

Scenario Analysis for a Transuranic Transmutation by Using Fast Reactors

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Abstract

The Korean once-through and fast reactor cycles have been analyzed by using the dynamic analysis method. At first a once-through fuel cycle analysis was performed based on Korea's nuclear power plant construction plan up to 2015 and a postulated nuclear demand growth rate by using a logistic model after 2015. The once-through fuel cycle calculation showed that the nuclear power demand would be 46 GWe and the total amount of accumulated spent fuel by 2100 would be ~92000 t. Second, the fuel cycle parameters of the sodium-cooled fast reactor and accelerator driven system scenarios were estimated and compared with those of the once-through fuel cycle. From the calculation results, it is shown that the fast reactor cycle can effectively reduce the amount of spent fuel accumulation and the inventory of the transuranic elements.

I. INTRODUCTION

In Korea, 16 pressurized water reactors (PWRs) and 4 Canada deuterium uranium (CANDU) reactors are currently operating. The total electricity capacity of these reactors is 17.7 GWe. The nuclear capacity is expected to increase to 25.2 GWe in 2015 [1]. Currently, Generation-IV (Gen-IV) reactor systems are being developed with fuel and coolant materials different from those of the conventional nuclear reactor, aiming at considerably increasing the safety and economic efficiency and drastically minimizing the radioactive wastes of the current reactor designs. In Korea, the Korea Advanced Liquid Metal Reactor (KALIMER) [2,3] has been under development since 1992, which is a pool-type sodium-cooled fast reactor (SFR). The KALIMER has electric and thermal powers of 600 and 1500 MW, respectively. Recently, a KALIMER burner reactor was newly developed for a transmutation of the transuranics, which has a breeding ratio of 0.75. In addition, as an accelerator driven system (ADS), the Hybrid Power Extraction Reactor (HYPER) [4,5] has been studied since 1997. The HYPER has electric and thermal powers of 350 and 1000 MW, respectively. The HYPER system is designed to transmute transuranics (TRU) and some of the long-lived fission products such as I-129 and Tc-99.

In this study, a symbiotic fuel cycle between the existing nuclear power plants and the SFR and ADS systems is analyzed. For a comparative analysis of the fuel cycle options, the once-through fuel cycle was analyzed at first based on the current nuclear power plant construction plan and existing nuclear power plants such as the PWR and CANDU reactor. After setting up the once-through fuel cycle model, the SFR and ADS scenarios were modeled based on the same nuclear energy demand prediction used for the once-through fuel cycle. Then the important fuel cycle parameters such as the amount of spent fuel (SF) and corresponding plutonium, minor actinides (MA) and fission products (FP) inventories were estimated and compared with those of the once-through fuel cycle. The calculation was performed by using the modified DYMOND [6,7] code, which has been used for an analysis of the Gen-IV roadmap studies [6].

II. ONCE-THROUGH FUEL CYCLE

By using the long-term nuclear power plant construction plan for Korea, the nuclear power demand is expected to grow from 13.7 GWe in 1999 to 25.2 GWe in 2015. For the years 2016 to 2100, a logistics model [8] was used to estimate the growth rate of nuclear power. For the reactor information of the once-through fuel cycle, currently operating reactors were considered. The reactor life time was assumed to be 40 and 30 yrs for the PWR and CANDU reactor, respectively. In this scenario, all the CANDU reactors were assumed to be shutdown after their life time and there will be no more CANDU reactor constructions. The reactor specifications used in this study are presented in Table 1.

Table 1 Reactor Specifications

	PWR	CANDU	SFR	ADS
Reactor power, GWe	1.0	0.713	0.6	0.35
Burnup, GWd/t	40	7	113	190
U enrichment, wt%	4	0.71	-	-
Life time, yr	40	30	60	60
Thermal efficiency, %	35	35	39	35
Load factor, %	85	85	85	85
Cycle length, yr	1.5	1	1.5	0.5
Number of batches	3	1	4	7.5
Mass fraction in charge				
U	1.0	1.0	0.6674	0.1653
TRU	-	-	0.2826	0.8601
FP	-	-	0.0481	0.0037
Mass fraction in discharge				
U	0.9471	0.9890	0.6501	0.1525
TRU	0.0113	0.0037	0.2718	0.6520
FP	0.0416	0.0072	0.0781	0.1955

Figure 1 shows the predicted nuclear power demand variation with time. It can be seen that the demand is expected to be 46.3 GWe in 2100. The electricity capacity of each reactor to meet this energy demand depends on the nuclear power demand curve. When all the CANDU reactors are shutdown, the electricity generation is dominated by the PWR after 2040. As shown in Fig. 2, the number of operating PWRs increases with time and becomes ~46 in 2100 for the reactor power of 1.0 GWe, while the number of CANDU reactors becomes zero after 2030.

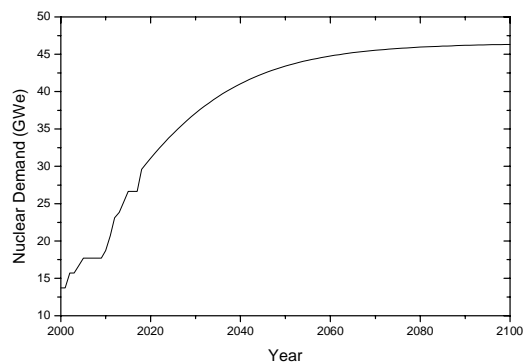


Fig. 1 Nuclear power demand prediction

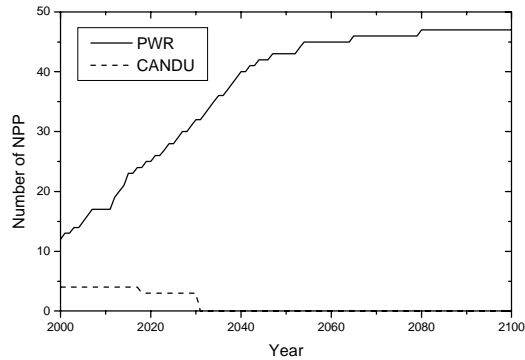


Fig. 2 Number of operating reactors (Once-through cycle)

The PWR SF inventory, shown in Fig. 3, increases with time and becomes 83200 t in 2100. After 2040, the CANDU SF remains constant at ~9100 t. Eventually, the total SF will be 92000 t in the year 2100. The amount of U, TRU and FP in SF will be 86800 t, 1140 t, and 4370 t, respectively.

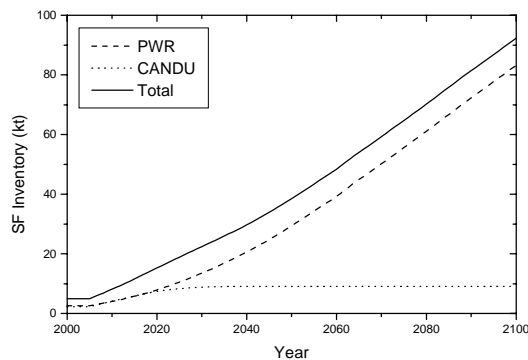


Fig. 3 Spent fuel inventory from each reactor (Once-through cycle)

III. SFR SCENARIO

The core layout of the SFR (KALIMER-600 burner) consists of 84 inner driver fuel assemblies, 114 middle assemblies and 132 outer fuel assemblies. The active core height is 113.0 cm and the equivalent core diameter is 343.8 cm. The average TRU content is 28.26 % at the beginning of the equilibrium cycle (BOEC) and 27.18 % at the end of the equilibrium cycle (EOEC). The fuel cycle strategy in this study assumed an integral fuel cycle in which almost all the TRUs are recycled in a closed fuel cycle. The SFR specifications and fuel material inventory changes from the BOEC to the EOEC are also given in Table 1.

In this study, the deployment fraction of the SFR was assumed to be 50 % for 2040–2100. In order to feed the SFR, it was also assumed that the PWR SF is reprocessed from 2035 and the SFR SF reprocessing begins in 2040.

As shown in Fig. 4, the number of PWRs increases until 2040 and it becomes 40 by 2055. After 2055, the number of operating PWRs starts decrease and becomes 25 in 2100. The number of SFRs increases

continuously and becomes 37 in 2100. In these calculations, it was assumed that the nuclear industry had an enough construction capacity. However, the actual construction capacity should be considered in a later study.

The total SF increases very slowly with time and it reaches 36700 t which is reduced by 60% when compared with that of the once-through cycle. The variation of the TRU inventory is shown in Fig. 5. After 2040, the TRU in the SF increases very slowly with time and it becomes ~400 t in 2100, which is 65% lower than that of the once-through cycle. The in-core TRU increases with time and becomes ~400 t in 2100. The transmuted amount of TRU until 2100 is ~235 t. The above results show that the SFR burner cycle can contribute to a reduction of the SF and TRU inventories through a transmutation process. In the future, however, an optimization study is needed to minimize the out-core TRU inventory.

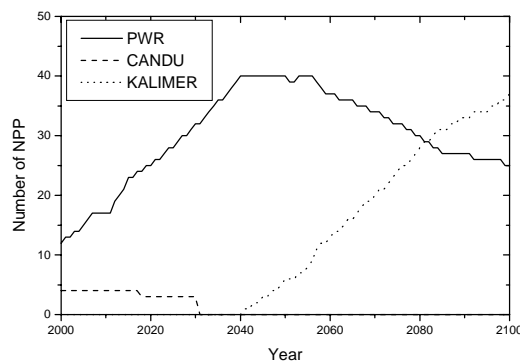


Fig. 4 Number of operating reactors (SFR cycle)

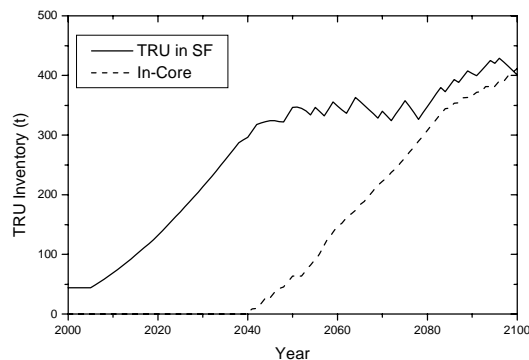


Fig. 5 TRU Inventory (SFR cycle)

IV. ADS SCENARIO

The ADS (HYPER) system is being studied to transmute TRU and some of the long-lived fission products such as I-129 and Tc-99. The basic ADS system has a 1000 MWt reactor power and its effective multiplication factor is 0.98. The inventory of TRU is 6510 kg at a BOC and 282 kg of the TRU is transmuted per year. In the case of the fission products, I-129 and Tc-99 are transmuted at the rates of 7 and 27 kg/yr, respectively.

The core of the ADS consists of 42 inner core fuel assemblies, 54 middle assemblies and 90 outer fuel assemblies. The cycle length is ~0.5 yr and the number of batches is 7 for the inner core and 8 for the middle and outer cores. The reactor specifications and fuel material inventory changes from the BOEC to the EOEC are given in Table 1. The FP including RE is assumed to be separated from the TRU through a metal fuel reprocessing.

The deployment fraction of the ADS was assumed to be 40% for 2040–2100. In order to feed the ADS, it was also assumed that the PWR is reprocessed from 2035 and the ADS SF reprocessing begins in 2040.

As shown in Fig. 6, the number of PWR and ADS will be ~25 and ~63, respectively, in 2100. In these calculations, it was also assumed that the nuclear industry had a capacity enough to construct all the plants required to provide the electricity demand.

In the ADS cycle, the final SF inventory includes CANDU SF only since almost of all the PWR SF will be reprocessed until 2100. The TRU inventory variations are shown in Fig. 7. The TRU in the SF will be 34 t which is much smaller when compared with the once-through cycle. Until 2100, the in-core TRU inventory increases with time and it becomes 320 t in 2100. The ADS can transmute TRU by 570 t until 2100. Also, the accumulated transmutions of I-129 and Tc-99 are 14 and 55 t, respectively. These results show that the ADS cycle can reduce the SF and TRU inventories effectively through the transmutation when compared with the once-through or SFR cycles. However, an economic analysis should be performed to determine the optimum scenario for reducing the TRU inventory.

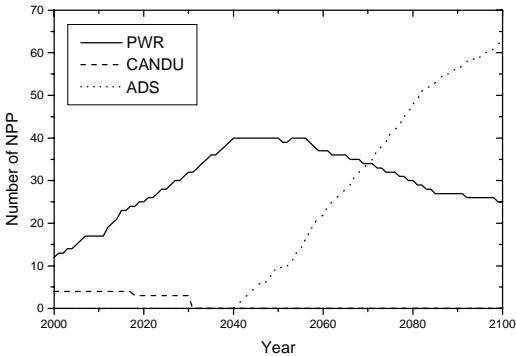


Fig. 6 Number of operating reactors (ADS cycle)

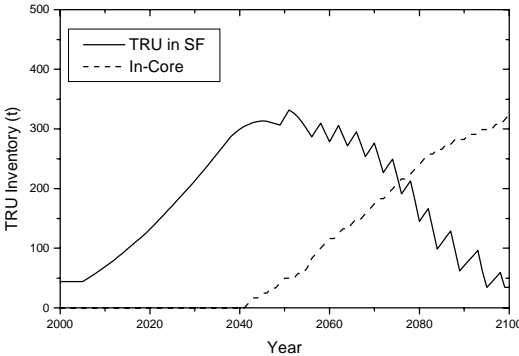


Fig. 7 TRU inventory (ADS cycle)

V. SUMMARY

The Korean nuclear fuel cycle scenarios including the once-through and fast reactor cycle have been investigated. The once-through fuel cycle can be summarized as follows:

- The nuclear power demand grows to 46.3 GWe in the year 2100.
- The amount of total SF is expected to be 92000 t in 2100.
- The amount of TRU is estimated to be 1140 t in 2100.

The results of the fast reactor cycle can be summarized as follows:

- The total SF inventories of the SFR and ADS cycles are 36700 and 9100 t, respectively.
- The total amount of TRU in the SF for the SFR and ADS cycles are 400 and 34 t, respectively.
- The SFR and ADS can transmute the TRU by 235 and 570 t, respectively.

From the above results, it is shown that the SFR and ADS scenarios can effectively reduce the inventories of the SF and TRU. In the future, an economic analysis is recommended for an implementation of an advanced fuel cycle scenario.

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