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Developing risk breakdown structure for nuclear power plant decommissioning projects in Korea focusing on radioactive concrete dismantle

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A B S T R A C T

The number of nuclear power plants (NPPs) preparing for dismantling under permanent suspension owing to environmental problems or end of designed lifespan is increasing worldwide. In NPP decommissioning, structural and job risk analysis and management, considering the characteristics of radioactive contamination, are critical because they are directly related to the safety of workers. However, structural disasters and job risk factors that may present during decommissioning work are not largely addressed compared to the risk of dismantling facilities such as nuclear reactor dismantling. Furthermore, characterizing NPP decommissioning is difficult owing to the unsophisticated work breakdown structure. Thus, risk breakdown structure (RBS) for risk analysis is not systematically established because risk factors are not classified according to the specified dismantling work characteristics. Therefore, the purpose of this study is to establish an RBS reflecting the characteristics of the NPP dismantling work according to structural/job as a primary step for risk analysis and management. Each work's risk factor is analyzed based on similarity to the construction-dismantling work, targeting the cutting work when dismantling the radioactive concrete structure, which presents the most significant risk, and derives the risk factors by matching them with structural and human damage factors. The RBS model established in this study is expected to be used as primary data for risk analysis and the safety evaluation of NPP dismantling works in the future.

Keywords: nuclear power plant; decommissioning; hazard; risk analysis; work breakdown structure; risk breakdown structure

Introduction

With the increase in permanently suspended nuclear power plants (NPPs) worldwide, industries related to decommissioning NPPs that have reached their designed lifespan are expanding. In Korea, a total of 12 NPPs are expected to be permanently closed by 2029. Kori unit 1, the first commercial NPP in Korea, entered a permanent shutdown state in 2017, and decommissioning work thereof is ongoing [1]. However, contrary to major advanced

NPPs abroad, there have been no cases of dismantling commercial reactors in Korea, and only rough regulations and systems have been implemented to manage them. Furthermore, there are insufficient detailed guidelines for actual implementation, policies, and procedures.

NPP decommissioning work presents many potential risks because the work is conducted in confined spaces near the radial concrete structure. Unlike general dismantling in the construction industry, NPP decommissioning work can have more potential risk factors, such as increased resources and time consumption. Major agencies and ministries related to most NPPs systematically analyze and manage potential risk during the dismantling process. They also have a strategy to respond to risks during the decommissioning phase through preliminary identification. However, considering the structural and job risks during the decommissioning phase are relatively less than the radiological risk. In addition, the risk breakdown structure (RBS) is not defined by the characteristics of the work (work process, utilization equipment, work location); thus, it is difficult to use them as guidelines for actual decommissioning work [2]. In this regard, the U.S. Department of Energy reported that structural risk management is critical in NPP decommissioning work with similar characteristics to dismantling work.

Accordingly, previous studies have attempted to construct an RBS that considers the structural risk for each work characteristic based on the similarity between the general construction dismantle work and the demolition work of radioactive concrete structures. However, work breakdown structure (WBS) is simplified when constructing the RBS; for example, the WBS consists of three levels. This makes it difficult for the RBS to characterize the NPP dismantling work itself, or to address workplace injury from safety hazards that have not been previously addressed [1-4]. Therefore, the WBS should be sophisticated, and job risk from workplace injury should also be managed.

In this study, we develop an RBS model that considers main characteristics of NPP decommissioning by identifying hazards and developing a detailed WBS according to structural and job risks (workplace injury). Developing a sophisticated RBS is essential to analyze and assess the risks for NPP decommissioning. The rest of this paper is structured as follows. First, literature review section presents NPP decommissioning work characteristics and related risk management. In the Methodology section, WBS is constructed based on similarity with construction demolition work, and work risk factors are derived. After the structural and job risk factors of construction demolition work being derived, the RBS is developed by matching structural and job risk with WBS-related work hazards. The scope of this study is cutting work during the dismantling of radioactive concrete structures with the highest frequency of structural and job accidents and hazards during the NPP dismantling work process. The RBS established in this study is expected to be used as primary data for risk analysis, and safety evaluation of NPP dismantling works in the future.

Literature Review

Globally, more than half of the total NPPs have entered a full-fledged aging phase, i.e., they have been in operation for more than 30 years. This situation is different depending on the country or power plant, but NPPs typically operate for 30 to 60 years. In some cases, owing to the deterioration of facilities due to long-term operation, difficulty in securing technical safety, economic degradation, political/social reasons, etc., the structure stops producing electricity and permanently closes its operation. Thereafter, preparations begin for decommissioning the reactor, such as withdrawal and transfer of spent fuel, drainage of coolant, and decontamination, after the permanent suspension has been determined. NPP decommissioning is defined as 'All technical and managerial activities taken to safety, and completely disposing nuclear facilities that have lost their utility value from the surrounding environment [5]'.

Decommissioning is "Administrative and technical measures taken to release all or part of the regulatory requirements applicable to the facility" according to the International Atomic Energy Agency (IAEA) definition [5]. Simply, decommissioning does not merely refer to demolition of facilities. It encompasses a series of processes, including the establishment of decommissioning plans, licensing, pollution investigation, decontamination, demolition, waste disposal, restoration of sites, and deregulation of sites. The term "Closed-circuit" was previously used, but the current Nuclear Safety Act uses the terminology "Decommissioning [6]" The U.S. Atomic Industrial Forum classifies the decommissioning into three phases: immediate dismantling, five stages of delay dismantling, and six stages of permanent sealing. The U.S. Eportselectric Power Research Institute (EPRI) classifies the dismantling phase into four phases [7]:

1st phase: a strategy for decommissioning
2nd phase: organizational transformation
3rd phase: facility conversion
4th phase: final decommissioning

NPP decommissioning is a long-term project that takes several years, during which various decommissioning wastes are generated in large quantities. Failure to correctly classify and dispose of waste generated in large amounts in a relatively short period will result in a relatively high disposal cost. In addition, when dismantling radioactive plant systems and equipment, radiation exposure to workers and radiation leaks to the environment can occur [8]. Accordingly, major agencies and ministries related to NPPs have established and operated guidelines for safe dismantling of NPPs. Furthermore, they have developed a strategy to respond to risks during the dismantling phase through preliminary identification.

Risk is the likelihood that a hazard will cause specific harm or injury to someone or something. In particular, it is the likelihood of accidents or ill-health occurring at work and its consequences [9]. It can also be defined as the likelihood of harm (injury or adverse health effect), the potential severity of the damage, and the frequency or duration of exposure to damage [10]. In decommissioning work, risk can be defined as potential risk factors and loss factors that adversely affect the safe completion of work. The decommissioning project management plan recognizes, analyzes, and monitors uncertain events and situations affecting decommissioning work in advance to minimize risk factors and maximize opportunity factors that enable successful completion of the project [11]. There are many potential risk factors and loss factors because they have the characteristics of completing decommissioning work near uncertain spaces. In particular, the risk increases exponentially with increase in the required workforce and time. Therefore, efforts are necessary to minimize potential risk factors and uncertainties for the decommissioning project's safe completion. The preliminary work of risk management to reduce risks and uncertainties is achieved by being aware of the risk factors, analyzing the causes, and establishing countermeasures against these factors. Subsequently, the procedure is performed to monitor the degree of risk reduction by checking whether the measures are implemented. Among these steps, it is crucial to identify risk factors according to the nature and characteristics of business for effective risk management [12].

However, previous studies have shown that structural disasters and job risk factors that may occur during decommissioning work are not largely addressed compared to the risk of dismantling facilities, such as nuclear reactor dismantling [2]. Furthermore, there is insufficient characterization of NPP decommissioning owing to low WBS level for deriving hazard factors, as well as insufficient viewpoints of risk factors, such as one side among structural risk and job risk. For example, Jeong et al. [3] and Kim et al. [4] identified risks for workers' safety only, not structural damage based on radiological and non-radiological hazards. Kim et al. [2] classified the risk breakdown structure for NPP decommissioning focusing only on structural damage. They all classified the WBS level using the second or third level, which does not address in detail the characteristics of NPP decommissioning. Thus, structural damage and job risks of workers are not systematically established. Therefore, building a sophisticated RBS consisting of detailed WBS and structural and job risks is necessary to characterize NPP decommissioning.

Methodology

Structure of the RBS model

The risk for general construction-dismantle work may consist of structural (physical) damage to facilities and workplace injuries, based on the case study of accidents and damages at construction sites. The RBS for this study can be structured by matching the risk for general construction dismantles work and hazards from NPP work activities as follows:

1) The WBS is constructed to derive activities that characterize NPP decommissioning work.
2) Structural/job risks are derived through the profile of construction risk factors.
3) The hazards are identified using IAEA definition considered the international standard.
4) The hazard index of radioactive concrete cutting work of the WBS is derived from matching IAEA NPP decommissioning hazards.
5) The RBS has constructed structural/job risk factors matching the hazard of each WBS activity.
6) The RBS is modified and supplemented by expert interviews.

WBS for NPP decommissioning

Project Management Institute (PMI) in the U.S. defines WBS as a "hierarchical classification based on the outcomes of all services performed to achieve business goals and produce the required outcomes." [13]. To construct the WBS, first, the characteristics of the cutting work of NPP decommissioning, which is the scope of the study, were identified. Due to domestic circumstances, as the research subjects' cases were relatively limited, professional verification itself was impossible; thus, the overall validation was conducted through a few experts' opinions. Hence, the understanding of the main works of decommissioning, which is difficult to find similarities with the construction work, and the structural risk breakdown structure for each work of NPP decommissioning work prepared in this study were revised and supplemented. Unlike general dismantling work in the construction industry, NPP decommissioning work cannot be unconditionally from top to bottom. Because there are radiated parts of shielding concrete, the sequence and method of dismantling work are applied differently to each area. Furthermore, because the shielded concrete structure's interior space is confined, structural risks like installing openings and connecting passages for the decommissioning work should be considered. Owing to the characteristics of having to work close to the radial concrete, it is essential to consider the working time. In particular, time shortening is important for work related to temporary structures, requiring the prevention of possible structural risks.

Next, based on the literature review, WBS was prepared for the entire decommissioning. A detailed WBS was established to identify and specify risks for cutting work. It was based on the work procedures of the current decommissioning plan of Kori 1 [14]. The manual was prepared by applying the preparation procedure in ISO45001:2018, which stipulates the safety and health management system. The manual was designed to establish, implement, and maintain a safety and health management system to improve safety and health, eliminate risk factors, and minimize risks during NPP decommissioning work. Based on the work procedure criteria designed in this way, a WBS was established for this study of NPP decommissioning projects (Figure 1). Four classification levels were employed: Level 1, Level 2, Level 3, and Level 4. Level 1 was divided into work packages of NPP decommissioning, comprising preparation, cutting non-radial concrete, temporary storage of the remains, decontamination, punching, cutting of radial concrete, and transportation work. As previously explained, hierarchical classifications were organized by selecting the radial concrete cutting work with a higher risk of difficulty. In this

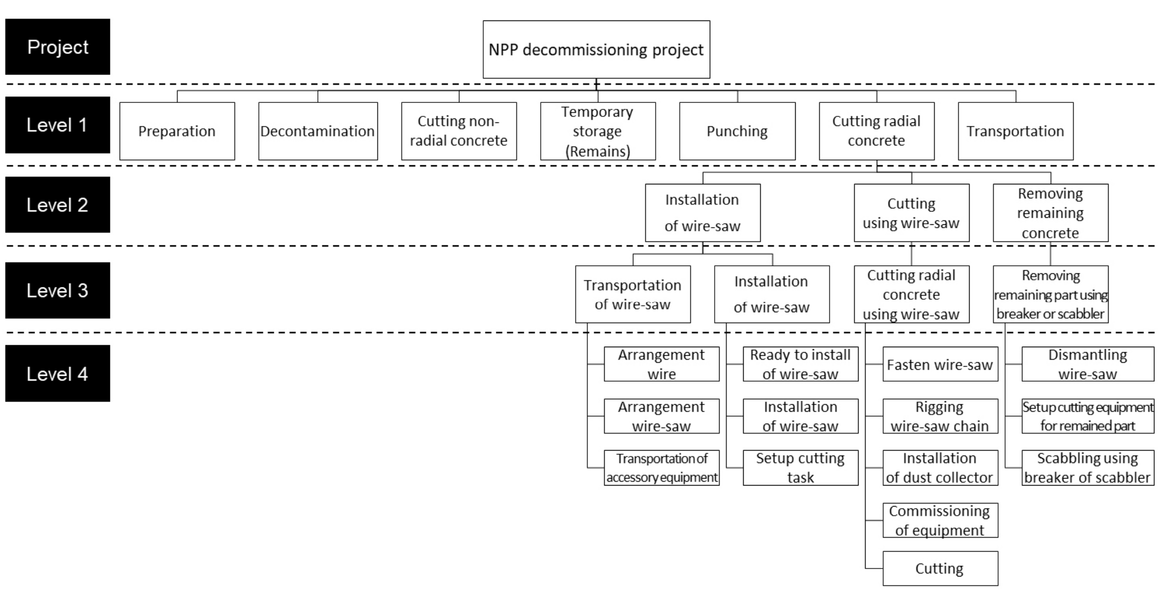

Figure 1. WBS for NPP decommissioning project

study, diamond wire saws, as the leading equipment, were employed using the dry method, as there existed a risk of radioactive contamination if water were to be used. Level 2 comprised three tasks classified as installation of wire saw, cutting using wire saw, and removing remaining concrete. Level 3 comprised the main tasks performed as part of each work activity of Level 2. Level 4 contained the details of the job characteristics (work location/element/work equipment) listed in Level 3 and was divided into 14 tasks. The risk factor was analyzed by connecting Level 3 and Level 4 to derive risks characterizing the NPP decommissioning characteristics.

Structural/job risks

Structural risks indicate possible direct damage to equipment or facilities, such as structures themselves or temporary objects, due to various potential risks in the construction process. Job risks represent workplace injuries that harm human body or subsequently owing to structural risks. Both structural and job risks are derived by analyzing the profile of risk factors for each work specified in the construction industry field. These structural and job risks combined with hazards based on the similarity with NPP decommissioning work would construct the RBS.

The structural and job risks were derived from the literature [15]. Thereafter, to clarify the items of structural/job risks in the construction industry as matched structural/job risks that could occur in the NPP decommissioning work, interviews were conducted with seven experts from working-level staff and research institutes with more than ten years of experience in the field of NPP decommissioning projects and structures. Through group meetings and interviews, factors with overlapping meanings were combined and removed, and the concept of each factor was specified. The factors of structural/job risks that can occur during NPP decommissioning work were derived (Tables 1 and 2). The structural risks consist of eight factors: collapse, collision, detachment, dust, electric failure,

Table 1. Structural risks (damage to equipment or facility)

No	Structural risks	Description
1	Collapse	The collapse of demolished materials
2	Collision	Collision in equipment or confined spaces
3	Detachment	Departed from the main body
4	Dust	Scattered dust from drilling or cutting work
5	Electric failure	Owing to power overload and shortcuts, power failures
6	Fall	Fall from heights
7	Fall object	Temporary structures or equipment falls forwards
8	Radioactive contamination	Exposed to radioactive material, including form (solid, liquid, gaseous)

Table 2. Job risks (workplace injury)

No.	Job risks	Description
1	Collision	Collided by human, equipment
2	Cut	Part of a worker's body is cut off by drilling or cutting tools
3	Eye injury	Eyes are exposed to dust or physically hurt
4	Electric shock	Electric injury due to inadequately disconnected circuits, inadvertent connection
5	Fall	Fall from heights
6	Jam	Worker's body is jammed between equipment or narrow space
7	Projectile injury	Injury by flying fragments during construction work such as cutting, wire saw installing.
8	Radioactive contamination	Exposed to radiation
9	Respiratory disease	Respiratory damage due to dust generated during drilling or cutting

fall, fall object, and radioactive contamination. Job risks consist of nine factors: collision, cut, eye injury, electric shock, fall, jam, projectile injury, radioactive contamination, and respiratory disease.

Hazard identification

A hazard is a potential source of harm, for example, inadequate working space, working at height, and heavy lift [10]. Each work associated with NPP decommissioning has hazards, which is a fundamental and crucial step in constructing a systematic RBS. In Korea, Article 28 of the Nuclear Safety Act (Demolition of power plant reactors and related facilities), and Article 26 of the Enforcement Rules of the same Act (Application for Approval Decommissioning Plan for Nuclear Reactor Facilities) stipulate concerning the decommissioning of nuclear reactors. However, even this is a situation where it is mandatory to prepare a brief safety management plan in the decommissioning plan. Accordingly, operators carrying out NPP decommissioning will establish a decommissioning plan and safety evaluation plan based on arbitrary analysis and necessary conditions. It is difficult to respond to possible structural and job risks from decommissioning work. Therefore, it is difficult to identify the risk factors for NPP decommissioning based on Korean standards; thus, it is necessary to identify the risk factors for each NPP decommissioning work according to international standards.

According to the global standard, the IAEA defines preparation guidelines for establishing a decommissioning plan to protect the public, workers, and the environment, and ensure that no harm is committed [16]. Most advanced countries in nuclear power have established safety management systems based on these guidelines. However, it is essential to develop detailed items before NPP decommissioning because of the variety of decommissioning technologies and construction methods as well as the uncertainty involved. In addition, NPP decommissioning is characterized by working in spaces near radial structures; thus, workers perform decommissioning according to various radiological and non-radiological restrictions. Therefore, they are exposed to structural and operational threats, such as collapse, fall, explosion, and damage. The decommissioning plan report, which describes the execution plan of the decommissioning work, shall include a plan for safety assessment and management.

However, most countries and agencies do not recognize safety from a construction perspective as a significant factor because they prepare and comply with regulations based on IAEA safety assessment guidelines. Thus, in this study, structural/job risk from Korea’s construction safety risk factors are employed considering the circumstances of the dismantling of NPP decommissioning in Korea. Also, the hazards of IAEA as international standards are applied to the RBS model. The IAEA defines safety hazards as radiological, fire/explosion, electrical, non-ionizing radiation, chemical/toxic, physical, working environment, human/organizational, external hazards/initiating events, and other hazards (Table 3). In this study, the hazard index was retrieved from the safety hazards of IAEA and added to Table 3. The hazard index is utilized in the matching process of the radioactive concrete cutting work of the WBS.

Table 3. Identified hazards in NPP decommissioning (modified from (IAEA, 2013) [16])

No	Hazard type	Hazards	Hazard index
1	Radiological hazards	Direct radiation sources	A01
		Improper removal of shielding	A02
		Radioactive material, including form (solid, liquid, gaseous)	A03
		Criticality	A04
		Contaminated liquid or material	A05
		Other radioactive sources (smoke detectors, lightning rods)	A06
2	Fire/explosion hazards	Oxygen	B01
		Sodium	B02
		Explosive substances	B03
		Flammable gases (e.g., oxyacetylene, propane gas), liquids, dust	B04
		Combustible/inflammable materials	B05
		Compressed gases	B06
		Hydrogen generation	B07
		Overheating or fire, caused by, for example, portable heaters, an overload of electrical circuits, application of cutting techniques	B08
3	Electrical hazards	High voltages	C01
		Power overload and shortcuts, power failures	C02
		Inadequately disconnected circuits/prevention against inadvertent connection	C03
4	Non-ionizing radiation hazards	Non-ionizing radiation sources, including lasers	D01
		Electromagnetic radiation (e.g., microwaves)	D02
		High-intensity magnetic fields	D03
5	Chemical/toxic hazards	Chemotoxic material	E01
		Spills	E02
		Chemicals (aggressive chemicals)	E03
		Accidental mixing/combination of chemicals (e.g., in sewage systems, decontamination work)	E04
		Asbestos and other hazardous materials, such as lead or beryllium	E05
		Pesticide use	E06
		Biohazards	E07
6	Physical hazards	Kinetic energy	F01
		Potential energy (springs, Wigner energy in graphite)	F02
		Degraded or degrading structures, systems, and components	F03
		Steam	F04
		Temperature extremes (high temperatures, hot surfaces, cryogenics)	F05
		High pressure (pressurized systems, compressed air)	F06
7	Working environment hazards	Working at heights (e.g., ladders, scaffolding, man baskets),	G01
		Excavations, the formation of underground cavities(subsidence) from rain, waste degradation, etc.	G02
		Vehicle traffic	G03
		Heavy lifts, material handling, heavy equipment, manual lifting, overhead hazards, falling objects, cranes	G04
		Inadequate illumination	G05
		Inadequate ventilation	G06
		Noise (high noise areas and tools)	G07
		Dust	G08
		Pinch points, sharp objects	G09
		Confined space	G10
		Dangerous equipment, e.g., power tools, compressed gas cylinders, welding and cutting, water jet cutting/decontamination, abrasive decontamination techniques, grinding, sawing	G11
		Remote work area	G12
		Obstruction of passageways or exits	G13
8	Human/organizational hazards	Human error	H01
		Safety culture aspects	H02
		Assigning inadequate training for work steps	H03
		Assigning inadequate protective measures for work steps	H04
9	External hazards/initiating events	Ambient temperature extremes	I01
		Aeroplane crash	I02
		Storm and adverse weather conditions	I03
		Earthquakes	I04
		Flooding	I05
		External explosions and fires	I06
10	Other hazards	Degraded/corroded barriers, aging of materials	J01
		Unknown or unmarked materials	J02
		Spills	J03

Results and Discussion

The hazards of WBS level 4 activities in radioactive concrete cutting work were derived based on expert interviews. The hazards consider the work details according to work location, element, and work equipment, which is more suitable for characterizing NPP decommissioning compared to the previous studies using WBS level 3. The hazards were matched with IAEA hazards, and the hazard index was derived to construct the next phase of the RBS model. Table 4 shows the results of the matched hazard index between the construction hazard and IAEA hazard.

Table 4. Matching construction cutting work with IAEA hazards

Activities of WBS-level3	Activities of WBS-level4	Hazard description of WBS-level4	Hazard index matching with IAEA hazards
Transportation of wire-saw	Transportation of wire-saw	Structure interference, obstacle pass, equipment falls	G03, G04, G05, G10, G13, H01
	Arrangement wire-saw	Radioactive contamination area, interference with other works, narrow and limited space	A05, G05, G10, G13, H01
	Transportation of accessory equipment	Torsion of accessory equipment, working at heights, obstacle existence	G01, G03, G04, G05, G10, G13, H01
Wire-saw installation	Ready to install of wire-saw	Deviating accessory equipment, workers' accessibility to high-risk equipment	G10, G11, H01
	Installation of wire-saw	Deviating wire-saw	F01, G11, H01, H04
	Setting up	Equipment installation abnormality	C03, G11, H01
Cutting	Fasten wire-saw	Stacking object, hazards between equipment and cutting surface, Pass within working radius	G05, G10, G13, H01, H03
	Rigging wire-saw chain	Tension and torsion generation when installing the wire, risk of inserting wires into the cutting furrow	F01, G05, H01, H03
	Installation of dust collector	Dust generation	B08, C02, G08, H01, H04
	Commissioning of equipment	Deviating wire-saw, short-circuit/fire caused by electricity using	B08, C03, F01, G07, G11, H01
	Cutting	Snapping wire during work, workers' accessibility to impact zone	B08, C02, F01, G01, G07, G08, G10, G11, H01, H04
Removal of residual concrete	Dismantling wire-saw	Movement of the working position, transfer of heavy materials, removing the material, Exposing the cut surface	G01, G03, G04, G10, G13, H01, H03
	Setup cutting equipment for remained part	Transfer of heavy materials, fixation errors of equipment, using electricity	B08, C02, G01, G03, G04, G10, H01, H03
	Scabbling using breaker of scabbler	Installation errors of safety handrail, problem with temporary equipment, radioactively contaminated liquid	A05, B08, C02, F01, G01, G08, G10, H01, H04

The structural/job RBS was prepared based on the construction project risk profile. Based on the matching results of the NPP decommissioning process and the construction process, each work's structural/job risks were derived, as shown in Table 5 below. Due to the limitation of this study, large-scale surveys were not possible; thus, the classification results were more reliable by reflecting the opinions of a small number of experts. The table provides a single chart of structural/job risks by combining various factors for workers to easily identify multiple risks.

Table 5. Risk factors of NPP decommissioning (cutting work)

Activities of cutting work	Hazard index	Structural risk								Job risk								
		CA	CI	DE	DU	EF	FA	FO	RA	CO	CU	EI	ES	FL	JA	PI	RC	RD
Transportation of wire-saw	G03, G04, G05, G10, G13, H01		✓				✓	✓		✓				✓	✓			
Arrangement wire-saw	A05, G05, G10, G13, H01		✓				✓	✓	✓	✓				✓	✓		✓	
Transportation of accessory equipment	G01, G03, G04, G05, G10, G13, H01		✓				✓			✓		✓		✓	✓			
Ready to install of wire-saw	G10, G11, H01			✓				✓			✓	✓		✓	✓	✓		
Installation of wire-saw	F01, G11, H01, H04			✓				✓						✓	✓			
Setting up	C03, G11, H01			✓		✓							✓			✓		
Fasten wire-saw	G05, G10, G13, H01, H03		✓												✓			
Rigging wire-saw chain	F01, G05, H01, H03		✓	✓						✓	✓	✓			✓	✓		
Installation of dust collector	B08, C02, G08, H01, H04					✓							✓					
Commissioning of equipment	B08, C03, F01, G07, G11, H01			✓		✓		✓					✓	✓	✓	✓		
Cutting	B08, C02, F01, G01, G07, G08, G10, G11, H01, H04			✓	✓	✓		✓					✓	✓	✓	✓		✓
Dismantling wire-saw	G01, G03, G04, G10, G13, H01, H03		✓				✓	✓		✓				✓	✓			
Setup cutting equipment for remained part	B08, C02, G01, G03, G04, G10, H01, H03	✓	✓				✓	✓		✓				✓	✓		✓	
Scabbling using breaker of scabbler	A05, B08, C02, F01, G01, G08, G10, H01, H04		✓				✓	✓	✓	✓				✓	✓		✓	

CA, collapse; CI, collision; DE, detachment; DU, dust; EF, electric failure; FA, fall; FO, fall object; RA, radioactive contamination; CO, collision; CU, cut; EI, eye injury; ES, electric shock; FL, fall; JA, jam; PI, projectile injury; RC, radioactive contamination; RD, respiratory disease.

Although work activity matches many structural and job risk factors, we cannot evaluate it as an urgent work at high risk. Additional analysis from various perspectives, such as the magnitude of difficulty of the work, frequency, and depth of risk, is required. Considering the results of the structural/job risks derived, collision, fall, fall object from the structural risk, and collision, fall, and jam from the job risk were relatively more numerous than the others. This was judged to be because of the decommissioning work characteristics, which require installing temporary structures and heavy equipment in a confined space. Suppose structural/job risks are classified by NPP decommissioning's detailed work considering the work location, work object, and equipment used, then potential risks can be identified and prevented before each job is performed. Thus, appropriate NPP decommissioning plans, risk-reduction measures, and countermeasures in the event of a disaster can be established. It can also be expected to apply to the entire scope of NPP decommissioning plans and the decommissioning work of the bio-shield concrete building.

Conclusions

NPP decommissioning projects are increasing globally due to environmental issues or designed life termination. The commercial NPP decommissioning project in Korea has not been conducted yet, and has been in the work process since the Kori 1 NPP was permanently suspended in 2017. Structural and job risk analysis and management characterizing radioactive contamination are critical for decommissioning work because they are directly related to the safety of workers. However, previous studies have shown that structural disasters and job risk factors that may occur during decommissioning work are not largely addressed compared to the risk of dismantling facilities, such as nuclear reactor dismantling. Furthermore, there is insufficient study on characterization of NPP decommissioning owing to low WBS level for deriving hazard factors as well as insufficient viewpoints of risk factors, such as one side among structural risk and job risk.

Structural disasters and job risks of workers are not systematically established. Therefore, this study aims to develop a sophisticated RBS model that characterizes NPP decommissioning work, and considers both structural and job risk, which can be utilized as the primary stage of risk analysis for NPP decommissioning projects. This study contributes to the body of construction management knowledge by developing a detailed WBS and RBS model to identify risk-related NPP decommissioning work. The results show one single chart that combines hazards, structural, and job risks for radioactive concrete cutting work of NPP decommissioning. Thus, assisting project managers to easily recognize the various risk factors. However, the limitation of this study is that it does not consider the entire work process for NPP decommissioning. Future studies should include more scopes of work and risk assessment.

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