THORIUM-BASED FUEL UTILIZATION ANALYSIS IN FLUORIDE SALT-COOLED HIGH-TEMPERATURE REACTOR

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ABSTRACT

The Th-U fuel cycle, benefiting from its excellent breeding capability in both thermal and fast reactors, lesser long-lived minor actinide (MA), and the abundant reserves of Thorium, has become increasingly prominent and new Thorium reactors needs to be developed.

The Fluoride-cooling High-temperature Reactor (FHR)\(^1\), also known as Solid-fueled Molten Salt Reactor (MSR-SF) is a candidate reactor for Th-U fuel cycle. It can achieve excellent performance on safety and economy with a high temperature output. In the past, thorium-based fuels have been successfully utilized in HTGRs\(^2\) in Germany, USA, Japan and The Russian Federation.

The graphite coated fuel particles of the MSR-SF present some attractive advantages as high resistance to irradiation damages and high melting points, enabling to reach a high fuel burnup. The different layers of TRISO particle constitute excellent fission product and radionuclide barriers, which make TRISO particles a robust and attractive waste container. This guarantees the Thorium fuel based MSR-SF (TMSR-SF) can be operated in a “high burnup open fuel cycle”. The irradiated thorium pebble fuel would be discharged and temporarily stored out of the core to convert the 233U isotope, then refilled in batch mode or continuously to achieve a very high burnup, which is essential for thorium utilization.

In the present work, the neutronic properties, thorium utilization and radio-toxicity of three kind thorium-based fuel (enriched with 233U, 235U and 239Pu) in a whole-core model of TMSR-SF is compared.

The achievable burnup of the TMSR-SF at equilibrium state that characterizes the core neutronic properties is essential for the analysis of the equilibrium composition, the thorium utilization and the radio-toxicity. However, the depletion analysis is particularly complex in the pebble bed reactor because the fuel elements are small, numerous, and continuously recirculated through the system. A simplified methodology based on the infinite uniform bed method\(^5\) was used to estimate the achievable burnup and determine the equilibrium composition and neutronic properties of the core as well\(^6\). SCALE\(^4\) version 6.1 is used for describing the thorium fuel based TMSR-SF. A 238-group ENDF/B-VII library is selected for time-dependent cross-section processing which reveals fuel composition variation during irradiation. The depletion is performed at constant power and 388 nuclides are tracked in trace quantities.

The neutron spectra of the three fuel types at beginning of life(BOL) are shown in Fig. 1. With similar graphite-to-heavy metal ratio (C/HM), the spectra of different fuels reveal different inherent characteristics. However, the typical inelastic scattering resonance of FLiBe, particularly 19F and 6Li, is presented at the resonance dips around 0.1 MeV energy range for each fuel.
The evolution of $k_{\text{eff}}$ and CR with burnup for one batch mode (the fuel pebbles are stationary in core) are shown in Fig. 2. The achievable burnup and the equilibrium composition with multi-batch mode (the fuel pebbles recirculated through the core for certain times) will be simulated and reported. And the thorium utilization efficiency will be calculated also.

![Neutron spectra of the TMSR-SF for studied fuel options at BOL.](image1)

**Fig. 2** Neutron spectra of the TMSR-SF for studied fuel options at BOL.

The radio-toxicity of the discharged fuel in one batch mode are shown in Fig. 3. The radio-toxicity will be re-calculated with the equilibrium components, after the achievable burnup in multi-batch mode is simulated.

![Variation of $k_{\text{eff}}$ (top) and CR (bottom) with burnup for the three fuel options.](image2)

**Fig. 3** Variation of $k_{\text{eff}}$ (top) and CR (bottom) with burnup for the three fuel options.

![The radio-toxicities of the three fuel options after discharged.](image3)

**Fig. 4** The radio-toxicities of the three fuel options after discharged.

**REFERENCES**


