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A Once-Through Thorium Cycle For BWR's*

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Problems in application of thorium cycles include greater fissile inventory requirements,[1] the blending of highly enriched uranium or plutonium with thorium, and the necessity to recover and recycle the valuable U-233 produced in order to recover the costs of the initial inventory and enrichment. With these problems in mind, a "once-through" thorium cycle was developed for Boiling Water Reactors which minimizes the effect of thorium on the fissile inventory, which is initiated with ThO_2 fuel containing no initial fissile material, and which does not require U-233 recovery and recycle to make the application economically competitive. The design makes advantageous use of the inherent lattice heterogeneity and other characteristics of the BWR lattice to produce U-233 in ThO_2 without power distribution penalties and to improve reactor performance (thermal and transient margins). Standard BWR fuel assembly hardware was used to make the design backfitable with minimum manufacturing impact. Preliminary conclusions are that the once-through thorium application has potential to both reduce uranium ore requirements and increase BWR operating margins.

The design utilizes heterogenous location of thorium in the highest thermal flux locations of the BWR lattice[2,3] to maximize U-233 production rate during burnable absorber depletion. After fuel assembly discharge, the U-233 bearing ThO_2 rods are reassembled into fresh fuel assemblies or into breeder blanket bundles (BBB's) that are located at the core periphery. The breeder blanket assemblies have breeding ratios of 1.03 to 1.2 and fissile inventory ratios of 1.05 to 1.7, depending on conditions in the pre-breeder irradiation. The reactivity is very flat with burnup (Figure 1) and; therefore, the residence time of the breeder blanket bundles is limited by mechanical integrity, not by reactivity lifetime.

It is current practice in BWR design to reduce neutron leakage from the core by locating either natural uranium (first core) or last cycle fuel on the core periphery.[4] In the once-through thorium cycle, the BBB's replace the last cycle fuel on the core periphery. Thus, once the BBB's are in place, the number of bundles needed each cycle to sustain the reactor is reduced thereby conserving uranium ore.

Figure 1 illustrates the infinite lattice neutron multiplication factors versus exposure for the BBB design and a natural UO_2 bundle. The BBB reactivity versus exposure shapes are both greater and flatter than those of the natural uranium fuel. In typical BWR operations, it would take 15 to 20 years to reach an exposure of 40 GWD/ST in the peripheral (BB) bundles. Therefore, corrosion and/or hydriding probably will determine the allowable residence time of the low power breeder blanket bundles.

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DISCLAIMER

Table 1 summarizes material flow for a once-through BWR thorium application. The blanket is generated from the pre-breeder bundles (PBB's) in eight to ten cycles of operation. If PBB's were loaded throughout the lifetime of a BWR/6, it could generate almost three complete BBB blankets. Excess rods from the PBB's may be used in fresh fuel or may be used to fuel the blankets of other reactors. Earlier generation BWR 1-3's can incorporate greater numbers of ThO_2 rods in the PBB's and, therefore, can generate the blankets more rapidly as well as generating more excess U-233/ThO_2 rods for other reactors.

The PBB design requires about the same initial fissile inventory and separative work as a standard UO_2 fuel bundle. Thus, the design has promise for practical utilization of thorium without the usual increase in fissile inventory and would permit local breeding and U-233 generation in many existing operating reactors. The fissile inventory ratio (ratio of final to initial inventory) of the BBB's is greater than 1.05, therefore, the BBB's will build a substantial inventory of valuable U-233. In addition, current estimates indicate that the PBB/BBB designs will result in a savings of approximately 4% in uranium ore.

Analyses of the pre-breeder bundle performance indicate that the ThO_2 rods make the BWR steam void reactivity coefficient 10-15% less negative. Initially this appears to be due to combined effects of the ThO_2 rods on thermal utilization and resonance capture. As U-233 builds up, the large U-233 resonance fission integral and relatively large epithermal fission neutron production per capture causes a positive contribution to the steam void reactivity coefficient. The net effect is that axial power shapes and burnup dependent fuel assembly power mismatch are improved, as is performance in low probability pressure transients. The requirements for burnable absorbers also are decreased, with a beneficial effect on fuel cycle economics.

Analyses of the PBB and BBB bundle designs have been carried out with a 100 energy group spatial/spectral model. However, because of uncertainties in the analysis of mixed lattices of ThO_2/UO_2 rods, it is desirable that detailed full spectrum Monte Carlo analyses, additional experimental benchmark analyses, and detailed 3-D coupled nuclear-thermal-hydraulic-fuel cycle analyses be carried out to test the validity of the promising performance and trends that have been observed in analyses to date.

References

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Figure 1

Typical Infinite Lattice Neutron Multiplication Factors Versus Burnup

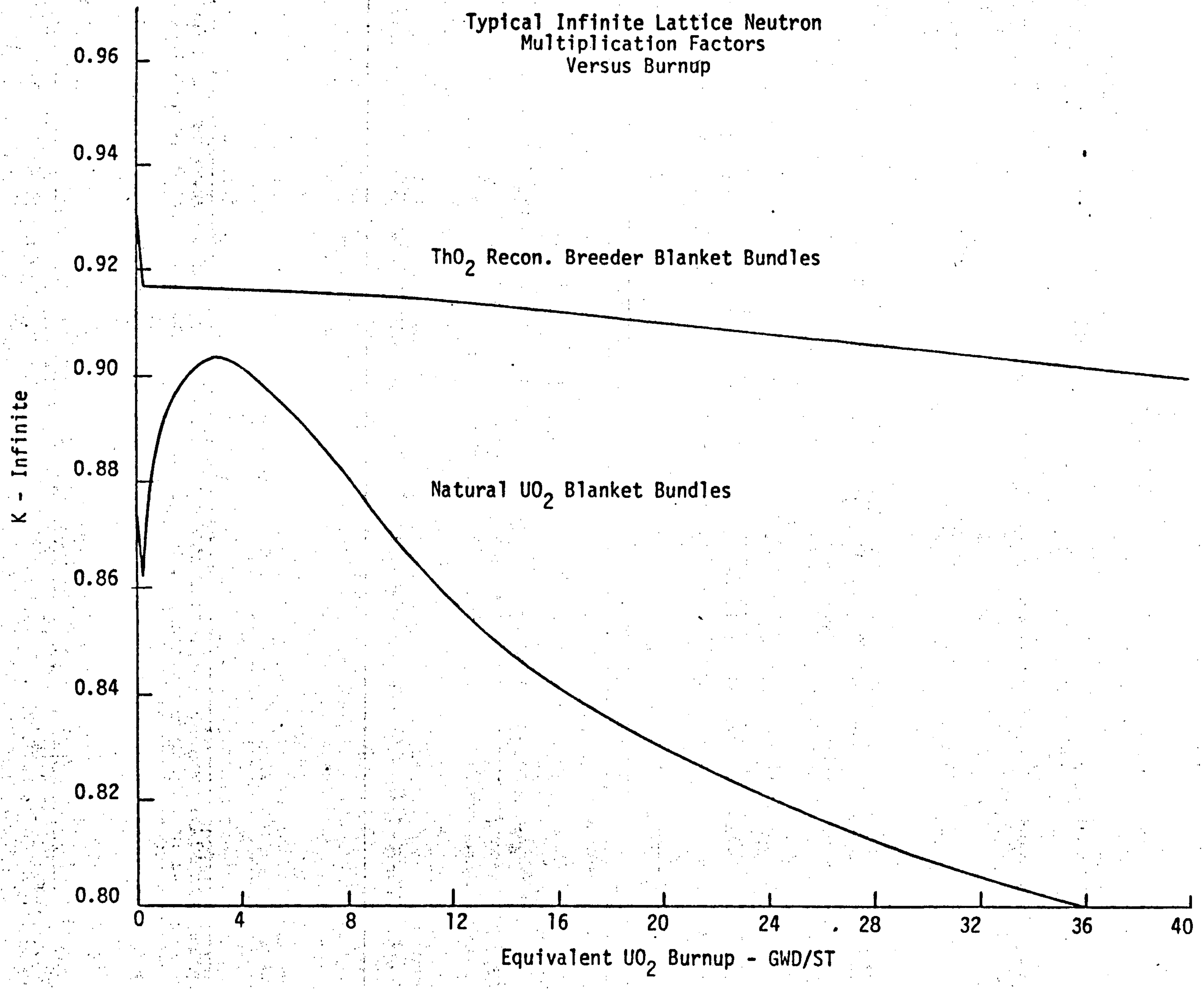

Table 1

Material Flow in a 748 Bundle, 110 MWe BWR/6 Once-Through Thorium Cycle Example

End of Cycle #	# of PBB's Discharged/Cycle	# of BBB Rods Produced/Cycle	Total ThO_2 Rods Available	Total BBB's
1	0	0	-	-
2	192	768	768	9
3	152	608	1376	16
4	180	1360	2736	33
5	188	752	3488	43
6	176	704	4192	51
7	180	720	4912	60
8	180	720	5632	69
9	180	720	6352	78
10	180	720	7072	87(1)
11-30	180	720	21472	265(2)

(1) First blanket of (84 bundles) BBB's completed.

(2) Does not include ThO_2 rods from 1, 2, and 3 cycle fuel.