Pyro-SFR Nuclear Fuel Cycle with Different Conversion Ratios

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1. Introduction

Which type of reactor to adopt determines which of nuclear fuel cycle to deploy. Which nuclear fuel cycle option to deploy is of great importance in the sustainability of nuclear power. SFR fuel cycle employing pyroprocessing (named as Pyro-SFR Cycle) is one promising fuel cycle option in the near future. Conversion ratio (CR) is a key characteristic to be considered while selecting a SFR. With regard to non-proliferation, only burner and break-even reactor with a CR less or equal to 1 are studied. Totally, 3 different CR, 0.35, 0.7 and 1 are evaluated. Uranium resource utilization and radioactive waste generation are essential criteria in nuclear fuel cycle system analysis, which considerably affects the future development of nuclear power in Korea. 100 percent dependence on uranium import and a large population with small territory is two special characteristics of ROK, which makes the uranium utilization and waste management pretty important. In this study, particularly the resource utilization efficiency and waste generation with regard to the promising advanced fuel cycle option was evaluated.

2. Method and NFC option

2.1 Method

One is equilibrium model and the other is dynamic model. Equilibrium model focus on the batch study with the assumptions that the whole system is in a steady state and mass flow as well as the electricity production all through the fuel cycle is in equilibrium state, which calculates the electricity production within a certain period and associated material flow to obtain several criteria for assessment of the sustainability of nuclear power, e.g., resource utilization, waste generation, environment affects. Dynamic model takes the time factor into consideration to simulate the actual cases. Compared with the dynamic analysis model, the outcome of equilibrium model is more theoretical which may offer relatively clear and direct comparisons, especially with regard to the large uncertainty of the development of the pyro-technology evaluated. In this study equilibrium model was built to calculate the material flow on a batch basis. Characteristics of the reference reactors are listed in Table 1.

2.2 Main components of nuclear fuel cycle

A fast reactor utilizes fast neutrons of which higher energy can burn both U-235 and transuranic elements (TURs). This aspect makes it possible to transmute the TRUs and extract energy at the same time. The spent PWR fuels would be processed to obtain TRU-bearing fuels for the fast reactors, while U partitioned from the spent PWR fuel would be disposed of as low and intermediate level radioactive wastes (HLW). The pyroprocessing has been developed to treat the spent oxide fuels discharged from PWRs and recycle metallic components containing TRUs for SFRs. The metal fueled SFR using alloys of Actinides-Zirconium (AcZr) has a high potential for recycling actinides by being integrated with the pyroprocessing. The TRU fuel after burning in the fast reactors would be repeatedly processed by the pyroprocessing and the recovered TRUs would be recycled into the fast reactors to close a fuel cycle as described in Fig 1. It should be notified that the reactor data and fuel composition after irradiation are mainly from a simple conceptual study by Origen. 2. 1.

Table 1. Characteristics of the reference reactors.

Reactor Parameters	CR=0.35	CR=0.70	CR=1.00
Electric power (MWe)	600	600	600
Thermal efficiency (%)	39.4	39.4	39.4
Thermal power (MWt)	1,522.8	1,522.8	1,522.8
Load factor	0.85	0.85	0.85
Cycle length (full power day)	250	304	550
Enrichment (%)	75	30	17
No. of batches	8	5	3
Burnup (GWd/tHM)	265.5	131.3	100.1

Table 2. Reference Fuel composition of SFR with different CRs

		BOC	EOC
CR=0.35	U	2.50E+05	2.15E+05
	Pu	6.58E+05	3.53E+05
	TRU	7.50E+05	3.98E+05
CR=0.70	U	7.00E+05	6.23E+05
	Pu	2.63E+05	2.15E+05
	TRU	3.00E+05	2.44E+05
CR=1.00	U	8.30E+05	7.31E+05
	Pu	1.49E+05	1.51E+05
	TRU	1.70E+05	1.68E+05

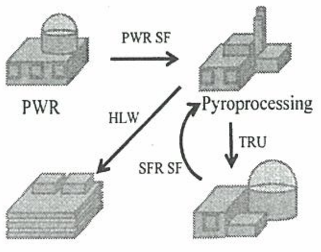

Fig. 1. Pyro-SFR Recycling

3. Results and Discussion

3.1 Uranium utilization

As shown in Fig. 2, the analysis of the three nuclear fuel cycle options revealed that the fuel cycle with the least CR requires the largest amount of uranium resources, while the Pyro-SFR Recycling with CR=1.0 consumes the least. SFR cycle with higher CR requires less uranium representing that the recycling options efficiently utilize the uranium resource and would therefore be economically competitive over the lower CR cycle with the increase of uranium price.

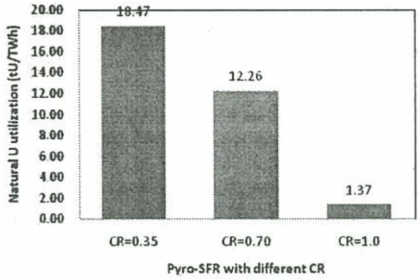

Fig. 2. Comparison of uranium requirements with nuclear fuel cycle options

3.2 Waste categorization

LILW-SL mainly comes from the reactor operation. The second contributor of LILW-SL is the back-end reprocessing. The Pyro-SFR introduces smaller amount of LILW-SL with regard to the ceramic form of waste used for fission products, such as Cs and Sr, decay storage, so the capacity of the near-surface disposal facility needed is the smallest among these four options. The capacity of geological disposal facility built for LILW-LL is determined by the volume of LILW-LL produced by each option. As listed in Table 3, setting the OT Cycle as the basis, the capacity of geological disposal facility for the Pyro-SFR Recycling was around 70%.

Almost all the HLW comes from the back-end of the fuel cycle. The analysis showed that the Pyro-SFR Recycling option produces the smallest amount of HLW since high heat generating elements such as Cs and Sr are selectively separated as LILW-SL for decay storage and TRUs are recovered to be used as fuel in the SFR by the pyroprocess. The waste containing Cs and Sr will be transferred into ceramic form for decay storage for around 300 years by surface disposal as LILW-SL. The removal of Cs, Sr, and TRUs from the HLW stream enables the volume of the HLW to be the smallest among the considered fuel cycle options.

Table 3. Radioactive waste generations

		CR=0.35	CR=0.70	CR=1.0
LILW-SL	Volume (m^3/TWh)	11.02	10.76	10.30
LILW-LL	Volume (m^3/TWh)	1.59	1.19	0.48
HLW	Volume (m^3/TWh)	0.07	0.05	0.03

4. Conclusion

In this study, the Pyro-SFR Recycling with 3 CRs was quantitatively investigated for nuclear energy policy development in ROK by employing the idealized equilibrium material flows focusing on the uranium utilization and radioactive waste generation.

CR has a great importance in nuclear fuel cycle with regard to uranium utilization and waste generation. On the whole, the volumes of LILW generated in Pyro-SFR Recycling with different CR differ considerably. Higher CR Pyro-SFR Recycling shows clear advantages in controlling HLW generation and uranium utilization. However, it should be notified that the proliferation resistance, technology availability have not been included in this study, which may provide a quite different picture.

5. References

[1] Ko, W.I., et al., 2001. Economic analysis on direct of spent pressurized water reactor fuel in CANDU reactors(IV) – DUPIC fuel cycle cost. Nuclear Technology 134, 167–186.

[2] OECD/NEA, 2009. Uranium 2009: Resources, production and demand.

[3] World Nuclear Association, 2009. Waste management in the nuclear fuel cycle, available at http://www.world-nuclear.org/info/inf04.html, updated June 2009.