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Preparation of the Applicable Regulatory Guideline on Mixed Waste in Korea Based on the Analysis of US Laws and Regulations

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Unit 1 of the Kori Nuclear Power Plant (NPP) and Unit 1 of the Wolsong NPP are being prepared for decommissioning; their decommissioning is expected to generate large amounts of intermediate-level, low-level, and very low level Waste. Mixed waste containing both radioactive and hazardous substances is expected to be produced. Nevertheless, laws and regulations, such as the Korean Nuclear Safety Act and Waste Management Act, do not define clear regulatory guidelines for mixed waste. However, the United States has strictly enforced regulations on mixed waste, focusing on the human health and environmental effects of its hazardous components. The U.S. Nuclear Regulatory Commission and the U.S. Department of Energy regulate the radioactive components of mixed waste under the Atomic Energy Act. The U.S. Environmental Protection Agency regulates the hazardous waste component of mixed waste under the Resource Conservation and Recovery Act. In this study, the laws, regulations, and authorities pertaining to mixed waste in the United States are reviewed. Through comparison and analysis with waste management laws and regulations in Korea, a treatment direction for mixed waste is suggested. Such a treatment for mixed waste will increase the efficiency of managing mixed waste when decommissioning NPPs in the near future.

Keywords: Kori-1, Nuclear power plant decommissioning, Waste management, Mixed waste, Laws and regulations

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1. Introduction

1.1 Background

Kori Unit 1 which was permanently shut down in June 2017 and Wolsong Unit 1 which was permanently shut down in December 2019 are preparing to decommission the nuclear power plants (NPPs). When decommissioning NPPs, it is expected that a larger amount of low-level radioactive wastes (LLW) and very-low-level radioactive waste (VLLW) will be generated. In particular, the amount of VLLW is expected to be about 60% of the total wastes [1]. And the generation of mixed waste (MW) is also expected to occur. The types of radioactive waste generated can be classified as follows [2]:

- Solid (large equipment, insulation, concrete chips, asbestos, etc.)
- Liquid (various waste liquids such as cooling water for spent nuclear fuel storage tanks)
- Gas (radioactive dust, aerosol, etc.)
- Mixed waste (waste oil, waste liquid, asbestos, lead, mercury, Polychlorinated biphenyl (PCB), insulating material, demineralized water contaminated sludge, etc.)

since mixed radioactive waste contains both radioactivity and hazards, there are many considerations for treatment and disposal. However, there are no clear guidelines for MW in Korea. Clear regulations need to be developed to minimize the potential and negative effects of MW treatment that may occur during decommissioning.

MW is defined as containing both radioactive and hazardous components in the United States of America (USA). MW has to be meeting LLW definitions. It also includes hazardous waste identified as a list in Subpart D of 40 Code of Federal Regulations (CFR) Part 261 or it contains LLW exhibits the characteristics of identified in Subpart C of 40 CFR Part 261 [3]. MW is generally produced through a variety of processes, including industrial, medical care and NPP facilities, etc. [4]. The hazardous waste components are usually organic solvents, metallic lead, chromate, and cadmium waste, or corrosive liquids. If these wastes exhibit hazardous properties or contain hazardous substances specified in 40 CFR Part 261, they may be regulated by Resource Conservation and Recovery Act (RCRA) [5].

In the United States, hazardous effects of MW on human health and the environment are expected to be fatal. Therefore, guidelines and test methods related to MWs are prepared and thoroughly managed. The U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) regulate the radioactive component under the Atomic Energy Act (AEA) [6] while the U.S. Environmental Protection Agency (EPA) regulates the hazardous waste component under the RCRA [7].

The purpose of this paper is to review the law and regulation related to the MW for the treatment and disposal in the United States, which has extensive experience in nuclear decommissioning and strictly manage hazardous wastes, and it was created to derive an applicable method for the MW in Korea.

1.2 Regulatory approach

Wastes and materials from the decommissioning of NPPs contain radioactive and non-radioactive components that may adversely affect humans and the environment [8]. Therefore the management of such waste and material should consider the radioactive and nonradioactive hazards [8].

In the past, regulations considering the problem of chemical toxic substances in radioactive waste were relatively, but nowadays, there is a growing awareness that not only radiation effects but also non-radiation effects should be considered when managing waste [5]. In recent decades, research has been conducted to efficiently manage various radioactive wastes in countries using NPPs, and many countries establish and manage regulations according to the types of radioactive and non-radioactive waste [5]. Management standards vary by country and type of waste, but the premise of protecting human health and the environ-

Table 1. Major chronological laws or regulations related to MW in the USA [9]

Year	History
1954	AEA is amended to assure the proper management of "source, special nuclear, or by-product material".
1965	SWDA issued.
1976	RCRA Subtitle C authorized EPA to regulate the identification and management of hazardous waste by generators, transporters, owners, and operators.
1980	EPA issued the first hazardous waste management regulations under RCRA. CERCLA authorizes EPA to regulate management and clean-up of sites contaminated with hazardous substances, including radionuclides.
1981	NRC issued licensing regulations for non-DOE operated LLW land disposal sites.
1984	HSWA is amended. LDR is established for hazardous waste. EPA established treatment standards for hazardous waste.
1985	LLW Policy Amendments Act provides for states to develop LLW land disposal sites.
1986	EPA issued a notice clarifying RCRA jurisdiction for MW. EPA issued the initial rule on the LDR program.
1987	DOE interpreted AEA definition of by-product material. EPA published LDR treatment standards.
1988	DOE establishes requirements for management of LLW and MW. EPA requires existing facilities that treat, store or dispose of MW to obtain interim status. EPA should be notified by MW generators.
1990	EPA approves conditional no-migration variance that exempts untreated LDR MW from RCRA LDR for TRU waste disposal at WIPP
1992	FFCA (Federal Facilities Compliance Act) defines MW EPA issues alternate hazardous debris treatment standards
1994	EPA promulgated treatment standards for newly identified organic toxicity characteristic wastes and establishes UTS
1995	EPA proposes the HWIR to allow certain RCRA listed waste.
1996	The WIPP Land Withdrawal Act amendment exempts MTRU waste designated for WIPP disposal testing.
1997	NRC, with EPA consent, approves disposal of certain commercial LLW treated MW NRC/EPA MW testing guidance is issued
1998	EPA issues final rule for metal-containing hazardous wastes.
1999	EPA issues regulations on storing MLLW under RCRA
2001	EPA issues final Rules on storage, treatment, transportation, and disposal of MW under RCRA

ment is the same [4].

In fact, in some countries, regulations are difficult because the management standards for radioactive and chemically hazardous waste are not consistent. In addition, if the organizations that manage radioactivity and non-radioactivity are different, regulations can become more complex. In general, MW contains radioactive and chemically toxic substances, so it may be difficult to meet regulatory standards [5].

2. Laws and regulations related to the mixed waste in the USA

MW is regulated by several agencies including EPA, NRC, and DOE. EPA is responsible for handling hazardous substances in MW. EPA requirements vary depending on the legal authority (Resource Conservation and Recovery Act, Toxic Substance Control Act, Comprehensive Envi-

ronmental Response Compensation and Liability Act, etc.) in which the waste is regulated [9].

Radionuclides are regulated under the AEA as amended. This law comprehensively allows NRC and DOE to regulate radioactive components. The AEA authorizes EPA to give radiation guidelines [7]. Therefore, EPA can be controlled for radioactive materials and controls. In fact, EPA manages radioactive mixed wastes that are expected to occur in three categories: Low-level mixed waste (LLMW), High-level mixed waste (HLMW), and Mixed transuranic waste (MTRU) [10]. The AEA generally authorizes NRC. The authority is to regulate the disposal of commercially produced radioactive waste and all HLWs. The AEA authorizes DOE facilities to produce and manage radioactive waste [6]. This includes LLW, TRU waste, LLMW, and MTRU waste, HLW, and accelerators–"Area 11 (e) by-products or naturally occurring radioactive substances (NORMs)" [6].

2.1 History of laws and regulations

NRC follows the AEA as amended in 1954 [6]. Congress established the Land Disposal Restriction (LDR) on Hazardous Waste and made EPA set standards for hazardous and solid waste. In other words, if EPA does not comply with the revised standards for hazardous waste, land disposal will be restricted in 1984 [11]. In 1986, EPA issued a notice clarifying RCRA jurisdiction over MW. Also, states in the USA stipulate that RCRA basic approval must be included MW [11]. Besides, a notice has been issued stating that existing facilities being stored or disposed of must acquire a temporary status under subtitle C of the RCRA, and MW generators must notify EPA [11].

In addition, NRC and EPA jointly issued a testing guide related to MW, guiding clear guidelines that generators can handle in 1997 [12]. As such, the United States is making an effort to establish and revise laws and regulations considering the hazardous effects of the MW. The main laws and regulations required to manage mixed waste in the United States are described in Table 1, which manages MW from cradle to grave.

2.2 Regulatory responsibility

NRC regulates the commercial utilization and disposal of "sources, by-products or special nuclear material". EPA regulates the storage, treatment, and disposal of materials containing hazardous chemicals as defined in the RCRA. MW must follow both AEA and RCRA requirements. Dual regulatory responsibility shown as table 2 has raised concerns in the federal, state, and private sectors and NRC and EPA recognized concerns about the application of excessive regulatory requirements.

However, dual regulation is inevitable. In response to concerns, NRC and EPA have committed to making a joint approach to the issue of MW [13]. Joint efforts are as follows: (1) developments of joint guidance documents, (2) holding workshops for federal and state regulators, (3) development and support at the national level on the quantities, characteristics, and treatment possibility of MW [13]. Furthermore, DOE and EPA also signed a joint agreement to dispose of MW [14]. DOE has its regulations and the order applies to DOE sites and contractors. In October 1992, DOE developed a site treatment plan for MW disposal under EPA and authorized state reviews [14].

Table 2 shows the management responsibilities of the agencies applicable to MW in the United States. Besides, each agency establishes standards and guidelines on MW according to relevant laws and regulates MW.

2.3 EPA requirements

Under the RCRA of 1976, EPA developed regulations to regulate hazardous waste. Unlike radionuclides, chemically hazardous non-radioactive waste requires management as its half-life is clear or unpredictable and is expected to last as long as the radioactive hazard [17]. The list and the standards of MW that generators and managers must meet are

Table 2. Management responsibilities and laws applicable to MW in the USA [14]

Agency	Responsibility	Law/Act
EPA	• Independent agency responsible for environmental protection issues • Establishment of radiation protection guidelines and national environmental standards [15]	• Clean Air Act • Clean Water Act • Resources Conservation and Recovery Act • Hazardous and Solid Waste Amendments • Comprehensive Environmental Response Compensation and Liability Act • Safe Drinking Waste Act • Toxic Substance Control Act • Pollution Prevention Act
NRC	• Protecting People and the environment • Ensuring the safe use of radioactive materials • Regulation on the use of source, by-protect and special nuclear material including license, inspection, and enforcement of requirements • Permission for commercial LLW disposal facilities	• Atomic Energy Act • Energy Reorganization Act • LLW Policy Amendments Act
DOE	• Responsible for overall policy on energy, environment, and nuclear security • Leading the national plan for the management and disposal of commercial LLW • Conduct research and development (R&D) on LLW disposal technology, and transfer that technology to the private sector	

described in 40 CFR Part 260-265 [16-19]. The LDR has been described in 40 CFR Part 268 [20] and the licensing program is in 40 CFR Part 270 [21]. EPA provides definitions of hazardous waste, disposal standards. It should be satisfied before land disposal. Also, EPA provides standards for hazardous waste disposal facilities.

The classification of MW is important to determine the treatment method of MW, the final waste form specification and special requirements. Hazardous waste is identified in 40 CFR Part 261 [17]. It is divided into "listed waste" and "characteristic waste". In order to effectively treat hazardous waste, it is essential to understand the meaning of solid waste. Solid waste contains not only physically solid waste but also liquid, semi-solid, or contained gaseous substances. Materials cannot become a hazardous waste unless it meets the definition of solid waste, and is not subject to the RCRA Part C hazardous waste regulations. Listed waste is divided into F, K, and P, U. Specific regulations are followed 40 CFR Part 261.31/32/33.

Characteristic waste has "ignitability, corrosivity, reactivity, and toxicity". Toxicity Characteristic is described as a list of 40 constituents. It consists of seven metals (Pb, Cr, Cd, and Hg) and 33 pesticides and solvent [17]. Table 3 summarized regulations of the codes, test methods for the four characteristics. Further information can be found in the relevant regulations (40 CFR Part 261.21/22/23/24). The test method can be found in SW-846. Mainly this test is used to evaluate the physical and chemical properties of solid waste [20].

In addition, EPA strictly restricted land disposal for hazardous waste. EPA has regulations to specifying such levels and treatment methods in accordance with RCRA Section 3,004 (m). It states that "Significantly has to reduce the toxicity and the potential for hazardous components to move from waste" [7]. The LDR of 40 CFR Part 268 applies to all hazardous waste. The LDR identifies the maximum concentration of hazardous components. It can be disposed of in the approved hazardous waste landfill or

Table 3. Summary of hazardous waste characteristics [17]

Characteristics	Standards	Test Methods
Ignitability	• Liquids with flashpoint of less than 60°C • Non-liquids that cause fires under certain conditions • Ignitable compressed gases and oxidizer	• Pensky-Martens Closed-Cup Method • Setaflash Closed-Cup Method • Ignitability of Solids
Corrosivity	• Aqueous wastes with a pH of less than or equal to 2 • A pH greater than or equal to 12.5	• Corrosivity Towards Steel
Reactivity	• React violently with water • Potentially explosive mixtures • Generates toxic gases	N/A
Toxicity	• Ingestion or absorption hazard • Contaminate groundwater	• Toxicity Characteristic Leaching • Processure(TCLP) [22]

specifies how to dispose of the waste in the approved hazardous waste landfill [23]. The LDR covers the prohibition of dilution and storage of waste. And it includes requirements for final testing before disposal and requirements for tracking and recordkeeping "cradle-to-grave" waste [16].

The clause presents the "Best Demonstrated Available Technology" (BDAT). This technique is the most effective techniques to reduce the inherent hazard and toxicity of hazardous substances in waste [24]. In accordance with this Act, LDR has set out BDAT treatment standards for [5]:

- Radioactive lead solids that have macroencapsulation
- Radioactive element mercury with a merged
- Radioactive hydraulic oil contaminated by mercury
- HLW generated during the reprocessing of vitrification

EPA establishes specific treatment standards of waste codes. The treatment criteria are mainly based on concentration. It does not necessarily have to be BDAT, but producers need to be approved for removing chemical properties by presenting specific technologies [20]. The tests carried out must be in accordance with regulatory guidelines and recommendations.

2.4 NRC requirements

NRC has the authority to license and regulate the use of "source, by-product, and special nuclear materials" under the AEA [25]. NRC regulations do not specify provisions for MW. But basically, the radioactive portion of the MW is regulated in accordance with LLW. The regulations for MW can be described the licensing requirements of LLWs (10 CFR Part 61) [26] and Radiation Protection Standard (10 CFR Part 20) [27].

NRC provisions permit land disposal close to the surface using a combination of normative and performance-based requirements (10 CFR Part 61.55–56). A near-surface disposal facility means that radioactive waste is disposed of within or within 30 m of the surface's upper. Agency control of access is required for 100 years (10 CFR Part 61.7) [26].

There are waste classification tables in 10 CFR Part 61.55. When determining the classification of radioactive waste, the radionuclide should be considered a response to potential hazards. Also, waste types, institutional controls, and effective disposal methods should be considered [28]. The physical form and characteristics are listed in Part 61.56(a). Waste shall not be packaged for disposal inboxes. Liquid waste shall be solidified or packaged with sufficient absorbent substance. Solid wastes containing liquids shall contain non-corrosive liquids. But the liquid should not exceed 1% of the volume in any case [28]. It must not be explosive or flammable in addition. Meanwhile, the main stability requirements are described in Part 61.56(b). The

Table 4. Concentrations of long-lived radionuclides (by 10 CFR Part 61.55) [28]

Radio-nuclide	Ci/m^3
^{14}C	8
^{14}Cin activated metal	80
^{59}Ni in activated metal	220
^{94}Nb in activated metal	0.2
^{99}Tc	3
^{129}I	0.08
	nCi/g
α-emitting transuranic nuclides with a half-life greater than 5-year	100
^{241}Pu	3,500
^{242}Cm	20,000

Table 5. Concentrations of short-lived radionuclides (by 10 CFR Part 61.55) [28]

Radio-nuclide	Ci/m^3		
	Class A	Class B	Class C
Total of all nuclides with less than 5-year half-life	700	(1)	(1)
^{3}H	40	(1)	(1)
^{60}Co	700	(1)	(1)
^{63}Ni	3.5	70	700
^{63}Ni in activated metal	35	700	7,000
^{90}Sr	0.04	150	7,000
^{137}Cs	1	44	4,600

(1) There are no set limits for these radionuclides in Class B or C wastes. These wastes shall be Class B unless the concentration of other nuclides in table 4 determines the waste for C independent of the nuclide.

waste must have structural stability. Waste should be packaged with as little empty space as possible [28].

Waste classified as Class A (minimum limit), B or C depends on the radionuclide present and its concentration. Radioactive half-life is the primary discriminator. Class A is classified if the concentration is less than 0.1 times the value in table 4 [28]. If it exceeds 0.1 times the value in table 4 but does not exceed the value in table 4, it is classified as Class C. Waste is not suitable for near-surface treatment if it is present in the waste at a concentration higher than table 4 of long-lived nuclides [28]. Therefore, MTRU is excluded from near-surface land disposal by NRC. Without long-lived radionuclides, significant concentrations of short-lived nuclides can be treated on the surface according to the provisions of table 4 and 5 [28]. If the concentration exceeds the Class C value, it cannot be treated for near-surface disposal [28].

NRC specifies the following exceptions for VLLW: 10 CFR Part 20.2002 is most commonly used to dispose of VLLW from hazardous or solid waste landfills allowed under the RCRA but can be used for all types of disposal [29]. The term “VLLW” has no legal or regulatory definition. This generally includes naturally occurring radionuclide and some residual radioactivity. 10 CFR Part 20.2002 is generally available to Class A waste licensees. In addition to wastes approved for disposal under 10 CFR Part 20.2002, various radioactive substances are disposed of in hazardous and solid waste landfills regulated under the RCRA [29]. Radioactive materials with a half-life of fewer than 65 days can be disposed of in landfills. It may include short-term nuclear medical radioactive isotopes, paper towels, bedding, and anything else from hospitals, or clinics. NRC determined that nuclides with a very short half-life would quickly disappear from dangerously [29]. NRC approves disposal of waste in consideration of disposal options and lower disposal costs while providing public health, safety, and environmental protection.

2.5 DOE requirements

DOE, authorized by the AEA, regulates the following substances concerning nuclear control [6]:

- Source material [IAEA, SECTION 11(z)]

U, Th, and other nuclides determined by NRC as

source material according to Section 61 of the AEA
- Special nuclear material [IAEA, SECTION 11(Aa)]
  Pu, a substance containing concentrated 233U or 235U, other substances determined by NRC under Section 51 of the AEA
- Byproduct material [IAEA, SECTION 11(e)]
  By-products contaminated by radiation in the process of producing or utilizing special nuclear materials but excluding special nuclear materials

With regard to the definition of by-products, the DOE has issued a regulation that contains an interpretation of radioactive material containing hazardous substances in 10 CFR Part 962 (i.e. MW) [30]. According to this rule, the term any radioactive material for byproduct materials means only actual radionuclides present in the material. DOE reserves the authority under AEA for the actual radionuclides in byproduct material. However, any nonradioactive hazardous substances are subject to EPA regulations under the RCRA [6].

DOE Order 5400.5 sets radiation exposure standards. These standards allow a total of 100 mrem·yr^{-1} exposure to the public. Of these, inhalation of particles in the air can only generate 10 mrem·yr^{-1}, and exposure to radionuclides from drinking water is limited to 4 mrem·yr^{-1}. Any disposed of radioactive or MW shall not contribute to public exposure in excess of these amounts. Also, all exposures should be limited to "as low as reasonably achievable (ALARA)" levels [23].

DOE Order 5820.2A deals with the management of radioactive waste, including HLW, TRU waste, and LLW. It contains several provisions that meet and extend the regulatory standards established by NRC. Promulgated in 1988, this order mandates the application of the concept of waste minimization, including waste separation, to the design and operation of processes [23]. The DOE is presently self-regulating. In accordance with the provisions of the FFCA signed on October 6, 1992, DOE developed a Site Treatment Plan to handle MW following EPA's review [10]. The DOE and EPA have signed to comply with the "Hanford Federal Facility Agreement and Consent Order" and conducted studies to improve the disposal requirements for radioactive MW stored on the Hanford site [31].

3. Forward direction of mixed waste laws and regulations in Korea

In general, hazardous waste is subject to laws and regulations of the Ministry of Environment (MOE) in Korea. However, Environmental laws and regulations do not be applicable to radioactive waste. Therefore, radioactive waste is regulated by the Radioactive Waste Management Act under the Ministry of Trade, Industry, and Energy (MOTIE) and Nuclear Safety Act (NSA) administered by the Nuclear Safety & Security Commission (NSSC). There are only comprehensive regulations related to radioactive waste. In other words, relevant laws and regulations do not provide clear guidance on hazardous materials. There are presently no regulations for MW.

At the 2019 Nuclear Safety Regulation Information Conference [32], there was a discussion on the necessity of developing clear requirements for this as the current domestic standards prohibit the acquisition of hazardous substances.

3.1 MOE requirements

In the definition of environmental laws and regulations in Korea, it is stipulated that radioactive materials and resulting in contaminated materials under the Nuclear Safety Act are excluded. Main environmental laws and regulations in Korea are shown in table 6.

The Waste Management Act describes designated waste. The wastes corresponding to NPPs such as oil, asbestos, PCBs, Toxic substances, etc. are shown in table 7. The regulations on the classification and identification of chemicals also specify criteria for the classification of hazardous substances. However, it excludes hazardous sub-

Table 6. Environmental laws and regulations in Korea

Laws and Regulations	Requirements
Waste Control Act, No.16699 [33], December 4 2020	This Act does not be applicable to radioactive substances under the Nuclear Safety Act and contaminated materials. Table 7 presents the criteria for the classification of listed wastes.
Chemical Substances Control Act, No.17326 [34], Oct 1 2020	This Act does not be applicable to chemical substances corresponding to radioactive substances according to 5 of Article 2 of the Nuclear Safety Act. The establishment and operator of hazardous chemical substance controlling facilities shall evaluate the effects of chemical accidents in advance and submit them to the MOE.
Enforcement Rule of the Chemicals Control Act, No.886 [35], December 12 2020	This rule quantified the amount prescribed by the MOE. The storage of toxic substances is limited to 500 kg. The transport of toxic substances can be up to 5,000 kg.
Act on Registration and Evaluation of Chemicals, No.17326 [36], May 26 2020	This Act does not be applicable to radioactive substances according to the Nuclear Safety Act and contaminated materials. Appendix1 of the Enforcement Decree of this Act presents the standards for the criteria of toxic materials.
Regulations on Classification, Labelling, etc. of Chemicals, Notice No.2020-52 [37], August 5 2020	These regulations include the identification criteria that the Chemicals Control Act and the Chemicals Registration and Evaluation Act must comply with. The name and identification number (Chemical Abstract Service number) of the hazardous chemical shall be written. In the case of mixture hazardous chemicals, the name of the mixture or the content (%) of the hazardous chemical shall be indicated. Table 8 provides the criteria for the classification concentration of the mixture. The requirements set out criteria by classifying them as physical, health, and environmental hazards. The criteria for classifying acute toxicity for materials are as shown in table 9.
Water Environment Conservation Act, No.15832 [38], November 27 2020	This Act prohibits leakage or disposal of specific water-hazardous substances, listed wastes under the Waste Control Act, and toxic constituents under the Chemical Substances Control Act in public waters.
Air Environment Conservation Act, No.16604 [39], May 27 2020	The MOE may regulate pollutants in the total amount of pollutants in areas where air pollution conditions exceed environmental standards and are considered to cause serious hazards to the health and property of residents or the growth of animals and plants.

stances emitted from NPPs. Environmental laws regulate chemical toxic substances, but there are exceptions to radioactive waste regulations. This means that if hazardous waste is non-radioactive, it can be listed waste that should be separately managed, treated, and disposed of under environmental laws and regulations. However, all wastes discharged from NPPs are considered radioactive waste and are not regulated under environmental laws. The generator (KHNP) autonomically manages about the deregulated wastes on the same basis as general waste by applying the environmental guidelines.

On the other hand, National Institute of chemical Safety (NICS) under the MOE discloses information on the names and hazards of chemical substances in relation to Article 42 of the Act on Registration and Evaluation of Chemicals and Article 51 of the Enforcement Regulations of the Act. NICS operates "National Chemicals Information System (NCIS)" to enable integrated search for chemical substances. The MOE has constructed and operates a comprehensive information system for chemical substances in accordance with the Article 48 of the Chemical Substances Control Act [34]. It is a comprehensive information portal that provides chemical substance handlers with information on chemical substance safety management information, chemical accident occurrence history and chemical accident response.

In addition, all chemicals are managed by the Korea

Table 7. Types of listed wastes containing hazardous material [33]

Type	Characteristics
Waste oil	Contains more than 5% of oil, wastes containing PCBs, absorbents, etc. is excluded.
Waste asbestos	• Containing more than 1% asbestos when occurring the dismantling and removal • Dust generated by grinding, cutting, and processing processes of solidified asbestos product
Waste containing PCBs	• Liquid (limited to those containing more than 2 mg per liter) • Non-liquid(containing more than 0.003 mg per effluent)
Waste toxic substances	It is limited to the cases of disposing of toxic substances under subparagraph 2 of Article 2 in the Chemical Substances Control Act.

Table 8. General marginal concentrations [37]

Hazardous categories	Concentration
Acute toxicity:	
- category 1 to 3	0.1%
- category 4	1.0%
Skin corrosion/irritation	1.0%
Severe eye damage/eye irritation	1.0%
Hazardous to the water environment	
- Acute Category 1	0.1%
- Chronic Category1	0.1%
- Chronic Category 2 to 4	1.0%

Table 9. Criteria of acute toxicity [37]

Category	Acute Toxicity Value by Exposure Path				
	Oral ($mg \cdot kg^{-1}$)	Percutaneous ($mg \cdot kg^{-1}$)	Inhalation (4 hours)		
			Gas (ppm)	Steam($mg \cdot L^{-1}$)	Dust/mist($mg \cdot L^{-1}$)
1	5	50	100	0.5	0.05
2	50	200	500	2.0	0.5
3	300	1,000	2,500	10	1.0
4	2,000	2,000	20,000	20	5

Occupational Safety and Health Agency website for the prevention of industrial accidents under the Occupational Safety and Health Act. There are a total of 20,346 types of chemicals. If a chemical is to be handled or transported, information on the chemical must be searched. After checking the hazardous information for each material, an MSDS (Material Safety Data Sheet) shall be prepared to handle the hazardous material. Those who transfer or provide chemicals shall prepare an MSDS. These include chemicals that meet the criteria for classifying physical risks, health, and environmental hazards. Each hazardous substance has a unique number. For example, Benzol is 71-43-2, KE-02150 [40].

However, according to Enforcement Decree of the Occupational Safety and Health Act, radioactive substances emitted from NPPs are excluded from chemical substances. Chemical substances excluding hazard and risk investigations (Article 85), chemicals excluded preparation and submission of MSDS, etc. (Article 86) include radioactive substances under the Nuclear Safety Act. In other words, hazardous chemical substances generated from NPPs are not subject to the Occupational Safety and Health Act.

Unlike the United States, domestic environmental laws do not apply regulations on radioactive waste emitted from NPPs, and there are no regulatory standards for mixed wastes that contain both hazardous and radioactive materials. There is no definition of mixed waste in all relevant environmental laws and regulations, and mixed waste is

Table 10. Nuclear laws and regulations in Korea

Laws and Regulations	Requirements
Nuclear Safety Act No.17359, June 6, 2020 [41]	Chapter 6 of this Act presents licensing standards for the construction and operation of radioactive waste management facilities, etc. The permission of the NSSC for waste management is essential. In addition, overall standards for packaging and inspection are presented.
Radioactive Waste Management Act No. 15082 [42], Nov 28, 2017	This law comprehensively stipulates what is necessary to safely and efficiently manage radioactive waste. It also provides regulations on the establishment and operation of the Korea Radioactive Waste Agency to efficiently manage radioactive waste.
Enforcement Regulations of Nuclear Safety Act No. 1616 [43], May 29, 2020	Article 96 Delivery of Radioactive Waste “In order to ensure safety, it should be in solid form. Radioactive waste should be removed from the hazardous of the explosion, flammability, and harmful substances”.
Regulations on Radioactive Waste Classification and Clearance Standards (NSSC Notification No. 2020-6 [44]), May 26, 2020	This regulation aims to establish clear standards for radioactive waste. If the concentration of radionuclides among radioactive wastes is found to be less than the permitted concentration for clearance, they are excluded from the application of the Nuclear Safety Act and can be disposed of on-site. Clearance refers to those that can be incinerated, buried, or recycled as general waste, not radioactive waste. Clearance tolerance is the radioactive concentration by radionuclide that can clearance radioactive wastes. The concentration should satisfy the permissible concentration or clearance dose shown in table 11 [44].
Regulation on Delivery of LILW (NSSC Notice No.2020-11 [45]), July 30, 2020	This regulation is designed to provide the delivery methods and procedures necessary to entrust LILW disposal to the operator of a radioactive waste disposal facilities. The waste generator shall request the facility operator to acquire the waste in compliance with this regulation.
Regulation on the Preparation of Plans for Decommissioning NPPs (NSSC Notice No. 2020-8 [46]), May 29, 2020	This regulation has defined as follows: “MW means wastes containing both radioactive and non-radioactive hazardous materials expected to be generated during the decommissioning process”.

not considered. However, the standard for incineration of radioactive waste only regulates the concentration of emissions by applying environmental laws to gases.

3.2 NSSC requirements

In Korea, radioactive MW cannot be disposed of in the radioactive waste repository due to its hazards, and radioactive wastes are excluded from the regulations under environmental law. Therefore, there is not enough the legal basis for disposing of hazardous waste emitted from NPPs. In other words, waste generators at NPPs must be disposed of in accordance with nuclear safety laws, even if they are hazardous waste. However, nuclear-related domestic laws only provide comprehensive standards for hazardous materials or do not specify any hazardous substances in the statute. Only the waste delivery clause can confirm the handling of hazardous waste. The detailed requirements of delivery are as follows. Waste should be in solid form to ensure safety during handling and after disposal. It should be physically and chemically stable and should not have fluidity. Waste must be corrosively mitigated and packaged to withstand corrosion. Wastes containing explosives, flammables, and ignitable substances should be properly disposed of to eliminate the risk. It should not impair the safety of workers. Wastes containing toxic or perishable and infectious substances should be eliminated from these hazards. More details are difficult to confirm.

Table 10 are summarized the laws and regulations related to radioactive waste. Hazardous materials are not clearly

Table 11. Restriction of radioactive concentration of LLW [44]

Radionuclide	Radioactive Concentration ($Bq \cdot g^{-1}$)
^{3}H	1.11×10^{6}
^{14}C	2.22×10^{5}
^{60}Co	3.70×10^{7}
^{59}Ni	7.40×10^{4}
^{63}Ni	1.11×10^{7}
^{90}Sr	7.40×10^{4}
^{94}Nb	1.11×10^{2}
^{99}Tc	1.11×10^{3}
^{129}I	3.70×10^{1}
^{137}Cs	1.11×10^{6}
Gross α	3.70×10^{3}

stated in the laws and regulations. In addition, the regulations on MW are only defined in the guidelines for preparing the final decommissioning plan report.

After reviewing the Nuclear Safety Act, Waste Management Act, etc., no clear classification criteria or treatment method for MW included hazardous waste was provided. Also, standards for the clearance of hazardous substances are not specified. Hazardous waste disposal is mentioned only in the waste delivery regulations and comprehensive standards are presented. In other words, Korea has not given strict consideration of hazardous waste when disposing of waste.

However, KHNP is managing the deregulated waste by creating its internal chemical management guidelines in compliance with environmental laws. The MOE is only monitoring the disposal of radioactive wastes.

3.3 Comparison of laws and regulations on mixed waste

In the United States, general waste is managed by the state. And Hazardous waste is managed by EPA, radioactive waste is managed by NRC. Regarding radioactive waste, NRC regulates twofold under the AEA and EPA under the RCRA showed as Fig. 1. In the case of radioactive MW generated from NPPs, the entire process of generation, storage, treatment, transport, and disposal is under “strict” management by NRC and EPA [5].

However, radioactive waste generated from NPPs in Korea is only regulated by the NSSC shown as Fig. 1. The MOE does not regulate radioactive hazardous waste. In the case of Korea, environmental regulations on waste generated from NPPs are insufficient rather than the U.S. environmental regulations.

EPA has proposed regulatory standards for MW in environmental laws such as identification of MW, land disposal restrictions, treatment technology to remove toxicities, the Act on Toxicity Identification, and the Pollution Prevention Act, etc. On the other hand, Korea has not considered regulations on MW.

In preparing the final decommissioning plan for Kori unit 1, the NSSC defined the MW. Other major relevant laws and guidelines do not even have a definition of MW. There is no identification standard for MW. In particular, nuclear laws do not provide clear regulatory standards for hazardous waste. Environmental laws regulate hazardous waste but exclude waste discharged from NPPs.

In Korea, environmental regulations are similarly managed by referring to US environmental regulations. However, major environmental laws, such as the Waste Management Act and Chemical Substances Management Act, are excluded waste generating from NPPs. In other words, the MOE does not manage radioactive materials.

Even in the case of the Nuclear Safety Act, there is a provision stating that when hazardous substances are generated, they are removed and disposed of. However, it does not provide clear legal guidelines. In other words, it is necessary to clear guidelines to regulate chemical hazards in the case of wastes generated from NPPs.

Tables 12 and 13 are comparisons of major environmental and nuclear laws and regulations in the USA and Korea.

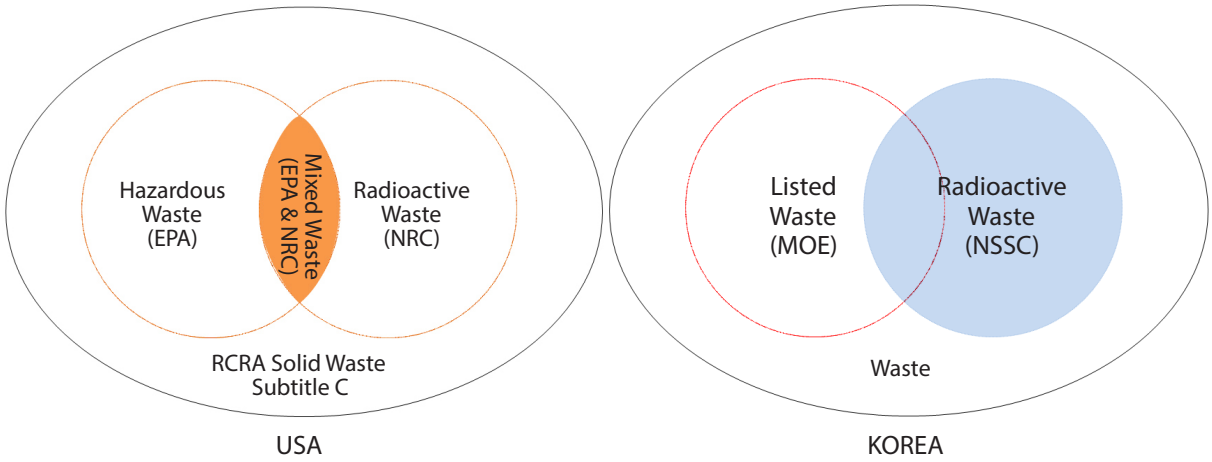

Fig. 1. Comparison of MW regulation framework the USA [47] and Korea.

Table 12. Comparison of environmental regulations on MW

USA (40 CFR Part~)	Korea
Overview and definitions (260) [16]	
Defined as listed waste and characteristic waste (261) [17]	
Producers of hazardous waste (262)	
Transportation of hazardous waste (263)	
Standards for hazardous waste management facilities (264 to 267) [18, 19]	
Land Disposal Restrictions (268) [20] • All waste must be approved by EPA before landfill. • Treatment technology Standards is provided.	
Permit requirements for hazardous waste management facilities (270, 124)	The radioactive materials are supposed to follow the rules of the NSSC under Nuclear Safety Act [33, 34].
Administered Permit Programs (270) [21]	
Toxicity Substance Control Act [22] (700~799); PCBs (761), Asbestos (763) • Presenting the Test Method 1311 • TCLP is provided.	
Environmental Radiation Protection Standards • SNF, HLW, TRU Waste (191) [15]	
The Clean Air Act (CAA) has a defined source-specific NESHAPs. • NESHAPs for radionuclide emissions (61) • Hazardous air pollutant emissions (63)	

Table 13. Comparison of nuclear regulations on MW

	USA (10 CFR Part~)	Korea
NRC	Licensing requirements of radioactive waste (61) [26] Radiation Protection Standard (20) [27] Alternative disposal (20.2002) [29] • Disposal of VLLW in hazardous waste are permitted under RCRA	Comprehensive management standards for radioactive waste are provided [42].
DOE	Byproduct Material (962) [30] • The nonradioactive hazardous component will be regulated RCRA	N/A
WAC	Each disposal facility manages waste by developing a specific WAC	There are comprehensive acceptance criteria. It is necessary to establish acceptance criteria for specific wastes.

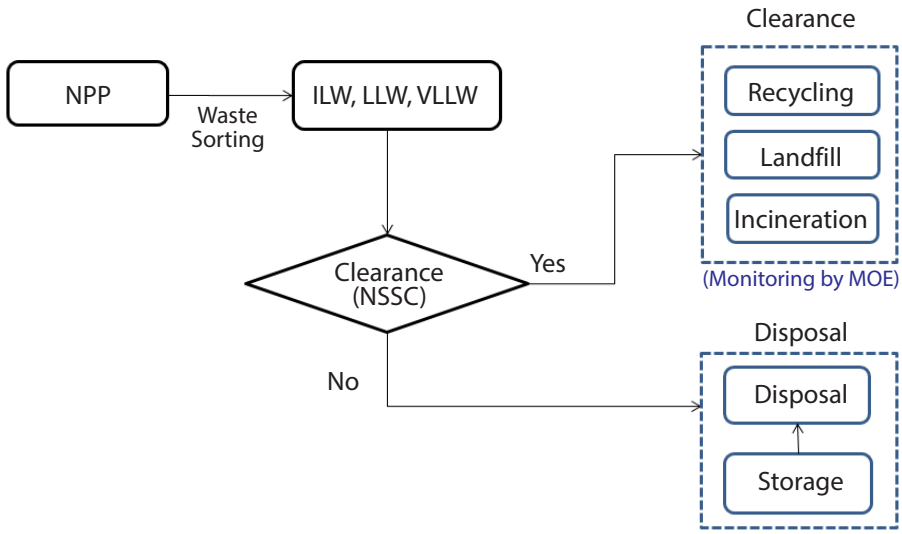

Fig. 2. Current status for waste treatment in Korea.

The USA has "strict" environmental regulations with EPA's authority on hazardous waste. However, the MOE in Korea does not regulate radioactive materials.

In the USA, NRC and DOE are regulated on "hazardous waste" under the RCRA. The nuclear laws and regulations in Korea do not provide clear guidelines on hazardous waste.

3.4 Applicability of regulation in Korea

EPA and NRC strictly regulate MW's hazardous effects on human health and the environment more seriously than the effects of radioactivity. Korea also should strictly manage MW by benchmarking the U.S. regulatory framework to protect people and the environment. If hazardous substances are detected in radioactive wastes, MOE should take part in regulation unlike the traditional methods regulated by NSSC. It is necessary to seek a plan to comply with the regulatory guidelines of the MOE.

Fig. 2 shows the current waste disposal flow in Korea. Presently, radioactive waste is regulated only by the NSSC. Clearance waste from NSSC may be incinerated, reclaimed,

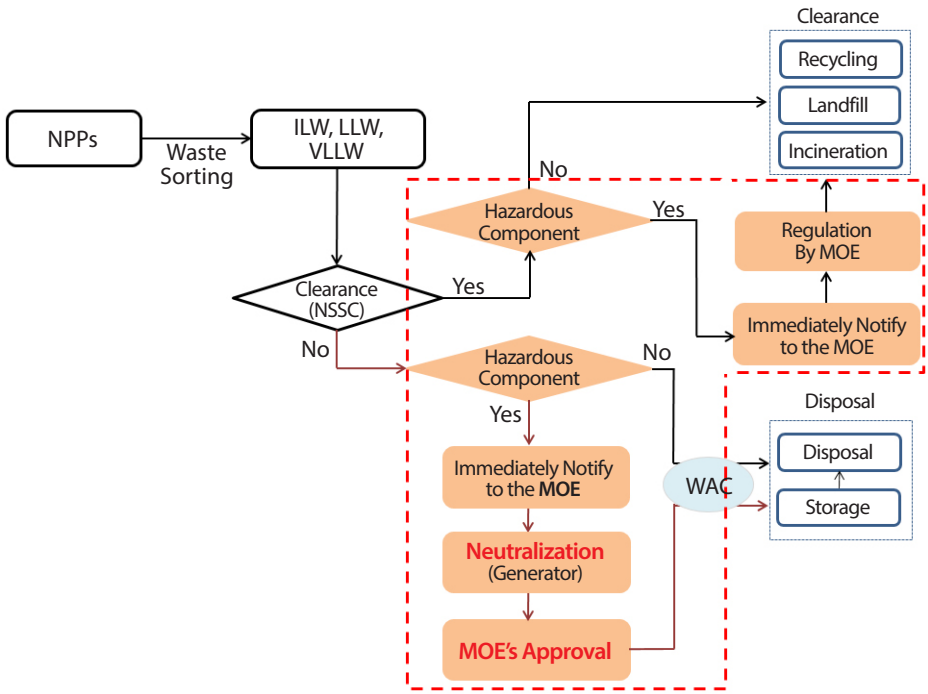

Fig. 3. Proposal of treatment option for MW in Korea.

or disposed of. The MOE only monitors waste disposal periodically. However, traditional waste disposal methods do not take into account hazardous MW.

By the way, the current status does not have a clear legal guide, but KHNP manages hazardous materials in compliance with the Chemical Substance Control Act. Internal procedures have been established to manage hazardous waste from clearance waste by the NSSC. In addition, hazardous substances are managed efficiently using MSDS in accordance with the Chemical Substances Registration and Evaluation Act. For example, the PCB code number is 97-1-394 and a mixture containing 0.005% or more is treated as a toxic substance [40].

Fig. 3 provides a more stringent regulation plan of MW that threatens people and the environment by benchmarking the USA case. Unlike the existing treatment method, when hazardous components are identified among the deregulated ILW, LLW, VLLW, the generator must immediately notify the MOE and follow the regulatory guidelines of MOE. When a hazardous component is found in clearance LILW, it is classified as MW. The MOE needs to present specific treatment standards for the removal of hazardous substances. Besides, the generator must treat the waste after receiving approval from the MOE that the hazardous components have been removed after neutralizing according to the guidelines of the MOE. At this time, it will be necessary to secure appropriate neutralization technology. In order to treat MW with Fig. 3, it is necessary to prepare clear guidelines explaining the identification form of the MW, treatment, and disposal. In addition, it is necessary to prepare clear waste acceptance criteria for treating and disposing of MW. Furthermore, securing technology capable of treating MW should be given priority.

The proposed treatment options will help strictly manage hazardous materials. Table 14 describes proposals for strict regulation of radioactive hazardous materials under the Environmental Act and the Atomic Energy Act.

Table 14. Proposal of regulations for mixed waste management

Laws and Regulations	Improvements
Waste Management Act Chemical Substances Control Act Act on Registration and Evaluation of Chemical Substances,	• The exclusion provision of radioactive waste shall be eliminated. • The following items shall be added or supplemented: Classification, Characteristic, and Treatment Standards • All hazardous wastes are approved by MOE
Nuclear Safety Act Radioactive Waste Management Act Regulations on Radioactive Waste Classification a Clearance Standards Regulation on Delivery of LILW	• Adding to a provision, "When disposing of hazardous waste, follow the regulations of MOE" • It is necessary to establish acceptance criteria for specific wastes

4. Conclusion

In Korea, radioactive MW cannot be disposed of in a radioactive waste repository due to its hazards. KHNP, which is expected to generate a large amount of radioactive waste due to decommissioning, needs thorough preparation for the treatment of radioactive waste. It is necessary to establish appropriate regulatory standards in Korea by benchmarking the cases of the United States with extensive experience in decommissioning the NPPs. The USA has strict management of MW based on dual regulations by EPA, NRC, and DOE.

However, Korea has yet to set clear standards for MW. Major environmental laws in Korea, such as Waste Management Act and the Chemical Substance Control Act, do not regulate radioactive waste generated from NPPs. Radioactive waste from NPPs is regulated by the MOTIE and the NSSC under the Radioactive Waste Management Act and the Nuclear Safety Act. Therefore, strict management of hazardous MW is required by benchmarking the U.S. case. For the strict management of hazardous chemicals, including MW, when disposing of wastes containing hazardous substances, a procedure for obtaining approval from the MOE must be established. The definition of MW should be included in the domestic environmental laws and appropriate regulatory standards should be established.

This report presents a treatment plan for the treatment and disposal of MW. If hazardous substances occur in ILW, LLW, or VLLW that are not deregulated, they shall be considered as MW and strictly managed. The producer shall notify the MOE immediately after the discovery of the hazardous substance and submit a plan to remove the hazardous substance. Also, the disposal of radioactive hazardous materials will be required approval from the MOE. At this time, the MOE needs to present standards and treatment methods for strict control over radioactive hazardous materials. In particular, the MOE, the MOTIE, and the NSSC should discuss and review identifying MW, establishing regulatory standards for MW, supporting the development of hazardous material removal technologies, and establishing specific Waste Acceptance Criteria for MW disposal.

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Appendix 1. List of abbreviations

AEA	Atomic Energy Act	MOE	Ministry of Environmental in Korea
ALARA	As Low As Reasonably Achievable	MOTIE	The Ministry of Trade, Industry, and Energy in Korea
ASTM	American Society for Testing and Materials	MTRU	Mixed Transuranic
BDAT	Best Demonstrated Available Technology	MSDS	Material Safety Data Sheet
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	NCIS	National Chemicals Information System
CFR	Code of Federal Regulations	NESHAPs	National Emissions Standard for Hazardous Air Pollutants
CAA	Clean Air Act	NPP	Nuclear Power Plant
CWA	Clean Waste Act	NRC	The United States Nuclear Regulatory Commission
DOE	The United States Department of Energy	NSSC	Nuclear Safety & Security Commission in Korea
DOT	Department of Transportation	NSA	Nuclear Safety Act in Korea
EPA	The United States Environmental Protection Agency	PCB	Polychlorinated biphenyl
FFCA	Federal Facilities Compliance Act	PPA	Pollution Prevention Act
HLMW	High-Level Mixes Waste	RCRA	Resource Conservation and Recovery Act
HSWA	Hazardous and Solid Waste Act	TRU	Transuranic waste
HWIR	Hazardous Waste Identification Rule	TSDF	Treatment, Storage, Disposal, Facility
IAEA	International Atomic Energy Agency	TSCA	Toxic Substances Control Act
ILW	Intermediate-Level Waste	TCLP	Toxicity Characteristic Leaching Procedure
KHNP	Korea Hydro & Nuclear Power	UTS	Universal Treatment Standards
LLW	Low-level Radioactive Waste	WAC	Waste Acceptance Criteria
LILW	Low and Intermediate Level Waste	WIPP	Waste Isolation Pilot Plant
LLMW	Low-Level Mixed Waste	VLLW	Very Low Level Waste
LDR	Land Disposal Restriction	SNF	Spent Nuclear Fuel
MW	Mixed Waste	SWDA	Safe Drinking Waste Act

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