Thorium utilization in a small long-life HTR. Part I: Th/U MOX fuel blocks

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HIGHLIGHTS

• We propose thorium MOX (TMOX) fuel blocks for a small block-type HTR.
• The TMOX fuel blocks with low-enriched uranium are recommended.
• More thorium decreases the reactivity swing of the TMOX fuel blocks.
• Thorium reduces the negative temperature coefficient of the TMOX fuel blocks.
• Thorium increases the conversion ratio of the TMOX fuel blocks.

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ABSTRACT

The U-Battery is a small, long-life and transportable high temperature gas-cooled reactor (HTR). The neutronic features of a typical fuel block with uranium and thorium have been investigated for a application of the U-Battery, by parametrically analyzing the composition and geometric parameters. The type of fuel block is defined as Th/U MOX fuel block because uranium and thorium are assumed to be mixed in each fuel kernel as a form of (Th,U)O2. If the initially loaded mass of U-235 is mostly consumed in the early period of the lifetime of Th/U MOX fuel block, low-enriched uranium (LEU) as ignited fuel will not largely reduce the neutronic performance of the Th/U MOX fuel block, compared with high-enriched uranium. The radii of fuel kernels and fuel compacts and packing fraction of TRISO particles determine the atomic ratio of the carbon to heavy metal. When the ratio is smaller than 400, the difference among them due to double heterogeneous effects can be neglected for the Th/U MOX fuel block. In the range between 200 and 400, the reactivity swing of the Th/U MOX fuel block during 10 years is sufficiently small. The magnitude of the negative reactivity temperature coefficients of the Th/U MOX fuel block decreases by 20–45%, which is positive to reduce temperature defect of the Th/U MOX fuel block. The conversion ratio (CR) of the fuel increases from 0.48 (typical CR of the LEU-fueled U-Battery) to 0.78. The larger conversion ratio of the Th/U MOX fuel block reduces the reactivity swing during 10 years for the U-Battery.

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1. Introduction

During the mid 1950s to the mid 1970s, (Th,U)O2 and (Th,U)C2 were tested and used as fuel in high temperature gas-cooled reactors (HTRs), like AVR and THTR (Bäumer et al., 1990) in Germany, and Fort St. Vrain in USA (Habush and Harris, 1968). There were several reasons to demonstrate the thorium–uranium fuel cycle at that time. Firstly, thorium is three times more abundant in nature compared to uranium. Secondly, Th-232 has an attractive potential for breeding to a fissile isotope, U-233, efficiently in thermal neutron reactors. Thirdly, U-233 is considered as the best of the fissile isotopes, U-235, Pu-239 and U-233 in epithermal or thermal spectrum from a neutronic point of view, because the number of fission neutrons per neutron absorbed, η, is 10–20% higher than that of U-235 and Pu-239. Finally, uranium resources were believed to be insufficient to support the development of nuclear industries on a large scale.

Since then, thorium has been an interesting nuclear fuel for various reactor applications (Lung and Gremm, 1998; IAEA, 2005; Grenèche et al., 2007), such as HTRs (Dahberg et al., 1974; Teuchert and Rüttin, 1975), molten-salt reactors (Furukawa et al., 1990; Nuttin et al., 2005), and water-cooled reactors (Radkowsky and Galperin, 1998; Galperin et al., 1997; Tondosow et al., 2005; Sinha and Kakodkar, 2006). In the past twenty years, the potential of

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