Update of the QUENCH Program

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Cooperative Severe Accident Research Program Meeting (CSARP)
Bethesda, ML, 15-17 September, 2009

Motivation

- Reflood is a prime accident management measure to terminate a nuclear accident
- Reflood may cause temperature excursion connected with increased hydrogen and FP release
- Simulation of core behaviour at (very) high temperatures and during quenching is still a matter of improvement
- QUENCH experiments (bundle+SET) provide data for development of models and validation of SFD code systems

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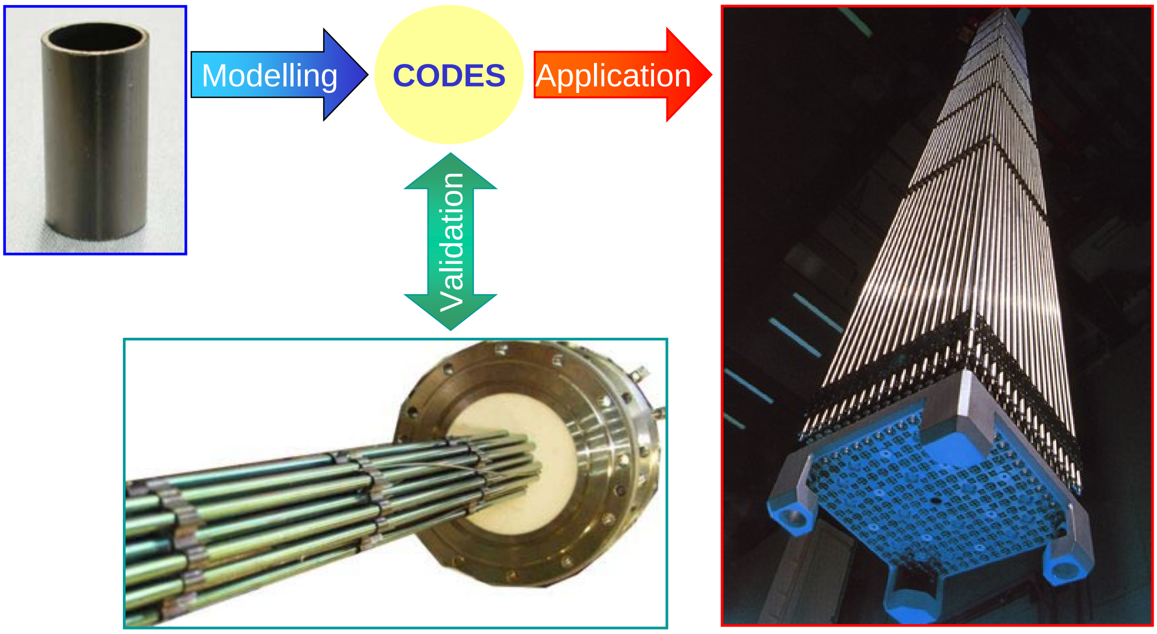
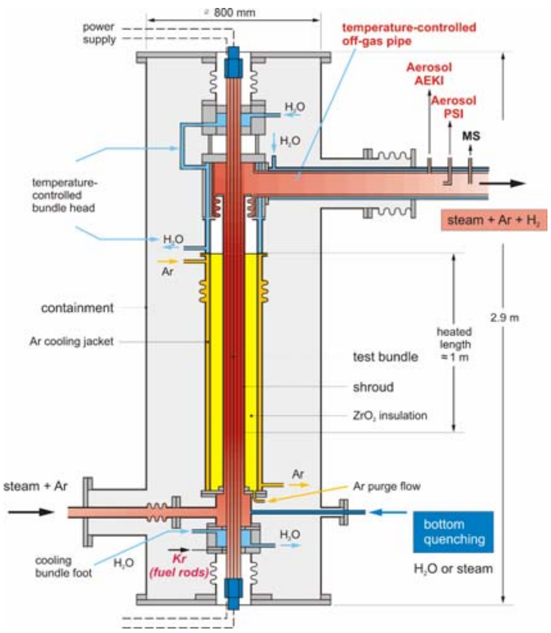
Procedure



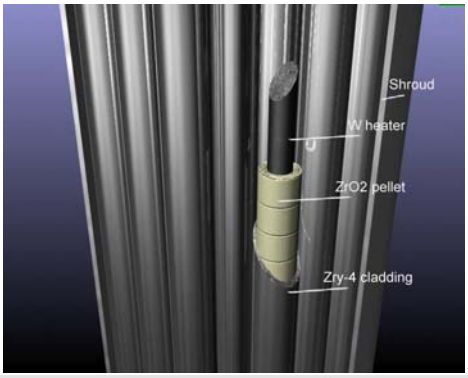
Main topics during the last year

- ACM bundle tests
  - QUENCH-14 with M5® cladding
  - QUENCH-15 with ZIRLO™ cladding
- Separate-effects tests (SET)
  - Oxidation of advanced Zr cladding alloys in various atmospheres
  - Neutron radiography for determination of absorbed hydrogen in SET samples and bundle rods
  - Single-rod experiments on failure of AgInCd control rods
  - High-temperature oxidation of hafnium

QUENCH bundle facility



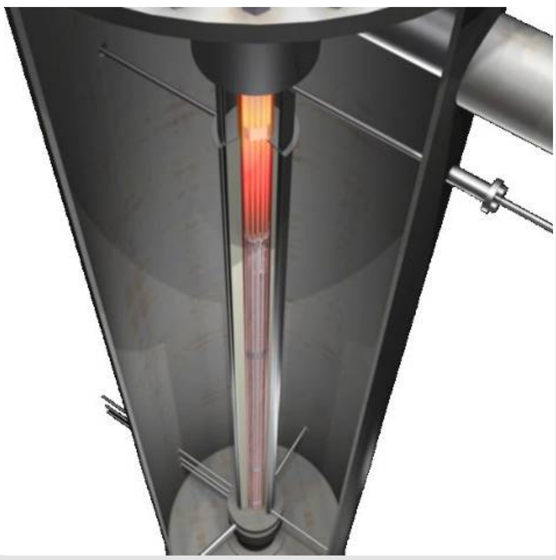
- o Bundle with 21-31 fuel rod simulators of ~2,5 m length
- o Electrically heated: ~1 m; max 70 kW
- o Fuel simulator: ZrO_2 pellets
- o Quenching (from bottom) with water or saturated steam
- o Off-gas analysis by mass spectrometer (H_2, steam …)
- o Extensive instrumentation for T, p, flow rates, level, etc.
- o Removable corner rods during test



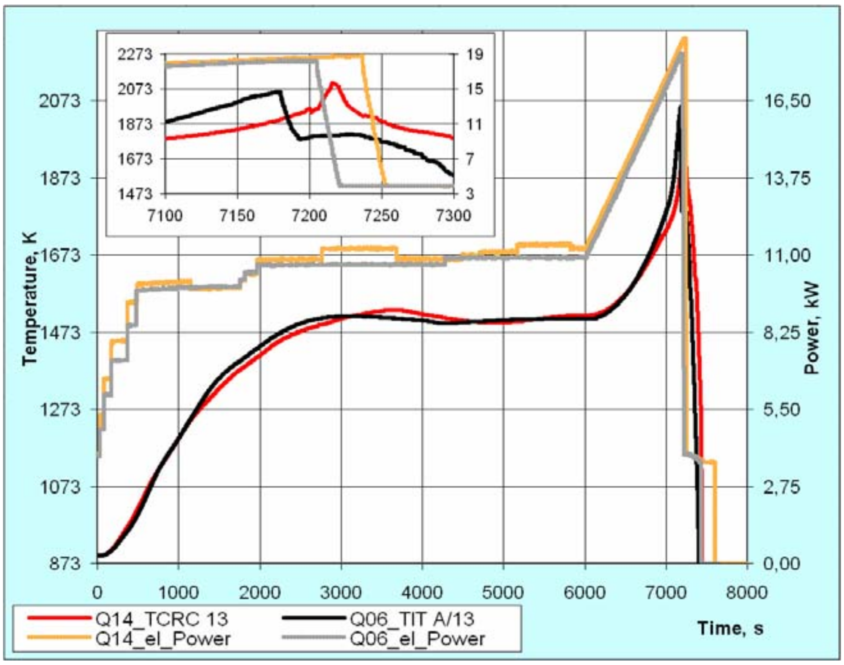
QUENCH-14 and QUENCH-15

- Bundle tests with M5® and ZIRLO™ claddings in the frame of QUENCH-ACM
- Test protocol identical to reference test QUENCH-06 with Zry-4 cladding (OECD ISP-45)
- Conducted at 2 July 2008 and 27 May 2009

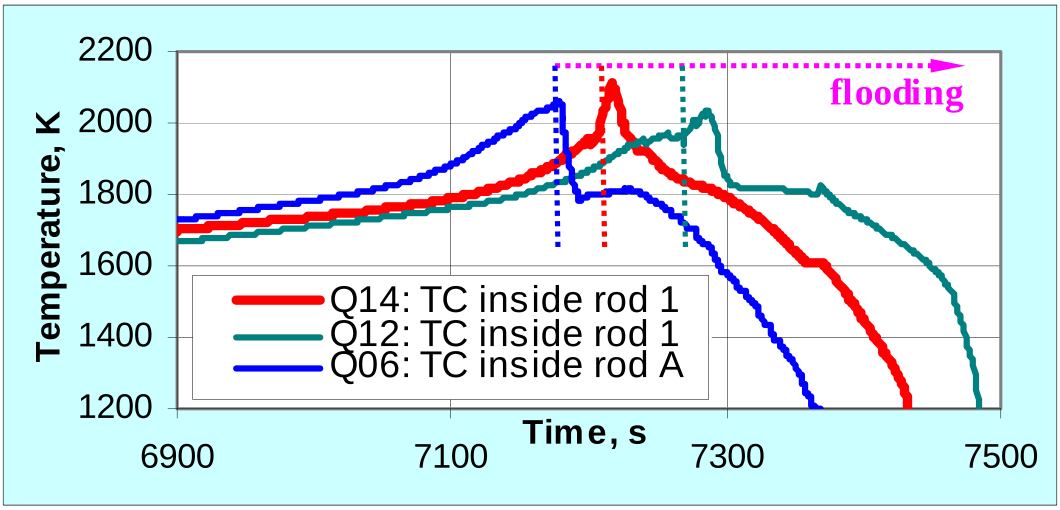
➡ First analyses of results indicate a similar global bundle behaviour of QUENCH-14/-15 and QUENCH-06



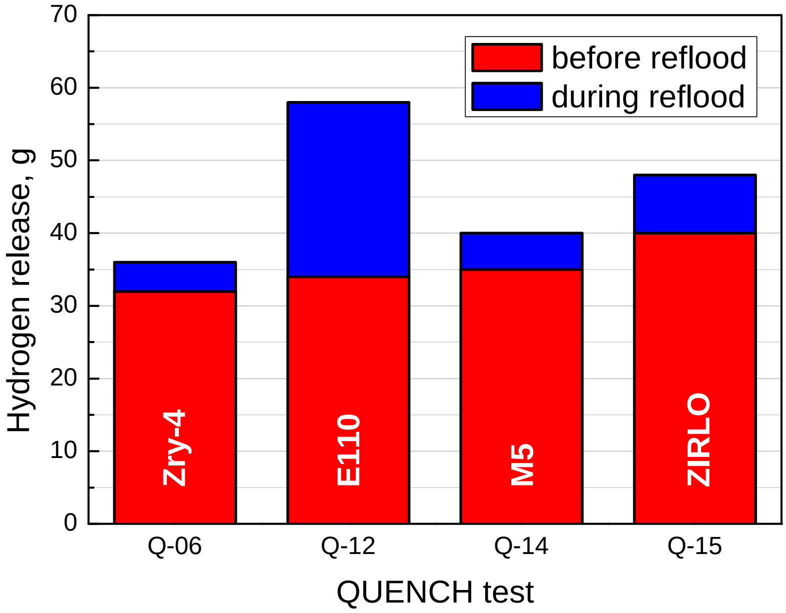
QUENCH-14: Power profile and temperature



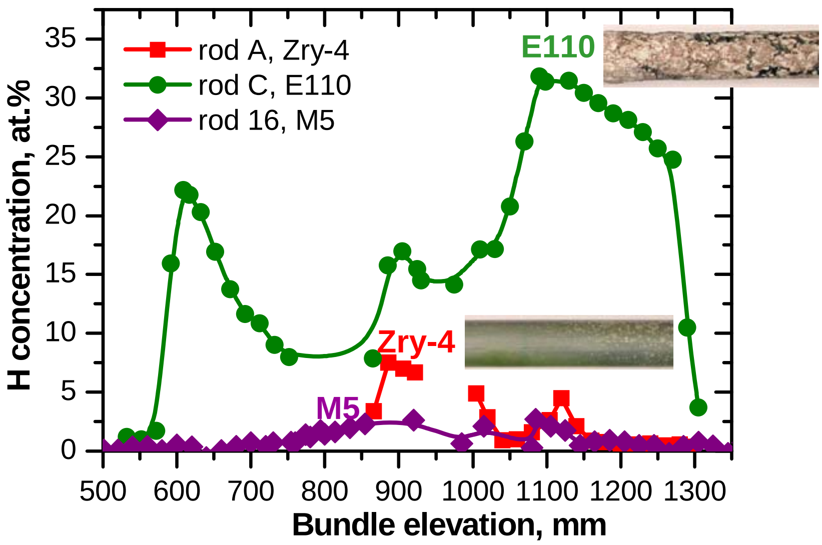
QUENCH-14: Temperature at reflood

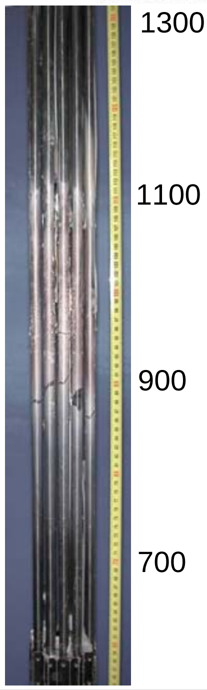


QUENCH-ACM: Hydrogen release



QUENCH-14: Hydrogen absorption





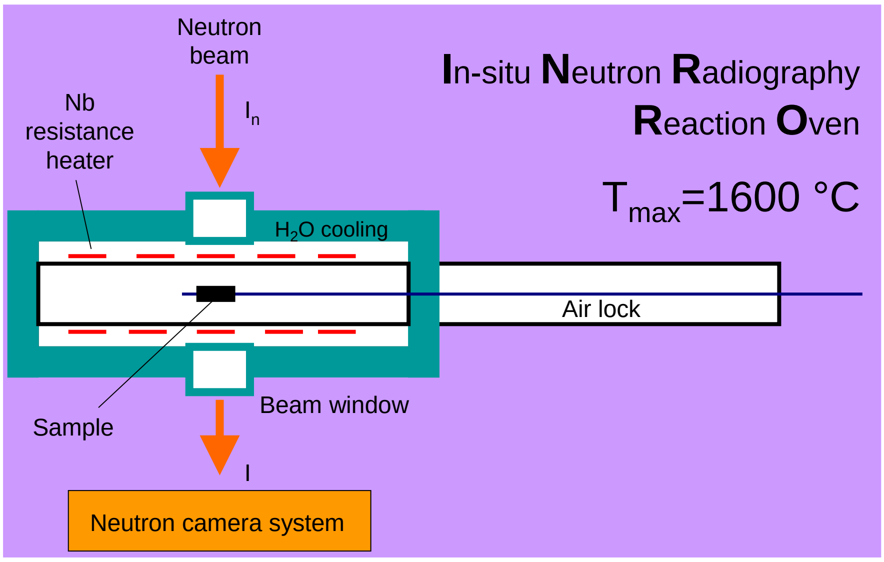
Post-test hydrogen content in corner rods and cladding

Separate-effects tests

- New furnace for in-situ neutron radiography commissioned at PSI
- Oxidation tests of advanced cladding alloys
  - Zircaloy-4, Duplex, M5, Zirlo, E110
  - Steam and air atmosphere
  - 600-1200 °C in TG
  - Higher temperatures in tube furnace (BOX)
- High-temperature oxidation of hafnium (preparation for QUENCH-Debris)
- Single-rod tests on degradation of AgInCd absorber rods

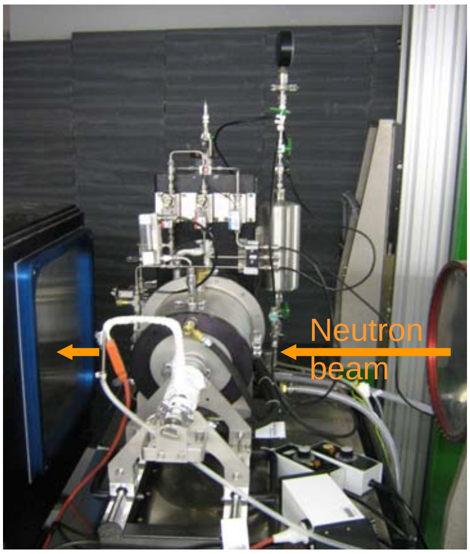
QUENCH-SR rig

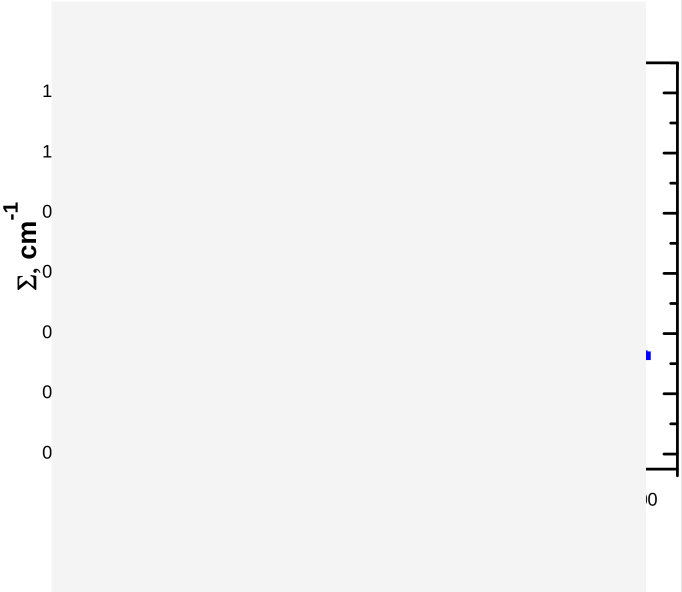
INRRO furnace for in-situ hydrogen analysis



Time- and space-resolved in-situ determination of hydrogen uptake by Zr alloys

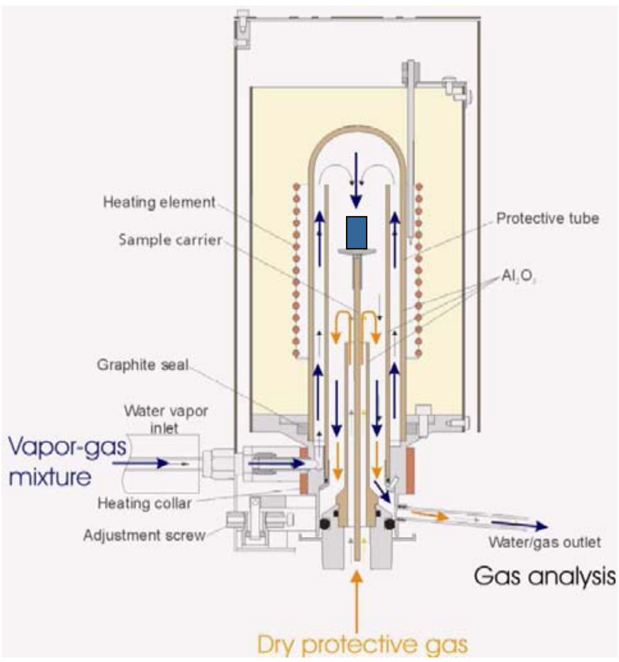
INRRO furnace for in-situ hydrogen analysis





Zircaloy-4, 6 h at 1000 °C in steam

TG with steam furnace



- Online mass gain during oxidation
- Max. temperature 1250°C
- Steam supply to the specimen from the top
- Ar as protective gas for the balance

⇨ Almost pure steam atmosphere at specimen

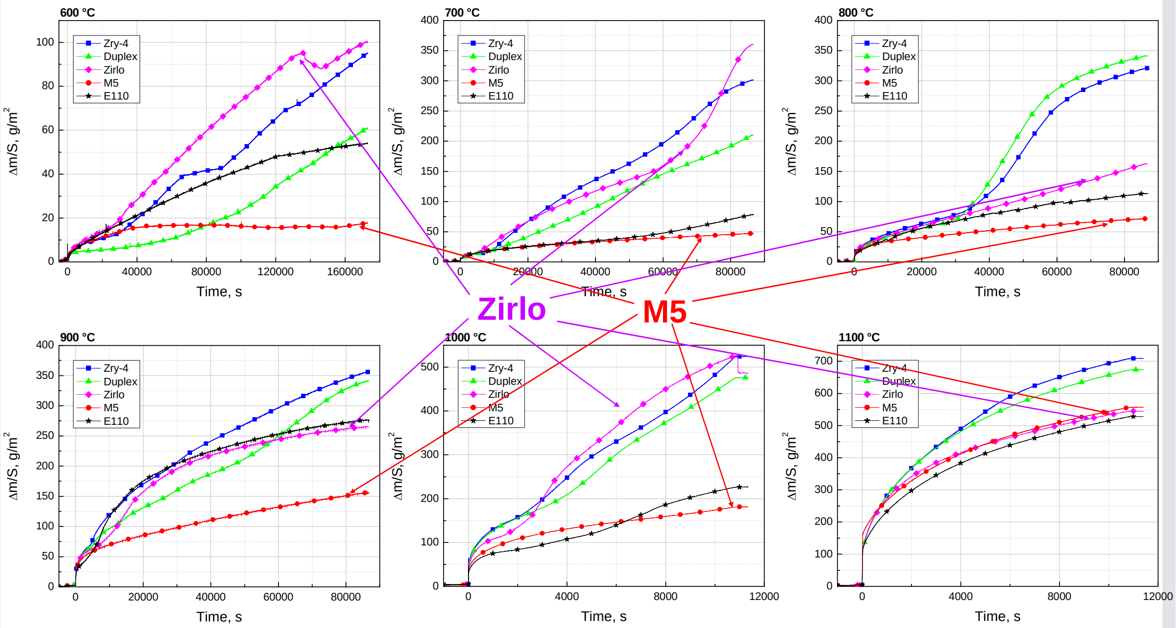
Specimens

- 2-cm cladding segments
- Both side oxidation allowed

Composition (main alloying elements)

Element	Zry-4	D4	M5	E110	ZIRLO
Nb	**-**	**-**	**1**	**1**	**1**
Sn	**1.5**	**0.5**	0.01	< 0.01	**1**
Fe	0.2	**0.5**	0.05	0.008	~0.11

Isothermal tests – TG results



Isothermal tests – Post-test appearance (1)

600 °C

700 °C

800 °C

Zircaloy-4 | Duplex | M5 | E110 | ZIRLO

Isothermal tests – Post-test appearance (2)

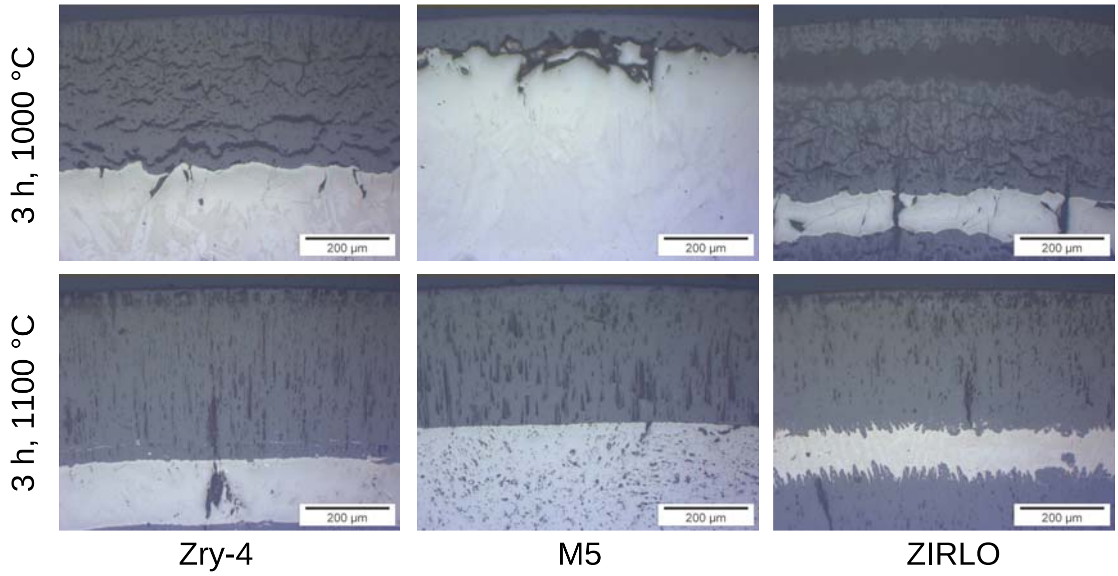
900 °C

1000 °C

1100 °C

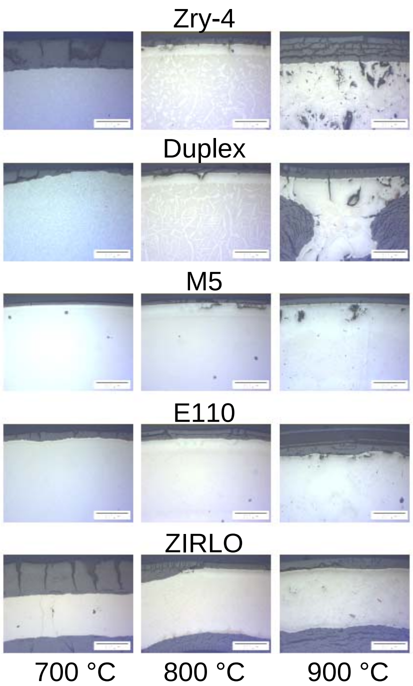
Zircaloy-4 | Duplex | M5 | E110 | ZIRLO

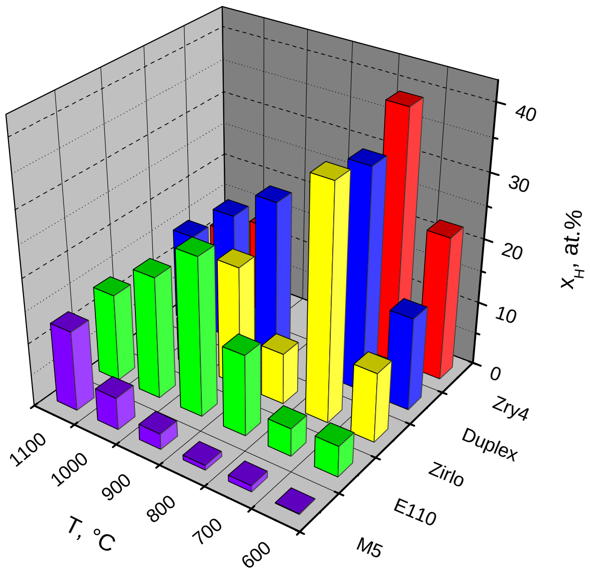
Isothermal tests – Metallographic images



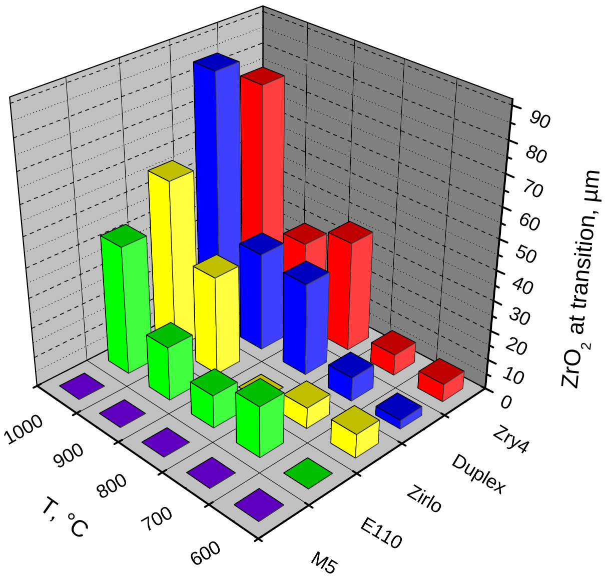
Typical oxide structures at 1000 and 1100 °C

Determination of H in Zry samples by NR





Transition to breakaway

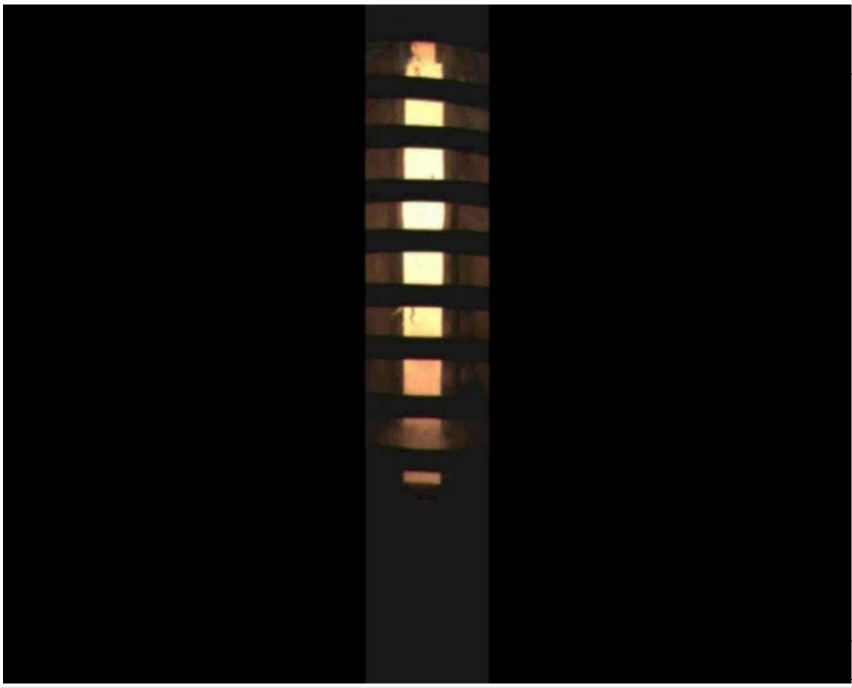


Temperature °C	Time at transition h	Oxide at transition µm
600	6-8	3-8
700	1-10	7-17
800	1-7	11-37
900	0.6-1.5	18-33
1000	0.3-0.7	43-85

AgInCd control rod tests in the QUENCH-SR rig

- Four tests retracing temperature history of 950 mm elevation in QUENCH-13
  - with and w/o inner oxidation of Zry-4 guide tube
  - with and w/o initial contact between Zry-4 and SS tubes
- One test retracing temperature history of 750 mm elevation in QUENCH-13
  - asymmetric, with holes
- One test without Zry-4 guide tube

Post-test appearance and failure temperatures



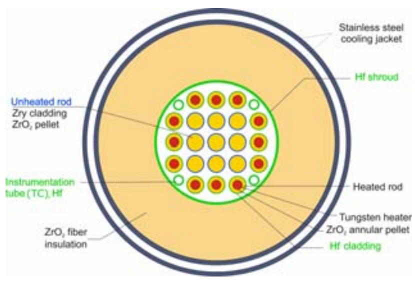
1450°C

SIC-11
w/o Zry-4 guide tube

QUENCH program 2010-2014

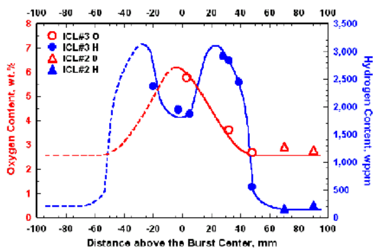
QUENCH-DEBRIS

- In the frame of EC-SARNET-2
- Investigation of formation and coolability of debris and melt in the core
- Two tests planned, final boundary conditions tbd.



QUENCH-LOCA

- In cooperation with German industry and GRS
- Investigation of ballooning and (secondary) hydrogen uptake of advanced cladding alloys in realistic bundle geometry
- Critical review of embrittlement criterion
- Complementary to various single-rod-tests worldwide (Halden, Studsvik, JHR (2015))



Finally…

You are invited to the

15th International QUENCH Workshop

Forschungszentrum Karlsruhe (FZK)

November 3-5, 2009

www.fzk.de/quench

Thank you for your attention