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A thorium-based fuel cycle for VVERs & PWRs – a nonproliferative solution to renew nuclear power

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The potential of thorium to breed fissile uranium has ensured that this element, found in large quantities throughout the world, can be considered for a possible fuel cycle for nuclear power reactors. A new thorium-based concept - the Radkowsky Thorium Fuel (RTF) concept -- has been proposed which offers several advantages, including: a reduced rate of plutonium generation in the fuel; a reduced level of waste generation per unit energy production; and enhanced proliferation resistance characteristics in the spent fuel.

The growth of commercial nuclear power in much of the world has effectively been stalled since the early 1970s as a result of a number of concerns, including waste disposal, cost, proliferation and safety. Recent concerns about global warming, and the Kyoto accords limiting CO2 however, suggest that future energy demands cannot be met solely through the burning of fossil fuels, and a return to some reliance on the nuclear option may be required; this transition would be significantly aided if the earlier concerns could be successfully addressed.

A novel reactor fuel-cycle concept based on the utilization of thorium has been proposed that addresses the proliferation and waste issues that currently contribute to limiting the expansion of nuclear power. The concept known as Radkowsky Thorium Fuel (RTF), was proposed by Alvin Radkowsky (former chief scientist of the Naval Reactors programme under Admiral H. Rickover (from the 1950s to the early 1970s) and is based in part on the ideas and experience of the Bettis Atomic Power Laboratory's Light Water Breeder Reactor (LWBR) programme as implemented and successfully demonstrated at the Shippingport reactor in the late 1970s.

THE CONCEPT

The RTF is a new fuel concept, not a new reactor design, 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:

- Be retrofittable into existing pressurized water reactors, and the Russian variant, the VVER, with minimum changes to existing systems/hardware.
- Be competitive economically.

- Have comparable Environmental, Safety and Health (ES&H) characteristics to those of existing PWRs/VVERs (i.e. within the current "safety envelope").

  Retrofittability is achieved via the key element of the RTF, the seed-blanket-unit (SBU), which is a one-for-one replacement for a conventional PWR/VVER fuel assembly. The fuel-to-moderator ratios in the seed, and enhance U-233 production and burning in the blanket. Two additional items enhance the nonproliferative characteristics of the RTF fuel:
- 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,
- 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 admixed uranium isotopes in order to force isotopic separation should extraction and use of the bred U-233 be attempted.

The RTF concept development team

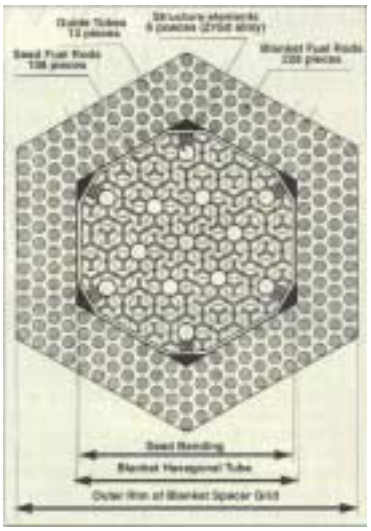
The Radkowsky Thorium Fuel concept is being developed by a broad-based team utilizing both US DOE funds, under the US Department of Energy's Initiatives for Proliferation Prevention programme, and private funding from Radkowsky Thorium Power Corp (RTPC) and foreign fuel fabricators; technical work is directed by Brookhaven National Laboratory, R&D efforts to develop and demonstrate the concept are currently focused at the Russian Research Centre - "Kurchatov Institute", and are aimed at testing of the seed-blanket-units in an operating VVER-1000 in about 2005. 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, Israel.

In addition, there has been some preliminary work done on assessing the potential of the RTF concept for the disposition of weapons-grade plutonium and initial results suggest that it is an attractive concept for further evaluation.

The high residence time of the blankets (~9-10 years, burnups on the order of 100 GWd/t), coupled with the superior neutronic performance of U-233, results in improved fuel utilization, and hence reduced fuel costs; coupled with the absence of higher-level actinides due to the Th cycle, the concept also has benefits for waste storage with reduced volume, activity and decay heat relative to a conventional cycle. While these latter improvements are relatively modest, additional studies currently underway suggest much more dramatic improvements with respect to toxicity of the waste.

INITIAL STUDIES

Initial development of the concept was performed by the Radkowsky Thorium Power Corp (RTPC). That effort resulted in very preliminary versions of PWR and VVER variants, and suggested 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%.



In 1996 a programme was initiated under the US DOE Industrial Partnering programme (IPP) (now the Initiatives for Proliferation Prevention programme). This R&D programme was aimed at developing and demonstrating key elements of the RTF concept. The project was carried out in co-operation with the Russian Research Centre - "Kurchatov Institute" (RRC-KI) under a subcontract with Brookhaven National Laboratory (BNL), and RTPC (through a Cooperative Research and Development Agreement with BNL). RRC-KI led a team that included participants from approximately 10 Russian institutes, as well as Gosatomnadzor (GAN), the regulatory organization. To-date, the main thrust of the programme has been focused on VVERs and Russian Federation fuel technology. Initial mechanical design of a demountable SBU for use in VVER-1000s and all required mechanical interfaces has been developed, and satisfactory neutronic and thermal-hydraulic performance over ~10 cycles has been confirmed by calculations. The calculations also essentially confirmed the initial estimate of reduction in overall plutonium production, obtaining a factor ~5 from a more refined modeling. Initial safety assessments show that the RTF version of a VVER, referred to as a VVERT, falls within the existing safety envelope. Experimental programmes to verify predicted neutronic and thermal-hydraulic performance, and qualify the fuel, have been defined, and key issues that need to be addressed have been identified.