Release behavior of gaseous and volatile fission products in irradiated thoria based fuel materials –a laboratory scale study using in-house developed facility at Trombay

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For safe operation of a nuclear reactor it is extremely important to have the fuel-clad compatibility under all the circumstances of the power generation. There are several factors that decide the compatibility during the fission process inside the cladded fuel producing power over months together. With burnup the fission gases, xenon (Xe) and krypton (Kr), and volatile corrosive fission products, iodine (I), tellurium (Te), etc. (Table-1) undergo transport towards the periphery of the fuel pin and then get released into the fuel-clad gap of 50 to 100 microns (Fig 1). The progressive gas release results in deterioration of thermal conduction across the gap normally filled with helium at several tens of bars pressures. The major fraction of the gases remains dispersed inside the fuel matrix as microbubbles. The dispersed bubbles as well as some undissolved solid phases formed by other fission products impart internal stress to the matrix under which the fuel pin swells and develops radial microcracks and voids (Fig 2). Thermal conductivity of the fuel matrix deteriorates. The volatile fission products such as Iodine and Tellurium though produced in small amount in comparison with the gaseous products, can put stake on the clad because of their high corrosive nature. Like the gases, these species also undergo transport to reach the clad's surface. Chemical interaction of I and Te results in degradation of mechanical property of clad and can lead to brittle fracturing and stress corrosion cracking of the clad ultimately.

With the increase of fuel burnup, the knowledge of thermal conductivity deterioration and thermal profile change across the pin, the extent of matrix swelling and clad corrosion from the redistribution of gas and volatile fission products is important to the fuel designers. The thermal and mechanical behaviors of fuel are thoroughly verified by carrying out the simulation analysis of the fuel performance using proven computer code.

The simulation needs among other information, the reliable data of transport properties of the relevant fission products to evaluate the products' accumulation in fuel-clad gap as well as inside the matrix.

The transport of inert gases and volatiles occurs through the combined paths of atomic diffusion inside grains and along grain boundaries, migration through micro cracks and outward displacement via thermal sweeping of micro pores and grain boundaries. Out of the various contributing kinetics in the transport process, the intragrain diffusion is more of the characteristics of the matrix. For any fuel, one needs reliable data acquisition of the diffusion property at the reactor

Fuel types	Xe +Kr	I+Te
PWR (^{235}U fuel)	22	4
PWR (MOX fuel PuO_2~30%)	24	4
AHWR (^{233}U fuel)	32	6
FBR (^{239}Pu fuel)	24	4

Table 1. Fission yields of gases and volatiles

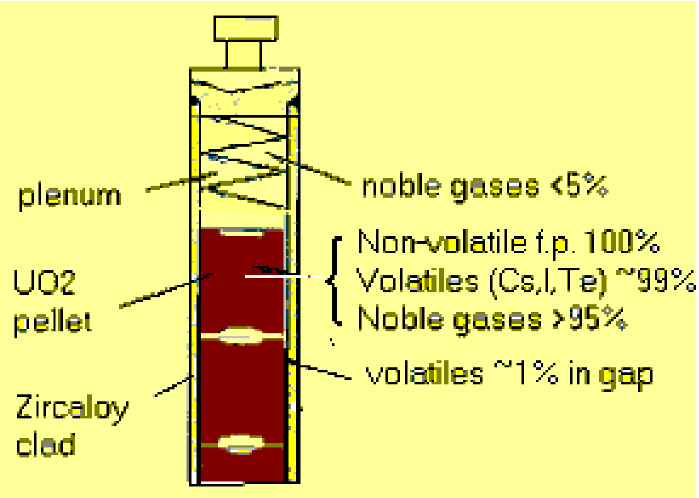


Fig 1. General view of fission product distribution in Pressurised Water Reactor fuel at high burn up

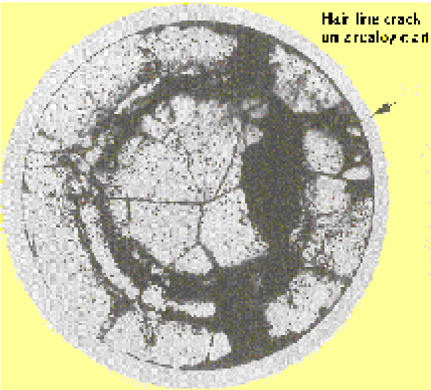


Fig 2. Micrographic image of PWR fuel pin's section (10mm dia.) showing the clad failure

operating temperatures of the fuel. (A fuel pin normally experiences the radial temperature gradient of 1500 to 600 K and 2000 to 900 K for thermal and fast reactors respectively). For the thoria-based fuel of the envisaged advanced heavy water reactors in the third phase of the nuclear energy programme in India, there has been the need of the data acquisition for the simulation analysis.

The measurement of the high temperature diffusion property in fuel is usually accomplished by using post irradiation annealing (PIA) technique. In this technique the specimen irradiated to a known dose is thermally annealed at elevated temperatures of interest and the quantity of fission product released as a function of time is measured with radiation monitors of the active isotopic fractions in the fission products.

The required PIA setups for the studies of fission gases and volatile fission products have been made at BARC and the transport properties were successfully measured using the facilities. The studies reveal that the diffusional transports of Xe, I, and Te in the thoria fuel occurs much more sluggishly as compared to those seen in urania. A typical result for the two fuel matrices is depicted in Fig 3.

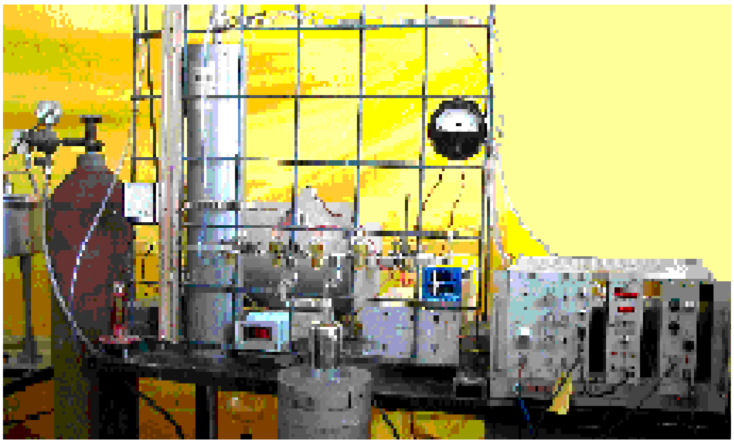
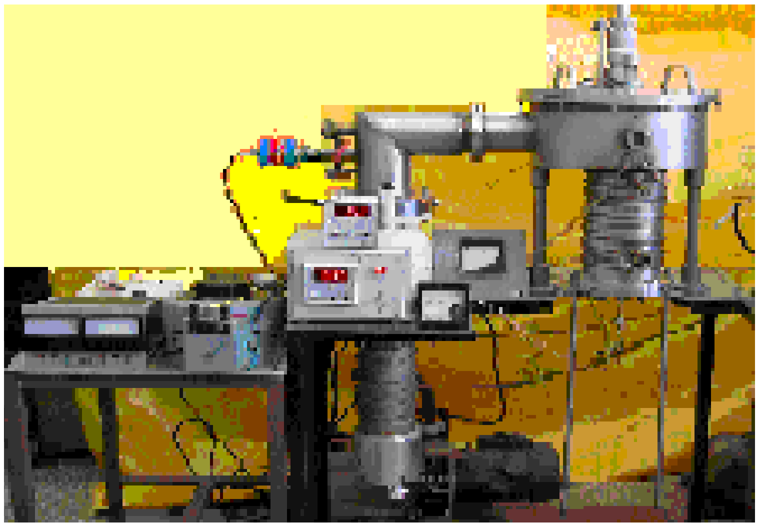


Fig 3: Post irradiation annealing setup for Xe and I and Te



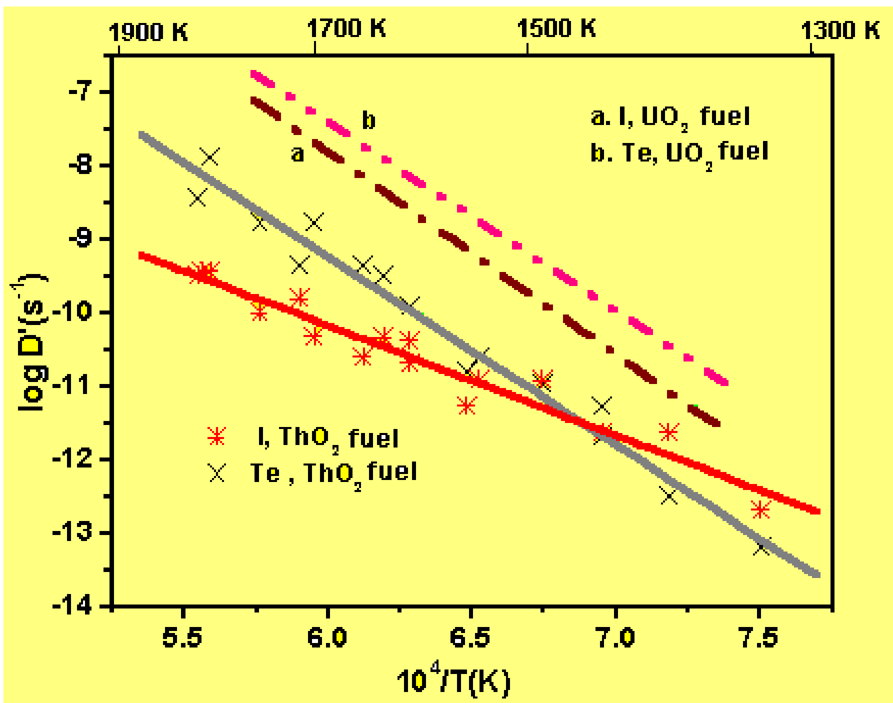


Fig 3. Apparent diffusivities (D¢) of I and Te in thoria-2mol% urania and in urania fuels at different temperatures