Dynamic Analysis of the Multiple Thorium Fuel Recycle Scenarios by Using CANDU Reactors

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The thorium fuel recycle scenarios through the Canada deuterium uranium (CANDU) reactor have been analyzed for two thorium fuel types: homogeneous $(Th,U)O_2$ and heterogeneous $(Th,U)O_2$-DUPIC fuels. The multiple recycling concept is modeled through the current dry process technology, which is a "thermo-mechanical process" developed for the direct use of spent PWR fuel in CANDU reactors (DUPIC) fuel cycle technology [1]. The thorium fuel cycle model was incorporated into the Korean once-through nuclear fuel cycle. The analysis was performed by the modified DYMOND code [2]. In the thorium fuel cycle, the thorium fuel CANDU reactor is deployed from 2020 at a capacity of 30%.

In the homogeneous fuel cycle model, a closed fuel cycle is achieved by a multiple recycle of the thorium fuel. The volume fraction of UO_2 in the $(Th,U)O_2$ fuel is 9% with an initial ^{235}U enrichment of 20 wt%. The discharge burnup is estimated to be 14000 MWd/t. In the calculation, the 43-element fuel bundle is chosen. For the heterogeneous fuel cycle, two kinds of fuel rods are considered: the thorium fuel and DUPIC fuels. In the 37-element standard CANDU fuel bundle, the outer 30 fuel rods are loaded with the DUPIC fuel, while the inner 7 fuel rods are loaded with the thorium fuel for a multiple recycling. For this fuel cycle model, it is assumed that the uranium fraction in $(Th,U)O_2$ is 10% and the rare earth fission products removal rate is 30% for the DUPIC fuel. The discharge burnup is 19000 MWd/t. In this case, natural uranium is used as a feed material.

For both thorium fuel cycles, the amount of annual natural uranium mining is compared in Fig. 1. The mined uranium for a homogeneous thorium cycle increases from 2030 to 2040, and it decreases rapidly once the recycling starts. The increase of the uranium mining is due to the use of enriched uranium in the homogeneous thorium fuel cycle. In the case of the heterogeneous thorium cycle, the uranium mining amount is always smaller when compared to the once-through cycle. The total amount of uranium mining until 2100 will be 389 and 380 kt for the homogeneous and heterogeneous thorium cycles, respectively. For the homogeneous thorium cycle, the thorium feed increases to ~100 t in 2040, but it decreases rapidly once the recycling starts. The amount of thorium feed for the heterogeneous cycle is very small when compared with that for the homogeneous cycle.

As shown in Fig. 2, the spent fuel of the homogeneous thorium cycle will be 59 kt in 2100, which is smaller by ~9% when compared with that of the once-through cycle. In the homogeneous thorium fuel cycle, there is in principle no spent fuel from the thorium-CANDU reactor since all the thorium-based spent fuel is recycled. The total spent fuel from the heterogeneous thorium fuel cycle is 53 kt in 2100, which is smaller by ~18% when compared with that of the once-through cycle.

In summary, when compared to the once-through cycle, the homogeneous thorium fuel cycle can save on the amount of uranium mining by 15% and reduce the inventories of the spent fuel, plutonium and minor actinides by 9, 9 and 8%, respectively. In the case of the heterogeneous fuel cycle, the amount of uranium mining can be reduced by 16%, and the amounts of total spent fuel, plutonium and minor actinides are reduced by 18, 24 and 25%, respectively. Consequently, both thorium fuel cycles can reduce the spent fuel, plutonium and minor actinides inventories. From the viewpoint of the material flow, the heterogeneous thorium fuel cycle seems to be more feasible. It is recommended, however, that an economical analysis of this fuel cycle be performed in the future.

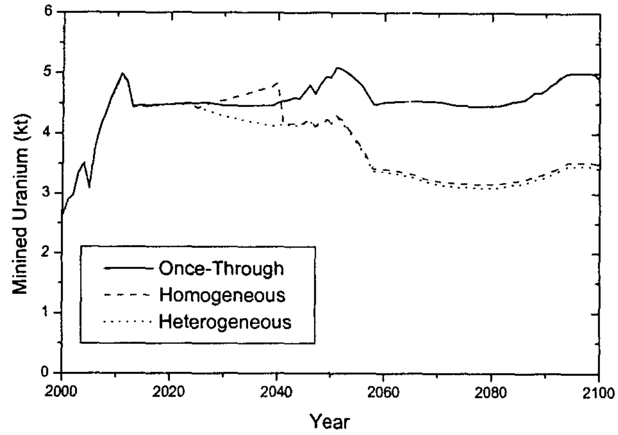

Fig. 1. Comparison of the amount of annual uranium mining

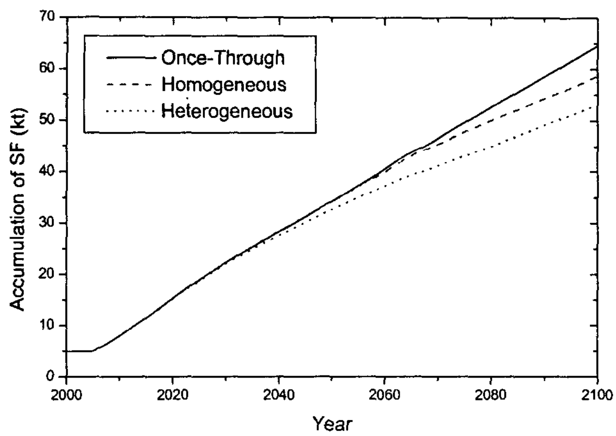

Fig. 2 Comparison of the spent fuel accumulation

References

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