Review of the QUENCH-12 (QUENCH/WWER) pre-test calculations and high-temperature oxidation rate of Zr1%Nb

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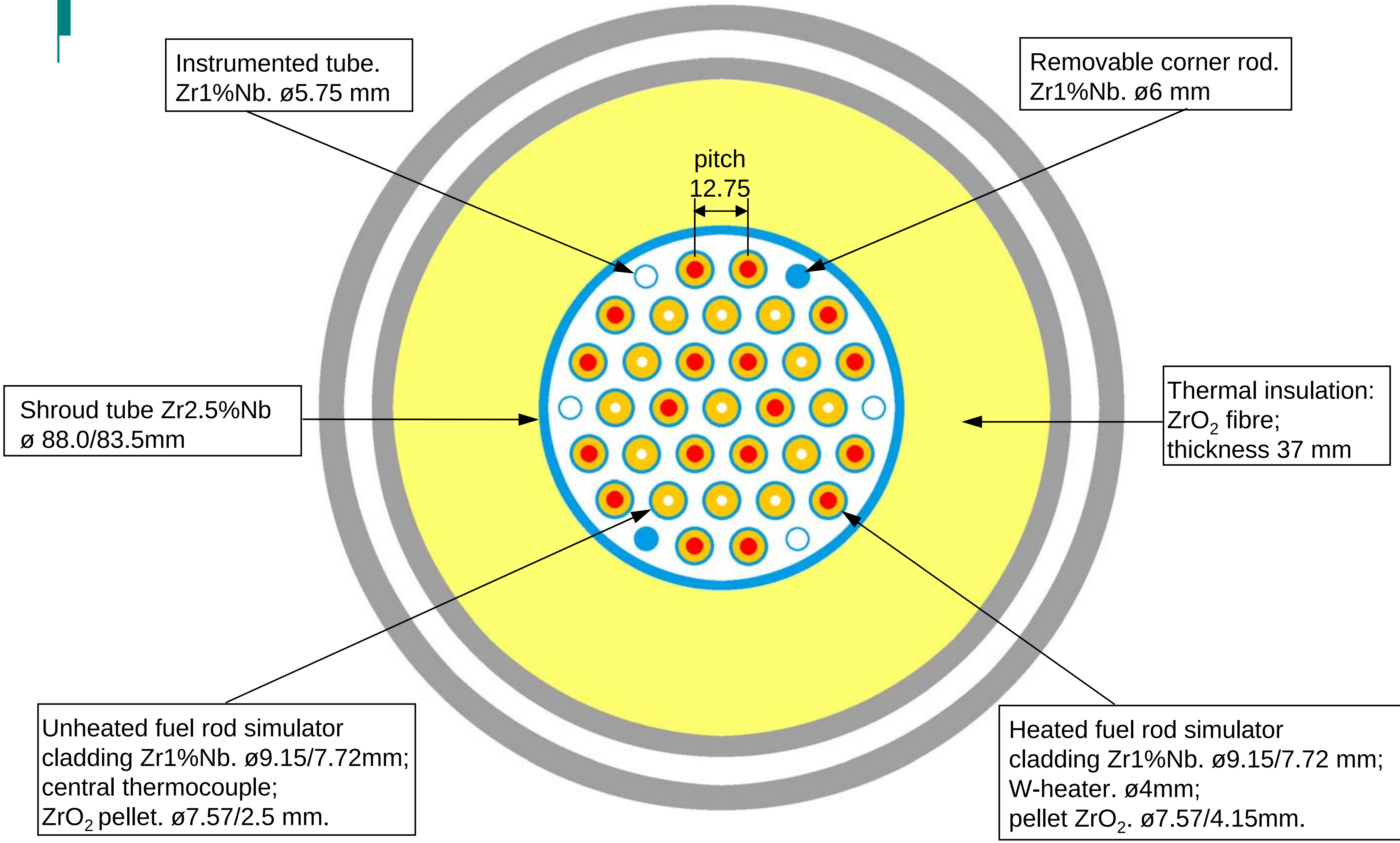
1. QUENCH-12 test objective.

2. Results of the SCDAP/SIM simulations (J. Birchley, T. Haste, *Paul Scherer Institute, Switzerland***).**

3. Results of the ICARE/CATHARE simulations (A. Volchek, Yu. Zvonarev, *Kurchatov Institute, Mosccow, with support from IRSN Cadarache***).**

4. Some new experimental results to Zr1%Nb oxidation (M. Große, U. Stegmaier, *Forschugszetrum Karlsruhe***).**



QUENCH-12: Cross section of the QUENCH/WWER-column

Test objective: test should be performed according to the scenario of the test QUENCH-06 (Zry-4 bundle contain 21 rod simulators)

Test stages:

- Heating of the bundle up to the temperature of 873 K in an atmosphere of flowing argon (3 g/s) and superheated steam (3 g/s. bundle inlet T=793 K).
- Stepwise electrical power increase to reach the maximum temperature of 1473 K during about 1500 s.
- Pre-oxidation of simulator claddings in superheated steam and argon at constant maximum temperature of 1473 K during 4050 s.
- Bundle heatup with the ramp rate of 6 W/s to the maximum temperature of 1973 K (sheathed thermocouple at the hottest elevation).
- Bundle reflood with water injected from the bottom with the flooding velocity of 1.4 cm/s.

Key parameters of the bundle oxidation by the test QUENCH-06:

H_2 production at the end of pre-oxidation phase (6011 s): **18.5 g**

Maximum oxide layer thickness after beginning of the transient phase (6620 s): **200 µm** (measured on withdrawn corner rod); H_2 production (6620 s): **20.4 g**.

Maximum oxide layer thickness to the start of temperature escalation (7120 s): **300 µm** (calculated with the SVECHA code); H_2 production (7120 s): **26.8 g**.

Average oxide layer thickness to the end of test (reflood started on 7178 s): **660 µm** (measured on the rods of hottest elevation); H_2 production (total): **35.7 g** (including 4 g during reflood).

Approximation of hydrogen production for QUENCH-12 on the base of metallic surface relationship between QUENCH-12 and QUENCH-06 bundles **(factor 1.22):**

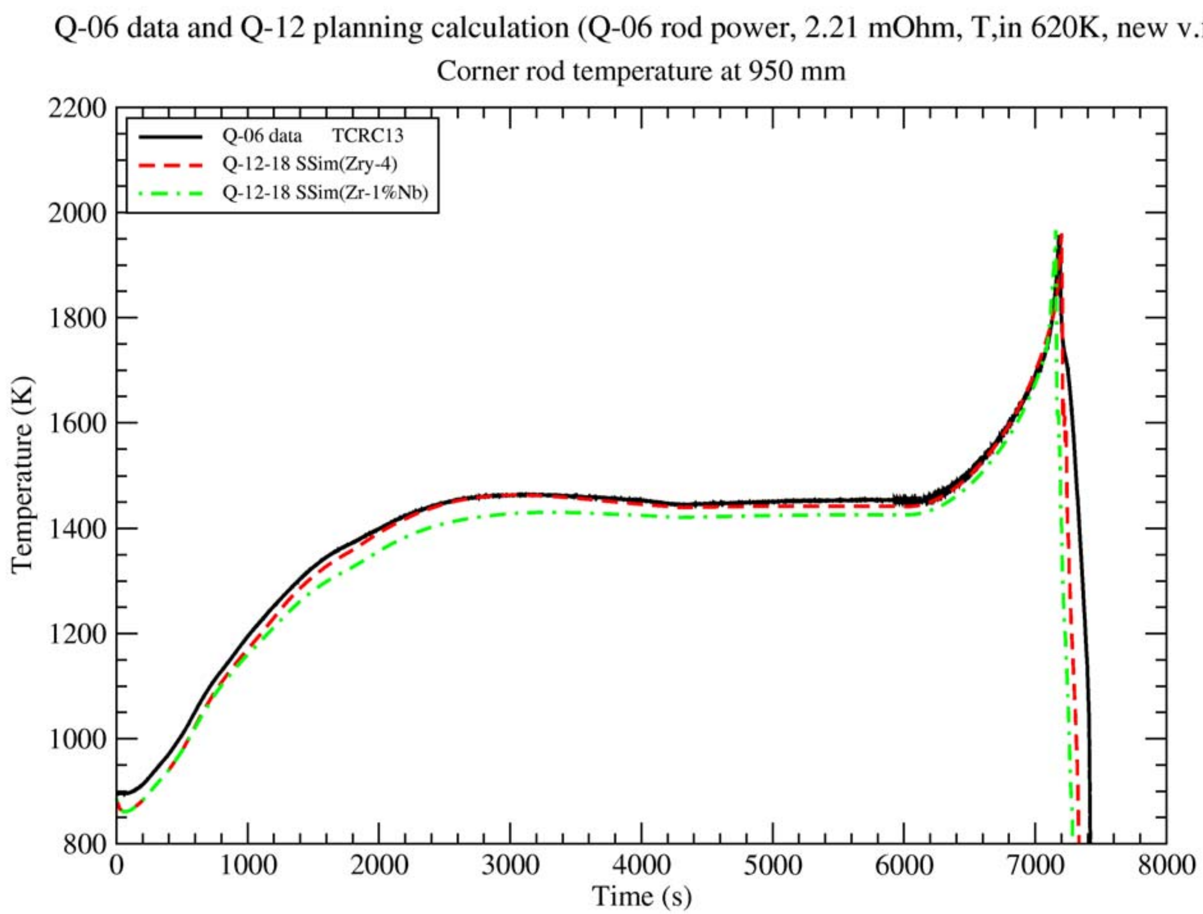
End of pre-oxidation phase: **22.6 g**

On reflood onset: **38.7 g**

Quench fluid flow rate

Average water injection rate during the for QUENCH-06: **42 g/s**.
The total bundle hydraulic cross-section for QUENCH-06: 30.07 cm^2.

The total bundle hydraulic cross-section for QUENCH-12: 32.8 cm^2.
Average water injection rate during the for QUENCH-12 → **46 g/s.**



SCDAP/SIM calculation results of temperature history during QUENCH-12.

Rod electrical power development is the same with QUENCH-06;

fitted parameter – el. resistance of {cables +slide_contacts} per rod: 2.21 mΩ (instead measured 3.9 mΩ)

/value 2.21 was approximated on the base of the same parameter for QUENCH-06: good calculated results for temperature profile during QUENCH-06 was reached with 1.5 mΩ (instead measured 3.6 mΩ)/ .

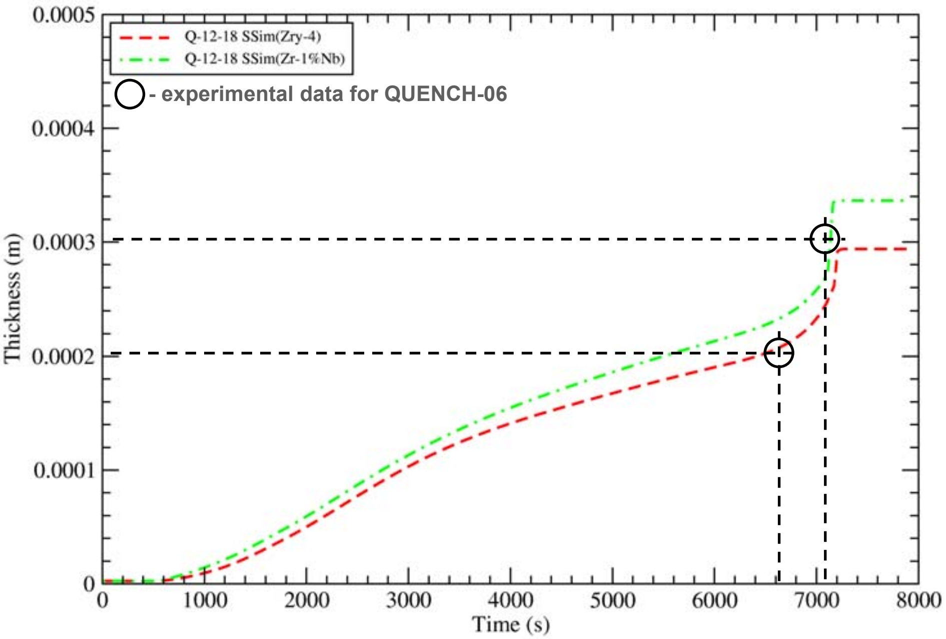
Surface S1 – central rod
Surface S2 – 6 inner heated rods
Surface S3 – 12 inner unheated rods
Surface S4 – 12 outer heated rods
Surface S5 – 6 corner rods
Surface S6 – shroud

Comparison of some selected view factors

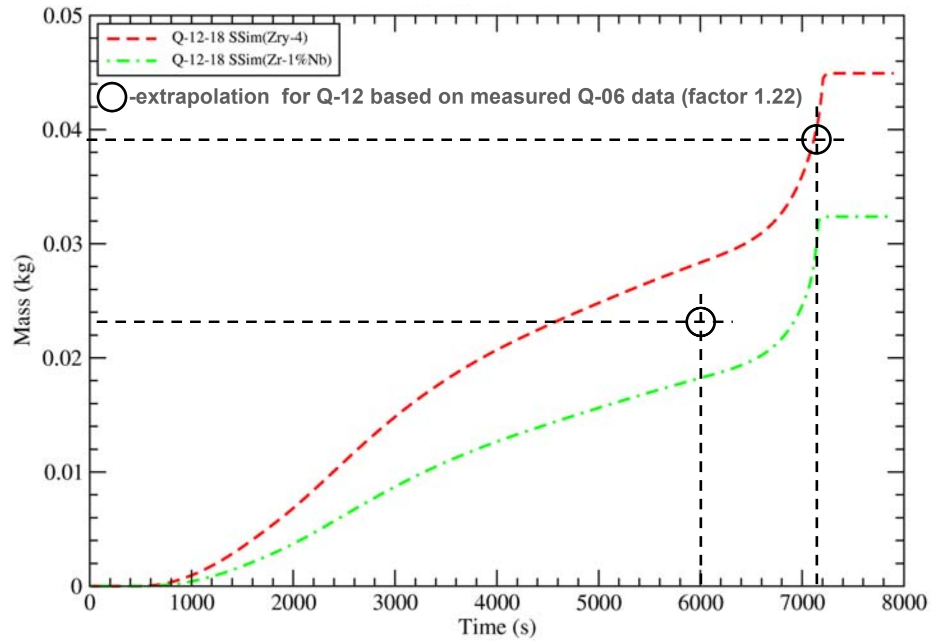
View factor	SCDAP	**IBRAE**
φ_{11}	0.032	**0**
φ_{13}	0.245	**0.113**
φ_{14}	0.080	**0.017**
φ_{35}	0.071	**0.048**
φ_{45}	-0.028	**0.122**

During SCDAP/SIM calculation were used the view factors, calculated by Dr. Vasiliev (IBRAE): the SCDAP model is rather approximate

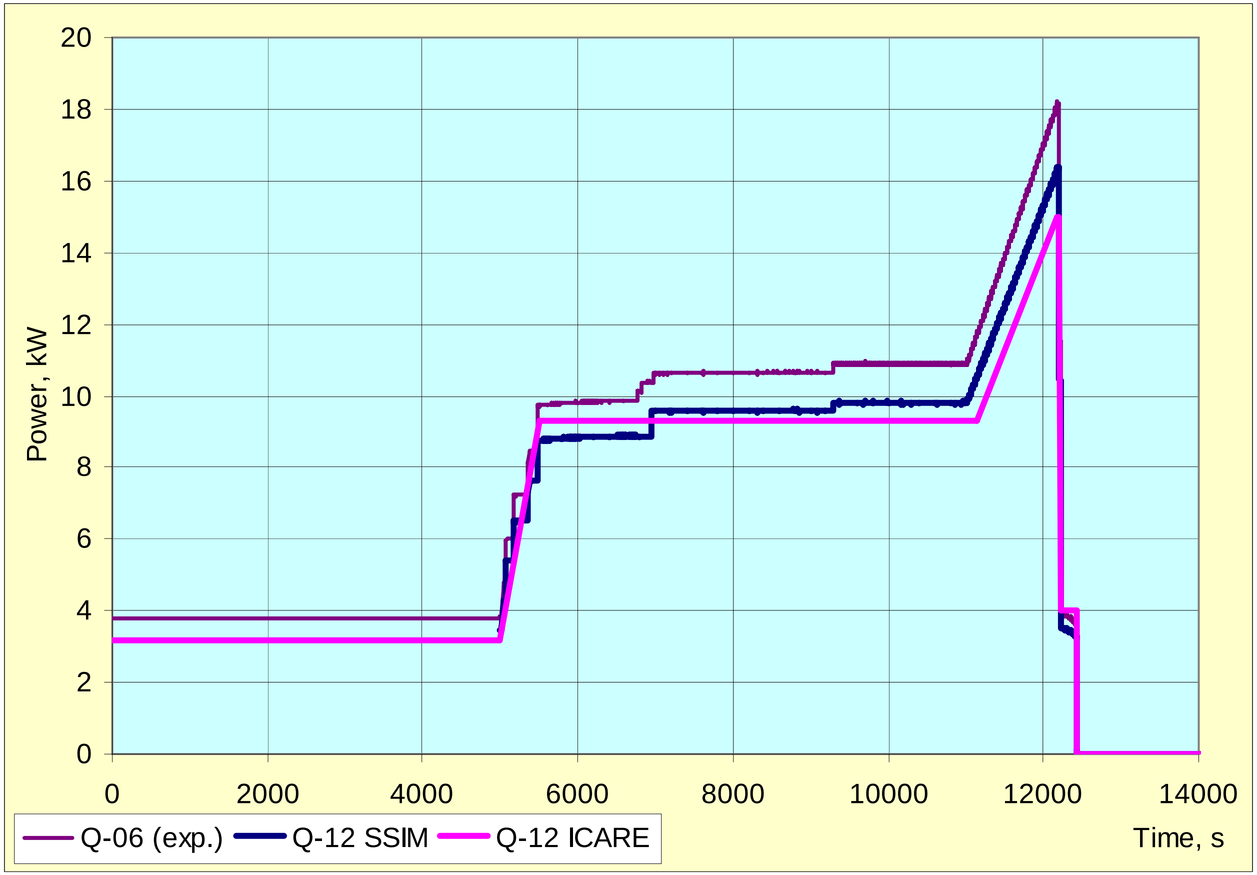
Oxide layer thickness at hottest elevation for QUENCH-12 bundle



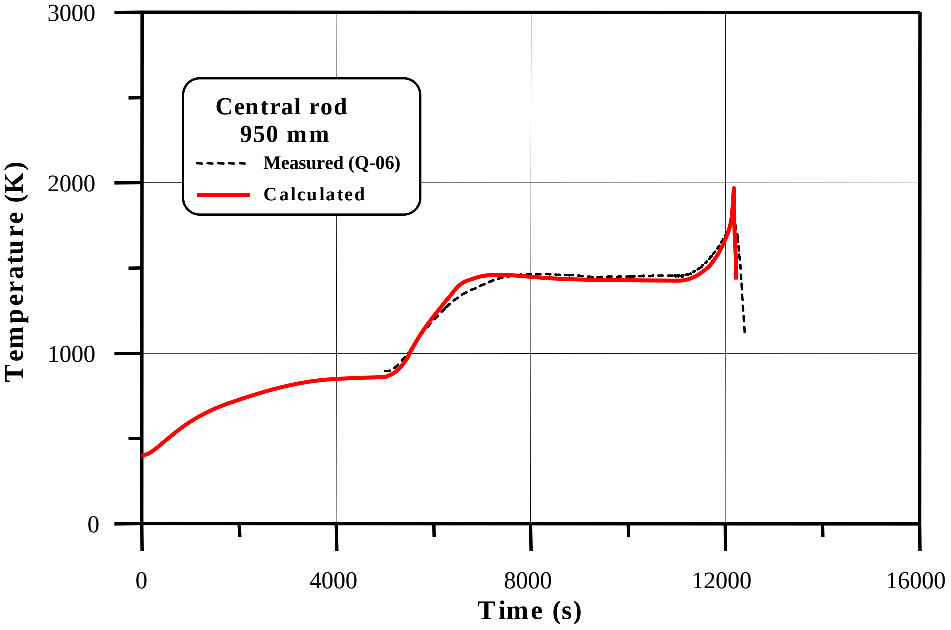
Hydrogen production for QUENCH-12 bundle

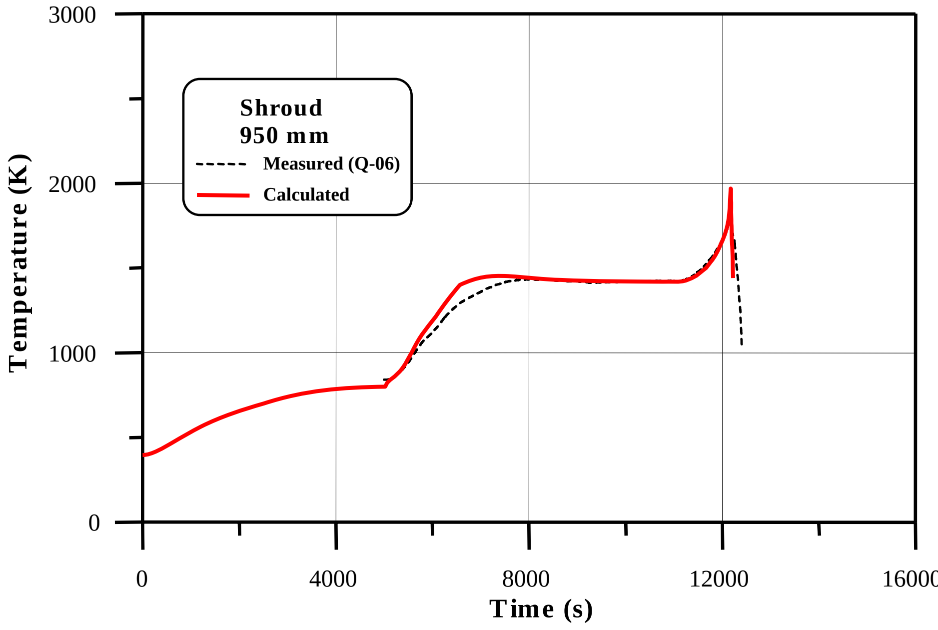


Results of the SCDAP/SIM calculations for two types of oxidation correlations, summarized in MATPRO: Zr1%Nb (KIAE, 1995) and Zircaloy-4



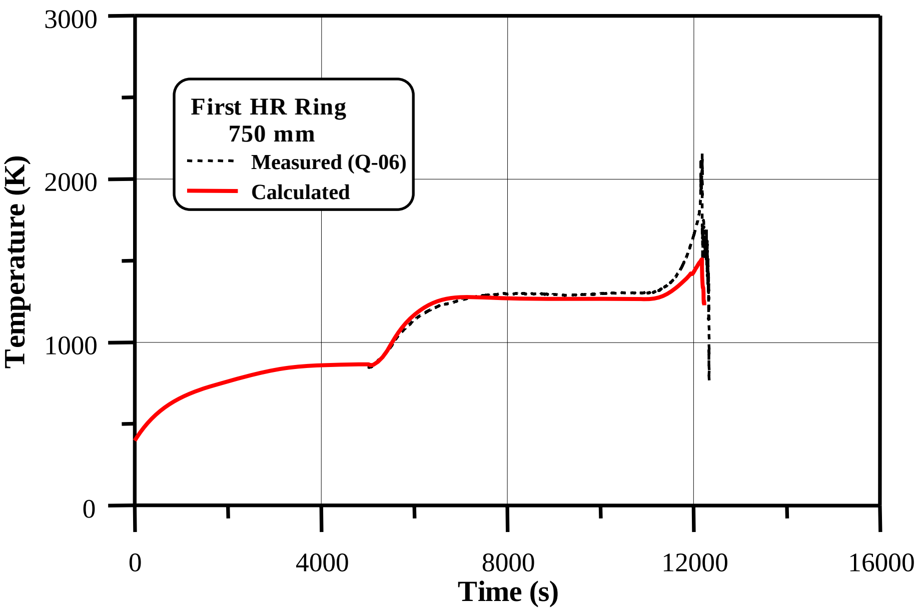
QUENCH-12: Total electrical power progress, used during SCDAP/SIM and ICARE calculations to achieve the QUENCH-06 temperature history

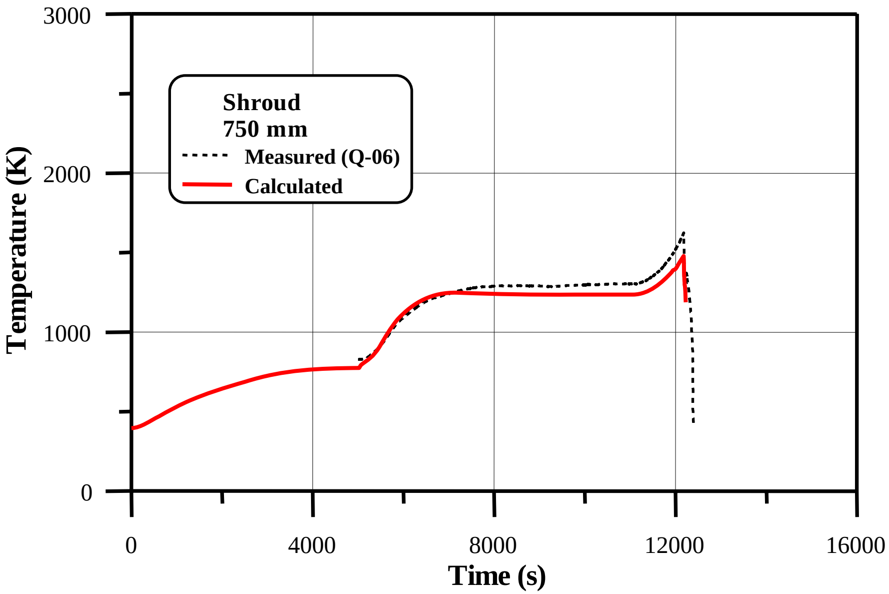




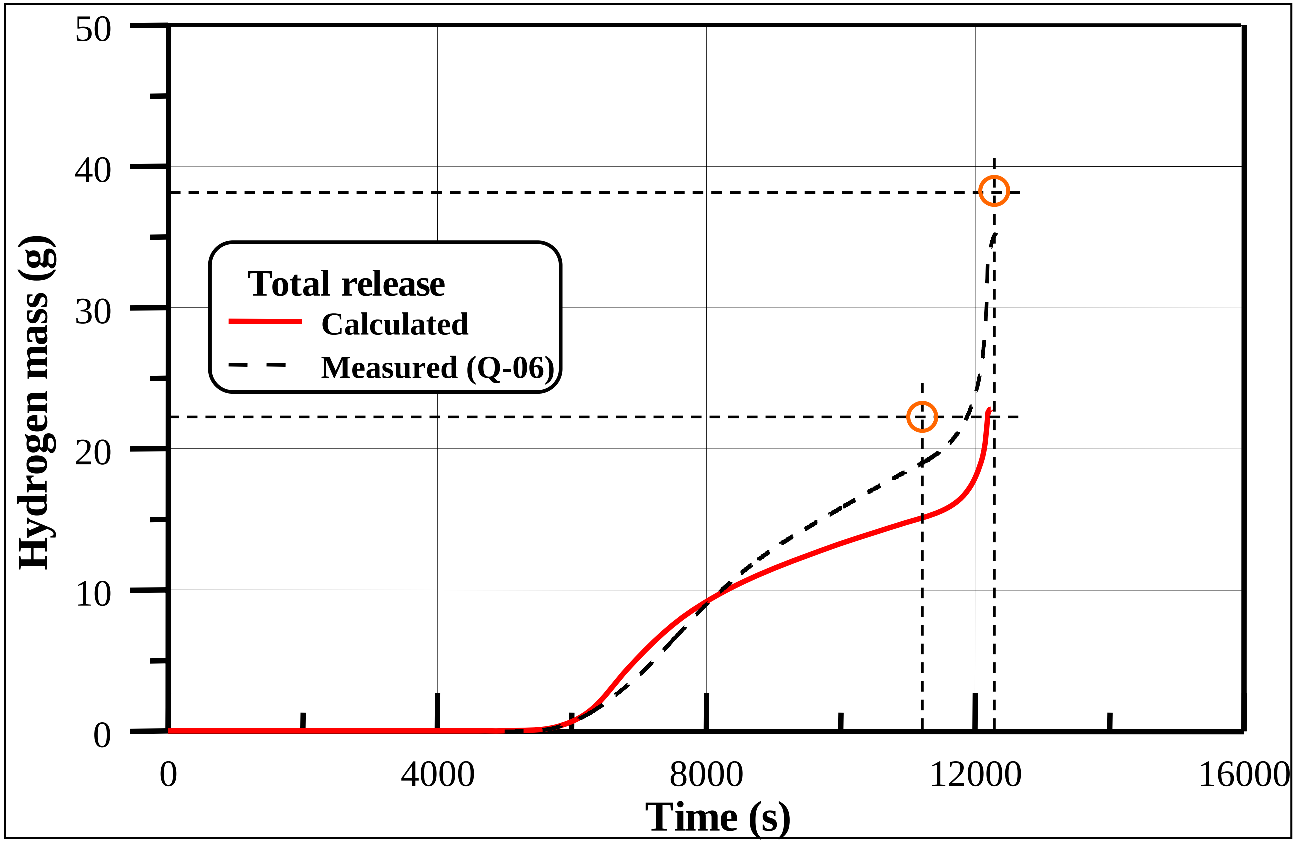
ICARE temperature calculation results for QUENCH-12, elevation 950 mm: good consistency with the QUENCH-06 test.

Used external to bundle electrical resistance of 3.73 mΩ / rod, this value based on the best estimation of resistance for QUENCH-06. Recent measured value is 3.9 mΩ.

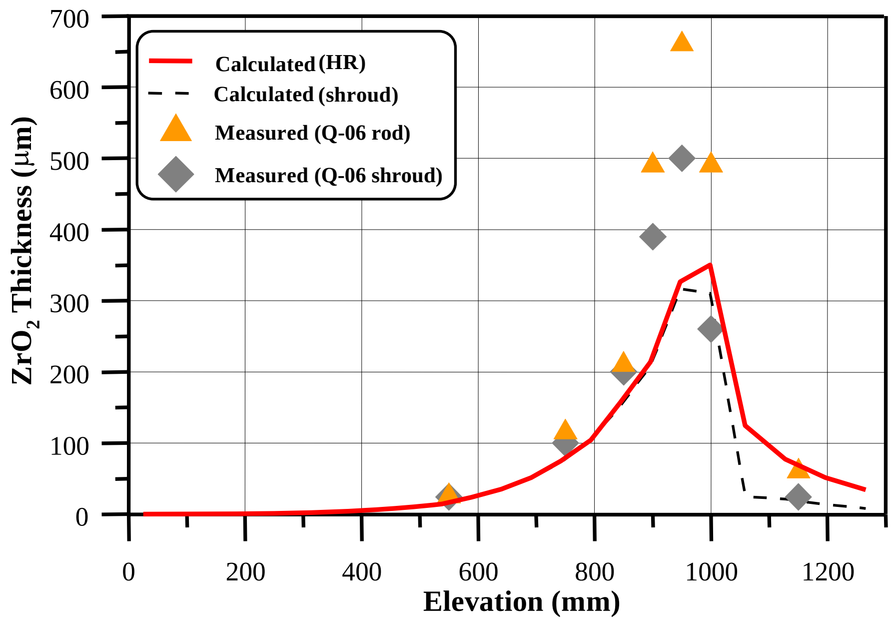




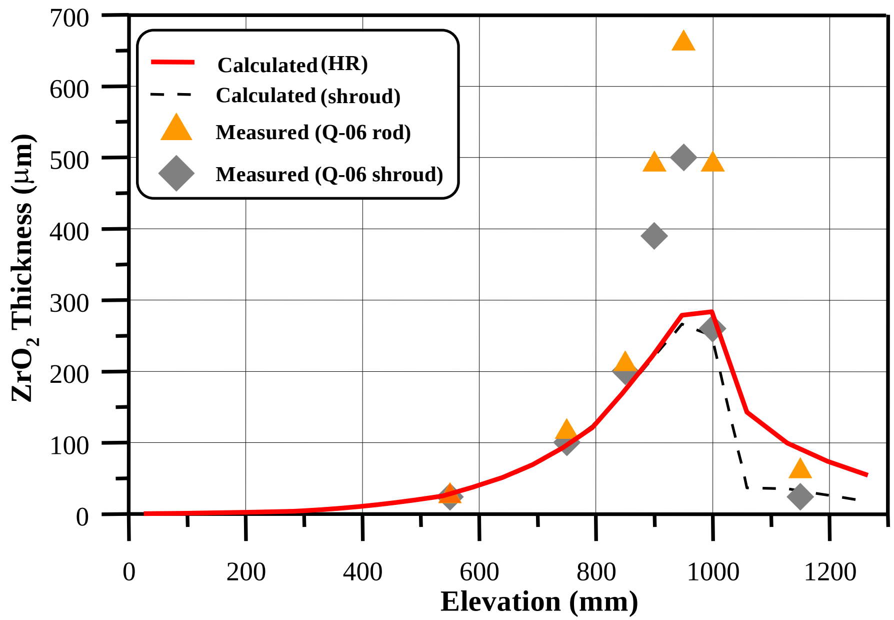
ICARE temperature calculation results for QUENCH-12, <u>elevation 750 mm</u>: lower temperatures in comparison with the QUENCH-06 test.



ICARE calculation results of hydrogen production for QUENCH-12:
underestimation in comparison with the data, extrapolated from the QUENCH-06 test.
Applied oxidation kinetic: Sokolov correlation.

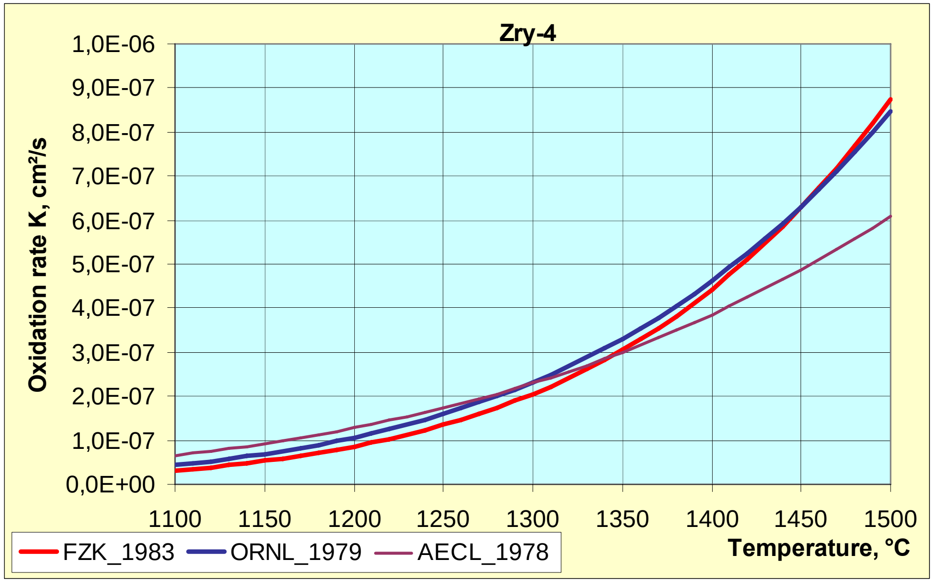


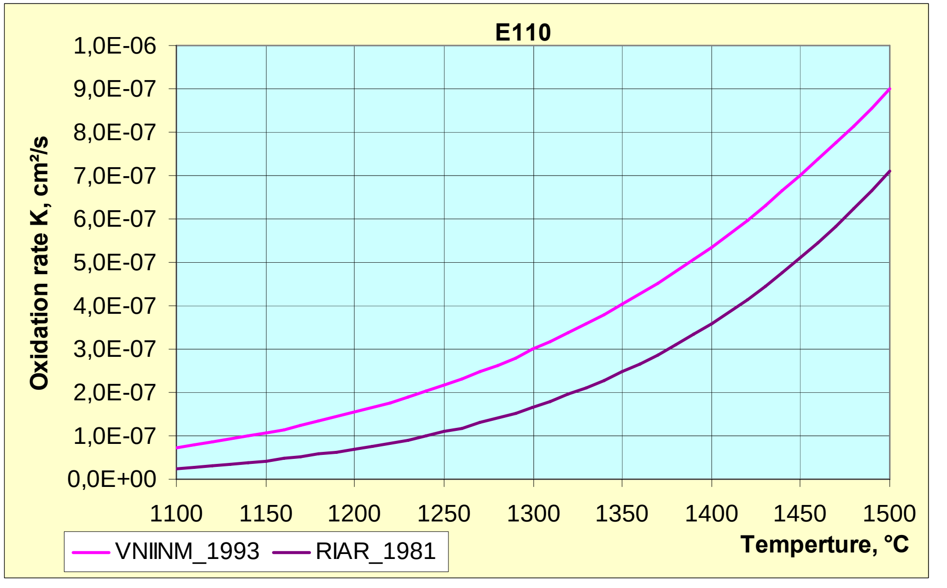
Oxide layer thickness calculated for QUENCH-12
on the base of the VNIINM oxidation kinetic for Zr1%Nb
(Sokolov correlation, 1993)



Oxide layer thickness calculated for QUENCH-12
on the base of the best-fitted oxidation kinetic for Zry-4

ICARE calculation results on oxide layer thickness for QUENCH-12:
the applied Sokolov correlation gives higher oxidation than correlation for Zry-4.
Contradiction to predicted lower hydrogen production.

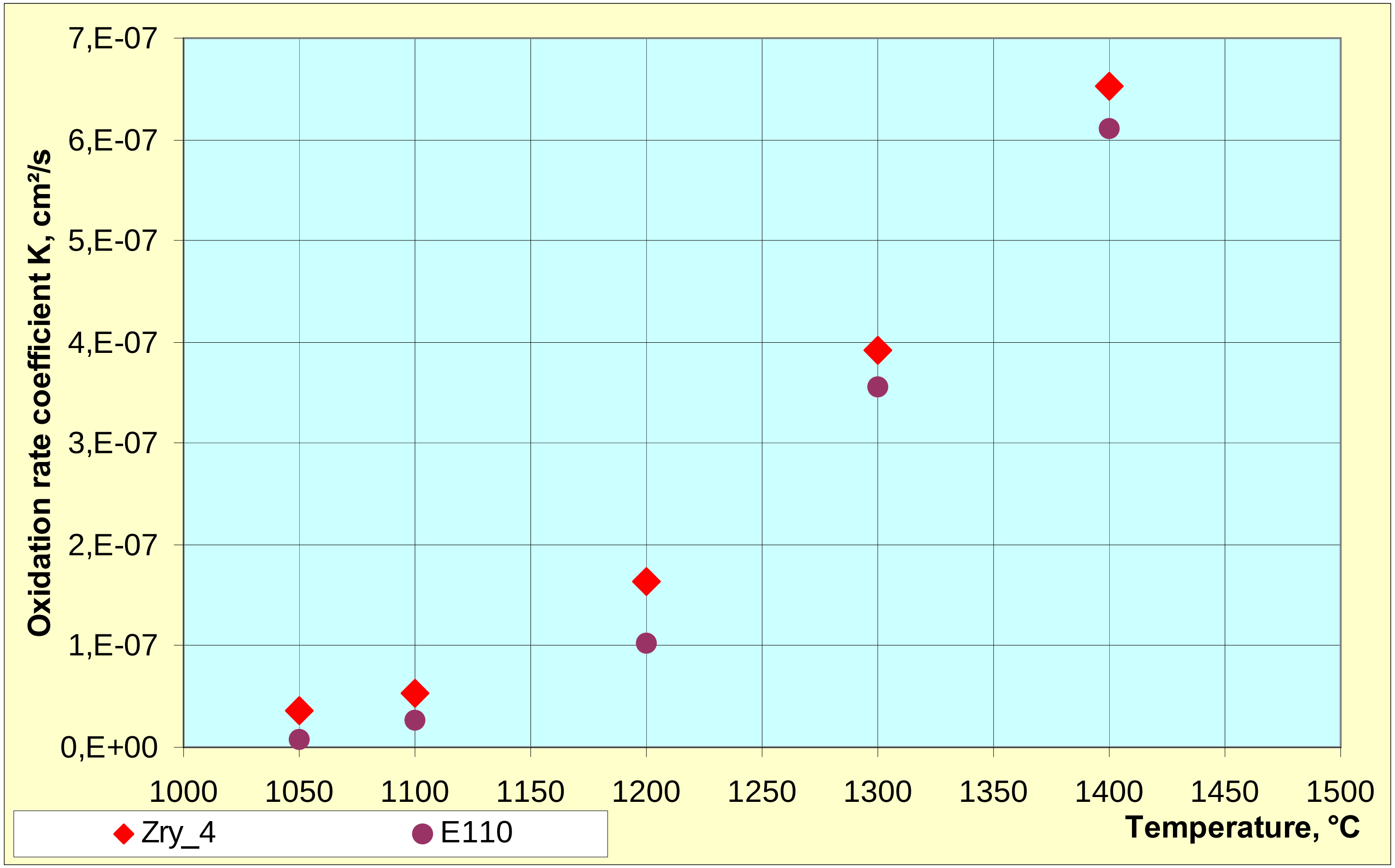




Zircaloy-4 oxidation kinetics

Zr1%Nb oxidation kinetics

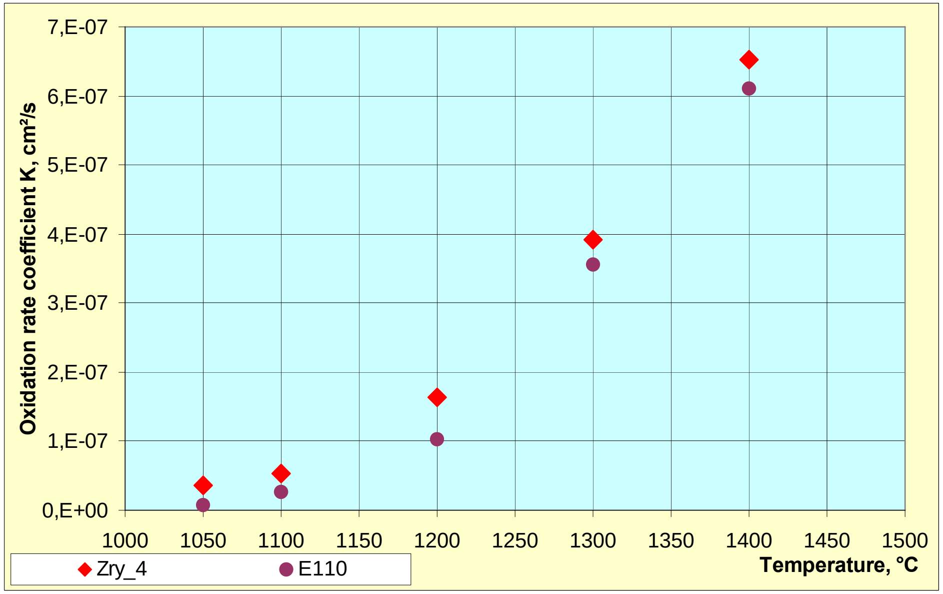
Different types of oxidation kinetics (for temperatures T<1500 °C).
What type should be applied for the QUENCH-12 simulation?

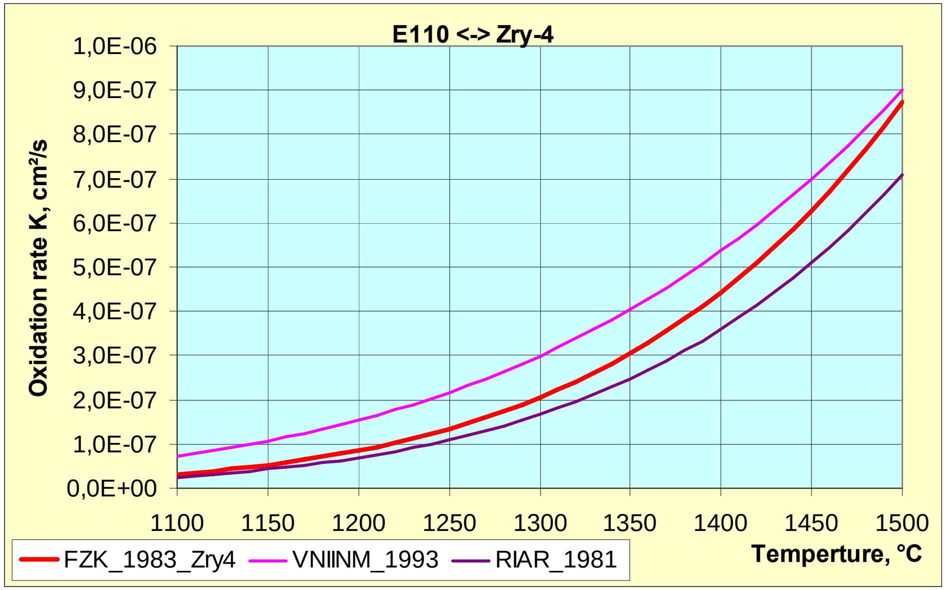


Recent FZK comparison results on oxidation of Zry-4 and Zr1%Nb: oxidation test in the BOX-rig under same boundary conditions.

/Cladding probe height ~20 mm; heating in the tube furnace/.

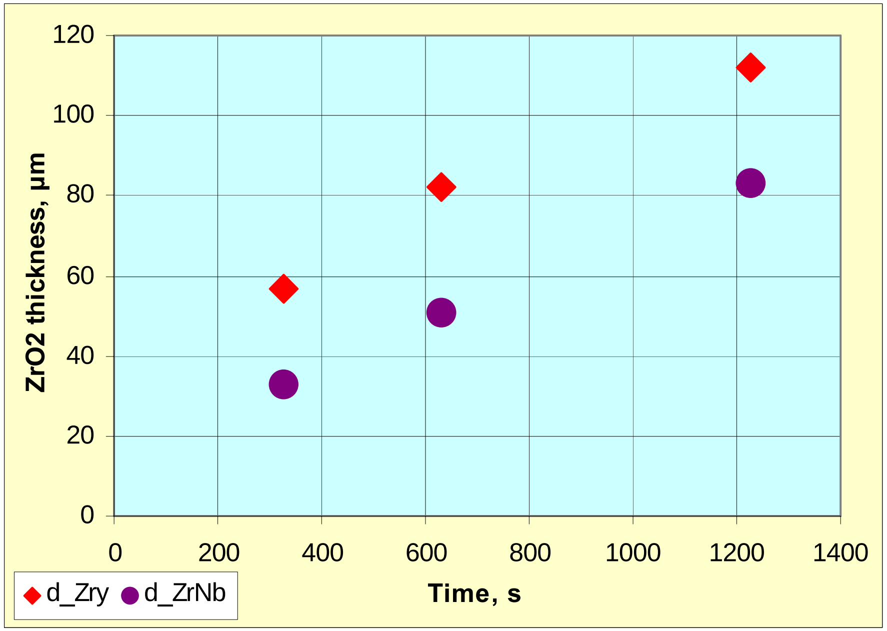
Clear lower oxidation rate for Zr1%Nb at all used temperatures.



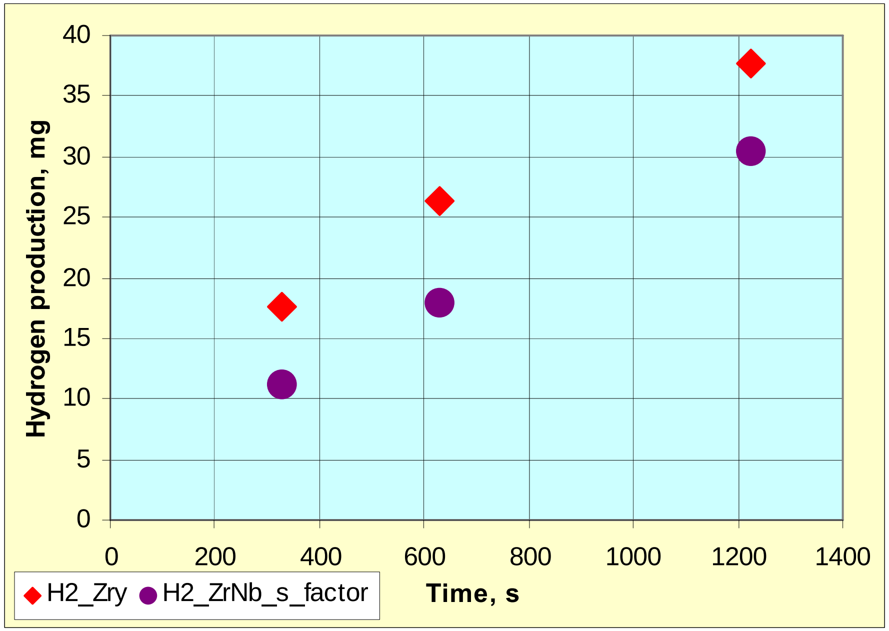


New FZK tests show lower oxidation rate for Zr1%Nb in comparison with Zry-4

Sokolov correlation overestimates the oxidation rate of Zr1%Nb



Comparison of oxide layer thickness



Comparison of hydrogen production

New FZK tests on oxidation of Zry-4 and Zr1%Nb in QUENCH-rig at 1150 °C.

/Cladding probe height ~20 mm, inductive heating/.

Oxidation rate and hydrogen production are lower for Zr1%Nb.

Influence of steam onset initiation during pre-oxidation of the Zr1%Nb claddings at 1150 °C

Steam onset during transient at ~850 °C: spalling of oxide scales

Steam onset during plateau of 1150 °C: homogeneous oxide layer

SUMMARY

• The pre-test calculations for the QUENCH-12 test (WWER bundle) were performed with codes SCDAP/SIM (PSI, Switzerland) and ICARE/CATHARE (KI, Moscow).

• The aim of modelling was the assessment of electrical power and hydrogen production under conditions of reproduction of the same temperature history at elevation 950 mm as during QUENCH-06.

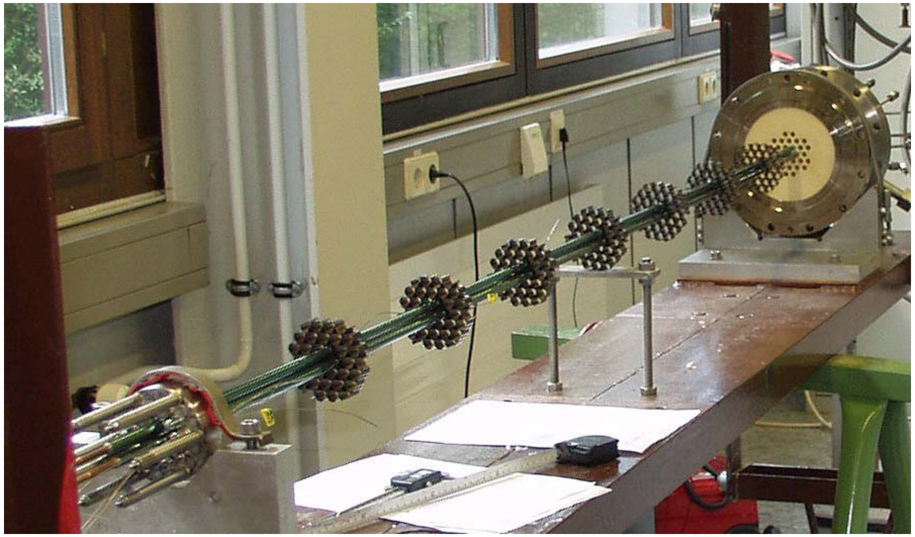
• The separate calculated view factors for the WWER bundle were implemented by SCDAP/SIM.

• Both codes showed that the temperatures at all elevations (except 950 mm) are lower for QUENCH-12 than at the same elevations for QUENCH-06.

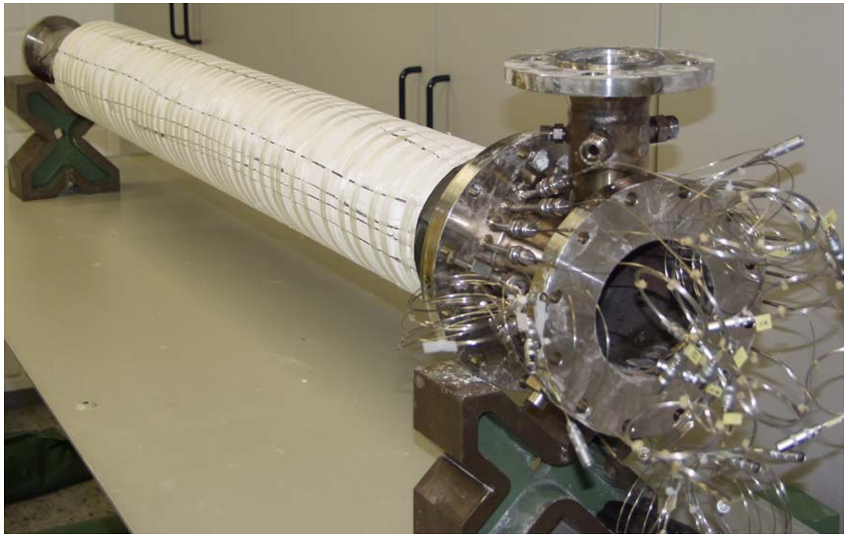
• Two type of oxidation correlations for both codes were used: VNIINM-1993 correlation for Zr1%Nb and the best-estimated correlation for Zircaloy-4. Result of modelling: the applied correlation for Zr1%Nb overestimates the oxidation rate and simultaneously underestimate the hydrogen production.

• New FZK tests on comparison of oxidation rate between Zircaloy-4 and Zr1%Nb show that in the temperature range 1100 °C – 1500 °C the oxidation rate for Zr1%Nb is lower than for Zircaloy-4.

Status of simulator fuel assembly mounting on 26.06.2006



Bundle mounting: running



Shroud mounting: completed