First X-ray diffraction characterizations of a spent nuclear fuel sample with Zy-4 cladding at MARS beamline of the SOLEIL Synchrotron

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Microstructural changes in a bulk sample composed of spent fuel and Zr-based cladding (full pellet diameter, 1 mm in width and 50 µm in thickness) have been investigated by high-resolution X-ray diffraction (HR-XRD) on the MARS beamline at SOLEIL Synchrotron.
The sample was cut from a fuel rod (UO_2 pellet with a 4.5% enrichment in ^{235}U and Zy-4 cladding) with a burn-up of about 60 GWd/t, irradiated for a period of 5 annual cycles in a PWR reactor.
HR-XRD measurements were performed in different areas: at various radial positions on the fuel pellet, on the internal zirconia layer, on the Zy-4 cladding and on the external zirconia layer. The diffraction patterns were recorded with a 17.2 keV incident X-ray beam and with different beam sizes to define different projected areas on the sample.
The lattice parameter and diffraction peak broadening variations were derived from the diffraction patterns recorded at different radial positions within the irradiated UO_2 pellet and compared to the results reported by some authors [1,2]. The crystallite sizes and micro-strains were evaluated from the peak broadening analysis. These X-ray diffraction (XRD) results give quantitative data to investigate the microstructure changes induced by irradiation: the high burn-up structure (HBS) on the periphery or the sub-domains [3] observed in the center of high burn-up UO_2 fuel pellets and also the irradiation effects on the microstructure of Zy-4 cladding and the zirconia phases.

To complete these characterizations, HR-XRD measurements were done with pristine samples of UO_2, ZrO_2 and Zy-4.

To our knowledge this is the first time that such XRD measurements have been performed on a bulk sample of spent fuel and cladding by means of synchrotron radiation.

[1] J. Spino, D. Papaioannou, J. Nucl. Mater. 281 (2000) 146.

[2] M. Amaya, J. Nakamura and T. Fuketa, J. Nucl. Sci. Technol. 45 (2008) 244.

[3] J. Noirot, I. Zacharie-Aubrun, T. Blay, Nucl. Eng. Technol. 50 (2018) 259.