Thorium utilisation in a small long-life HTR. Part III: Composite-rod fuel blocks

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HIGHLIGHTS

- Composite-rod fuel blocks are proposed for a small block-type HTR.
- An axial separation of fuel compacts is the most important feature.
- Three patterns are presented to analyse the effects of the spatial distribution.
- The spatial distribution has a large influence on the neutron spectrum.
- Composite-rod fuel blocks react a reactivity swing less than 4%.

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ABSTRACT

The U-Battery is a small long-life high temperature gas-cooled reactor (HTR) with power of 20 MWth. In order to increase its lifetime and diminish its reactivity swing, the concept of composite-rod fuel blocks with uranium and thorium was investigated. Composite-rod fuel blocks feature a specific axial separation between UO 2 and ThO 2 compacts in fuel rods. The design parameters, investigated by SCALE 6, include the number and spatial distribution of fuel compacts within the rods, the enrichment of uranium, the radii of fuel kernels and fuel compacts, and the packing fractions of uranium and thorium TRISO particles. The analysis shows that a lower moderation ratio and a larger inventory of heavy metals results in a lower reactivity swing. The optimal atomic carbon-to-heavy metal ratio depends on the mass fraction of U-235 and is commonly in the 160–200 range. The spatial distribution of the fuel compacts within the fuel rods has a large influence on the energy spectrum in each fuel compact and thus on the beginning-of-life reactivity and the reactivity swing. At end-of-life, the differences caused by the spatial distribution of the fuel compacts are smaller due to the fissions of U-233 in the ThO 2 fuel compacts. This phenomenon enables to design fuel blocks with a very low reactivity swing, down to less than 4% in a 10-year lifetime. Among three types of thorium fuelled U-Battery blocks, the composite-rod fuel block achieves the highest end-of-life reactivity and the lowest reactivity swing.

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1. Introduction

In order to extend the potential of thorium and put its breeding capacity in thermal and epithermal spectrum to good use for block-type high temperature gas-cooled reactors (HTRs), we propose the concept of composite-rod fuel block with uranium and thorium. The concept originates from the seed-and-blanket concept (Olson et al., 2002; Radkovsky and Galperin, 1998; Ding and Kloosterman, 2012b) and micro-heterogeneous fuel assemblies (Shwageraus et al., 2004) for light water reactors (LWRS).

As an example, the composite-rod fuel block concept was applied to the U-Battery, which is a block-type HTR with a thermal power of 20 MWth (Ding and Kloosterman, 2011, 2013). This paper investigates the neutronic performances of the composite-rod fuel block by parametric analysis of composition and geometric parameters by SCALE 6 (ORNL, 2009). The second section of the paper describes the concept of composite-rod fuel block. The third section investigates the neutronic effects of the composition and geometric parameters, including the number of UO 2 fuel compacts, the radii of fuel compacts and fuel kernels, the packing fraction of TRISO...