INTEGRATING FOUR-DIMENSIONAL GEOGRAPHICAL INFORMATION AND MOBILE TECHNIQUES INTO RADIOLOGICAL ACCIDENT EMERGENCY RESPONSE TRAINING

by

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Technical paper
DOI: 10.2298/NTRP1201084T

When radiological accidents occur, radioactive material may spread into the atmosphere, causing large-scale and long-term contamination. To diminish the effects of such accidents, researchers from many countries have investigated training programs in emergency response to radiological accidents, especially in the wake of several serious radiological accidents. Although many training programs have been proposed, this study identifies two problems: the lack of effective data representation and the lack of complete training records. Therefore, by considering various requirements for relief and evacuation work at radiological accident sites, it integrates four-dimensional geographical information and mobile techniques to construct a training platform for radiological accident emergency response. During training, groups of participants learn to respond to simulated radiological accident scenarios. Moreover, participants can use the training platform to review and discuss training details. Judging by the results, the training platform has not only increased the effectiveness of training programs, but also complied with standard operating procedures for radiological accident emergency response in Taiwan. In conclusion, this study could serve as a useful reference for similar studies and applications.

Keywords: radiological accident, geographical information, emergency response, mobile, training

INTRODUCTION

Our study describes the research on radiological accident emergency response training. Radiological accidents can be caused by mismanagement of radioactive sources, careless use of radioactive materials, nuclear power plant accidents and radiological dispersal device (RDD) attacks. Such accidents highlight the importance of radiological accident emergency management.

On March 11, 2011, a 9.0 magnitude earthquake that caused a tsunami affected all nuclear power plants in Japan. Although the Japanese government attempted to respond to the many emergent radiological events, the environment was, nevertheless, contaminated. In the meantime, based on the levels of classification of the International Nuclear and Radiological Event Scale (INES), as announced by the International Atomic Energy Agency (IAEA) [1], the status of Fukushima Daiichi nuclear power plant in Japan was identified as a major accident. Clearly, if the Japanese government had not previously adopted response strategies, the radiological accident would have been much graver.

As for emergency management in the United States, the Federal Emergency Management Agency (FEMA) made it clear that four phases – mitigation, preparation, response, and recovery – constitute an interdependent cycle [2]. Each phase has its own purpose. To either eliminate the probability of a disaster, save lives and minimize the damage, provide emergency assistance or restore things to their original status, respectively. In order to apply this cycle to radiological accident emergency management, many countries have formulated various strategies (*e. g.*, establishing radiation policies, monitoring radiological activities, scheduling evacuation routes, organizing relief personnel and instituting emergency response centers). Given the rapid development of information technology (IT), IT-based methodologies and applica-

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tions have also been proposed. These methodologies and applications could be used for responding effectively to radiological accidents. Training programs could be an important means of promoting strategies, methodologies and applications regarding radiological accident emergency management [3].

However, during trainings in radiological accident emergency response, simulating a scenario may prove to be difficult. For example, governmental agencies may not be willing to create a radiological training site, since such a site could affect participants and the environment. This study, therefore, uses four-dimensional (4-D) geographical information and mobile techniques to construct a radiological accident emergency response training platform (RAERTP) that offers simulated radiological accident scenarios. Through RAERTP, participants are given an opportunity to practice emergency responses.

LITERATURE REVIEW

Based on experiences from several serious radiological accidents (*e. g*., the Three Mile Island accident in the United States, Chernobyl accident in Ukraine, and the Tokaimura accident in Japan), IAEA offers several training programs, including those for nuclear safety, radiation, transport and waste safety, and radiation protection. Many countries have also spent their own resources on improving radiological accident emergency response training. The training consists of following major steps [4-8].

Training of personnel and organizations. In order to avoid radiological accidents due to human error, personnel and organizations should undergo periodic trainings, so as to acquaint them with the management of radiological facilities, equipment monitoring and possible risks. For example, in the United States, the Department of Energy offers a variety of radiological training programs, including the tracking and dispersion of radioactive materials and mapping of ground contamination through aerial monitoring; expanding emergency preparedness and response capabilities that provide rapid predictions for transporting, diffusion and depositing of radionuclides; locating radioactive materials and handling of damaged nuclear weapons and medical assistance and treatment of exposed or contaminated patients upon radiation [9]. Moreover, many medical organizations and schools also offer training courses in radiological accident emergency rescue. For example, Collander *et al*., [10] have designed an "all-hazards" hospital disaster preparedness training course that combines classroom lectures, skills sessions, tabletop sessions and disaster simulations for teaching the principles of hospital disaster preparedness to hospital-based employees.

Training in information collection and communication. To protect the safety of a nation and its people, establishing radiological monitoring and altering its networks is necessary. National networks could be of use in monitoring the normal radiological situation, providing for early warnings when abnormal radiological events occur, assessing the dose and risk to the public when a radioactive contamination is detected, assuring co-ordinated action across national boundaries, informing national and international parliaments in real-time, alerting the public immediately and improving the reliability of existing diagnostic and prognostic transport models [4]. Therefore, during training, participants have to practice information collection and communication via these networks.

Some correlated studies are listed here. Huang [11] developed a Web-based nuclear accident emergency response information system for retrieving nuclear accident information. Mabit and Bernard [12] integrated geostatistics and variography to establish and map the pattern of ^{137}Cs redistribution. Drndarević *et al.*, [13] designed and proposed Universal serial bus-based applications to perform environmental monitoring and measurement. Lesjak [14] developed an automatic early warning system for monitoring environmental changes. Syrakov [15] *et al*. detected the transport, dispersion, chemical, and radioactive transformations of pollutants through BERS, and Zeb *et al*., [16] applied a radiation protection robotic assistant to perform wipe testing of sealed radiation sources.

Training of decision makers. During radiological accidents, governmental agencies and personnel have to deal with these accidents based on available information and experience. To prompt decision making, Decision supporting systems (DSS) have become popular. These systems analyze accidents and evaluate their impacts. While in training, participants are expected to practice prescribed DSS procedures. For example, Nukatsuka *et al*., [17] proposed MEASURES to improve the nuclear preparedness technology with an application to urban safety, and Rafferty [18], applied FORIA to synthesize published information based on the application of radiological countermeasures in forests and the secondary impact. Mamikhin [19] used ECORAD to predict the radionuclide dynamics of ^{90}Sr and ^{137}Cs in contaminated forest ecosystems. For the purpose of radiological accident emergency management, RODOS [20] has been established in many European countries. In addition, Monte [21] developed MOIRA-PLUS to identify optimal remedial strategies for restoring radionuclide contaminated aquatic ecosystems and drainage areas. Velasco [22] *et al*., constructed the RSP to simulate the behavior of radionuclides in semi-natural environments and the consequences of exposure on the population.

PROBLEMS

After reviewing correlated studies, this study recognized two problems in radiological accident emergency response training.

Lack of effective data representation. Many training programs are based on event sheets. Event sheets depict essential information and parameters of the pre-planned event sequence that refer to former accident analyses or simulated accident results [3]. The public – medical professionals, members of the military and law enforcement – are participants in the training. However, they might fail to comprehend geographical relationships regarding the training sites, despite the use of maps and other assistance tools. For example, the Taiwanese government holds at least two large-scale radiological accident emergency response training sessions at its nuclear power plants, airports and harbors every year, since Taiwan is located in the earthquake belt and there are four nuclear power plants on the island. The participants, training scenarios and sites differ. During training, participants cannot always reach their assigned locations from the training sites. Training managers then have to describe the geographical relationships between the training sites. Unfortunately, the effectiveness of this training seems to be poor.

Lack of complete training records. After radiological accident emergency response training, participants must review the training details. Based on the comparison of results before and after the training, training managers are expected to understand the effectiveness of the program. In the meantime, training managers can reflect on and discuss the training. However, few of the training programs automatically recorded the details and several offered merely partial records. Moreover, many training programs are independent applications, inconvenient when used on training sites, since the participants frequently do not stay long at fixed locations. Therefore, training managers and participants need an assistance system for recording the training details, particularly when they have difficulties in carrying out their training missions and synchronizing the reports of the results. For example, based on event sheets used for training programs, training managers would propose response strategies for simulated radiological accidents. According to these strategies, if the participants performed in an incorrect manner, training managers were obliged to refer to the records in order to find an understanding of the underlying causes.

APPROACH

When radiological accidents occur, the affected areas can stretch over several square meters to several square kilometers. Identifying the accident sites is the first step in emergency response. Using paper-based maps to indicate the sites is a common method with several advantages: it enhances the comprehension of real world conditions, co-ordinates the efforts of relief personnel and emergency services, offers a generally accepted model, provides a direct guide; serves as the quickest method for confirming the locations, and offers large volumes of information [23]. Inaccurate geographical information will delay the relief work. Similarly, the advantage of training programs is that the participants can rapidly determine their standing positions and moving rientations when they embark on various missions at the training sites. For example, when the participants take the wrong route to the simulated radiological accident sites, they waste time.

The Geographical information system (GIS) is more powerful than paper-based maps, since GIS pinpoints and geocodes longitude, latitude, and other geographic co-ordinates of the routes. Moreover, GIS-based spatial data can be edited, revised and transferred for emergency response purposes [24]. Since the changes caused by radiological accidents may be continuous, they have to be represented in training programs. Based on these changes, the strategies for emergency response can vary. After the training, participants should be able to understand the designed relief processes and its possible flows. They should be able to handle contingent conditions while the radiological accidents enfold. Therefore, this study integrates time-dependent accident changes and GIS to form a 4-D training platform. When accessing information, the participants find it easy to operate mobile devices (*e. g*., cell phones) instead of heavy devices (*e. g*., desktop computers) on both radiological accident sites and the training ones, since mobile devices do not require a powerful supply. Adding 4-D GIS to mobile devices could be useful for radiological accident emergency response training.

For successful information exchange between the devices, the Web has many advantages, such as reliability, low-cost, convenience, and speed. Therefore, during training, training managers and participants would be able to immediately perform several information exchanges. When information is communicated, our training platform saves time for both those who send and those who receive commands. For example, when training managers ask the participants to go to their assigned shelters, the communication and the real moving routes are recorded. The training platform then transfers these details into video-format records. Training managers and participants can review the contents of the training process by browsing and inquiring. In sum, the proposed approach provides both clear data representation and prospective training details.

IMPLEMENTATION

Simulator-assisted scenarios extend the spectrum of training programs [3]. To simulate radiological scenarios, this study adopts a Gaussian plume model that was embedded in HotSpot methods [25]

$$C(x, y, z, H) \quad \frac{Q}{2\pi u_{\mathrm{y}} \sigma_{\mathrm{z}}} \exp \quad \frac{y^2}{2\sigma_y^2}$$
$$\exp \quad \frac{(z \quad H)^2}{2\sigma_z^2} \quad \exp \quad \frac{(z \quad H)^2}{2\sigma_z^2} \qquad (1)$$

where C is the pollutant concentration, Q – the emission rate, H – the effective chimney height, and σ_{y} and σ_{z} are the horizontal and vertical diffusion coefficients, respectively. X is the down-wind distance, y – the side-wind distance for assessing point-to-the center line of plume, z – the height of the assessing point, and u – the average wind speed. When the predicted radiation dispersion and radiological impact are identified, the impact is represented through RAERTP.

RAERTP is a web-based, three-tier framework (fig. 1). Training managers could operate our platform in training centers via computers for the client tier. In the meantime, participants could connect to the RAERTP via their mobile devices at the training sites. This platform is designed to support mobile phones. However, the main operating systems of mobile phones can be divided into three categories: Apple iOS, Google Android, and Microsoft Windows Mobile. The mobile interfaces of our training platform are based on Google Android, since this operating system is an open platform that enables programmers to construct system components for free. The middle tier is for data operation. During training, the Web server could execute data analyses based on the commands received from training managers and participants. For example, RAERTP enables training managers to organize participants through e-mails and short message service (SMS). Finally, a data transmission between the Web and database servers exists in the data tier.

This study applies several information techniques, including Microsoft ASP.Net toolkits and the AJAX programming language, in order to develop needed platform components. The Web server is the Microsoft IIS Version 7, the database server, Microsoft SQL Server Version 2008. Moreover, since the characteristics of radiological accidents (*e. g.*, location, weather, affected areas, relief paths and modeling buildings) would be displayed through a map platform, this study uses the Google Map [26] for providing geographical information. In other words, when the participants find themselves at the training sites, they can swiftly obtain crucial geographic information. So as to represent similar information through operation devices, the RAERTP also complies with several standards that have been set by the Open Geospatial Consortium, Inc. [27]. These standards include the Web map service for exchanging map images between geospatial databases, the Web feature service offering geographical features through HTTP protocols, the Web processing service for standardizing geospatial processing services and, finally, the keyhole markup language for distinguishing geographical annotations and their visualization.

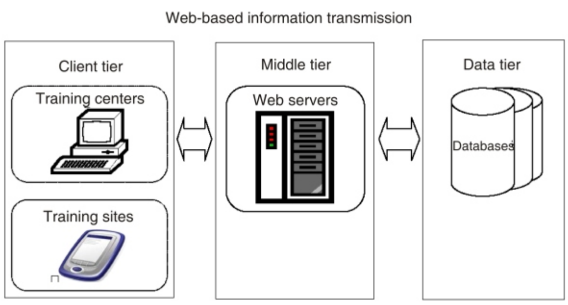

Figure 1. The framework of the RAERTP

TESTING

In this study, RAERTP was tested at the second nuclear power plant in northern Taiwan. The testing scenario was that of a heavy earthquake causing a tsunami affecting the nuclear plant. According to INES, the nuclear accident was identified as being of Level 6. A significant release of radioactive material was detected. Based on the standard operating procedure for radiological accident emergency response, as prescribed by the Atomic Energy Council in Taiwan [28, 29], an emergency response center was established and relief personnel organized. In compliance with the training platform, the participants were to carry out eight tasks.

– *Identify the accident sites*. After the alerts regarding radiological accidents were given out, training managers had to mark the accident sites and confirm the affected areas in the GIS (fig. 2).
– *Broadcast accident details*. To inform the participants of a radiological accident, training managers publicized details of the accident through e-mails and SMS in the RAERTP. They could either key in the accident details manually or import the pre-designed templates.
– *Record site results*. To simplify the documentation of site results during relief work, participants could directly fill in the templates that are embedded in the RAERTP.
– *Report site conditions*. The embedded e-mails and SMS enabled participants to report site conditions immediately. For example, fig. 3 shows that the participants used mobile phones to report the conditions at a site associated with specific geospatial data.
– *Detect the radiation dose*. At simulated radiological accident sites, participants used monitoring devices to detect the radiation dose. Moreover, radiological changes at the sites were represented through RAERTP (fig. 4).
– *Offer instructions regarding relief work*. Based on the information received, training managers rec-

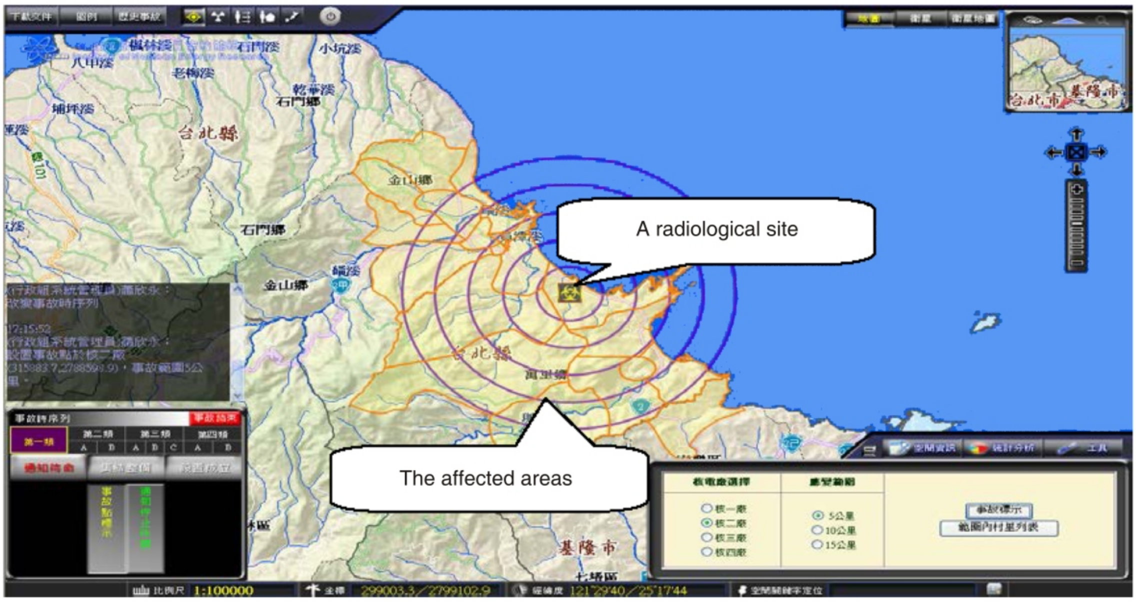

Figure 2. Identifying the accident sites in the GIS

Figure 3. Reporting the site conditions via mobile phones

ommend relief strategies, confirming the controlled areas and announcing evacuation routes. For example, fig. 5 shows that the participants should evacuate to temporary shelters and follow evacuation routes upon the training managers' confirmation of the status of the site in question. RAERTP calculates the time for evacuation based on several variables, such as the distance from and the length of the evacuation route and walking speed.

– *Complete the relief work*. When the simulated radiological accidents are under control, training managers can observe the results through the 4-D GIS in the platform.

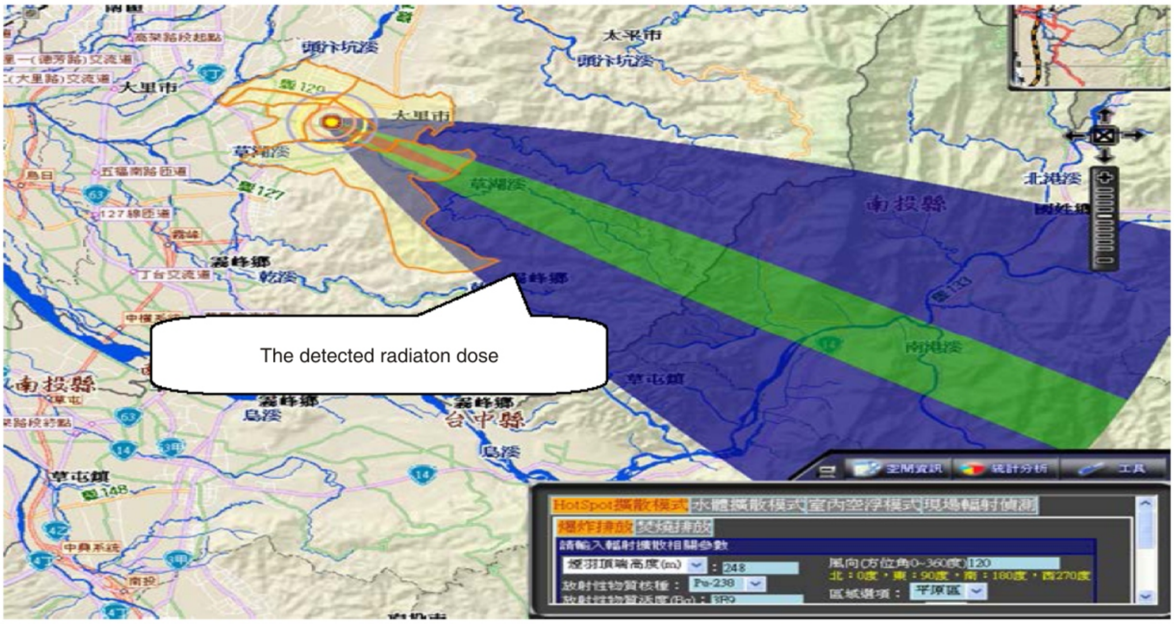

Figure 4. The changes of radiation dose

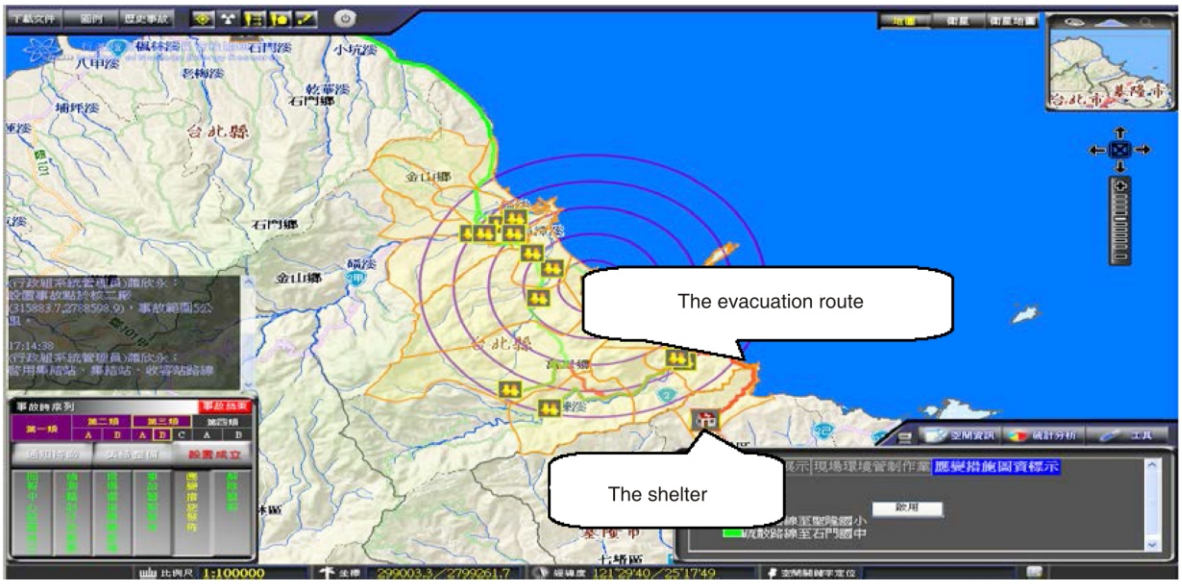

Figure 5. The evacuation routes

– *Represent training details*. Upon the conclusion of the training, the RAERTP automatically represents the training details. Training managers and participants can then discuss gained experiences. For example, fig. 6 shows that the RAERTP transferred the moving route into a video-format record.

DISCUSSION

Based on the results of the testing, although RAERTP achieved anticipated objectives, two ways of improving the system need to be discussed.

– *Integrating with other emergency response systems*. Radiological accidents may accompany accidents to create complex disasters. Therefore, integrating other emergency response systems with RAERTP is essential. For example, following a radiological accident, a fire may break out in the reactor core. In such a situation, training managers and participants need to consider several relief strategies.
– *Evacuation training of the public*. Assisting the public to escape from accident sites to temporary evacuation shelters is a priority in radiological accidents. However, relief personnel may be limited

Figure 6. The recorded training details

and the affected areas may be large. If the public could contribute to its own evacuation, the burden of relief work would decrease significantly. Therefore, offering evacuation training to the public is of utmost importance.

CONCLUSIONS

The experience from previous radiological accidents has shown that training programs are important. If governmental agencies and personnel lack experience in radiological accident emergency response, the damage increases. To enhance the effectiveness of radiological accident emergency response, this study has devised a 4-D GIS training platform that could operate within the existing mobile devices operating system. RAERTP offers several key advantages.

– *It provides an alternative to conventional decision making*. To engage participants in the training programs, the training platform provides data representation through 4-D GIS. Compared to textual descriptions or paper-based maps, participants would be able to promptly obtain the characteristics of radiological accidents from our training platform. In other words, training managers and participants would be able to make an informed decision more easily, given enough information. For example, in assisting the public to evacuate accident sites, training managers and participants need to know the size of the population and the locations of the shelters.
– *It increases cooperation among the participants of the training*. During training, training platforms enabled not only the transfer of information among many operational devices, but also recorded training details. Participants were given an insight into standard relief operating procedures and a number of possible radiological accident response scenarios. Moreover, our training platform is Web-based. Governmental agencies and personnel could undergo online training without the limitations of time and space. After the training, participants are given the possibility to refer to the records in order to discuss the details of the training and exchange ideas. In cases of real life radiological accidents, these possibilities of cooperation among personnel seem to offer endless possibilities.

ACKNOWLEDGEMENTS

The authors would like to thank all members at the Research Center for Hazard Mitigation and Prevention, National Central University; the GIS Research Center, Feng-Chia University, as well as the Institute of Nuclear Energy Research, Atomic Energy Council, Executive Yuan. This study was financially supported under contracts NL1000375 and NCU100G901-11.

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Received on September 8, 2011
Accepted on February 18, 2012

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ИНТЕГРИСАЊЕ ЧЕТВОРОДИМЕНЗИОНИХ ГЕОГРАФСКИХ ИНФОРМАЦИЈА И МОБИЛНИХ ТЕХНИКА РАДИ УВЕЖБАВАЊА РЕАГОВАЊА У РАДИОЛОШКИМ АКЦИДЕНТИМА

У случају радиолошког акцидента може се догодити да се радиоактивни материјал ослободи у атмосферу и изазове дуготрајну контаминацију широких размера. Суочивши се у последње време са неколико тежих радиолошких акцидената, истраживачи у бројним земаља развили су програме обуке за деловање током оваквих догађаја. Мада су предложени многи тренинг програми, уочавају се два проблема који су нотирани у овом раду: недостатак ефективног представљања података и недостатак планова обуке. Стога, разматрајући различите захтеве за процес евакуације на локацији акцидента, тренинг програм интегрише четвородимензионе географске информације и мобилне технике како би се направила тренинг платформа за реаговање у ванредним ситуацијама у случају радиолошког акцидента. Затим, учесници могу користити тренинг платформу ради поновног прегледа и расправе о детаљима вежбе. Судећи по резултатима платформа за вежбе не само да је повећала ефикасност тренинг програма, већ се уклопила у предвиђене стандардне процедуре за случај акцидента у Тајвану. Може се закључити да овај рад може послужити као корисна референца за сличне студије и примене.

Кључне речи: радиолошки акциденӣ, ī еоī рафска информација, реаī овање у ванредним околносӣима, мобилне везе, ӣренинī