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INVITED PAPER

Korean Status and Prospects for Radioactive Waste Management

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Abstract : *The safe management of radioactive waste is a national task required for sustainable generation of nuclear power and for energy self-reliance in Korea. Since the initial introduction of nuclear power to Korea in 1978, rapid growth in nuclear power has been achieved. This large nuclear power generation program has produced a significant amount of radioactive waste, both low- and intermediate-level waste (LILW) and spent nuclear fuel (SNF); and the amount of waste is steadily growing. For the management of LILW, the Wolsong LILW Disposal Center, which has a final waste disposal capacity of 800,000 drums, is under construction, and is expected to be completed by June 2014. Korean policy about how to manage the SNF has not yet been decided. In 2004, the Atomic Energy Commission decided that a national policy for SNF management should be established considering both technological development and public consensus. Currently, SNF is being stored at reactor sites under the responsibility of plant operator. The at-reactor SNF storage capacity will run out starting in 2024. In this paper, the fundamental principles and steps for implementation of a Korean policy for national radioactive waste management are introduced. Korean practices and prospects regarding radioactive waste management are also summarized, with a focus on strategy for policy-making on SNF management.*

Keywords: *Low-and intermediate-level radioactive waste, Spent nuclear fuel management, Management policy and strategy*

1. INTRODUCTION

The safe management of radioactive waste is a national task required for sustainable generation of nuclear power, and for energy self-reliance, in Korea. Since the initial introduction of nuclear power in Korea in 1978, rapid growth in nuclear power has been achieved. At present, there are 23 operating reactors at four nuclear power plant (NPP) sites in Korea, and as the demand for domestic electricity increases, the demand for more NPPs will grow. According to “the 6th Basic Plan of Electricity Supply and Demand,” a total of 34 reactors will be in operation by 2024. This large nuclear power generation program has produced a significant amount of radioactive waste, and the amount of waste is steadily growing. Moreover, due to wide application of radioisotopes, the annual generation rate of related radioactive waste from industry, hospitals, and research institutions is also increasing.

In accordance with the fundamental principle of radioactive waste management recommended by the International Atomic Energy Agency (IAEA), the objective of radioactive waste management is 'protecting human health and environment now and in the future, without imposing undue burden on future generations'. The radioactive waste management facilities have been in operation so that the current generation, the beneficiary of nuclear energy, is responsible for the safe management of radioactive waste. In Korea, 'the radioactive waste management measure' was approved by the Atomic Energy Commission in September 1998. In this measure is a declaration of the basic principles that radioactive waste management should be under government responsibility, with a top priority on safety; that radioactive waste generation should be minimized, and the site selection process should be transparent; and finally, that the principle 'polluters pay' should be adopted. Then, in order to meet the international standard and practice of radioactive waste management, a new law on radioactive waste management was promulgated in March 2008 that laid the foundation for the Radioactive Waste Management Fund, and for a new organization named the Korea Radioactive Waste Agency(KORAD) [1].

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Radioactive waste is defined in the Nuclear Safety Act as radioactive materials (including spent nuclear fuel), or substances contaminated by them, that are subject to disposal [2]. In Korea, radioactive wastes are classified into two categories; low- and intermediate- level waste (LILW); and high-level waste (HLW), according to their specific activity and degree of heat generation. Currently, there is no plan to reprocessing, therefore, only spent nuclear fuel (SNF) comes under HLW. The radioactive wastes generated to date are being stored at reactor sites, and LILW is to be disposed of in the Wolsong LILW Disposal Center (WLDC), which is now under construction in Gyeongju City. Concerns, however, are mounting as the national policy for SNF management has not been decided yet. Since the capacity for wet storage at reactor sites is gradually saturated, it is time to establish the long-term national policy for SNF management, as well as short-term, on-site management options (e.g., re-racking and transshipment).

In this paper, the current status of radioactive waste management in Korea, including recent LILW management strategy and SNF management policy-making, is described. The future prospects of radioactive waste management are also discussed.

2. THE CURRENT STATUS AND PROSPECT OF LILW MANAGEMENT

2.1 LILW Generation

Since Kori-1 started operation in 1978, the amount of LILW has consistently increased. Additionally, the more radioactive isotopes are used in industries, hospitals and institutes; the more radioactive waste from those sources is produced. The total accumulation of LILW to date is about 120,000 drums (200ℓ equivalent) as of the end of December 2012 (Table 1). Table 2 shows the estimate of long-term generation of LILW based on the 6th basic plan of electricity supply and demand. It is assumed that Kori-1 has a 10-year life extension, the other reactors are to be operated during its design life and a total of 34 reactors are to be constructed by 2024. It is also assumed that 1-year of preparation will be carried out before decommissioning. Each plant will take ten years to decommissioning at the end of their functional life-span.

Table 1. LILW currently stored on site - as of 31 December 2012

Site		Storage capacity (drum)	Stored (drum)
NPPs	Kori(4)	50,200	41,197
	Yeonggwang(6)	23,300	22,010
	Uljin(6)	18,929	16,497
	Wolsong(5)	13,240	10,264
	Shin-Kori(2)	10,000	297
	Sub-total(23)	115,669	90,265
RI waste Storage		9,750	3,095
KAERI		39,438	21,708
KEPCO-NF		8,900	6,546
Sub-total		58,088	32,138
Total		173,757	122,403

2.2 The Status of the 1st Stage Construction of the LILW Disposal Facility

Gyeongju City in Gyeongsang Buk Do (Gyeongsang-North Province) was designated as a LILW disposal site as a result of local referendum in November 2005, and Wolsong, the rural area of Gyeongju City, was selected as the final candidate in January 2006. KORAD has responsibility for construction and operation of the WLDC, which has a final waste disposal capacity of 800,000 drums within the area of about 2,100,000 m^2. As the first stage of the disposal center construction (Fig. 1), six silos are under construction to accommodate 100,000 drums (35,200 m^3). They are expected to be completed by June 2014. The surface facilities, such as a waste inspection and storage building, a radioactive waste treatment building, the main control center, and the equipment maintenance shop, are all completed. The underground facility is divided into an operation tunnel, a construction tunnel, an entrance shaft for workers, and six silos. Waste packages are disposed of in separate vertical silos using concrete disposal containers. The 1st stage construction is about 95% complete as of the end of June 2013.

In addition, in order to enhance the safety and reliability of the WLDC, an in-situ demonstration test facility was constructed in part of the construction tunnel. Experiments and research evaluating long-term degradation of the engineered barriers, and gas emissions of the dry active waste have been undertaken, and a 10-year

Table 2. Estimate of LILW generation

Category of waste	Operational waste		Decommissioning waste		Total	
	No. of drums	ratio (%)	No. of drums	ratio (%)	No. of drums	ratio (%)
ILW	136	0.03	21,036	4.2	21,172	2.2
LLW	362,787	75.2	143,953	28.7	506,740	51.5
VLLW	119,621	24.8	336,711	67.1	456,332	46.3
Total	482,544	100.0	501,700	100.0	984,244	100.0

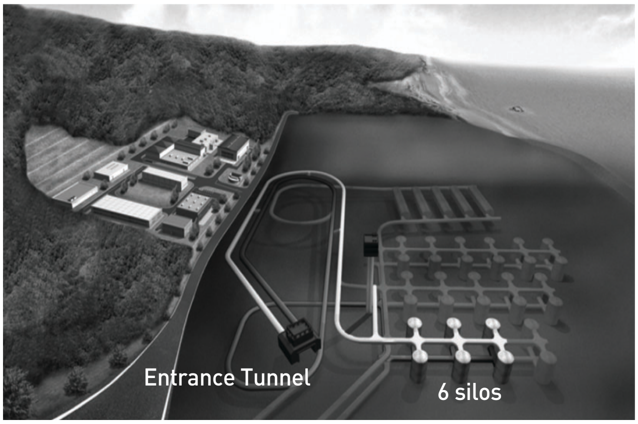

Fig. 1. Layout of the 1st stage Wolsong LILW Disposal Center.

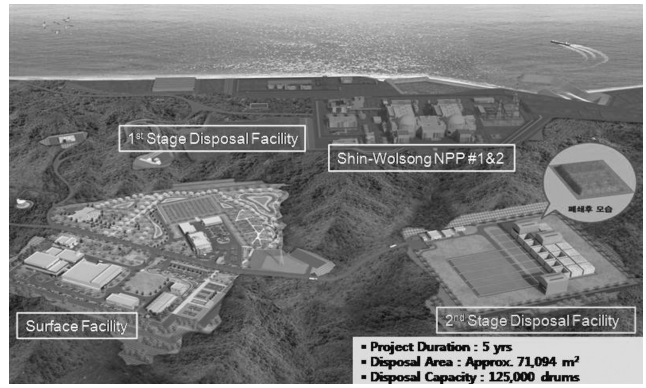

Fig. 2. Plan for the 2nd stage expansion of the Wolsong LILW Disposal Center.

monitoring program will be conducted to verify the safety measures.

2.3 New Classification and Management Strategy of LILW

In 2009, a new classification of radioactive waste was created by which radioactive waste is now sorted into six categories (i.e., high level, intermediate level, low level, very low level, very short lived and exempt waste). This classification was recommended by the IAEA, taking account of disposal options by half life, radioactivity and various types of radioactive waste (Table 3) [3].

The result of an estimate of the expected accumulation of LILW, based on the new classification, along with plans for additional NPP construction (Table 2), shows that it would exceed 800,000 drums, the total capacity of WLDC. This is why it is necessary that the facilities for volume-reduction be operated, that radioactive waste be sorted according to a more detailed classification, and that new strategies of treatment and disposal are developed considering the characteristics and activity of the wastes. In other words, it is essential to secure technologies and to improve the system so that comprehensive management of the WLDC might be realized. Most of decommissioning waste is metal or concrete, and under the new classification about 67.1% of decommissioning waste is VLLW (4.2% ILW and 28.7% LLW), it is desirable to dispose of them separately, according to a proper method, from among geological disposal; engineered vault-type disposal; and trench-type disposal, by considering waste characteristics [4].

In view of this point, KORAD has been preparing for construction of the engineered vault facility as the 2nd stage, which is due for completion at the end of 2016, and which can accommodate up to 125,000 drums (Fig. 2). As the silo, and the engineered-vault, facilities are to be co-located at the WLDC, the individual and integrated safety assessments of these facilities are being undertaken. In addition, construction of the trench disposal facility is also planned for VLLW, generated in large volume in the process of decommissioning NPPs in the near future [5].

Table 3. New waste classification of IAEA 2009

LILW Classification		Disposal method
Existing classification	New classification	
Exempt Waste, EW	Exempt Waste, EW	Clearance
LILW ▹ Short lived waste ▹ Long lived waste	VSLW	Clearance after storage decay
	VLLW	Trench-type Near Surface Disposal
	LLW	Engineered vault-type Near Surface Disposal (~30m)
	ILW	Engineered Geological Disposal (hundreds of meters)

3. THE CURRENT STATUS AND PROSPECT OF SNF MANAGEMENT

3.1 Generation and Storage of SNF

SNF is considered nuclear fuel material used as reactor fuel, or nuclear fuel material having caused nuclear fission by other methods, in Article 2 of the Nuclear Safety Act. A stepwise approach of SNF management from temporary and interim storage to deep geological disposal should be adopted because of its high level of radioactivity and heat emission.

The total SNF stored at reactor sites in Korea is about 12,700 THM, as of the end of December 2012(Table 4). A pressurized water reactor(PWR) (Kori, Yeonggwang and Uljin NPPs), which uses low-enriched uranium, generates about 14-19 tons of heavy metal (THM)/unit/year of SNF, and a pressurized heavy water reactor (PHWR) (Wolsong NPP), which uses natural uranium, generates about 97 THM/unit/year of SNF. Thus, about 33,000 THM from PWR and 12,000 THM from PHWR are expected to have been accumulated by 2083 (Fig. 3).

Owing to insufficient at-reactor storage capacity for SNF, there is concern about SNF management. Even with further storage-expansion programs such as re-racking of storage pool or transshipment of SNF between units, the at-reactor SNF storage capacity will run out starting in 2024 (Table 5). After the Fukushima accident in March 2011, the safety of temporary storage facilities

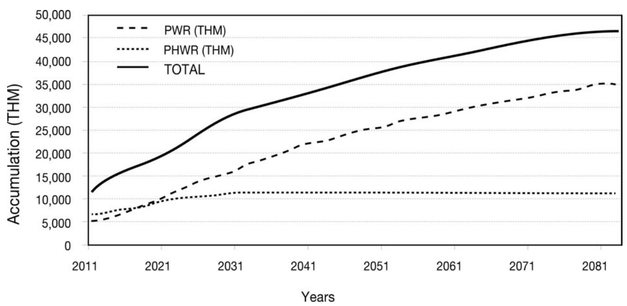

Fig. 3. Long-term estimate of SNF generation.

Table 4. SNF currently stored at reactor sites- as of 31 December 2012

Site		Storage Capacity(THM)	Stored(THM)
PWR	Kori(6 NPPs)	2,690	2,030
	Yeonggwang(6 NPPs)	3,320	2,075
	Uljin(6 NPPs)	2,327	1,724
	Shin-Wolsong(1 NPP)	219	-
	Subtotal	8,556	5,829
PHWR	Wolsong(4 NPPs)	9,443	6,878
Total (23 NPPs)		17,999	12,707

Table 5. Expected saturation year of at-reactor SNF storage & options of storage expansion

Site	Saturation year (expected)		Expansion options
	current	extended	
Kori	2016	2028	transshipment
Yeonggwang	2021	2024	Replacement into HDR transshipment
Uljin	2018	2028	transshipment
Wolsong	2017	2026	Construction of additional MACSTOR

for SNF has become an increasingly hot issue, and there is a definite need for an intensive review of the current situation.

3.2 SNF Management Options

There are three approaches to SNF management: direct disposal, disposal after reprocessing, and partitioning and transmutation. Direct disposal is a method to permanently isolate the SNF from human and environment as it is. Reprocessing, on the other hand, is a process to extract fissile materials (e.g., Pu-239, U-235) from SNF, after which the recovered plutonium and uranium are recycled as fuel for existing light water reactors or fast breeder reactors. As a result, the volume of HLW is significantly reduced. Partitioning and transmutation, an innovative technology that has not yet become practical, is done to change HLW into LILW before disposal.

3.3 SNF Management Policy-Making in Korea

Energy policies, economic conditions, environmental issues, technologies, public acceptance and international circumstances must all be considered when a government makes an SNF management policy. The present national policy for SNF management in Korea is 'wait and see', under which SNF is being stored temporarily at reactor sites, under the responsibility of plant operator, until national policy is decided.

Discussions of SNF management policy have been initiated by the Atomic Energy Commission (AEC). The 220^{th} AEC in 1988 approved that SNF would be managed in interim storage until national policy is decided, and concentrated interim storage would be constructed away from reactor sites by December 1997. In December 2004, two main decisions were made in the 253^{rd} AEC. One thing was to construct an LILW disposal facility first, and the other thing was to carry on adopting

Table 6. AEC decisions on SNF management policy

Order	Decisions
The 220th (Jul.1988)	-SNF to be stored at interim storage until national policy is made -Interim storage to be constructed as centralized facility away from reactor by end of 1997
The 236th (Dec.1994)	Method of interim storage changed from wet storage to wet or dry storage
The 249th (Sep. 1998)	National policy on SNF management to be made under public consensus
The 253th (Dec. 2004)	Siting LILW disposal facility and SNF interim storage to be separately carried out
The 255th (Dec.2008)	Technology for non-proliferating pyroprocess and sodium cooled fast reactor to be developed

SNF management policy, which was to include the construction of an interim storage facility for SNF; considering technology development and public consensus. Table 6 shows the decision history of the AEC on SNF management policy in Korea.

3.4 Progress of the Stakeholder Engagement

According to a decision by the 253rd AEC, the government prepared to gather public opinion concerning governmental management policies on SNF. A task force team to gather public opinion on SNF was established in the Conflict Management Committee under the aegis of the National Energy Commission, headed by the President; and follow-up actions were determined in April 2007. In April 2008, the task force team submitted to the government 'the Recommendation Report for Public Engagement Process', which presented its vision, principles, schedules, and methods of gathering public opinion on SNF management policy. In order to establish a legal basis of the gathering of public opinion, an amendment of the Radioactive Waste Management Act was made in December 2009. However, clear scientific evidence based on the opinion of nuclear experts was required prior to gathering public opinion from local residents. KORAD undertook a study on SNF management options to technically support the policy-making through expert-group consensus. A study named “Development of Options and Roadmap for SNF Management” was implemented by the consortium of Korean Nuclear Society, the Korean Radioactive Waste Society, and Green Korea 21, from December 2009 to August 2011.

The Korean government established a “Forum for SNF Management Policy,” which consisted of 23 representatives, including experts in various fields, members of NGOs, and local residents around NPP sites. The Forum was convened in November 2011 and pursued its objectives until August 2012. After a 10-month review of management options for SNF, and the gathering of public opinions, the Forum submitted a final report to the government in September 2012, recommending that an interim storage facility should be constructed no later than 2024, the Stakeholder Engagement Program should commence as soon as possible, and that regulatory standards for the interim storage facility should be legislated. Then, in November 2012 the Korea Atomic Energy Promotion Commission decided to proceed with the stakeholder engagement process under the provision of the Radioactive Waste Management Act based on the recommendations by the Forum.

The stakeholder engagement program will be carried out until the end of 2014 by the Stakeholder Engagement Committee (SEC). As a part of the program, the public debate process will be initiated on a national level. Once the SEC, which consists of 15 commissioners who are experts in the fields of human-and-social science and engineering, representatives from NGO and delegates of NPP-site residents; is set up in the 2nd half of 2013, the supporting group and subcommittees will be organized and the actual implementation plan will be made. The comprehensive and in-depth discussions, focusing on all feasible options on SNF management, including interim storage, will take place at the SEC. After a consent-based result is made, the SEC, as a temporary advisory body based on the Radioactive Waste Management Act, will submit their recommendation report to the government and the AEC. Then, the “Basic Plan on Radioactive Waste Management” will be made by the government with the full respect and consideration of the SEC recommendations. For the sake of effective progress in the stakeholder engagement program, KORAD will give full support to the SEC.

3.5 Technology Development for SNF Management

Under the current conditions in the Korean nuclear energy industry, major concerns exist over the efficiency of nuclear fuel usage and SNF management. To cope with them and to support policy-making based on technical backgrounds and evidence, new technologies for SNF management should be developed. A national roadmap to development of technology for SNF management should include priorities against the risk of funds flowing overseas in case domestic technology is not secured.

In 2011, KORAD completed development of the “Technology Roadmap for Radioactive Waste Management” for the government. The roadmap covers a variety of technology fields required for the transportation, storage, treatment and disposal of radioactive waste. Based on this roadmap, KORAD is focusing on step-by-step development of core technologies through domestic and international cooperation.

The technologies for transportation and storage of SNF have been under development since the mid-1980s. The technology for SNF transportation has been considerably advanced and resulted in the development of the KN-18 cask for transportation of CE-type nuclear fuel by domestic or international cooperative work. When it comes to the technologies for storage, the MACSTOR/KN-400 system was developed by improving the MACSTOR-200 technology for dry storage of CANDU fuel at the Wolsong site. Joint research on the development of domestic models for an SNF transportation and storage (dual purpose) system is now in progress among industries, universities and institutes under the lead of KORAD. However, since the national policy and interim storage site have not yet been determined, technologies for a concrete storage cask are also being developed. Fig. 4 shows Dual Purpose Metal Cask (KORAD-21) and Concrete Storage Cask (KORAD-21C) accommodating 21 PWR-SNF assemblies.

The technologies for SNF disposal are being developed to support the process of national policy-making and stakeholder engagement. R&D for HLW disposal has been carried out within the nuclear energy R&D since 1997. It is currently subject of a feasibility study on elemental technology, results of which are to be applied to development of concepts for disposal according to waste characteristics. The conceptual design of the SNF disposal facility has been suggested but technologies for operation and closure of the facility, and its radiation protection program have not been developed yet. In 2006, the KAERI Underground Research Tunnel (KURT) was constructed in order to develop radioactive waste disposal technology and to demonstrate core elemental technology for a disposal system. In KURT, various in-situ tests are done and other technologies, such as site investigation and post-closure management, will be carried out after building the underground-disposal research laboratory, the condition of which is very similar to the deep environment of an actual HLW disposal facility (400-1,000 m underground). In order to quantitatively assess the Korean geological environment for deep geological disposal of SNF, an integrated DB system is under development by KORAD (Fig. 5).

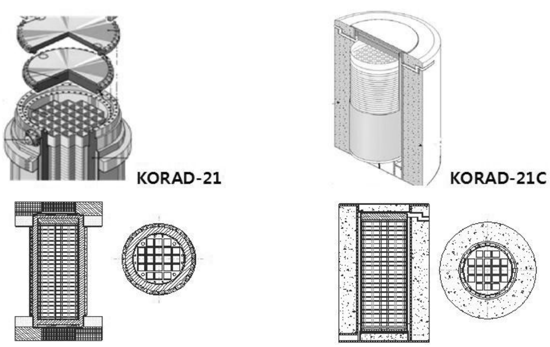

Fig. 4. SNF casks being developed by KORAD.

4. CONCLUSION

Safe and efficient management and disposal of radioactive waste is one of the national challenges for making use of nuclear energy sustainable. Much effort has been devoted to the site selection of a LILW disposal facility, and the Wolsong LILW Disposal Center is currently under construction. KORAD is continuing its efforts toward improvement of the safety and reliability of the WLDC. A variety of options for LILW treatment and disposal in relation to waste-characteristics should be adopted, as well as a new classification of LILW in Korea. A comprehensive, disposal-facility-management system based on proper LILW disposal options by source and radioactivity, and a volume reduction facility, should be set up at the WLDC. At the same time, technologies and management systems should also be developed.

After a successful experience siting the LILW disposal facility, the Korean government are convinced that, above all, it is important to build public confidence in making an effective national policy for SNF manage-

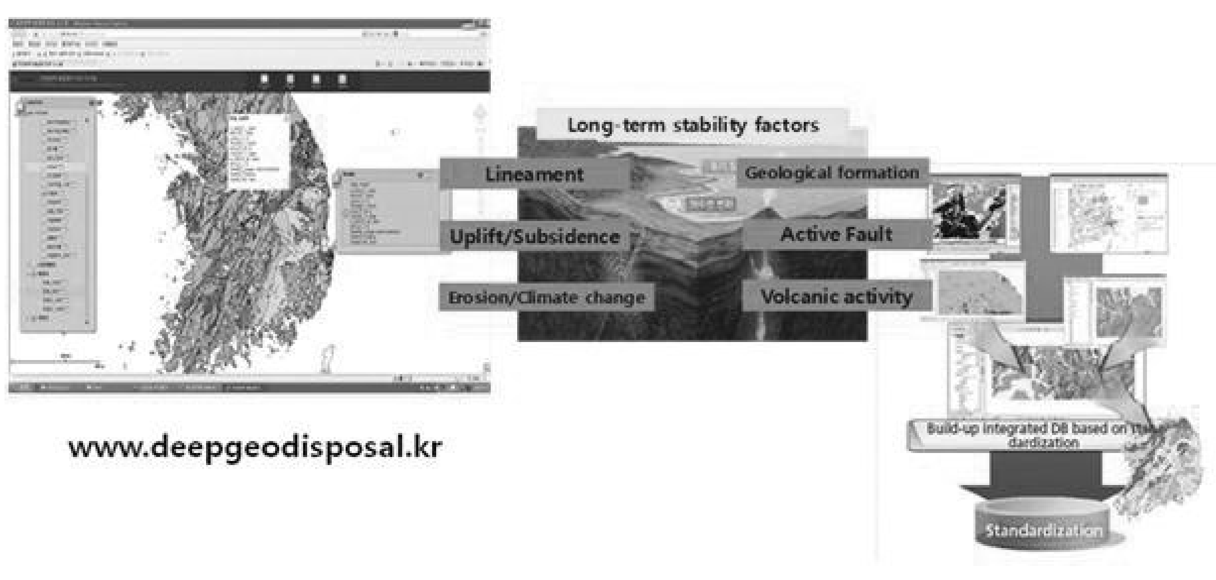

Fig. 5. Geo-environment database system for deep geological disposal.

ment. Furthermore, it is desirable to establish national policy in a timely manner based on social consensus and public confidence. KORAD will give its full support to draw open and fruitful outcomes from the stakeholder engagement program for making policies for SNF management.

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