Applying burnable poison particles to reduce the reactivity swing in high temperature reactors with batch-wise fuel loading

J.L. Kloosterman*, H. van Dam, T.H.J.J. van der Hagen
Interfaculty Reactor Institute, Delft University of Technology, Mekelweg 15, NL 2629 JB Delft, The Netherlands

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Abstract
Burnup calculations have been performed on a standard HTR fuel pebble with a radius of 3 cm containing 9 g of 8% enriched uranium and burnable poison particles (BPP) made of $\text{B}_4\text{C}$ highly enriched in $^{10}\text{B}$. The radius of the BPP and the number of particles per fuel pebble have been varied to find the flattest reactivity-to-time curve. It was found that for a $k_{\infty}$ of 1.1, a reactivity swing as low as 2% can be obtained when each fuel pebble contains about $10^7$ BPP with a radius of 75 $\mu$m. For coated BPP that consist of a graphite kernel with a radius of 300 $\mu$m covered with a $\text{B}_4\text{C}$ burnable poison layer, a similar value for the reactivity swing can be obtained. Cylindrical particles seem to perform worse. In general, the modification of the geometry of BPP is an effective means to tailor the reactivity curve of HTRs.

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1. Introduction
During the operation of a nuclear reactor, the reactivity effect of fuel burnup must be compensated by some means of long-term reactivity control, especially when the reactor operates with batch-wise fuel loads. An elegant way for such a control is the use of burnable poison in the fuel elements to balance the reactivity loss caused by fuel burnup and fission product poisoning by the reactivity gain due to the disappearance of the burnable poison.

The gas-cooled high temperature reactor (HTR) has some attractive properties not offered by other reactors. The application of TRISO coated fuel particles makes it possible to reach very high burnup values and ensures the containment of fission products up to a fuel temperature of 1600 °C (Kogeler and Schulten, 1989). Together with the use of burnable poison, which reduces the role of the active reactivity control mechanisms, this paves the way for long-term unattended reactor operation, which could make HTR technology applicable to areas like ship propulsion and (co)generation of heat and electricity in remote areas.

The HTR concept we had in mind when initiating this study is a mixture of the block-type HTR with batch-wise fuel loads and the pebble-bed type HTR with continuous loads. We consider a reactor that consists of a graphite-walled core cavity filled with fuel pebbles that contain not only TRISO coated fuel particles, but also some burnable poison particles (BPP). After some years of operation, all fuel pebbles are replaced with fresh ones. Because the core inventory is replaced as a whole, we call this concept the cartridge-fueled pebble-bed HTR. However, we want to emphasize that the concept of BPP described here is fully applicable to other batch-wise fueled HTRs as well. Also to the common block-type HTR!