Disposal Cost of Pyro-Waste

S. K. Kim, M. S. Lee, W. I. Ko
Korea Atomic Energy Research Institute
1045 Daedeokdaero, Yuseung-gu, Daejon 305-353, Republic of Korea
Corresponding author : sgkim1@kaeri.re.kr

1. Introduction

Currently, studies on the advanced nuclear fuel cycle are underway to develop Pyroprocess technology, which enables recycling uranium and TRU in the spent nuclear fuel remaining in PWRs as the nuclear fuel for fast reactors[1]. Also, deep geological disposal of pyro-radioactive waste is receiving careful study.

This study aims primarily to compare the disposal cost of HLW(high-level waste) generated from spent nuclear fuel, specifically, between direct disposal and Pyroprocess. Previous studies reported multiple economic advantages of Pyroprocess. First, radioactive waste is reported to significantly decrease to about 1/100 in terms of the required land area for a repository. Second, Pyroprocess technology is found highly agreeable to nonproliferation[2].

2. Pyro-waste

Table 1 presents the amount of Pyro-waste. Table 1 is the results estimated with Origen-Arp, and the standard nuclear fuel is 10-MtHM PWR spent nuclear fuel. As seen in the table, pyroprocessed radioactive waste is largely divided into long-lived waste and interim decay waste.

Long-lived waste includes metal, monazite and I and Tc, processed in off-gas. The metal is uranium and TRU produced in pre-processing, and monazite refers to RE or TRU generated after refining an eutectic salt, LiCl + KCl. Nd is the most dominant nuclide in RE, while TRU contains Pu and others.

Table 1. Pyro-waste

Items	Long-Lived Waste			Interim decay Waste	
	Metal	Monazite	Filter	SAP	Fly ash
		LiCl + KCl	Off-Gas	LiCl	Off-Gas
Major Nuclides	U, TRU	RE, TRU	I, Tc	Sr, Cs	Cs
Mass (kg)	3,136.4	664.9	455.5	2,845.7	318.7
Heat (W) 40 years after disposal	-	297	0.06	2,597	3,253
Density (g/cm^3)	6.71	3.57	1.65	2.37	2.74
Volume (L)	467.4	186.2	276.0	1,200.7	116.3
Heat density (W/L)	-	1.59	0.0002	2.16	27.97
Strategy	200 m disposal	500 m disposal	Trans-mutation	Long-term Storage	Long-term Storage

Interim decay waste contains Sr and Cs as primary nuclides generated after refining LiCl, a molten salt used in the process of reduction. After all, radioactive waste pyroprocessed is largely divided into metal and ceramic block types.

The storage made from STS304L used to dispose metal waste can hold 7 metal blocks. To dispose 20,000-tU spent nuclear fuel from a PWR with the method aforesaid, 22,200 cans are consumed.

To dispose ceramic waste in a vertical disposal hole, 20,000-tU spent nuclear fuel from a PWR would require 504 disposal holes. In other words, assuming 4-m interval between disposal holes, a tunnel would use 32 disposal holes.

Table 2 summarizes the required disposal tunnel for long-lived radioactive waste.

Table 2. Comparison of disposal specification

Items	Long-Lived Waste		
Waste Type	Metal	Ceramic	
Depth (m) W(m) × L(m)	200 5.3 × 200	500 4.0 × 150	500 4.0 × 190
Tunnel spacing (m) Borehole spacing (m)	40	40 4	40 5
Number of tunnels	2 tunnels	16	8
Package Type	MWDP	2 Overpacks	4 Overpacks
Number of packages (PWR SF 20,000 tU)	22,200 cans 2,470 MWDPs	1,007 overpacks	1,007 overpacks
Heat (kW/tunnel)	negligible	38 kW (1.187*32)	76 kW
Radioactivity(Ci) (40 years)	^{63}Ni: 3.08 × 10^6	^{137}Cs: 1.60 × 10^5	^{137}Cs: 3.20 × 10^5

3. Cost estimation

3.1 Terms

The following assumptions were taken here to estimate the disposal cost of pyro-waste based on the advanced nuclear fuel cycle. First, the advanced nuclear fuel cycle was assumed in line with PWR's spent nuclear fuel and fast reactor's nuclear fuel. Accordingly, ^{129}I and ^{99}Tc are burned in a fast reactor built in the future for a nuclide transmutation. Then, these two nuclides were assumed to go into a long-term storage in a long-term storage container placed in a 200-meter-deep underground spot. Second, the standard nuclear fuel was assumed to have 4.5% of initial enrichment and burn in a 55-GWD/MtU PWR followed by a 10-year cooling period. Third, every cost was estimated as of the end of 2009.

3.2 Cost estimation results

The major cost driver in direct disposal of spent nuclear fuel is caused by the disposal canister used to store spent nuclear fuel. Pyroprocess reduces radioactive waste to a great extent[3], requiring much fewer and smaller disposal containers, thereby potentially saving disposal cost.

Waste reduction leads to fewer disposal tunnels and less drilling work for disposal holes. Conservatively, the cost is easily estimated using the unit-module concept. Differently put, cost per disposal container was defined as the unit module, which was multiplied by the number of disposal containers to get the disposal cost.

^{129}I as a nuclide with a long half-life, however, was considered to undergo transmutation in a fast reactor and excluded from the disposal cost of pyro-waste. Sr and Cs nuclides are put in long-term storage.

The disposal of metal waste and monazite cost approximately 14.05MEUR and 53.27 MEUR, respectively. The cost share of each container is presented in Fig. 1.

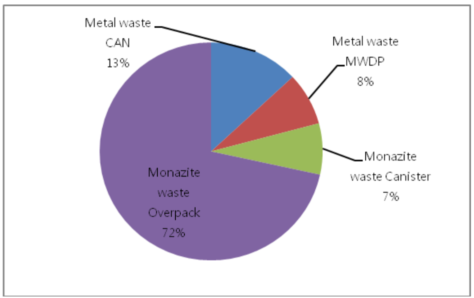

Figure 1. Cost share of canister for Pyroprocess-waste

In Fig. 1, overpacks used to dispose monazite waste are most costly as the outer container of an overpack is made of expensive copper powder in favor of corrosion resistance.

According to previous findings on the concept of KRS direct disposal, 20,000-ton PWR was estimated to require 11,375 disposal containers at 95.7kEUR apiece. Therefore, the total cost of disposal containers was estimated to amount to 1,088,750 kEUR[4].

Consequently, the disposal cost for Pyroprocess was found to be equivalent to about 1/16 of that for direct disposal. Moreover, the cost for containers used to dispose metal waste and monazite was found to account for 20.9% and 79.1%, respectively, of the total container cost.

Disposal tunnels and holes take up the second largest share of construction investment, and illustrated by the graph in Fig. 2. As in Fig. 2, disposal holes and tunnels excavated to dispose waste pyro-processed cost 6.9 MEUR and 4.3 MEUR, respectively, whereas direct disposal costs 309 MEUR and 308.3 MEUR.

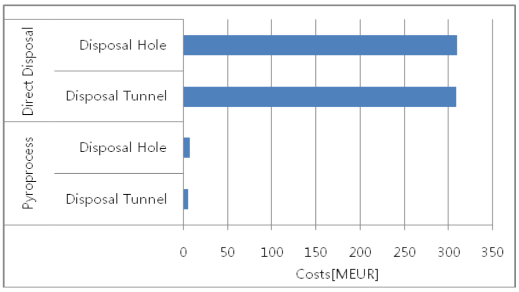

Figure 2. Construction investment

Hence, the disposal holes and tunnels for Pyroprocess option cost about 2.2% and 1.4% of direct disposal cost, respectively. This is attributable to significant reduction in excavation volume as the size and the number of disposal tunnels and holes decrease in Pyroprocess option. All in all, the excavation cost in Pyroprocess option was found to be equal to some 1/55 of that in direct disposal.

4. Conclusion

A comparative analysis was conducted in this study regarding the disposal cost of HLW(High-Level Waste) from 20,000-ton PWR nuclear fuel, focusing on Pyroprocess and direct disposal. A cost estimation of major cost drivers in disposing pyroprocessed waste found that the canister would cost 67.32 MEUR and that the disposal holes and the disposal tunnels would require about 11.2 MEUR for excavation. The estimates amount to 1/16 and 1/55, respectively, of the cost for direct disposal of HLW waste. The significant cost savings in pyro-processed radioactive waste result from the significant reduction in radioactive waste to be disposed thanks to the recycling in a fast reactor of uranium and TRU recovered from spent fuel.

However, future research efforts are required to estimate the cost of Pyroprocess to recognize a break-even point between Pyroprocess and direct disposal option.

References

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