10	Experiment (6)	Direct contact condensation in the porous; inlet resistance upon reflooding; Condensation behaviors on super hydrophobic surfaces; Reverse flow critical point, *etc*.
11	Severe accident (5)	Hot leg LBLOCAs in a PWR; The pre-inerting simulation of small modular reactors; Hydrogen distribution; Dissolution of uranium dioxide by molten zircaloy; A molten metal droplet penetrating into sodium pool.
Total number of papers :147		

3 Synopsis of keynote speeches

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

3.1 Perspective to make nuclear power plants more resilient

Prof. Akio Gofuku (Okayama University) firstly described the lessons learned from Fukushima Daiichi accident and some investigation results from the viewpoints of human factors and the ways to make nuclear power plants (NPPs) more resilient including improvement of hardware such as the capacity of components, component arrangement, and additional installation of components, software tools to support the activities of plant staffs and improvement of education and training of operators and staff in NPPs. See the detail of Prof. Gofuku's paper in this issue.[1]

Fig.3 Prof. Gofuku.

3.2 3-D thermal-hydraulic computation of key NPP components by CFD porous media model

Prof. Su Guanghui (Xi'an Jiaotong University) introduced the applications of computational fluid dynamics (CFD) porous media model in reactor pressure vessel (RPV), steam generator (SG) and passive residual heat removal-heat exchanger (PRHR-HX). Based on the porous media model of CFD software, the thermal and heat transfer (T&H) behaviors of the reactor core, SG, and PRHR-HX has been analyzed. The detailed 3D T&H characteristics were obtained and the results are instructive for the design, operation and maintenance of equipment. He stressed that CFD technology will play more important role in the design and safety assessment of nuclear systems.

Fig.4 Prof. Su Guanghui.

3.3 Insights from accident probability calculation for spent fuel transportation and storage

In the presentation of Hyun Gook KANG (Korea Advanced Institute of Science and Technology) risks of spent fuel transportation and storage were analyzed using probabilistic approach for three probable accident scenarios. Event trees for three accidents scenarios were developed. Probabilities and consequences were calculated for each accident sequence using his developed methods. For convenient risk management, a software was developed and accident conditions are able to be freely set by users in the software. In case of maritime transportation, risk was dependent on route and ship speed. With the same accident condition, high navigation speed of transportation ship induced low risk because of low accident probability. See the detail of Prof. Kang's paper in this issue.[2]

3.4 Hualong 1#'s nuclear reactor design and relative safety issues research

Prof. YU Hongxing (Nuclear Power Institute of China) introduced the reactor core design, safety design, design validation and construction. He presented that Hualong One is a safe, reliable and economic Generation III PWR NPP with comprehensive active and passive design, which Considers feedback from Fukushima accident and engineering experience in China. The detailed design has been finished and one unit constructed in 2015

and the future work will mainly focus on practically eliminating the possibility of large radioactive releases, accident tolerance fuel research and design optimized.

Fig.5 Prof. Kang.

Fig.6 Prof. Yu Hongxing.

3.5 Research on real-time on-line risk monitor technology in nuclear power plant

In the presentation of Prof. Wang He (Harbin Engineering University), he respectively introduced the risk monitor, features of real time online risk monitor (RORM), key technologies and human machine interface (HMI) design of RORM software. As a plant specific real-time analysis tool, risk monitor was used to determine the instantaneous risk based on the actual status of the systems and components. He explained the process of RORM including getting the configuration information of NPP from state monitoring system or operator support system (OSS）in real-time, updating the online risk models and the reliability data of the equipment automatically, analyzing the instantaneous risk and other information and supporting the decision making process of operator and manager in NPP. On-line risk modeling, updating, model analysis, reliability data on-line acquisition, analysis and storage, risk criteria and thresholds are the key technologies of RORM.

Fig.7 Prof. Wang He.

3.6 Temporal aspects of multilevel flow modeling

Prof. Emeritus Morten Lind (Department of Electrical Engineering, Tech. Univ. Denmark) discussed lessons on automation and human machine interaction in complex industrial systems.

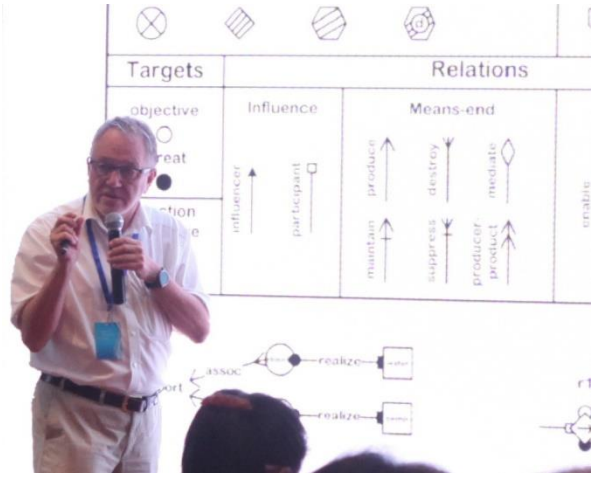

Fig.8 Prof. Lind.

He described that the current digital control room using large screen displays to present plant information for the operator and alarm shows in

abnormal situations cause information overload of the operator. Information is mainly presented according to engineering documents and not according to operational needs or tasks. It is difficult to derive meaning from sensor data in abnormal situations. His proposed multilevel flow modeling (MFM) deals with temporal aspects of complex systems by the basic concepts of functions and roles, the cause-effect relations used for reasoning and updating cause-effect trees according to changing plant evidence.

3.7 JMCT monte carlo simulation analysis of BEAVRS and SG-III shielding

Prof. Li Deng (Institute of Applied Physics and Computational Mathematics) stressed the necessity to establish a virtual reactor simulation tool of predictive capability of coupling with state-of-the-art fuels performance, neutronics, thermal-hydraulics, and structure models, with existing systems and safety analysis tool. In his study, J particle transport system (JPTS) package has been developed based on the three frameworks. The capabilities of strong computer aided design (CAD) modeling, visualization result output and large scale parallel computation are shown. Analyzing hot zero power (HZP) conditions of BEAVRS with Monte Carlo code JMCT, MC21 and OpenMC to assess code accuracy against available data. Assessing the feasibility of analysis of radiation shielding using JPTS. JPTS package is with the capability of the full-core pin-by-pin and radiation shielding.

3.8 Design features and demonstration strategy of a transportable fluoride-salt cooled high-temperature Reactor (TFHR)

Prof. Hu Linwen (Massachusetts Institute of Technology) firstly presented an overview of MIT Nuclear Reactor Laboratory (NRL) and MIT Reactor (MITR). Then she introduced the MITR's fuel and materials research program and Fluoride salt cooled High-temperature Reactor (FHR) research in U.S. Design features of a Transportable FHR (TFHR) and demonstration strategy of TFHR using a sub-critical facility at MITR are shown in details.

3.9 Transition of the mission success probability under severe accident conditions: analysis by the GO-FLOW methodology and the consideration of uncertainty

Prof. MATSUOKA Takeshi (Utsunomiya University) presented that mission success probability of nuclear power plant system has been evaluated under accident conditions with the consideration of uncertainty. Analyses have been made by the GO-FLOW methodology, which is utilized as key technology to the research activity on going at Harbin Engineering University. A hypothetical sequence of accident conditions has been settled based on the Fukushima Daiichi accident. Mission success probabilities with uncertainty ranges have been obtained with the growth of accident. He also stressed that uncertainty ranges of mission success probabilities are important information for operators to correspond to accident situation. Uncertainties are produced by failure data distribution, analysis model uncertainty, lack of knowledge and so on. Estimation of uncertainty needs to be performed and shown in "risk monitor" system. The present analyses have shown that mission success probabilities of nuclear power plant with the growth of accident will be easily obtained by the GO-FLOW methodology. See the detail of Prof. Matsuoka's paper in this issue.[3]

3.10 Using accelerators to simulate neutron damage in reactors: current progress, challenges, and issues

Prof. Lin Shao (Texas A&M University) firstly introduced Neutron-atypical features of accelerator testing including defect imbalance, void suppression by pulsed beam, beam induced carbon contamination. Then the current progress was displayed in developing radiation tolerant alloys including oxide dispersion strengthened (ODS) alloys and nanograined alloys.

4 Concluding remarks

The 8th International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2016) was held in Chengdu, China in September 26-28, 2016, 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 ten invited presentations and one hundred and forty-nine technical papers at the ISSNP2016, the subject of which were mostly related with (1) reactor physics, (2) safety analysis, (3) I&C, (4) equipment, (5) nuclear safety, (6) nuclear fuel, (7) thermal hydraulic, (8) advanced reactor, (9) Simulation and modeling, (10) experiment, (11) severe accident. The overview of the ISSNP2016 was given in this report, and the condensed summaries of major keynote presentations by international experts were included.

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