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A Study on the Methodology for Economic and Environmental Friendliness Analysis of Back-End Nuclear Fuel Cycles

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Abstract - The economic and environmental friendliness analysis of the nuclear fuel cycle options that can be expected in Korea were performed. Options considered are direct disposal, reprocessing and DUPIC (Direct Use of Spent PWR Fuel In CANDU Reactors). By considering the result of calculation of the annual uranium requirement and nuclear spent fuel generation by analysis of nuclear fuel material flows in the nuclear fuel cycle options, we decided the time of back-end nuclear fuel cycle processes and the volume. Then we can analyze the economic and environmental friendliness by applying the unit cost and unit value of each process, respectively

Key Words : Economic, Environmental, Direct Disposal, Reprocessing, DUPIC

INTRODUCTION

The choice of back-end nuclear fuel cycle options is very important for nuclear policy in Korea, where the nuclear energy is much depended for the electric power on. The nuclear fuel cycles are very different from the other fuel cycles, since it needs many processes and is various. The back-end nuclear fuel cycle can be divided into the system of using the recycled uranium and direct disposal. The object of this study is to develop the methodology for economic and the environmental friendliness analysis.

Radioactive waste storage in Korea

The solid radioactive waste packed to the drum

Table 2. 1. Condition of the LLW management (unit: drum)

	Storage ability	Annual generation (expected) (drum/unit ¤year)	Stored value	Full time (expected)
Kori (4 plants)	50,200	210	29,343	2014
Youngkwang (6 plants)	23,300	210	12,073	2011
Uljin (6 plants)	17,400	210	9,691	2008
Wolsung (4 plants)	9,000	150	4,216	2009
Total (20 plants)	99,900	-		-

Table 2. 2. Condition of the spent fuel storage (1999.12)

	Accumulation generation		Annual generation		Storage ability		Full time (expected)
	MTU	Bundle	MTU	Bundle	MTU	Bundle	
Kori (4 plants)	1,076	2,675	65	162	1,737	4,225	2008
Youngkwang (6 plants)	667	1,604	75	178	1,696	4,038	2008
Uljin (6 plants)	425	992	75	178	1,563	3,723	2007
Wolsung (4 plants)	1,916	101,408	381	20,164	4,807	254,352	2006
Total (20 plants)	4,084	-	596	-		-	-

are transported to the storage house in nuclear power plant and stored classificationally, and then will be disposed in final disposal facility which will be constructed in the future. In Kori nuclear power plant, the storage space will be saved until 2014, in Youngkwang will be saved until 2011, in Uljin will be saved until 2008, and in Wolsung, will be saved until 2009. So the final disposal facility must be constructed at least before 2008.

The amount of spent fuel has been stored is 4,804ton in the four nuclear power plant sites (Three PWR plant sites, and one CANDU plant site) present in Dec, 1999, and will be cumulated 11,000MTU at 2010, and will be cumulated 34,000MTU at 2040 in Korea. The present condition of the radioactive waste management is described in Table 2.1 and Table 2.2.

The back-end nuclear fuel cycle options that can be expected in Korea

Direct Disposal

The direct disposal fuel cycle option is the simple, non-recycle fuel cycle option that all spent fuel generated at PWR and CANDU plant is stored and then disposed finally. In this case, the method of interim storage and the capacity of disposal must determine the spent fuel generation value. And radioactivity effect of long lived nuclide that is generated when spent fuel is treated specially, and final disposal technology of plutonium toxicity nuclide must be considered.

Reprocessing

The reprocessing options is the fuel cycle option that spent fuel generated from the PWR nuclear power plants is reprocessed, and then the recovered plutonium is recycled to the PWR nuclear power plants after re-enrichment. This option is under the international restrictions, because of the plutonium generation. But this option is expected to decrease the environmental effect, because the uranium can be used effectively and the HLW (high level waste) value, which must be treated carefully is decreased as same as in the DUPIC (Direct Use of Spent PWR Fuel In CANDU Reactors) option.

DUPIC (Direct Use of Spent PWR Fuel In CANDU Reactors)

In most countries, the reactors of single type have been operated, but especially in Korea the PWR reactors and the CANDU reactors have been operated at the same time. The PWR reactor is especially characteristic that the low enriched U-235 fuel, about 3.5wt% is refueled and light water is used as cooling water and moderator.

The nuclear fuels in PWR reactor are eliminated as spent fuels in which there are the fission product and the actinide material, and product by neutron irradiation. Especially, the result that the value of fission product included the U-235 remained after burning, and Pu-239 and Pu-241 produced of neutron capture, in the actinide exchange into the weight content rate shows 1.1 ~1.3 wt%, enrichment rate in 30~40 GWD/MTU burn scope, generally. This nuclear content rate is higher than 0.7wt%, the U-235 content rate in natural uranium. So the spent fuel from the PWR reactor can be used as the CANDU fuel from the simple arithmetic point of view. The Korea has been the study of DUPIC center, because the PWR reactor and CANDU reactor have been operated simultaneously. Fig 3.1 shows flow of the fuel cycle options.

Basic assumptions for the analysis

The valuation period in this study is from 1978 when the nuclear power plants begin to work in Korea to 2100. It was assumed that the nuclear power plant will be constructed until 2030, and then will not be constructed, and nuclear system up to the year 2015 are based on the 5th long term power development plan of Korean government. Since the nuclear power systems after the year 2016 are not determined, it is expected that the electric consumption rate will increase about 20 percent, by two cases. In CASE 1, it was assumed that 8 PHWRs will operate, and In CASE 2, assumed that 16 PHWRs will operate. The four PHWRs of them have been operated and the rest of them will be constructed. The installed capacity of nuclear power plants was shown in Fig 4.1 and Fig 4.2.

The amount of the power generation until 2000 was used the exact data and the amount of the power generation after 2001 was expected that 80 percent of the PWR installed capacity and 85 percent of the PHWR installed capacity. And the lifetime of the nuclear power plant was expected to be 40 years. The basic assumption is shown in Table 4.3. The introduction time and the capacity of the spent fuel interim storage facility, the final disposal facility, the reprocessing facility, and the DUPIC facility was determined by analyzing the nuclear material flow of each option of CASE 1 and CASE 2.

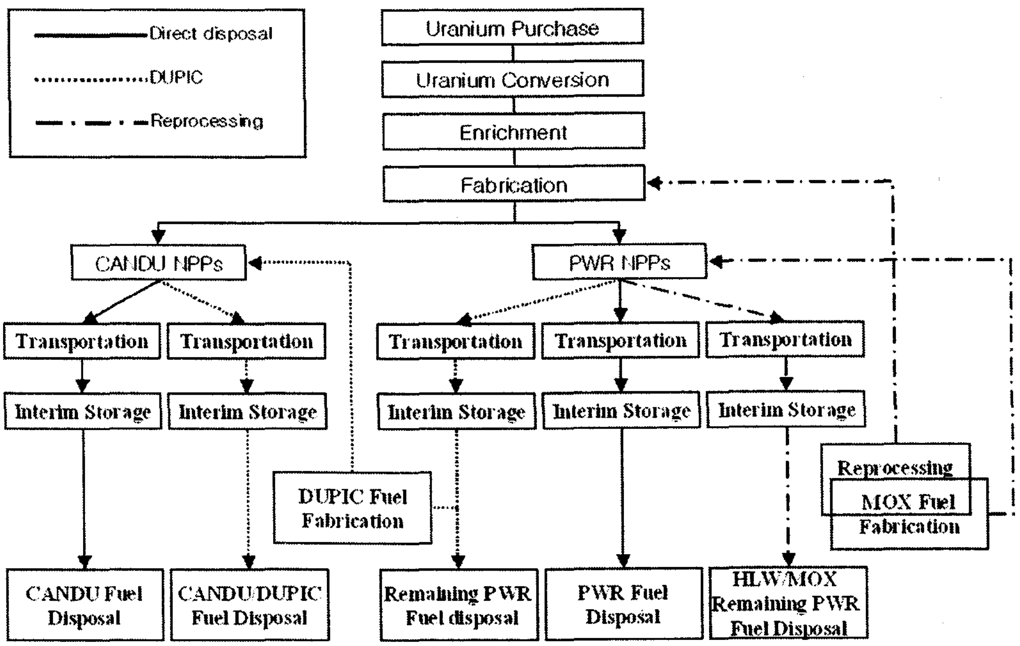

Fig. 3. 1. Nuclear fuel cycle options

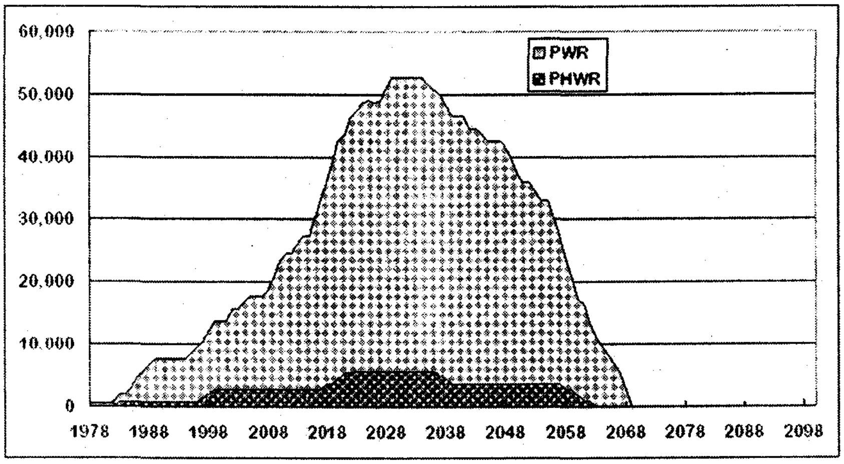

Fig. 4. 1. Installed capacity of nuclear power plants of CASE 1 (MWe)

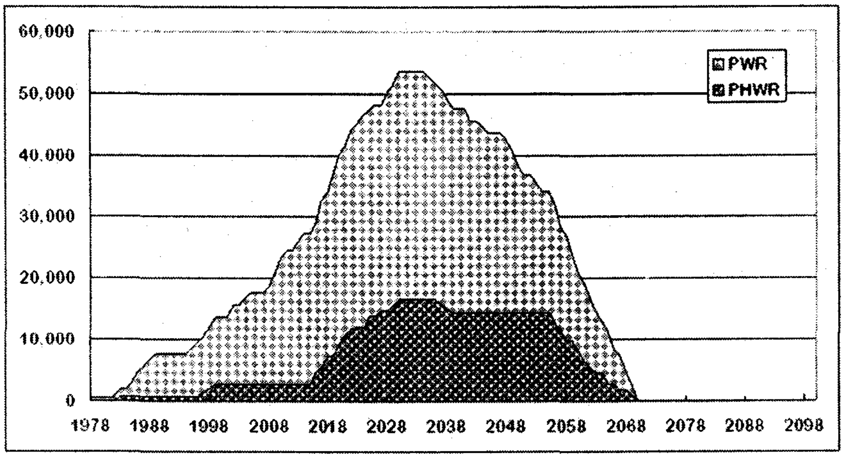

Fig. 4. 2. Installed capacity of nuclear power plants of CASE 2 (MWe)

Table 4. 1. Basic assumption

Parameter	PWR	CANDU
Plant capacity [MW (electric)]	KSNP: 1,000 KNGR: 1,400	700 - until 2015 900 - after 2015
Plant load factor	Real data - until 2000 80% - after 2001	Real data - until 2000 85%- after 2001
Lifetime	40yr	40yr
Fuel discharge burn-up (MWd/TU)	33,000(1978 ~ 1984) 40,000(1985 ~ 1996) 43,000(1997 ~)	7,500(U fuel) 15,000(DUPIC fuel)
Fuel enrichment	3.3%(1978 ~ 1984) 3.8%(1985 ~ 1996) 4%(1997 ~) 5%(MOX Pu fuel)	0.71%

The economic analysis

The unit cost of fuel cycle of processes for the economic analysis is described in Table 5.1. The unit costs of most processes are quoted from the OECD/NEA study in 1994, and discount rate is determined as 5%. But the unit cost of DUPIC is calculated directly, because DUPIC was not considered in the OECD/NEA study in 1994. The DUPIC study team in KAERI supplied the cost of the DUPIC processes.

The result of the direct disposal option is shown in Table 5.2, Fig 5.1 and Fig 5.2

Table 5. 1. Unit cost of fuel cycle

	Physical Unit	Cost ($/unit)
Uranium	(kgU)	50.0
Conversion	PWR (kgU)	8.0
	PHWR (kgU)	8.0
Enrichment	(kgSWU)	110
Fabrication	PWR (kgU)	275.0
	PHWR (kgU)	65.0
	MOX (kgHM)	1100.0
	DUPIC (kgHM)	615.0
Transportation	PWR (kgHM)	50.0
	PHWR (kgHM)	13.0
	DUPIC (kgHM)	50.0
Interim Storage	PWR (kgHM)	180.0
	PHWR (kgHM)	35.0
	DUPIC (kgHM)	60.0
Reprocess	PWR (kgHM)	720.0
Final Disposal	PWR (kgHM)	610.0
	PHWR (kgHM)	73.0
	HLW (kgHM)	90.0
	DUPIC (kgHM)	390.0

Table 5. 2. Direct disposal fuel cycle cost (unit: $/MWh)

Component	CASE1	CASE2
Uranium	1.712	1.628
Conversion	0.213	0.202
Enrichment	1.875	1.598
Fuel Fabrication	0.975	1.002
Transport	0.118	0.115
Reprocessing	0.000	0.000
MOX Fabrication	0.000	0.000
DUPIC Processing	0.000	0.000
Storage	0.409	0.387
Final Disposal	0.341	0.306
Sub total for Back-End	0.868	0.808
Total	5.643	5.238

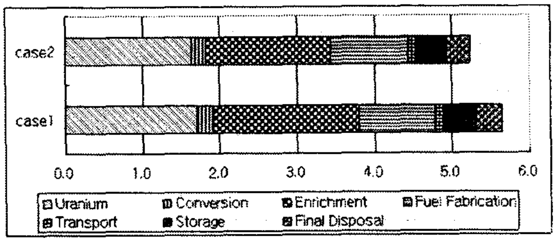

Fig. 5. 1. Direct disposal fuel cycle cost (unit: $/MWh)

The environmental friendliness analysis

The value of the radioactive waste generation was checked for the environmental friendliness analysis. The annual generation value and the accumulation generation value are calculated as the unit value of the radioactive waste generation, and for the objective comparison between options, the value was coverted to the cost. The unit value of the radioactive waste generation are quoted from the papers that Chow, B. G. and Jones, G, S. (1999) and Won Il Ko, Ho Dong Kim and

Myung Seung Yang, (2001) [2, 5]. The generation value of all nuclear fuel cycle processes was studied in these theses, but in this study. The value of nuclear fuel cycle processes operated in Korea is analyzed. And the LLW (Low level waste) generation value that is generated from the power plant is referred the real data in the last 10 years. The LLW generation value in the latest 10 years is shown in the Table 6.1. The unit value of the nuclear fuel cycle processes is shown in Table 6.2, the unit cost by converting the generation values to the costs is shown in Table 6.3, and the result of disposal option is shown in Fig 6.1, Fig 6.2, Fig 6.3 and Fig 6.4.

Table 6. 1. LLW generation value in the last 10 years

	Kori			Youngkwang			Uljin			Wolsung		
Yr	Drum (200 ℓ)	Power (Mwe)	㎥/Gwe	Drum (200 ℓ)	Power (Mwe)	㎥/Gwe	Drum (200 ℓ)	Power (Mwe)	㎥/Gwe	Drum (200 ℓ)	Power (Mwe)	㎥/Gwe
1990	2,491	3,137	158.8	1,296	1,900	136.4	924	1,900	97.2	231	679	68.0
1991	2,129	3,137	135.7	990	1,900	104.2	1,081	1,900	113.7	207	679	60.9
1992	2,199	3,137	140.2	1,076	1,900	113.2	1,077	1,900	113.3	225	679	66.2
1993	1,995	3,137	127.2	888	1,900	93.4	988	1,900	104.0	187	679	55.0
1994	1,236	3,137	78.8	836	1,900	88.0	1,018	1,900	107.1	220	679	64.8
1995	1,963	3,137	125.1	989	2,900	68.0	1,028	1,900	108.2	220	679	64.8
1996	1,178	3,137	75.1	934	3,900	47.9	748	1,900	78.7	267	679	78.6
1997	1,756	3,137	111.9	1,249	3,900	64.0	742	1,900	78.1	336	1,379	48.7
1998	2,038	3,137	129.9	1,076	3,900	55.1	404	2,900	27.8	668	2,079	64.2
1999	1,128	3,137	71.9	973	3,900	49.9	923	3,900	47.3	580	2,779	41.7
AVE			115.4			82.0			87.5			61.3

Table 6. 2. Unit waste generation value

		PWR	MOX	CANDU	DUPIC
Fabrication (㎥/MTHM)	LLW	0.23	1.27	0.23	2.11
	ILW	-	3.35	-	0.2
	HLW	-	-	-	0.13
Operation (㎥/Gwe)	LLW	94.8	94.8	61.3	61.3
	ILW	1.1	1.1	1.6	1.6
Storage (㎥/MTHM)	LLW	0.007	0.007	0.0035	0.007
	ILW	0.077	0.077	0.039	0.077
Reprocessing (㎥/MTHM)	LLW	-	3.17	-	-
	ILW	-	1.25	-	-
	HLW	-	0.115	-	-
Disposal (㎥/MTHM)	LLW	0.007	0.007	0.0035	0.007
	ILW	0.2	0.2	0.1	0.2
	HLW	-	0.115	-	-
	S/F	1.5	1.5	1.5	1.5

Table 6. 3. Unit Cost of waste disposal

Components		Value in this study
LLW	$/m³	8,150
ILW	$/m³	16,300
HLW	$/m³	260
SF (PWR)	$/kg	610
SF (CANDU)	$/kg	73

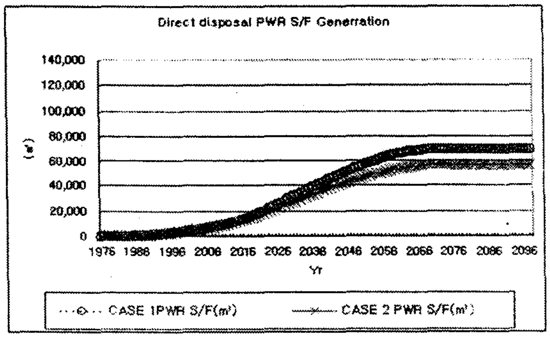

Fig. 6. 1. Accumulation value of the PWR S/F (Direct disposal)

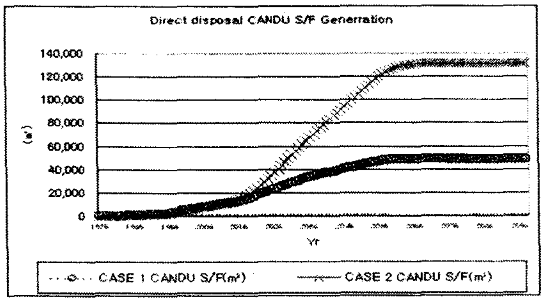

Fig. 6. 2. Accumulation value of the CANDU S/F (Direct disposal)

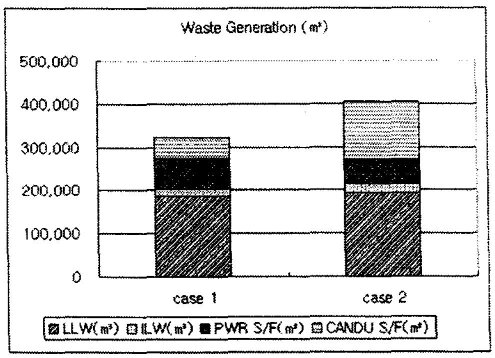

Fig. 6. 3. Waste generation (Direct disposal)

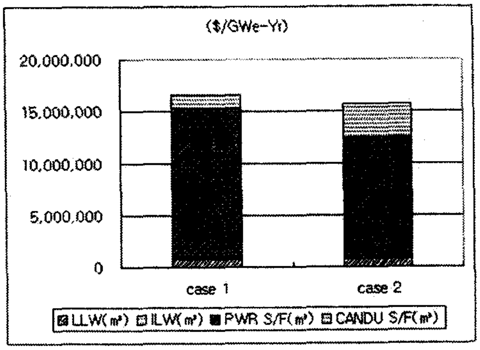

Fig. 6.4. Cost for disposal (Direct disposal)

Conclusion

In this study, the back-end nuclear fuel cycle options that can be expected in Korea such as direct disposal, reprocessing and DUPIC are considered. The nuclear material flow could be known, because two cases of installed capacity of nuclear power plant was expected. And the value of the nuclear fuel requirement and the annual spent fuel generation was calculated by the analyzing the nuclear material flow of the each option. The introduction time and the capacity of the spent fuel interim storage facility, the final disposal facility, the reprocessing facility, and the DUPIC facility were determined. Therefore the costs of the fuel cycle processes can be calculated, and then the economic of the nuclear fuel cycle options can be compared with each other. And the amount of the radioactive waste release rate can be known, and the environment friendliness of the options can be compared with each other by the result that the value of the radioactive waste (LLW, ILW, HLW) generation is changed to each costs.

The method of the economic and environmental friendliness analysis should be performed as a precondition of back-end fuel cycle policy. This study should help to decide the back-end fuel cycle policy in Korea.

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