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Development of virtual reality-based radiological emergency exercise system

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Keywords: Effective dose rate; Emergency planning zone; Exercise evaluation program; Public response action; VR based radiological exercise system

Abstract

New concept for exercise technology such as virtual reality (VR)-based exercise system is introduced to alleviate the difficulties in personnel mobilization and to meet the soaring demand for target participants in exercises through an alternative approach to the exercise system. An exercise system was developed to facilitate the resident public with practical and efficient radiological emergency exercise available. An implementor of the exercise system does not only simply proceed exercises according to the scenarios prepared but also practices exercises by actively manipulating the system by him/herself. Thus, he/she can evaluate the result of his/her own practices and improve the practices. Because the system does not require a specific exercise location for practices and calling-on large number of the public for exercises is possible, the system expects to overcome various limitations of the current exercises. Currently, an exercise system was developed with VR-based exercise scenarios for the major occupational groups as a representative group, and a mobile VR gear exercise system was developed. However, an implementor can experience scenarios of unexpected situations resulted in the destruction of infrastructure such as roads and bridges and complex situations brought from combination of an earthquake and tsunami other than normal situations of successes of events

Introduction

Fukushima Daiichi Nuclear Power Plant (NPP) accident in 2011 had increased public fear about the accidents of the radioactive release from the NPPs and brought on drastic changes in Physical Protection and Radiological Emergency Act, emergency regulations, and emergency response systems in Korea. Among these changes, the greatest changes from the impact of Fukushima accident are the introduction of precautionary action zone (PAZ) of 3-5 km and extension of Urgent protective action Planning Zone (UPZ) of 20-30 km from 8-10 km of previous Emergency Planning Zone (EPZ). From these changes, large number of the public residing in the greatly extended EPZ areas must participate in the various emergency exercises has tremendously increased.

Many Member State (MS) countries of the International Atomic Energy Agency (IAEA), who utilize the nuclear powers, have reinforced in stipulating the corresponding laws and systems for the radiological emergency preparedness and response to prepare for the accidents of radioactive material releases. Korea also has greatly reinforced and set up a radiological emergency preparedness and response system to prepare for the accidents of radioactivity releases according to its revised Act on Physical Protection and Radiological Emergency (APPRE) [1]. In addition, it strongly stipulates the corresponding various radiological emergency exercises in its Nuclear Safety and Security Commissions' notice [2]. Many emergency response organizations under the national preparedness and response system such a nuclear power licensee, Korea Nuclear and Hydro Power (KHNP); regulatory authority such as Nuclear Safety and Security Commission (NSSC); Local Emergency Management Centers (LEMCs); corresponding emergency expert organizations such as Korea Institute of Nuclear Safety (KINS) and Korea Institute of Radiological and Medical Science (KIRAMS) shall rigorously implement these various radiological exercises, and be participated in the exercises. In addition, Korean NSSC stipulates relevant response organizations to implement exercises such as initial exercise, sectional drills on site, full-scale exercise on site, integrated exercise or/and unified exercise, respectively. These exercises are to test the effectiveness of the emergency exercises and check the readiness of relevant emergency response facilities and preparations of corresponding response organizations, in accordance with the articles in its Notice [2].

Most of these exercises are proceeded with the type of vast personnel mobilization and aim at participation of the corresponding response organizations under the Korean national emergency response system. Among these exercises, relevant local government jointly with a nuclear power licensee under its jurisdiction hosts and conducts an integrated exercise biennially per site while NSSC jointly with many relevant central government ministries, local governments and a nuclear power licensee do implement and conduct a unified exercise annually per site.

On the other hand, the status of exercises, especially that of unified exercises where the vast number of the public is directly involved and mobilized, has been evaluated as at the low efficiency level and personnel participations by the public in the exercises are extremely limited. The major reason for the poor participations by the public is understood that there are many physical difficulties to limit and control of the economic activities of the public for an exercise. In addition, a unified exercise is the largest exercise among all exercises, which NSSC involving the coordination with many central government ministries and local governments needs to plan and prepare for more than ten-month period and repetition of the same exercise is almost impossible. On the other hand, many local governments have experienced difficulties in maintaining experienced public officials for radiological emergency exercises due to the rather frequent internal move of the public officers, who have hands-on expertise in responding to a radiological emergency exercise, every other year. In the meantime, many radioactivity release accidents to occur expect to be complex radiological disasters like that of Fukushima, where a radiological emergency was initiated and caused by the combination of an earthquake and tsunami. However, the current radiological emergency exercises, specifically the current emergency exercise practices with the personnel mobilization method by the government are understood to be almost impossible to cope with and to respond to a complex disaster like Fukushima accident.

In addition, the low effectiveness or efficiency of emergency exercises yielded from the public distrust on the NPPs and their indifference to the relevant exercises are estimated to be the critical issues [3]. We can summarize the practical limitations and problems and effects on the national emergency response system in Table 1.

Table 1: The practical limitations and problems and effects on the national emergency response system

Practical limitations/problems	Effects on the national emergency response system
Personnel mobilization	Difficulties in controlling and limiting economic activities of the public
Long plan and preparation period for a unified exercise	Impossible for repetition of the same exercise
Frequent internal move of public officers with expertise	Difficulties in maintaining experienced public official
Complex radiological disaster	No scenarios to cope with these kinds of exercises
Public distrust on the NPPs & indifference to relevant exercises	Low participation in exercises

Here at the point where these limitations are pointed out, demands for a radiological exercise system applied with new technology such as virtual reality (VR)-based technology that enables large number of the public residing around the NPPs practicing a radiological exercise with more practical and effective manner when there occurs a real radiological disaster were brought up [3]. There have been increasing demands of new concepts such as virtual reality (VR)-based 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 [4~7]. However, these varieties of VR-based system are directly not related to the development of VR based radiological emergency exercise system."

This may result in a study of developing VR-based radiological emergency exercise system with multi-purposes, which considers the specific features of demands mentioned previously. Thus, in this study, we would like to propose the system components of an exercise system including corresponding protocols, an exposure dose model used for the evaluation of the exercise system from the selecting nodes and movement routes by an implementor of the exercise practices, and finally the results of the study on the VR contents that are employed in the system.

Materials and methods

Virtual reality-based radiological emergency exercise system

Main purpose of the application of virtual reality in a radiological emergency exercise is to repeat the response actions such as protective actions or exercise contents at individual locations (nodes) in a VR based radiological emergency exercise system without physically participating in an actual radiological exercise until an exercise participant is comfortable with the response actions during an emergency.

Figure 1 is a specific example of VR based exercise scenarios with an event tree structure, which we developed in the previous study to understand the spectrum of exercises [8]. Because VR based scenarios can provide both series of successes and series of failures in the exercise scenarios, the user of this system not only experience variety of combinations of successes and failures through the scenarios but also cope with the varieties of prompt response actions when failures occur.

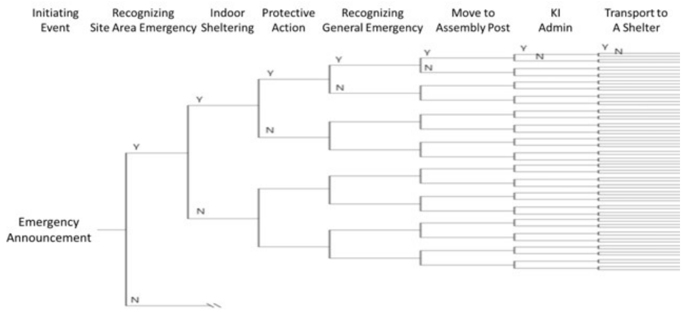

Figure 1: Event tree method for series of successes and failures

In the meantime, it is almost impossible to implement all possible kinds of probable scenarios in the VR based emergency exercise system. Thus, 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 [8,9]. By using PSA 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 employed. 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.

To enhance the exercise efficiency, we decide to conduct the evaluation of an exercise. We are planning to evaluate an 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 with using the dose rates in specific times and locations and information on the location of a participant or behaviors such as response actions according to the time during an exercise.

In this paper, we introduce how to calculate the dose rates in specific times and locations and approximate the participant's location according to an exercise scenario. We are planning to judge the possibility of the application through the example calculations.

To determine major event units, radiological emergency related acts, enforcement decrees, enforcement regulations and notifications from the NSSC are reviewed and roles of emergency response agencies and organizations under the national radiological emergency response system are studied and analyzed. Also, 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 a nuclear power plant, it is normal to proceed with the emergency sequences described above. However, only a site area and general emergency require response actions by the public as shown in Table 2.

For the dispersion of radioactive material released in the air the K-REDAP program employs a puff model with a releasing time over 24 hours and dose assessment in the 16 sectors with the radius range from 1 km to 40 km in the Cartesian coordinate system [10].

In the study, followings are assumed: the radioactive sources are the radioactive material released from the reactor containment building, with a release rate of 40%/day to atmosphere during post-accident, and the core melting of 70% damage. The main reason for this assumption was based on the reach of effective dose estimations for indoor sheltering and evacuation of the public. In addition, wind blow directions in 230 to 240 degrees with wind speeds of 1.5 to 1.8 m/sec and atmospheric stability of D's are assumed [11].

Effective doses to whole body in the 16 sectors within radii of 1, 2, 5, 8, 10, 20, 30 and 40 km after 2 days of radioactive material released are listed in Table 3.

We calculate the effective dose rates during 2 days by dividing the effective dose values listed above by 48 hours. In Table 4, effective dose rates in the 16 sectors with different radii are listed. Even though this is not the case in real situation, we assumed a constant dose rate in each individual sector during 2 days for the calculation.

Table 2: 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, protective action
Notification of a general emergency	Recognizing a general emergency, evacuation action, moving to assembly posts, transport to a shelter

Table 3: Effective doses after 2 days of radioactive materials released from the NPP [mSv]

	1 km	2 km	5 km	8 km	10 km	20 km	30 km	40 km
N	5690.00	17600.00	1950.00	477.00	236.00	98.80	33.00	77.50
NNE	5690.00	17600.00	1430.00	382.00	236.00	38.80	39.40	1.13
NE	5690.00	5490.00	1090.00	107.00	61.90	0.53	0.14	0.06
ENE	5690.00	5490.00	79.80	2.59	0.12	0.00	0.00	0.00
E	5690.00	8920.00	12.00	0.02	0.00	0.00	0.00	0.00

ESE	5690.00	8920.00	0.02	0.00	0.00	0.00	0.00	0.00
SE	5690.00	1560.00	0.00	0.00	0.00	0.00	0.00	0.00
SSE	5690.00	1560.00	0.00	0.00	0.00	0.00	0.00	0.00
S	5690.00	457.00	0.00	0.00	0.00	0.00	0.00	0.00
SSW	5690.00	457.00	0.00	0.00	0.00	0.00	0.00	0.00
SW	5690.00	24.10	0.00	0.00	0.00	0.00	0.00	0.00
WSW	5690.00	24.10	0.00	0.00	0.00	0.00	0.00	0.00
W	5690.00	701.00	0.00	0.00	0.00	0.00	0.00	0.00
WNW	5690.00	701.00	0.55	0.00	0.00	0.00	0.00	0.00
NW	5690.00	3170.00	27.70	6.42	1.59	0.00	0.00	0.00
NNW	5690.00	3170.00	928.00	110.00	69.20	20.80	4.47	1.58

Table 4: Effective dose rates in individual sectors within the radii from 1 km to 40 km [mSv/h]

	1 km	2 km	5 km	8 km	10 km	20 km	30 km	40 km
N	118.54	366.67	40.63	9.94	4.92	2.06	0.69	1.61
NNE	118.54	366.67	29.79	7.96	4.92	0.81	0.82	0.02
NE	118.54	114.38	22.71	2.23	1.29	0.01	0.00	0.00
ENE	118.54	114.38	1.66	0.05	0.00	0.00	0.00	0.00
E	118.54	185.83	0.25	0.00	0.00	0.00	0.00	0.00
ESE	118.54	185.83	0.00	0.00	0.00	0.00	0.00	0.00
SE	118.54	32.50	0.00	0.00	0.00	0.00	0.00	0.00
SSE	118.54	32.50	0.00	0.00	0.00	0.00	0.00	0.00
S	118.54	9.52	0.00	0.00	0.00	0.00	0.00	0.00
SSW	118.54	9.52	0.00	0.00	0.00	0.00	0.00	0.00
SW	118.54	0.50	0.00	0.00	0.00	0.00	0.00	0.00
WSW	118.54	0.50	0.00	0.00	0.00	0.00	0.00	0.00
W	118.54	14.60	0.00	0.00	0.00	0.00	0.00	0.00
WNW	118.54	14.60	0.01	0.00	0.00	0.00	0.00	0.00
NW	118.54	66.04	0.58	0.13	0.03	0.00	0.00	0.00
NNW	118.54	66.04	19.33	2.29	1.44	0.43	0.09	0.03

In Figure 2 effective dose rates in the sectors with radii of 8, 10, 20 and 30 km, respectively along an evacuation route of the study are depicted.

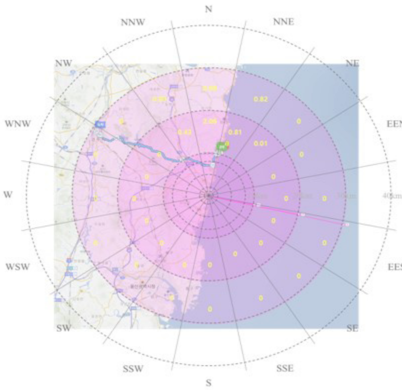

Figure 2: Effective dose rates in the sector with radii of 8, 10, 20, and 30 km along an evacuation route (mSv)

Calculation of exposure dose according to a scenario

To calculate an exposure dose to student group when taking an evacuation route, nodes of concern are as follow:

Node 1: Playground of Gampo high school (10 km ~ 20 km N)

Node 2: Classroom of Gampo high school (10 km ~ 20 km N)

Node 3: Home at Woosuk villa (10 km ~ 20 km N)

Node 4: Assembly post in Gampo town office (10 km ~ 20 km N)

Node 5: Refuge Shelter of Gyungju Gymnasium (20 km ~ 30 km WNW)

As shown in Fig. 3, various evacuation routes can be organized through a combination of nodes.

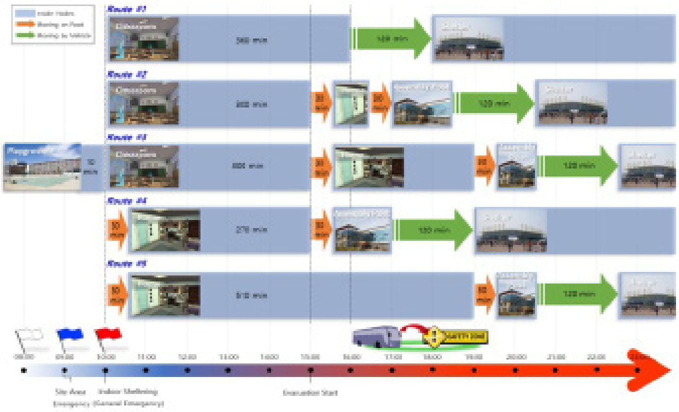

Figure 3: Nodes (stay time) and outside the nodes (moving time) on an evacuation route

Routes consist of series of nodes that eventually reach a refuge shelter. We determined 5 possible routes for the student group as follows:

Route #1: Node 1 – Node 2 – Node 5

Route #2: Node 1 – Node 2 – Node 3 – Node 4 – Node 5

Route #3: Node 1 – Node 2 – Node 3 – stay at Node 3 – Node 4 – Node 5

Route #4: Node 1 –Node 3 – Node 4 – Node 5

Route #5: Node 1 –Node 3 – stay at Node 3 – Node 4 – Node 5

Exposure doses per Route are calculated using data in Table 4 and Figure 2, and the results are given in from Table 5 to Table 9.

Table 5: Exposure doses per Route #1

Node	Outside node	External dose rate [mSv/h]	Shielding factor	Ambient dose rate [mSv/h]	Hour [h]	Dose [mSv]
Playground		2.060	1.000	2.060	0.167	0.343
Classroom		2.060	0.050	0.103	6,000	0.618
	On foot	2.060	1.000	2.060	0.167	0.343
	By bus	0,000	1.000	0.000	2.000	0.000
	Total	-	-	-	8.333	1.305

Table 6: Exposure doses per Route #2

Node	Outside node	External dose rate [mSv/h]	Shielding factor	Ambient dose rate [mSv/h]	Hour [h]	Dose [mSv]
Playground		2.060	1.000	2.060	0.167	0.343
Classroom		2.060	0.050	0.103	5.000	0.515
	On foot	2.060	1.000	2.060	0.500	1.030
Home		2.060	0.200	0.412	1.000	0.412
	On foot	2.060	1.000	2.060	0.500	1.030
Assembly post		2.060	0.200	0.412	1.500	0.618
	By bus	0.000	1.000	0.000	2.000	0.000
	Total	-	-	-	10.667	3.948

Table 7: Exposure doses per Route #3

Node	Outside node	External dose rate [mSv/h]	Shielding factor	Ambient dose rate [mSv/h]	Hour [h]	Dose [mSv]
Playground		2.060	1.000	2.060	0.167	0.343
Classroom		2.060	0.050	0.103	5.000	0.515
	On foot	2.060	1.000	2.060	0.500	1.030
Home		2.060	0.200	0.412	3.500	1.442
	On foot	2.060	1.000	2.060	0.500	1.030
Assembly post		2.060	0.200	0.412	1.000	0.412
	By bus	0.000	1.000	0.000	0.4	0.000
	Total	-	-	-	12.667	4.772

Table 8: Exposure doses per Route #4

Node	Outside node	External dose rate [mSv/h]	Shielding factor	Ambient dose rate [mSv/h]	Hour [h]	Dose [mSv]
Playground		2.060	1.000	2.060	0.167	0.343
	On foot	2.060	1.000	2.060	0.500	1.030
Home		2.060	0.200	0.412	4.500	1.854
	On foot	2.060	1.000	2.06	0.500	1.030
Assembly post		2.060	0.200	0.412	1.500	0.618
	By bus	0.000	1.000	0.000	2.000	0.000
	Total	-	-	-	9.167	4.875

Table 9: Exposure doses per Route #5

Node	Outside node	External dose rate [mSv/h]	Shielding factor	Ambient dose rate [mSv/h]	Hour [h]	Dose [mSv]
Playground		2.060	1.000	2.060	0.167	0.343
	On foot	2.060	1.000	2.060	0.500	1.030
Home		2.060	0.200	0.412	8.500	3.502
	On foot	2.060	1.000	2.060	0.500	1.030
Assembly post		2.060	0.200	0.412	1.000	0.412
	By bus	0.000	1.000	0.000	2.000	0.000
	Total	-	-	-	12.667	6.317

The accumulated doses and total evacuation elapsed time per Route are summarized in Table 10.

Table 10: Overall accumulated doses and total evacuation elapsed time per Route

Route No.	Route #1	Route #2	Route #3	Route #4	Route #5
Dose [mSv]	1.305	3.485	4.772	4.875	6.317
Elapsed Time [h]	8.167	10.667	12.667	9.167	12.667
	8 hrs 20 mins	10 hrs 40 mins	12 hrs 40 mins	9 hrs 10 mins	12 hrs 40 mins

Application Results

As you can notice dose received by a student group when she/he follows a success route (Route #1) that an exercise system aims at is about 20.66% of dose received when she/he does not follow the exercise guide's directions, stays at home (Route #5), and about 65.8% of the longest exercise time (~4 hrs 20 min less), and finally is forced to go to a shelter. Also, elapsed time to finish an exercise when following a success route is less than two third of the time spent to finish an exercise when they do not follow the directions given by the exercise guides. Therefore, we can fully convince the student group participants with this act that they should follow the directions given by the exercise guides to receive a minimum dose and to successfully finish the exercise within a time constraint. In this time, there occurs a radiological emergency at the NPPs, Korean government activates national radiological emergency response system and local governments, who have the NPP(s) under their jurisdiction, implement response protective actions to protect the public residing near the NPPs. During an emergency the public residing within the emergency planning zones (EPZs) takes either action of indoor sheltering in place or that of evacuation from the areas according to the relevant emergency zones. To prepare for these kinds of situations, repetitive radiological exercises are required to respond effectively to an emergency by response organizations and the public [8].

In this study, we developed a VR-based Radiological Emergency Exercise System (VREES) for the public residing around the NPPs in order to respond effectively to an emergency when there occurs an accident of radioactivity release. This new exercise system would resolve the limitations of current exercises such as impossibility of repetitive exercises arisen from the current personnel mobilization and non-existence of various scenarios. In addition, this system can increase the efficiency of the exercises because an implementor of exercise practices manipulates an exercise device at his/her individual will instead of practicing exercises being proceeded based on the scenarios of simple successes of events. Especially, we can get over the issues of the low level on the public participation since an exercise does not require the public to conduct an exercise at the specific locations.

The system proceeds an exercise with the assumption that there occurs a radiological emergency caused by an unexpected accident of the radioactivity release from the NPPs. There could exist several causes that bring radioactivity release accidents.

However, because the evacuation processes after radioactivity releases occur are the most important matters in the resident public point of view, assumptions for the correct causes of the accidents were excluded in the study.

The public implementors experience the different exposure doses from the radiation released according to the various scenarios that they select during the practices. Ambient dose rates and resultant accumulated exposure doses will vary depending on the movement routes that an implementor selects and whether protective actions are taken or not during the practices. By displaying the values of resulting exposure doses from the exercise practices in number, an implementor realizes the consequence and impacts on exposure doses from the selection of the evacuation routes and taking proper protective actions or not during his/her practices. In addition, an implementor realizes and fully comprehends how much he/she can reduce the resultant exposure doses by selecting the different evacuation routes without repeating the same choices in the selection of the evacuation route(s) and gain benefits from taking proper protective actions during an emergency by the practices. Thus, we can maximize the objectives and obtain the effectiveness of an exercise.

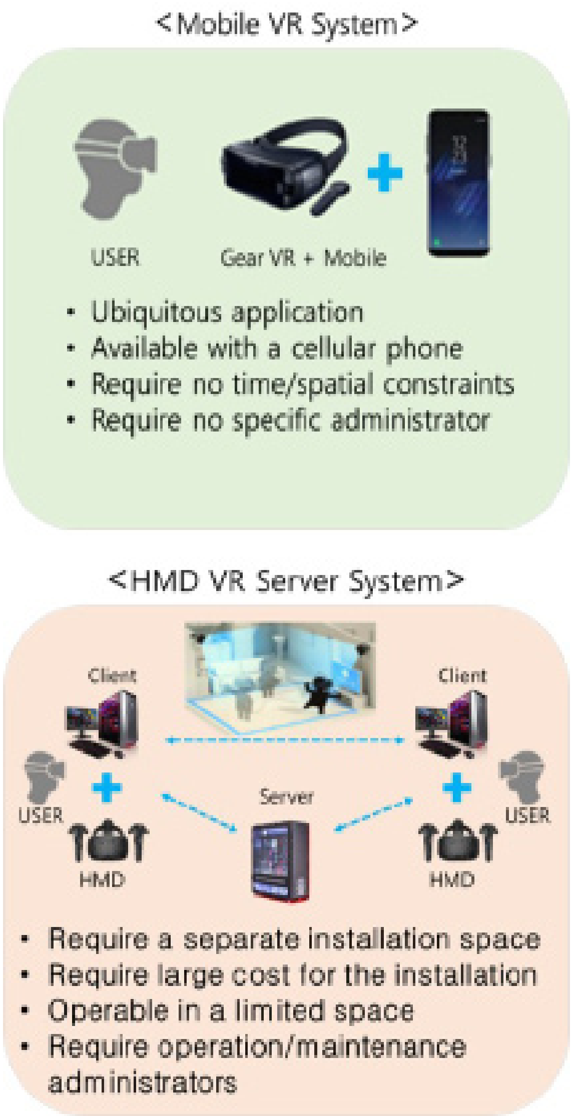

Figure 4: VR Platform

For the reasons explained previously, we decided the composition of the VREES to be based on the mobile VR gear-based devices. In addition, an implementor during the exercise practices does not only simply watch the screen displayed by the VREES but also actively involves in practicing with using the controller of a VR gear device. In other word, an implementor of practices can choose routes for movements or select choices for the protective actions with using the controller of a gear device in the virtual reality space. Through the hands-on experience by active practices for protective actions in the virtual reality space, the public can increase the level on an exercise efficiency.

Contents of Virtual Reality

Prologue of an exercise

The VREES is developed for exercise practice implementors of various occupational or age groups. A guidance of manipulating a VR gear device is located at the beginning part of a practice for seniors and starters, who are first encountering with these kinds of systems even though many implementors are practiced hands in such devices. Thus, when an implementor wears a VR gear device, he/she can exercise a practice after a tutorial session of manipulating the device is finished.

We assume many exercise practicing implementors of the VREES are the resident peoples who have no basic knowledges about the nuclear or radiological emergency at all. Thus, we arrive at judgements that we need to provide users of the VREES with fundamental knowledge on nuclear or radiological emergency before exercises proceed. Because radiation is colorless, unscented, and tasteless, humans cannot recognize it with their senses. By teaching the basic knowledges about the radiation beforehand, we intend to help the implementors to understand what the radiation is. In addition, we explain the background knowledge related to radiological exercises such as radiation types, internal and/or external exposure to radiation, methodologies to prevent and reduce possible exposures to radiation and corresponding response actions according to the classifications of an emergency. Implementors of exercise practices can learn the basic knowledges on radiological emergency and understand better about emergency exercises through this session as described in Figure 5. After finishing this preliminary session, main exercise practicing session starts. When an implementor moves into a screen where he/she selects a personal character such as one of students, the public, or personnel of emergency response organizations, then he/she can exercise practices.

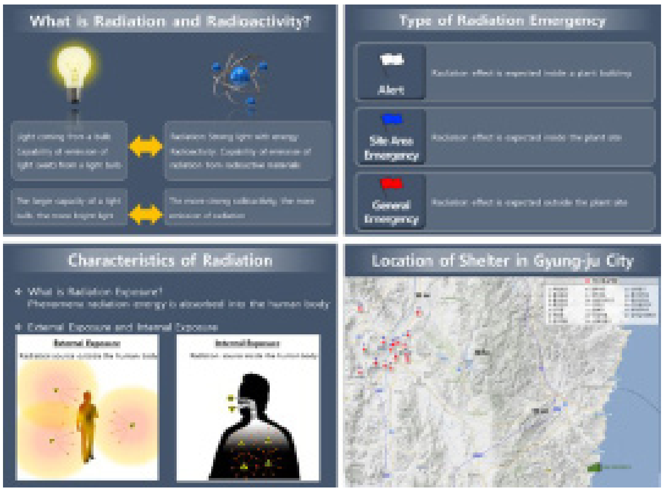

Figure 5: Captured screens for tutorial and preliminary training lesson

Originally, we intended to classify the personal characters into various occupational groups such as businessmen, fishermen, farmers, housekeepers, and students. However, even though different persons belonging to different occupational groups recognize an emergency at different specific locations, the protective actions they shall take are the same. Because the final goal of an emergency exercise is the evacuation of the resident public to a safe shelter, the ultimate destination of an exercise is the same as a safe shelter regardless an exercise is practiced by any person of different occupational groups. In other words, even though a member of students, the public or responding personnel of emergency response organizations is selected for an exercise practice, his/her final destination is a safe shelter. That is the reason why we select a student as a representative person among different occupational groups.

Selection of nodes, protective actions, and movement routes

If an implementor selects a personal character among different occupational groups, main session of a practice starts with moving the screen into the location where an implementor shall start his/her emergency response action. In case when a student character is selected, a screen moves into the playground where an emergency is notified, and the corresponding exercise practice starts. The VREES handles an emergency exercise, which is quite different from other simulated exercises, and it covers 20~30 km ranges from the public resident houses to a safe shelter. Therefore, there are limitations to simulate all locations in such vast exercise ranges within the virtual reality spaces. To overcome these limitations, we introduce concepts of nodes, where major exercise events such as indoor sheltering or evacuations occur, and protective actions should be undertaken by the exercise implementor. For a student case, a node can be a playground, classroom, individual home, assembly post, or safe shelter. When we simulate the nodes, we utilize the simulation of the actual adjacent areas of a nuclear power plant by 3-D physical modelling the geographical features and topography from the pictures taken by unmanned aerial vehicles such as drones for the sense of realism and sense of immersion, respectively, given to the exercise implementor. On top of this 3-D modelling, we make use of non-player characters (NPCs) to save the playing time for preventing the simulation sickness and insert various sound effects for the sense of realism. An implementor physically experiences the virtual reality with various senses during a session of practices.

At each node, an event occurs, and an implementor will take corresponding protective actions for the event occurred. For a student case, five nodes such as a playground, classroom, individual home, assembly post, and safe shelter are required for practicing an exercise. On the playground, after recognizing an emergency notified, an implementor enters a classroom to minimize the external/internal exposure from radiation as soon as possible. After entering a classroom, take protective actions necessary for minimizing the exposure to radiation indoor. Wash hands and face to remove any possible contamination and follow teachers' instructions such as closing windows, shutting off the heating, ventilation and air conditioning (HVAC) system to prevent the flowing in of outside air into the classroom. In addition, change clothes and seal up worn clothes outdoors in a waste bag. After finishing protective actions, learn the lessons on administering iodine prophylaxis (KI) by an infirmary teacher and practice the administration of KI, if necessary. Following teacher's guide, get on the buses and move to a safe shelter. After arriving at a shelter, follow the guide's instruction for personnel monitoring of accumulated exposure dose and decontamination procedure, if needed; perform registration for an evacuee; wait in the reception area; receive daily necessities; and wait for the guide's next instructions. In the meantime, after getting into a student's house instead of entering a classroom, wash hands and face to remove any possible contamination, change clothes and seal up worn clothes outdoors in a waste bag, and follow instructions such as closing windows, shutting off the HVAC system, and listening to radio or television or checking online for further instructions.

Evaluation of an exercise

When an implementor of exercises finishes a practice session, the result of his/her practice is displayed on a screen. Through this process, the implementor can supplement his/her poor management in the practice. We developed the exercise evaluation module with exercise evaluation factors by considering the most important aspects in the radiation protection area such as time, distance, and shielding. An elapsed time is determined according to the movement route selected by an implementor. When the implementor choose the next node through a movement between the two different nodes, a movement route is determined. According to movement time from a node to the next, staying time inside a node, shielding factor inside a node and ambient dose rate inside a node and in each movement route, projected exposure doses are estimated. Through the utilization of user interface (UI) in the VR space, we display accumulated doses to an implementor. In addition, a judgement on whether protective actions are taken or not is made and the result of the judgement is displayed in an exercise record.

Because the resident public is usually lack of knowledge on radiation, they do not understand what the exposure dose values mean even though the accumulated exposure dose values are provided to them. Therefore, to help them understand the meaning of the exposure dose, we compare the exposure doses to radiation in daily life with that estimated to be received during an exercise to help them have an objective understanding on exposure to radiation as shown in Figure 6. For example, annual exposure dose to natural background radiation, exposure doses from medical practices such as computer tomography (CT) and magnetic resonance image (MRI) scanning, respectively, are displayed as auxiliary indicating values, and these values are available to compare with the exposure dose values estimated to be received during an exercise practice.

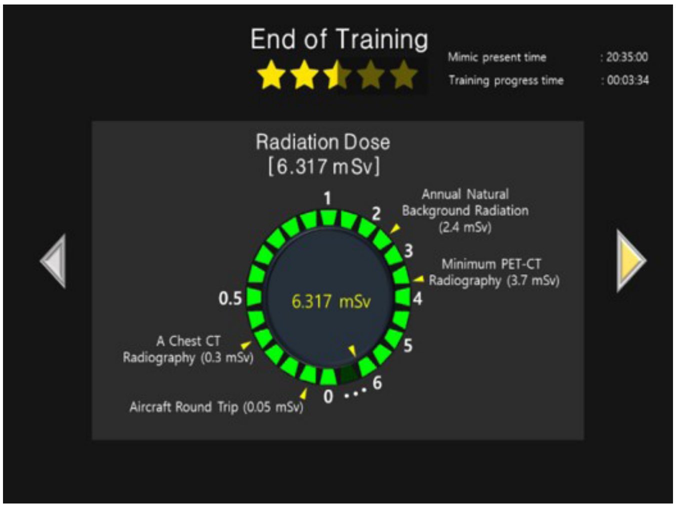

Figure 6: Captured screen of a total exposure dose estimated to be received during a practice.
(Including comparison with the exposure doses to radiation in daily life)

In addition, to identify the importance of selection in movement routes, movement routes that are selected by an implementor and those recommended by the response action guides from the local government are displayed on a screen for a comparison as shown in Figure 7.

Figure 7: Captured screen of comparison of selected with recommended evacuation route

Results & discussions

Determination of exercise method

Because, for a real accident where radiation releases occur, the public along with all emergency response associated agencies and organizations such as a central government, local governments, a licensee and expert organizations shall be participated in an accident to take the necessary emergency response actions, we might need to proceed an exercise by utilizing the VREES like when we play a "war-game" where all participating organizations are involved simultaneously in the same VR based space. In an exercise proceeding with a "war-game" type of method, participants can grasp the status of accident progresses, that of corresponding responses at a glance, and the specific duties of the individual response organizations, and they understand the cooperation system among the individual organizations. However, a major disadvantage for the public is that there is too much unnecessary information for them. Because the VREES is dedicated only to the public, the system is developed with major contents of response actions by the public during the occurrence of an accident. Thus, the system is developed as a VR-based system on the first-person view contrasting to a "war-game" method, which handles the overall status of an exercise.

Virtualization of the diffusion/dispersion of radioactivity in visual

Because the VREES handles radioactivity release accidents, we intend to increase the sense of realism by visualizing the diffusion/dispersion of the radioactivity. However, actual radiation is colorless, unscented, and tasteless as previously described and there are limitations to articulate radiation through visuals. To overcome this, we developed an UI screen for the implementor of exercises to recognize his/her practice record by indicating the values of the ambient radiation dose rates and those of accumulated exposure doses in numerical values as shown in Fig. 7.

Approximation of ambient dose rates

Using the K-REDAP program first, we calculate the effective doses in the 16 sectors within radii of 1, 2, 5, 8, 10, 20, 30, and 40 km after 2 days and 7 days of radioactive material released. After we obtain the effective doses in each sector, we divide the effective dose values either by 48 hours for indoor sheltering or by 168 hours for evacuation case, according to the Korean standards for determining urgent public protective actions [12], to obtain an effective dose rate in each individual sector. Because this program also calculates effective doses to the thyroid in the 16 individual sectors with the same radii, thyroid protection is recommended when a projected effective dose to the thyroid in a specific sector approaches the intervention level of 100 mGy. However, one should note that the method of calculating effective dose rate values for the specific locations and times used in this study essentially differs from either that of obtaining dose rate values derived from the Korean standards for determining urgent public protective actions [9] or that of using dose rate values for "monitoring and comparison with operational intervention levels or measured operational quantities in perspective," recommended by the IAEA [13]. As explained previously, the computer program doesn't provide the ambient dose rate values by a time series but contributes to estimate the averaged dose rate values after 2 days or 7 days after a radioactivity release. It also does not provide specific effective dose values at a specific location, but an averaged value with in a sector between the two radii. Therefore, during either sheltering or evacuation processes, it is not available to calculate both ambient dose rates and exposure doses to an implementor of practices. For this reason, we estimate averaged ambient dose rate values (dose per hour) from the calculated effective dose value divided either by 48 hours for indoor sheltering or 168 hours for evacuation case. Effective dose rate in each individual sector with a specific radius is not constant over the period of time, whereas we assumed it was. Because we do not have other information available on the effective dose rates in real time at specific locations and times, we assume average values of effective dose rates in the individual sectors with radius range of 1-40 km over the time period of concern. In a real situation, the effective dose gradually increases with time when a release of radioactive material starts and then slowly decreases with time when the release of radioactive material stops. However, we assume an average constant value for the effective dose during the time of concern. Therefore, this assumption might lead to overestimation of doses in the individual sectors in the long range.

Comparison with Other Similar Works

"Developing a virtual reality application for training Nuclear Power Plant operators: Setting up a database containing dose rates in the refueling plant: Operators in Nuclear Power Plants can receive high doses during refueling operations. A training program for simulating refueling operations will be useful in reducing the doses received by workers as well as minimizing operation time." A virtual reality application is developed within the framework of the CIPRES project. The application requires doses, both instantaneous and accumulated, to be displayed at all times during operator training. Therefore, it is necessary to set up a database containing dose rates at every point in the refueling plant. This database is based on radiological protection surveillance data measured in the plant during refueling operations. Some interpolation routines have been used to estimate doses through the refueling plant. Different assumptions have been adopted in order to perform the interpolation and obtain consistent data. In this paper, the procedures developed to set up the dose database for the virtual reality application are presented and analyzed [4]."

"A collaborative Virtual Reality System (VRS)-RAPID (Real-time Analysis for Particle transport and In-situ Detection) code system is a software system for an intuitive and fast input preparation; on-the-fly simulation of nuclear systems using RAPID; 3D, 2D, and tabular visualization of RAPID outputs; nuclear inspection and detection capabilities; and possibility for collaboration of users at different sites. The latter feature provides an excellent capability for training of students and professionals. Different layers of X3D models are used for the visualization of the nuclear system and to display the code output and the system environment. VRS-RAPID can be accessed via a web browser from a variety of devices, including computers, tablets, and smart-phones. [14]."

"State of Virtual Reality Based Disaster Preparedness and Response Training: The advent of technologically-based approaches to disaster response training through Virtual Reality (VR) environments appears promising in its ability to bridge the gaps of other commonly established training formats. Specifically, the immersive and participatory nature of VR training offers a unique realistic quality that is not generally present in classroom-based or web-based training, yet retains considerable cost advantages over large-scale real-life exercises and other modalities and is gaining increasing acceptance. Currently, numerous government departments and agencies including the U.S. Department of Homeland Security (DHS), the Centers for Disease Control and Prevention (CDC) as well as academic institutions are exploring the unique advantages of VR-based training for disaster preparedness and response. Growing implementation of VR-based training for disaster preparedness and response, conducted either independently or combined with other training formats, is anticipated. This paper reviews several applications of VR-based training in the United States, and reveals advantages as well as potential drawbacks and challenges associated with the implementation of such training platform [15]."

"SIGES-PERE: A Collaborative GIS for Radiological Disaster Management SIGES-PERE: A Collaborative GIS for Radiological Disaster Management: They present a collaborative-application to the National Center of Disaster Prevention in Mexico (CENAPRED), which is focused on helping in the decision making process during the radiological disasters, related to "Laguna Verde" nuclear plant. This application coordinates the activities of External Plan of Radiological Emergency (PERE) that has been generated for this purpose. In addition, the application is based on a Geographical Information System (GIS) into a collaborative architecture to support the interaction from several entities, which work with special training groups in a virtual reality environment. The architecture consists of a collaboration model and it generates a schema of components to find out the independence and standardization of the system so that it can be implemented in any GIS-platform [16]."

While the VREES is an exercise system for the public having various occupations, and an exercise covers vast spaces differing from the general exercise systems for the experts, which are restricted to specific spaces. To overcome this, we introduce concept of nodes, where exercise actions are undertaken by the implementers, and incorporate the degree of freedom for the implementer to select movement routes by his/her own will.

Conclusion

The VREES expects to overcome the various limitations of current exercises such as the low level on the participation by the current personnel mobilization, impossibility of repetitive exercises and non-existence of various scenarios. An implementor of the practices does not only simply proceed an exercise according to the scenarios being prepared but practices an exercise by actively manipulating the system by him/herself. Thus, he/she can evaluate the result of his/her own practices and improve the practices. Especially, because the VREES does not require a specific exercise location for practices, calling-on large number of the public for exercises expects to be possible.

The VREES is an exercise system for the public having various occupations, and an exercise covers vast spaces differing from the general exercise systems for the experts, which are restricted to specific spaces. To overcome this, we introduce concept of nodes, where exercise actions are undertaken by the implementors, and incorporate the degree of freedom for the implementor to select movement routes by his/her own will.

We select the three different group as a representative group in the development VR-based radiological emergency exercise scenarios, and a VR gear exercise system that targets group use for the trial basis is developed. However, for various occupational groups, we developed radiological exercise scenarios, which an implementor can experience scenarios of unexpected situations that result in the destruction of infrastructure such as roads and bridges other than normal situations of successes of events. In addition, he/she can also experience complex situations brought from a combination of an earthquake and tsunami like in Fukushima NPP accident.

Lastly, because the licensee, who is a cause provider for a radiological exercise; the local governments, who are the responsibility holder of protecting the public; and the resident public, who are the exercise practicing targets to be protected from the radiation; are under the different situations, broad collection of feedback among stakeholders, exchange of opinions between mutual parties for the improvement of the system, and close cooperative relationship through the constructive conversations and communications should be established on the aspect of VREES application.

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