Main Results of the Bundle Test QUENCH-10 on Air Ingress

J. Stuckert[1], J. Birchley[5], C. Homann[2], S. Horn[3], Z. Hozer[6], A. Miassoedov[4], J. Moch[1], G. Schanz[1], L. Sepold[1], U. Stegmaier[1], L. Steinbock[1], M. Steinbrück[1]

[1]Institut für Materialforschung, [2]Institut für Reaktorsicherheit, [3]Institut für Medizintechnik und Biophysik, [4]Institut für Kern- und Energietechnik;
[5]Paul Scherrer Institut, Switzerland, [6]KFKI Atomic Energy Research Institute, Hungary

10th International QUENCH Workshop, Karlsruhe, October 26-28, 2004

Introduction

Experiment QUENCH-10 on air ingress during a spent fuel pool accident was successfully conducted at FZK on 21 July 2004. This was the first of two experiments to be performed in the frame of the EC supported LACOMERA programme [1]. It was proposed by AEKI Budapest and supported by PSI (Switzerland). The main objective of this test was to examine the oxidation and nitride formation of Zircaloy during air ingress, before flooding the bundle with water.

Test conduct and pertinent results

In common with the previous QUENCH experiments [2], the bundle was heated by a series of stepwise increases of electrical power from room temperature to ~600 °C in an atmosphere of flowing argon (3 g/s) and preheated steam (3 g/s). The bundle was stabilised at this temperature, the electrical power being ~4 kW. During this time the operation of the various systems was checked.

In a first transient, the bundle was heated by power increase to about 1350 °C. This marked the start of the pre-oxidation phase to achieve a cladding oxidation of up to 600 µm. The power was controlled to maintain a more or less constant hydrogen production rate of about 5 mg/s after the peak value of 16 mg/s, caused by the previous heat-up. This procedure led to a slow increase in temperature to 1420 °C. This phase lasted 6800 s. Since the oxide thickness could not be measured online, it was estimated on the basis of pre-test calculations done at PSI and FZK and online monitoring of hydrogen release. The total hydrogen release from the beginning of the test to this point was 46 g.

To achieve an adequate duration of the subsequent air ingress phase, the bundle was then cooled to maximum temperature of about 880 °C. This was done by decreasing the electrical power abruptly from 13.2 to 6.9 kW. The temperature was reached after 2300 s. Hydrogen generation dropped rather quickly to about 0.4 mg/s due to this cooling so that nearly no further oxidation occurred. Towards the end of this phase, one of the corner rods was extracted from the test bundle. The metallographic measurement resulted in maximum layer thickness of 514 µm at elevation 950 mm.

In the subsequent air ingress phase, the steam flow of 3 g/s was replaced by 1 g/s of air, but with unchanged argon flow and power. This change in flow conditions had the immediate effect of reducing the heat transfer so that the temperatures began to rise again. The temperature increase and oxidation were somewhat slower than expected, and therefore it was decided to increase the electrical power stepwise as it had been agreed in such a case during the preparation of the test. Due to this procedure, oxidation increased such that the heat release eventually drove the temperatures beyond the final target value of 1800 °C. The duration of this phase was 1770 s. Complete consumption of oxygen and partial consumption of nitrogen (about 0.1 g/s) were observed toward the end of this phase. The total uptakes of oxygen and nitrogen were ~84 and 8 g, respectively. At the end of the air ingress phase a second corner rod was removed. The rod broke during drawing at the elevation of about 900 mm. The measured oxide layer thickness on the corner rod amounted to 613 µm (elevation 850 mm). The temperature maximum shifted from elevation 950 mm (before reflood) to elevation 850 mm.

Then reflood was initiated by turning off the air flow, switching the argon injection to the top of the bundle, rapidly filling the lower plenum of the test section and injecting ~50 g/s of water. The power was reduced to 4 kW after a further 10 s to simulate decay heat. Right at the beginning of reflood, there was indication of a short and mild temperature excursion in the upper part of the bundle, leading to maximum measured temperatures of about 1930 °C. However, cooling was established almost immediately, and complete quenching of the bundle was achieved after about 150 s. A modest release of hydrogen (~5 g) was observed during the reflood. A significant fraction of the nitrogen (3.5 g) previously taken up was released.

Detection of He by the mass spectrometer indicated a first small failure of a fuel rod simulator after 20 min in the pre-oxidation phase and a much larger failure after 13 min in the intermediate cool-down phase. A further increase in the measured helium concentration with quench initiation indicated an extended failure of cladding tubes during this highly transient phase.

The shroud failed shortly after initiation of reflood. The analysis of the water level movement showed a shroud breach between elevation 800 mm and 850 mm. The water filled the annulus between shroud and cooling jacket, and finally the water level reached the bottom of off-gas pipe.

After the test visual inspection of the bundle and the inner shroud surfaces was performed with help of an endoscope. This demonstrates the formation of nitride spots on the inner shroud surface at elevations between 400 and 600 mm.

Large amounts of zirconium oxide particles were found at the bottom of off-gas pipe after the test. The particle size analyses demonstrated, that majority of particles had a diameter of about 25 µm. But the particles with the diameter of 1.5 mm determine the main weight of the powder. Analysis of chemical composition of powder showed that the main component (about 95%) is ZrO_2.

Summary

- The QUENCH-10 test was performed in six stages: 1. Stabilisation at 600°C, 2. First transient, 3. Pre-oxidation, 4. Cool-down to increase duration of air ingress phase, 5. <u>Air ingress</u>, 6. <u>Quench.</u>
- The bundle was pre-oxidised in superheated steam during 6800 s at maximum temperature of ~1400 °C (controlled at elevation 950 mm). The maximum oxide layer thickness at the end of the pre-oxidation was 514 µm (measured at the 1^{st} withdrawn corner rod).

- The bundle was cooled to ~880 °C (max. temperature at elevation 950 mm) before the air ingress.
- The air ingress phase lasted 1750 s. The electrical power was stepwise slightly increased to accelerate oxidation. Complete consumption of oxygen (~84 g) and partial consumption of nitrogen (8 g) were observed toward the end of this phase. The maximum oxide layer thickness at the end of air ingress phase was more than 600 µm (measured with help of the 2nd withdrawn corner rod). The temperature maximum shifted from elevation 950 mm (before reflood) to elevation 850 mm.
- Cooling of the bundle was established almost immediately after reflood initiation, and complete quenching of the bundle was achieved after about 150 s. During the reflood 3.5 g nitrogen were released (about 44% of nitrogen taken up during air ingress).
- The first failure of a fuel rod simulator was detected after 20 min in the pre-oxidation phase. The shroud failed shortly after the initiation of reflood at an elevation between 800 mm and 850 mm.
- Before reflood initiation 47.6 g hydrogen were released, whereas 5.2 g hydrogen were released during quenching.
- The visual inspection of the bundle showed a formation of nitride spots on the inner shroud surface at the elevations between 400 mm and 700 mm.
- Large amounts of zirconium oxide particles were found in off-gas pipe after the test. The majority of particles has a size of about 25 µm, the particles with the diameter of 1.5 mm mainly determine the weight of the powder.

4. Relevant Publications

[1] A. Miassoedov, H. Alsmeyer, B. Eppinger, L. Meyer; M. Steinbrück, “Large scale experiments on core degradation, melt retention and coolability (LACOMERA)”. FISA–2003: EU Research in Reactor Safety, Luxembourg, L, November 10-13, 2003. Preproc. S.239-44.

[2] L.K. Sepold, A. Miassoedov,; G. Schanz, U. Stegmaier, M. Steinbrück, J. Stuckert, C. Homann. „Hydrogen generation in reflooding experiments with LWR-type rod bundles (QUENCH Program)”. Nuclear Technology, 147(2004) S.202-15.