A Pebble-Bed Breed and Burn Reactor

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ABSTRACT:

The unique feature of a "breed-and-burn" (B&B) reactor, such as the TWR under development by TerraPower, is that it can breed plutonium in depleted uranium feed fuel and then fission a significant fraction of the bred plutonium, without having to reprocess the fuel. In order to initiate the chain reaction, the B&B core must first be fed with an adequate amount of fissile fuel such as enriched uranium. Thereafter, the B&B core is capable of continued operation while being fed solely with depleted uranium. As the B&B reactor operates longer and longer, the uranium utilization approaches the fraction of the loaded depleted uranium that has been fissioned.

However, in order to sustain the chain reaction in the B&B mode of operation it is necessary to fission, on average, approximately 20% of the depleted uranium fed. For pin-type fuel this corresponds to a peak discharge burnup of close to 35% and peak cladding radiation damage of about 550 displacements per atom (dpa). The experimental and demonstration fast reactors that operated in the past have proven that the HT-9 fuel cladding can maintain its mechanical integrity up to 200 dpa. Therefore, in order to benefit from B&B reactors it is necessary to develop and license fuel and cladding materials that will demonstrate integrity up to close to 3 times the dpa levels they were subjected to so far.

The objective of the proposed project is to assess the feasibility of designing a sodium-cooled B&B fast reactor that will be able to establish and maintain a B&B mode of operation when fueled with depleted uranium while discharging the fuel at a peak radiation damage that is significantly closer to 200 dpa than to 550 dpa present designs call for. The proposed novel approach uses pebble-type fuel instead of fuel rods and fuel assemblies commonly used for sodium fast reactors. Unique features of the proposed pebble-bed concept include on-line refueling method that enables an effectively 3-D fuel shuffling and a peak-to-average discharge burnup of nearly 1 (versus ~1.7 in conventional B&B cores) along with nearly zero burnup reactivity swing. For the same peak discharged dpa and burnup, the Pebble-Bed Breed-and-Burn (PB-B&B) reactors offer nearly 170% the fuel utilization of conventional pin-fueled B&B reactors. A successful development of PB-B&B reactors will offer at least 30-fold increase in the uranium ore utilization versus that achieved in contemporary LWRs, without need for fuel reprocessing and recycling. If and when structural materials and fuel capable of withstanding larger radiation damage and burnup levels become available, the fuel utilization of the PB-B&B reactors will be even higher. Moreover, per GWe-yr of electricity generation, the PB-B&B energy system will require a small fraction of natural uranium supply and enrichment capacity relative to those required to support a LWR based energy system. The energy value of the depleted uranium stockpiles ("waste") accumulated in the US so far is equivalent to, when used in the PB-B&B reactors, several centuries of the total 2010 USA supply of electricity. Therefore, a successful development of the PB-B&B reactors could provide a great measure of energy security and cost stability.