Report on the 15th International Workshop on Nuclear Safety and Simulation Technology

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Abstract: The 15th International Workshop on Nuclear Safety and Simulation Technology (IWNSST2013) was held on August 30- September 1, 2013 at Harbin Engineering University (Harbin, China) as a part of the 60th anniversary events of Harbin Engineering University. There were eight lectures presented by invited speakers from five countries (*i.e.* China, Denmark, Japan, Korea, and Norway), and the audience of the workshop was the teachers and PhD students of about 60 persons from Harbin Engineering University. The subjects of the presentations were: (i) Lessons from the Fukushima Daiichi Accident, (ii) Functional modeling approach and its application, and (iii) Advanced system analysis and simulation technologies. The summaries of all presentations are compiled in this paper.

Keyword: Fukushima Daiichi Accident; functional modeling approach; Bayes' theorem; situation awareness; radiological software tools

1 Introduction

The 15th International Workshop on Nuclear Safety and Simulation Technology (IWNSST2013) was held on August 30-September 1, 2013 at Harbin Engineering University (Harbin, China) as a part of the 60th anniversary events of Harbin Engineering University. The purpose of this article is to give readers of this journal (IJNS) a comprehensive summary of this three-day workshop.

2 Workshop program and organization of this report

2.1 Workshop program and participants

The 15th International Workshop on Nuclear Safety and Simulation Technology (IWNSST2013) was organized by the College of Nuclear Science and Technology of Harbin Engineering University. The timetable of the three-days workshop is as shown in Table 1. The list of the workshop organizers as well as the six invited speakers from five countries (China, Denmark, Japan, Korea, and Norway) is given in Table 2. There were 60 audience of teachers and PhD students from Harbin Engineering University.

2.2 Organization of this report

The contents of 8 papers presented at the workshop will be introduced in the subsequent chapters by classifying: (i) Lessons from Fukushima Dai-ichi accident, (ii) Functional modeling approach and its application, and (iii) Advanced system analysis and simulation technologies**.**

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Table 1 Time table of the 15th International Workshop on Nuclear Safety and Simulation Technology, August 30-September 1, 2013.

Time	Items	Speakers
	August 30, Fri.	
8:45	Opening address	Prof. Puzhen Gao
9:00	Lecture 1:Perspective on Post-Fukushima Severe Accident Research Chair: Prof. Xinrong Cao	Prof. Jun Sugimoto
10:20	Group photo & coffee break	
10:50	Lecture 2: Lessens learned from the Fukushima Dai-ichi accident Chair: Prof. Xinrong Cao	Mr. Takashi Nitta
12:10	Lunch break	
14:00	Lecture 3: Bayes' Theorem and its application to nuclear power plant safety Chair: Prof. Poong Hyun Seong	Prof. Takeshi Matsuoka
15:20	Coffee break	
16:40	Lecture 4: Approaches at KAIST NICIE Lab to quantifying situation awareness in nuclear power plant MCRs Chair: Mr. Terje Johnsen	Prof. Poong Hyun Seong
17:30	Dinner	
	August 31, Sat.	

9:00	Lecture 5: Overview and status of functional modeling Chair: Prof. Ming Yang	Prof. Morten Lind
10:20	Coffee break	
10:40	Lecture 6: A new functional modeling framework of risk monitor system Chair: Prof. Takeshi Matsuoka	Prof. Hidekazu Yoshikawa
12:00	Lunch break	
14:00	Lecture 7: Reliability analysis of digital I&C systems by a functional modeling approach Chair: Prof. Morten Lind	Prof. Ming Yang
15:20	Coffee break	
14:20	Lecture 8: Radiological software tools supporting improved nuclear safety Chair: Prof. Hidekazu Yoshikawa	Mr. Terje Johnsen
17:30	Dinner	
	September 1, Sun.	
8:40	Option1: Technical tour to Automation College Option2: HEU exhibition tour to ship museum and history exhibition	
10:00	The 60th Anniversary ceremony at north stadium	
11:40	Lunch	
13:00	Opening ceremony of ISUP* and EXPO** at sunshine hall, qihang activity center	
12:30	IFUP at lecture hall, activity center EXPO at sunshine hall, qihang activity center	
17:00	Closing ceremony and Banquet, Faculty saloon, qihang activity center	
19:00~ 21:00	The 60th anniversary's evening party at Qihang theater	

*IFUP: 2013 International Forum for University Presidents on Information and Communication Technology Education (IFUP-ICT'13)

**EXPO: 2013 HEU Educational Expo

Table 2 List of workshop organizers and invited speakers.

Name	Affiliation	Country
Prof. Zhijian Zhang	Harbin Engineering University (HEU) Workshop representative	China
Prof. Ming Yang	Harbin Engineering University (HEU) Workshop secretary	China
Prof. Puzhen Gao	Harbin Engineering University (HEU) Workshop organizers	China
Prof. Xinrong Cao	Harbin Engineering University (HEU) Workshop organizers	China
Prof. Jun Sugimoto	Kyoto University	Japan
Mr. Takashi Nitta	The Japan Atomic Power Company (JAPC)	Japan
Prof. Poong Hyun Seong	Korea Advanced Institute of Science and Technology (KAIST)	Korea
Mr. Terje Johnsen	OECD Halden Reactor Project	Norway
Prof. Hidekazu Yoshikawa	Kyoto University/ Harbin Engineering University (HEU)	Japan /China
Prof. Morten Lind	Technical University of Denmark (DTU)/ Harbin Engineering University (HEU)	Denmark/ China
Prof. Takeshi Matsuoka	Utsunomiya University/ Harbin Engineering University (HEU)	Japan /China

Photo 1 shows a photo of the workshop room at College of Nuclear Science and Technology, Harbin Engineering University.

Photo 1. A snap of the workshop room.

Photo 2 shows the group photo of speakers with female attendants, while photo 3 that of with male attendants.

Photo 2. Group photo of speakers with female attendants.

Photo 3. Group photo of speakers with male attendants.

Photo 4 shows a snap of opening ceremony of IFUP and EXPO at sunshine hall, qihang activity center in the afternoon of September 1, where the workshop speakers participated.

Photo 4. Opening ceremony of IFUP and EXPO.

3 Lessons from Fukushima Dai-ichi accident

3.1 Perspective on Post-Fukushima Severe Accident Research

Prof. Jun Sugimoto (Kyoto University) overviewed the consequence of Fukushima Dai-ichi accident, and then he proceeded on the main subject of the perspective on post-Fukushima severe accident research. The summary of his lecture is given in the following paragraphs.

After Fukushima Dai-ichi accident, several investigation committees in Japan issued reports with lessons learned from the accident. Among those lessons, some recommendations have been made on severe accident research. Similar to the EURSAFE efforts under EU Program[1], review of specific severe accident research items had been already conducted before Fukushima accident by a working group of Atomic Energy Society of Japan (AESJ) in terms of significance of consequences,

Photo 5. Prof. Jun Sugimoto.

uncertainties of phenomena and maturity of assessment methodology[2]. After the Fukushima accident re-investigation has started by this working group, and it was found that additional effects of Fukushima accident such as core degradation behaviors, sea water injection, containment failure/leakage and re-criticality have been found out. As the result, the review results are categorized into nine major fields; (i)core degradation behavior, (ii)core melt coolability/retention in containment vessel, (iii)function of containment vessel, (iv)source term, (v)hydrogen behavior, (vi)fuel-coolant interaction, (vii)molten core concrete interaction, (viii)recriticality, and (ix)instrumentation in severe accident conditions.

In January 2012, in collaboration with the above working group, Research Expert Committee on Evaluation of Severe Accident was established in AESJ, in order to investigate severe accident related issues for future LWR development, and to propose action plans for future severe accident research.

Based on these activities with adding his personal view, Prof. Sugimoto summarized the perspective of important severe accident research issues after Fukushima accident. According to Prof. Sugimoto, those are: (i) investigation of damaged core and components, (ii) advanced severe accident analysis capabilities and associated experimental investigations, (iii) development of reliable passive cooling system for core/containment, (iv) analysis of hydrogen behavior and investigation of hydrogen measures, (v) enhancement of removal function of radioactive materials of containment venting, (vi)

advanced instrumentation for the diagnosis of severe accident, and (vii) assessment of advanced containment design which excludes long-term evacuation in any severe accident situations.
Professor Sugimoto also briefly introduced severe accident research now conducted at Kyoto University.

More details are described in Professor Sugimoto's paper[3] in this issue.

3.2 Lessons learned from the Fukushima Dai-ichi accident

The lecture by Mr. Takashi Nitta (The Japan Atomic Power Company) started by reviewing the technical causes of Fukushima Dai-ichi accident, and then presented his view on lessons learned from Fukushima Dai-ichi accident. The summary of his lecture is given in the following paragraphs.

Photo 6. Mr. Takashi Nitta.

Two years and five months have passed since the Fukushima Dai-ichi accident which was caused by the tsunami of extra-ordinary enormous scale in Japanese history due to the Great East Japan Earthquake occurred on March 11, 2011.

The Nuclear Safety Division of the Atomic Energy Society of Japan (AESJ/NSD) organized a series of seminars in 2012 to investigate multifaceted aspects of this accident from the viewpoint of nuclear power professionals, and the division published the final report of the members' investigation at the end of March,2013[4]. Mr. Nitta contributed this activity as the vice chairman of AESJ/NSD.

According to the report, the issues identified during the seminar were itemized into not a few subjects such as (i)defense in depth (DiD) concept, (ii)safety design and severe accident management, (iii)nuclear safety regulation, (iv)emergency preparedness and response, (v)probabilistic risk assessment, (vi) feedback of operational experience, (vii)safety research, and so on.

Mr. Nitta concluded that the following six items are the major important lessens learned from Fukushima Dai-ichi accident.
(1) Ensuring nuclear safety by the DiD:
The importance of DiD for ensuring nuclear safety was recognized. DiD concept is believed to be valid even after the Fukushima Dai-ichi Accident. The protection against external hazards must be enhanced according to the DiD concept.
(2) Severe accident measure and its effectiveness:
Provision against unexpected accident is needed. Flexible measures mainly by mobile facilities will be effective against external hazards. Safety management will be more important as higher levels of DiD. Total safety system including off-site support should be considered.
(3) Emergency preparedness and response:
It is important to clarify the sharing of responsibility, to have common understanding of the emergency management timeline among relevant organizations and to improve continuously emergency preparedness, and response plans based on feedback from exercise.
(4) Future safety research:
Safety research should be conducted continuously based on the mid-and-long term roadmap for promoting the nuclear safety.
(5) Nuclear safety regulation:
In order to achieve the effective and efficient regulation based on the up-to-date scientific knowledge and to restore public trust, the training of regulatory experts is required.
(6) Close communication of the information:
As communication is related to all above issues, close communication among relevant organizations is important for ensuring nuclear safety.

4 Functional modeling approach and its application

4.1 Overview and status of functional modeling

Prof. Morten Lind (Technical University of Denmark /Harbin Engineering University) gave comprehensive lecture on functional modeling approach and its application. The summary of his lecture is given in the following paragraphs.

Photo 7. Prof. Morten Lind.

Functional modeling is an exciting research field which is highly relevant for the engineering disciplines. It addresses basic questions about the relations between means and ends or purposes and our understanding of complex physical artifacts like industrial systems and infrastructures.

Functional modeling is currently applied to Nuclear Power Plants in projects in Europe and Asia. Functional modeling has its roots in AI research and is reaching a promising level of maturity. Modeling tools are becoming available (such as Multilevel Flow Modeling). Functional modeling has therefore the potential to play a central role in future advancement of systems engineering.

Concerning the introduction of MFM and the basic principle of control function in MFM refer to Refs.[5,6], respectively, in the past issues of IJNS. A practical example of applying the basic principle of control function in MFM for the modeling of operating modes of a Japanese Fast Breeder Reactor is also given in the past issues of IJNS[7] .

More details are described in Professor Lind's paper[8] in this issue.

4.2 A new functional modeling framework of risk monitor system

Prof. Hidekazu Yoshikawa (Kyoto University /Harbin Engineering University) explained his on-going development of a unique risk monitor system for nuclear power system composed by plant DiD risk monitor for the whole plant system and reliability monitors for individual sub-systems and equipments composing the whole plant. He divided his presentation into two parts: already developed in the past and a new part to be attacked in future, where the latter part was related with his idea of how to apply functional modeling framework for composing plant DiD risk monitor. The summary of his lecture is given in the following paragraphs.

Photo 8. Prof. Hidekazu Yoshikawa.

Prior to his presentation on the framework of Risk Monitor System for nuclear power plant (NPP), Prof. Yoshikawa stressed that, by observing the situations in Japan where Fukushima Dai-ichi accident occurred, the risks of NPP which should take into account are not only the ones at daily operation to avoid severe accident occurrence and during severe accident when it may be necessary for civil evacuation, but also for long-term risk management on post-severe accident.

The risk monitor system which Prof. Yoshikawa proposes consists of (i) Plant DiD Risk Monitor and (ii)Reliability monitor. The general description of the both monitors and the relation between the both are described in Ref.[9], and the hitherto studies had been almost directed to the development of reliability monitor for PWR safety systems by using GO FLOW method, for example, in Ref.[10].

Regarding the Plant DiD Risk Monitor, he proposed to configure it by an integrated functional modeling method. Wherein, he proposed to develop the Plant DiD Risk Monitor on the basis of his developed graphical methodology for analyzing proper task allocation between operators and machine in the man-machine system of nuclear power plant[11].

Further details are described in Professor Yoshikawa's paper[12] in this issue.

4.3 Reliability analysis of digital I&C systems by a functional modeling approach

Prof. Ming Yang (Harbin Engineering University) presented his on-going research on the reliability analysis of digital I&C systems based on functional modeling approach. The summary of his lecture is given in the following paragraphs.

Photo 9. Prof. Ming Yang.

Digital I&C systems have been widely applied in various industrial systems including nuclear power plant. While the cost effectiveness and flexibility of digital I&C systems is widely recognized, it is very difficult to prove the high levels of reliability and safety which digital I&C system can achieve. On one hand, it is very hard to evaluate the reliability of a specific digital I&C system as a whole using statistics methods because the digital I&C systems are small sample systems. On the other hand, the matured reliability analysis methods for hardware based system are not applicable to digital I&C systems because the digital I&C systems consist not only of hardware but also of software or firmware. The failure mechanism of software is quite different from that of hardware. The very complex interaction within and between hardware and software of digital I&C system makes both qualitative and quantitative reliability analysis more difficult than the reliability analysis of a hardware based system.

In Prof. Ming Yang's presentation, he proposed to use Multilevel Flow Models (MFM) for analyzing the reliability of digital I&C systems at nuclear power plant with the following considerations:
(i)MFM is a functional modeling method which can be built at different abstraction layers. It can be used to build even for the system conceptual design and preliminary design period when the information is lacking, and it can be easily updated step by step when more and more materials become available.
(ii)MFM can decompose a complex system with interrelated mass flows, energy flow and information flow. Not only each flow structure is relative simple and easy to analyze, but also the software reliability can be modeled, analyzed and tested in the context of the system that the software is designed to control.
(iii)It will be very easy to analyze the effects of software failures on the whole digital I&C system.
(iv)MFM clearly describes the design intent and means of implementation of a system and therefore it is very easy to understand.

In his presentation, the methodologies for digital I&C systems and the developmental tools to model, analyze and test digital I&C systems were introduced with the demonstration of the related software under development.

5 Advanced system analysis and simulation technologies

5.1 Bayes' Theorem and its application to nuclear power plant safety

Prof. Takeshi Matsuoka (Utsunomiya University/Harbin Engineering University) made a lecture on the basic knowledge of Bayes' Theorem mainly from the aspect of PSA in nuclear power plant safety assessment. The summary of his lecture is given in the following paragraphs.

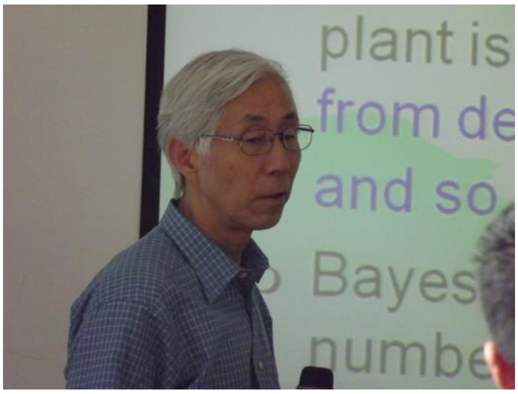

Photo 10. Prof. Takeshi Matsuoka.

Probabilistic safety assessment methods are widely used for the safety evaluation of nuclear power plant. It has been realized, however, that the method has to deal with the rarity of events with lack of meaningful statistical data. Therefore, traditional statistical method is not well applicable to PSA.

Bayes' theorem has been paid much attention for its application to PSA, as you see from such situation that the analyst knowledge is changed when new evidence becomes available. For this case, Bayes' theorem can provide us the method to update the data coherently with the new evidence.

In his presentation, he first discussed on two types of probability, *i.e.*, subjectivistic and frequentistic probabilities. Then he explained Bayes' theorem in detail, and how to interpret the Bayes' equation. He also explained the concept of a pair of conjugate distributions as that between prior distribution and likelihood. He also discussed on the meaning of the sequential evaluation, two or three steps evaluation, and concluded that the Bayes' theorem gives the same result with the lump evaluation.

Prof. Matsuoka explained how the failure data of components are evaluated by the Bayes' theorem with some examples of demand probability of the start of diesel generator and failure of pressure sensor. He also extended the discussion on the evaluation of frequency of nuclear power plant accident. These are frequency of fires in the reactor compartment and frequency of core melt accident with the experience of Fukushima Dai-ichi accidents.

Then Prof. Matsuoka explained that the Bayes' theorem can be well incorporated into system reliability analysis with the use of Bayesian network. As an example of Bayesian network, he took the case of Hugin-light (name of commercially available software) and showed some model analysis. He then went on the hot discussion between favorable and critical peoples on the Bayes' methods by contrasting their opinions briefly.

He also stressed that the Bayesian methods can provide a logical framework for safety analysis of nuclear power plants. According to him, the frequentists seem to be objective, but they limit the available evidence to only statistical values. In actual situation, however, we have to make judgment to decide what the evidence is. Furthermore, our knowledge about nuclear power plant is formed not only by statistical data but also from design considerations, operating environment, and so on. Bayesian methods can translate these beliefs into numbers, and assessors become coherent. Then the group of assessors has high chances to reach a common decision.

More details are described in Professor Matsuoka's paper[13] in this issue.

5.2 Approaches at KAIST NICIE Lab to quantifying situation awareness in nuclear power plant MCRs

Prof. Poong Hyun Seong (Korea Advanced Institute of Science and Technology) presented on his long term researches and developments on human factors study to quantify situation awareness (SA) in NPP Control Rooms conducted by the KAIST NICIE (Nuclear I&C and Information Engineering) Lab.
The summary of his lecture is given in the following paragraphs.

The content of his lecture was divided in four parts.
The first part was related with quantifying individual situation awareness by using eye tracking system.
The second part of his lecture was on quantifying team situation awareness by analyzing the team members' conversation.

Photo 11. Prof. Poong Hyn Seong.

Besides these experimental approaches for SA, Prof. Seong also introduced some attempts to quantify SA in analytical ways. In the third part on introducing first analytical approach, Bayesian inference method was used with the assumption of ideal operator, while real operators' characteristics such as working memory decay, imperfect mental models were also included for the second analytical approach.

Lastly as the fourth part, he presented his lab's effort to develop a tool for supporting their analytical work.

More details are described in Professor Poong Hyun Seong's paper[14] in this issue.

5.3 Radiological software tools supporting improved nuclear safety

Mr. Terje Johnsen (OECD Halden Reactor Project) started his lecture by introducing OECD Halden Reactor Project with his software engineering section's activity, and then proceeded to the main subject of radiation software tools development. The summary of his lecture is given in the following paragraphs.

The OECD Halden Reactor Project (HRP) is an international research cooperation with 20 members countries and more than 100 organizations world wide focusing on safe and reliable operation of nuclear power plants. The HRP research program is hosted by the Norwegian Institute for Energy Technology (IFE) at its Halden establishment.

The IFE has long been involved in the development of tools and providing guidance for increasing radiation safety in the nuclear industry. Tools developed within the HRP project, and bilateral projects between IFE and various nuclear countries, have successfully been utilized in ensuring safety at numerous nuclear sites, *e.g.*, the Andreeva Bay in Russia, Chernobyl NPP, Leningrad NPP, Fugen NPP, sites operated by TEPCO, sites targeted by Danish Decommissioning, *etc*.

Radiological tools developed at IFE have been greatly contributing to safer operation of nuclear installations through supporting the following activities:
(i)advanced management (recording, analyses and visualization) of relevant data, using 3D or 2D representation of the environment the data are connected to,
(ii)planning (optimizing costs and safety) and demonstrating work protocols, with real (or semi-real) time risk analyses and visualization,
(iii)training workers well and cost efficiently (practice in realistic interactive environment, evaluate workers' performance), and
(iii) advanced communication (radiological situation, work plans, impact assessments, *etc*.) within and between work teams, to advisors, regulators and the public.

Photo 12. Mr. Terje Johnsen.

The VRdose system is one of the most important radiological tools developed at IFE. This tool is a 3D simulation software package for supporting work in nuclear environments. This tool has initially been developed for planning maintenance and outage work, and is now being further developed for widening the areas of application. The IFE is also conducting important developments towards exploring the possibilities in the utilization of hand-held and portable devices for *in-situ* work support. In addition, the IFE is also investigating the opportunities in application of advanced 3D geographical information systems in supporting wide scale radiological mapping.

All these ongoing developments have a common aim of providing wider range of support tools primarily for the nuclear industry, but also with promising application in the oil and gas industry, for such areas as: (i)designing, safely operation and decommission of facilities, (ii)characterization and remediation of contaminated sites, (iii)regulatory supervision of legacy sites, (iv)crisis management, and (v)education of future workers.

Out of the applications mentioned above, software support for improving safety and efficiency of nuclear decommissioning projects is, currently, of special interest due to the high focus of the international nuclear industry on this specific topic.

More details are described in Mr. Terje Johnsen's paper[15] in this issue.

6 Concluding remarks

The 15th International Workshop on Nuclear Safety and Simulation was held on August 30 – September 1, 2013 at Harbin Engineering University (Harbin, China) as a part of the 60th anniversary events of Harbin Engineering University. There were eight lectures presented by invited speakers from five countries (China, Denmark, Japan, Korea, and Norway), and the total number of the workshop participants was about 60 persons. The eight lectures were classified into the three subjects of (i) Lessons from the Fukushima Daiichi Accident, (ii) Functional modeling approach and its application, and (iii) Advanced system analysis and simulation technologies, and the summaries of all lectures are compiled in this paper.

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