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Awareness Patterns Regarding Radiation Safety Management in Fields Related to Radiation Safety Regulations: Focusing on Companies that Must Report Radiation Sources

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ABSTRACT

Background: This study aims to analyze radiation safety management and regulatory perceptions, focusing on companies that must report radiation sources. The intent is to reduce the gap between regulation measures and addressing real concerns while improving practical safety management measures and regulations for all stakeholders.

Materials and Methods: Radiation safety officers at a total of 244 reporting companies using radiation generators (79.8%) and sealed radioisotopes (15.1%) were surveyed using a questionnaire.

Results and Discussion: The perception that regulation is stronger than the actual risk of the radiation source used was 3.47 points (out of 5 points), indicating a score above average. The most important factors and considerations were education and training (48%) as a human factor, safety devices of the radiation source (71.3%) as a hazardous material factor, the use of radiation (50.8%) as an organizational environment, and the radiation effect of nearby facilities (67.2%) as a physical environment. Radiation safety management educational experience ($F=5.030$, $p<0.01$), the group with high subjective knowledge ($t=6.017$, $p<0.001$), and the group with high objective knowledge ($t=1.989$, $p<0.05$) was found to be better at radiation safety management.

Conclusion: It is necessary to standardize the educational experience regarding radiation safety management because each staff member has individual differences in educational experience. It is necessary to provide more information on how to solve radiation accidents via educational content. Applying radiation safety regulations based on the factors that significantly affect radiation safety management shown in this survey will help improve safety.

Keywords: Regulation, Safety Management, Reporting Company, Regulation Service Satisfaction, On-Site

Original Research

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Introduction

After the Fukushima nuclear accident in Japan, the general public's interests and fears regarding nuclear energy and radiation dramatically increased; hence, the requirement for a review of safety regulations at that time was raised [1, 2]. Nuclear safety regulatory agencies around the world are now paying attention not only to the safety culture of nuclear power plants but also to the safety culture within regulatory agencies. Therefore, international organizations are urgently trying to apply various safeguards regarding safety culture in radiation-related fields [3, 4]. Safety culture was discussed at the 7th Nuclear Safety Convention Review Meeting held at the International Atomic Energy Agency (IAEA) in 2017. Regulatory oversight bodies have many contacts and influences in the industry through regulatory activities and monitoring. Therefore, it was pointed out that the regulatory body itself needs to strengthen its efforts with an emphasis on safety culture. Various policy and practical measures to strengthen the safety culture are essential and need to be implemented. For fundamental and long-term safety management, it is necessary to think about safety culture and fundamentally improve it [5]. In previous studies, improvement of safety-related facilities, equipment, and facilities was required to prevent safety-related accidents or industrial accidents. However, it is argued that physical improvement is difficult to achieve in an organizational state where an in-house safety culture is not established [6].

In this regard, in accordance with 'Article 53 of the Nuclear Safety Act,' any person who intends to produce, sell, transfer, or use radioactive isotopes, etc., is required to obtain permission from the commission as prescribed by Presidential Decree. In addition, a person who intends to use or move a radioactive isotope for a purpose or quantity less than that prescribed by the Ordinance of the Prime Minister or a radiation-generating device less than the purpose or capacity prescribed by the Ordinance of the Prime Minister shall report to the commission as prescribed by Presidential Decree. Radioactive isotopes are subject to notification of use, etc., as highlighted in Article 65 of the same act, and radiation-generating devices are subject to notification of use, etc., as highlighted in Article 66 of the same act. The specific use or capacity of the notification target must also be determined. As of October 2021, there were a total of 7,986 (84%) reporting companies, far more than the 1,533 (16%) permitting companies.

In terms of hazardous material standards, reporting companies have a relatively lower level of risk than permitting companies. Therefore, regarding human factors, physical factors, and organizational factors, which are major safety considerations, regulations under the Nuclear Safety Act are less stringent for reporting companies than permitting companies [7]. Since radiation safety regulations in Korea are centered on permitting companies, there is a large quantity of survey data on permitting companies. Due to the lack of strict regulations for reporting companies, there is a lack of basic data on reporting companies. Since the government is attempting to change the regulations of reporting companies, it is necessary to make effective changes based on the realistic data available. Regarding the safety of radiation practices, appropriate regulations must be secured [8]. This study aims to identify the safety requirements experienced in the field by targeting radiation safety managers of reporting companies. It is intended to identify the reality and regulatory awareness of radiation safety management that are experienced and recognized in the field. This study aims to help improve safety by minimizing the gap between the regulatory standards required by the government and the regulations experienced in reality.

Materials and Methods

1. Characteristics of the Research Target

The target of the survey is radiation safety management staff at reporting companies nationwide. The total number of reported companies is 7,986, and among the total number of reported companies, 6,598 of the companies are classified as industrial companies. The survey samples were industrial companies (74.2%), public companies (14.8%), research institutes (7.4%), and educational institutes (2.9%). This sample was surveyed in a proportion similar to that of the population.

The surveyed areas were the metropolitan area (41.4%), Yeongnam area (26.2%), Chungcheong area (21.3%), and Honam area (11.1%). This area is a criterion for classification under the Nuclear Safety Act. The radiation sources used by the reporting companies are radiation generators (79.8%) and sealed radioactive isotopes (15.1%). The respondents to the survey were radiation safety managers from 244 reporting companies. Only 79.5% of the respondents directly performed radiation safety work.

Radiation safety managers of permitting companies must have a license from the state to handle radioactive materials and must receive legal training every year. However, there is no compulsory education for the radiation safety staff of the reporting companies. Nonetheless, 83.6% of the cases had educational experience in radiation safety management, and 14.3% had no educational experience. A 2.0% of radiation safety staff did not remember their training experience.

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2. Composition of the Questionnaire

The target of the survey is radiation safety management staff at reporting companies nationwide, based on companies reported in 2011. The research tool is a questionnaire. The composition of the questionnaire was based on tools developed in the study of Han [9] and Han and Cho [10]. In order to examine the attitudes towards safety management in the field, the level of radiation safety management at the site, how to solve a radiation accident, and the level of awareness of radiation risk (out of 10) were measured. Five items of subjective knowledge and five items of objective knowledge were measured. The smaller the gap between subjective knowledge and objective knowledge, the better the understanding of one's practical knowledge level. To examine the current state of radiation safety regulations, the level of safety regulation (two questions), the level of regulatory requirements (five questions), and the level of safety regulation service provisions (five questions) were measured (Table 1). Human factors (one question), hazardous material factors (three questions) (Table 2), organizational environmental factors (three questions), and physical environmental factors (four questions) (Table 3) were measured to identify important factors for on-site radiation safety management. Six

Table 1. Awareness Patterns on Radiation Safety Regulations

Classification	Mean ± SD[a]
Regulatory level	
The radiation source management system of the relevant institution is appropriate.	2.08 ± 0.80
Regulations are stronger than the actual risk of the radiation source used.	3.47 ± 0.92
Total[b]	5.54 ± 0.91
Regulatory requirements	
Regulations should be stronger on organizational systems related to radiation work.	3.57 ± 0.85
Regulations on the status and management of radiation sources should be stronger.	3.55 ± 0.84
Facilities should be more regulated.	3.51 ± 0.90
Education and training should be more regulated.	3.58 ± 0.84
Regulations on radiation exposure management should be stronger.	3.91 ± 0.87
Total[b]	18.13 ± 3.72
Regulatory service satisfaction	
Regulatory agencies help our company's radiation safety management.	3.81 ± 0.84
Regulatory agencies provide sufficient information on radiation safety management.	3.74 ± 0.84
Regulatory standards are suitable for institutional safety management.	3.78 ± 0.81
Regular inspections by regulatory agencies are necessary for safety management.	3.81 ± 0.85
The regulatory actions of the regulatory agencies are credible.	3.78 ± 0.80
Total[b]	18.92 ± 3.43

SD, standard deviation.
[a]The higher the score, the more stringent the regulations on radiation safety management, the higher the level of regulatory requirements, and the higher the level of satisfaction with regulatory services.
[b]The radiation source regulation level averaged 5.54 points (out of 10 points), the radiation safety management regulatory requirement was averaged at 18.13 points (out of 25 points), and the satisfaction level of safety regulation service provision was averaged at 18.92 points (out of 25 points).

Table 2. Human and Hazardous Material Factors Recognized as Important for Radiation Safety Management

Variable	No. (%)
Human factors	
Factors related to human behavior	
Educational training	117 (48.0)
Professional experience in handling	42 (17.2)
Health screenings	27 (11.1)
Wearing a personal dosimeter	19 (7.8)
Designation of the safety officer	14 (5.7)
Reward and punishment	11 (4.5)
Regulation	9 (3.7)
Task suitability	5 (2.0)
Hazardous material factors	
Characteristics of the radiation source	
Radiation source safety devices	174 (71.3)
Radiation source characteristics	42 (17.2)
Radiation source types	18 (7.4)
Location of the radiation sources	8 (3.3)
Etc.	2 (0.8)
Evaluation of radiation exposure dose	
Internal exposure	93 (38.1)
Exposure of nearby people	81 (33.2)
External exposure	63 (25.8)
Etc.	7 (2.9)
Radioactive waste management	
Waste collection or disposal	128 (52.5)
Source and amount	79 (32.4)
Disposal	27 (11.1)
Etc.	10 (4.1)
Types and causes of radiation accidents	
Equipment damage or defects	88 (36.1)
Radiation source leakages	30 (12.3)
Loss of radiation sources	26 (10.7)
Authorized or unintentional releases	20 (8.2)
Facility or equipment contamination	18 (7.4)
External whole body exposure	11 (4.5)
Personal radioactive contamination (internal)	10 (4.1)
Personal radioactive contamination (external)	9 (3.7)
Radioactive material generation	8 (3.3)
Off-site (air/water/soil) contamination	6 (2.5)
Personal body injury	5 (2.0)
Etc.	5 (2.0)
Dosimeter not being worn or lost	4 (1.6)
External local exposure	4 (1.6)

Table 3. Organizational and Physical Environmental Factors Recognized as Important for Radiation Safety Management

Variable	No. (%)
Organizational environment	
Operations	
Use of radiation	124 (50.8)
Manpower management	52 (21.3)
Installation of facilities	43 (17.6)
Usage/Storage/Sales quantity	21 (8.6)
Purchasing and sales planning	4 (1.6)
Radiation handling methods and safety management	
Proper handling methods	59 (24.2)
Education training	47 (19.3)
Personal exposure management	35 (14.3)
Safety management regulations or procedures	27 (11.1)
Organization and responsibilities	18 (7.4)
Radiation protection policies	18 (7.4)
Workplace management	17 (7.0)
Radiation source management	11 (4.5)
Radiation area management	4 (1.6)
Measuring equipment or measurement plans	3 (1.2)
Data recording management	3 (1.2)
Contamination management	2 (0.8)
Accident risk and countermeasures	
Maintaining emergency preparedness	71 (29.1)
Impact of accidents	65 (26.6)
Accident type and probability of occurrence	53 (21.7)
Emergency planning	51 (20.9)
Etc.	4 (1.6)
Physical environment	
Facility	
Radiation source size and dosage	143 (58.6)
Facility location	60 (24.6)
Facility room layout	22 (9.0)
Structure of the facility	13 (5.3)
Company location	5 (2.0)
Etc.	1 (0.4)
Environment around the facility	
Human accessibility	140 (57.4)
People around the facility	68 (27.9)
Social environment	25 (10.2)
Geography	10 (4.1)
Etc.	1 (0.4)
Safety facilities and system	
Shielding	111 (45.5)
Facility safety devices	98 (40.2)
Signage	16 (6.6)
Alarms	14 (5.7)
Exhaust and drainage systems	4 (1.6)
Etc.	1 (0.4)
Radiation effects on the environment	
Effects of direct radiation	164 (67.2)
Contingency planning	34 (13.9)
Effects of exhaust	30 (12.3)
Effects of drainage	8 (3.3)
Etc.	8 (3.3)

questions were asked, including the characteristics of the institution and the general characteristics of the individual (Table 4).

Subjective knowledge consisted of five items. They consisted of questions related to radiation safety management in the field through prior research with field experts. It should be noted that subjective questions do not have correct answers. These questions measure whether respondents' overestimate or underestimate their level of self-knowledge.

Q1) I know the company's radiation manager.

Q2) The manager of the company conducts regular inspections of the radiation equipment.

Q3) I know the principles and structure of radiation equipment.

Q4) I know the button to stop the radiation equipment in

Table 4. General Characteristics of Subjects

General characteristics	No. (%)
Direct radiation safety work	
Yes	194 (79.5)
No	50 (20.5)
Radiation safety management training experience	
Yes	204 (83.6)
No	35 (14.3)
Uncertain	5 (2.0)
Number of radiation safety management training experiences (Only respondents were processed; 1.95±2.912 times[a])	
1	124 (69.7)
2	30 (16.9)
3 or more times	24 (13.5)
Total	178 (100.0)
Radiation safety management experience	
0	15 (6.1)
Within 1 year	55 (22.5)
1–5 years	119 (48.8)
6–10 years	35 (14.3)
More than 10 years	20 (8.2)
Total	244 (100.0)

[a]Subjective knowledge was significantly higher in the case of radiation safety management training experience ($p<0.001$), the number of radiation safety management trainings increased ($p<0.05$), and radiation safety management experience of 10 years or more ($p<0.001$). There was no difference in objective knowledge level with radiation safety management training experience, the number of radiation safety management training times, and radiation safety management experience. Subjective knowledge was measured with five questions. Regarding whether you know the company's radiation officer, whether you know about performing regular inspections on radiation equipment, whether you know the principle and structure of radiation equipment, whether you know a device that blocks radiation in case of an emergency, and whether you are aware of the safety regulation management system. Objective knowledge was measured with four questions. The presence of natural radiation, the composition of radioactive material in the human body, radiation exposure in the nuclear power plant area, and the half-life of radioactivity.

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an emergency.

Q5) I know the safety regulation management system for radiation equipment.

Objective knowledge consisted of four items. Subjective knowledge consisted of the most basic theoretical knowledge of radiation obtained from field experts and previous research. Objective questions have correct answers. This measurement was intended to identify the gap between the subjective and objective knowledge levels of the respondents.

Q1) Humans are exposed to radiation anywhere on earth (correct).

Q2) All human bodies contain radioactive materials (correct).

Q3) Residents near nuclear power plants in Korea are more exposed to radiation than residents in other cities (false).

Q4) Radioactivity decreases over time (correct).

3. Analysis Method

Statistical analysis was performed using the SPSS/WIN statistical program version 24.0 (IBM Co.). For descriptive statistical analysis, the average and standard deviation were used to determine the perception of radiation safety management in the field, the level of awareness of radiation safety regulations, objective knowledge, and subjective knowledge. Frequency and percentage were used to characterize human factors, hazardous material factors, and environmental factors related to radiation safety management. The *t*-test and one-way analysis of variance were used for the difference in awareness level of radiation safety management in the field according to general characteristics and the difference in perception of radiation safety regulation. The Scheffe method was used as a post-test.

Results and Discussion

1. General Characteristics of Subjects

The number of people in charge who directly performed radiation safety work was 79.5%, and 20.5% did not directly perform safety work—83.6% had experience in radiation safety management training, 14.3% had no training, and 2.0% did not remember. The average number of radiation safety management trainings was 1.95 times, with 69.7% of those who received education only once, 16.9% of those who received it twice, and 13.5% of those who received it three times or more, and 48.8% of those with 1–5 years of radiation safety management experience, 22.5% of those with less than 1 year, 14.3% of those with 6–10 years of experience, and 8.2% of those with more than 10 years of experience. Under Article 106 (education and training) of the current Nuclear Safety Act, nuclear-related business operators are required to provide the education and training necessary for securing safety and preventing radiation damage to radiation workers and persons entering the radiation management area (Table 4) [7].

2. Awareness Patterns for On-Site Radiation Safety Management

As for the level of radiation safety management in the field, the average score of 7.91 (out of 10) was 21.7%, and 8 and 9 points were 20.1%, respectively, indicating that radiation safety management is relatively good in the field. Regarding whether they knew how to solve a radiation accident, the average score of 6.74 (out of 10) was 8 points (16.8%), 6 points 14.3%, 9 points 13.9%, and 10 points 13.5%. It is recognized that the person in charge knows how to solve a radiation accident well. The perception of radiation risk was on average 6.53 points (out of 10), with 10 points being 21.3%, which was considered very safe, while 1 point 13.5% thought it was very dangerous (Table 5).

3. Awareness Patterns of Radiation Safety Regulations

The perception that the regulation is stronger than the actual risk of the radiation source used was 3.47 points (out of 5 points), indicating a score above average. The score of 2.08, indicating that the current radiation source management system is appropriate, was below the average. A stronger regulation was desired with an average score of 3.91 (out of 5), indicating that the regulation should be stronger for radiation exposure management. The average score of 3.51 (out of 5) indicated that regulations should be strengthened for radiation facilities that were not strong. All five items received a score of 3.5 or higher out of 5, so it appears that respondents are demanding relatively stricter regulations. Regular inspections by regulatory agencies are necessary for safety management, with a score of 3.81 (out of 5), indicating a high level of satisfaction. Regulatory agencies had a low score of 3.74 (out of 5 points), indicating that they provide sufficient information on radiation safety management.

Regulatory measures deal with the issue of how much regulation should be implemented, how to secure the necessary information to carry out regulation, and how to change the

Table 5. Awareness Patterns for On-Site Radiation Safety Management

Classification	Score	No. (%)	Mean ± SD
The level of radiation safety management that safety officials consider themselves (1 point very poor, 10 points very good)	1	1 (0.4)	7.91 ± 1.82
	3	4 (1.6)	
	4	6 (2.5)	
	5	16 (6.6)	
	6	23 (9.4)	
	7[a)]	32 (13.1)[a)]	
	8[a)]	49 (20.1)[a)]	
	9[a)]	49 (20.1)[a)]	
	10[a)]	53 (21.7)[a)]	
	No response	11 (4.5)	
The level of subjective knowledge about action methods in case of radiation accident (1 point unknown level, 10 points very knowledgeable level)	1	4 (1.6)	6.74 ± 2.43
	2	6 (2.5)	
	3	21 (8.6)	
	4	17 (7.0)	
	5	22 (9.0)	
	6	35 (14.3)	
	7	19 (7.8)	
	8	41 (16.8)	
	9	34 (13.9)	
	10	33 (13.5)	
	No response	12 (4.9)	
The level of awareness of radiation risk (1 point very dangerous, 10 points very safe)	1[a)]	33 (13.5)[a)]	6.53 ± 3.20
	2	10 (4.1)	
	3	13 (5.3)	
	4	7 (2.9)	
	5	19 (7.8)	
	6	9 (3.7)	
	7	19 (7.8)	
	8	40 (16.4)	
	9	31 (12.7)	
	10[a)]	52 (21.3)[a)]	
	No response	11 (4.5)	
Total		244 (100.0)	

SD, standard deviation.
[a)]The higher the score, the better the site safety management, the better the know how to solve an accident, and the higher the radiation safety awareness.

behavior of regulation in the desired direction by implementing policy. As the industrial environment changes and the level of knowledge is accumulated, regulatory means should be developed into new and efficient means. However, the possibility of change is limited by the status, structure, and style of the regulatory body. No matter how good control measures appear and are utilized, they are often not reflected due to structural problems or the regulatory style in the past (Table 1) [4].

4. Human and Hazardous Material Factors Recognized as Important for Radiation Safety Management

As a human factor related to radiation safety management, education and training were recognized as the most important at 48.0%. It is necessary to check the regulatory standards for education and training under the Nuclear Safety Act [11]. As a risk factor related to radiation safety management, safety devices account for 71.3% of the characteristics of the radiation source, which is recognized as the most important factor. For the evaluation of radiation exposure dose, internal exposure was recognized as the most important, accounting for 38.1%. In radioactive waste management, collection/treatment was 52.5%, and more than half recognized it as important. In terms of radiation incident types and causes, equipment damage/defect was recognized as the most important with 36.1%. Equipment replacement, education reinforcement, environmental improvement, and procedure revision have a direct effect on resolving the cause of accidents (Table 2) [4].

5. Organizational and Physical Environmental Factors Recognized as Important for Radiation Safety Management

Regarding the organizational environment in relation to radiation safety management, the use of radiation in operation is recognized as the most important variable at 50.8%. In terms of radiation handling method/safety management, the method of use was recognized as the most important variable with 24.2%. Regarding the risk of accidents and countermeasures, the maintenance of emergency response posture was perceived as the most important variable with 29.1%. Regarding the physical environment related to radiation safety management, the size and capacity of the radiation source in the facility is recognized as the most important variable at 58.6%. The environment around the facility is recognized as the most important variable, with the accessibility of people at 57.4%. In terms of safety facilities and systems, shielding was recognized as the most important variable at 45.5%. Regarding the radiation effect on the surrounding environment, the effect of direct radiation was recognized as the most important variable with 67.2% (Table 3).

6. Differences in Radiation Safety Management Awareness Levels in the Field according to General Characteristics

In the case of radiation safety management education ex-

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perience ($F = 5.030$, $p < 0.01$), the group with high subjective knowledge ($t = 6.017$, $p < 0.001$), and the group with high objective knowledge ($t = 1.989$, $p < 0.05$) was found to be better in radiation safety management. If the radiation source used is a sealed radioactive isotope or a radiation generator ($F = 5.137$, $p < 0.01$), if you have experience in radiation safety management education ($F = 5.459$, $p < 0.01$), a group with high subjective knowledge ($t = 6.069$, $p < 0.001$), the group with high objective knowledge ($t = 1.989$, $p < 0.05$) knew better how to deal with radiation accidents. In the case of radiation safety management education experience ($F = 4.557$, $p < 0.05$), in the case of more than 10 years of radiation safety management experience ($F = 3.533$, $p < 0.01$), the group with high subjective knowledge ($t = 2.810$, $p < 0.01$), and the group with higher objective knowledge ($t = 2.335$, $p < 0.05$) perceived that radiation was safer (Table 6).

7. Differences in the Level of Regulation on Radiation Safety Management, Regulatory Requirements, and Regulatory Service Satisfaction

Recognition of the level of regulation on radiation safety management was not related to the presence or absence of radiation safety management education, subjective knowledge, objective knowledge, and high or low level of radiation safety management in the field. In the event of a radiation accident, the group that knows how to solve a radiation accident well ($t = -2.594$, $p < 0.01$) and the group that perceives radiation as dangerous ($t = -2.734$, $p < 0.01$) perceive that the radiation source regulation is stronger. There was no difference in the level of radiation safety management regulatory requirements with respect to radiation safety management education experience, subjective knowledge, objective knowledge, level of radiation safety management in the field, and awareness level on how to solve a radiation accident. The group that perceives radiation as dangerous recognizes that radiation safety management regulations should be stronger ($t = -2.115$, $p < 0.05$). The level of radiation safety management regulatory service provision was not related to objective knowledge and radiation risk perception. In the case of radiation safety management education experience ($F = 9.000$, $p < 0.001$), the group with high subjective knowledge level ($t = 3.089$, $p < 0.01$), the group with good radiation safety management in the field ($t = 6.338$, $p < 0.001$), and the group who knew how to solve a radiation accident well ($t = 2.872$, $p < 0.01$) was highly satisfied with the radiation safety management regulatory service (Table 7).

Table 6. Differences in Radiation Safety Management Awareness Levels in the Field according to General Characteristics

Variable	Mean ± SD	t/F	p-value
The level of radiation safety management that safety officials consider themselves[a]			
Radiation safety management training experience			
Yes (a)	8.07 ± 1.78	5.030**	0.007
No (b)	7.15 ± 1.77		(a > c)
Uncertain (c)	6.60 ± 2.51		
Subjective knowledge			
High group	8.42 ± 1.55	6.017***	0.000
Low group	6.89 ± 1.92		
Objective knowledge			
High group	8.15 ± 1.90	1.989*	0.048
Low group	7.68 ± 1.73		
The level of subjective knowledge about action methods in case of radiation accident[b]			
Radiation source			
Sealed radioactive isotope (a)	7.32 ± 2.57	5.137**	0.007
Radiation generator (b)	6.77 ± 2.33		(a, b > c)
Other (c)	4.60 ± 2.63		
Radiation safety management training experience			
Yes (a)	6.96 ± 2.44	5.459**	0.005
No (b)	5.79 ± 2.04		(a > c)
Uncertain (c)	4.60 ± 2.07		
Subjective knowledge			
High group	7.40 ± 2.31	6.069***	0.000
Low group	5.49 ± 2.13		
Objective knowledge			
High group	7.32 ± 2.34	3.588***	0.000
Low group	6.21 ± 2.40		
The level of awareness of radiation risk[c]			
Radiation safety management training experience			
Yes (a)	6.79 ± 3.12	4.557*	0.011
No (b)	5.00 ± 3.21		(a > b)
Uncertain (c)	6.40 ± 4.16		
Radiation safety management experience			
0 (a)	5.57 ± 2.71	3.533**	0.008
Within 1 year (b)	6.85 ± 2.99		(e > a, d)
1–5 years (c)	6.61 ± 3.23		
6–10 years (d)	5.15 ± 3.53		
More than 10 years (e)	8.26 ± 2.33		
Subjective knowledge			
High group	6.96 ± 3.12	2.810**	0.005
Low group	5.72 ± 3.20		
Objective knowledge			
High group	7.04 ± 3.15	2.335*	0.020
Low group	6.07 ± 3.19		

SD, standard deviation.
[a]The higher the score, the better the site's radiation safety management, and the lower the score, the poorer the site's radiation safety management.
[b]The lower the score, the poorer the solution, and the higher the score, the better the solution.
[c]The higher the score, the safer the radiation, and the lower the score, the more dangerous the radiation.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 7. Differences in the Level of Regulation on Radiation Safety Management, Regulatory Requirements, and Regulatory Service Satisfaction

Division	Safety regulation level[a]			Safety regulatory requirements[b]			Regulation service satisfaction[c]		
	Mean±SD	t/F	p-value	Mean±SD	t/F	p-value	Mean±SD	t/F	p-value
Radiation safety management training experience									
Yes	5.52±0.90	0.495	0.610	18.05±3.61	0.537	0.585	19.32±3.32	9.000***	0.000
No	5.65±1.01			18.41±4.24			17.06±2.91		(a>c)
Uncertain	5.80±0.45			19.60±4.72			15.80±5.40		
Subjective knowledge									
High group	5.49±0.89	−1.022	0.308	18.22±3.66	0.705	0.481	19.42±3.33	3.089**	0.002
Low group	5.62±0.93			17.86±3.82			17.99±3.43		
Objective knowledge									
High group	5.47±1.02	−1.082	0.280	18.07±4.08	−0.227	0.821	19.27±3.54	1.480	0.140
Low group	5.60±0.80			18.18±3.39			18.61±3.30		
Radiation safety management level									
High group	5.46±0.95	−1.801	0.073	18.52±3.71	1.951	0.052	19.93±3.31	6.388***	0.000
Low group	5.68±0.84			17.54±3.64			17.15±2.92		
Awareness of how to solve a radiation accident									
Known group	5.39±0.97	−2.594**	0.010	18.07±3.92	−0.535	0.593	19.54±3.40	2.872**	0.004
Unknown group	5.70±0.83			18.33±3.46			18.26±3.39		
Awareness of the dangers of radiation									
Safety	5.41±0.93	−2.734**	0.007	17.77±3.77	−2.115*	0.036	19.18±3.43	1.277	0.203
Danger	5.74±0.87			18.81±3.55			18.59±3.46		

SD, standard deviation.
[a]The higher the score, the stronger the regulation, and the lower the score, the more appropriate the regulation.
[b]Higher scores demand stronger regulation, and lower scores demand weaker regulation.
[c]The higher the score, the higher the satisfaction with the regulatory service, and the lower the score, the lower the satisfaction with the regulatory service.
*$p<0.05$, **$p<0.01$, ***$p<0.001$.

Conclusion

The safety culture principles or guidelines presented by the IAEA (2009) or the U.S. Nuclear Regulatory Commission (2014) may function as safety functions, but most of the normative content is abstract. Since it is presented as a desirable behavior pattern at the level, it is often not linked to the interaction according to the actual situation or context [12, 13]. Therefore, it is of utmost importance to identify important safety factors in the field.

Zohar's study [14] emphasizes that the importance of safety management positions, safety education and training, and safety-related procedures directly correlates with the significance of fostering a positive safety atmosphere within the organization. A strong safety atmosphere ultimately facilitates proper safety management. The most important factors in this study were education and training (48%) as a human factor, safety devices of a radiation source as a hazardous material factor (71.3%), the use of radiation as an organizational environment (50.8%), and the radiation effect of nearby facilities as a physical environment (67.2%). In conclusion, it was determined that, diagnosing and supplementing these substantial and important factors in the field should be prioritized.

Organisation for Economic Co-operation and Development (OECD)/Nuclear Energy Agency (NEA) (1999) mentioned that in order to promote the safety culture of operators, the influence of the safety culture of regulatory agencies should also be considered [15]. The usefulness of organizational culture has been dealt with in various studies, such as organizational psychology [16], but discussions on the organizational culture of nuclear regulatory agencies began in earnest after the Fukushima accident [17]. At an international workshop held in June 2015, regulatory agencies in each country defined the Fukushima nuclear accident as a close call to regulatory agencies and urged measures to strengthen safety culture. In 2016, a report (OECD/NEA) called 'Safety culture of effective regulatory organizations' was published [18]. The IAEA's Nuclear Safety Group (2017) points out that the totality of nuclear safety-related systems, organizations, and cultures is not effective and urges attention to safety culture, especially the safety culture of regulatory agencies, to correct this ideology [19]. Regulatory agencies' activities, such as regulatory strategies, daily supervisory duties, work-

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place methods, and behaviors to deal with safety issues, have a profound influence on the safety culture and sense of responsibility of business operators. Therefore, the attitudes, words, and actions of industry workers and regulators who frequently interact with each other in the regulatory process have important meanings [4]. In this study, the regulatory body believes that the regulation is stronger than the actual radiation risk in the field. Nevertheless, strong regulations are required for the management of radiation exposure. The need for regulation was demanded in the field because it is helpful for site safety management. The safety atmosphere for these regulatory bodies should also be considered.

Due to the Fukushima nuclear accident, vulnerabilities highlighted the concerns that nuclear power plants and the safety capabilities of the business organizations that operate them need to consider, as well as the regulatory agencies that independently supervise them [4]. Therefore, on-the-spot regulation considering the characteristics of the various variables shown in this study is also necessary. Most of the research on the existing organizational level safety culture focuses on developing guidelines for safety culture compliance. In fact, there is relatively little interest in how well organizational members accept these guidelines in the field [20]. The requirements for education and training, regulations with low conformity, strict requirements for radiation exposure, and inspection of important risk factors should be supplemented with regulations suitable for the characteristics of the reporting companies in Korea. The IAEA emphasized the need to pay more attention to the practical implementation aspects of safety standards [21]. Safety culture is one of the fundamental causes of accidents and is also used as a leading indicator for predicting safety performance [22, 23]. If site safety regulation is conducted on the basis of the results of this study, a higher level of effective safety culture can be realized.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Ethical Statement

According to the Bioethics and Safety Act in Republic of Korea, an approval from the ethics committee is not required.

Author Contribution

Conceptualization: Han E. Methodology: Han E. Formal analysis: Han E. Funding acquisition: Choi Y. Project administration: Choi Y. Visualization: all authors. Writing - original draft: Han E. Writing - review & editing: all authors. Approval of final manuscript: all authors.

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