Karlsruhe Institute of Technology

Analysis of the absorbed hydrogen in cladding tubes applied in the QUENCH-LOCA tests

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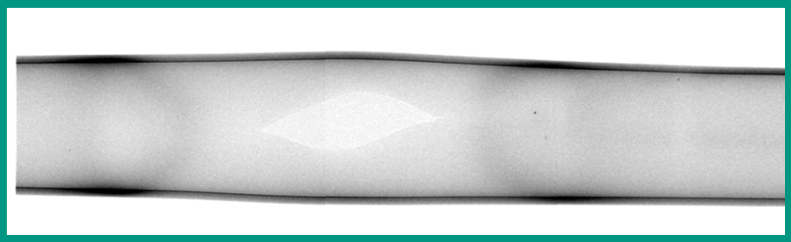

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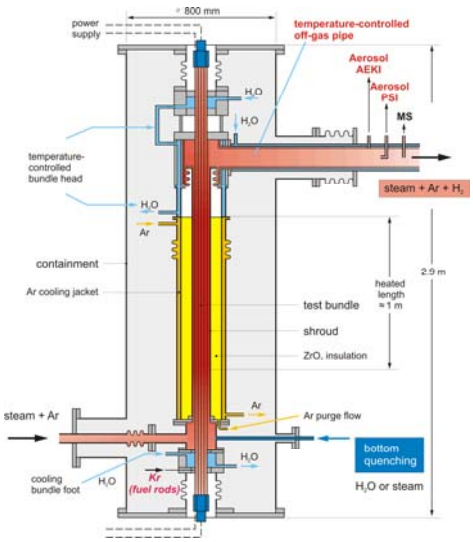
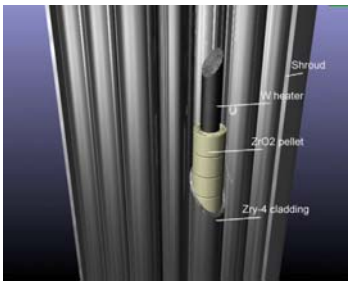
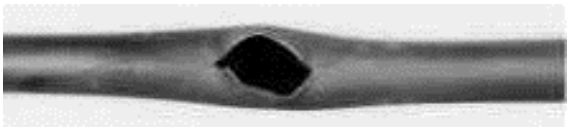
Introduction

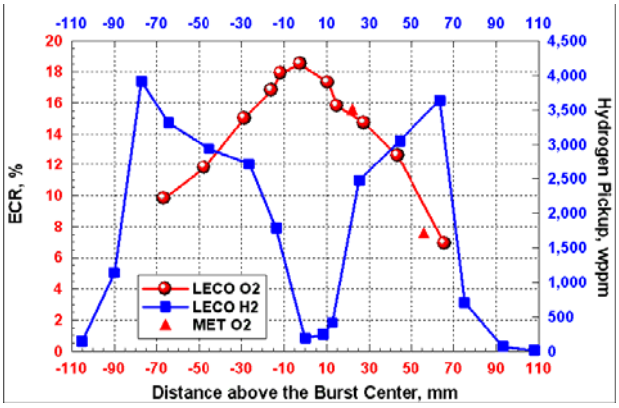


In the framework of the KIT QUENCH program design basis loss of coolant accidents (LOCA) and severe accidents (accidents beyond LOCA) are simulated experimentally on fuel rod bundle scale in large scale tests.



Introduction

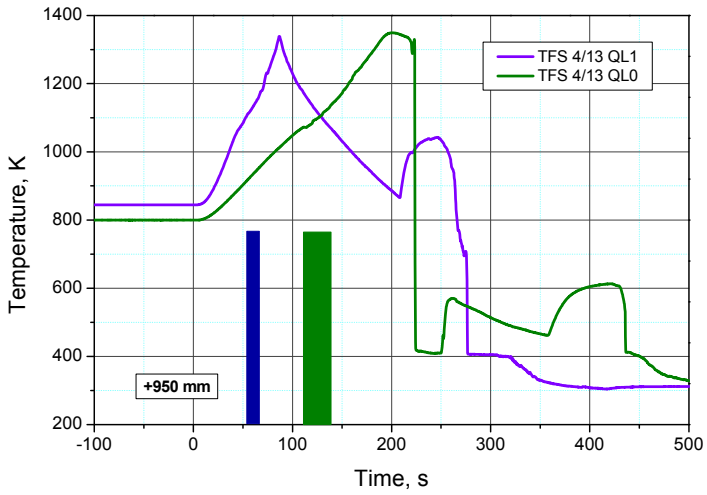




Influence on mechanical propoerties?

M. Billone et al.
NUREG/CR-6967/ANL-07/04

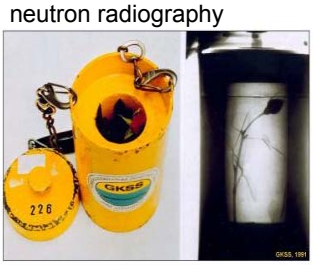
Comparison of the temperature scenarios of QUENCH-L0 (commissioning test) and QUENCH-L1 (reference test)



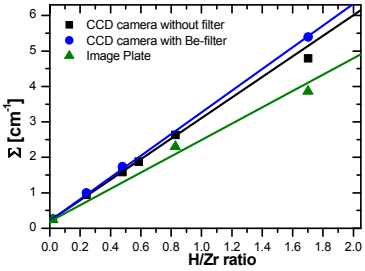
Neutron imaging

X-ray radiography

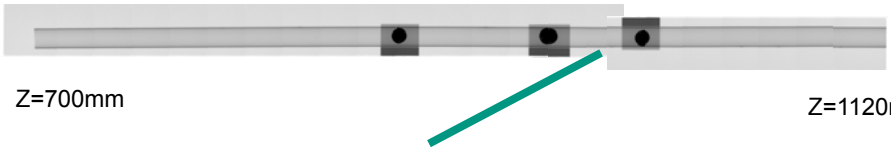
neutron radiography



GKSS Geesthacht 1991

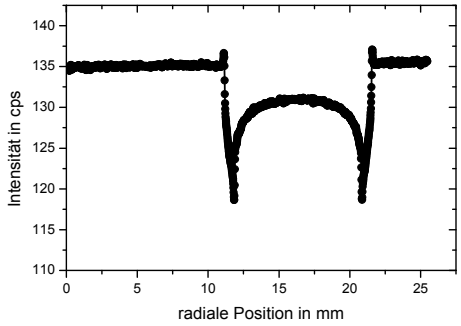


Results Radiography rod QL0-#15 (p_i = 3 bar)



Z=700mm

Z=1120mm

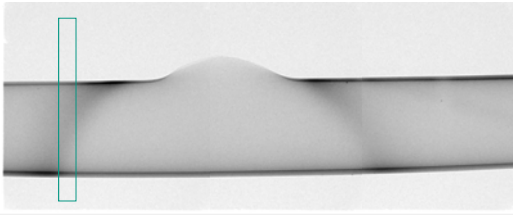


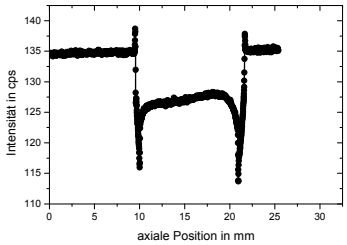
Σ = 0.215,

Is in the range measured for not-oxidized Zry-4

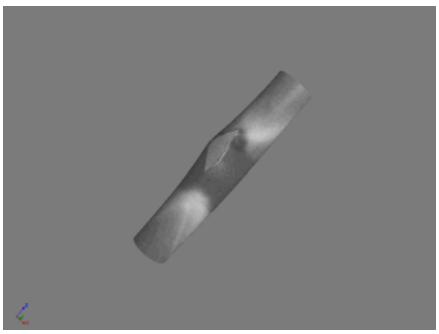
(Σ = 0.197 .. 0.216)

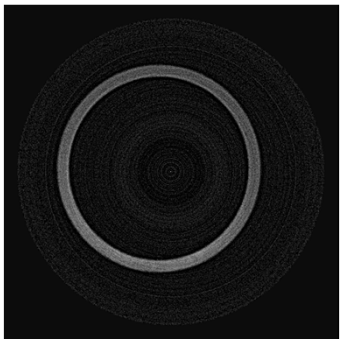
Results Radiography rod QL0-#03 (p_i = 55 bar, Δt = 104 s)





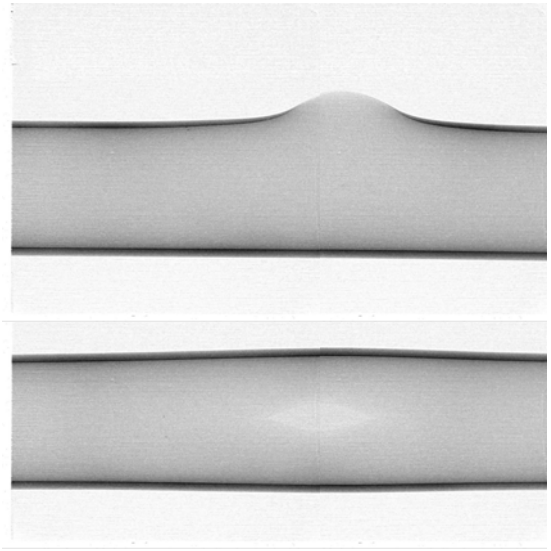
Results Tomography rod QL0-#01 (p_i = 50 bar, Δt = 112 s)



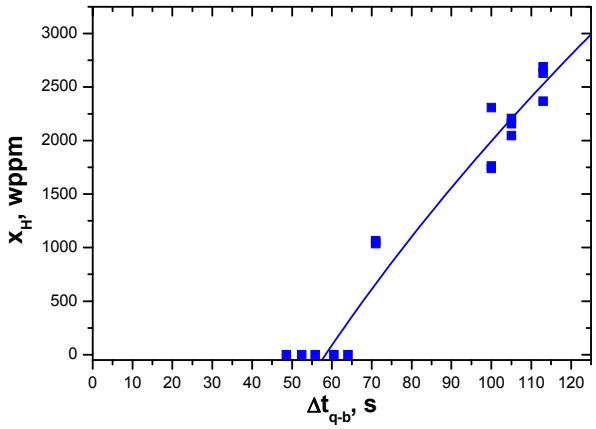


x_H ~ 2700 wppm

Results Radiography rod QL0-#17 (p_i = 40 bar, Δt = 71 s)

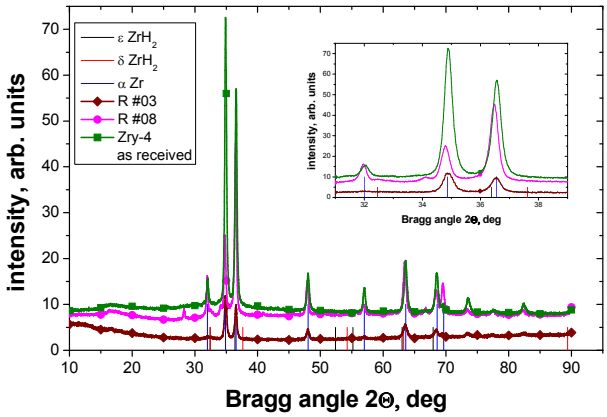


Results Tomography QL0



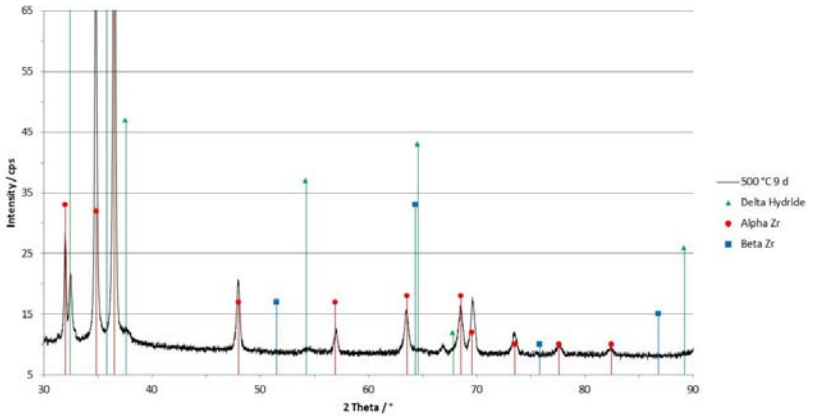
Dependence of the maximal hydrogen concentrations in the hydrogen enriched bands on the time between burst and quenching

Results XRD QUENCH-L0



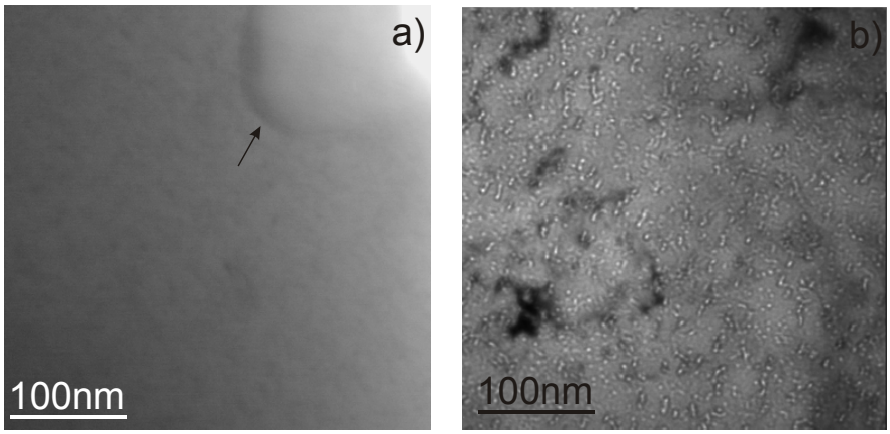
XRD pattern measured at the as-received state and two samples from the QUENCH-L0 test

Comparison with XRD pattern of a laboratory specimen



X-ray diffraction pattern of a laboratory sample cooled with lower cooling rate

Results TEM QUENCH-L0



as-received

inside the hydrogen enriched bands

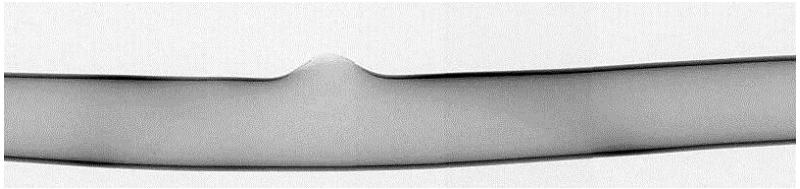
Results tensile tests QL0

Ruptures near to burst opening due to hydrogen embrittlement | Rupture across the burst opening middle due to stress concentration | Rupture near end plugs after plastic deformation

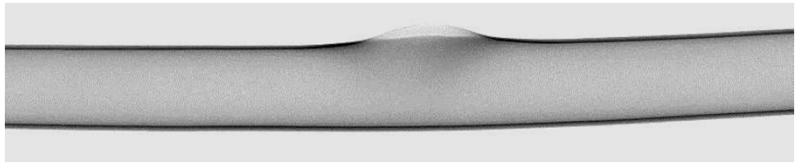
The rods do not show hydrogen bands fail after plastic deformation.

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



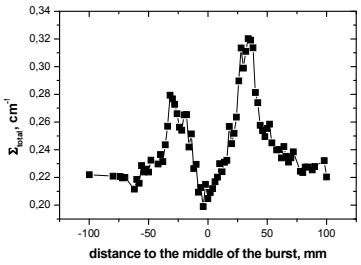
#06



#08

First glance to the results of n radiography of QL1 samples

axial distribution of the total macroscopic neutron cross section



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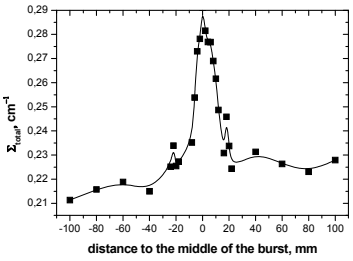

#08

Summary and Conclusions (1)

- 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.
- Bragg peak shift observed in the XRD investigations give hints for a undercooled solution of hydrogen in the α-Zr lattice.
- Numerous inhomogeneities were found in the hydrogen enriched bands by means of TEM.
- Strong influence of the hydrogen bands on the crack positions in the tensile tests.

Summary and Conclusions (2)

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

Outlook:

Mechanical test at QUENCH-L1 will be performed soon.

Next QUENCH-LOCA test (L2) is planed 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

The QUENCH-LOCA tests and pre-test investigations are sponsored by the German Verein der Grosskraftwerksbetreiber **VGB**

KIT:
The QUENCH team, particularly C. Goulet, J. Moch, C. Roessger

PSI:
S. Hartmann

Thanks for your attention, questions?