Neutron Radiography and Tomography
Investigations of the Secondary Hydriding of Zry-4
during Loss of Coolant Nuclear Accidents


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In the framework of the KIT QUENCH program design basis loss of coolant accidents (LOCA) and severe accidents (accidents beyond LOCA) are simulated experimentally on fuel rod bundle scale in large scale tests.

Introduction

Influence on mechanical properties?

M. Billone et al.
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Calibration

a) Radiography

![Graph showing the relationship between H/Zr ratio and sum of cross sections for different imaging methods.]

- **CCD camera without filter**
- **CCD camera with Be-filter**
- **Image Plate**

b) Neutron tomography

![Graph showing the relationship between H/Zr ratio and sum of cross sections for radiography and tomography.]

- **Radiography**
- **Tomography**
Comparison of the temperature scenarios of QUENCH-L0 (commissioning test) and QUENCH-L1 (reference test)

Results Radiography rod QL0-#15 ($p_l = 3$ bar)

$\Sigma = 0.215$, 
Is in the range measured for not-oxidized Zry-4 
($\Sigma = 0.197 .. 0.216$)
Results Radiography rod QL0-#03 ($p_i = 55$ bar, $\Delta t = 104$ s)

Results Radiography rod QL0-#17 ($p_i = 40$ bar, $\Delta t = 71$ s)
Results Tomography rod QL0-#01 ($p_i = 50$ bar, $\Delta t = 112$ s)

\[ x_H \sim 2700 \text{ wppm} \]

Results Tomography QL0

Dependence of the maximal hydrogen concentrations in the hydrogen enriched bands on the time between burst and quenching
Results tensile tests QL0

The rods do not show hydrogen bands fail after plastic deformation.

The rods containing hydrogen bands fail by double rupture in the hydrogen bands or by stress concentration at edges of the burst crack.

First glance to the results of n radiography of QL1 samples
First glance to the results of n radiography of QL1 samples

axial distribution of the total macroscopic neutron cross section

Summary and Conclusions

- The secondary hydriding during LOCA was investigated by means of neutron imaging, XRD, TEM and mechanical tests.

- **QUENCH-L0:**
  - The hydrogen is enriched in bended bands oriented non-symmetric to the tube axis.
  - The extension of the hydrogen enriched bands and the maximal hydrogen concentration in it seems to depend on the time between bursting and quenching and on the temperatures during this time.
  - Maximal hydrogen concentrations of ~2600 ppm was determined. No hydrogen was found for $\Delta t < 70$ s.
  - No influence of inner pressure or crack length is obliviously.
  - Strong influence of the hydrogen bands on the crack positions in the tensile tests.

- **Quench-L1**
  - Hydrogen bands not clear visible.
  - Different hydrogen distribution because of blockage after bending of the tubes
Outlook

Mechanical test at QUENCH-L1 will be performed soon.

Modelling of the hydrogen distributions?

Next QUENCH-LOCA test (L2) is planned for December 2012 using the same geometry and temperature scenario like QUENCH-L1 but with a bundle consist of fuel rod simulators with M5™ claddings.

Thanks

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Thanks for your attention, questions?