First Results of the QUENCH-13 Bundle Experiment with a Silver-Indium-Cadmium Control Rod

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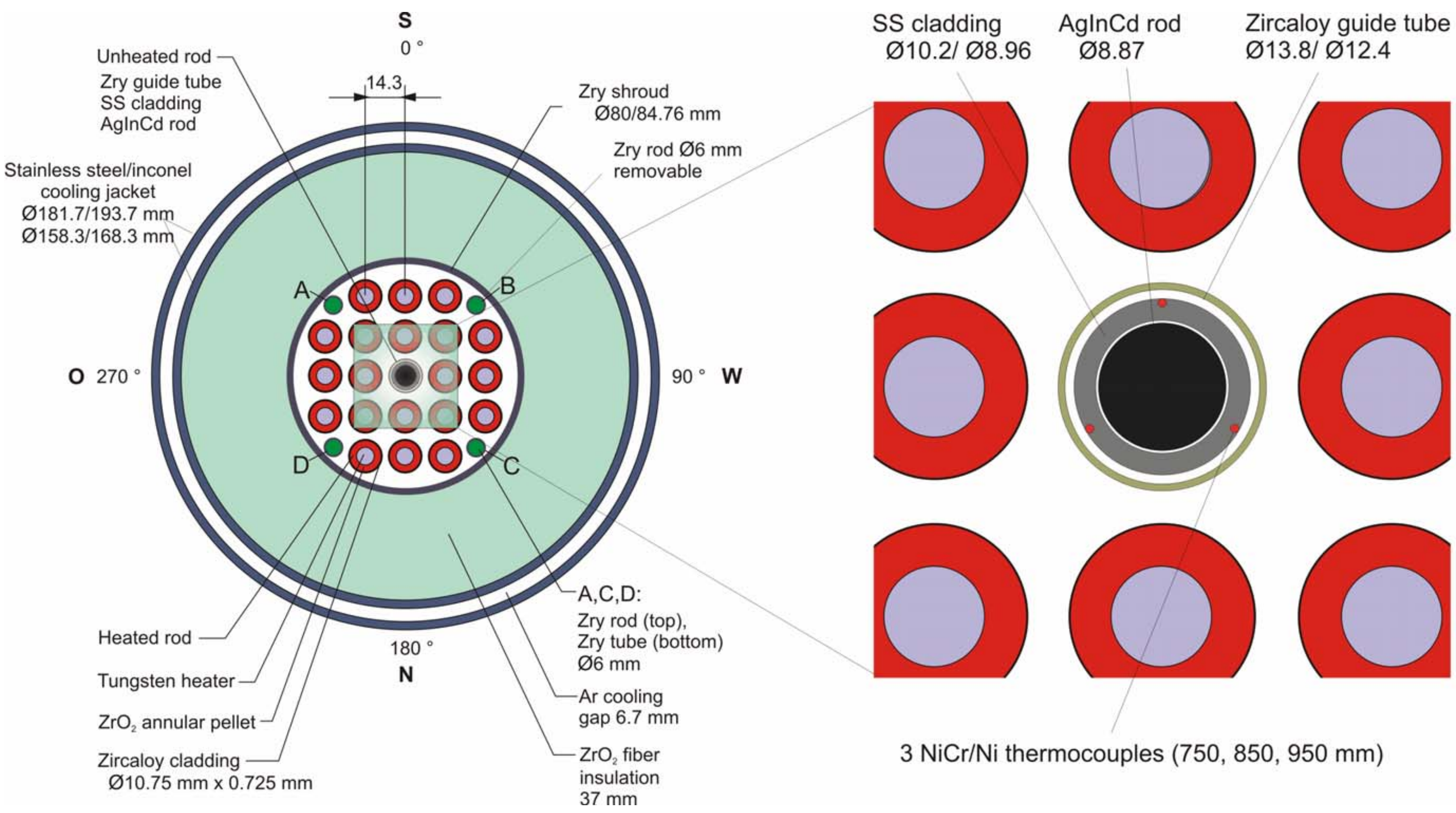
Objectives of the QUENCH-13 test

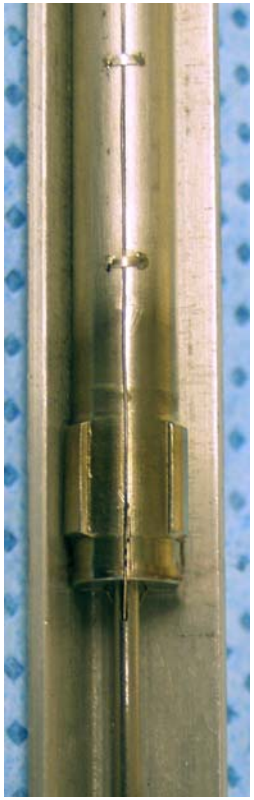
- investigation the effects of the presence of a silver/indium/cadmium (AIC) control rod on early-phase bundle degradation and on reflood behaviour under integral conditions

- measurement, in realistic geometry, release of silver/indium/cadmium aerosols following control rod rupture

QUENCH-13: Cross section of the test bundle



Control rod status



TC fastening at outer surface of cladding

guide tube bottom

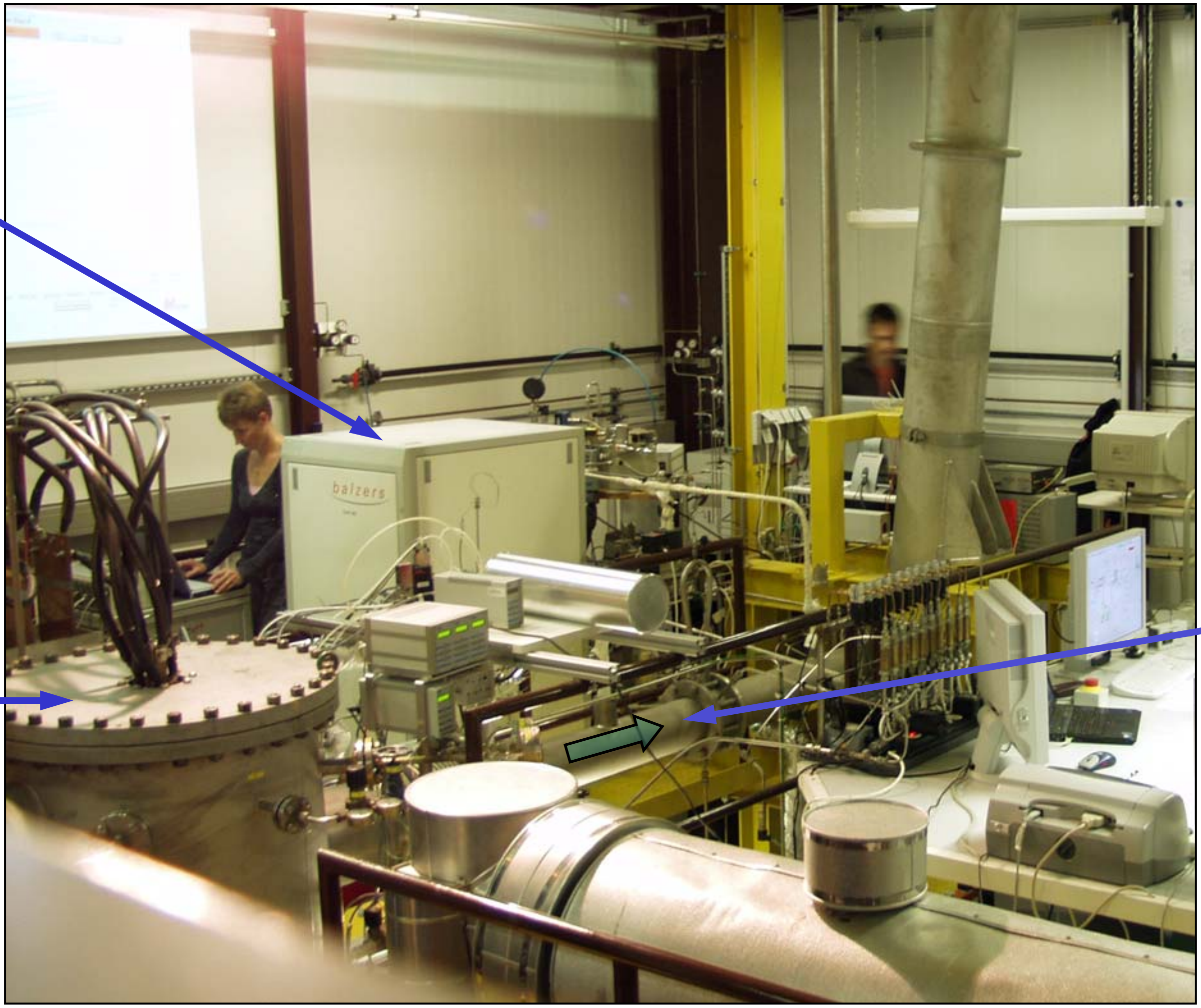
guide tube top

Absorber rod	**material**	**80 Ag, 15 In, 5 Cd (wt-%)**
	dimensions	∅ 8.87 mm, L=1068 mm (Elev. -15 to 1053 mm)
Cladding of absorber rod		**SS**, ∅ 10.2 / 8.96 mm L = 1083 mm (Elev. -20 to 1063 mm)
Guide tube of absorber rod		**Zircaloy-4**, ∅ 13.8 / 12.4 mm L = 1187 mm (Elev. -42 to 1145 mm) Holes (2x**4**): ∅4 mm (Elev. -34 and +1179 mm)
Internal rod pressure of absorber rod		0.12 MPa abs. (He)

Components of the QUENCH facility

mass spectrometer

containment with electrically heated bundle



off-gas pipe

QUENCH-13: connection of PSI and AEKI aerosol measurement devices to the off-gas pipe

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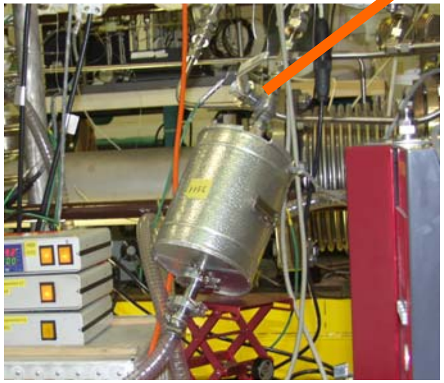
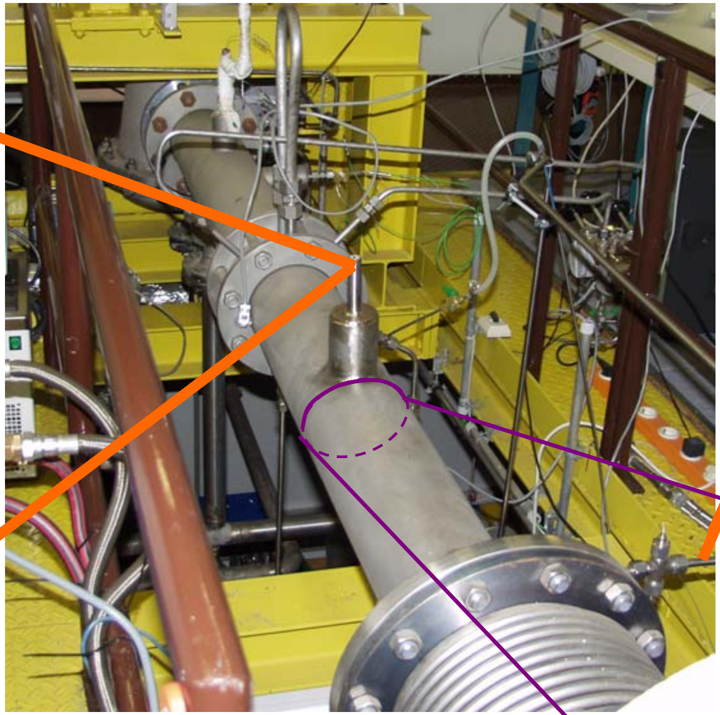
Equipment from PSI

ELPI
online measurement

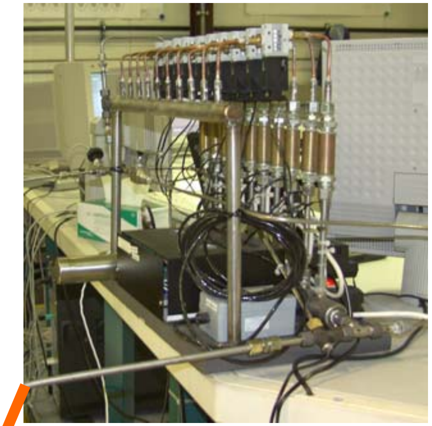


BLPI, 3 time exchanged during the test



off-gas pipe with two sampling points

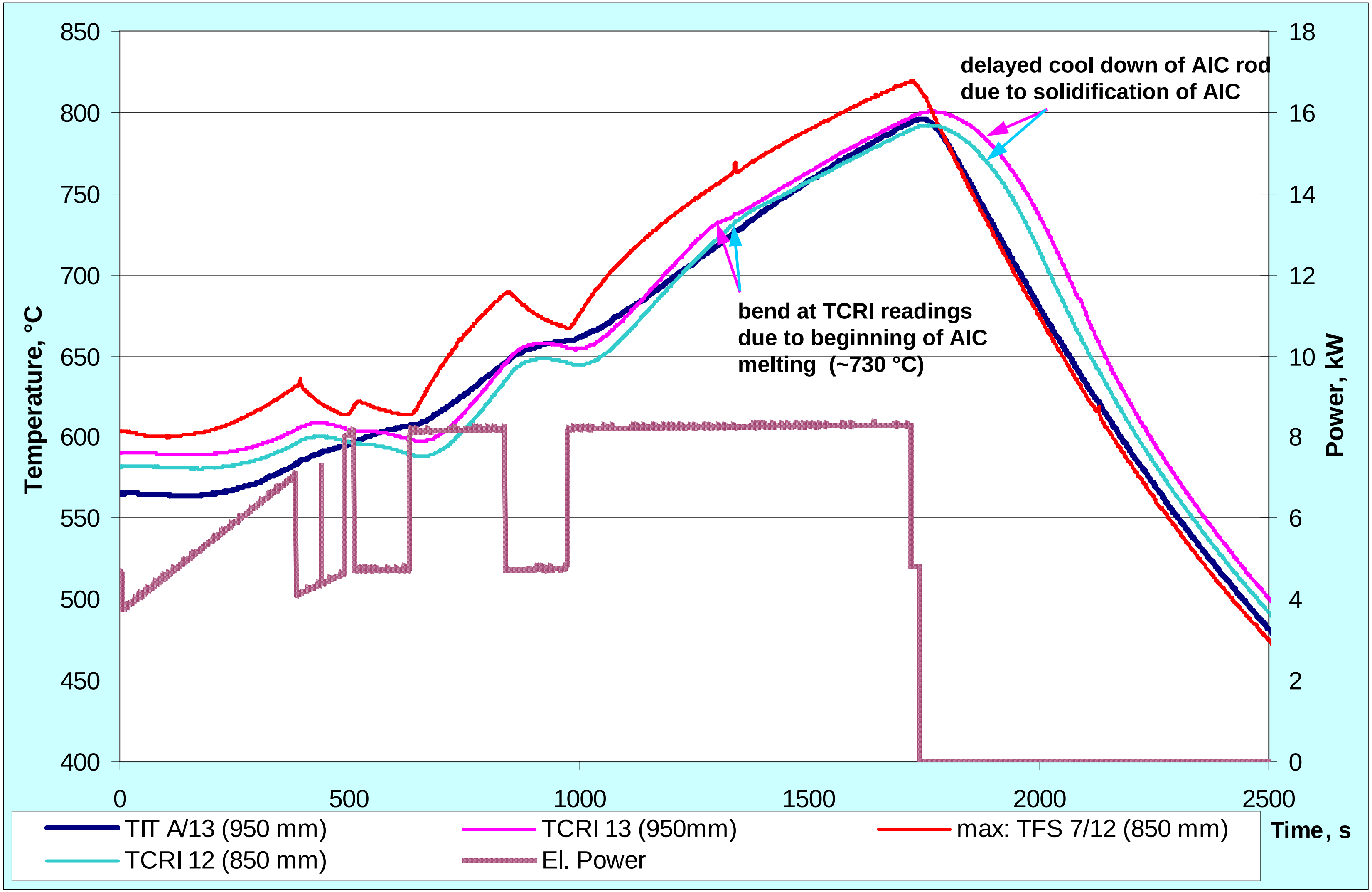
Equipment from AEKI



10 impactors
switched during the test

Ni-plate with pocket
installed inside off-gas pipe
under sampling tube

Preliminary test to investigation of the bundle behaviour and testing of the aerosol measurement equipment.
TC between control rod claddings (TCRI) shows initiation of AIC melting at 850 mm and 950 mm.



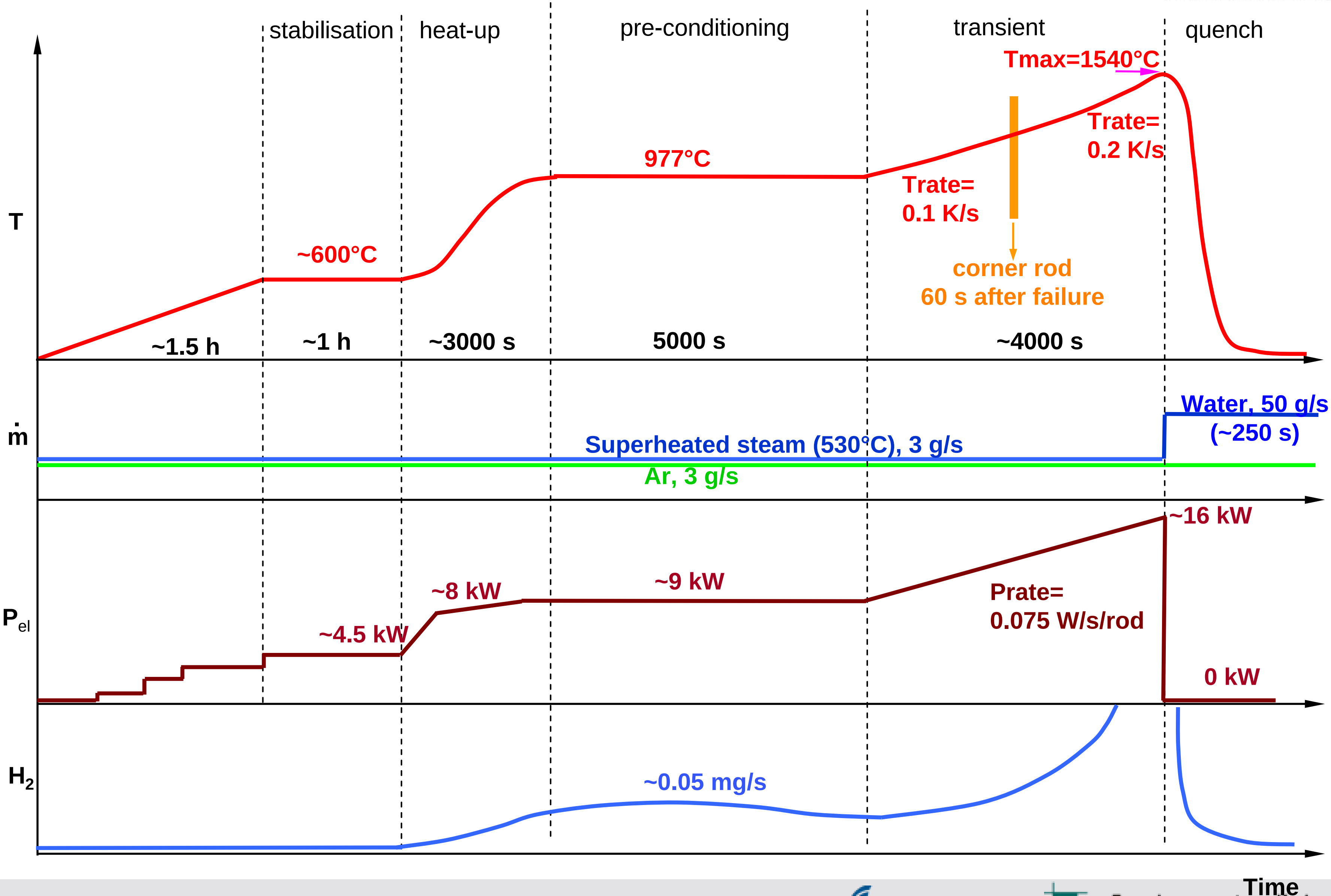
Pretest modelling support:

1. SCDAP/SIM simulations: J. Birchley, T. Haste, *PSI, Switzerland***.**

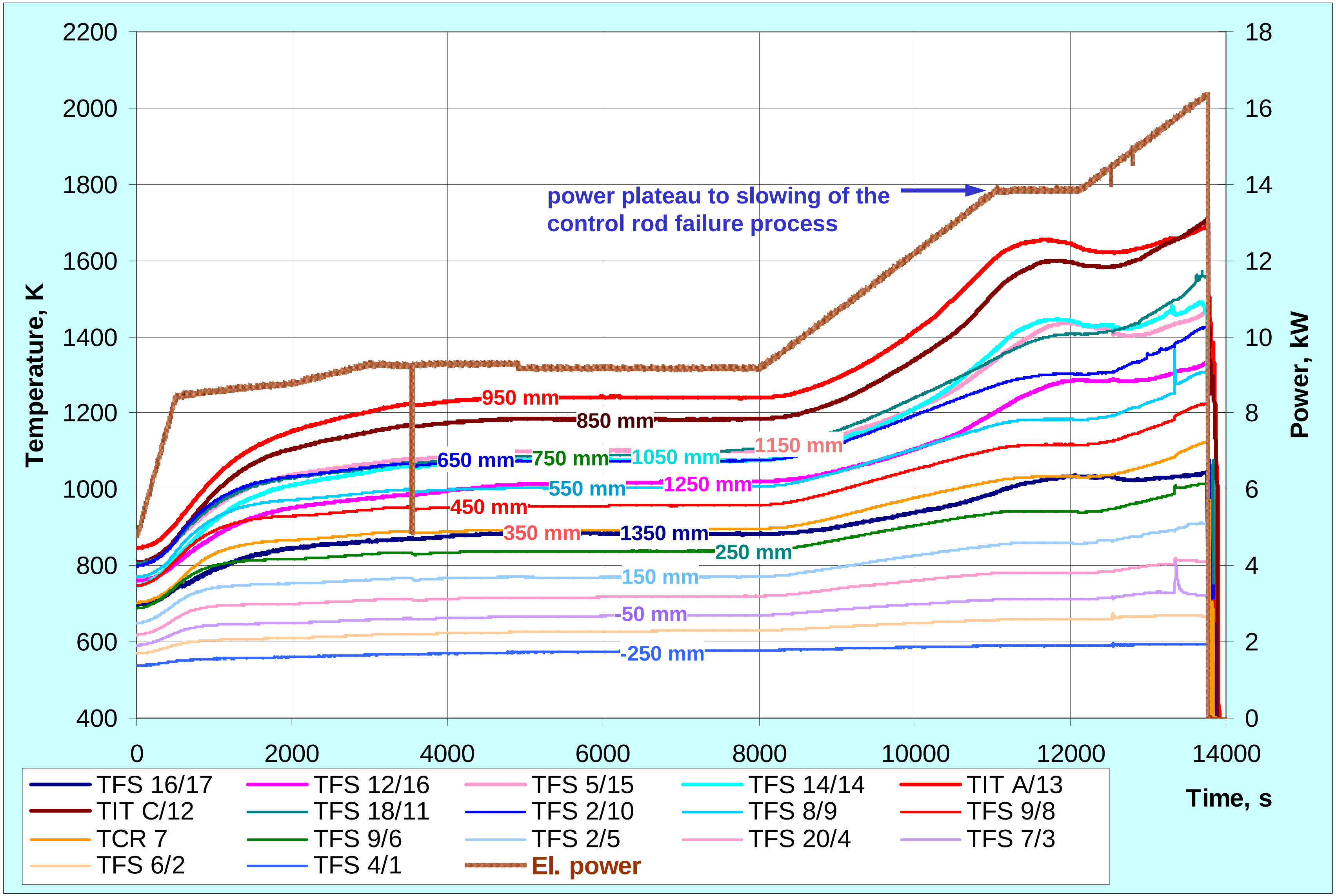
2. ATHLET-CD simulations: H. Austregesilo, Ch. Bals, *GRS*, Germany.

3. MAAP-4 simulations: Y. Dutheillet, EdF, France

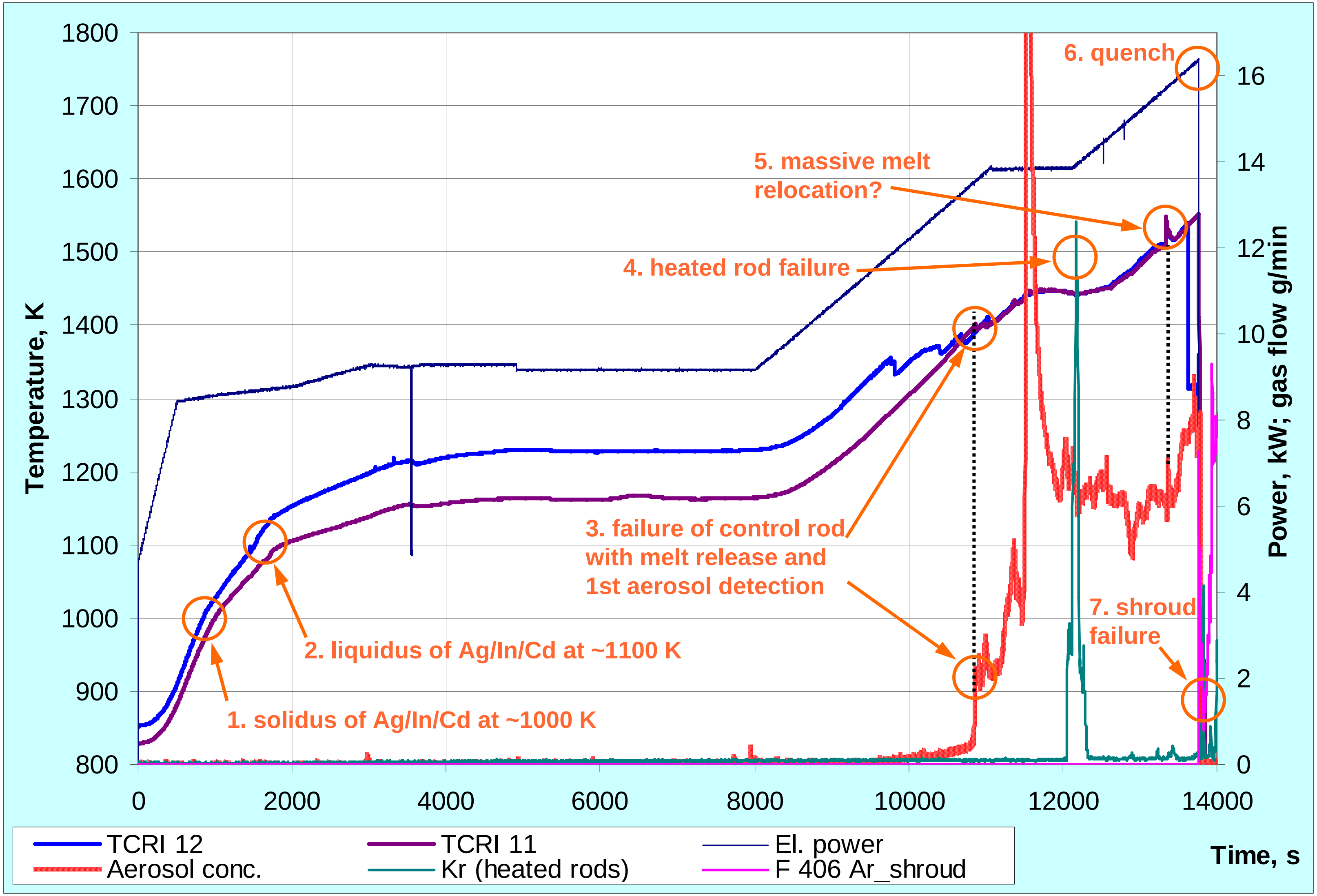
Time scheme of the QUENCH-13 test



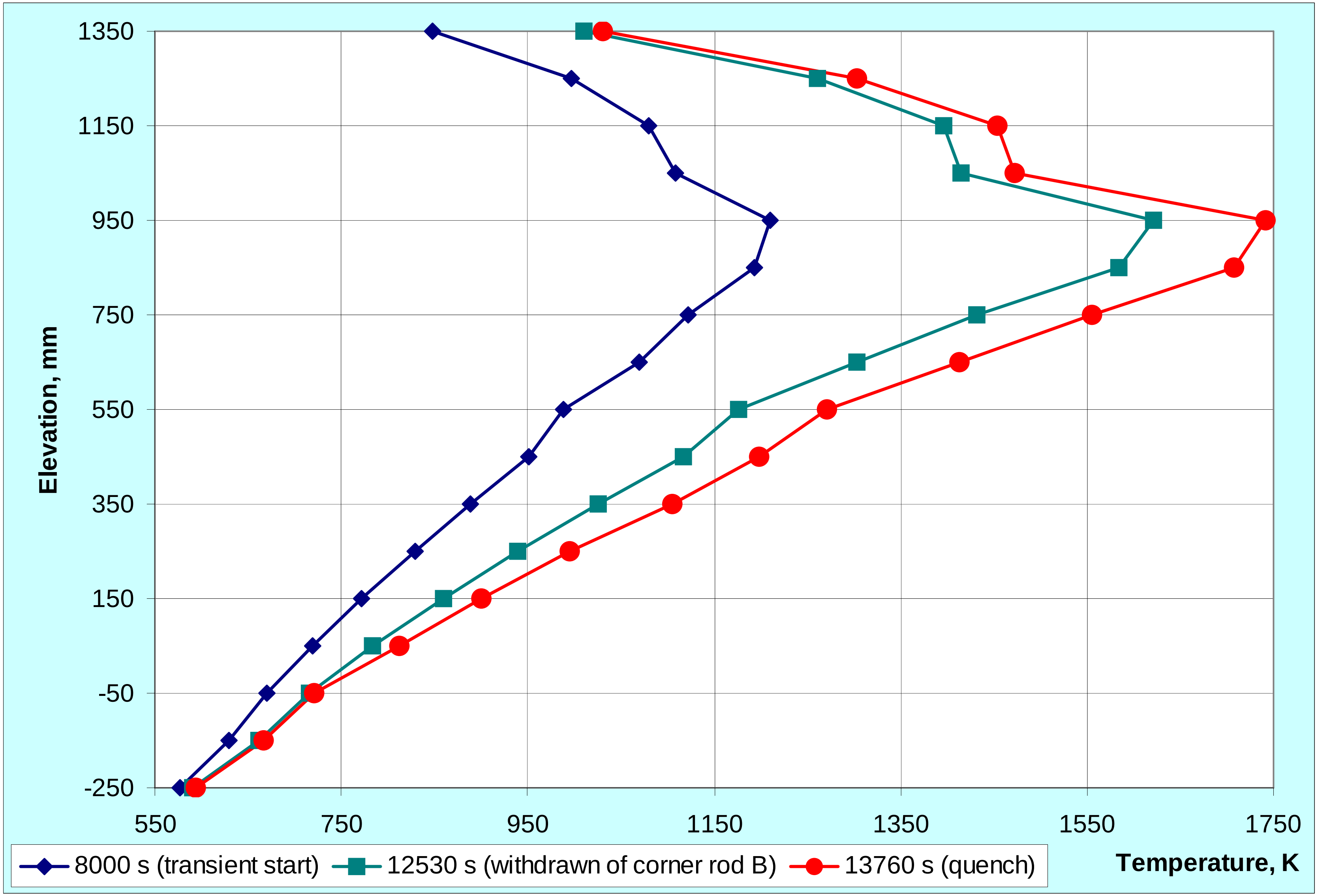
QUENCH-13: selected readings of the bundle thermocouples



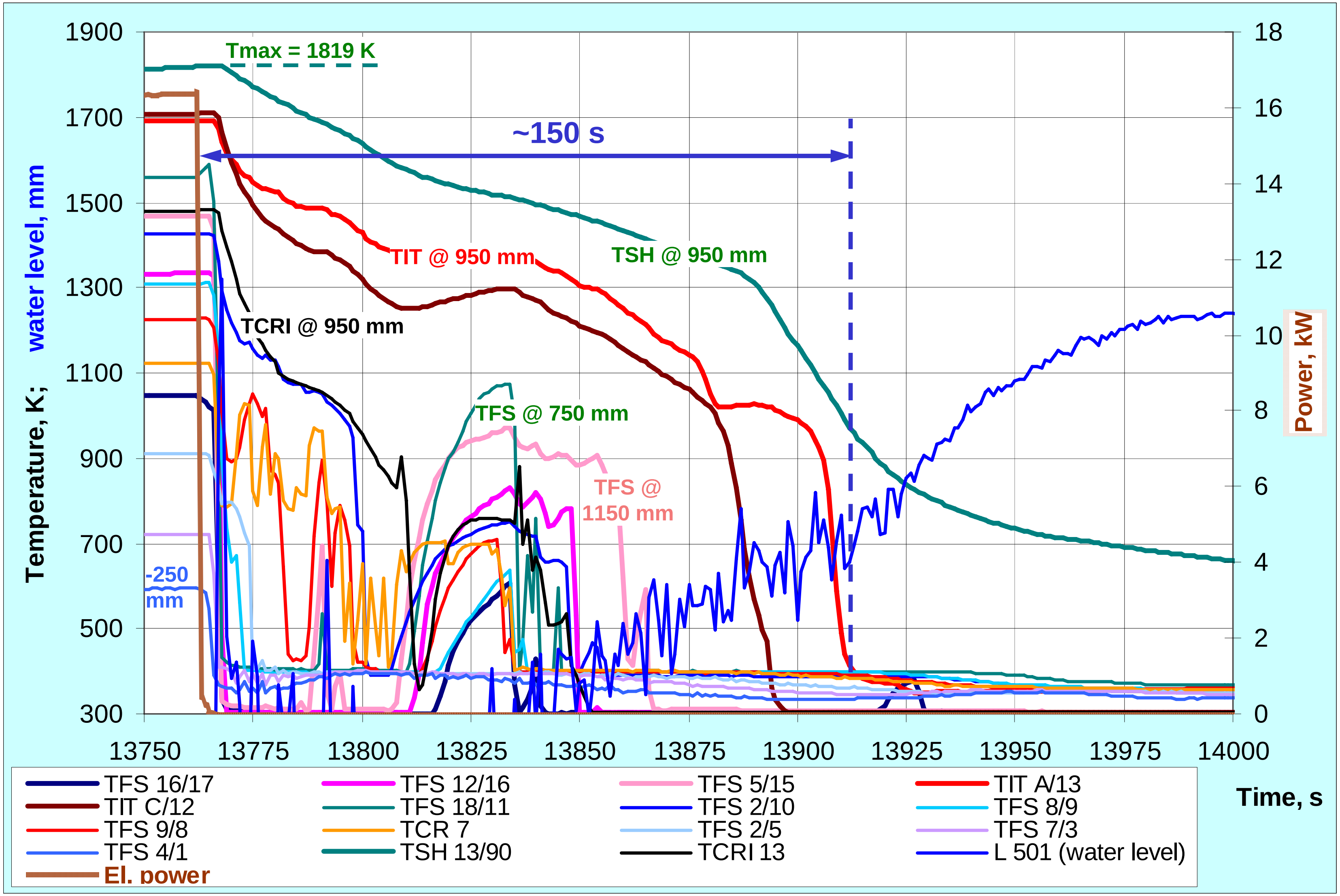
QUENCH-13: sequence of events



QUENCH-13: axial temperature profiles during transient phase



QUENCH-13, quench phase: bundle cooling during ~150 s



QUENCH-13: withdrawn corner rods, breakaway oxidation between 850 and 1000 mm

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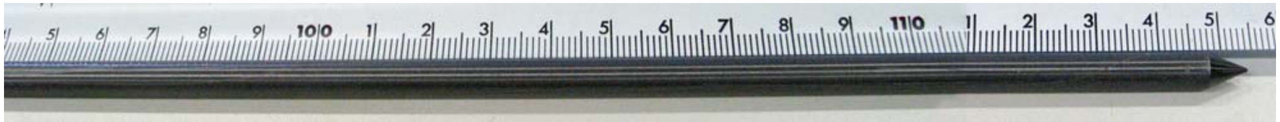
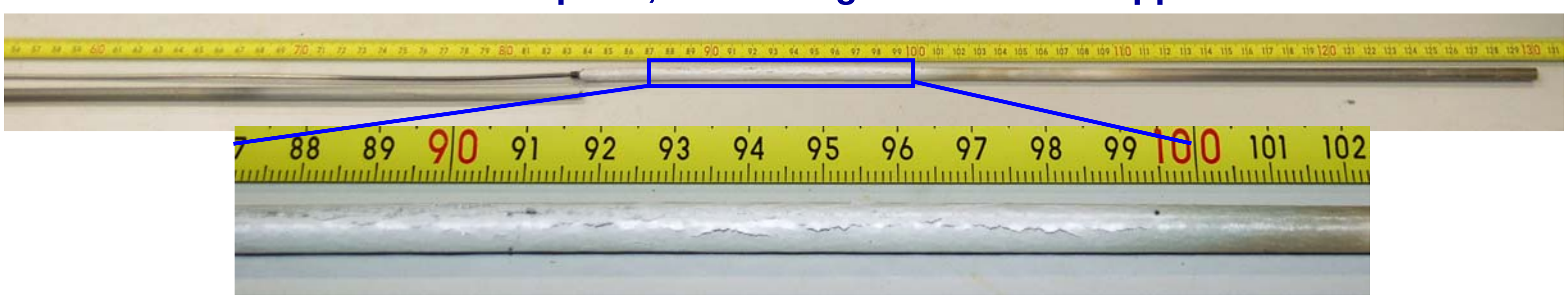
corner rod B after pre-test (800 °C, oxide layer thickness less of 5 µm)



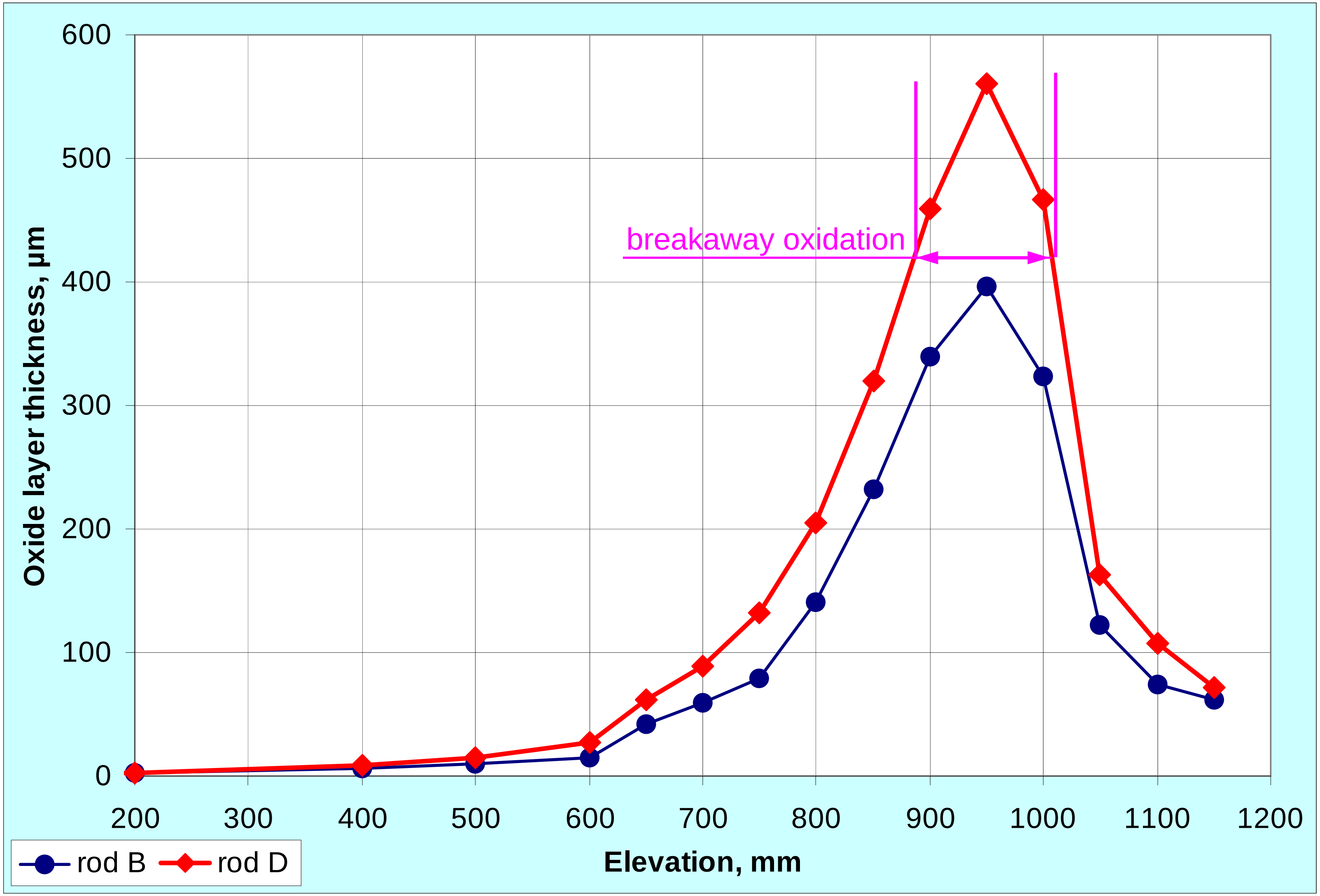
corner rods B, D:
B – withdrawn at 12538 s after corner rod failure (beginning at ~10850 s) ,
D – withdrawn after test.

B
D

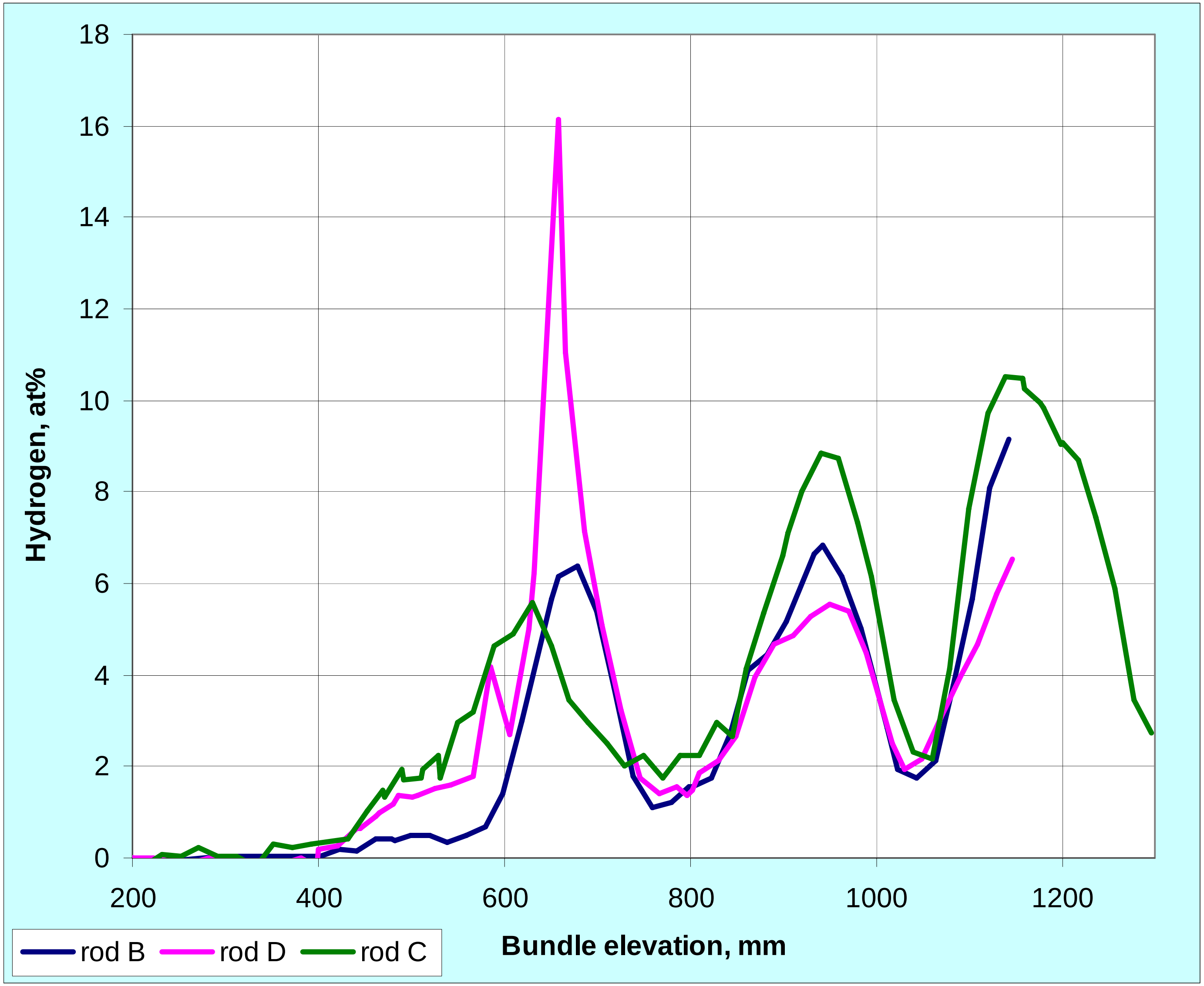
corner rod C:
breached into two parts, lower TC guide tube and upper full rod.

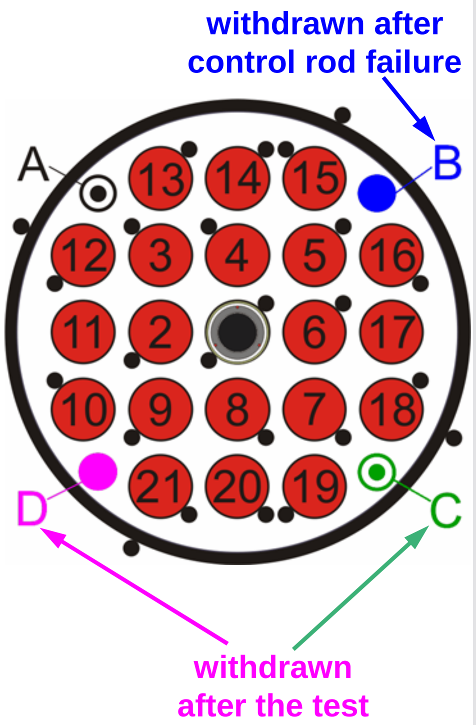


QUENCH-13: axial oxide layer thickness distribution measured with eddy current



QUENCH-13: hydrogen uptake by corner rods
/results of neutron radiography by PSI (M. Große)/

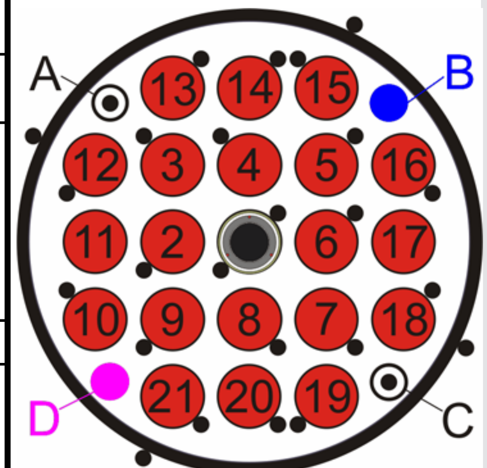




QUENCH-13, videoscope: cracks formation and ZrO_2 spalling in upper part of the bundle

	
rod B: 1050 mm, circumf. crack at rod 5	rod D: 1050 mm, circumf. crack at rod 21
	
rod B: 990 mm, spalling at shroud and lost of cladding piece at rod 16	rod D: 1020 mm, spalling of friable outer oxide sub-layer at rod 10
	
rod B: 950 mm, spalling at shroud and rod 6	rod D: 930 mm, crack at rod 9, spalling at rod 8
	
rod B: 880 mm, spalling at rods 16 & 6	rod D: 880 mm, spalling at rod 21
	
rod B: 650 mm, bulk dense oxide layer	rod D: 670 mm, boundary between surface friable and bulk dense oxide layers

positions of videoscope observations: 2 corner rods



QUENCH-13, videoscope: Ag/In/Cd melt relocation into lower part of the bundle

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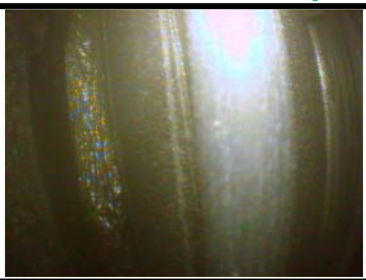
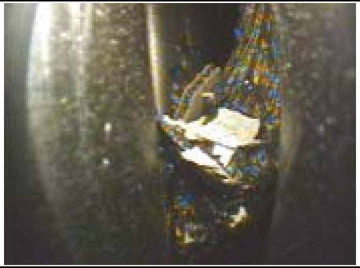
rod D: 550 mm, lower edge of spacer grid SG 3

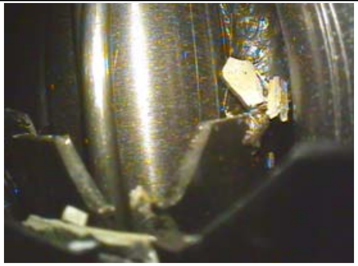


rod C: 550 mm, solidified melt behind rod 7



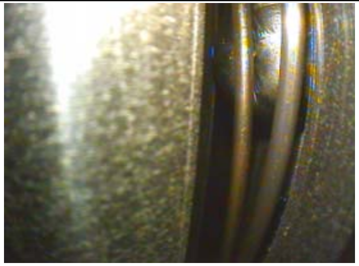
rod D: 250 mm, solidified melt with SG debries

rod C: 250 mm, solidified melt at rod 8

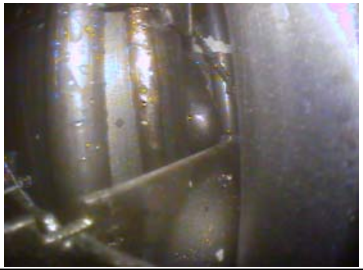


rod D: 190 mm, upper edge of spacer grid SG 2

rod C: 50 mm, solidified melt at rod 6

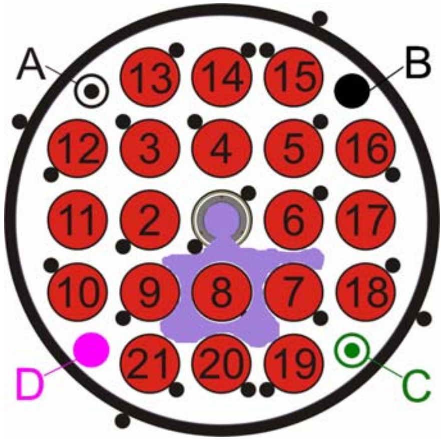


rod D: 20 mm, 130 mm under SG2

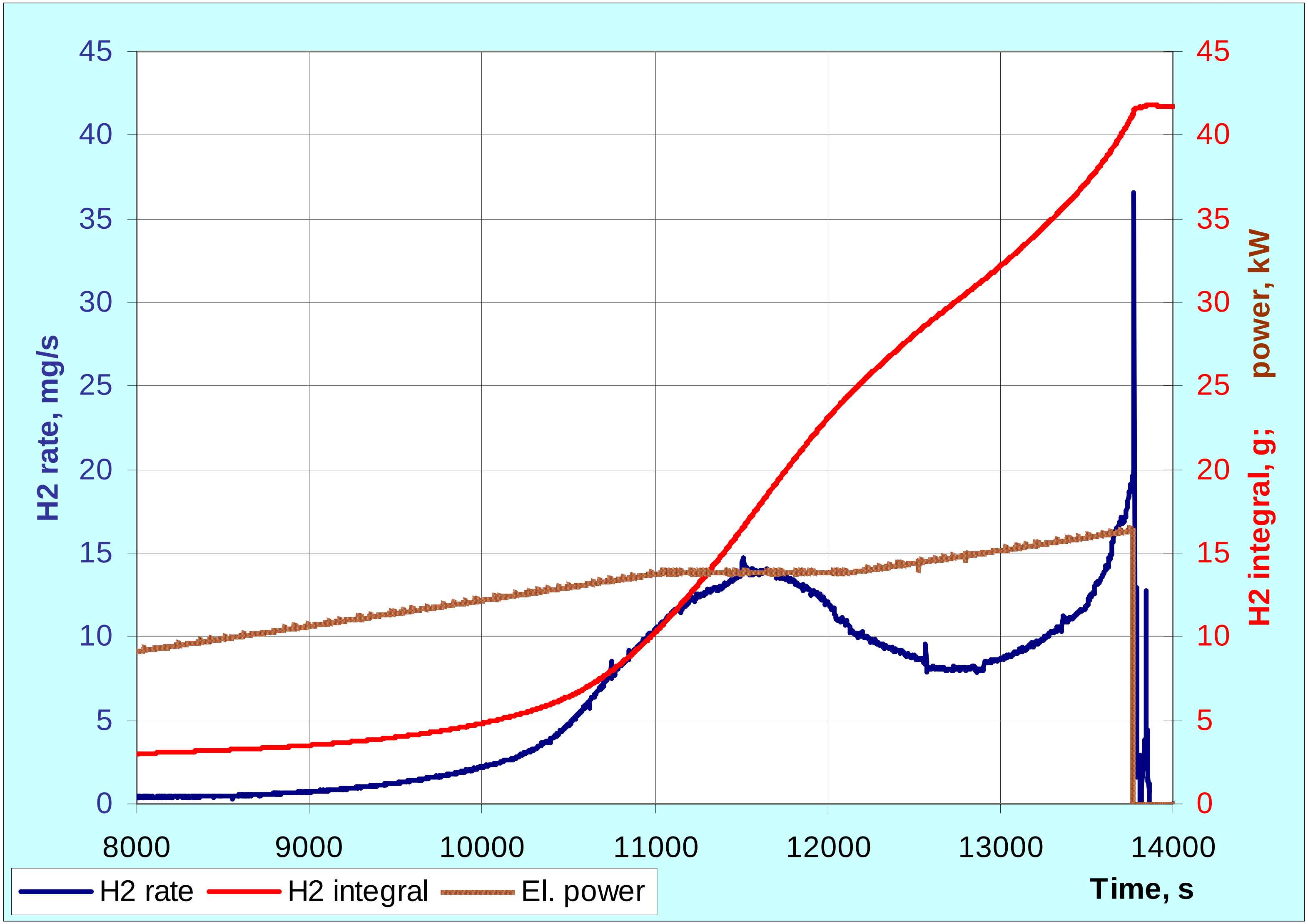


rod C: -50 mm, upper edge of SG1

probable Ag/In/Cd melt distribution (axial: between 3rd and 1st spacer grids):

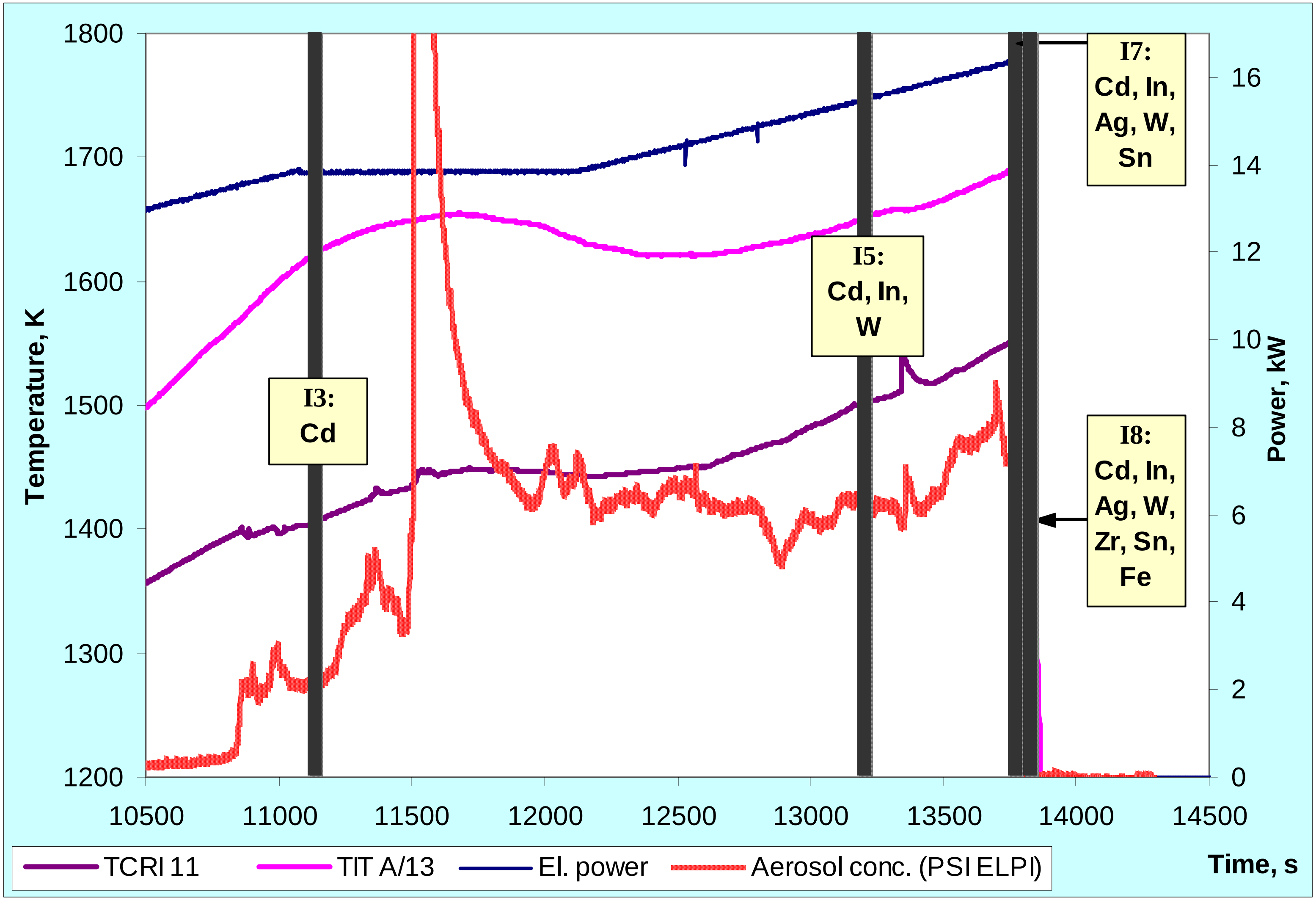


QUENCH-13: hydrogen release

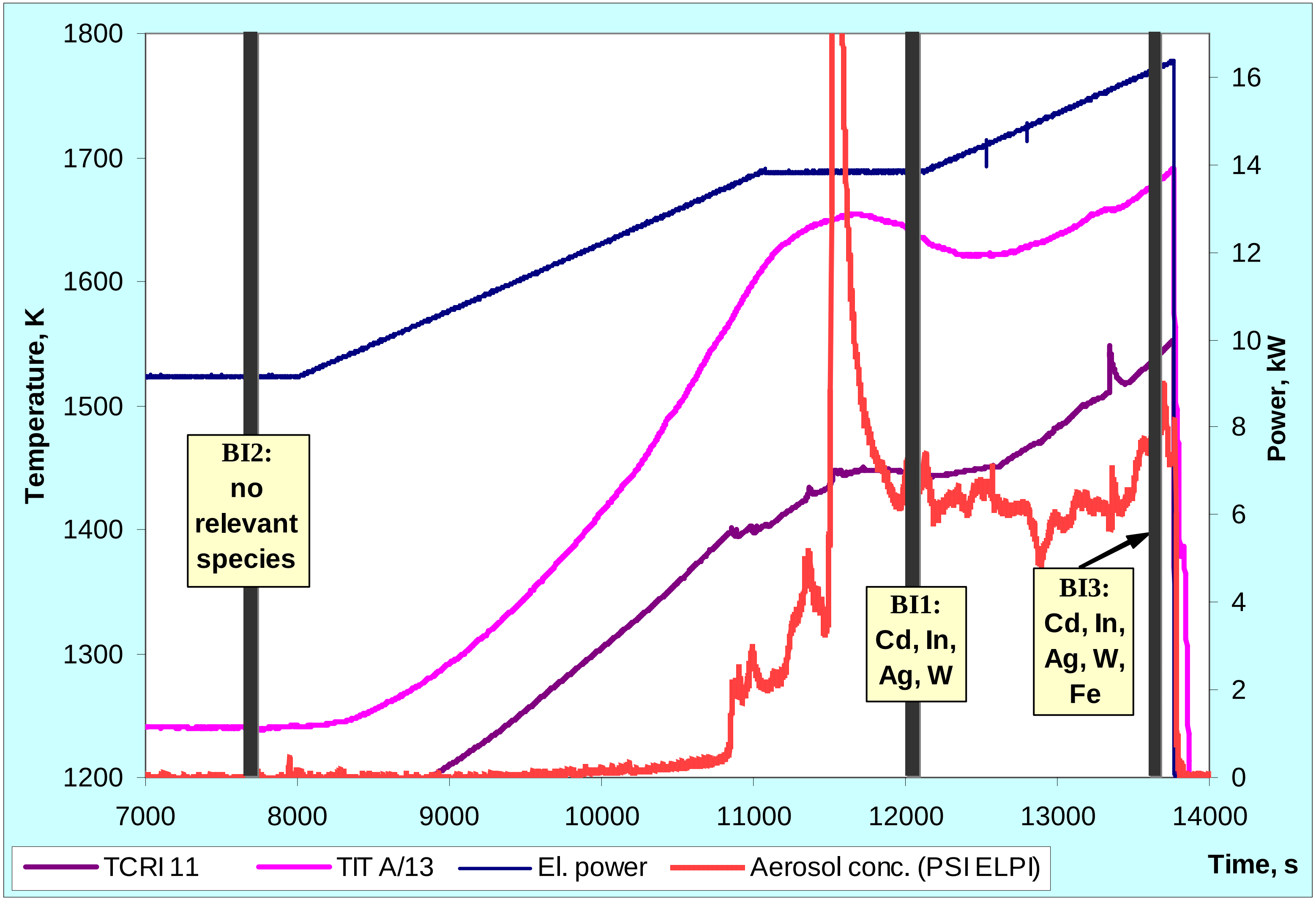


H_2 production before reflood ~42 g, during reflood ~0.5 g

QUENCH-13: AEKI aerosol measurement at bundle outlet. Analysis of impactors content.

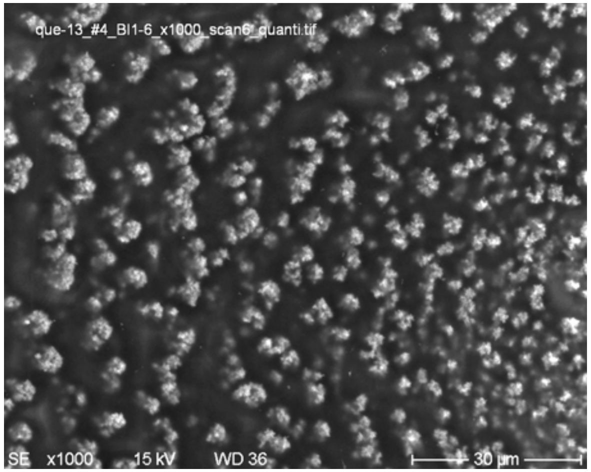


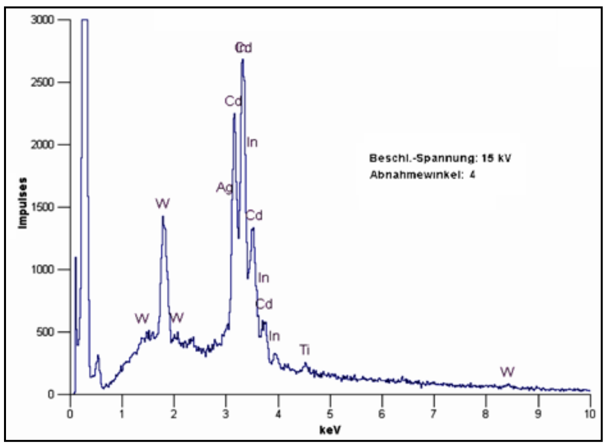
QUENCH-13: PSI aerosol measurement at bundle outlet. Analysis of BLPI impactors content.



QUENCH-13: quantitative analysis of PSI BLPI impactors content

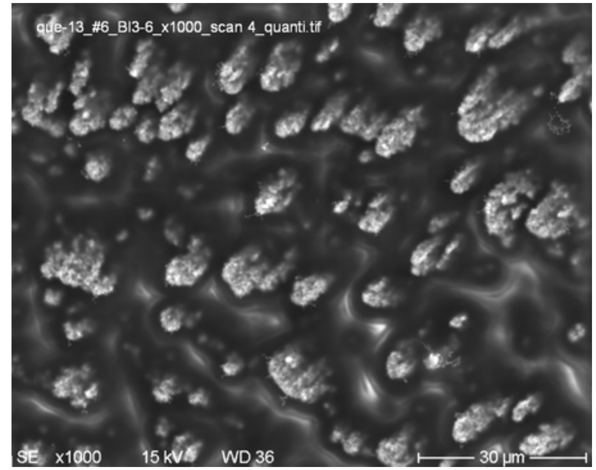
Sample BI1: collected after control rod failure

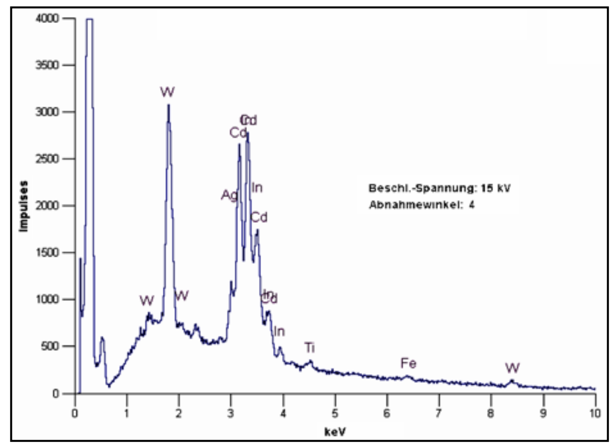




	Cd	In	Ag	W
wt%	42	41	2.5	14.5

Sample BI3: collected before reflood





	Cd	In	Ag	W	Fe
wt%	33	31	8	27	1

SUMMARY

- The QUENCH-13 experiment investigated the effects of the presence of a Ag/In/Cd control rod on early-phase bundle degradation. Different aerosol measurement equipment was used, amongst others the on-line monitoring system.

- The preliminary test at the maximum temperature 800°C was performed. Melting of absorber material was shown by changes in heat-up rate at temperatures of about 1000 K (solidus).

- The electrical power changing during the test corresponds completely to calculated values up to the control rod failure, which was detected with intensive aerosol release. Then the temporary power plateau was applied to delay the process of the control rod degradation.

- A first corner rod was withdrawn following the control rod failure. A maximum oxide layer thickness of ~400 µm was reached at elevation 950 mm. A second and a third corner rods, which were withdrawn after the test, have a maximum oxide layer thickness of ~550 µm and evident development of cracks inside the oxide layer. Axial distribution of accumulated hydrogen shows 3 peaks with maximum of 16%.

SUMMARY (cont.)

- The test was terminated at Tmax = 1813 K, by reflood with cold water at 52 g/s, and switching off the electrical power. The total hydrogen production was ~42 g. Only negligible mass of hydrogen (~0.5 g) was released during the reflood.

- Some failure of heated rods occurred during a second part of the transient phase (after the power plateau), while shroud failure was observed just after the initiation of reflood.

- EDX analysis of aerosols collected after control rod failure shows significant content of Cd (42 wt%) and In (41 wt%) with minor parts of Ag and W. The content of Ag and W increased during the following transient.

- The post-test videoscope investigations of the bundle were performed at positions of three withdrawn corner rods. The relocated Ag/In/Cd melt was detected between third (550 mm) and first (-150 mm) spacer grids.