The Geological Disposal Concepts for the High Level Radioactive Wastes from a Spent Fuel Recycling Process in Korea - 9297

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ABSTRACT

The electricity generated from the nuclear power plants is around 40 % of the total required electricity in Korea and according to the basic energy development plan, this proportion will be raised up to about 60 % in the near future. To implement this plan, the most important factor is the back-end fuel cycle, namely a safe management of the spent fuel or high level radioactive wastes from the nuclear power plants. Various researches are being carried out to manage spent fuel effectively in the world. In our country, as one of the management alternatives which is more effective and non-proliferation, the pyro-processing method is being actively developed to retrieve reusable uranium and TRU, and to reduce the volume of high level waste from a Nuclear power plant. This is a new dry recycling process. In this paper, the amount of various wastes and their characteristics are estimated for a pyro-process. Based on the information, the geological disposal alternatives are developed. According to the amount and the characteristics of each waste, the concepts of the waste packages and the disposal containers are developed. And also from the characteristics of the radioactivity and the heat generation, a multi-layer depth is considered to dispose of these wastes. The various proposed alternatives in this paper can be used as input data for the design of a deep geological disposal system. And they will be improved through the application of real site data and a safety assessment in the future. After that, the final disposal concept will be selected with various assessments and its optimization will be carried out.

INTRODUCTION

Since the first commercial nuclear power plant in 1978, Kori unit 1, there are now 20 operating nuclear power plants at 4 sites in Korea. There are 4 CANDU reactors in Wolsong and 16 PWR reactors in Kori, Uljin, and Youngkwang. Also, 8 units are under construction or in the planning phase. The electricity from the nuclear power plants is around 40 % of the total required electricity in Korea and according to the basic energy development plan, this proportion will be raised up to about 60 % in the near future. To implement this plan, the most important factor is the back-end fuel cycle, namely a safe management of the spent fuel or high level radioactive wastes from these nuclear power plants. Spent fuels from these reactors are being temporarily stored in the storage facilities of each power plant, wet type or dry type.
Various researches are being carried out to manage spent fuel effectively in the world. Korea launched a long-term R&D program for a spent fuel direct disposal technology development in 1997 and the Korean Reference spent fuel deep geological disposal System (KRS-V) has been developed.

Now, in our country, as one of the management alternatives which is more effective and non-proliferation, the pyro-processing method is being actively developed to retrieve reusable uranium and

TRU, and to reduce the volume of high level waste from a Nuclear power plant. This is a new dry recycling process. So, a disposal system for the high level waste from this process should be developed.

In this study, the characteristics of the various wastes from this recycling process are analyzed and their amount is estimated. And based on the waste information from these analyses and the technologies from the KRS-V system, the geological disposal alternatives for the wastes are developed. Namely, according to the amount and the characteristics of each waste, the concepts of the waste packages and the disposal containers are developed. And also from the characteristics of the radioactivity and the heat generation, a multi-layer depth is considered to dispose of these wastes.
The proposed various alternatives in this paper can be used as input data for the design of the deep geological disposal system. And they will be improved through thermal and structural analyses with the application of real site data and a safety assessment in the future. After this, the final disposal concept will be selected with various assessments and an optimization will be carried out.

THE PURPOSE AND THE DESIGN GOALS

Disposal Scenario

A long-term R&D program for a spent fuel direct disposal technology development was initiated in 1997 in Korea and, as a direct disposal of spent fuels scenario, the Korean Reference spent fuel deep geological disposal System (KRS-V) for PWR spent fuels and CANDU spent fuels was developed at the end of 2006, as shown in Figure 1.

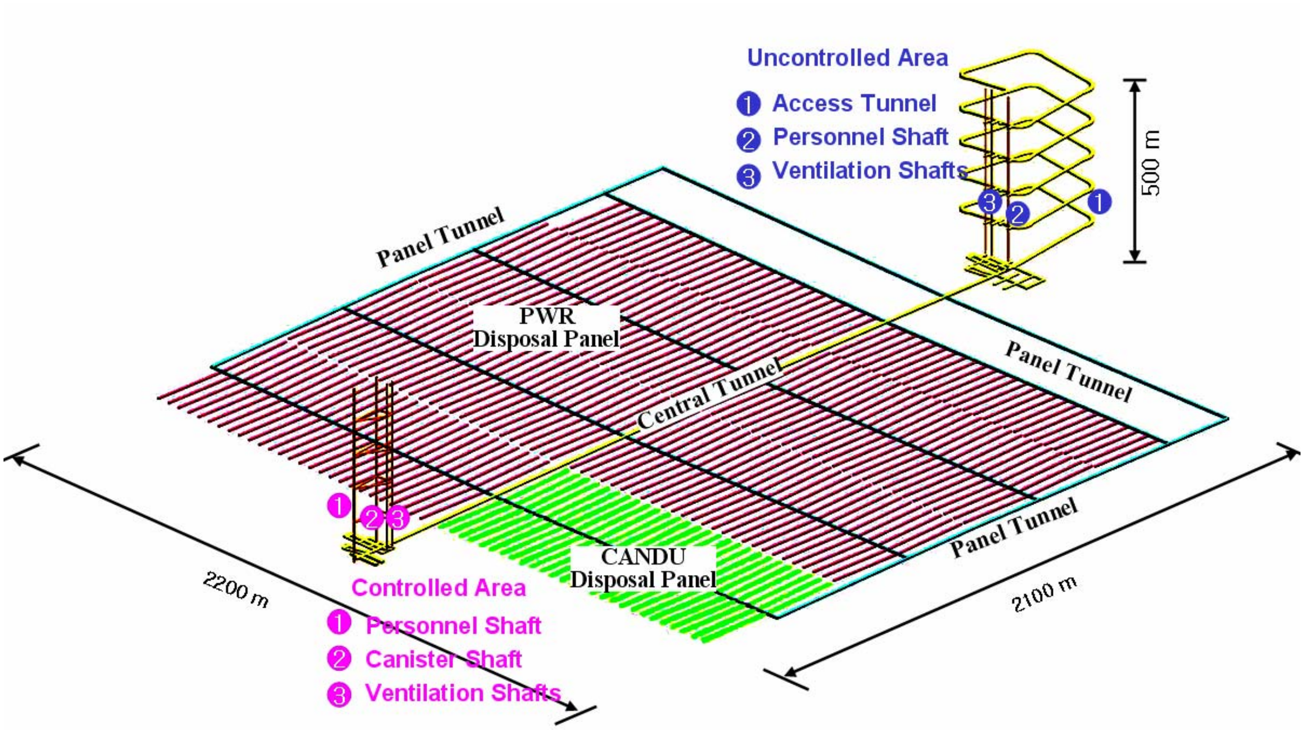

Figure 1. Layout of the Korean reference HLW Vertical disposal system.
(Green panel is for CANDU canisters.)

Spent Fuels Recycling Scenarios

Now, in our country, as one of the management alternatives which is more effective and non-proliferation, the pyro-processing method for a PWR spent fuels recycling is being actively developed to retrieve reusable uranium and TRU, and to reduce the volume of high level waste from a nuclear power plant. This is a new dry recycling process. So, a disposal system for the high level waste from this process should be developed.

A flow chart of a management scenario for the PWR spent fuels pyro-process is shown in figure 2.

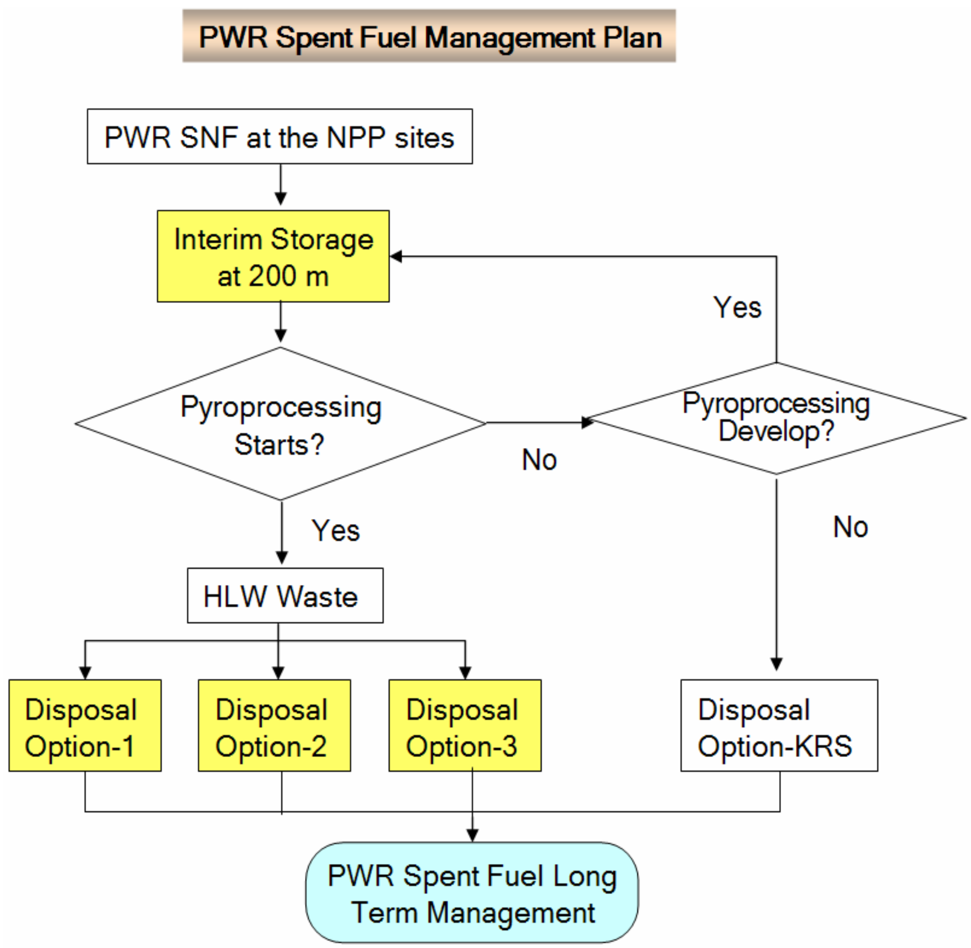

Figure 2. The concept of the PWR spent fuels management plan.

Purpose and Design Goals

The purpose of the study is to develop the options for the geological disposal of a HLW mainly from the pyro-processing of PWR spent fuels. The disposal system should meet the four design goals described as follows;

- Co-disposal of HLW from pyro-processing and all the wastes with long-lived radionuclides
- Very long-term storage (management) of HLW
- Improvement of the disposal density (spent fuel/area)

- Retrievability enhancement (+reversibility)

This study may guide us to what might be needed for developing a disposal system for totally different sources compared with spent fuels

CHARACTERISTICS OF THE WASTES

There are 3 kinds of waste from a pyro-processing. The first one is a metal waste. A metal waste is most massive but its radioactivity is too weak to be high level waste. The second is the wastes to be high level are VWF and CWF from a molten LiCl-KCl salt. And the last is the CWF(Ceramic Waste Form) from an Off-gas waste and VWF(Vitrified Waste Form) from molten LiCl salt purification which show highly heat generating. But they are expected to be stored in an interim storage facility, since they have relatively mid-lived radio-nuclide such as Cs or Sr.

The sub processes producing radioactive wastes are four in numbers, as shown in figure 3. First process is a chopping/decladding process from which a metal waste is obtained. Second one is a voloxidation process, in which an off-gas waste is generated. The third and fourth processes are a reduction and a refining process, in which impurities are gathered through a purification of the used molten-salts. The produced wastes can be divided into three categories such as a metal form, CWF, and VWF.

The 42 nuclides in a spent nuclear fuel are distributed into waste categories based on their physical and thermodynamic properties when they exist in metal, oxide, or chloride forms. The treated atomic groups are Uranium, TRU, Noble metal, Rare earth, Alkali metal, Halogens, and others.
The mass of each waste is estimated by the distribution results. The off-gas waste is included as a CWF. The heat generations by the wastes in this pyro-process are calculated using an ORIGEN-ARP program. As for the results, the produced wastes are divided into three categories such are a Metal form, CWF, and VWF. Here, the mass amounts and the heat generation rates are estimated.
Table 1 represents a brief summary of the characteristics of the waste from the pyro-processing of PWR spent fuels. The reference PWR spent fuel is a 10 MTHM of oxide fuel with 4.5 wt% U-235, 45,000 MWD/MTU burn up and 5 years cooling time.

Table 1. Characteristics of the wastes from the pyro-process of PWR spent fuels

	Long-Lived Waste			Interim decay Waste	
	Metal	Ceramic	Vitrified	Ceramic	Vitrified
		LICl+KCl	LiCl+KCl	off-gas+LiCl	LiCl
Major nuclide	NM+U+TRU+RE	Cs+α	Sr+TRU+RE	Cs	Sr
Weight (kg)	3,158.53	0.65	936.21	600.94	67.99
Volume (L)	470.7	0.3	419.8	231.8	30.5
Heat (W)	-	0.9	4,200 (49.3 after 100 yrs)	12,500 (6.72 after 300 yrs)	6,000 (4.23 after 300 yrs)
Container	1	2	3	4	5
Disposal Depth	200	500	500	200	200
Disposal Methods	Silo or Tunnel	With waste 3	KRS or Cavern	Tunnel Storage and then final disposal	Tunnel Storage and then final disposal

→ **10MTHM of oxide fuel with 4.5 wt% U-235. 45,000 MWD/MTU, 5 yrs cooling**

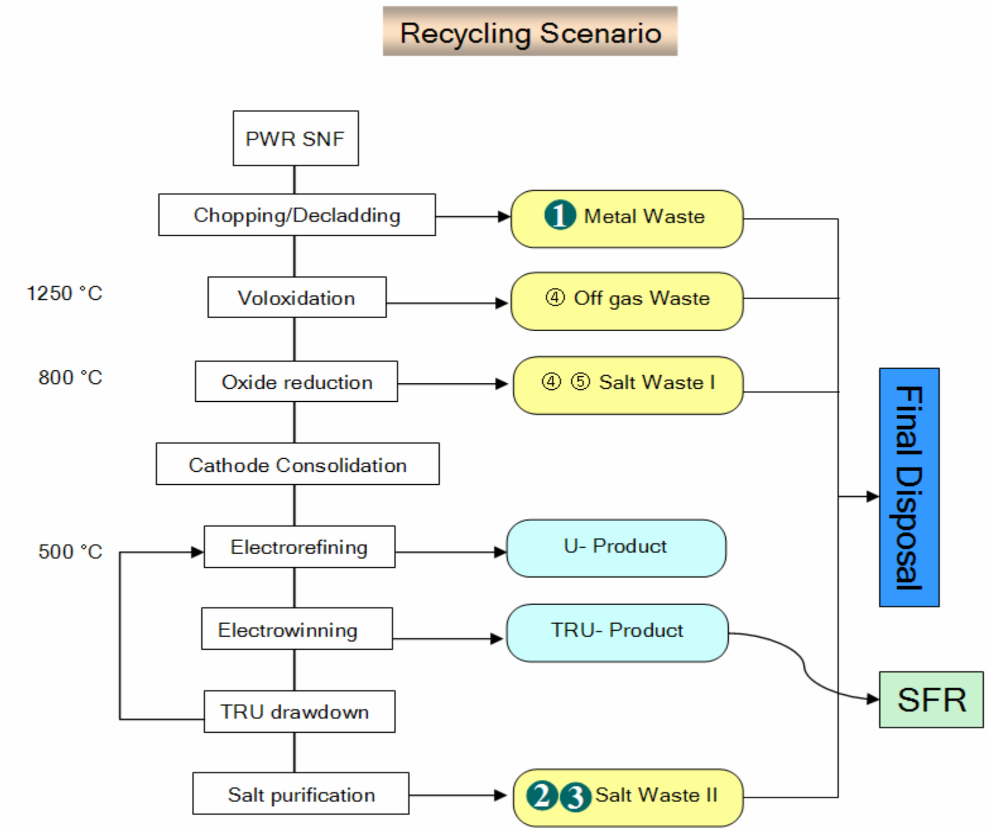

Figure 3. Recycling Scenario for the PWR spent fuels

Metal Waste Forms

The estimated amount of metal wastes is around 3.16 tons from 10 MTU of PWR spent fuels. Two different conditioning methods, a compaction and an ingot, can be proposed. But in this paper, the focus is on a compacted metal waste. The ingot method is proposed in order to recycle some parts of the metal waste. Due to a negligible heat generation, the waste will be disposed of at a shallow depth (200 meter level). In addition, large amount of metal wastes is expected from the decommissioning of NPPs. These wastes will be disposed of together with the metal wastes from the pyro process.
The compacted metal waste will be disposed of in a c-MDP(Compact Metal Disposal Package). A c-MDP will contain four cans of compacted metal wastes. The weight of a c-MDP with wastes is around 13.3 tons. Thickness of a c-MDP will be determined through a radiation shielding calculation. Total numbers is 855 c-MDPs from 26,000 tU spent fuels generated by 24 PWR reactors which can be disposed of in one tunnel or one silo.

Vitrified Waste Forms-HLW

The estimated amount of vitrified waste forms is around 0.94 ton from 10 MTU of spent fuels and it can be conditioned in one block. The conditioning method has not yet been fixed. Around 2,600 blocks are expected from 24 PWRs. Initial heat generations rate is quite high, 4.2 kW/block and around 50 watts/block after 100 years. Major radionuclides are 90Sr and 241Pu. This waste form is a real HLW

from the pyro-processing. 99 percent of decay heat is generated during a period of 100 years after a pyro-processing. This means that it is efficient to store them for 100 years in an open tunnel.
These waste forms will be disposed of in a SNDC(Storage and Disposal Container). Three types of SNDC are proposed depending on the number of canisters in a SNDC. Thickness of a SNDC is determined by considering the radiation shielding and corrosion rates. 150 mm for a radiation shielding, 10 mm for corrosion. Copper coated SNDC is being proposed. Total of 1,300 SNDC-2 are expected from the 26,000 tU spent fuels generated by 24 PWR reactors. Disposal option-1 and 2 are based on the SNDC-2 overpack.

Ceramic Waste Forms-ILW

Amount of ceramic waste forms is estimated. Around 0.6 ton from 10 MTU is generated and it can be conditioned in one block. The conditioning method has not yet been fixed. Around 2,600 SR(Storage Racks) are expected from 24 PWRs. One SR may hold 6 cans. Initial heat generation rate is quite high, 2.0 kW/block. The diameter of a block is determined by limiting the maximum temperature at the center of the block. Major radionuclide is 137Cs. Most of them will decay out for 300 years. This waste form is regarded as an ILW after 300 year storage. However, the wastes have to be stored for 300 years, and disposed of in a geological repository after that period. 9 tunnels are needed for the whole ceramic wastes from 24 PWRs. Due to a high heat generation, they will be stored at a disposal tunnel for at least 300 years before its closure, which also enhances the retrievability.

Vitrified Waste Forms -ILW

This waste form is regarded as an ILW after 300 years storage, too. However, these wastes have to be stored for 300 years, and disposed of in the geological repository after that period. 2 tunnels are needed for the whole wastes from 24 PWRs. Due to a high heat generation, they will be stored at a disposal tunnel for at least 300 years before its closure, which also enhances the retrievability.

DISPOSAL CONCEPTS FOR THE WASTES

Design Criteria

In this paper, focused on the high-level waste from the pyro-process, three different options are proposed for the disposal of these waste forms. The design criteria are as follows;

- Disposal system should be constructed at two separate levels. One shallow level at 200 meter is for the waste with no decay heat. The other deep level at 500 meter is for the HLW. The wastes containing most of short-lived radionuclides such as Cs-137 and Sr-90 should be stored at the shallow level and disposed of at that level.
- Also, the tunnels at the shallow level will be used for the interim storage of PWR spent fuels before the start of pyro-processing.
- Each waste is disposed of in the separately designated tunnel.
- A tunnel or a silo should be compared for the metal waste.
- Wastes with long-lived radionuclides or high decay heat should be stored for a period and then disposed of at 500 meter level.

- For enhancing the retrievability, all the wastes should be stored for at least 100 years in open tunnels.
- The site information should be from the KURT (KAERI Underground Research Tunnel)
- The application and characteristics of the buffer will be determined later.

General Disposal Concepts of the Wastes from a Pyro-processing

The metal waste and the interim decay waste will be disposed of at a depth of 200 m. The metal wastes can be emplaced in a silo to reduce the disposal area. The interim decay waste, ceramic waste form-ILW and vitrified waste form-ILW, will be stored and disposed of in the tunnels. At first, they will remain open to remove the decay heat from the wastes for around 100 ~ 300 years, and then the tunnels will be closed with buffer material and monitored. The ceramic waste and the vitrified waste are considered as HLW waste. So they are disposed of at a 500 m level of the rock formation. They will be emplaced in the disposal tunnel and remain open for 100 ~ 300 years to improve the disposal density and the retrievability. After that, the disposal tunnels will be closed with buffer material.

Disposal option I for HLW

PWR spent fuels will be stored at an EL -200 m depth before a pyro-processing. After the process, the metal wastes will be disposed of in a tunnel(or Silo) disposal at an EL -200 m depth. And the ILW of the ceramic waste and vitrified waste will be stored for 100 – 300 years at an EL -200 m and then a final disposal(Closure). The high level wastes will be stored for 100 years at an EL - 500 firstly and then a final disposal(Closure). Figure 4 shows the concept and the procedure of option I for the HLW disposal.

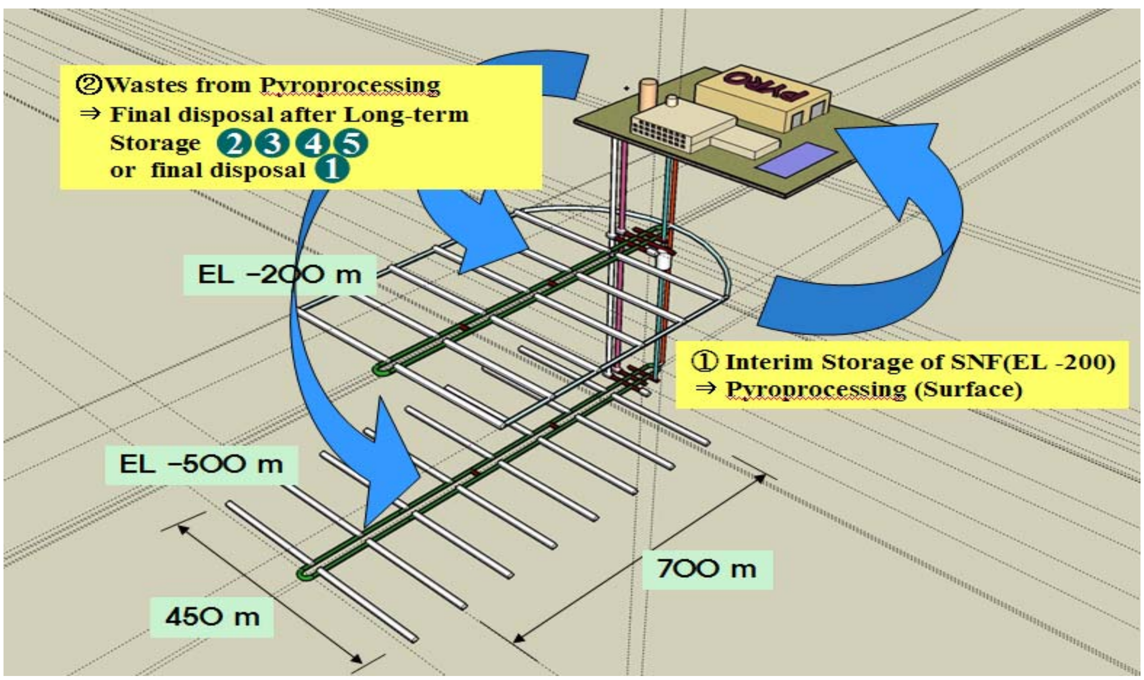

Figure 4. The concept and the disposal procedure of option I.

Disposal option II for the HLW

PWR spent fuels will be stored at an EL -200 m depth before a pyro-processing. After the process, the metal wastes will be disposed of in a tunnel(or Silo) disposal at an EL -200 m depth. And the ILW of the ceramic waste and the vitrified waste will be stored for around 100 – 300 years at an EL -200 m and then a final disposal (Closure).
In this option, for the disposal of the high level wastes, the concept of a square overpack named K-PEM(Korean Prefabricated EBS Module) will be introduced to enhance the efficiency of the storage remarkably(Figure 5, 6). In this titanium overpack, two canisters with a vitrified waste form will be contained. Also, a double layered buffer concept in the K-PEM will improve the thermal performance. Titanium replaces the copper for improving the corrosion resistance and the structural stability with a thickness of 20 mm. Figure 7 shows the concept and the disposal procedure of option II for the HLW.

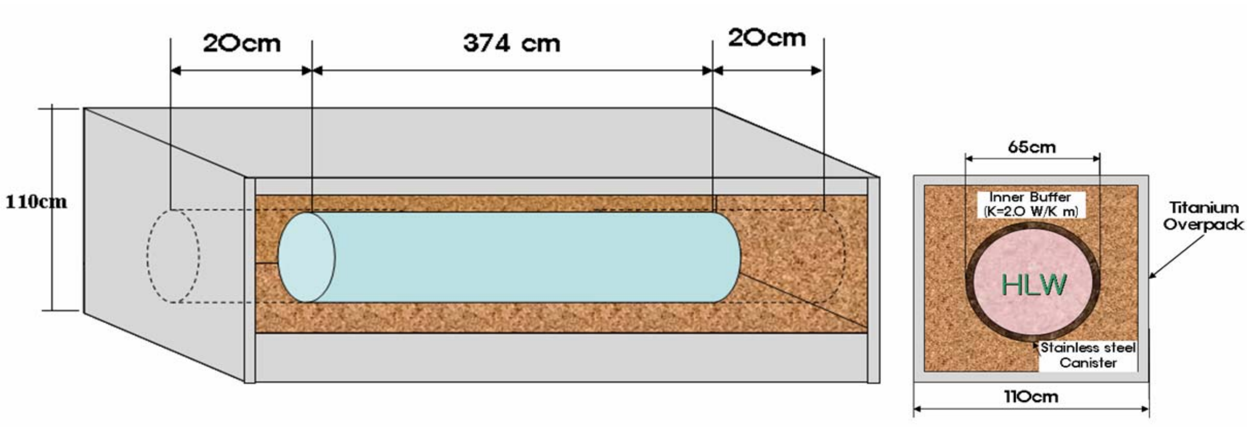

Figure 5. The concept of the K-PEM for the vitrified HLW.

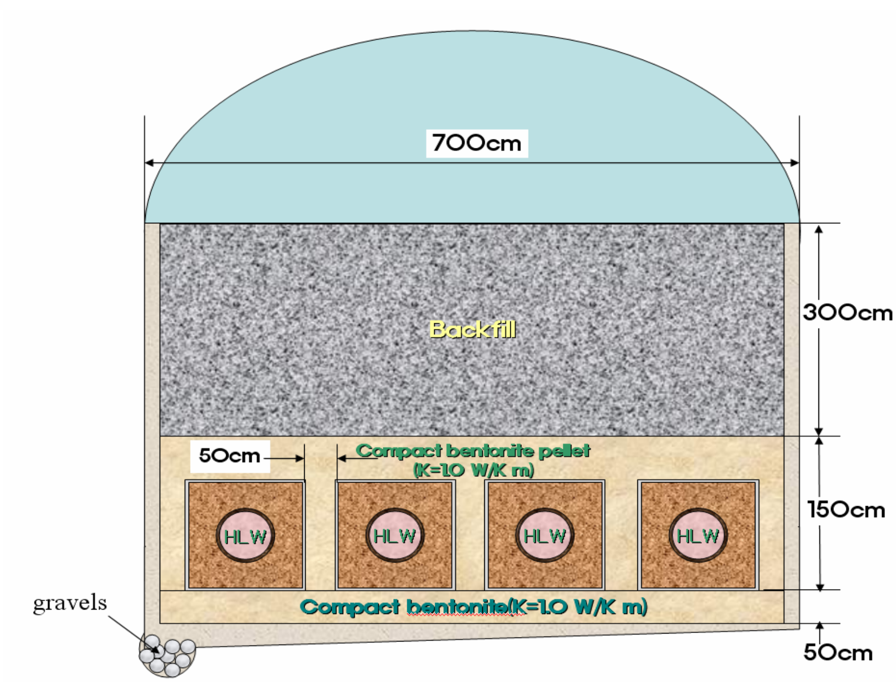

Figure 6. Concept of the K-PEM disposal.

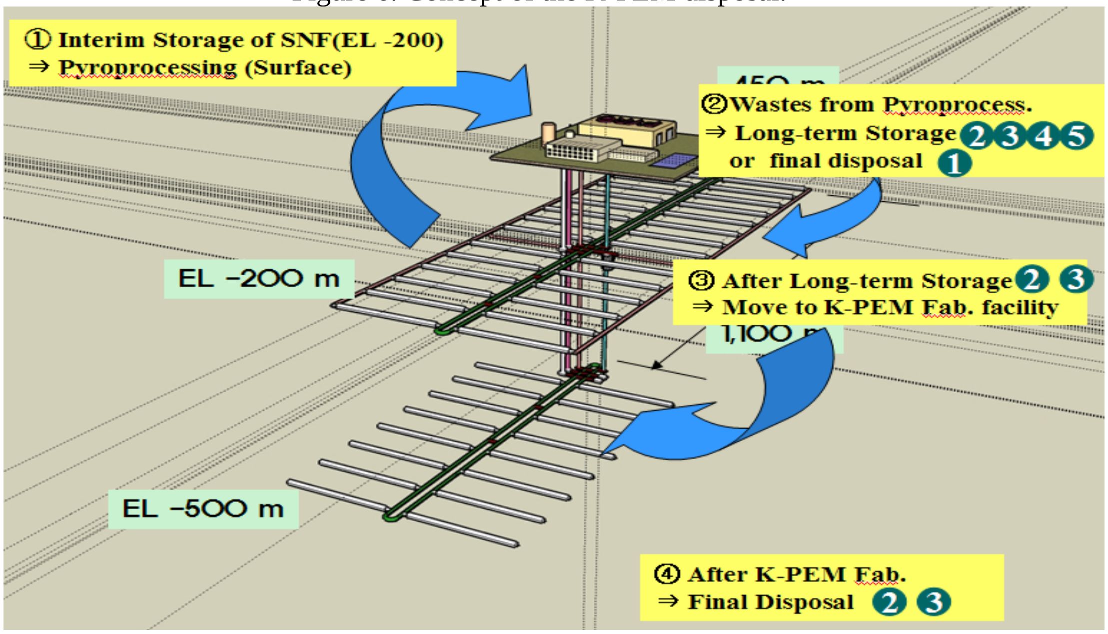

Figure 7. The concept and the disposal procedure of option II.

Disposal option III for the HLW

PWR spent fuels will be stored at an EL -200 m depth before a pyro-processing. After the process, the metal wastes will be disposed of in a tunnel(or Silo) disposal at an EL -200 m depth. And the ILW of the ceramic waste and the vitrified waste will be stored for 100 – 300 years at an EL -200 m and then finally disposed with its closure. The high level wastes will be stored for 100 yrs at an EL - 200 firstly. After that, they will be transported to EL-500 and finally disposed in a vertical emplacement type like KBS-3 type. Figure 8 shows the concept and the disposal procedure of option III for the HLW disposal.

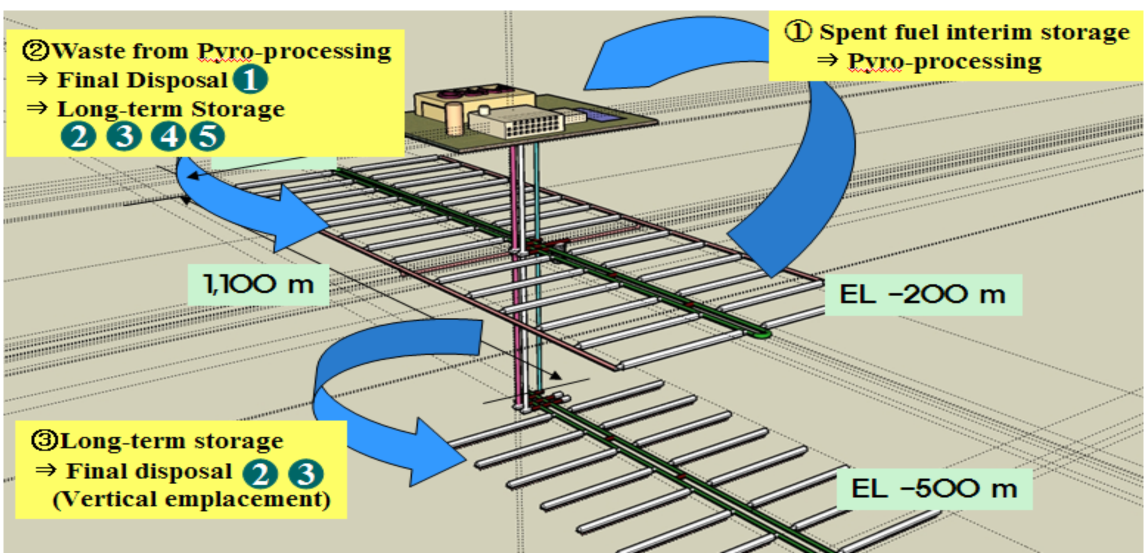

Figure 8. The concept and the disposal procedure of option III.

CONCLUSION

In this study, the characteristics of the various wastes from a spent fuels recycling process are analyzed and their amounts are estimated. And based on the waste information from these analyses and the technologies from the KRS-V system, the geological disposal alternatives for the wastes are developed. Namely, according to the amount and the characteristics of each waste, the concepts of the waste packages and the disposal containers are developed. And also from the characteristics of the radioactivity and the heat generation, a multi-layer depth is considered to dispose of these wastes.

There are 3 kinds of waste from a pyro-processing. They are a metal waste, a VWF and a CWF from a molten LiCl-KCl salt, and a CWF from an Off-gas waste and a VWF from a molten LiCl salt purification.

- The metal waste is the most massive but its radioactivity is too weak to be a high level waste.
- The second is the wastes with a high level radioactivity. They are expected to be disposed of in a deep geological rock formation.
- The last shows a high heat generating rate. They are expected to be stored in an interim storage facility, since they have relatively mid long-lived radio-nuclides such as Cs or Sr.

The disposal alternatives for the wastes from the pyro-process are as follows;

- The metal waste and the interim decay waste will be disposed of at a depth of 200 m. The metal wastes can be emplaced in a silo to reduce the disposal area.
- The interim decay waste, ceramic waste form-ILW and vitrified waste form-ILW, will be stored and disposed of in tunnels at a 200 m level.
- The ceramic waste and the vitrified waste considered as a HLW waste are to be disposed of at a 500 m level in the rock formation. They will be emplaced in a disposal tunnel and remain open for 100 ~ 300 years to improve the disposal density and the retrievability. After this, the disposal tunnels will be closed with buffer material.

The various proposed alternatives in this paper can be used as input data for the design of a deep geological disposal system. And they will be improved through the application of real site data and a safety assessment in the future. After that, the final disposal concept will be selected with various assessments and an optimization will be carried out.

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