Thorium Based Fuel Designed to Reduce the Proliferation Potential and Waste Disposal requirements of Light Water Reactors

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Abstract

The recent revival of interest in thorium-based fuel cycles is motivated by its potential to address concerns related to proliferation potential and waste disposal. The main source of proliferation potential and radiotoxicity is plutonium (Pu) generated during the burnup of a standard light water reactor (LWR) fuel. A significant reduction in quantity and "quality" of Pu may be achieved by replacing the U-238 fertile component of SEU fuel (slightly enriched uranium) by Th-232.

Several Th-based fuel design options investigated in recent years (1-5) demonstrated the basic feasibility of Th-based fuel cycles for LWR's of current and next generation technology. Two main design variants were considered: homogeneous and heterogeneous. The homogeneous design adopted a mixture of ThO_2 and UO_2, with a uranium volume fraction and enrichment sufficient to obtain the required burnup and cycle length. The heterogeneous design, an example of which is presented in this paper, adopted a seed-blanket assembly design, where the U and Th fuel parts are spatially separated. The results of the detailed fuel cycle analysis prove that the homogeneous design does not provide optimal/adequate performance of the fuel cycle as regards reduction of proliferation potential, fuel utilization, and economics.

The heterogeneous design concept considered in this paper, known as Radkowsky Thorium Fuel (RTF), is based in part on the ideas and experiences of the Bettis Atomic Power Laboratory's Light Water Breeder Reactor (LWBR) program as implemented and successfully demonstrated at the Shippingport reactor in the late '70s.

The RTF is a new fuel concept, not a new reactor that builds on the successful LWBR experience. In addition to reducing the proliferation potential of the standard nuclear fuel cycle, and reducing the requirements for spent fuel storage and disposal, the design is subject to the following constraints:

1. retrofittable into existing PWRs/VVERs with minimum changes to existing systems/hardware;
2. competitive economically; and
3. operational and safety characteristics comparable to those of existing LWRs (i.e., within the current "safety envelope").

The fuel-to-moderator ratios in the seed and blanket regions are different, and optimized to reduce Pu production in the seed, and enhance U-233 production and burning in the blanket. The uranium used in the seed region is enriched up to 20% only, which is accepted as the non-proliferative limit. Two additional items enhance the non-proliferative characteristics of the RTF fuels:

1. in addition to reducing the production of Pu by a factor of ~5 - 7 relative to a standard PWR/VVER, the plutonium that is produced has a high content of Pu-238, Pu-240, and Pu-242 which makes it impractical for use in a weapon; and
2. it employs a once-through fuel cycle with no reprocessing, with the bred U-233 burnt in situ; in addition, the U-233 that is produced, is denatured by the initial admixed uranium isotopes in order to force isotopic separation (which is impracticable) should extraction and use of the bred U-233 be attempted.

The long residence time of the blankets (~9 yrs.), and relatively high burnups, coupled with the superior neutronic performance of U-233, results in improved fuel utilization.

Reference designs of PWR and VVER variants confirm reductions in the production of plutonium by a factor of ~5 - 7 relative to conventional fuel cycles. In addition, reductions in waste volume by a factor of ~2, as well as reductions in decay heat and activity were realized, along with fuel-cycle cost savings of more than ~10%.

A cross section of the currently proposed RTF seed-blanket unit (SBU) design is shown in Figure 1. Note that the SBU is a one-for-one replacement for a conventional 17x17 PWR fuel assembly; as shown in the Figure, the guide tubes positions of a standard PWR design are preserved, and the guide tubes are used as a structure for the separate grid plate design for the seed and the blanket parts of a fuel assembly. The resultant design permits the independent movement of the seed and blanket portions of the SBU required by the in-core fuel management scheme.

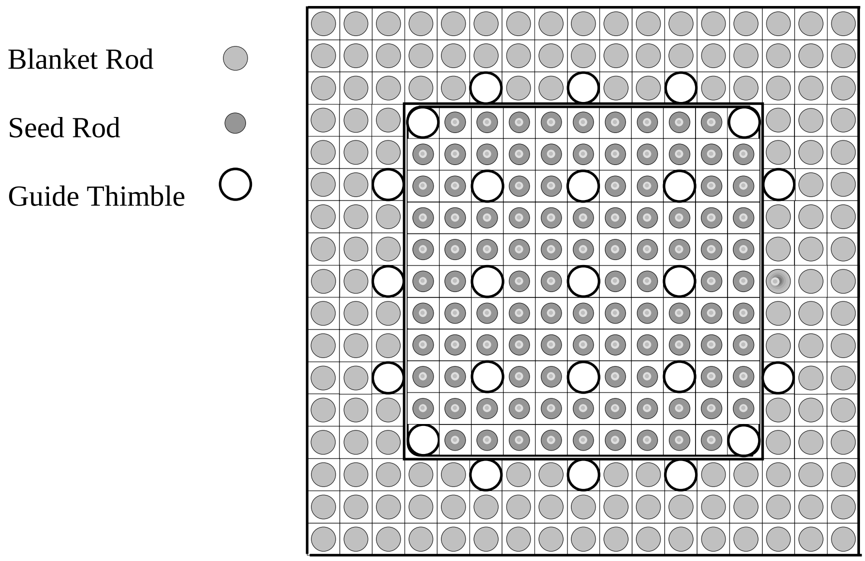

Fig. 1: Seed-Blanket Fuel Assembly

The concept is being developed by a broad-based, international team utilizing both U.S. DOE funds under the Initiatives for Proliferation Prevention program, and private funding from Thorium Power, Inc.; technical work is directed by Brookhaven National Laboratory. R&D efforts to develop and demonstrate the concept are currently focused at the Russian Research Center-Kurchatov Institute in Russia, and are aimed at testing of SBUs in an operating VVER-1000. Additional work in support of this effort, and the design of a PWR variant is being performed at the Massachusetts Institute of Technology, and Ben Gurion University of the Negev.

In addition, there has been some preliminary work done (3) on assessing the potential of the RTF concept for the disposition of weapons-grade and reactor-grade plutonium. The main design objective of the RTF Pu-incinerator design is to mediate a compromise of the two performance parameters: a high Pu incineration rate and a low residual content of Pu in the discharged fuel stockpile, while preserving operational/control and safety characteristics. Initial design studies indicate that approximately 700 kg of Pu may be incinerated annually with the residual Pu content in the 25-35% range.

References

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