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Experimental investigations with neutron radiography of hydrogen effects by elastic stresses on cladding tubes under conditions similar to interim dry storage

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Abstract. During operation in light-water reactors, Zircaloy cladding tubes take up hydrogen that precipitates under specific temperature–pressure conditions after operation in the form of zirconium hydrides. These zirconium hydrides have a detrimental effect on the mechanical stability of the cladding tubes. The conditions for their formation and their orientation need to be forecasted in order to determine that the spent nuclear fuel remains shielded during interim dry storage. Internal and external stresses that affect the cladding tubes throughout their slow cooling process during interim dry storage may worsen and accelerate the cladding tubes' embrittlement with regard to possible reorientation processes of zirconium hydrides. Generally, hydrogen in solid solution follows gradients in temperature, concentration, and stress. Consequently, hydrogen moves from higher to lower temperatures and from lower to higher stresses due to the thermodynamically more favourable conditions.

In order to investigate elastic stress conditions similar to those during interim dry storage of hydrogenated cladding tubes, a modified mobile tensile testing machine was designed to elongate zirconium samples under defined temperatures of up to 500 °C. During the experiments, hydrogen movements within the samples are monitored by in situ neutron radiography. Because of the very low neutron cross section of zirconium, the metal is nearly invisible for neutrons, and the contrarily behaving hydrogen that scatters neutrons strongly appears as dark contrast in neutron images. Due to the sample's different cross section profile, the tensile stress created by the tensile testing machine is amplified and thus should lead to visible hydrogen movements.

This paper describes neutron radiography experiments under different temperature–time conditions with hydrogenated tensile zirconium samples that simulate stress conditions of cladding tubes during interim dry storage.

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