exploring fuel alternatives

by Ray Sollychin

Under INPRO, experts are looking at the possibility of using thorium-based fuel cycles to help achieve sustainable nuclear energy in the 21st century.

Thorium, like uranium, is a fertile material that can be used to produce fissile material, which in turn could be used as fuel in a nuclear reactor. The use of thorium to support future large-scale deployment of nuclear energy systems is being explored under INPRO in a Collaborative Project entitled "Further Investigation of Thorium Fuel Cycles". Parties involved in the project include the European Commission, India, Canada, Slovakia, Russian Federation, China, France and the Republic of Korea.

Neutrons from a fission reaction initiated by U235 can also be used to convert through capture fertile material, such as U238 and Th232, to generate new fissile material, Pu239 and U233, respectively. This is important for extending the availability of fissile material which makes nuclear energy sustainable.

The main concern from producing a large quantity of Pu239 is related to proliferation of material since Pu239 can be used to make a nuclear weapon. The same concern exists for proliferation of materials with the use of thorium, since U233 can theoretically be used in a nuclear weapon. However, a small amount of the the fission product U232, whose radioactive decay emits a powerful, highly penetrating gamma ray, makes U233 weapons significantly more difficult to conceal and much more dangerous to handle. Moreover, there are no known U233-based weapons under development in the world today and under the testing moratorium currently in place, a successful development of new weapons technology based on U233 would be difficult to demonstrate or test.

The proliferation-resistance of the thorium fuel cycle could also be improved in future designs of thermal reactors through 'recycling' U233 inside the reactor without removing it from the secured reactor facility for reprocessing.

Using thorium could reduce the production of plutonium and transuranic elements and help with the disposition of military plutonium. In some specific reactor designs using thorium, plutonium can be 'burned', offering a practical and economical method for disposing of nuclear weapon material.

Thorium fuel has better thermal and physical properties as well as irradiation performance than uranium fuel. It could be a better fuel option for nuclear energy system designs that operate at a higher temperature, such as non-electricity applications. Furthermore, the melting point of thorium dioxide is about 500 degrees Celsius higher than that of uranium dioxide. This difference provides an added margin of safety in the event of a temporary power surge or loss of coolant in a reactor.

Another possible advantage of the thorium fuel cycle is related to the long-term management of spent-fuel. A smaller quantity of high-level, spent fuel with fission products that have shorter half-lives is produced by thorium fuel cycles in comparison to the uranium-plutonium fuel cycles. The engineering for the long-term waste disposal in the thorium fuel cycle may be less demanding than the uranium-plutonium fuel cycle, from the point of view of both repository lifetime and space requirements.

The high radioactivity of the thorium spent fuel, mainly due to the presence of the gamma-ray emitting U232 and its decay chains, creates engineering challenges, but not fundamental physics problems, to the designers and operators of spent-fuel management facilities. On the other hand, the presence of strong gamma-ray emitters also provides opportunities for innovative developments of new industrial applications. For example, thorium spent fuel can be incorporated into the design of long-lived fuel (for small and medium sized reactors without onsite refuelling) as an inherent deterrent for sabotage or theft during shipment to a centralized spent fuel processing center. Other applications may be related to the sterilization of medical equipment and use in food irradiation, radiation-therapy equip-

INPRO Thorium Steps

During a IAEA/INPRO consultancy meeting in January 2009 a number of thorium-based fuel cycle options were identified for consideration by Member States of INPRO. In the meeting, the following three groups of fuel cycle options suitable for short-term to mid-term applications were identified:

❶ Once-through uranium/thorium fuel cycle in HWR, PWR, BWR and HTGR. This includes the conventional once-through, fuel shuffling and recycling of mechanical-reconfigured fuel;

❷ Once-through plutonium/thorium fuel cycle in HWR, PWR, BWR and HTGR. This is similar to the first option except existing Pu239, instead of U235, is used to start the fission process prior to sufficient creation of U233 in the reactor core. A special variation of this are designs for the purpose of reducing the plutonium as potential weapon material; and

❸ Synergism between fast reactors (FRs) and thermal reactors, in which a number of FRs are operated as factories for converting Th232 into U233 to feed other reactors.

In addition to the participating members of the collaborative project, several observers from Thorium Power (USA), Thor Energy (Norway) and the Institute of Energy Research at Juelich (Germany) took part in the meeting.

ment, medical diagnostic equipment and custom inspection facility, etc.

Economics of Thorium Fuel

When implemented on a large-scale, the thorium fuel cycle can potentially offer an economic advantage over the current uranium-based open fuel cycle, despite the expectation that the fabrication cost of thorium fuel may be higher than uranium fuel.

The expected possibly higher cost is based on the more difficult handling of U233 and the associated highly radioactive U232. Other factors, however, may mitigate the higher fabrication cost, for example, there is no enrichment required in the thorium fuel cycle, and fewer conversion process steps are required to manufacture natural thorium oxide into fuel forms ready for first irradiation than in the case of uranium.

Further, the 'recycling' capability of thorium fuel and the possibility of higher temperature operation will likely provide some additional economic benefit. The conversion from fertile Th232 to U233 is done during fission, i.e., while energy is generated, and the resulting fissile U233 can continue to undergo fission and produce energy for a long time (higher burn-up), up to the limit imposed by the behavior of the fuel cladding material and supporting structures. Higher temperature operation of future thorium-based reactor designs should increase the nuclear energy systems' thermal efficiency from the current best of 34% to as high as 50% or even higher, directly contributing to a reduction of the fuel cost per unit of energy generation.

Why Can't We Start Using Thorium?

The utilization of thorium could start today, in the current generation of nuclear energy systems with some redesign and relicensing. However, in a once-through fuel cycle (i.e., no recycling to recover the remaining U233 after discharge), the use of thorium fuel is not very economical.

Several advanced designs are being developed to more optimally use thorium with improved utilization efficiency or with specific purposes (for example, plutonium disposition). These include modified designs or evolutionary designs based on current reactor types, such as India's Advanced Heavy Water Reactor and thorium-based VVR-100 jointly developed by the USA and Russia; thorium-based Pebble-Bed Reactor, fast reactors (liquid metal cooled and gas cooled); and advanced designs such as Molten-Salt Reactor and Accelerator Driven System.

In addition, several reactor concepts have been proposed and are currently being developed with the objective of meeting the needs of small energy users. Some of these design concepts can be optimized for the use of thorium fuel.

The biggest challenge facing the introduction of the thorium fuel cycle for commercial power generation is the lack of fuel-fabrication-related infrastructure.

The nuclear industry has benefitted from the availability of similar infrastructure for the uranium fuel, which was made possible by investment in the past for non-civil applications. However, the fuel-fabrication infrastructure for the thorium fuel cycle will have to be developed for commercial considerations.

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