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What happens during nuclear accidents? – Contributions of neutron imaging to nuclear safety

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The hydrogen uptake during steam oxidation of the nuclear fuel cladding made from zirconium alloys is very important for the development of nuclear accidents. It changes the time scale of hydrogen release and degrades the mechanical properties of the fuel cladding. The hydrogen uptake results in an embrittlement of the zirconium alloy connected with a strong reduction of the thermo-shock stability. If emergency cooling successes, the cladding can be destroyed and the nuclear fuel can be redistributed with strong consequences for the coolability of the damaged reactor core.
At Karlsruhe Institute of Technology the processes occurring during loss of coolant accidents (LOCA´s) and severe accidents (accidents beyond LOCA) were simulated experimentally at bundle scale in the large scale QUENCH experiments. The study of the hydrogen release and uptake during the accident scenario simulated are a main goal of these tests. Parallel to the large scale experiments separate effect tests are performed to study the hydrogen uptake and diffusion in various zirconium alloys applied for cladding tubes.
Neutron radiography and tomography was applied to examine the hydrogen concentration in different samples. The hydrogen distribution and diffusion in samples from the separate effect tests and in samples prepared from the large-scale tests. The correlations between the total macroscopic neutron cross section and the hydrogen concentration were determined using calibration specimens. This calibration makes a fully quantitative analysis possible. The kinetics of the hydrogen uptake in steam and hydrogen containing atmospheres and the hydrogen diffusion at temperatures above 850°C were investigated in-situ.
The post test examinations of samples prepared from QUENCH-LOCA tests show the formations of hydrogen enriched bands oriented non-perpendicular to the tube axis. As the main parameters that control the hydrogen uptake during the time between burst of the cladding rods and quenching and the temperatures occurring in these time intervals were indentified.
Different commonly used cladding alloys show strong differences in the hydrogen uptake during severe accident simulation test. Very important for the hydrogen uptake is the oxide layer morphology. The formation of the so-called "breakaway"oxide results in nearly one order of magnitude higher hydrogen concentration after the test compared to samples with a compact oxide layer.

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