Simulation of QUENCH-03 and -15 Scenarios with the Code AC² modified for Cr-coated Claddings compared with ASTEC

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Abstract

One of the key factors influencing the progression of unmitigated accidents is the fuel cladding. It is an important part of the defense-in-depth concept. Zirconium (Zr) alloys perform well under normal operational conditions. At higher temperatures the accident progression can escalate due to a strong exothermic reaction. Various studies have indicated that alternative materials could partially enhance the behavior under accident conditions. Currently, there are ongoing developments in Accident Tolerant Fuels (ATF). Of particular interest are iron-chromium-aluminum (FeCrAl) alloys or the coating of existing Zr alloys, which are already widely used in nuclear power plants.

The main objective of the presented works is the application of a newly developed first in-house model for ATF at the PSS Group at RUB. This model specifically addresses the oxidation of Chromium (Cr)-coated claddings. It is implemented into a modified AC² version, a system code package developed by GRS gGmbH for the simulation of selected phenomena or complete accident sequences in nuclear power plants.

The investigated large scale bundle experiments were conducted at the QUENCH test facility of KIT. In these tests, beyond design basis conditions in light water reactors with subsequent re-flooding were considered. The sequences consist of a stabilisation, heat-up, transient and quench phase. Comparing both sequences, QUENCH-15 was conducted additionally with a pre-oxidation phase before the transient phase. QUENCH-03 / QUENCH-15 aim at investigating the hydrogen source term when water or steam is injected into an uncovered and overheated core of a light water reactor. These experiments were conducted with Zry-4 / ZIRLO™ for the test fuel rod simulators and temperatures of 2000°C / 1880°C were measured. Thus, severe accident conditions were reached with temperatures beyond the eutectic melting temperature of the binary Zr-Cr system. This marks the very latest failure time for the protective chromium layer at around 1332°C.

The conducted sequences were calculated as they were. However, the new option for Cr-coating oxidation in AC² is used for fuel rod simulators and shroud, assuming a dense chromium layer on the Zr-alloy. The QUENCH-03 input deck was furthermore altered from the original 21- to a 24-rod layout, as in QUENCH-15. Additionally, the newest ASTEC version was applied to QUENCH-15 using correlations for Cr-coating of KIT via user input. This allows a code crosswalk of both codes.

The analyses of the simulation results focus primarily on the code capabilities to represent the thermal behaviour of the rods as well as the oxidation behaviour in comparison with original Zr-oxidation. Both input decks were optimized for the particular sequence. This ensures reliable results when reviewing original hydrogen generation using Zr-alloy oxidation kinetics and the hypothetical potential benefit of the Cr-coating. The tentative simulations using Cr-oxidation show overall slightly lower temperatures than the experimental data of the QUENCH tests with Z-alloy as well as significantly lower hydrogen generation, as expected.

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The results were obtained using
- an in-house modified version of the GRS software package AC² 2021.0 at PSS and GRS and
- ASTEC V3, developed by IRSN, at KIT.