APPROACHES AND APPLICATIONS OF HUMAN RELIABILITY ANALYSIS IN NUCLEAR POWER PLANTS IN CHINA

Xiufeng TIAN [1], Jinggong LIU[1], Xuhong HE[2]

[1] CNNC China Nuclear Power Engineering Co., Ltd: No.117 Xisanhuanbeilu, Haidian District, Beijing, P.R.China, 100840. liujga@cnpe.cc, tianxf@cnpe.cc, liukx@cnpe.cc
[2] Lloyd's Register Consulting – Energy AB: PO. Box 1288, 17225 Sundbyberg, Sweden, xuhong.he@lr.org

Abstract

This paper presents the situation of human reliability analysis (HRA) works in China nuclear power plant (NPP) probabilistic safety assessment (PSA) studies. *The HRA activities of three representative research organizations are introduced. Recent activities in research and development of HRA in China focus on HRA for new NPP builds, the research of HRA in digital NPP, and integration of HRA with human factor engineering (HFE) design. The paper also describes HRA methods applied in China. Finally, Future efforts on HRA areas in China are suggested.*

I. INTRODUCTION

In Mainland China by 2015, operating nuclear reactors produce approximately an annual 16800 MW electricity power on mainland China. Nuclear power accounts for about 3% of total power supply. More than 24 reactors are under construction and a couple of more are planned. The key to the nuclear power development is safety. HRA is an evaluation of the potential for and mechanisms of human error that may affect plant safety.

Since late 1980s, the need for improved HRA methodologies for application to nuclear power plant PSA has motivated research and development works in China. There are many organizations working on PSA/HRA for operating NPPs and new builds, including design companies such as China Nuclear Power Engineering Co. (CNPE), Shanghai Nuclear Engineering Research and Design Institute (SNERDI), , universities such as Tsinghua University, University of South China, and research institutes such as Suzhou Nuclear Power Research Institute Co.,Ltd,.

Tsinghua University has started PSA and HRA research and plant pilot studies since late 1980s.

Human Factor Institute of University of South China (HFI-USC) was founded in 1987. It is the first research institute specializing in human factor engineering and HRA of nuclear power plants. The HRA team have completed HRA models for Dayabay, Lingao phase 1&2, Qinshan phase 1&3 NPPs, and is developing new HRA research related to digital I&C and SOP.

SNERDI has completed PSA/HRA model in 1989 for Qinshan phase 1, and developed HRA models for Chashma Nuclear Power Plant Unit 1&2, CAP1000, CAP1400. HRA code and HRA integrated with HFE design are also their research objectives.

CNPE started the research work on HRA in 2005 for Qinshan phase 2 NPP. CNPE has finished the PSA/HRA for Fuqing unit 1-4, Hainan unit 1&2, Tianwan unit 3&4, and currently is developing the PSA/HRA for Tianwan unit 5&6, Fuqing unit 5&6, small modular reactors, etc. According to the requirements of NPP projects, HRA models in level 1 PSA, level 2 PSA, internal fire PSA, internal flooding PSA, seismic PSA, spent fuel pool PSA were developed. From 2008, digital I&C technology has been widely used in the new nuclear power plants in China. Advanced main control rooms (MCR) is replacing the conventional MCR as the vital parts of a NPP. Operator interactions face a significant change in digital control rooms. CNPE has conducted a digital HRA research to support the PSA/HRA studies.

II. Activities in research and development of HRA in China

In recent years, the research and development of HRA in China mainly focus on the flowing fields.

II.A. PSA/HRA in NPP Projects

As one important element of PSA, HRA need to be developed for the design and operation of NPPs in China. The scope of PSA includes level 1 PSA, level 2 PSA, internal event, external event and spent fuel pool PSA. CNPE is working on multiple design tasks of new NPP projects including ACP1000, ACP600, ACP100, Hualong No.1, etc.

II.B. Research of PSA/HRA in digital NPP

Digital control systems are being used in new, advanced nuclear power plants in China. The digital human–system interfaces (HSIs) applied in NPPs offer potential for improved operator performance, however if not appropriately applied, they may introduce new burdens for the operators. Existing HRA methods are limited in the evaluation of the influence of digital HSIs on operator performance, and are difficult to give out advisable suggestion for the improvement of digital HSIs. The primary objective of the PSA/HRA research is to develop HRA methods in digital NPP and to properly assess the risk of NPPs.

II.C. Integration of HRA with HFE Design

There are certain interfaces between HRA and other HFE elements such as task analysis, procedure development, HSI design, staffing, training program development and human factors verification and validation. PSA/HRA analyses are generally conducted early in the design process, so it is necessary to make assumptions about functional allocation, human actions performance, and the quality of the HSI design, procedures, and related performance shaping factors, which should be confirmed and refined as the design effort progresses. Thus the integration of HRA with HFE Design is also an important research aspect.

III. Chinese HRA Methods

The HRA methods applied or modified in China are summarized below.

III.A. Human Cognitive Reliability (HCR) + Technique for Human Error Rate Prediction (THERP)

HCR and THERP methods have different focuses in HRA. HCR focuses on time-related cognitive behaviors and is used to evaluate human error probability during diagnosis period; THERP mainly deals with sequence actions, and is used to make an evaluation of the action errors.

III.B. Accident Sequence Evaluation Program HRA Procedure (ASEP)

ASEP method is a simplified version of THERP method, and was generally applied for the pre-accident HFEs in China.

III.C. The Standardized Plant Analysis Risk (SPAR) HRA (SPAR-H)

SPAR-H method provides different worksheets for Low power/shutdown (LP/SD) and at-power conditions. The SPAR-H method is straightforward, easy to apply, and is applied to evaluate the post-accident HFEs in China.

III.D. The methodology of combination of HCR/ORE, CBDTM and THERP

The methodology of combination of HCR/ORE, CBDTM and THERP was applied for the post-accident HRA in China. The cognitive HEP is calculated by combining the CBDT and HCR/ORE. The THERP method is applied to calculate the execution HEP.

III.E. Modified HCR/ORE+THERP

In order to calculate the HFPs in digital HSIs, new PSFs are introduced into conventional HRA methods and used for the evaluation of human performances. The modified HCR/ORE and THERP method are applied to HRA in several digital NPP design projects in China.

IV. Challenges on HRA technique in China

Challenges on HRA technique in China cover the following aspects:

IV.A. HRA methods in digital NPP

HRA for the advanced MCR should be able to consider the possible effects of new HSIs on the operator performances. But current HRA methods are difficult to reflect the operator performance under the digital HSIs.

IV.B. HRA data

Most currently available human error data is collected in the operations of the conventional plants and simulators. It is necessary to study the characteristics of human performance in digital HSIs to get more information and data about when, where and how operators will fail and what is the impact associated with these human failures.

IV.C. Different types of procedures

Different types of procedures are applied in NPPs of China, such as Emergency Operations procedure (EOP), symptom-based emergency operating procedures (SOP). The impacts of procedures on human performance should be considered in PSA/HRA.

IV.D. The application of HRA /PSA in the HFE program

In order to address important human error mechanisms in the design of the HFE aspects of the plant to minimize the likelihood of human error, and detect errors and recover from them, the modeling of human actions must be of sufficient quality.

II. CONCLUSIONS

This paper introduces some organizations in China who are active PSA/HRA and their activities and experiences. It presents the current activities in research and development of HRA.

Multiple HRA approaches are applied in the research and development of HRA in China, such as HCR/ORE+THERP, ASEP, SPAR-H, HCR/ORE+CBDT+THERP, Modified HCR/ORE+THERP. Modified HCR/ORE+THERP can be applied for HRA modeling in digital NPP.

This paper also discusses the challenges on HRA technique in China. HRA methods in digital NPP need to be further developed. More relevant HRA data, especially HRA data in digital NPPs, is necessary to be collected in order to properly assess the risk of NPP operation and to determine the risk of PSA applications, including being able to assess the impact of upgrading to digital controls. Procedures are important for the safety operation of NPP, and have important influences on human performance. The impacts of different types of procedures need to be evaluated by the further research. In the HFE program of design NPPs, PSA/HRA needs to be integrated in HFE activities. PSA/HRA should be applied in MCR design, procedure development and training development.

REFERENCES

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