Abstract / Introduction

As a supporter and leader in nuclear fuels and materials research and reactor life management, Canadian Nuclear Laboratories (CNL) has taken the opportunity to broaden their capabilities, investing in a shielded dual beam Scanning Electron Microscope + Focused Ion Beam (SEM/FIB) connected to a glove box. The dual beam is presently being installed at the Fuels and Materials hot cell (FMC) facility at Chalk River Labs. Défi systèmes France created an innovative solution for pairing a modified Zeiss SEM/FIB CROSS BEAM 550L with a custom designed glove box, and incorporating a custom shielded enclosure with a connection tunnel and manipulator driven sample holder gripper that has been delivered to CNL depicted in Figure 1. The installation of a lead wall and the use of Wälischmiller A200 manipulators will turn this system into a functional expansion to our hot cell capabilities, allowing us to preform operations involving PIE work on reactor components as well as fuel.

In the past two years, CNL successfully developed the capabilities of an active FEI Versa Dual Beam (SEM/FIB) for structural material PIE. These capabilities allow for the synergy between mechanical tests performed at multiple length scales, ranging from component tests to micrometer gage length tensile tests and nanoindentation, with the combination of component scale fractography and high resolution Transmission Electron Microscopy to link the deformation mechanisms and mechanical properties of ex-service structural materials. Currently, there is a void in performing PIE on fuel for the purposes of commercial reliability. In addition, there are few facilities in the world licensed to handle active fuel which also contain analytical SEMs and FIBs. Therefore the next step is to develop these capabilities at CNL’s fuel and materials hot cells for fuel PIE.
Some benefits of performing fuel PIE with a shielded dual beam (SEM/FIB) include extracting direct sections from regions of interest in the fuel pellet-clad interaction zone using the FIB and subsequently mechanically testing and/or characterizing them using the Transmission Electron Microscope to learn new information about fuel chemistry, porosity, and retention and distribution of fission products at high burnup. Fuel produced with manufacturing defects can be examined using an analytical approach including electron backscattered diffraction (EBSD) and electron dispersive spectroscopy (EDS) to produce high resolution maps of local chemistry changes and highlight damaged or cracked regions. Using the FIB in 3D Slice & View mode on high burnup fuel allows for direct examinations of crack propagation and fuel microstructure as a function of depth with $10^{-15}$ nm resolution.

2. Shielded Dual Beam (SEM/FIB) Customizations

A number of custom modifications were made by Défi systèmes France to nuclearize the duel beam (SEM/FIB) to create a system that can be loaded remotely as well as tolerate high radiation fields.

2.1 Sample Transfer and Loading

Sample loading is accomplished by using the sample holder gripper that allows for locking by way of a 90° rotation of the sample plate as shown in Figure 2. With the use of this gripper tool, sample loading is achieved without opening the door using the principle of the ZEISS insertion airlock.

![Figure 2. Sample holder gripper (a) approaching the sample stage and (b) locking the sample in place](image)

2.2 Sample Recovery

Catch pans have been added to critical loading areas to catch samples should they be dropped during loading as illustrated in Figure 3.

![Figure 3. Catch pan below sample stage used for sample recovery.](image)

2.3 Instrument-Glove Box Connection

The connection between the glovebox and the Zeiss CROSS BEAM 550L is carried out by means of a disconnecting tunnel shown in Figure 4.
2.4 Mobility

The modified Zeiss SEM/FIB CROSS BEAM 550L has been put on a rail system. It can be disconnected from the glove box and pushed back for maintenance access as seen in Figure 5.

![Figure 4. Disconnecting tunnel linking Zeiss CROSS BEAM 550L with glove box](image)

2.5 Nuclearization of Detectors

Tungsten shielding has been added to radiation sensitive components such as the Electron Dispersive Spectroscopy (EDS) detector and the Electron Backscattered Diffraction (EBSD) detector as exemplified in Figure 6.

![Figure 5. Rail system used to roll modified Zeiss SEM/FIB CROSS BEAM 550L away from glove box to perform maintenance.](image)

![Figure 6. Nuclearized EDS (left and center) and EBSD (right) detectors covered with tungsten shielding.](image)