Neutron Radiography of Zircaloy-4 Fuel Cladding Material Containing Hydrogen and Deuterium

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Thermal neutron radiography (NR) using an Image Plate detector has been used as a non-destructive testing method to investigate the hydrogen and deuterium distribution in Zircaloy-4 cladding material of nuclear fuel. Neutron radiography measurements were performed on L3 spectrometer at NRU reactor at Chalk River Laboratories. The pin-hole geometry was used for the beam collimation providing an L/D = 450. The field of view was about 8×8 cm². The specimens were prepared with known amounts of hydrogen using a gaseous low pressure hydrogen technique that was developed at CNL. The results show that the NR technique is sensitive to the hydrogen distribution in Zircaloy-4 sheath within ~ 40 wt ppm and with a spatial resolution of 0.1 mm (see Figure 1). The contrast in the radiography image is caused by transmission differences of samples with different hydrogen content. The integrated logarithm of transmission (ILT) that is a function of the total macroscopic neutron cross section has been calibrated experimentally and a linear equation was derived between gray levels and nominal hydrogen concentration. Figure 2 shows the profile of ILT of specimens Ref and Tb77. The gradient in the hydrogen concentration along the length of Tb77 specimen, found by NR technique (Figure 2 (b)), has been confirmed by hot vacuum extraction mass spectrometry (HVEMS) method. Due to the small cross section of deuterium, the results show that the sensitivity of this method is not adequate for imaging variation in deuterium concentration below 400 wt ppm.
Figure 1: Neutron radiography image of the hydride tubes compared to the reference specimen (Ref) which is not hydrided. The arrows indicate the top and bottom edges of the samples. The red line represents the analysis line used to calculate the integrated logarithm of transmission (ILT).

Figure 2: Profile of integrated logarithm of transmission (ILT) of (a) reference sample “Ref” and (b) sample “Tb77”. The blue line is the fit curve.