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Seed and blanket thorium-reprocessed fuel ADS: Multi-cycle approach for higher thorium utilization and TRU transmutation

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ABSTRACT

In the previous publication, the seed and blanket thorium-reprocessed fuel ADS was designed for efficient transmutation of TRU waste from the spent nuclear fuel. In this study, the multi-cycle core was designed in order to increase thorium utilization and TRU waste transmutation. For that purpose, the reprocessed fuel assemblies inside the subcritical core are shuffled for twice burnt while the thorium assemblies are remained inside the reactor until the end of reactor life. As the result, at the equilibrium state, the thorium fuel contribution to total core power is improved (35.7%) compared to the startup cycle and it has benefit in flattening the power peaking inside the subcritical core. Compare to the startup cycle, less reprocessed fuel is loaded but the reprocessed assemblies are shuffled and burnt twice, hence, the TRUs are transmuted in a deeper level. At discharge, the reduction of radiotoxicity from the TRU waste is about 20% with 1% uncertainty, mainly due to the reduction of Pu and Am.

1. Introduction

The seed and blanket thorium-reprocessed fuel ADS was investigated, illustrating its great potential for transuranic (TRU) waste transmutation and in-core fuel management (Vu and Kitada, 2013). Besides, thorium fuel has been utilized as based fuel instead of uranium fuel in order to reduce the reactivity swing of the ADS, showing its advantages in terms of low actinide production and fuel availability. However, for single cycle seed and blanket ADS, the utilization of thorium is very limited, only about 3% of thorium fuel is utilized and the breeding ^{233}U isn't recovered to produce energy. Besides, it is taken into account that the once burnt ADS fuel can be recycled and burnt in a deeper level. Therefore, multi-cycle ADS is proposed for more efficient transmutation and thorium utilization extension. According to the proposal, the reprocessed fuel assemblies are shuffled and burnt twice while the thorium assemblies are remained inside the reactor until the end of the reactor life. The transmutation rate and other neutronic parameters of the core at equilibrium cycle and the radiotoxicity at discharge are also investigated.

2. Seed and blanket thorium-reprocessed fuel ADS equilibrium core

2.1. Seed and blanket ADS

The seed and blanket ADS model is based upon the design of the typical ADS in Trellue research (Trellue, 2003). However, instead of loading the whole core with reprocessed fuel as in original design, individual reprocessed fuel assemblies were inserted as seed and thorium assemblies were inserted as blanket of the core to make a heterogeneous configuration. The modification shows the advantages in terms of transuranic waste transmutation as well as fuel assembly fabrication and in-core fuel management. The heterogeneous approach with the individual assemblies of seed and blanket fuel solves the power peaking factor problem due to burnup since the power contribution of the blanket increases with time of radiation and flattening the power peaking factor of the core. The utilization of thorium fuel in blanket produces much less actinide compared to uranium fuel and the breeding ^{233}U from thorium helps to compensate the burnt TRUs in reprocessed fuel, thus, reducing the reactivity swing (Vu and Kitada, 2013).

Thorium and reprocessed fuels were introduced into the core in the oxide form. For the reprocessed fuel, Pu and MA are reprocessed from the 45 GWd/t burnup spent PWR fuel and 7 years cooling (Tsujimoto et al., 2004). The layout for startup cycle is shown in Fig. 1a and the cycle at equilibrium state is illustrated in Fig. 1b.

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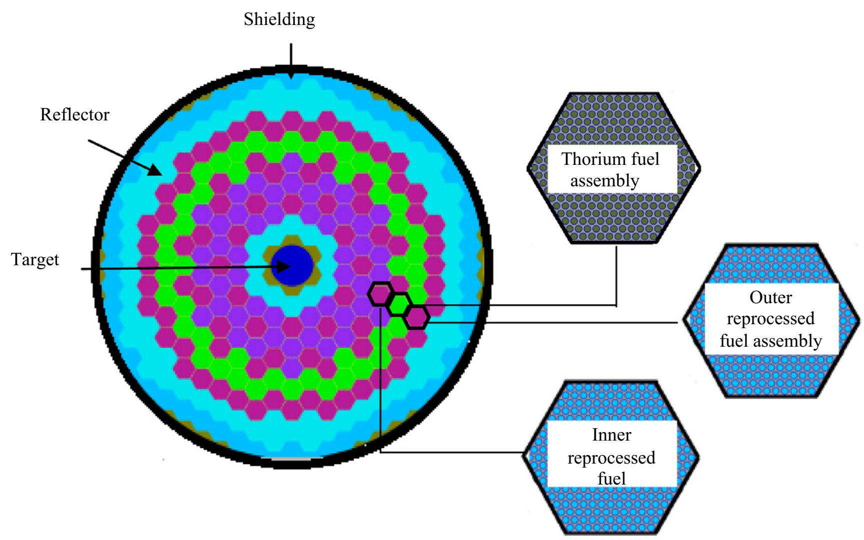

Fig. 1a. Layout of seed and blanket ADS core at startup cycle.

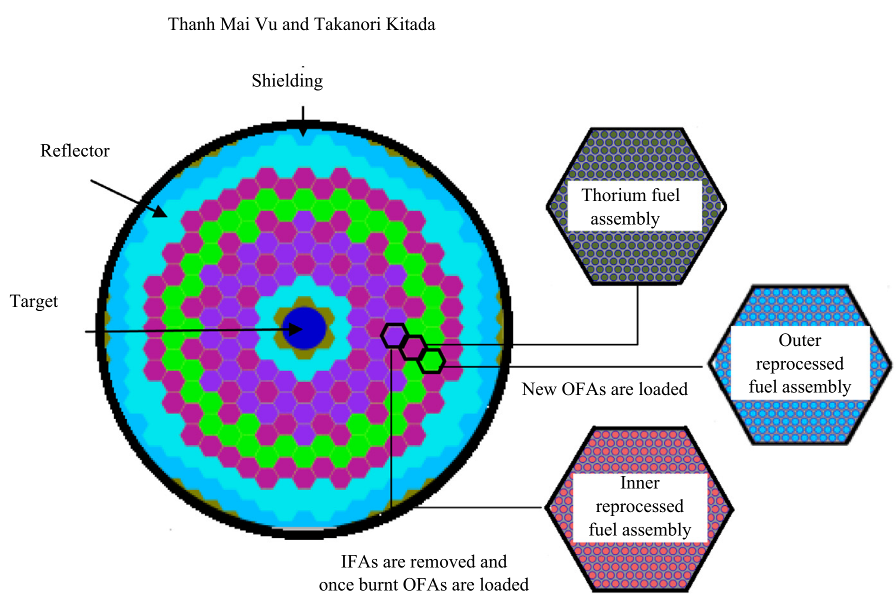

Fig. 1b. Layout of seed and blanket ADS core at equilibrium state.

2.2. Muti-cycle seed and blanket ADS

The subcritical core is heterogeneous with three individual regions: thorium fuel assemblies (TFA), inner reprocessed fuel assemblies (IFAs) and outer reprocessed fuel assemblies (OFAs). Inner and outer reprocessed fuel assemblies have the same composition at the first cycle (Fig. 1a). After the first cycle, thorium assemblies are remained inside the core until it is mainly utilized. After being burnt for one cycle, the inner reprocessed fuel assemblies are removed and the outer reprocessed fuel assemblies are shuffled into the inner fuel region for further radiation (Fig. 1b). The fuel assemblies shuffle scheme is illustrated in Table 1. In order to compensate for the lower fission-to-capture rate caused by the decreasing of fissile materials due to fission and only the small amount of ^{233}U breeding after first cycle, the enrichment of the reprocessed fuel at the second cycle is higher compared with the subsequent ones. No other than that, the enrichment for subsequent cycle is consistent.

Table 1
Fuel assemblies shuffle scheme for seed and blanket thorium-reprocessed fuel ADS for first 15 cycles.

Cycle	IFA	OFA	TFA
1	OFA1	OFA1	TFA1
2	OFA2	OFA1	TFA2
3	OFA2	OFA1	TFA3
4	OFA2	OFA1	TFA4
5	OFA2	OFA1	TFA5
6	OFA2	OFA1	TFA6
7	OFA2	OFA1	TFA7
8	OFA2	OFA1	TFA8
9	OFA2	OFA1	TFA9
10	OFA2	OFA1	TFA10
11	OFA2	OFA1	TFA11
12	OFA2	OFA1	TFA12
13	OFA2	OFA1	TFA13
14	OFA2	OFA1	TFA14
15	OFA2	OFA1	TFA15