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Development of guideline for safe decommissioning of concrete structures for nuclear facilities based on a comparative analysis with the previous asbestos dismantlement studies

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ABSTRACT

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The need to develop procedures and safety assessments for decommissioning is emerging as more nuclear power plants worldwide are planning closures for safety, political, and social reasons. However, due to the lack of empirical examples and data related to the decommissioning of nuclear power plants, it is not easy to develop and verify the procedures and safety assessments for decommissioning. Therefore, countries with little or no nuclear decommissioning experience should establish a strategy to conduct safe decommissioning through the analysis of existing cases. While most of the guidelines for the decommissioning of nuclear facilities focus on radiological risks, they are relatively negligent in handling non-radioactive risk factors. As nuclear decommissioning has many similar characteristics to the dismantling of concrete structures, a proper decommissioning plan considering those risk factors should be formulated to protect workers and prevent accidents. Thus, this study aimed to develop procedures for the safe decommissioning of concrete structures in nuclear facilities, taking into account not only radiological risks but also structural hazards. In this study, we proposed the basic guidelines for avoiding the safety risks with the decommissioning process of radioactive concrete structures in nuclear facilities through the comparison with asbestos dismantling that had similar processes from the preparation stage to the disposal stage and systematic management through many empirical cases. And we verified their validity through expert interviews.

Keywords: safety guideline; decommissioning process; dismantling; nuclear facility; radioactive concrete structure; comparative analysis

Introduction

The number of nuclear facilities that are planned to be shut down, as they reach the end of their design lifetime, or earlier for safety or political and social reasons, has been increasing worldwide. This has led to increase the awareness of the importance of developing safety standards and requirements for decommissioning [1]. As a result, industries related to decommissioning nuclear facilities are expanding, and research in various fields is underway to establish guidelines for safe decommissioning and secure the safety of dismantling them. Thus, for countries that have no experience in decommissioning nuclear power plants, it is necessary to establish a strategy to conduct safe decommissioning work through the analysis of existing cases.

However, most of the guidelines for the decommissioning of nuclear facilities focus on radiological risks and are relatively negligent in handling non-radioactive risk factors. In order to protect workers from nuclear decommissioning and prevent accidents, an appropriate decommissioning plan should be formulated, which takes into account both radioactive and non-radiation risks. In this regard, the U.S. Department of Energy (DOE) [2] noted that nuclear decommissioning has similar characteristics to demolishing concrete structures and, likewise, the management of structural hazards is important. Therefore, the purpose of this study is to develop procedures for the safe decommissioning of concrete structures in nuclear facilities by considering radiological risks and structural hazards [3]. Unlike the general dismantling of the construction industry, however, the decommissioning of nuclear power plants cannot be carried out unconditionally. This is because the concrete for radioactive rays shielding has been radiated, so the order and method of decommissioning are applied differently depending on the area.

The process of asbestos dismantling, which is managed as a Group 1 carcinogen, is similar to nuclear decommissioning. As the asbestos dismantling process has many applications, it has to be managed systematically. In this study, we proposed the development of safe decommissioning process of nuclear facilities in comparative analysis of commonalities with asbestos dismantling process and consideration of the specificity of nuclear decommissioning process and verified its adequacy.

Literature Review

Decommissioning of Nuclear Facilities

According to the International Atomic Energy Agency [4], decommissioning is defined as administrative and technical actions involving decontamination, dismantling and removal of radioactive materials, waste, components and structures taken to allow removal of some or all of the regulatory controls from nuclear facilities. Decommissioning is taken on the basis of prior planning and assessment to ensure safety during operations and conducted to achieve a gradual and systematic reduction in radiological risks.

The United States, the largest holder of nuclear facilities, has a lot of decommissioning experience, and the dismantling is still underway for continued nuclear power generation in line with the government's policy of reducing risks and ensuring the protection of the environment and public and workers' health in connection with the dismantling. The U.S. fully regulates all decommissioning projects by the Nuclear Regulatory Commission in the event of dismantling commercial reactors operated by private operators. In addition, in accordance with 10CFR50.82(a)(4)(i) of Code of Federal Regulations [5], the power reactor licensee is required to submit a post-shutdown decommissioning activities report (PSDAR) to the NRC within two years following permanent cessation of operations.

There are three strategies for decommissioning: immediate dismantling, deferred dismantling, and entombment [6]. Immediate dismantling is a form of decontamination and dismantling of equipment, structures, and radioactive wastes immediately after the approval is processed after the plant shuts down. It includes the prompt removal and process of all radioactive materials from the facilities for long-term storage or disposal. Major nuclear power plant-operating countries such as Germany and France prefer immediate dismantling methods, which are characterized by reusing sites, enhancing economic feasibility, and utilizing experienced personnel. Deferred dismantling is a strategy for long-term storage in which final dismantling of a facility is delayed and maintained in a safe condition. In this method, dismantling proceeds when the level of radioactive materials has reached a particular standard for a certain period through safety management and operation to reduce the systematic dose by the radioactive half-life effect following the time delay after obtaining the approval for the dismantling process. The deferred dismantling method is often used at multi-purpose sites if some facilities are shut down and others continue to operate. In addition, some countries may choose it due to the radiation graphite problem of graphite moderated furnace, the cost of dismantling, and the lack of radioactive waste disposal sites. Entombment is a strategy for locking radioactive contaminants in structurally long-lasting substances until radiation decreases from regulatory control to levels that allow the release of facilities. The presence of radioactive materials at the site means that the facility will eventually be designated as a surface waste site, and that it needs to meet the criteria of the facility. Table 1 shows the decommissioning strategies appropriate for each country's situation.

There are two ways to decommission nuclear power plants: hot to cold and cold to hot. The first method is usually implemented in countries with adequate experience in decommissioning nuclear power plants, such as the United States and Germany. In this method, high radiation dose areas are dismantled first followed by low radiation dose areas. This method has the advantage of reducing the decommissioning period, cost, and exposure to radiation. However, this requires experience and thorough preparations. The second method is usually implemented in countries with little or no experience in decommissioning nuclear power plants. In this method, dismantling proceeds from low radiation dose areas to high radiation dose areas. From this method, it is possible to gain experience in decommissioning nuclear power plants. However, in this method, there is a possibility of re-contamination in low-contamination areas while dismantling high-contamination areas.

Table 1. Each country decommissioning strategies

Nation	Strategies for Decommissioning
USA Germany France	Transition from Deferred dismantling to Immediate dismantling
Japan	Immediate dismantling / Deferred dismantling
UK	Deferred dismantling (due to the nature of the reactor type)
Canada Bulgaria	Deferred dismantling

Nuclear power plants generally operate for 30 to 60 years, although they vary depending on the situation in the country or power plants. In Korea, 24 nuclear power plants are in operation and 12 design lifetime is expected to be completed by 2029 [7]. In the case of Gori-1 reactor, immediate dismantling and gradual dismantling are underway. Thus, this study is based on the process of decommissioning concrete structures that make up the reactor in the immediate dismantling method.

Comparative Analysis of the Demolition Process of Nuclear Facilities and Asbestos Structures

Procedure of Asbestos Demolition

Asbestos, which is used in insulation, is a fibrous inorganic material that exists in nature with a very stable chemical structure. However, it is currently prohibited because it is a Category 1A carcinogen [8]. Asbestos is a soft non-flammable material available in the form of fine fiber strands, as shown in Figure 1. When asbestos enters the lungs through the respiratory tract, asbestos fibers cannot be released from the lungs and thereby damages the cell membrane of the lungs causing pneumoconiosis, asbestosis, and fibrosis of the lungs, which eventually results in cancer [9]. The characteristics of asbestos are defined in the Material Safety Data Sheet.

If the sum of the area of the wall, flooring, ceiling, and roof materials containing more than 1% asbestos is more than 50 m^2, the Asbestos Safety Management Act stipulates the management guidelines. To dismantle asbestos, preliminary investigation for analyzing asbestos content and pre-training of workers should be conducted. The education of workers handling asbestos includes the effects of asbestos on the human body, the form of disease occurring, measures to prevent disease outbreaks, and safe working methods.

The main contents of the asbestos dismantling process stipulated in the Asbestos Safety Management Act is listed below.

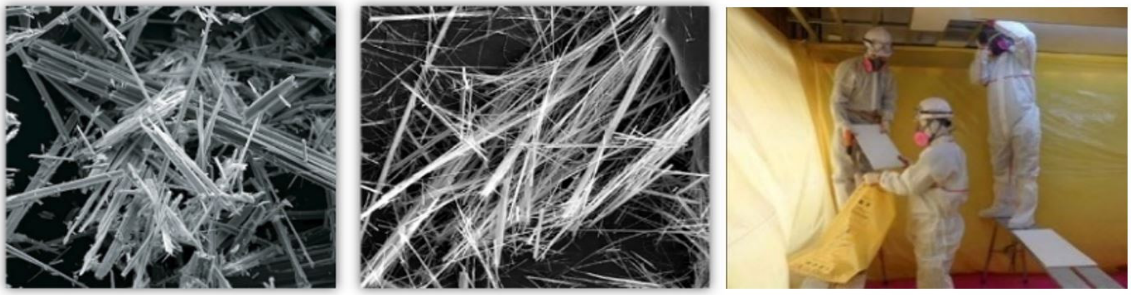

Figure 1. Asbestos crystalline and dismantling foreground.

First, as a preliminary investigation, the history of materials used in the building or the analysis of components are investigated for the presence of asbestos in the building. This is not provided in the relevant laws, but prior verification is required in accordance with the procedures prescribed by the Asbestos Disorder Prevention Rules. In the preliminary investigation, samples are collected and analyzed to examine the type of finishing materials used in each room and the shape of asbestos-containing substances. Methods for measuring asbestos concentration include the Bulk Sample analysis method, the X-ray diffraction method, the Air Sample analysis method, and the polarized microscope method. If asbestos content is confirmed as a result of the investigation, the type, location, scope of them are recorded and preserved until the end of the dismantling.

Second, if asbestos content is found to be above the regulations, a work plan for asbestos dismantling and removal can be established, and the dismantling work can be carried out after obtaining approval for submission from the head of a local labor office. The document of work plan includes procedures and methods for dismantling and removing asbestos, removal facilities and disposal methods to prevent scattering of asbestos, and plans for measures to protect workers, and education should be provided to inform workers of the work plan.

Third, a warning board must be installed before dismantling. The warning sign of "Authorized Personnel Only" should be manufactured and installed at least 70cm in width, 50cm in length with a letter size of 8cm in width and 10cm in length in accordance with the regulations.

Fourth, the employer must provide workers with special filter masks or air supplied respirators, and personal protective eyewear, impervious protective clothing, protective gloves, protective boots, etc., and the worker must wear protective gear. When asbestos dismantling activities begins, all but decommissioning workers will be banned from entering the workplaces and smoking or eating food will be prohibited in the workplace.

Fifth, the interior dismantling space of asbestos shall be equipped with a negative pressure air filtration ventilation system with the high efficiency particulate air filter (HEPA filter) after sealing off openings such as windows and blocking all existing ventilation systems and electrical equipment. At this time, the negative pressure should be measured from start to the end of work using a negative pressure recorder and it should be maintained at -0.508 mmH_2O. It is recommended to double cover impermeable polyethylene sheets with a thickness of not less than 0.15 mm on the floor and 0.08 mm on the wall. In addition, decontamination facilities should be installed in the passageways for the entry and exit of equipment and dismantling workers.

Disposal of Asbestos Dismantling Waste

Asbestos waste must be disposed because it contains more than 1% concentration of asbestos by weight. A particular concern is the management of brittle asbestos waste. Moreover, friable materials are more likely to release fiber into the air.

Disposal of waste containing disassembled asbestos is prescribed in the Enforcement Decree of the Occupational Safety and Health Act and special management industrial wastes disposal standards of the Wastes Control Act. The requirements of the person in charge of special management of industrial waste management are stipulated by qualifications and educational background. The container must be wiped or vacuumed with a HEPA vacuum cleaner. Additionally, the material should not be broken into smaller pieces to fill them into containers unless it is performed under negative air conditions with the capability of applying a mist when necessary to reduce fiber levels. Waste materials, including discarded polyethylene sheeting, sealing tape, cleaning materials, protective clothing, vacuum bags, and other contaminated materials, are treated as any other asbestos-containing material for disposal [10]. The regulations stipulate that asbestos waste should be disposed of in containers or packages marked with a label saying “asbestos content.” The final disposal of wastes is managed through reclamation.

The electric machine used for dismantling should be equipped with short circuit breakers to prevent electric shock accidents caused by wet work. After the completion of dismantling work, equipment such as ladders and temporary workbench should be cleaned with a wet mop or vacuum cleaner equipped with a HEPA filter. If a negative pressure-tightening system is installed, it must be operated continuously while cleaning and HEPA filters must be replaced or repaired in an enclosed workplace where negative pressure is maintained.

The transport vehicle for asbestos disposal shall be marked as an industrial waste collection vehicle on the outside of the vehicle body, and measures shall be taken to prevent waste asbestos from scattering or leaking. The container shall be of a structure in which dust cannot be blown and shall be taken to prevent it from falling or moving during transport. The form of the container shall be constructed in a structure suitable for the appearance and shape of the waste so that asbestos dismantling materials are not damaged. The storage container shall be of a structure in which asbestos does not penetrate, and proper marking shall be made so that it can be shown that asbestos waste is included on the outside.

Waste asbestos should be disposed in a landfill pursuant to Article 15 of the Waste Disposal Act. This shall be performed at the final disposal site authorized by the Mayor or Provincial Governor. Additionally, disposal shall not be performed via marine dumping.

Procedure of Nuclear Facilities Decommissioning

It is important to ensure stability against contamination and damage risks to workers and the surrounding environment because the hazard risk caused by the release of radiation is high when the reactor is decommissioned. In Korea, the Nuclear Safety Act has set the standards for decommissioning and provides for management of spent nuclear fuel, interim management, and permanent disposal [11]. However, these regulations only established the general items that should be included in the decommissioning plan and the fact that it should be submitted to the Nuclear Safety and Security Commission before decommissioning the reactor. Moreover, there is no specific licensing procedure for the period between permanent shutdown of the reactor and restoration of the site. The detailed guidelines for preparing the decommissioning plan will be provided in the following sections.

Radioactive Waste Management

As there are several types of radioactive nuclide whose half-life varies from 82 million to 6500 years, proper understanding and precise analysis techniques are required for different types of spent nuclear fuel. Radioactive materials are classified into nuclear fuel materials, spent nuclear fuel, radioisotopes, and nuclear fission products.

The radioactive wastes resulting from nuclear decommissioning should be disposed as radioactive materials or contaminated materials. Depending on the concentration of radioactive materials and the characteristics of dismantling materials, the treatment method of radioactive wastes will also vary. The disposal methods are classified into self-disposal waste and radioactive waste based on the degree of contamination, and radioactive waste is disposed of through solidification and stabilization. Radiation waste is disposed using technologies like heat treatment and liquid waste treatment, and then sealed in a transport container and transported to a storage location. The key technology for disposing radioactive waste, various technologies are applied to separate radioactive materials to reduce volume and reduce risk [12].

The equipment and tools used for dismantling the facility are disposed in the same manner as the structure on the premise of contamination by exposure.

The permanent storage of radioactive waste is prescribed by the Radioactive Waste Management Act along with the characteristic criteria for waste disposal, radiological characteristics of waste package, and chemical properties of waste. The method of checking the suitability of wastes should include preliminary inspection, acceptance test of disposal facilities, application method of preliminary inspection and acceptance test, physical characteristics of waste packaging, and chemical characteristics of waste packaging, etc. Moreover, the safety assessment should be conducted by stipulating the measures for nonconforming waste packages in case of nonconformity.

Guideline for Safe Decommissioning based on the Comparative Analysis with the Asbestos Dismantlement Process

The similarity between nuclear decommissioning and asbestos dismantling process is that it must comply with the prescribed regulations to ensure safety from the preparation to the implementing phase in the process of handling hazardous wastes. Although the preparation steps and process for decommissioning nuclear power plants have several differences in compliance with larger structures and procedures, the overall procedure is similar to that of asbestos. In this study, the process for maintaining safety was derived by comparing the commonalities with the asbestos dismantling process, whose performance data were accumulated and systematic management was performed for several years, and the specificity of the nuclear decommissioning process alone. The commonalities and differences between asbestos and nuclear facility dismantling processes are summarized in Table 2.

As shown in Table 2, both activities have some common features, i.e., they are both subjected to intensive management through special regulations because they produce carcinogens and are strictly managed from the pre-preparatory stage by special law. Furthermore, maintaining the stability to prevent the respiratory disease caused by scattering is a major requirement. However, this is different in the case of nuclear facilities, which are larger in scale and pose a higher safety risk in the working environment, such as protection of workers against radiation exposure during the dismantling of concrete structures. Additionally, for decommissioning nuclear facilities, the disposal plan should be established, provided that the equipment deployed is contaminated with radiation.

Table 2. Comparison of Asbestos Demolition and Nuclear Decommissioning

	Asbestos	Nuclear Power Plant
Law related to dismantling	Asbestos Safety Management Act	Nuclear Safety Act
Environmental risk factor	Asbestos: Release of carcinogen in category 1A	Cancer caused by exposure to radioactive materials
Interior space	HEPA filter ventilation	HEPA filter ventilation, Self-dust collection
Worker	Wearing protective clothing	Wearing protective clothing and equipment for monitoring radiation exposure
Equipment used	Clean and take all out of the workspace	Can be taken out after some decontamination, Mostly disposal
Law related to disposal	Wastes Control Act	Radioactive Waste Management Act

Based on the empirical data from the asbestos dismantling process and the similarities/differences in each phase of the dismantling technology of radioactive structures, a comparative analysis was performed based on the process of deriving the risk factors in each phase of decommissioning the radioactive concrete structure.

A work breakdown structure draft was presented based on a comparative analysis aforementioned using the empirical data from the asbestos dismantling process the decommissioning procedure of radioactive structures and overseas related data [13]. As shown in Table 3, the overall process was subdivided into three levels. The first level, i.e., from the preparation stage to the dismantling and transportation stage, was divided into seven stages, whereas the second level was subdivided based on the required processes of each stage. In level 3, the work was detailed and classified into a progress process.

Table 3. Decommissioning (Decontamination/Dismantlement) Process

Level 1	Level 2	Level 3
Work Type	Work Content	Work Detail
1. Preparation Work	1.1 Installation of utility supplies such as electric power	1.1.1 Carrying internal power supplies
		1.1.2 Installing internal power supply
	1.2 Lighting installation	1.2.1 Transporting to the interior of lighting fixtures
		1.2.2 Installing of lighting equipment
	1.3 Installation of temporary ventilation system	1.3.1 Transporting to the interior of temporary ventilation system
		1.3.2 Installing connections with existing vents
	1.4 Installation of air pollution monitor	1.4.1 Transporting to the interior of air pollution monitor
		1.4.2 Installing air pollution monitor
	1.5 Installation of a frame scaffold in a containment building (exterior of bioshield wall)	1.5.1 Material conveyance
		1.5.2 Installing intertruss bracing and column member
		1.5.3 Transport and installation of rope for the safety board
		1.5.4 Carrying and installation of brace
		1.5.5 Transport and installation of safety rails, fixed clamps
		1.5.6 Transport and installation of scaffold top furring strips, perforated plate, etc.
		1.5.7 Repetition of 1.5.1 to 1.5.6 (dismantling from the upper management layer)

Table 3. Decommissioning (Decontamination/Dismantlement) Process (Continued)

Level 1	Level 2	Level 3
Work Type	Work Content	Work Detail
2. Cutting Work (non-radioactive area)	2.1 Drilling and cutting the slab core for each floor in the containment building	2.1.1 Bringing in a core drilling machine (located on the working floor slab)
		2.1.2 Interlayer slab transportable standard marking and drilling
		2.1.3 Conveyance hole to crane connection (prevent fall and drop)
		2.1.4 Moving and storing to temporary storage after completion of drilling according to cut size by section
	2.2 Preparing to demolish the non-radioactive area outside the bioshield wall	2.2.1 Bringing in crushing equipment (breakers, rebar cutters, etc.)
		2.2.2 Bringing in crushed concrete collection equipment (back hoe, etc.)
		2.2.3 Marking crushable depth by vertical position
	2.3 Crushing of non-radioactive area outside the bioshield wall	2.3.1 Crushing of non-radioactive area (measuring the degree of contamination by certain sections)
		2.3.2 - Immediately stop crushing when a radioactively contaminated meter warning sounds - Rapidly block and decontaminate contaminated areas
		2.3.3 Moving the crushing remnants to a temporary storage using the collection equipment and storing them
3. Temporary storage (non-contaminated demolition residue)	3.1 Checking the contamination level of temporary storage and taking outside	3.1.1 Checking the contamination level of the temporary storage area
		3.1.2 Carrying out after loading outer vehicle
4. Decontamination work	4.1 Sampling using a scabbler	4.1.1 Conveyance of scabbler
		4.1.2 Removing surface with scabbler
		4.1.3 Conducting a sample nuclide analysis
		4.1.4 Determination and marking the removal location, depth based on analysis results
	4.2 Surface decontamination with scabbler	4.2.1 Surface decontamination using scabbler
		4.2.2 Disposal of radioactive concrete residue
5. Drilling Work	5.1 Marking removal range using wheel saw (rail stone cutting machine)	5.1.1 Transport wheel saw to work zone
		5.1.2 Installation of wheel saw using core drilling
		5.1.3 Making groves as deep as the removal using the wheel saw
	5.2 Drilling for safety and transportation and fixed to overhead polar crane	5.2.1 Conveyance of piercer
		5.2.2 Perforation of marked area
		5.2.3 Installing the chain in the perforated part
	5.3 Drilling for wire installation during cutting work	5.3.1 Perforation up to concrete cutting mark
6. Cutting Work (radioactive area)	6.1 Wire saw installation	6.1.1 Wire saw transport
		6.1.2 Wire saw installation
	6.2 Cutting using wire saw	6.2.1 Cutting radioactive concrete using wire saw
	6.3 Removal of residual concrete	6.3.1 Removal of residual concrete with breaker or scabbler
7. Transport work	7.1 Concrete perforation for lifting	7.1.1 Setting drilling location according to site condition
		7.1.2 Perforation of marked area
		7.1.3 Inserting wire into perforated hole
	7.2 Lifting concrete	7.2.1 Putting it down on the floor using the crane
	7.3 Transporting to the temporary storage, storing, and decontamination	7.3.1 Transport to the temporary storage and open storage
		7.3.2 Decontamination in temporary storage (out-of-process work if necessary)
	Re-cutting according to transport method	7.3.3 Carrying out additional work, such as re-cutting, when changing transport containers and methods
	7.4 Taking outside	7.4.1 Containment in carrying container
		7.4.2 Loading on the transporting vehicle
		7.4.3 Taking outside using transporting vehicle

Additionally, the risk factors were derived for each process. In this study, the risk factors were derived from surveys and in-depth interviews of 12 experts in the relevant field, including research institutes, construction management experts, structural engineering experts, and dismantling-related mechanical experts. Furthermore, we presented procedures and risk avoidance measures for each detailed process based on the decommissioning process of the structure through the in-depth interviews with experts. Finally, after reviewing the procedures presented in ISO criteria [14-16], the scope of application was confirmed through verification by external members specializing in ISO certification and evaluation of applicable items and procedures. The process of revising the procedures for problems derived from the assessment was repeated.

The work was initially divided into five stages: (1) Preparation Work, (2) Decontamination work, (3) Drilling Work, (4) Cutting Work, (5) Transport work. However, we divided the work into seven stages as above, as we had obtained results from in-depth expert interviews that countries with little or no experience in decommissioning should cut the areas of non-radiation and radiation, respectively, to ensure safety.

In the preliminary investigation and preparation phase, the decommissioning plan should be established by analyzing the characteristics of the reactor structure and separating the radioactive and non-radioactive parts. The process should start by dismantling the non- radioactive area and end by dismantling the radioactive area. The activities in the exterior part of the reactor, which is the non- radioactive area, shall be planned in accordance with the safety standards of general construction work, whereas the activities in the radioactive area should be planned by considering the exposure to radioactive materials. The process of analyzing the exposure dose criteria and exposure volume by location in advance is the key to the safety assessment for decommissioning.

During the dismantling phase, it is important to establish a carry-in plan for equipment, ventilation and lighting facilities, etc. The suitability of filters for ventilation of the dismantling space should be analyzed. The dismantling of structures in non-radioactive areas should be performed using small and medium-sized dismantling equipment among the existing equipment.

To perform the decontamination work, a scaffold or mobile gondola should be installed for decontamination. As the decontamination equipment and workers are located on the scaffolding, the risk factors for decontamination work includes the risk of exposure due to damage to protective clothing, delay of work, and risk factors, such as falls and stenosis. The decontamination technology is divided into mechanical, physical, chemical, and electrochemical decontamination. However, mechanical decontamination is usually applied to structures. The removal of contaminants by polishing, among various physical methods, consists of devices with abrasives attached to them and devices that can collect the powder of polished contaminants. The abrasive can be distinguished from the automatic operation method and worker's direct operation. The dust collection method is also similar.

During the dismantling phase of the radioactive area, removal of radioactive contaminated parts of the reactor is made up of unmanned or manned and is under construction and demonstration of various equipment for the development and application of dedicated equipment, some of which are practical. The demolition of the radioactive parts of the structure is executed using special equipment, such as wire saw, after decontamination. To ensure stability against scattering dust during cutting, the primary dust should be collected by directly inhaling from the cutting surface. In the secondary collection, it is important to maintain the performance of filters in ventilation facilities for external pollution prevention. Additionally, continuous pollution measurement is required to ensure safety.

After cutting, the volume is reduced through heat treatment and stored in a transport container. Based on the type of radioactive materials and the limit of radioactivity, transport types and containers are classified into types L, IP, B, C, and fissile materials. Type L is classified as a radiation drug, Type IP is a low-level waste, Type A is a new fuel, Type C is air transport, and for fissile material, regulations not in the IAEA are classified as separate regulations in Korea. The safety of transport containers shall be ensured using the main test of transport containers to prevent the risk of movement or leakage of contaminants during long-term storage. Additionally, technologies, such as evaporation concentration, chemical sedimentation, organic ion exchange, reverse osmotic pressure, electrodialysis, ultrafiltration, and microfiltration are applied with liquid waste treatment technology. Generally, melting technology is used for disposing metal waste and to reduce the volume of waste for disposal by melting metal. Finally, the treatment techniques of concrete should be decontaminated on the dismantling structure, and mechanical decontamination, chemical decontamination, volume reduction technology, post-corrosion recycling, and hardening techniques should be applied.

6.2.1 Cutting radioactive concrete using wire saw

Preceding work	Detailed work	Risk factors and checkslists
- Work with wheel saw - Drill perforation - Fixing to the crane - Wire saw installation	① Fixing wire saw	Make sure that the wire saw is placed stably
	② Installation of wire saw chain	Connect the wire between the main body of the wire saw and the cutting surface
	③ Installation of dust collector	Install the dust collector on the cutting surface airtightly
	④ Running test	Check for the abnormality in the rotation of the wire saw
	⑤ Cutting	If there is no problem with the running test, check the operation of the equipment during the cutting Check the safety of wire saw shut down during final cutting

Detailed Work	Risk Avoidance and Safety Assurance Measures
① Fixing wire saw	- Check whether or not stuffs are placed near the location of wire saw equipment - Secure safety of the area around the wire connection part between the wire saw equipment and the cut surface - Check the installation status of work radius workers' curfew facilities
② Installation of wire saw chain	- Check for risk factors such as strain, twist when installing wires in the grooves of the wire saw body and cut area - Check the stability of wire insertion into the cutting surface groove
③ Installation of dust collector	- Examine the adequacy of scattering dust collection on the cutting surface by dry cutting method - Check whether dust is generated around the dust collector - Examine the adequacy of dust treatment collected in the dust collector
④ Running test	- Check whether the degree of wire tension during operation of wire saw is normal - Check that the wire saw is operating out of the cutting groove
⑤ Cutting	- Confirm wire cutting during cutting work - Prohibit access to range of breakaway from wire saw of workers during the final cutting work

Figure 2. Example of detailed work process flow chart and risk avoidance and safety guideline.

In Figure 2, 6.2.1 correspond to the code number of the detailed process. It displays the preceding work to complete and cooperate with the preceding work and scheming the detailed work in chronological order. Risk factors derived for each process include activities that are distinct from asbestos dismantling, resulting in dangerous factors, such as collapse, fall, eye attack, fire, etc. Thus, the guidelines for risk avoidance and reduction based on the scenarios for decommissioning concrete structures in nuclear power plants based on the derived risk factors and checklists were deduced.

Finally, the process and guidelines were verified through the risk assessment of asbestos dismantling techniques, self-comparative verification that considers the characteristics of nuclear power plant concrete structures, and consultation with experts in the nuclear field and specialist in ISO standard procedure certification assessment.

Conclusions

In this study, the basic guidelines for deriving hazards and avoiding safety risks in the decommissioning process of radioactive concrete structures in nuclear facilities were presented by comparing it with the asbestos dismantling process, which is has similar processes from the pre-stage to the disposal stage due to lack of empirical verification.

As the measure for each phase, the preparation phase derived the risk factors that could occur during decontamination and dismantling based on the scenario and the safety management. Moreover, the decommissioning procedure was derived considering the structural safety of the decontamination and dismantling process. In the cutting work, the need to design an equipment and manpower layout and introduce exposure prevention technologies, such as unmanned dismantling technology, in the radioactive concrete area were discussed. The need for differentiation based on the size and degree of contamination of storage containers after dismantling, volume reduction technology of wastes, and safety assessment through secondary decontamination work were also discussed.

As decontamination and dismantling of radioactive structures are an important process that determines cost and safety, the preparation of decommissioning process is indispensable. Moreover, additional research is consistently required to develop procedures and guidelines for safety assessment in each phase of decommissioning.

In this study, there were limitations in comparative analysis with the asbestos dismantling process due to security issues preventing access to drawings of nuclear facilities. However, we hope that future studies will develop complementary guidelines by demonstration actual decommissioning and segmentation of processes.

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