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Microstructural Characterization of Irradiated U-Pu-Zr Fuels

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Fast reactor technology provides a path to transmute long-lived transuranic actinide isotopes contained in spent nuclear fuels. However, development and demonstration of this technology requires an in-depth understanding of the fuel performance. The Advanced Fuels Campaign (AFC) seeks to demonstrate the technologies needed to transmute actinides by developing candidate nuclear fuels and possible transuranic transmutation compositions. As part of the AFC program, candidate nuclear fuels are subjected to irradiation testing and detailed postirradiation examination (PIE), which provides data on reactor fuel performance and input into future fuel design choices.

Baseline postirradiation examination (PIE) consists of non-destructive test such as visual examinations, neutron radiography, gamma spectrometry, dimensional inspection, and destructive tests including fission gas release, optical microscopy, and analytical chemistry. These tests gather relevant data on key performance parameters of the fuel: irradiation growth and swelling, fission gas release (FGR) fractions, fission product and fuel constituent migration, and fuel-cladding chemical interaction (FCCI). While baseline PIE provides an engineering or macroscopic scale evaluation of fuel performance, further characterization is needed to attain phenomenological study of the fuel behavior.

This contribution reports the results from electron microscopy-based characterization of irradiated U-20Pu-10Zr irradiated as part of the AFC-2E experiment. Initial PIE of the pin showed that plenum retained fission gas and thus the cladding was intact, while optical microscopy indicated extensive FCCI. We conducted scanning and transmission electron microscopy (SEM and TEM, respectively) of the fuel cross-section to provide further insight into irradiation-induced microstructural evolution of the fuels, including but not limited to constituent redistribution and FCCI behaviors.

Figure 1(a) shows the stitched BSE micrographs of irradiated U-20Pu-10Zr fuel pellet cross-section and identifies constituent redistribution and FCCI. Constituent redistribution in metallic fuels is a complex process driven by gradients in temperature and chemical potential, which produce radially-distributed changes in local fuel composition. The local fuel composition evolves dynamically as swelling, FGR, and sodium infiltration alter the thermal conductivity of the fuel. Figure 1(a) shows the formation of the concentric zones within irradiated fuel pellet. Current understanding dictates that these concentric zones should during irradiation correspond to several different phases from the U-Pu-Zr ternary phase diagram including γ (central region), γ+ζ (intermediate ring), and δ+ζ (outer ring) phases, where γ is a bcc solid solution of γ-U, ε-Pu, and β-Zr known as γ (U, Pu, Zr), ζ is a solid solution of U and Pu, and δ is δ-UZr_2. To investigate the historical understanding of the constituent redistribution, the phases in each zone were identified using selective area electron diffraction (SAED) analysis in TEM. The cross-sectional specimens were prepared in a FEI QUANTA 3D field emission gun (FEG) dual beam FIB/SEM using a standard lift-out approach and the lift-out locations are labeled for reader's convenience in Figure 1(b). Understanding the limitations imposed by the small sample sizes (20 μm × 20 μm × 100 nm), over 15 lamellae were prepared across the radius of the fuel pellet to capture most relevant fuel behaviors. All prepared TEM lamellae were examined in a FEI Talos TEM F200X scanning/transmission electron microscope (S/TEM). We will provide the microstructural and microchemical data in the form of STEM micrographs, corresponding X-ray maps and point scans, and SAED patterns of the fuel and FCCI region [1].

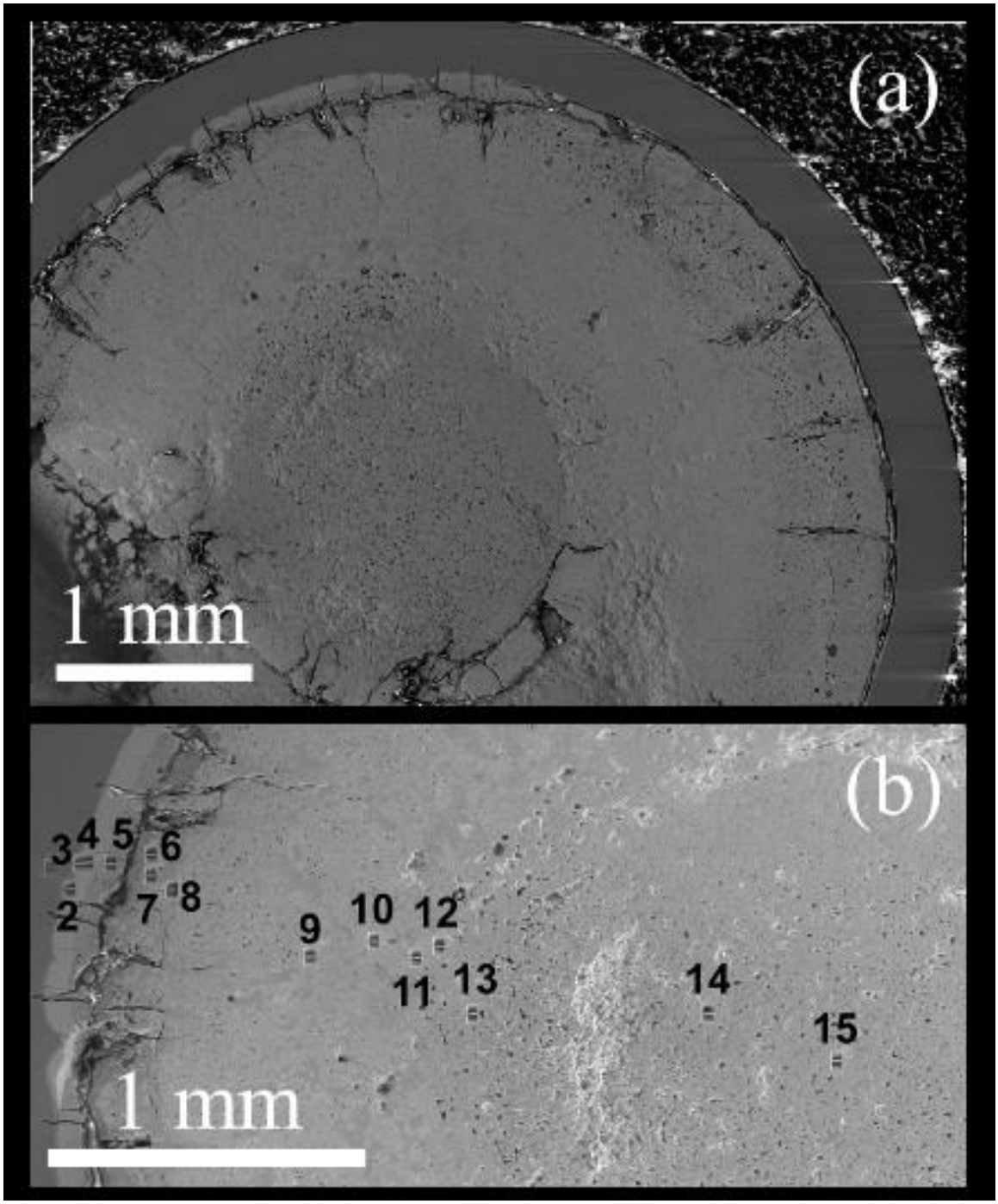

Figure 1. Overview of the irradiated U-20Pu-10Zr fuel: (a) stitched BSE-SEM cross-section overview and (b) lift-out locations for further TEM analysis. Scale bars denote 1 mm.

References

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