Analysis of a Thorium-DUPIC Cycle for Different Nuclear Demand Scenarios

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1. Introduction

Recently, the thorium fuel cycle has been studies as an option for a Generation-IV (Gen-IV) [1] reactor development. It can save on natural uranium resources for a pressurized water reactor (PWR) as well as a Canada deuterium uranium (CANDU) reactor. It also has a proliferation-resistant feature which is one of the main goals of the Gen-IV reactors.

This study investigates the multiple recycling thorium fuel cycle scenario in a CANDU reactor by a dynamic analysis method. The multiple recycling is modeled by dry process technology. The dry process considered in this study is a thermo-mechanical process developed for the direct use of spent PWR fuel in the CANDU reactors (DUPIC) fuel cycle. [2] This study estimates the spent fuel inventory as well as the amount of other important nuclear materials.

In this study, the long-term energy supply plan of Korea [3] was used. From this plan, the nuclear power is expected to grow from 13.7 GWe in 1999 to 27.3 GWe in 2020. Also, two kinds of nuclear growth rates are used; first 0% grow from 2020 to 2100, and second a growth rate by considering a logistics model [4].

2. Dynamic Modeling of the Thorium Fuel Cycle

The reactor systems considered in this study are typical 1000 MWe PWR and 713 MWe CANDU (CANDU-6) reactors. The heterogeneous thorium cycle is modeled using 37-element standard CANDU fuel bundle.

In this study, the DYMOND code [5], which was developed by Argonne National Laboratory (ANL) for the Gen-IV roadmap study, was modified for a modeling of the dry reprocess. The heterogeneous $(Th,U)O_2$-DUPIC fuel was designed to burn the PWR spent fuel in the CANDU reactor. The fuel bundle has both thorium and DUPIC fuel elements in a 37-element standard CANDU fuel bundle. The thorium fuel is mixed with the uranium located in the inner 7 fuel elements and it is continuously recycled. The DUPIC fuel is located in the outer 30 fuel elements and replaced after each fuel cycle. This fuel cycle is a partially-closed fuel cycle as shown in Fig. 1. In this model, the required amount of thorium and uranium is calculated as follows:

$$M_{Th} = R_{Th-DUP} \cdot F_{Th-U} \cdot F_{Th}$$
$$M_U = R_{Th-DUP} \cdot F_{Th-U} \cdot F_U$$
$$M_{DUP} = R_{Th-DUP} \cdot (1 - F_{Th-U})$$

where $R_{Th\text{-}DUP}$ is a thorium-DUPIC fuel request, $F_{Th\text{-}U}$ is a $(Th,U)O_2$ fraction in the thorium-DUPIC fuel, and F_{Th} and F_U are the ThO_2 and UO_2 fractions in the fresh $(Th,U)O_2$ fuel, respectively.

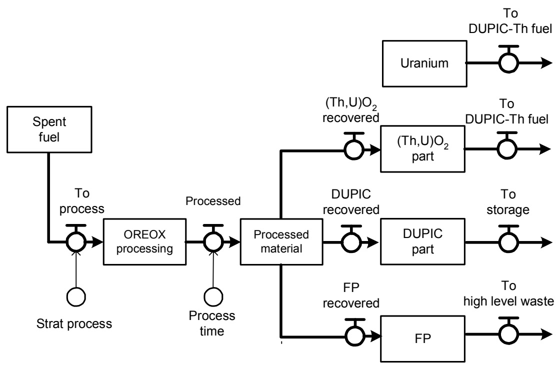

Fig. 1 A DYMOND model of Heterogeneous thorium cycle

3. Fuel Cycle Analysis Results

For the once-through cycle with a 0% growth rate, the electricity generation is dominated by the PWR after 2030. The number of operating PWR in 2100 is expected to be ~27 for the reactor power of 1.0 GWe. For the logistics model, the operating PWR will increase to ~47 at 2100.

Fig.2 compares the annual uranium mining for the once-through and thorium cycles with two different demand growth rates. In the thorium fuel cycle, the uranium mining for the PWR decreases slowly as the thorium-CANDU reactor capacity increases, and the mined uranium for the CANDU reactor decreases and eventually becomes zero after 2030. It can be seen that the amount of uranium mining is lower after 2025 when compared to that of the once-through cycle. For the thorium fuel cycle, the total amount of uranium mining until 2100 will be ~380 and 560 kt for the 0% growth and logistics model, respectively, which are ~16 and 20% lower when compared to the once-through cycle.

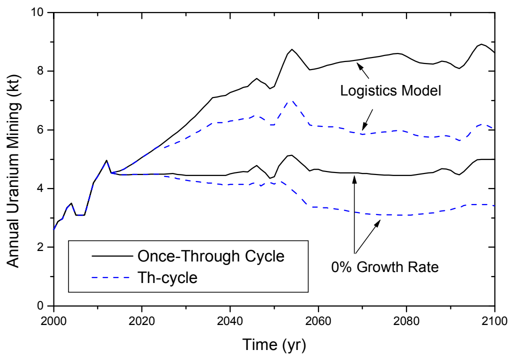

Fig. 2 Comparison of the annual uranium mining

The feed of the natural uranium and thorium fuel increase from ~2025 to 2040, but they rapidly decrease after the recycling starts.

In the once-through cycle, the spent fuel (SF) inventory gradually increases with time and the total SF will be ~64 and ~90 kt for 0% growth and logistics model, respectively. After 2030, the CANDU SF remains constant at the value of ~9 kt because no more spent fuels are produced from the CANDU reactors. The total amount transuranic element (TRU) in the SF will be 647 and 827 t for 0% growth and logistics model, respectively. In the thorium fuel cycle, the total SF will be ~53 and ~70 kt for 0% growth and logistics model, respectively. These values are 17 and 29% lower, respectively, compared with the once-through cycles.

From the above results, it can be concluded that the thorium fuel cycle can save on the natural uranium resources and reduce the spent fuel accumulation.

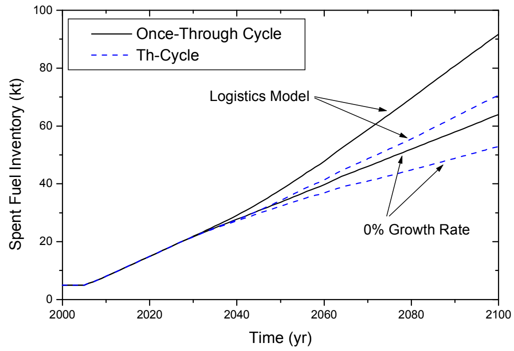

Fig. 3 Comparison of the spent fuel inventories

Acknowledgements

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