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The digital simulation and fuzzy evaluation to reduce the likelihood of unsafe behavior in nuclear decommissioning

Meng-kun Li [a], Yong-kuo Liu [a,*], Min-jun Peng [a], Chun-li Xie [b], Li-qun Yang [a]

[a] *Fundamental Science on Nuclear Safety and Simulation Technology Laboratory, Harbin Engineering University, Harbin 150001, China*
[b] *Traffic College, Northeast Forestry University, Harbin 150040, China*

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ABSTRACT

Workers' behavior during the dynamic process of nuclear decommissioning is a complex phenomenon. In a nuclear environment, some workers may spontaneously and inadvertently engage in unsafe behavior which has high risks of serious injury and accident. In this paper, we determined and classified some of the unsafe behavior of workers in the nuclear decommissioning process. The evaluation factor system and the AHP model were established. The safety of behavior of virtual human, a trainee controlled in digital simulation, was quantified by fuzzy evaluation method. A primary virtual training method to reduce the chance of unsafe behavior was proposed and a safety training simulation software was developed. The feasibility of the proposed methods was tested through a hypothetical case.

1. Introduction

Human behavior modeling and simulation has become one of the most challenging research topics in many sectors where safety of human activity is a key issue. In the process of nuclear decommissioning, workers' behavior on site can affect the progress of the whole operation, as unsafe behavior not only endangers workers' safety, but also hinders the whole work. Therefore, there is a need to detect safe and unsafe behavior and take reasonable and feasible measures to improve personnel safety.

When workers engage in difficult activities in nuclear decommissioning, safe behavior is important. However, as a result of long operating lifetime of nuclear facilities, decommissioning tasks are not one of the every-day nuclear engineering duties, and expertise in this field is rare among operators. If a worker is not well informed about the working procedure or does not have enough safety awareness, they could cause an accident. Hence a personnel training before working in nuclear decommissioning is necessary in many cases.

Virtual simulation is increasingly being used in nuclear decommissioning, for equipment simulation and personnel training. References (Vermeersch and Bosstraeten, 1998; Vermeersch, 2005) have introduced a 3D-ALARA planning tool, VISIPLAN, which can be used for dose assessment, optimization of radiation protection for workers in complex nuclear installations, and work-planning in a 3D model. Reference (Szoke et al., 2014) has introduced a real-time software tool for modeling nuclear environments, visualizing radiation, planning a sequence of activities in a modeled environment, optimizing protection against radiation and producing job plan reports with dose estimates. References (Mól et al., 2009; Freitas et al., 2014) have introduced applications of game engine in nuclear facilities, which can be used for training for operation of nuclear facilities, dose assessment for optimization of operational routines, simulating the nuclear facility's structure, and training of personnel in nuclear and radiological installations. References (Park et al., 2008; Jeong et al., 2014, 2016) have introduced methods to visualize nuclear-decommissioning environments, evaluate a worker's dose, estimate work time and optimize the trajectories of workers during decommissioning of nuclear facilities.

In contrast to the above research results, the proposed methods in this paper and the developed software aim to evaluate the safety of virtual human that user controlled in a digital training environment, and reduce the likelihood of unsafe behaviors of workers through personnel training. In this paper, we combined virtual simulation with fuzzy evaluation for evaluating the safety of trainee's behavior without considering the safety of mechanical equipment and the safety culture of the management in nuclear decommissioning. The trainee can control a virtual human to explore the virtual environment, search for optimal means to complete the assigned task on time and engage in unsafe behavior that

* Corresponding author.
E-mail address: lyk08@126.com (Y.-k. Liu).

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could have harmful implication during the nuclear decommissioning process. This method could be useful for strengthening safety awareness of the trainee, correcting unsafe behavior, reducing the occurrence of accidents, and reducing casualties through better training.

The rest of the paper is organized as follows: Section 2 introduces a method to evaluate worker's behavior based on fuzzy evaluation. Section 3 presents the developed software which is used to strengthen safety awareness and reduce the chance of unsafe behavior using virtual simulation. Section 4 shows a hypothetical case to test the efficiency of the proposed method, and concludes with a summary in Section 5.

2. Safety evaluation of workers' behavior in nuclear decommissioning

A behavior evaluation method was proposed based on virtual simulation technology for personnel training and reducing the chance of unsafe behavior during nuclear decommissioning. Some of the inputs to the evaluation method were generated during the virtual training. Other input data was produced through survey and test of the concerned personnel before the virtual training.

2.1. Analysis of unsafe behavior in nuclear decommissioning

Nuclear decommissioning is a dynamic and complex work. Unsafe behavior refers to all the behavior that does not conform to safety rules, regulations and operating procedures. According to the references (He, 2004; Ye et al., 2014; GB6441-86), unsafe behavior of a worker can be divided into 13 categories:

(1) The wrong operation, ignoring safety provisions or warnings.
(2) Application of outdated safety device.
(3) Use of unsafe equipment.
(4) Manual operation with unsuitable tools.
(5) Improper storage of objects
(6) Venturing into a dangerous place
(7) Climbing unsafe position.
(8) Operating under lifted objects.
(9) Improper operation on the machinery while the machinery is in operation.
(10) Distracting behavior.
(11) Ignoring personal protective equipment.
(12) Unsafe costume.
(13) Dealing with dangerous goods carelessly.

One empirical finding from Heinrich's book that became known as Heinrich's Law states: in a workplace, for every accident that causes a major injury, there are 29 accidents that cause minor injuries and 300 accidents that cause no injuries. Heinrich thinks, people's unsafe behavior and unsafe state of objects and equipments are the direct cause of accidents and enterprise accident prevention measures are to eliminate unsafe behavior of people and unsafe state of the objects. Heinrich's research shows that most industrial accidents are caused by the unsafe behavior of workers (Heinrich, 1931). Hence, adequate training is essential for reducing the likelihood of accidents before the implementation of safety critical work.

2.2. Evaluation factor system

The parameters influencing individual unsafe behavior are cognition, emotion, personality and external factors. Individual physiological, psychological defects and fatigue, lack of safety knowledge and external factors distracting workers, are likely to cause unsafe behavior (Cai et al., 2008; Ye et al., 2014).

According to the reference (Ye and Li, 2005) and the operating experiences of the Hongyanhe nuclear power plant in China, we observed that physical quality, psychological quality, professional knowledge (e.g., skills, preparedness, understanding etc.), safety measures and environmental conditions have an important influence on safety. Hence, the evaluation factors for safety of behavior are as shown in Fig. 1.

2.3. AHP-Fuzzy method for evaluating safety of behavior of virtual human

The AHP is a structured method to organize and analyze complex decision-making process, based on mathematics and psychology which was proposed by Saaty in the 1970s (Saaty, 2008a,b).

Fig. 2 shows the flow of AHP-Fuzzy comprehensive evaluation method to evaluate safety of workers. Firstly, an evaluation factor system is determined. The hierarchical structure of AHP model is established based on the evaluation factor system. The weights of evaluation factors are determined using AHP methodology. Then, the so called membership function of every factor is determined, and actual values of the evaluation factors are determined based on membership functions. Finally, the safety of the behavior of the virtual human is evaluated using fuzzy comprehensive evaluation method and denoted as a safety index. If the safety index is critical, a warning is sent out. Otherwise, the evaluation method goes back to the step of quantifying until the evaluation ends.

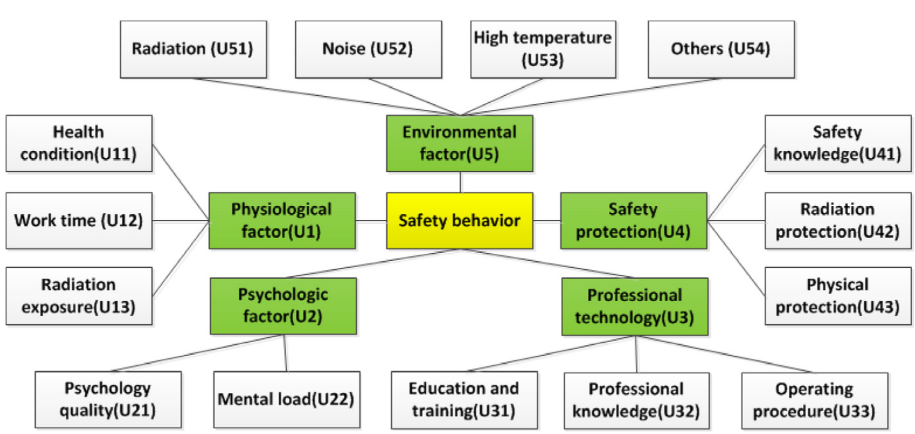

Fig. 1. The evaluation factors of safety of behavior.