

In-depth analysis of volatile fission products in high burnup SFR fuel using a (U,Pu)O₂ SIMMOx approach

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In the context of Generation IV Sodium-cooled Fast Reactor (SFR), the U_{1-y}Pu_yO_{2-x} Mixed Oxides (MOx) containing 20 % to 30 % Pu/(U+Pu) have been identified as the best candidate for fuels [1]. Under nominal operation conditions, at the level of the maximum neutron flux plane, the temperature at the core of the pellet can reach up to ~2473 K and up to ~873 K at the periphery. These values significantly exceed those observed for PWR fuels. Moreover, the physico-chemical and microstructural properties of the fuel are significantly affected by the continuous generation of Fission Products (FPs) within (U,Pu)O₂ matrix [2]. Such a high thermal gradient leads to fuel restructuring during irradiation and migration of volatile FPs such as iodine and cesium to the colder fuel regions. At high burnup, this phenomenon leads to the development of a layer enriched with volatile FPs, commonly referred to as “Joint Oxyde-Gaine” (JOG) [3]. Consequently, for the successful development of such reactors, it is mandatory from a nuclear safety perspective to understand the effect of irradiation on the fuel, particularly focusing on the effect of FPs and the JOG formation.

Due to its very high radiotoxicity, the characterization of irradiated fuel presents inherent challenges [4]. Isolating and studying distinct parameters such as porosity, FPs, JOG, oxygen-to-metal ratio (O/M), among others, remains challenging. Furthermore, these materials have complex compositional dynamics that change continuously throughout their lifecycle. To overcome these challenges, a “separate effect” approach using innovative materials referred to as “SIMFuel” [4,5] or “SIMMOx” [6,7], is required. These materials consists of fresh fuel doped with stable isotopes of FPs, thereby limiting the radiological risk associated with experimentation. Furthermore, both FPs number and content in these materials can be tailored to investigate the effects of selected FPs. As illustrated by the recent examination of SIMMOx, information has been collected about the speciation of FPs and the interaction between FPs and (U,Pu)O₂ matrix with a Nd local enrichment with higher Pu content [6,7]. Moreover, there is currently no research addressing the influence of volatile FPs, responsible of JOG formation, on a MOx including all other FPs.

In our work, we are developing a new approach to incorporate volatile FPs into SIMMOx and study the JOG formation. This process starts with a diffusion couple between volatile FPs compounds and SIMMOx, in order to incorporate iodine and cesium in material, using temperature activation. Preliminary tests on UO₂ matrix have demonstrated the successful incorporation of iodine and cesium into the material thanks to different migration/transfer mechanisms induced by the temperature gradient. Additionally, the microstructure (porosity and defects) would be representative of the spent nuclear fuel.

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