HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2020 Vol.9, No.2 47–55

REM
Radiat Environ Med

Review

Radiation Emergency Medicine Strategies Based on the Classification and Analysis of Nuclear and Radiological Emergencies

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Received 24 December 2019; revised 6 May 2020; accepted 8 June 2020

Due to the unique nature of nuclear energy and radiation, nuclear disasters have radiation-based biological and psychological effects on both the immediate and over time effects. The radiation effects on human beings can be deterministic, stochastic, and psychological. It is necessary to establish a strategy that can reasonably reduce these effects in nuclear and radiological emergencies. For effective response, it is important to establish a phased resource utilization plans for radiation emergency medicine at national level. In this study, the definition of emergency preparedness categories according to the international atomic energy agency publication was used to classify and analyze past nuclear and radiological emergencies. So we assumed scenarios using our classification and analysis results. And also radiation emergency medicine strategies should be arranged based on the roles of medical response institute during nuclear and radiological emergencies occured.

Key words: emergency preparedness category, nuclear emergencies, radiation emergency medicine

1. Introduction

With the diversification and growth in the fields of nuclear energy and radiation use, information regarding the occurrence of historically relevant nuclear and radiological emergencies are increasing. There has also been an increase in the number of countries using nuclear and radiation technologies. Therefore, we can estimate that the likelihood of nuclear and radiological emergencies are increasing as well. Therefore, international atomic energy agency (IAEA) provides international standards for categorization and analysis of nuclear emergency.

Large-scale nuclear and radiological emergencies have the potential to cause extensive and long-term damage to a wide area. Radiation, in particular, has deterministic, stochastic, and psychological effects on the human body. In order to minimize these effects, strategies on radiation emergency medicine for persons accidentally exposed to radiation need to be arranged previously. And also strategies must be part of a nationally arranged in order

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Table 1. Accident Cases

Case of Accident	Cause of Accident
1 Fukushima Daiichi Japan, 2011 [2, 3]	Reactor
2 Chernobyl USSR, 1986 [4, 5]	
3 Three Mile USA, 1979 [6]	
4 Idaho Falls USA, 1961 [7]	Research Reactor
5 Monju Japan, 1995 [8]	
6 Lagoona Beach Detroit USA, 1996 [8]	
7 Chalk River Canada, 1958 [8]	
8 Boris Kidrich Institute Yugoslavia, 1958 [9]	
9 Venus Belgium, 1965 [9]	
10 Constituyentes RA-2 Facility Argentina, 1983 [9]	
11 Chelyabinsk USSR, 1968 [9]	Nuclear Fuel Fabrication Facility
12 Tokaimura Japan, 1999 [10]	
13 Mayak Scientific Production USSR, 1957 [11]	Radioactive Storage Facility
14 Harmarville Pennsylvania USA, 1967 [12]	Large-scale Radiation Irradiation Facility
15 Brescia Lombardia Italy, 1975 [13]	
16 Chicago Illinois USA, 1896 [14]	Medical Radiation Facility
17 Washington Columbia USA, 1905 [14]	
18 Australia, 1970 [15]	
19 Riverside Methodist Hospital Ohio USA 1974 [16]	
20 Los Alamos New Mexico USA 1, 1945 [9]	Experimental Facility
21 Los Alamos New Mexico USA 2, 1946 [9]	
22 Los Alamos New Mexico USA 3, 1958 [9]	
23 Radium dial USA and Other, 1920 [17]	Malicious Use of Source
24 Cesium Suicide USSR, 1960 [18]	
25 Radium Suicide USSR 1960 [19, 20]	
26 Mexico City Mexico, 1962 [21]	Orphaned Source
27 Sanlian China, 1963 [22]	
28 California USA, 1979 [23]	Portable Source
29 North Atlantic Ocean USSR, 1961 [24]	Nuclear Powered Material
30 Chazhma Bay Vladivostok USSR, 1985 [25]	

for nuclear emergency preparedness response system. In this study, we intend to arrange radiation emergency medicine (REM) strategies that can be usuful during nuclear and radiological emergencies occurred.

For this purpose, we investigated previous cases of nuclear and radiological emergencies and classified them into possible disaster scenarios by emergency preparedness category, as defined in the IAEA publication[1]. The ultimate goal of this study is to arrange REM strategies for nuclear emergency preparedness.

It was hard to find the study that established a response strategy based on various nuclear and radiological scenarios. Therefore, the classification and analysis of nuclear and radiological emergencies in the past could be very necessary.

2. Accident Cases and Standards for Classification

30 accident cases (Table 1) were collected. They were analyzed and used to make scenarios needed to establish strategies.

Nuclear and radiological emergency cases investigated in this study are diverse. They include accidents in nuclear power plants, research reactors, a nuclear fuel fabrication facility, a medical radiation facility, the malicious use of a radiation source, and also orphaned source as well. These nuclear and radiological emergency cases were classified using the emergency preparedness category concept introduced in the IAEA's GSR (General Safety Requirements) part 7 publication. The IAEA publication describes five accident categories with specific definitions, as shown in Table 2.

2.1 Emergency Preparedness Category 1

Category 1 defines an accident that can occur at a facility, such as a nuclear power plant, where the accident has a significant and critical impact on people at off-site facilities. The Fukushima nuclear plant disaster is representative of cases in this category. In this study, this category is characterized by highly concentrated radioactive materials being diffused widely. Therefore, all available response options should be arranged that can respond to this type of accident.

Table 2. Definition of the Emergency Preparedness Categories[1)]

No.	Definition
Category 1	Facilities, such as nuclear power plants, for which on-site events (including very low probability events) are postulated to be capable of causing severe deterministic health effects off the site.
Category 2	Facilities, such as research reactors and nuclear reactors, used to provide power for the propulsion of vessels (e.g., ships and submarines).
Category 3	Facilities, such as industrial irradiation facilities, for which on-site events are postulated can give rise to doses that warrant urgent protective action on the site, or for which such events have occurred in similar facilities.
Category 4	Activities and acts that can give rise to a nuclear or radiological emergency that might warrant protective action and other emergency response actions in accordance with international standards in an unforeseen location.
Category 5	Areas within emergency planning zones and emergency planning distances in a State for a facility in category I or II located in another State.

2.2 Emergency Preparedness Category 2

Category 2 includes accidents that occur at facilities, such as research reactors, which require emergency action to protect persons who stay outside of nuclear facilities. As defined in category 1, this category includes cases where a radiological effect can be observed. And it will have a significant deterministic radiation effect on the persons who stay off-site. The category also includes nuclear submarines. In this study, representative cases of category 2 include the accidents at the sodium reactor in Japan and on the nuclear submarine in the north atlantic ocean and so on.

2.3 Emergency Preparedness Category 3

Category 3 includes accidents that occur at industrial facilities related to radiation. In this study, the JCO critical accident in Japan is included in category 3 representatively.

2.4 Emergency Preparedness Category 4

Category 4 includes cases where an accident occurs at an unpredictable places requiring urgent protective action, especially during transportation of this source and orphaned radiation sources. The Goiania accident could be representative case of category 4.

2.5 Emergency Preparedness Category 5

Category 5 includes events or accidents that occur in neighboring countries with emergency preparedness categories 1 and 2. In this study, it is defined if the emergency planning zone, designated by the facilities in categories 1 and 2 in the neighboring country, is within its territory. Europe, where small areas are packed into many countries, is at risk of category 5 accidents.

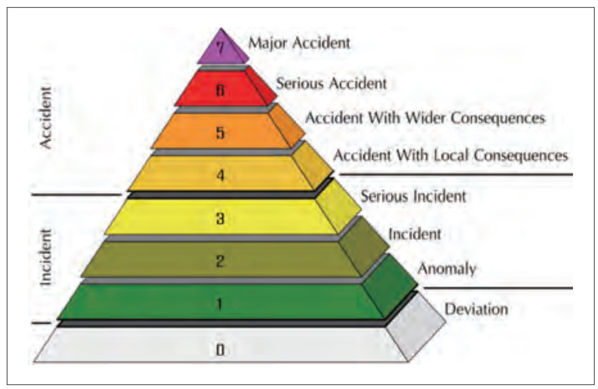

Fig. 1. International Nuclear Event Scale [7)]

3. Methods of Estimating the International Nuclear Event Scale (INES)

3.1 Definition of the INES Scale

The INES is a concept by the IAEA that was inspired by the richter scale, which compares the magnitude of an earthquake with the level of an international nuclear accident. INES covers events and activities at facilities involving radiation sources. It is used to evaluate the nuclear and radiological emergencies in which radioactive materials are released into the environment and the public is exposed to radiation. The events are classified as 0 to 7, with 0 indicating "deviation," 1 to 3 indicating "incidents," and 4 to 7 indicating "accidents." "Incident" describes an event where the hazard is confined within a facility. "Accident" describes an event whose risks extend beyond the facility. The INES hierarchy scale is shown in Figure 1.

3.2 Methodology and criteria for estimating the INES scale

The IAEA suggested various methodologies for

Table 3. Summary of Rating Based on Individual Doses [26)]

Level of Exposure	Minimum rating	Number of Individuals	Actual Rating
The occurrence of a lethal deterministic effect or the likely occurrence of a lethal deterministic effect as a result of a full body exposure to a few Gy	4	Few tens or more	6
		Between several and a few tens	5
		Less than several	4
The occurrence or likely occurrence of a non-lethal deterministic effect	3	Few tens or more	5
		Between several and a few tens	4
		Less than several	3
Exposure leading to an effective dose greater than ten times the statutory annual whole body dose limit for workers	3	100 or more	5
		10 or more	4
		Less than ten	3
Exposure of a member of the public leading to an effective dose in excess of 10 mSv or the exposure of a worker in excess of the statutory annual dose limits	2	100 or more	4
		10 or more	3
		Less than ten	2
Exposure of a member of the public in excess of the statutory annual dose limits or the exposure of a worker in excess of dose constraints	1	100 or more	3
		10 or more	2
		Less than ten	1
Cumulative exposure of workers or members of the public in excess of statutory annual dose limits	1	1 or more	1

Table 4. Classification of Accident Cases [27)]

*EPC	Cause of Accident	INES Scale	*NSRS
1	Electricity generation reactor	*1~7	*NBO
2	Research reactor	1~7	
	Nuclear Powered Material	1~6	
3	Nuclear Fuel Fabrication Facility	1~5	
	Radioactive Waste Storage Facility	1~5	
	Large-scale Radiation Irradiation Facility	1~4	
	Medical Radiation Facility	1~4	*NERBO
	Experimental Facility	1~5	
4	Portable Source	1~5	
	Malicious Use of Source	1~6	Illegal
	Orphaned Source	1~6	
5	Neighboring Countries	1~7	Other Countries

* EPC: Emergency Preparedness Category
* NSRS: Nuclear and radiation Safety Regulation Standard
* NBO: Nuclear Business Operator
* NERBO: Nuclear Energy Related Business Operator
* '1~7' means that it is possible to estimate from 1 to 7 of the INES Scale

estimating the INES scale. However, since the INES scale is preliminary to arranging radiation emergency medicine, this study used the number of people exposed to radiation and the levels of radiation exposure to estimate the INES scale. The criteria are set out in Table 3.

4. Classification of Accidents

The nuclear emergency cases investigated were classified, as shown in Table 3, based on the emergency preparedness category introduced in IAEA GSR part 7.

The definitions of the nuclear and radiation safety regulation standard were applied. The nuclear business operator (NBO) and nuclear energy-related business operator (NERBO) are distinguished by the type of facility and the type of radiation source and so on. By comparing the five categories, it is clear that categories 1 and 2 were included in NBO. Category 3 also belongs to NBO and NERBO. Category 4 was partly included in NERBO and partly classified as cases of illicit use outside the boundaries of the law.

The detailed content of an accident from a classified category was analyzed. The INES Scale was scored according to the accident type shown in Table 4.

Table 5. Workforce Composition of REMAT

Occupational Classification	Number of People Required (Basic)	Number of People Required (Expansion)
Medical Doctor	1	2
Radiation expert	1	2
Registered Nurse	2	3
Emergency Medical Technician	2	2
Administrator	0	1
Total	**6**	**10**

5. The Available Options in Radiation Emergency Medicine

5.1 Operation of the Radiation Emergency Medical Assistant Team (REMAT)

The REMAT (Radiation Emergency Medical Assistant Team) is equipped with specialized personnel and organized training on how to treat persons with radiation injuries, including radiation contamination and radiation exposure, in the aftermath of a nuclear and radiological emergencies. As a first step, a REMAT composed of basic workforce is dispatched to the on-site and off-site where a nuclear emergency occurred.

5.2 Assessment of internal exposure at off-Site

Evaluating internal exposure is important for the implementation of radiation emergency medicine for radiation injuries. In addition, internal contamination is not as easily observed as external contamination. Thus, a strategy is needed to enable rapid internal contamination assessment at off-site where near by nuclear and radiological emergencies occurred.

5.3 Operation of radiation emergency clinics at off-site

A preparedness and response strategy is needed to install and operate a patient-receptive radiation clinic at off-site, considering the uniqueness of radiation casualties caused by nuclear and radiological emergencies.

First, after the actions in chapter 5.1 have been taken, action 5.3 is followed for more precise and rapid radiation emergency medicine.

5.4 Operation of radiation effect counseling team at off-site

A review of past accident cases reveals that, apart from biological effects, psychological turbulence also occur due to the uniqueness of the effects of radiation on health. Reviewing past cases of accidents, it has been found that psychological turbulence occurs due to the specificity of the effects of radiation on health in addition to biological effects. Due to this specificity, it is necessary to operate a counseling team for those with mental and psychological anxiety at the nuclear emergency off site.

5.5 Operation of designated hospitals for medical response

Medical institution located near an area where nuclear facilities are installed and operated should be designated previously in order to provide assistance of radiation emergency medicine in the event of a nuclear and radiological emergencies.

5.6 National Radiation Emergency Medical Center (NREMC) extended operation

When nuclear and radiological emergencies occur in a wide area that probably cannot be covered by the NREMC, so extended operation is required to respond appropriately in the event of mass casualties. For the NREMC extended operation, all previously designated personnel belongs to the NREMC temporarily. Both NREMC regular personnel and reserve personnel will perform radiation emergency medicine action. The reserve personnel are expected to increase and maintain their proficiency through training programs before nuclear and radiological emergencies occurred.

5.7 Operation of telephone counseling service

nuclear and radiological emergencies engender confusion and amplify insecurity not just for residents but also for those who general public. Such specificity may requires the declaration of a state of emergency at the national level. When disasters are declared at the national level, organizations with nuclear and radiation experts should provide telephone counseling services in order to release public anxiety.

5.8 Operation of biological dosimetry team

Biodosimetry technology estimates an individual's dose based on the level of biomarkers induced by ionizing radiation. It is an alternative in cases of suspected radiation exposure when physical dosimeters are not available. It also offers an additional advantage in reflecting the biological damage, considering variations in susceptibility across individuals.

Table 6. Possible Effect by each Accident [26]

EPC	Cause of Accident	DE	SE	PE	Diff
1	Electricity generation reactor	+	+	+	+
2	Research reactor	+	+	+	+
	Nuclear Powered Device	+	+	+	+
3	Nuclear Fuel Fabrication Facility	+	−	+	+
	Radioactive Waste Storage Facility	+	+	+	+
	Large-scale Radiation Irradiation Facility	+	−	+	+
	Medical Radiation Facility	+	−	−	−
	Experimental Facility	−	−	−	−
4	Portable Source	+	−	−	+
	Malicious Use of Source	+	−	+	+
	Orphaned Source	+	−	+	+
5	Neighboring Countries	+	+	+	+

* EPC: Emergency Preparedness Category / * DE: Deterministic Effect / * SE: Stochastic Effect
* PE: Psychological Effect
* Diff: Diffusive (This category is characterized by the high radioactivity being diffused widely to different areas.)
* +: "occurred"
* −: "did not occur"

Table 7. Response Strategies Available for Accidents Occurring Off-Site

EPC \ Option	5.1	5.2	5.3	5.4
1	A 6-members team	1 team with NaI Portable Gamma Spectroscopy	Operating 1 clinic with 1–2 designated medical institutes	Operating 1 Counseling Center
2	A 10-members team	2 teams with NaI Portable Gamma Spectroscopy	Operating 1 clinic with 3 designated medical institutes	Operating 2 Counseling Centers
3	Two 6-members teams	1 team with Mobile Whole Body Counter	Operating 2 clinics	Operating 3 Counseling Centers
4	Three shifts	2 teams with Mobile Whole Body Counter	Operating 3 clinics	Operating 4 Counseling Centers

5.9 Internal exposure assessment in specialized institute
This is required when precise assessments of the internal radiation exposure dose are required in specialized institute. Analysis of radioactivity concentration and assessment of the radiation dose shall be conducted based on in vitro biological samples derived from persons exposed to radiation.

6. Arrangement of the Strategy Phases

6.1 An evaluation of the probable effects by category
In Table 6, the possibility of occurrence is noted.

6.2 Four phase response strategies by response options
Based on the severity of nuclear and radiological emergencies, it is important to check which of the nine options is available and which phase of a response strategy have to take. The nine options described in Chapter 5 are divided into four phases for each category as response strategy. Table 7 shows strategies to deal with on-site and off-site when nuclear and radiological emergencies occur. The options are 5.1 to 5.4, based on the descriptions in Chapter 5.

Table 8 shows strategies to be handled by the inside of specialized institution facilities in the event of a nuclear emergency. Options are marked 5.5 to 5.9 based on what is described in Chapter 5.

7. Arrangement of Response Strategies

The 30 accident cases were classified using the emergency preparedness category, and standard scenarios were prepared to estimate the potential radiation injury cases of each classified category. Based on the standard scenarios, we estimated the INES scale ratings. As a result, the response strategies were arranged, comprising nine options and four phases, as shown in Table 9.

Table 9 also shows the maximum level applied in each category for response strategy.

In category 1, all available options should be used to

Table 8. Response Strategies at the Radiation Emergency Medical Institute

Phase \ Option	5.5	5.6	5.7	5.8	5.9
1	Cooperating with 1 designated institute	Operating 1 clinic	Work from 9 AM to 6 PM	Work from 9 AM to 6 PM	Work from 9 AM to 6 PM
2	Cooperating with 2 designated institutes	Operating more than 2 clinics	Work 24 h	Work 24 h	Work 24 h
3	Cooperating with 3 designated institutes	Extend to the isolation ward	Operating ARS (Automatic Response Service) System	Monday to Sunday	Monday to Sunday
4	Cooperating with 4 designated institutes	Securing an additional hospital ward	Operating ARS (Automatic Response Service) System for 24 h	Operating an International Cooperation System	Operating an International Cooperation System

Table 9. Maximum Level Applied Response Strategies

EPC \ Option	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9
Category 1	Phase 4	Phase 4	Phase 4	Phase 4	Phase 4	Phase 4	Phase 4	Phase 4	Phase 4
Category 2	Phase 4	Phase 3	Phase 2	Phase 2	Phase 2	Phase 3	Phase 3	Phase 3	Phase 3
Category 3	Phase 2	Phase 3	Phase 2	Phase 1	Phase 2	Phase 2	Phase 3	Phase 2	Phase 1
Category 4	Phase 4	Phase 4	Phase 3	Phase 2	Phase 2	Phase 2	Phase 3	Phase 2	Phase 2
Category 5	-	-	-	-	Phase 4	Phase 1	Phase 4	Phase 4	Phase 4

the maximum. Various radionuclides may be dispersed when nuclear and radiological emergencies of category 1 occur. Category 2 has a smaller extent of diffusion and amount of dispersion of hazardous material (radionuclide) when compared with category 1. The number of casualties from radiation injuries that can occur is relatively small compared with category 1. Therefore, a lower level response strategy is required. Category 3 is a facility without a nuclear reactor, and the quantity of radionuclide to be dispersed in the event of an accident is lower than category 2. In addition, the analysis shows that the number of radiation casualties is limited. Therefore, a level of response strategy phase below category 2 is required. Category 4 describes accidents that occur in unpredictable places. Therefore, as many resources as possible should be placed at the site of the accidents. Category 5 does not utilize “Option at an Accident Off-Site” because it is a diffusion accident emanating from other countries. The role of a designated hospital and specialized NREMC institute is particularly crucial in strategies that address the events in category 5.

8. Conclusion

When nuclear and radiological emergencies occur, effects of accident are likely to spread beyond on-site and off-site. While radiation has an immediate deterministic effect, a stochastic effect takes place later in the process. For this reason, appropriate response measures should be taken early in the accident. This study aims to arrange response strategy of radiation emergency medicine in the event of nuclear and radiological emergencies occurred. Accident cases were classified and analyzed using by emergency preparedness category definition based on criteria recommended by the IAEA. We also estimated which of the classified categories are included in the INES. In addition, publications of IAEA was quoted in order to estimate possible consequences by accident type. Thereafter, nine options were suggested for radiation emergency medicine. And nine options were subdivided into four phases according to the level of severity. The appropriate response strategy of radiation emergency medicine options and phase were selected and arranged for all five categories. The response strategy of radiation emergency medicine derived from this study can support respond quickly and properly at the national level when nuclear and radiological emergencies occurred. The advantage of this study is that it has a plan to apply emergency strategies on a scale-by-scale basis, but the limitaion is that it is difficult to verify their effectiveness because we have a little experience in real situation. And also this study focused only on radiation emergency medicine. Nevertheless, in the event of a nuclear emergency, various safety measures are required. Therefore, we will provide more diverse safety measures in future research.

Acknowledgements

This study was supported by a grant from the Korea

Institute of Radiological and Medical Sciences (KIRAMS) and funded by the Ministry of Science and ICT (MIST), Republic of Korea: 50445-2020.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that can be construed as potential conflicts of interest.

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