CORE DESIGN AND FUEL MANAGEMENT STUDIES OF A THORIUM-BREEDER PEBBLE BED HIGH-TEMPERATURE REACTOR

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An inherently safe thorium-breeder pebble bed reactor has great potential to improve the safety and sustainability of nuclear energy. The aim of this work is to determine the conditions under which breeding is possible in a thorium-breeder pebble bed reactor (PBR) and to present possible core designs for such a reactor. A method is developed to calculate the equilibrium core configuration of a thorium-breeder PBR, consisting of a driver channel and a breed channel. The SCALE system is used for cross-section generation and fuel depletion, and a two-dimensional (r, z)-flux profile is obtained using the DALTON neutron diffusion code. With the code scheme, the influence of several geometrical, operational, and fuel management parameters on breeding capability can be studied. Four fuel reprocessing schemes are investigated. The first scheme recycles breeder pebbles into the driver channel after some delay for additional 233Pa decay. The second scheme reprocesses the discharged breeder pebbles to make driver pebbles with higher 233U content. The third scheme also reprocesses the uranium isotopes from the discharged driver pebbles. Criticality, and thus breeding, can only be achieved in practice for this case. The fourth scheme, which adjusts the driver pebble residence time to find a critical core, is used to design a thorium-breeder PBR under practical operating conditions. A breeder reactor can even be achieved for a 150-cm core diameter, the same as for the uranium-fueled HTR-PM, but the design presented operates at a significantly lower reactor power, 71 MW(thermal) compared with 250 MW(thermal).

Note: Some figures in this paper may be in color only in the electronic version.

I. INTRODUCTION

For future energy supply, the combination of the inherent safety and high-temperature applications of the pebble bed reactor (PBR) design and the use of thorium as a nuclear fuel could be a promising option. The thorium fuel cycle offers several interesting advantages. Thorium is three to four times more abundant in the earth’s crust than uranium, the use of thorium can reduce the radiotoxicity and the required storage time of nuclear waste, and the Th/233U fuel cycle has favorable nuclear properties for use in thermal breeder reactors, compared with the 238U/Pu cycle.1,2

In the past, the use of thorium inside a PBR has been investigated to reduce the consumption of uranium resources and to reduce the amount of higher actinides produced in or fed to the reactor, especially in combination with plutonium.3–5 Thorium pebbles were also used in practice in the 1980s in the 300-MW(electric) Thorium High-Temperature Reactor (THTR), but highly enriched uranium was added to these pebbles to drive the fission chain reaction.6 The overall conversion ratio (CR) of the THTR was still far below 1.

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