Indian Experience in Manufacture of Thorium based Fuels

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India has about four times more thorium resources than uranium. Utilisation of thorium for large scale energy production is a major goal in the Indian three stage nuclear power programme. The first phase is being realized through Pressurised Heavy Water Reactors (PHWR's) using natural uranium as fuel. The second phase will be based on sodium cooled fast reactors (SFR) for power generation and to enhance fissile material inventory in terms of ^{239}Pu and ^{233}U. Thermal reactor like Advanced heavy Water Reactor (AHWR) would burn the ^{233}U in the third stage with thorium, producing power from thorium. Thorium, a fertile material has to be converted to ^{233}U for generation of nuclear energy. As an option, thorium can be deployed along with either enriched uranium or plutonium for its utlisation in a reactor. This has been demonstrated by using (Th-LEU) mixed oxide (MOX) or (Th-Pu) MOX as fuels in LWRs, HWRs and HTRs on a limited scale. The fabrication of these MOX fuels is similar in most respects to the well established UO_2 or (U-Pu) MOX type fuels being used in LWRs and HWRs. In India thoria fuel bundles fabricated at BARC and Nuclear Fuels Complex (NFC), Hyderabad have been used in PHWRs for initial core flux flattening. Thoria based (Th-Pu) MOX fuels of different types, viz. (i) (Th-4%Pu) MOX of TAPS-BWR fuel design (ii) (Th-6.75%Pu) MOX of PHWR fuel design and (iii) (Th-8%Pu) MOX of AHWR fuel design have been fabricated at BARC and test irradiated in the Pressurized Water Loop (PWL) of CIRUS reactor. As part of the AHWR fuel development programme, (Th-1%Pu) MOX and (Th-10%LEU) MOX fuel pins have been fabricated for irradiation in the regular fuel position of Dhruva. These fuels were fabricated by the conventional powder-pellet route as well as by coated agglomeration pelletization route. ThO_2, being a perfectly stoichiometric compound with very high melting point, cannot be sintered to very high density (>96%T.D.) even at reasonably high temperature (1700^{0}C). Additives like Nb_2O_5 have considerable effect in the sintering behavior of ThO_2 and ThO_2 based fuels and help in lowering down the sintering temperature for achieving high density fuel pellets.

Thorium can be utilized in a sustainable manner by its use in closed fuel cycle mode in form of (Th-^{233}U) fuel. ^{233}U generated in the reactor from Th is accompanied with ^{232}U whose daughter products are hard gamma emitters. The radiation levels in ^{233}Useparated after reprocessing of thoria based fuel increases considerably within short span of time. Advanced fabrication methods more amenable for the fabrication of (Th-^{233}U) MOX fuel remotely inside shielded hot-cells are being developed. Experimental studies have been carried out using natural UO_2 with thoria. These processes help in reducing the operations involving dusty UO_2 powder and also reduce the number of steps to be carried out in hot-cells. To achieve large scale manufacturing, extensive automation and deployment of equipments which can be remotely operated is necessary. Several developments in fabrication processes and equipments are being carried out in these areas in BARC, especially for the use of thorium based fuel in AHWR. To demonstrate automation and remotisation and to gain fuel fabrication experience inside hot cell, a mock up facility has been set up at BARC.

As Thorium dioxide is a stable compound, recycling of process rejects of thoria based fuels either by dry or wet route is difficult unlike UO_2 based fuel. Stable oxidation state of thorium oxide limits oxidative-reductive processing of sinter rejects and leads to difficulty during dissolution in nitric acid. The presence of UO_2 (15% to 30w %) in the ThO_2-UO_2 fuel pellets makes it amenable to oxidative–reductive processing by modifying the fabrication parameters. Pellets of acceptable quality could be obtained by limiting the powder from rejected pellets to ≤15 wt% by recycling of sinter rejects mixed with freshly prepared ThO_2-UO_2 powder.

This paper brings out the experiences and developments in fabrication of Thorium based fuels. It also provides an overview of various manufacturing aspects associated with use of thorium based fuels on a large-scale and as a sustainable option.

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Mr. Arun Kumar graduated in Metallurgical Engineering from BIT Sindri (Ranchi University) in 1972 & joined the 16th orientation course for engineers and scientists of BARC Training School. On successful completion of the training, he joined Radiometallurgy Division (RMD), BARC in 1973 where he began his career in plutonium bearing nuclear fuel fabrication. He has since gained expertise on these fuels over the last 35 years. He has made important contributions in the development of UO_2 - 4%PuO_2 MOX fuel for use as an alternative fuel for Tarapur BWR reactor. Mr. Arun Kumar was responsible for fabrication of several experimental MOX fuel assemblies which showed excellent performance during loop irradiation in CIRUS and paved the way for the introduction of MOX fuel in TAPS. Mr.Arun Kumar moved to Tarapur in 1987 for setting up of an industrial scale Advanced Fuel Fabrication Facility (AFFF) for fabrication of MOX fuel. During his stay at AFFF Tarapur, till 2003, he was associated with the installation, commissioning and utilization of the facility for the fabrication of MOX BWR fuel assemblies and 19 element MOX PHWR bundles, which were introduced for the first time in TAPS BWR & PHWR. He was also involved in fabrication of test fuel pins for PFBR for irradiation studies. He returned to Radiometallurgy Division, BARC in 2004 and took up the responsibility of fabrication and supply of (U, Pu)C mixed carbide fuel pins for FBTR. His current responsibilities also include development of high breeding ratio fuel for FBRs, planning and setting up of an integrated fuel fabrication plant for PFBR at Kalpakkam & design and planning of fuel fabrication facility for thorium based fuels for the Advanced Heavy Water Reactor (AHWR). One of his recent contributions has been development of mechanically bonded metallic fuels for future Indian fast reactors and TRISO coated fuels for Compact High Temperature Reactors (CHTR).Fabrication of Mixed Oxide fuel pins for PFBR is one of the major activities he is currently engaged in. He also has the responsibility of the safe and secure transport of special nuclear material.

He is recipient of DAE Special Contribution Award for excellence in Science, Engineering & Technology in 2008 and Group Achievement Award for FBTR fuel fabrication in 2009.

He has more than 100 technical publications to his credit. At present he is Director Nuclear Fuels, Group.