Technical Paper https://doi.org/10.7733/jnfcwt.2017.15.4.355

The Dismantling and Disposal Strategy of a Biological Shield for Minimization of Radioactive Concrete Waste During Decommissioning of a Nuclear Power Plant

원전 해체 방사성 콘크리트 폐기물 최소화를 위한 생물학적 차폐체 제거 및 처분 전략

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(Received July 13, 2017 / Revised August 18, 2017 / Approved September 18, 2017)

The decommissioning of Kori unit 1, which was permanently shut down in June of 2017, will be the first instance of the dismantling of a commercial nuclear power plant in Korea. The disposal of waste during the dismantling process accounts for a large part of the total decommissioning cost. Therefore, structures consisting of activated and contaminated concrete must be economically and safely dismantled by establishing a proper dismantling strategy. This study focuses on optimized dismantling and disposal scenarios pertaining to a biological shield. Several dismantling cases, regulations and technologies related to waste treatment as these practices pertain to nuclear power plants are analyzed. To minimize the amount of waste from the biological shield dismantling process, an optimized dismantling scenario is presented and disposal alternatives for dismantled concrete waste are proposed.

Keywords: Decommissioning, Concrete waste, Biological shield, Volume reduction, Waste disposal

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2017년 6월에 영구정지 된 고리 1호기의 해체는 한국의 상업 원전에 대한 첫 해체 사례가 될 것이다. 해체 과정 중에 발생하는 폐기물에 대한 처분은 전체 해체 비용의 많은 부분을 차지한다. 따라서 방사화 및 오염된 콘크리트 구조물은 적절한 해체 전략을 수립하여 경제적이고 안전하게 해체되어야 한다. 본 논문에서는 생물학적 차폐체에 대한 최적화된 해체 및 처분 시나리오를 연구하였다. 해체사례, 폐기물 처분 규정 및 처리 기술을 분석하였다. 그리고 생물학적 차폐체 제거 과정의 폐기물 발생량을 최소화하기 위해서, 최적 해체 시나리오를 제시하였고 폐기물 처분 방안을 도출하였다.

중심단어: 해체, 콘크리트 폐기물, 생물학적 차폐체, 감용, 폐기물 처분

1. Introduction

The decommissioning of Kori unit 1, Korea's first commercial Nuclear Power Plant (NPP), is planned in the immediate future. It will be the first large-scale dismantling experience of a commercial NPP in Korea. Thorough preparations and establishment of proper strategies are required to lead this project successfully. In particular, waste management is the key factor for the successful decommissioning project because waste disposal cost accounts for more than 40% of the total decommissioning cost.

According to the national policy direction of the nuclear decommissioning industry confirmed by the 5th Atomic Energy Promotion Council (AEPC) in 2015, the target of decommissioning waste generation was set at 14,500 EA of 200 L drums per unit. This amounts to 18.1% of the expected initial decommissioning waste generation of 80,000 EA of 200 L drums per unit [1]. Therefore, active and efficient volume reduction efforts are needed to reach the target. Radioactive waste generated from dismantling depends on various factors such as the operation history of a NPP, dismantling strategy, regulations for radioactive waste and cooling period after shutdown. Therefore, establishing proper dismantling strategies through case study and regulatory analysis could contribute to significant reduction of waste generation.

Concrete waste will take the major portion of decommissioning waste accounting for more than 50%. Many researches for the volume reduction and recycling of concrete waste have been carried out in Korea. However, it is necessary to establish specific dismantling and disposal processes for radioactive concrete structures, in preparation for the first NPP decommissioning project.

Radioactive concrete waste can be divided into contaminated concrete and activated concrete. Contaminated concrete waste can be reduced significantly by applying proper decontamination technologies. However, deeply activated concrete is hard to be removed by decontamination. Therefore, an efficient treatment strategy for activated concrete is essential for the minimization of the radioactive waste disposal.

The most important and massive activated concrete structure in a NPP is the biological shield around the reactor vessel. The biological shield has been activated by thermal and resonance neutron flux during the operational period. Establishment of proper dismantling and disposal strategies of the biological shield enables significant radioactive waste minimization and disposal cost savings. In this study, an optimized dismantling scenario of biological shield concrete is suggested through the analysis of international cases, applicable regulations and technologies.

2. Methodology

In order to develop an optimized biological shield dismantling and disposal scenario, international dismantling experiences were reviewed. As a result, dismantling pro-

Table 1. Biological shield dismantling cases

Reactor	Nation	Capacity (MWth)	Reactor type	Shutdown year	Cutting technology
Big Rock Point	USA	240	BWR	1997	Diamond wire cutting
La Crosse	USA	165	BWR	1987	Diamond wire cutting
KRR-2	South Korea	2	Research Reactor	1995	Diamond wire cutting
ASTRA	Austria	10	Research Reactor	1999	Wire cutting
MZFR	German	200	Research Reactor	1984	Remote-controlled electrohydraulic demolition excavator

cess of biological shield was analyzed. Table 1 shows the information about the biological shield dismantling cases.

2.1 Big Rock Point [2]

Big Rock Point was a Boiling Water Reactor (BWR) operated from 1962 to 1997. The biological shield demolition required segmenting and removing for burial over 1,500 tons of highly activated concrete surrounding the previously-removed reactor vessel. To access the activated concrete, the biological shield overburden concrete had to be removed. This concrete was cut and removed in 50 pieces, each weighing approximately 40,000 lbs. To minimize burial costs the activated concrete surrounding the reactor cavity was cut into individual concrete blocks, leaving the balance of the non-activated mass concrete intact. Cutting was done from the top down in a plunge cut or band saw fashion. In all, 4 rows of 8 blocks were cut and removed.

2.2 La Crosse [2, 3]

La Crosse was a BWR built in 1967 as part of a federal project to demonstrate the viability of peacetime nuclear power. The biological shield wall had significant challenges due to very tight tolerances. Precise wire access and rigging holes had to be diamond core drilled at compound angles through up to 10 feet of concrete and steel plate in order to penetrate the circular edge of the shield wall without touching the vessel. With precision layout and specially designed angle brackets all holes were drilled in the proper orientation. Cutting then proceeded from the top down, cutting the biological shield wall into 20 ton sections. In all, 23 separate sections of biological shield wall were cut and removed.

2.3 KRR-2 [4, 5]

Korea Research Reactor-2 (KRR-2) was one of the KAERI's first two research reactors before the development of High-flux Advanced Neutron Application Reactor (HANARO). For the dismantlement of the biological shield, matrix sampling from the surface and along the depth of the concrete was carried out. From the result of the radioactivity sampling, the cutting line between the activated and non-activated area was designed. For the dismantling, the technologies of a core boring, diamond wire sawing and hydraulic crushing were applied. Total 1,913 tons of concrete was dismantled. Among the dismantled waste, 13.2% of the concrete waste was classified as radioactive waste which were stored in the 38 EA of 4 m^3 containers and 59EA of 200 L drums.

2.4 ASTRA [6]

ASTRA was a 10 MWth Austrian research reactor which had been operated for 39 years. It was a Materials

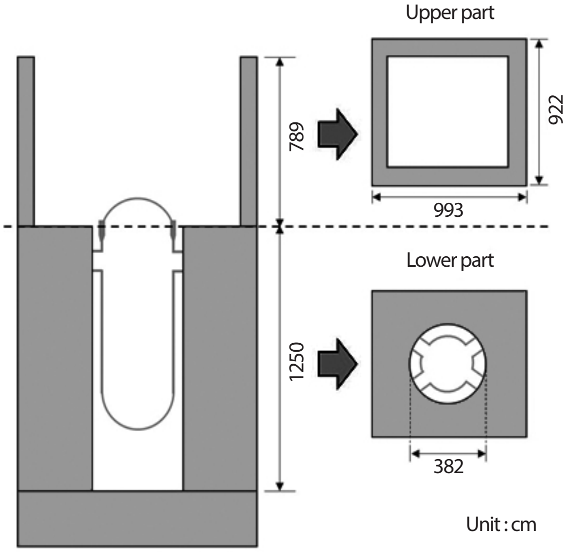

Fig. 1. Geometrical structure of Kori unit 1 biological shield [8, 9].

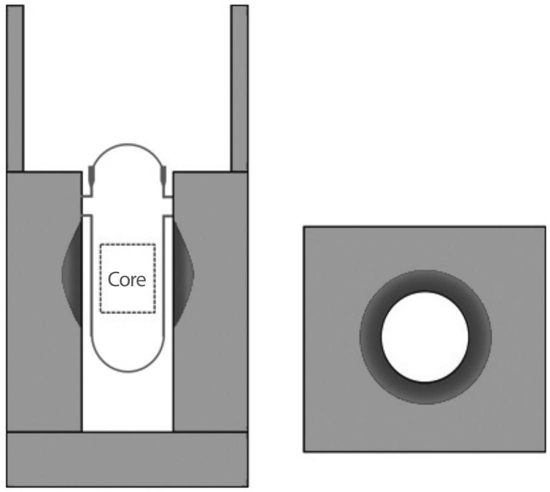

Fig. 2. Conceptual profile of the activation of the Kori unit 1 biological shield.

Test Reactor (MTR). After extensive sampling was performed, the biological shield was divided into blocks of between 7 and 9 tons considering the limitation by the 10-ton-capability of the crane. Wire cutting was chosen as the most promising method for cutting the shield. Among 1,580 tons of removed concrete waste, only 26.5 ton (1.7%) was classified as radioactive waste.

2.5 MZFR [7]

MZFR was a German's 200 MWth multi-purpose research reactor constructed in the early 1960s. It was used as a prototype reactor for the development of reactor materials and the testing of fuel elements and heavy water systems. For the dismantling of the biological shield, remote handling system was applied due to the radiological conditions. This case could be referred to as a good example in case of dismantling a biological shield in a poor work environment with the limited space and the ambient dose rate that was too high for manual work.

3. Activation analysis

3.1 Activation distribution profile

The shape and thickness of a biological shield vary depending on the specific reactor type and design. Therefore, recognizing the exact shape and size of a biological shield should be the first step for establishing dismantling strategies. Fig. 1 shows the geometrical structure of the Kori unit 1 biological shield [8, 9]. The biological shield can be divided into an upper part and a lower part. The upper part is a rectangular-type structure with a thickness of about 30 cm. The lower part is a cylindrical-type structure with a thickness of 200 to 267 cm. The density of the concrete is 2.24 g·cm^{-3} and total amount of the concrete is 2,100 tons [10].

After identifying the geometrical features, the characteristics of the radioactive distribution of the concrete structure should be analyzed through accurate sample analysis for an optimal design of cutting lines. Extensive characterization efforts contribute substantially to the overall cost of a decommissioning project [11]. The degree of activation is different depending on the impurities of concrete [12] and neutron flux history during operational period. It also depends on the cooling period after a shutdown. After a NPP is permanently shut down for decommissioning, there

Table 2. Results of the activation analysis [12]

Item	No impurity	Impurity 1	Impurity 2	Impurity 3	Impurity 4	Impurity 5
Specific activity (Bq·g^{-1})	3.99×10^{2}	2.44×10^{3}	8.62×10^{3}	5.12×10^{2}	1.27×10^{4}	8.14×10^{3}
Major nuclide of waste level	C^{14}	Eu^{152}	Eu^{152}	Co^{60}	Eu^{152}	Eu^{152}
$\sum_{i=1}^{n}\frac{A_i}{CW_i}$	2	20,275	82,143	1,032	101,548	57,969
Waste Level	VLLW	LLW	LLW	LLW	LLW	LLW

A_i : Specific activity of isotope I (Bq·g^{-1}), CW_i : The radioactivity limit of clearance waste (Bq·g^{-1})

should be a safety management period of at least 5 years to cool down the spent nuclear fuels. An estimation of activation products inventory in the biological shield of Kori unit 1 shows the radioactivity of the biological shield concrete decreases exponentially with the cooling period and is reduced up to 1% of the initial radioactivity after a 10 years of cooling period [10]. Therefore, the exact activation inventory of the biological shield needs to be measured just before the dismantlement for an accurate analysis of radioactivity.

Sampling should be carried out from the surface and along the depth of the concrete and sufficient sampling is needed taking into account the adequacy of representation. A core drilling machine is used to take samples. From the sampling results, a three dimensional mapping of the vertical and horizontal radioactivity is possible to design accurate cutting lines.

Activation is proportional to the neutron flux during operational period. Therefore, international cases of biological shield activation distribution show intense activation around the core area and they generally have bell-shaped distribution vertically showing the highest activity at the effective core center [6, 8]. Meanwhile, horizontal radioactivity distribution shows exponential reduction from the inner wall [5, 6]. Considering this horizontal and vertical activation distribution, the three-dimensional radioactivity distributions could be drawn to design efficient cutting lines. Fig. 2 shows conceptual profile of the activation of the Kori unit 1 biological shield.

3.2 The estimation of radioactive waste level from the biological shield

The level of radioactive waste generated from dismantling the biological shield can be calculated differently depending on the impurities contained in the concrete. Some impurity nuclides with a large neutron absorption cross section have a large effect on the radioactive nuclide inventory. Table 2 shows the result of the activation evaluation of a light water reactor biological shield in the case of including no impurity and in the case of using impurity information applied from 5 reference data including NUREG/CR-3474 [12]. The evaluation results show that the most activated part of the biological shield is Very Low Level Waste (VLLW) when impurity is not contained and Low Level Waste (LLW) when impurity is contained. Based on this study, it can be predicted that VLLW or both LLW and VLLW will be generated from the biological shield.

3.3 The estimation of radioactive waste amount from the biological shield

The degree of activation of biological shield concrete depends significantly on the impurities contained in the concrete. Unlike metallic materials, which are specified in the technical standards of the American Society of Mechanical Engineers (ASME), concrete has no limit on the content of constituents, and the content of impurities can

Table 3. Radioactive waste generation according to the biological shield activation depth

	Activation Depth (cm)											
	10	20	30	40	50	60	70	80	90	100	110	120
Activated Volume (m^3)	4.5	9.2	14.2	19.4	24.8	30.5	36.4	42.5	48.8	55.4	62.2	69.3
Drums (EA)	27	54	84	114	146	179	214	250	287	326	366	407
Percentage to the Target (%)	0.18	0.38	0.58	0.79	1.01	1.24	1.48	1.72	1.98	2.25	2.52	2.81

Table 4. Cutting Technique for concrete [11]

Technique	Cutting Speed	Liquid Waste	Solid Waste	Approximate Cost	Containment	HEPA Ventilation	Maximum Cut
Diamond Wire	7-9 $ft{\cdot}h^{-1}$	3-5 $gal{\cdot}min^{-1}$	Material debris	\$300$\cdot h^{-1}$rental	No	No	Unlimited
Water Jet	5 $ft^2{\cdot}h^{-1}$	1.4 $gal{\cdot}min^{-1}$	Material debris	\$174 $K{\cdot}unit^{-1}$	No	No	Unlimited
Controlled Explosive	Immediate	None	None	Varies	Yes	Yes	~ 6 in
Bristar	3-20 h	None	None	\$210 / 44 lbs	No	No	1 ft
Flame Cutting	10 $ft{\cdot}h^{-1}$	None	None	\$200 plus gas	Yes	Yes	60 in
Thermic Lance	1"dia×12" $deep{\cdot}min^{-1}$	None	None	\$75$\cdot unit^{-1}$	Yes	Yes	1 ft
Rock Splitter	10 $min{\cdot}hole^{-1}$	No	Yes	\$5000$\cdot unit^{-1}$	Yes	Yes	Unlimited
Various Saws	150 $in{\cdot}min^{-1}$	Yes	Yes	\$700-\$1500$\cdot unit^{-1}$	Yes	Yes	1/3 blade diameter

vary greatly depending on factors such as the manufacturing process and added aggregates. Therefore, there is a limit to calculating the activation amount of biological shield concrete based on precise impurities information. However, from the cases of the United States, which has a lot of decommissioning experiences, the activation amount of biological shield concrete can be estimated. In the case of the US commercial NPPs, the activated band of concrete in a biological shield seldom exceeds a depth of 4 ft from the vessel wall [11]. Based on the maximum activation depth and the active fuel length, activated volume can be roughly calculated. Table 3 shows the results of calculating activation amount according to the activation depth. It also shows the number of drums needed when filled in 200 L drums, and the percentage to the target value of 14,500 drums. The activated volume was calculated based on the active fuel length of 366 cm, and was calculated for every 10 cm of activation depth up to maximum 4 ft (120 cm). The filling ratio per drum was assumed to be 85% to meet the Waste Acceptance Criteria (WAC). From the calculation results, it can be predicted that up to 407 drums will be generated depending on the activation depth, which corresponds to 2.81% of the target of 14,500 drums. It is a large amount of waste as waste generated from a single structure, thus efforts for the minimization of waste generation will be needed to reach the target.

4. dismantling strategy

4.1 Preparation phase

One of the most important part of the preparation phase is planning ahead for thorough radiation protection management for workers to minimize the radiological risk. A dose distribution estimation around the Reactor Pressure Vessel (RPV) of Kori unit 1 assessed using an MCNP code shows a maximum dose of 22.9 $Sv \cdot h^{-1}$, which is too high for workers to perform tasks [8]. Therefore, the measurement and assessment of spatial dose should be performed in advance before the dismantling work and appropriate radiation protective actions such as work time management, installation of shielding walls, and protective clothing should be taken based on the criteria for dose limit (100 $mSv \cdot 5\ yrs^{-1}$ and 50 $mSv \cdot yr^{-1}$). Depending on the result of dose evaluation, remote dismantling method can be considered as in Germany.

In addition, prior to dismantling a biological shield, decontamination must be preceded in order to minimize unnecessary contamination and radioactive waste generation. Surface contamination must be accurately identified through surface radiation measurements and removed by applying proper decontamination technologies. In particular, the upper part of the biological shield of Kori unit 1 was filled with the primary water during reloading periods, thus the possibility of contamination is high. Decontamination also improves the working environment by reducing spatial radiation dose [8].

Finally, cutting technique should be determined considering various aspects including cutting speed, potential exposure of workers to radiation, maintenance frequency, limited accessibility in congested area, dust emissions, spread of contamination, generation of secondary waste, fire hazards, and industrial safety issues associated with working at heights. Methods for dismantling concrete structures are diverse in that each has particular advantages and disadvantages related to cost, personnel exposure, and overall effectiveness. Table 4 shows various options for current cutting techniques [11]. Analysis of the various properties of cutting techniques suggests that diamond wire cutting and water jet cutting are best suited for biological shield concrete cutting. Techniques with limited cutting size, such as controlled explosive, bristar, thermic lance, and saws are not suitable for biological shield concrete, which is a very big structure. Flame cutting has a major disadvantage which is the generation of large quantities of heat, smoke, and toxic gas. Rock splitter uses a hydraulically operated expanding wedge placed into a drilled hole to fracture the surrounding concrete. Therefore, the technique is not suitable for biological shields that require precise cutting depending on the radioactivity distribution. The major advantage of diamond wire cutting and water jet cutting is that they do not need to consider airborne contamination, thus there is no need for additional purification system such as HEPA ventilation. However, two techniques generate liquid waste due to the nature of the technology.

4.2 Cutting process

After the three-dimensional activation distribution is identified through the analysis of the representative samples of the biological shield, it is necessary to establish a cutting plan distinguishing the activated region and the non-activated region. The biological shield concrete cutting strategies can be divided into the method of cutting from non-activated area and the method of cutting from activated area. If the first method is selected, the biological shield structure will be cut sequentially from top to bottom, and the activated part will be finally cut off after cutting off the non-activated outside part. The advantage of this strategy is that it minimizes secondary contamination by removing non-activated parts first then handling activated parts. However, this strategy has a major disadvantage that large amounts of non-activated concrete blocks may also need to be processed later for self-disposal. The activated area of the biological shield is calculated to be about 155 tons at the maximum, accounting for only 7.4% of the total biological shield concrete of 2,100 tons and the remaining 1,945 tons of concrete should be treated as self-disposal. Waste generated from a radiation controlled area can be self-disposed by incineration, landfill, and recycling when the radiation level is evaluated below clearance level. However, they are generally treated separately from general industrial waste and disposed in form of burial in a dedicated landfill. Therefore, even though self-disposal is more economical than radioactive waste disposal, the disposal cost is higher than general industrial waste and disposal procedure is stricter. Furthermore, it is difficult to secure disposal sites.

The method of removing the activated part first can be an alternative to overcome the disadvantage. According to this method, the activated portion of the biological shield is selectively removed with a margin from the inner wall. The remaining non-activated part of the structure is demolished after the radiation controlled area is released after all the radioactive parts are removed from the reactor containment building. By doing so, large quantities of non-activated concrete can be treated as clean waste and disposed of as general industrial waste. When comparing the two methods, it is considered that removing the activated part first is better strategy both procedurally and economically.

4.3 Waste classification

The removed radioactive concrete block shall be classified according to the radioactive waste classification standard set forth in the Act. According to the activation analysis of the light water reactor biological shield, it can be predicted that the removed radioactive concrete block consists of LLW, VLLW, and Clearance Waste (CW). Since the disposal cost is lowered as the level of radioactive waste is lowered in general, it is necessary to precisely cut the removed concrete block according to the classification of radioactive waste through accurate analysis. In order to minimize waste disposal, it is important to actively carry out clearance and maximize the amount of CW for self-disposal. At the beginning of dismantling the biological shield, the activated concrete blocks are cut with margin, thus the radioactive waste disposal will be minimized through effort to maximize possible CW by accurate sample analysis and dose assessment.

5. Waste disposal stratigies

5.1 Applicable regulations

In 2013, radioactive waste classification system in Korea was revised reflecting the international standard recommended by International Atomic Energy Agency (IAEA) [13], and specifies Low and Intermediate Level Waste (LILW) further into the Intermediate Level Waste (ILW), Low Level Waste (LLW) and Very Low Level Waste (VLLW) [14]. The level of radioactive waste is classified according to the radioactive concentration and can be self-disposed if the concentration is less than clearance level. LLW and VLLW are expected to be generated from dismantling the biological shield and they should be precisely classified and disposed of according to each WAC.

5.1.1 LLW

WAC for LLW is specified in the NSSC Notice [15] which contains the requirements for the delivery methods and procedures, structural integrity of packages, the properties of the LILW and other necessary matters in order to deliver the waste packages to the repository operator. The LLW should be in solid form or solidified to have no fluidity and packed in non-flammable containers. The disposal cost per a drum is 12,190,000 Won [16]. Waste disposal cost in Korea is relatively expensive, therefore efforts for waste minimization and recycling are needed to save decommissioning costs.

Table 5. Disposal cost for radioactive waste in France and the UK [19]

Country	Classification	Cost (KRW)	Reference
France	LILW-SL	4.6 million Won·m^{-3}	ANDRA 2009 report
	LLW	6.5 million Won·m^{-3}	
	VLLW	0.69 million Won·m^{-3}	
UK	ILW	16.4 million Won·m^{-3}	NDA 2012 report
	LLW/VLLW	1.6 million Won·m^{-3}	NDA 2009 report

5.1.2 VLLW

The category of VLLW has been newly enacted and VLLW generated in large volumes from decommissioning activities plans to be disposed of at the second phase of the repository currently under construction in Gyeongju. However, WAC for VLLW has not been established. Considering the international trend of VLLW disposal, WAC for VLLW in Korea is likely to be differentiated from LLW in terms of disposal convenience and disposal costs.

The UK allows soft-sided packaging as well as 210 L drums for VLLW and even non-containerized waste may be accepted for disposal through the waste enquiry process [17]. In the United States, VLLW is not defined as a category of legal radioactive waste but uses the term Low-Activity Waste (LAW). US Nuclear Regulatory Commission (NRC) permits the disposal of LAWs at hazardous or municipal landfills by applying an alternative disposal method according to 10 CFR 20.2002 [18]. In other words, the US considers the disposal of VLLW as part of clearance, which provides benefits for disposal costs and disposal convenience. The US is also increasing the efficiency of disposal through soft-sided packaging for VLLW generated in a large quantity.

In many leading countries, waste disposal costs are differentiated according to waste classification. In France, the disposal cost for VLLW is about one-tenth of the disposal cost for LLW. The UK also applies about one-tenth of ILW disposal cost for VLW/VLLW disposal cost. Table 5 shows the disposal cost of radioactive waste in France and the UK [19].

Nuclear Energy Agency (NEA) says the usefulness of introducing the category of VLLW comes from the fact that, while it may not be acceptable to dispose of it as industrial waste, it is neither economical nor necessary to dispose of it in LLW repositories [20]. From the international trends and understanding of VLLW, Korea’s WAC for VLLW is expected to be more beneficial in terms of packaging convenience and disposal cost.

5.2 Applicable technologies

Radioactive concrete waste from decommissioning activities has been a great concern in nuclear industry and comprehensive technologies for radioactive concrete waste treatment have been researched and suggested including manufacturing radiological protection shields [21,22], manufacturing prefabricated items for disposal facilities such as containers, cells and vaults [21], utilizing radioactive concrete as infilling materials for radioactive waste drums [23-25], utilizing radioactive concrete as mortar for immobilizing LLW. Each method has both advantages and disadvantages. In this paper, technologies applicable to Korean circumstances are introduced based on regulations, feasibility, and cost efficiency.

5.2.1 Separation of clean aggregates from radioactive concrete waste

It was found that considerable volume reduction of contaminated or activated concrete can be achieved by separating clean dense aggregate particles from the cement stones [26-28]. It is based on the fact that most of the radionuclides in concrete mainly exist in the porous cement stones [29, 30]. The key factor of the technology is to remove cement mortar or cement paste attached to the surface of aggregates. KAERI also has researched and developed this technology and verified it by experimenting with dismantled concrete from KRR-2 and UCP [31, 32]. It is proved that significant volume reduction is possible by mechanical and thermal treatment. The technique is to heat crushed concrete aggregates to deteriorate the adhered cement paste by dehydrating it followed by a milling process to such an extent that the aggregates are not broken, so that the contaminated or activated mortar and cement paste is selectively removed. In the experiment, the activated heavy weight concrete from dismantling KRR-2 was crushed and sieved into gravel (>5 mm), sand (1-5 mm) and paste (<1 mm) [32]. The experiment shows that by simple mechanical crushing, larger doses of radiation were detected in the cement paste than the aggregates. After heating and milling process, the adhered mortar layer of aggregates was reduced considerably and the specific radioactivity of gravel and sand decreased additionally below the clearance level. The experimental results show that most of the radionuclides in the concrete could be removed from the gravel and sand aggregates. After crushing the highly activated heavy weight concrete waste from dismantling KRR-2 and applying heating and milling process, the recovery rate of aggregates which could be self-disposed reached up to 80% for coarse aggregates and 38% for fine aggregates.

This technology is expected to contribute to significant volume reduction of radioactive concrete waste and disposal cost savings. The technology is particularly useful for activated concrete and concrete where contamination is deep so decontamination technology is difficult to be applicable.

5.2.2 Blending

Blending is the mixing of higher radionuclide concentration waste with lower radionuclide concentration waste to produce a final homogeneous mixture, of lower concentration waste that may meet the WAC of disposal facilities. The NRC's current position on blending is that large scale LLW concentration averaging and blending may be conducted when it can be demonstrated to be safe [33]. If it is possible to blend LLW and VLLW from the biological shield into VLLW, it will be highly beneficial in the cost perspective assuming that the disposal cost of VLLW is much lower than the disposal cost of LLW. The limit of blending is that it does not reduce the overall volume of radioactive waste. Furthermore, to introduce blending, it is necessary to consult with regulatory body and establish relevant regulations. However, if applied according to the situation, it will greatly contribute to reduction of disposal cost by minimizing the disposal of LLW.

5.3 Waste disposal

5.3.1 Disposal of LLW

LLW might be the highest level of radioactive waste generated from the biological shield. Efforts to reduce the volume of LLW are essential because the disposal cost of LLW is expensive in Korea. In order to reduce the waste disposal amount, it is necessary to minimize unnecessary waste generation by precise waste classification and prevention of secondary contamination. After the waste is classified, it is important to select effective waste treatment methods. The aggregate separation method is a highly effective technology in reducing the volume of radioactive concrete waste. According to the study, the volume could be reduced up to about 80%. The effectiveness of the technique has been demonstrated in the decommissioning of KRR-1 & 2. Clean aggregates separated from the paste can be disposed or recycled as a CW. By applying this technology to the LLW, a significant amount of waste volume reduction is expected to be possible.

5.3.2 Disposal of VLLW

The WAC for VLLW is not yet established. However, it is expected that WAC for VLLW will be more flexible and disposal cost for VLLW will be much cheaper than LLW considering the direction of national policies and international cases. Many leading countries in radioactive waste management such as the US, Sweden, Spain, UK, Japan, France, Finland classifies VLLW as the category of radioactive waste legally or practically and suggests more flexible criteria and economic disposal cost [18]. The optimized disposal strategy of VLLW can be determined through economic evaluation after the specific WAC for VLLW is established. In this study, two methods are suggested.

The first method is to cut VLLW concrete to fit the size and weight limit of the WAC and soft-sided package without further treatment. This strategy will be possible if the WAC for VLLW is more flexible in packaging and less expensive in disposal cost, as in the cases of the UK or the US. This method can save time, manpower and costs for additional waste treatment. However, there is a disadvantage that there will be no active volume reduction for a large amount of VLLW concrete that is expected to occur when NPPs are dismantled.

The second method is to apply the aggregate separation technique as in the case of LLW. This method is positive in that an active volume reduction is possible to achieve the waste disposal target. The remaining paste after separating the aggregates can be blended with the LLW paste to minimize the disposal cost. The cement paste of VLLW and LLW remaining after removing aggregates is homogeneous and the same type, which satisfies the conditions for blending. By applying a blending technique through accurate radioactivity analysis and maximizing VLLW, the disposal cost can be further reduced. The disposal strategy for VLLW can be selected from the two methods mentioned above after the economical evaluation is carried out in consideration of the processing cost of aggregate separation technology and disposal cost of VLLW after WAC for VLLW is established.

6. Conclusion

In this paper, a dismantling and disposal strategy for biological shields were presented by taking an example of Kori unit 1 which will be the first commercial nuclear decommissioning case in Korea. As the dismantling strategy, the activated parts have to be removed and the remaining structures have to be treated as clean waste after the release of the controlled area. After classification of activated blocks through accurate sample analysis, the aggregate separation and blending methods need to be implemented to minimize the waste volume and disposal cost of the radioactive concrete. If a separate WAC for VLLW is established, soft-sided packaging without further treatment can be considered as an alternative. It is expected that this study can contribute to the establishment of practical procedures for dismantling and waste disposal of the biological shield in an NPP.

Acknowledgement

This research was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KOFONS), granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 1305009). The work was also supported by the Research Fund of the KEPCO International Nuclear Graduate School (KINGS), Republic of Korea.

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