Nuclear Engineering and Technology 50 (2018) 745–750

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Application plan for radiological exposure model using virtual reality–based radiological exercise system

Dewhey Lee [a, *], Byung Il Lee [a], Younwon Park [a], Dohyung Kim [b]

[a] Best Engineering in Energy Solutions (BEES), Inc., Suite No. L504 KAIST Munji Campus, 193 Munji-ro, Yuseong-gu, Daejeon 34051, South Korea
[b] Orion EnC Co., Ltd, Suite No. 305, 37 Seongsuro 22-gil, Seongdong-gu, Seoul 04798, South Korea

ARTICLE INFO

Article history:
Received 10 October 2017
Received in revised form
4 January 2018
Accepted 2 March 2018
Available online 28 March 2018

Keywords:
Effective Dose Rate
Event Tree Methodology
Exercise Evaluation Program
Public Response Action
Virtual Reality–Based Radiological Exercise System

ABSTRACT

New exercise technology such as the virtual reality (VR)–based exercise system is required to meet soaring demand for target participants in exercises and to alleviate the difficulties in personnel mobilization through an alternative approach to the exercise system. In a previous study, event tree methodologies were introduced in setting up an exercise scenario of a VR-based radiological exercise system. In the scenario, the locations at which major events occur are rephrased as nodes, routes as paths, and public response actions as protective actions or contents of an exercise at individual locations. In the study, a model for estimating effective doses to the participants is proposed to evaluate the exercise system, using the effective dose rates at particular times and locations derived from a computer program. The effective dose received by a student when she/he follows a successful route is about a half of the dose received when she/he does not follow the exercise guide directions. In addition, elapsed time to finish an exercise when following a successful route is less than one-third of the time spent to finish an exercise when following the guide's directions.

1. Introduction

Attempts to hold an exercise to simulate a radiological disaster, with vast personnel mobilization, have been evaluated as hardly possible because large numbers of the public residing within the emergency planning zones (EPZs), which were greatly extended according to protective actions that were recently revised and updated after the Fukushima accident, shall have to participate in the exercise. Currently, precautionary action zones (PAZs) are "identified as 3–5 km radius areas where the population within the zones is instructed to immediately take an iodine thyroid blocking (ITB) agent, reduce inadvertent ingestion, and safely evacuate to beyond the urgent protective action planning zone (UPZ)." In the meantime, "UPZs are also identified as 5–30 km where people within the zones are instructed to immediately remain indoors (shelter in place) until evacuation, take an ITB agent, and reduce inadvertent ingestion. If there is a potential for a severe airborne release, the population is instructed to safely evacuate beyond the UPZ as soon as possible without delaying evacuation of the public within the PAZ within 1 h of the declaration of a General Emergency by the shift supervisor of the nuclear power plant (NPP)" [1].

On the other hand, the status of exercises has been evaluated as at low efficiency levels, and personnel participation by the public in exercises is very poor. To overcome these issues, there have been increasing demands of a new concept such as virtual reality (VR) technology applied to a radiological exercise system. In the meantime, varieties of VR-based systems have been developed and applied to NPPs and related areas abroad [2–5].

To develop a VR-based radiological exercise system, we made an effort to study the Fukushima Daiichi Accident Technical Volume 3/5 published by the International Atomic Energy Agency (IAEA) [6]. Major events by time series that occurred during the Fukushima NPP accident have been reviewed, and issues raised in the public protection points of view have been carefully considered. We also studied the public opinions on the current exercise system and reflected emergency experts' comments as much as possible in the development of the current exercise system [7,8]. Varieties of limitations exist in applying the current radiological response system to accident situations. To overcome or alleviate these kinds of problems to a maximum extent, it is believed that varieties of scenarios must be applied to the VR-based radiological exercise system.

* *Corresponding author.*
E-mail address: dewhey.lee@gmail.com (D. Lee).

https://doi.org/10.1016/j.net.2018.03.009

The performance level of an exercise greatly depends on the components of the exercise scenario. Therefore, the components of an exercise shall be selected carefully to meet the requirements, objectives, and performance goals of the exercise when it is organized and planned.

Exercise phases, which are required to minimize exposure to radiation in cases of radioactivity release, are defined as event units, and these event units are reclassified as successes or failures. To physically realize all cases of probable occurrence of event units defined and combinations of successes and failures, event tree technology was used, as explained in detail in our previous studies [9,10]. Event tree technology is a method to represent successes and failures of varieties of events by time series prepared to mitigate an initiating event and the following accident consequences in a tree-type structure.

To enhance the exercise efficiency, we decide to conduct an evaluation of an exercise. We are planning to evaluate the exercise based on the radiation exposure doses to the exercise participants. In the estimation of radiation exposure dose, we are going to calculate the exposure dose using the dose rates at specific times and locations and information on the locations of participants or their behaviors, such as response actions according to time during an exercise.

In this article, we introduce how to calculate the dose rates at specific times and locations and approximate the participant locations according to the exercise scenario. We are planning to judge the possibility of application through example calculations.

2. Methods and materials

2.1. Evaluation of a VR-based exercise system

The phases of a radiological emergency exercise are divided into major event units during an exercise, and the implementing objects of VR are determined by the exercise topics of the major events. In addition, relevant variables of the implementation are itemized to make virtualization easy.

Most emergency exercises generally proceed with response actions according to a preplanned major scenario event list. Similarly, a VR-based radiological emergency exercise system must be prepared according to the specific major scenario event list. Thus, major events that occur by time series during a radiological emergency are defined.

To determine major event units, radiological emergency–related acts, enforcement decrees, enforcement regulations, and notifications from the Nuclear Safety and Security Commission are reviewed, and roles of emergency response agencies and organizations under the national radiological emergency response system are studied and analyzed. In addition, exercise scenarios of personnel mobilization of emergency response agencies and organizations and major issues in the individual exercise phases are carefully reviewed.

A radiological emergency is classified into three phases: an alert, site area emergency, and general emergency. When an emergency occurs at an NPP, it is normal to proceed with the emergency sequences described previously. However, only a site area and general emergency require response actions by the public. At this point of time, physical conditions (i.e., traffic, communications, and roads), meteorological conditions (i.e., wind speed and direction), measures for public relations and communications, and environmental situations and conditions of the public (i.e., current position, health status, and patient's probable mobility) should be carefully considered. In addition, an exercise scenario prepared by the nuclear licensee should be displayed by time series to review the response actions to be taken by the individual emergency response agencies, organizations, and the public.

According to the main issues discussed previously, major events in individual phases during an emergency are determined. In the case of a site area emergency, the steps are 1) notification of a site area emergency as an initiating event, 2) recognition of the announced emergency, 3) conduction of indoor sheltering, and 4) taking of protective actions as defined by major event time series. In the case of a general emergency, the major time series steps are 1) notification of a general emergency as an initiating event, 2) recognition of the announced emergency, 3) conduction of evacuation action, 4) moving to assembly posts, 5) transport to shelter, 6) contamination monitoring, and 7) triage. However, activities after arriving at a shelter (i.e., contamination monitoring, decontamination, registration, receiving daily necessities, and so on) are not directly related to the public exercise items, and they have low priority in major event units. The public response actions were derived from an actual exercise scenario prepared for a national unified exercise conducted by the Korean nuclear regulatory authority jointly with central government ministries and local governments for the Wolseong NPPs. Major event units are listed in Table 1.

In the meantime, it is almost impossible to implement all possible kinds of probable scenarios in the VR-based emergency exercise system. Therefore, we used the event tree structure mainly applied in the Probabilistic Safety Analysis to understand the scenario spectrum, as explained in detail in our previous studies [9,10]. By using the Probabilistic Safety Analysis technology, we can consider almost all possible scenarios that may occur in a radioactive material release accident.

Exercise phases that minimize the exposure to radiation in cases of radioactivity release are defined as event units, and these event units are reclassified as successes or failures. To physically realize all cases of probable occurrence of event units defined and combinations of successes and failures, event tree technology is used. Event tree technology is a method to represent successes and failures of varieties of events in a time series prepared for mitigating an initiating event and following accident consequences in a tree-type structure.

2.1.1. Determination of movement route and movement time

Movement route approximates the exercise participant's location while movement time is an approximation of the time taken to arrive at a particular location according to the exercise scenario.

In this study, we choose a student group as a subject group for the exposure dose evaluation and decide to calculate the projected effective doses according to possible student actions during an exercise. We believe that the student group is normally very enthusiastic about participation in electronic game–like programs such as VR-based exercise systems. It is strongly believed that this

Table 1
Major event units during a site area and general emergency.

Initial event	Event unit
Notification of a site area emergency	Recognizing a site area emergency, indoor sheltering, and protective action
Notification of a general emergency	Recognizing a general emergency, evacuation action, moving to assembly posts, and transport to a shelter