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Impact of Neutron Spectrum Shift on Breed and Burn Reactor Concept

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Abstract

Neutronic analysis has been performed for an infinite fuel cell and a one-dimensional (1D) slab Breed and Burn (B&B) reactor with metallic fuel (U-10%wt Zr), cladding of HT-9, and coolant of lead bismuth eutectic (Pb-55.5%wt Bi). The purpose is to investigate the effect of the neutron spectrum on fuel burning in the B&B reactor and possibility to improve burnup performance of the B&B reactor by applying the neutron spectrum shift. The results of the fuel cell analysis indicate that inserting graphite moderator pins into a conventional fuel cell causes the neutron spectrum to shift into a softer one. This accelerates the transmutation of uranium-238 into plutonium-239 in the first burnup period. After a certain burnup period, the fuel cell can then provide a higher infinite neutron multiplication factor (k_∞), on the condition that the moderator pins are withdrawn. We then present the neutronic analysis for a 1D slab B&B reactor. The primary results of the analysis indicate that it is possible to improve burnup performance by applying a neutron spectrum shift, and that the shift increased maximum burnup of the core by about 2.44%.

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Keywords: Breed and burn reactor, neutron spectrum shift, neutronic analysis, burnup performance

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1. Introduction

The breed and burn (B&B) reactor concept, first proposed by Feinberg et al. [1], is self-sustainable by producing fissile fuel, such as Pu-239 (or Pu-233) from U-238 (or Th-232) during burnup. A conventional B&B reactor consists of a burning zone and a breeding zone. The burning zone contains a sufficiently high concentration of the fissile material to sustain a reaction chain. During operation, concentration of the fissile material decreases and the main portion of core power is generated in this zone. Some of the neutrons produced in the burning zone leak into the ambient, so-called breeding zone, and are absorbed by the fertile fuel, transmuting it into the fissile fuel.

There are two classes of B&B reactor designs: those with standard core configurations, and those with nonstandard core configurations [2]. In the first class, the B&B reactor core is composed of conventional linear assemblies, with fuel management accomplished by horizontally shuffling fuel assemblies during refueling outages. The first study of this class was conducted by Fischer et al. in 1979 [3] in collaboration with MIT [4]. They evaluated a fast-mixed spectrum core for both helium-cooled and sodium-cooled design layouts. Subsequently, Toshinsky et al. developed a lead-cooled B&B reactor concept in 1997 [5][6]. More recently, Yarsk et al. investigated a gas-cooled B&B concept in 2005 [7]. In the second class of nonstandard core design configurations, no horizontal shuffling of fuel assemblies is necessary. A burning wave travels through the fuel from the burning zone to the breeding zone. This concept was first proposed by Teller et al. in 1995 in the effort to develop a completely autonomous gas-cooled thorium B&B reactor [8]. Sekimoto studied a similar concept, the CANDLE reactor (constant axial shape of neutron flux, nuclide number densities and power shape during life of energy producing) [9]. In addition, several theoretical studies of a nuclear B&B waves moving through the core have been performed [10][11]. Currently, there are two projects underway that seek to commercialize B&B reactor technology. The first is the Energy Multiplier Module (EM^2) concept developed in late 2008 by General Atomics, which uses helium as a coolant and fuel in the form of UC pellets with SiC composite cladding [12]. The second is the Traveling Wave Reactor (TWR) developed by TerraPower LLC. This concept is a sodium-cooled B&B reactor, and is expected to be operational by the early 2020s [13].

Basically, a B&B reactor can use fertile-only feed fuel (natural or depleted uranium, or thorium) [2] without requiring enriched fuel. Hence, the concept requires high breeding gain in the breeding zone and good neutron economy to maintain criticality. These requirements lead to a high fuel-volume fraction or a bigger heterogeneous core with a fertile blanket in the active area. However, this design also requires a high amount of fuel in the core, thereby reducing the effectiveness of fuel utilization. A long irradiation time is generally necessary to produce sufficient fissile fuel from the fertile material in the breeding zone. This results in very high neutron fluence of the structural material.

The transmutation of fertile fuels, such as U-238 and Th-232, into fissile material is more effective in a softer neutron spectrum because of the higher neutron microscopic capture cross-section. For the fission reaction, however, a harder spectrum is more effective. Therefore, in this study we try to make the neutron spectrum in the breeding zone softer, and then make that in the burning zone harder again, a so-called neutron spectrum shift. To soften the neutron spectrum in the breeding zone, several moderator pins composed of graphite are inserted into the fuel cell in the breeding zone of the core. After a period of time, when enough fissile material has accumulated, only the fuel pins are shuffled into the burning zone. This fuel-shuffling scheme has the potential to improves the burnup performance of B&B reactors.

The purpose of this work is to demonstrate the possibility of improving the burnup performance of a B&B reactor by applying the neutron spectrum shift. Section 2 shows the effect of the neutron spectrum shift on fuel burning in the B&B reactors by analysing the infinite fuel cell to determine whether or not it is possible to improve burnup performance. To confirm the possibility of burnup performance improvement, we conduct a detailed analysis of two one-dimensional (1D) slab B&B reactors: (1) a reference core, a conventional B&B reactor, without moderator pins in the breeding zone; and (2) a breeding core with moderator pins in the breeding zone. These analyses are presented in Section 3. Section 4 contains a discussion about the impact of the neutron spectrum shift on burnup performance in the B&B reactor. Finally, conclusions and future work are presented in Section 5.