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Dynamic Analysis of Nuclear Waste Generation Based on Nuclear Fuel Cycle Transition Scenarios

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1. Introduction

As the move surrounding nuclear spent fuel management policy making finally arrived at a decision within the first half of this year, the Republic of Korea could begin preparation for permanent disposal of spent nuclear fuel. According to the recommendations submitted by the Public Engagement Commission on Spent Nuclear Fuel Management (PECOS), the government was advised to pick the site for an underground laboratory and interim storage facilities before the end of 2020 followed by the related research for permanent and underground disposal of spent fuel after 10 years. In the middle of the main issues, the factors of environmentally friendly and safe way to handle nuclear waste are inextricable from nuclear power generating nation to ensure the sustainability of nuclear power. For this purposes, the closed nuclear fuel cycle has been developed regarding deep geological disposal, pyroprocessing, and burner type sodium-cooled fast reactors (SFRs) in Korea [1].

Among two methods of an equilibrium model and a dynamic model generally used for screening nuclear fuel cycle system, the dynamic model is more appropriate to envisage country-specific environment with the transition phase in the long term and significant to estimate meaningful impacts based on the time-dependent behavior of harmful wastes.

This study aims at analyzing the spent nuclear fuel generation based on the long-term nuclear fuel cycle transition scenarios considered at up-to-date country specific conditions and comparing long term advantages of the developed nuclear fuel cycle option between once-through cycle and Pyro-SFR cycle.

2. Scenario Studies

2.1 Current status of Nuclear Power Program in Korea

In Korea, 24 commercial nuclear reactors including 20 PWRs and 4 pressurized heavy water reactors (PHWRs) are currently operating. The installed nuclear electricity generation capacity reached 20.7 GWe, supplying over one-thirds of its total electricity generation. According to the seventh Basic Plan for Long-term Electricity Supply and Demand approved by Ministry of Trade, Industry and Energy (MOTIE) recently on July this year [2], 13 nuclear power plants are newly planned including 2 reactors of 3000MWe (2028-2029) and a total of nuclear power capacity is forecast to reach 38.3 GWe, accounting for 23.4% of the total electricity sources capacity in 2029. Kori 1 and Wolsong 1 reactors will face shut down due to its lifetime by the time. Besides, nuclear energy directions suggested in the second National Energy Basic Plan for 2013-2035 contain that the share of the nuclear installed capacity in total installed capacity should decline from the 41 % of firstly set by 2030 to 29% that would require approximately 43 GWe of installed capacity [3]. This indicates that the installed nuclear capacity will be increased over 7% as of the current status 22% in 2014.

As shown in Table 1, the amount of accumulated spent fuel is 13,811 tHM until December 2014 – 6,397 tHM from PWRs and 7,417 tHM from PHWRs [4]. One of the significant issues of operating national nuclear power plants is delaying the saturation point. The PECOS recommendation include that the delayed saturation point through intra-site transshipment and high density spent fuel storage rack equipment and the government should complete a permanent disposal facility by 2051 [4].

Table 1. The current status of spent nuclear fuel in Korea as of December 2014

Reactor type	Site name (number of units)	Storage Capacity limit		Accumulation of spent fuels			
		Assembly or bundle	Mass (tHM)	Assembly or bundle	Mass (tHM)	Saturation level (%)	Saturation year
PWR	Kori(6)	6,494	2,691	5,322	2,153	82	2016
	Hanbit(6)	7,912	3,318	5,413	2,258	68	2019
	Hanul(6)	7,066	2,960	4,652	1,959	66	2021
	Shin-Wolsong(2)	523	219	64	27	12	2022
	PWR total	21,995	9,188	15,451	6,397		
PHWR	Wolsong(4)	499,632	9,443	391,872	7,414	78	2019
Total (24)		521,627					

2.2 Nuclear Fuel Cycle Transition Scenarios

Based on the two above-mentioned plans, the long-term projections for the nuclear electricity transition scenarios (2015~2105) estimated for the high, reference, and low cases are derived as shown in Fig. 1. In the reference scenario, beyond set years in the plans, a growth rate of electricity demand for the reference scenario is annually estimated to 0.98% for the next 25 years (2036-2055), maintaining 41% of the share of nuclear power until 2105. After 2056, decrease rate is adjusted to gradually down to 0% by 2105.

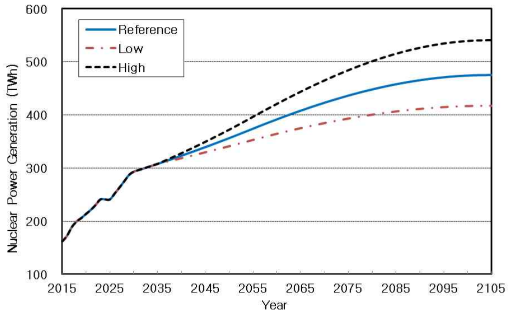

Fig. 1. Long-term projection of nuclear power generation.

In the high scenario, a growth rate of electricity demand increases 1.3 fold from the reference scenario while the share of nuclear power remains at 41% (2036-2055) and an annual growth rate of electricity demand decrease gradually down to 0% by 2105. Meanwhile, a growth rate of electricity demand increases 0.7 fold increase from the reference scenario and decrease gradually down to 0% by 2105. When it comes to the share of nuclear power generation and its amount in the reference scenario, the total installed capacity is expected to reach 64 GWe in 2105 while annual nuclear electricity demand reaches approximately 480 TWh indicating threefold increase from the current demand., In the high and low scenarios, the installed capacity are estimated to be 73 GWe and 56 GWe, respectively.

2. Dynamic Analysis of Nuclear Waste Generation

2.1 Spent Nuclear Fuel Accumulation

While all spent fuels from PWRs and PHWRs are not recycled in the open fuel cycle, PWR spent fuels are recycled in the closed fuel cycle by TRU separation from fission product through pyroprocessing [1]. Fig. 1 shows the amount of accumulated PWR and PHWR spent fuels for the open fuel cycle. The total of spent fuels generated annually from PWRs and PHWRs is about 750 tHM; by 2030, annual spent fuel arising will be over 880 tHM as illustrated in Fig. 1. Fig. 2. Shows the accumulation of spent fuel indicating that the total of 94,000 tHM spent fuel will be accumulated by 2100.

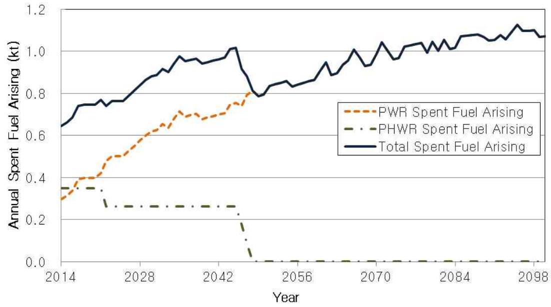

Fig. 1. Annual Spent Fuel Arising (Reference Scenario).

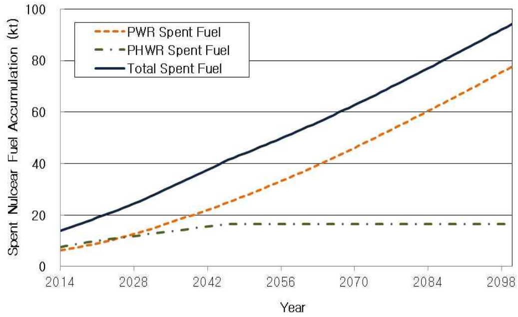

Fig. 2. Cumulative Spent Fuel (Reference Scenario)

On the other hand, as presented in Fig.4, the amount of PWR spent fuel is greatly decreased down to 5,000 tHM until 2100 by starting of the SFR in 2050 and the remaining PWR spent fuels will be used as fuel for SFRs after 2100. Fig. 3. illustrates installed capacity of nuclear power according to the SFR deployment scenario for the Pyro-SFR cycle strategy. By 2100, the share of the installed nuclear capacity of SFRs will be over 40% of the total.

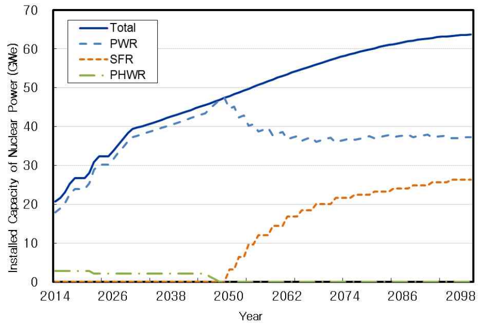

Fig. 3. Reactorwise Installed Power Capacity.

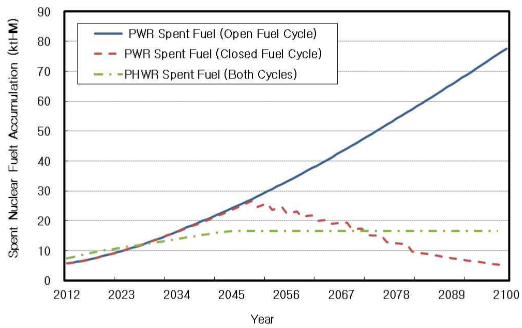

Fig. 4. Amount of PWR and PHWR spent fuels accumulation in comparison with open and closed fuel cycles (Reference Scenario).

3. Conclusions

In this study, a dynamic analysis was carried out to estimate the long-term projection of nuclear electricity generation, installed capacity, spent nuclear fuel arising in different fuel cycle scenarios based on the up-to-date national energy plans.

On the whole, while maintaining growth in nuclear power in Korea as noticed in the national energy plans, the findings of this research demonstrates that Pyro-SFR cycle shows long-term benefit with regard to the sustainability and environment-friendliness.

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