First results of the QUENCH-20 test with BWR bundle

J. Stuckert, M. Große, J. Laier, J. Moch, U. Peters, U. Stegmaier, M. Steinbrück

Abstract

Experiment QUENCH-20 with BWR geometry simulation bundle was successfully conducted at KIT on 9th October 2019. This test was performed in the framework of international access SAFEST infrastructure with the users from Swedish Radiation Safety Authority (SSM) in cooperation with Westinghouse Sweden, GRS and KTH.

The test objective was the investigation of a BWR fuel assembly degradation including a B_4C control blade. The test bundle mock-up represents one quarter of a BWR fuel assembly. The 24 electrically heated fuel rod simulators were filled separately with krypton (overpressure of 4 bar).

According to the pre-test calculations performed with ATHLET-CD, the bundle was heated to a temperature of 1230 K at the cladding of the central rod at the hottest elevation of 950 mm. This pre-oxidation phase in steam lasted 4 hours. Towards the end of this phase, the reference rod was extracted from the test bundle for determination of the oxide thickness axial distribution.

During the transient stage, the bundle was heated to a maximal temperature of 2000 K. The cladding failures were observed at temperature about 1700 K and lasted about 200 s. Massive absorber melt relocation was observed 50 s before the end of transition stage.

The test was terminated with the quench water injected with a flow rate of 50 g/s from the bundle bottom. Fast temperature escalation from 2000 to 2300 K during 20 s was observed. The mass spectrometer measured release of CO_x and few CH_4 during the reflood as products of absorber oxidation; corresponding production of B_2O_3 should be about 97 g. Hydrogen production during the reflood amounted to 32 g (57.4 g during the whole test) including 10 g from B_4C oxidation.

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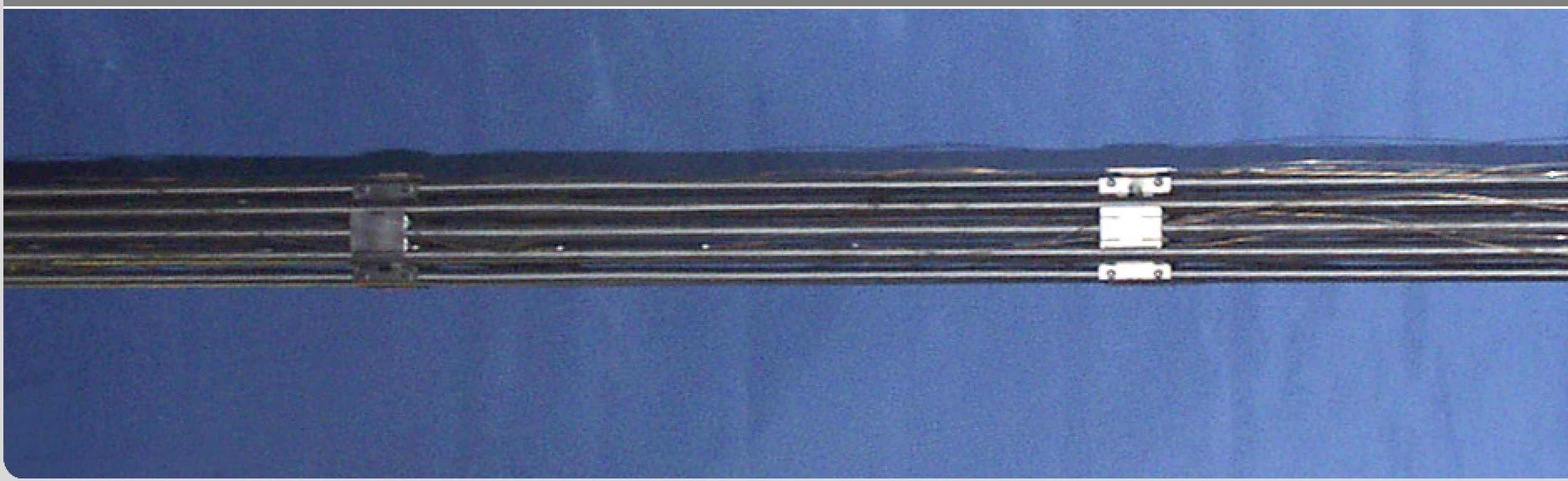
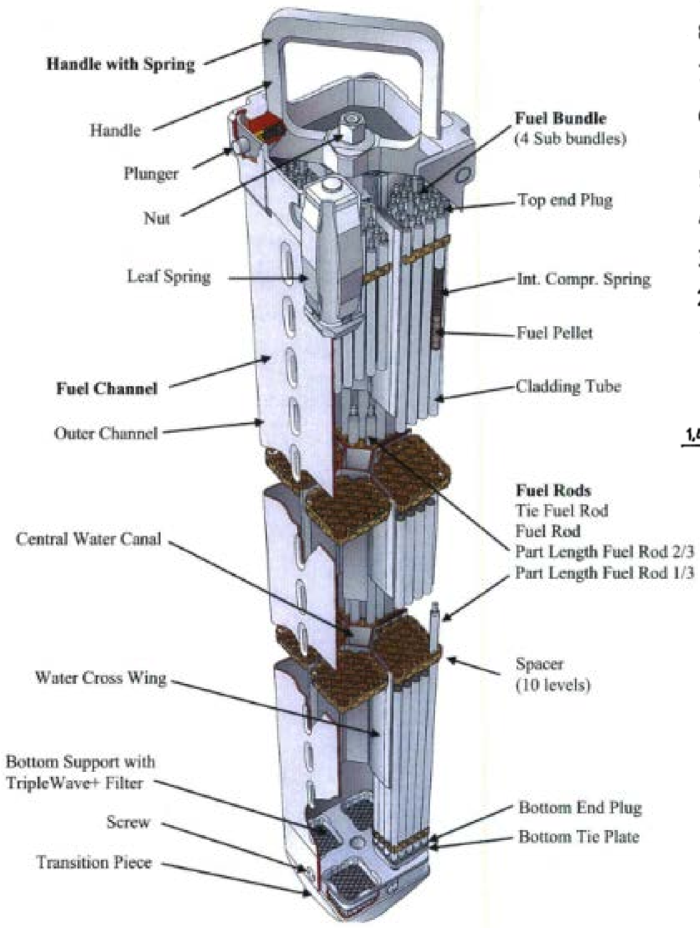
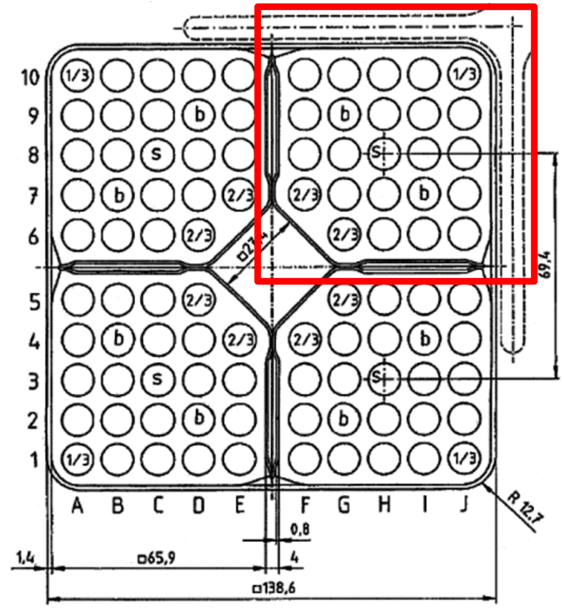
Institute for Applied Materials; Program NUSAFE



QUENCH-20 (SAFEST): Choice of BWR elements, which should be simulated during QUENCH-SAFEST

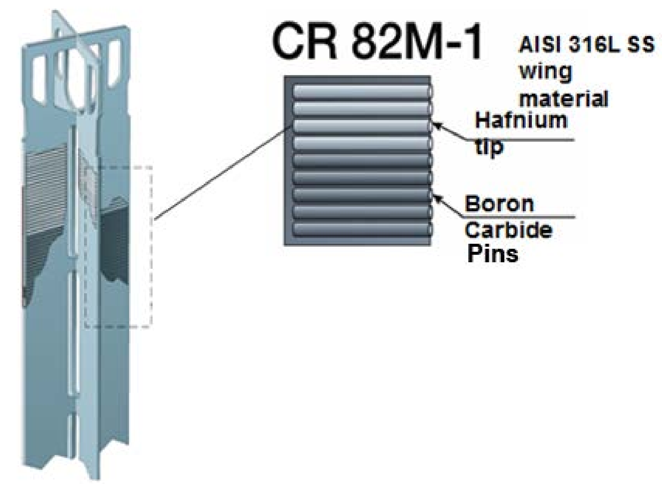


assembly SVEA-96 Optima



assembly cross section

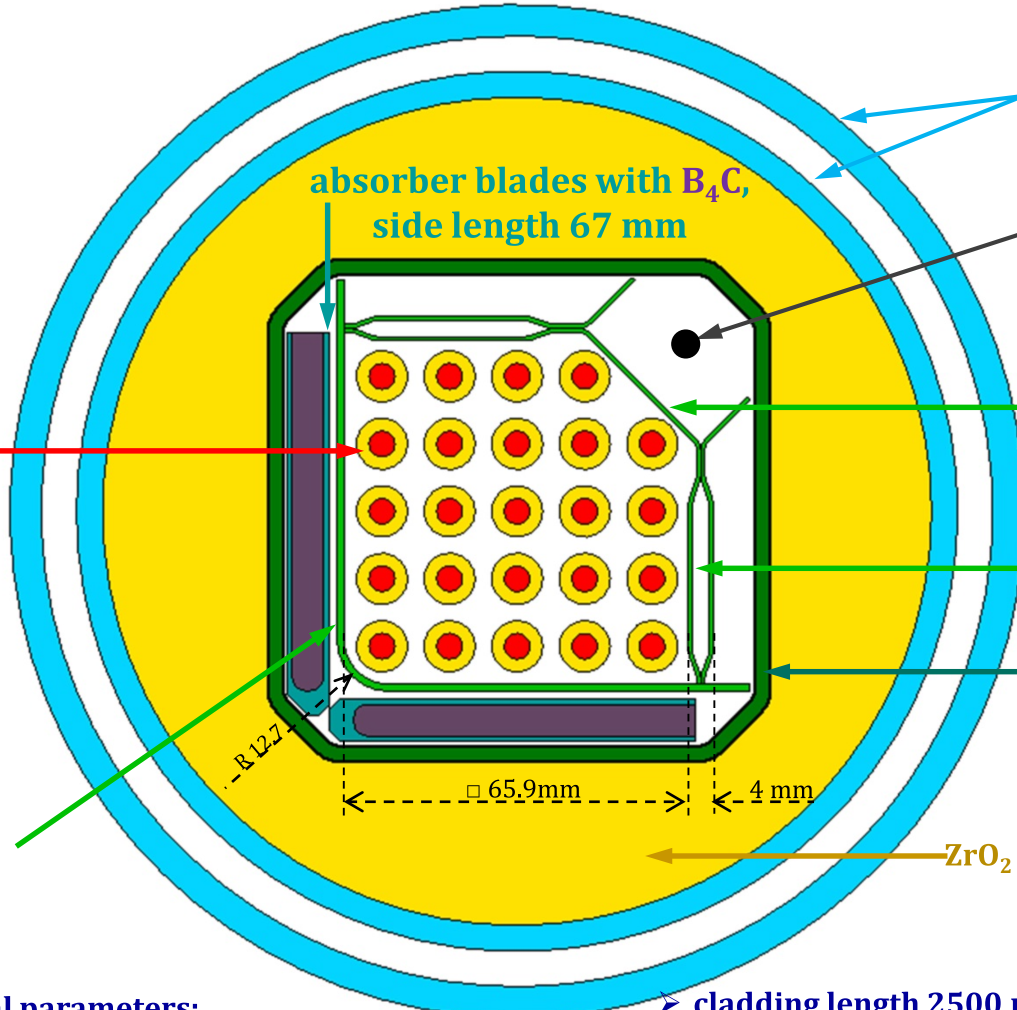
SSM proposal: study of high temperature degradation of BWR assembly mock-up in QUENCH facility (melt formation due to <u>eutectic material interaction</u> inside absorber cross)



absorber cross

QUENCH-20: suggested test bundle composition (¼ SVEA-96 OPTIMA2 assembly)

Karlsruhe Institute of Technology



Geometrical parameters:

- bundle pitch 12.898 mm;
- outer diameter of claddings 9.84 mm;
- thickness of claddings 0.605 mm;
- absorber blades: thickness 8.05 mm
- cladding length 2500 mm
- absorber and cannel box lengths 1600 mm
- water gap between channel box and absorber blade 2.5 mm (nominal inter-assembly gap in BWR-PROTEUS core is 13.8 mm -> water gap 2.875 mm)

QUENCH-20: delivered parts

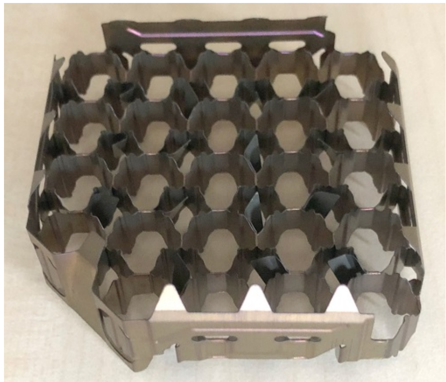
Zr shroud

channel box (low tin ZIRLO)

absorber blade (stainless steel)

horizontal holes for B_4C pins

B_4C pin



sleeve type spacer grid Inconel X750

claddings (Zry-2 with inner ZrSn liner)

QUENCH-20: instrumentation and preparation of parts

Q20 bundle instrumented with TCs

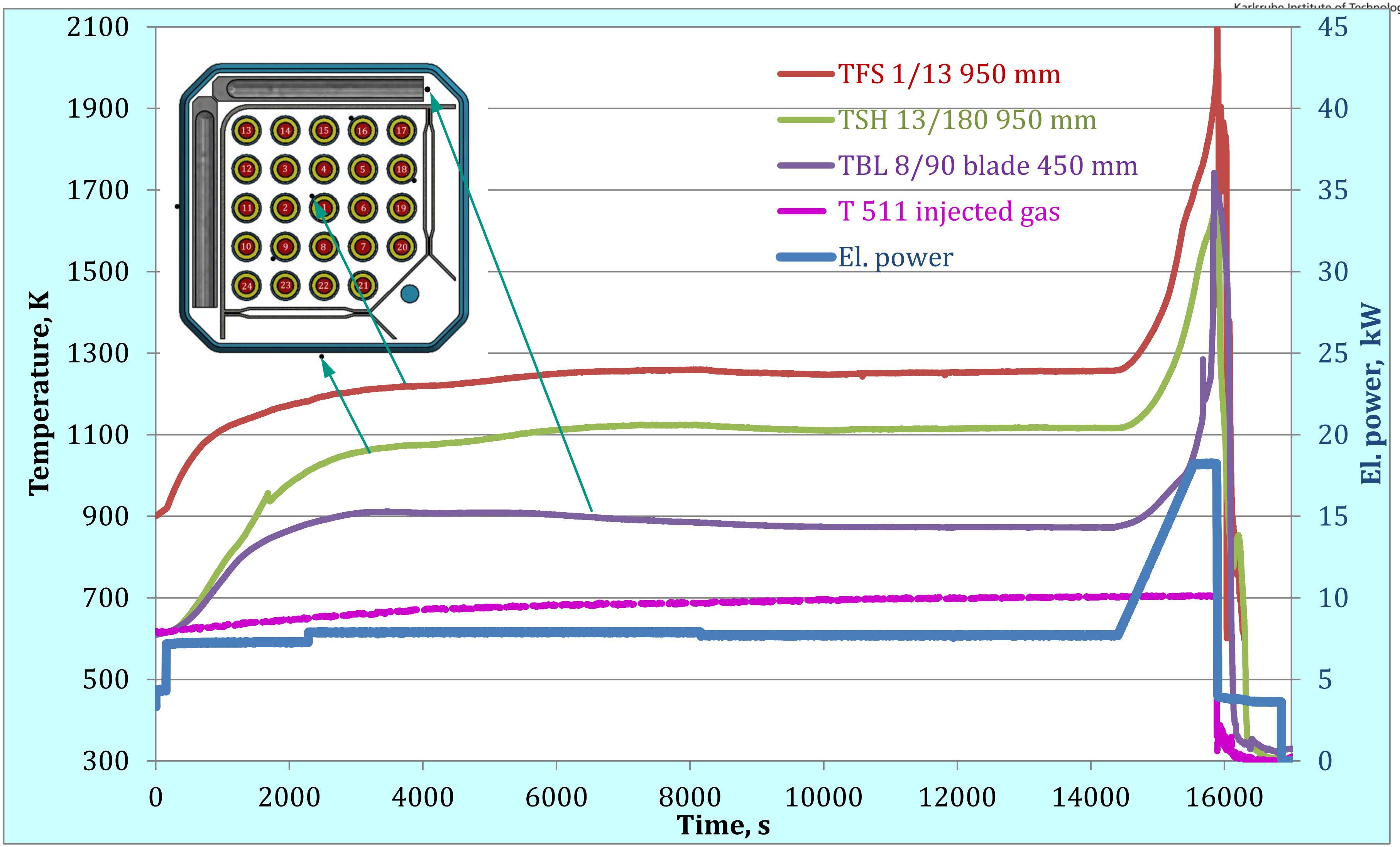
low temperature TC at shroud surface

high temperature TC at clad surface

Zr shroud connected to bundle foot

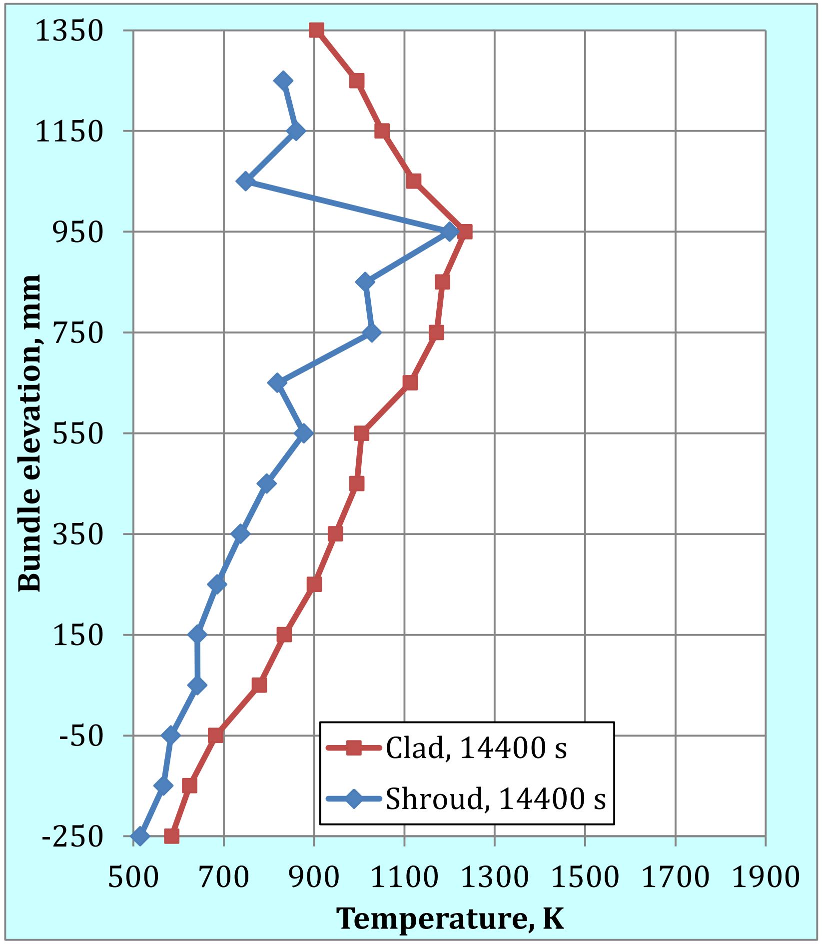
absorber blades filled with B4C pins and prepared for filling with He, then welded

QUENCH-20: test scenario

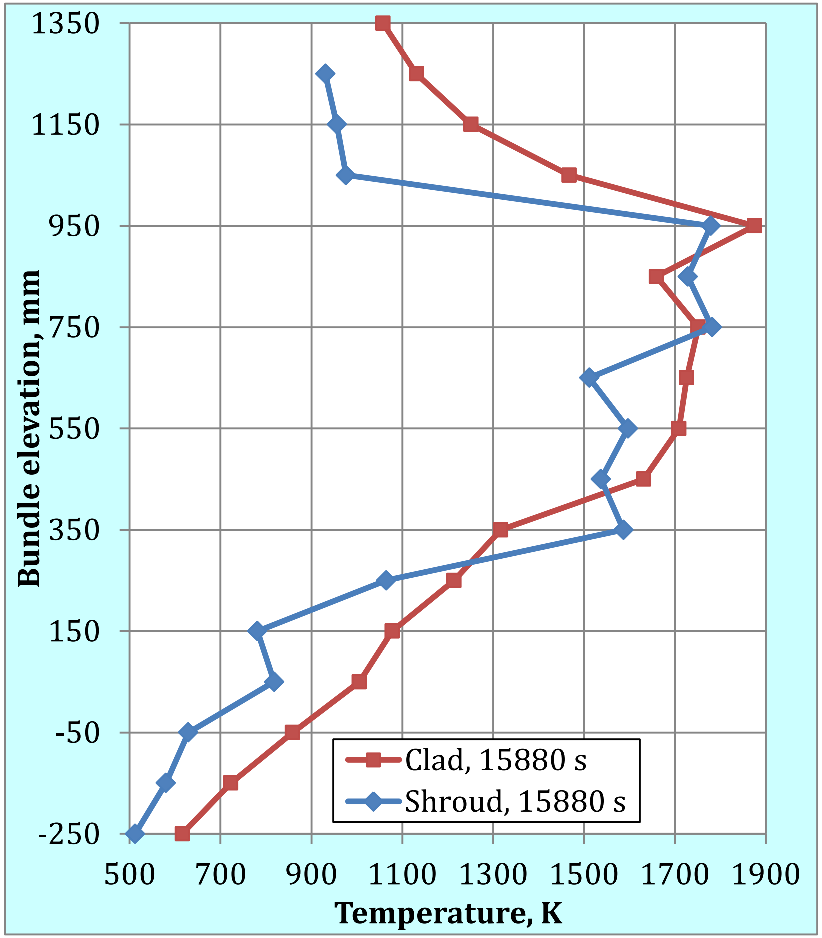


gas injection: Ar 3g/s during the whole test; superheated steam 3 g/s until the quench initiation

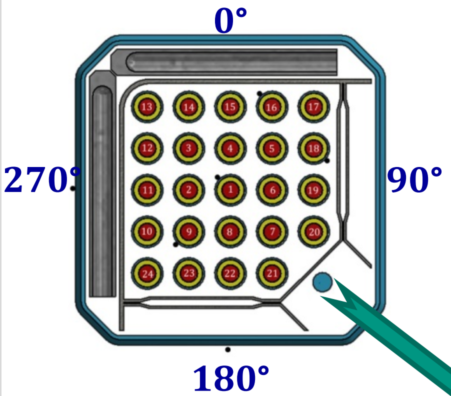
QUENCH-20: axial temperature profiles of outer cladding surfaces and outer shroud surface (temperatures averaged through the cross-section for each elevation)



on the end of pre-oxidation (14400 s)

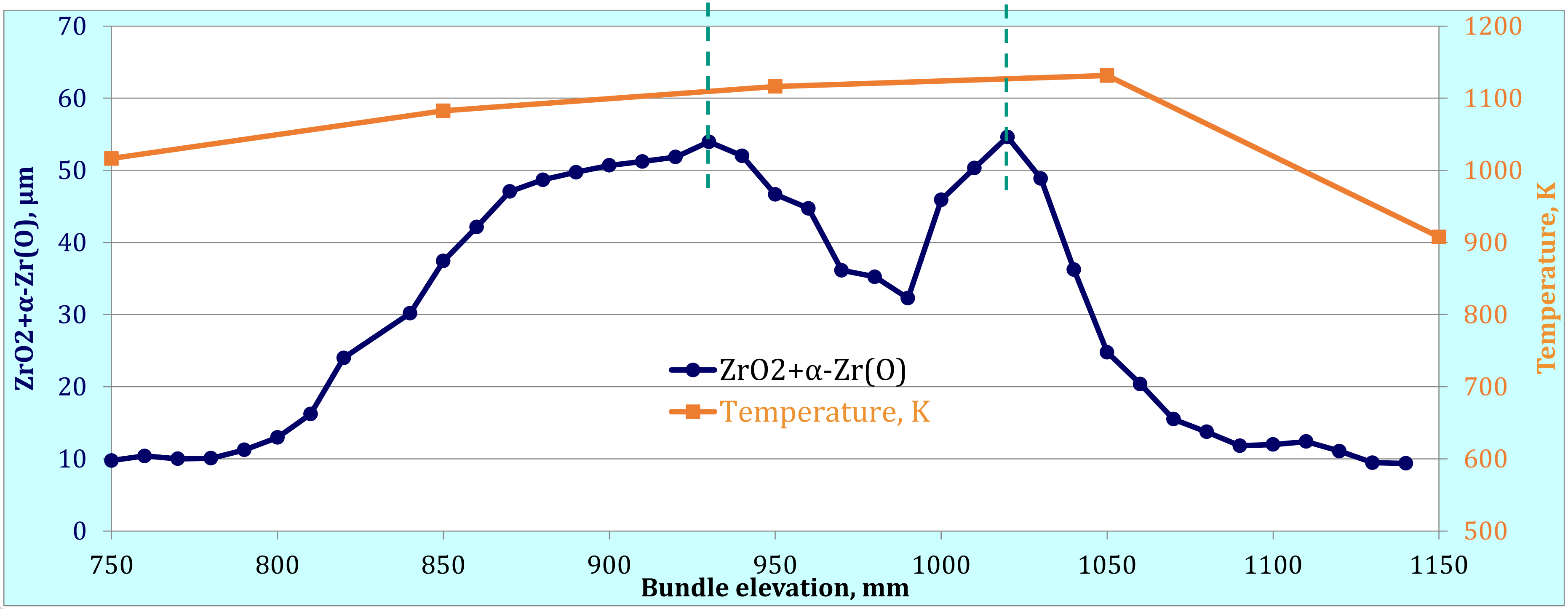


on the end of transient (15880 s)

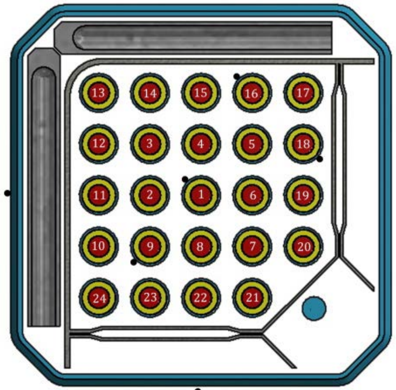


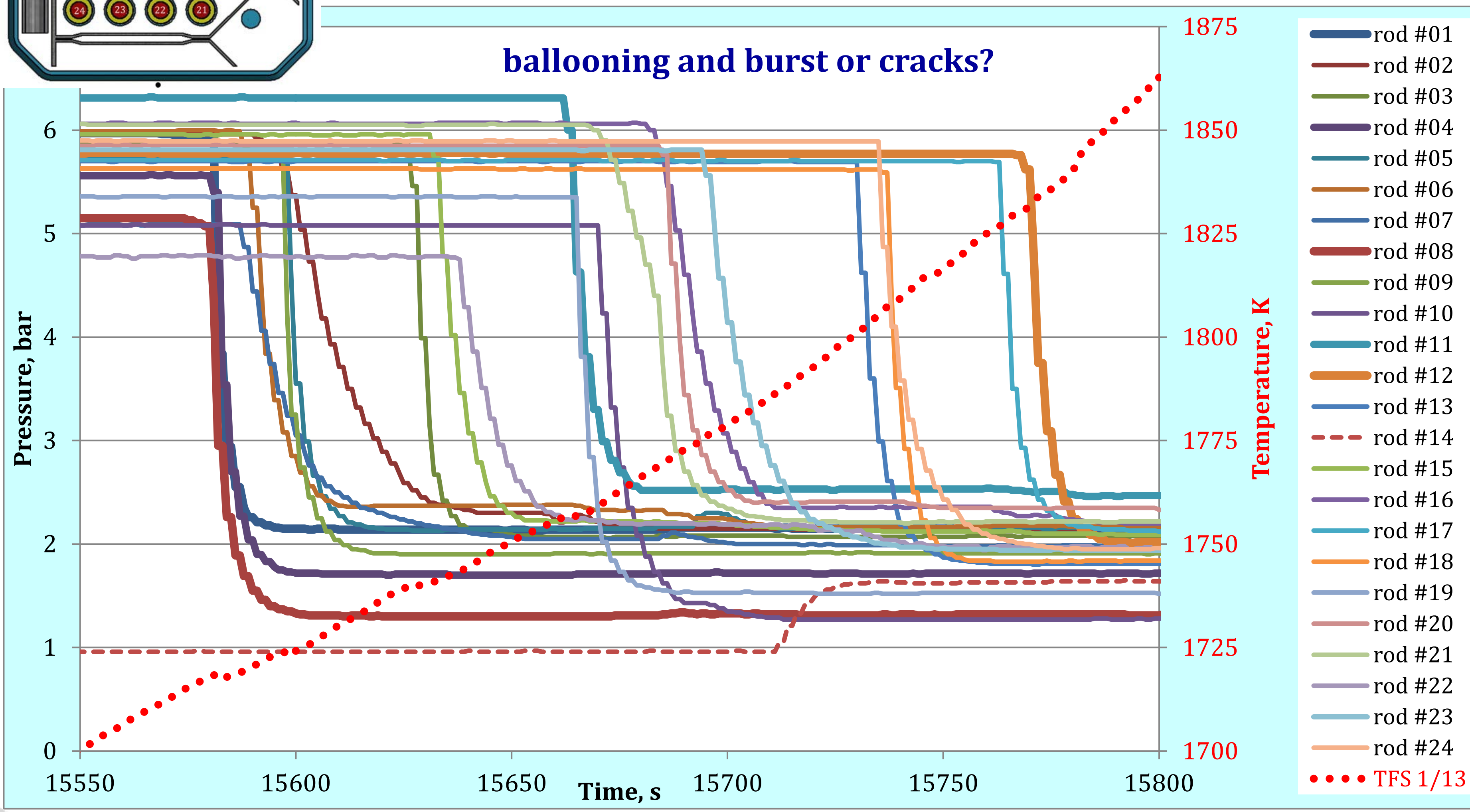
QUENCH-20: oxidation of Zry-4 corner rod withdrawn on the end of pre-oxidation

breakaway
(spalled oxide layer)

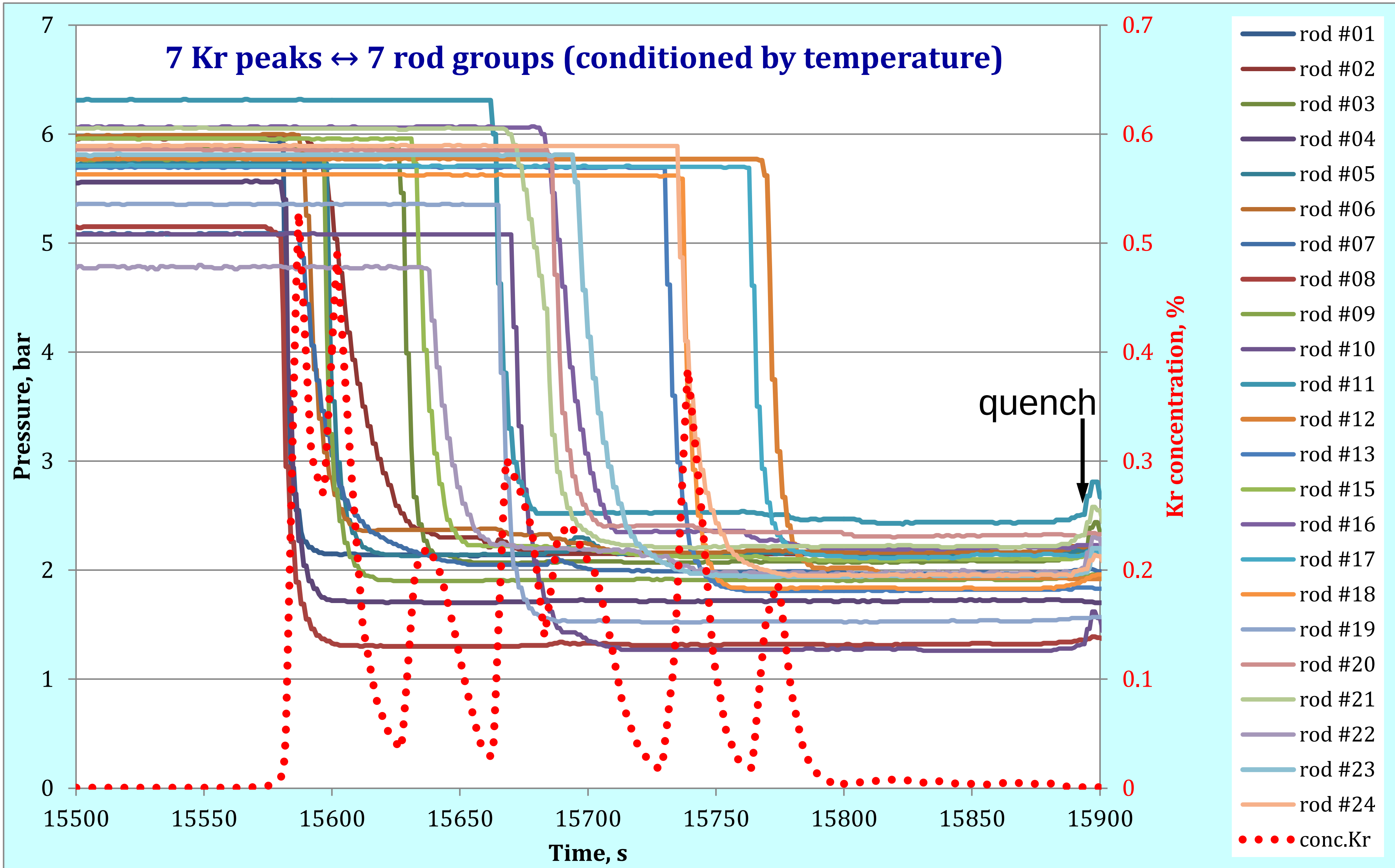


QUENCH-20: failure of rods; first failures: inner rods 1, 4, 8; last failure: outer rod 12

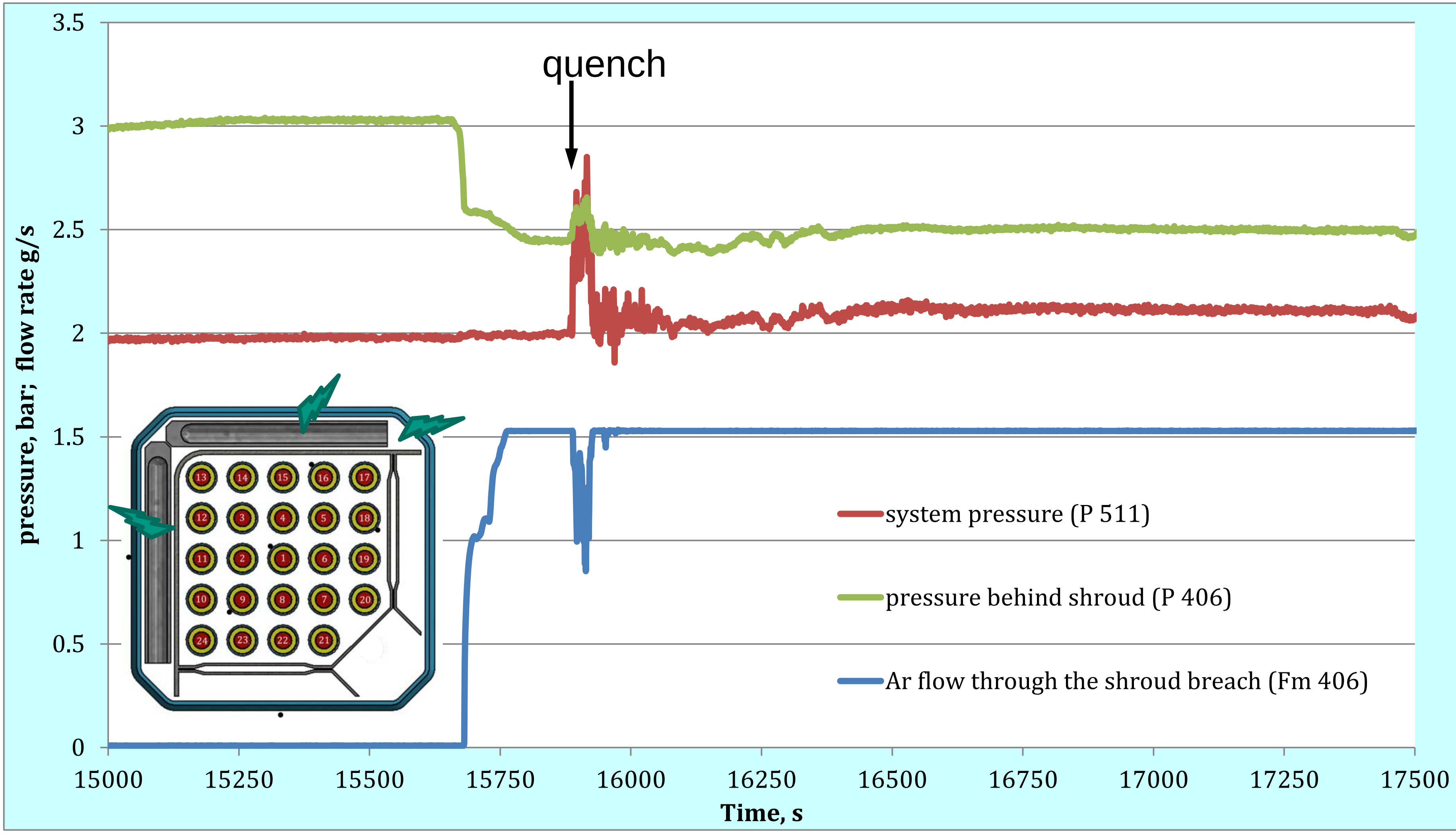




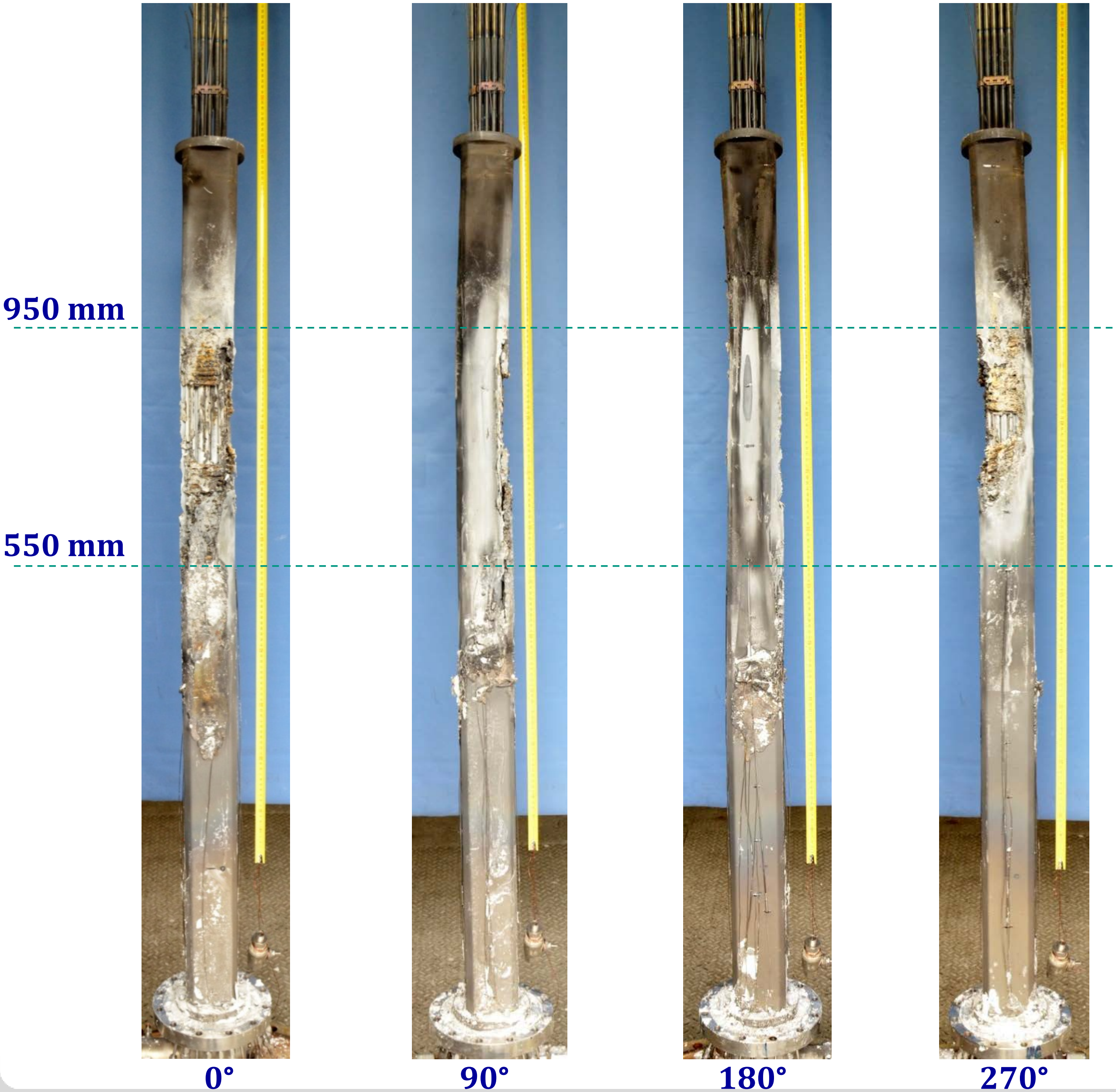
QUENCH-20: indication of rod failures by Kr release



QUENCH-20: shroud failure

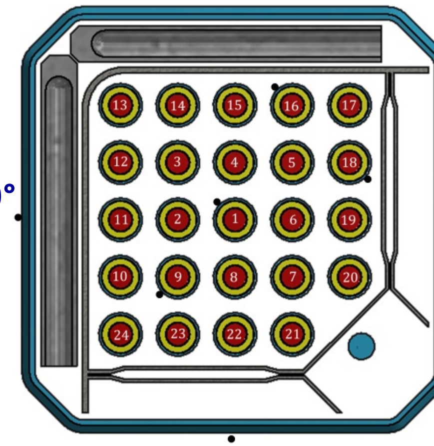


QUENCH-20 bundle surrounded by shroud: post-test view



0°

270°

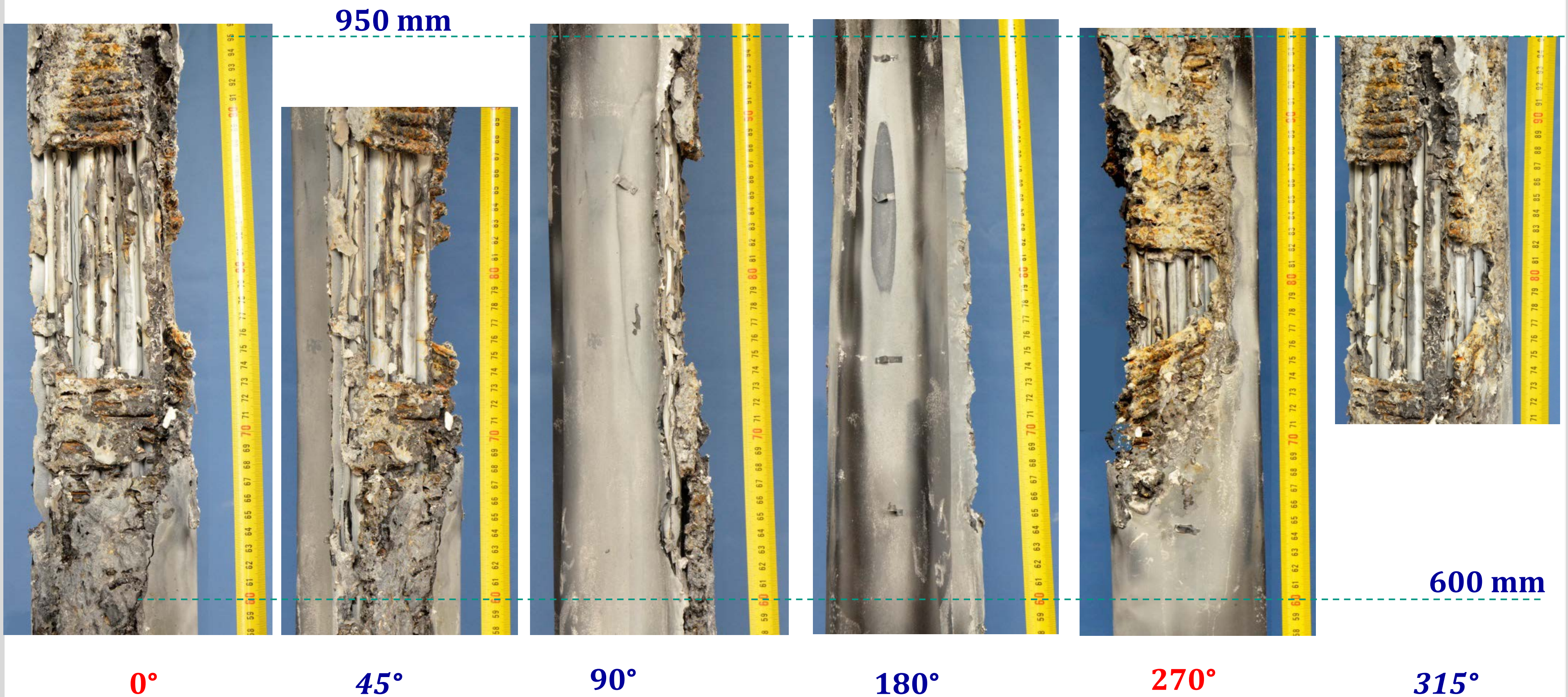


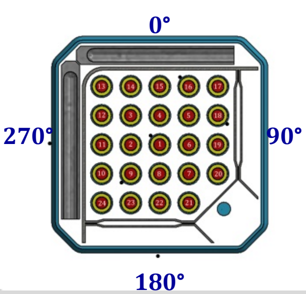
90°

180°

bundle cross-section, top view

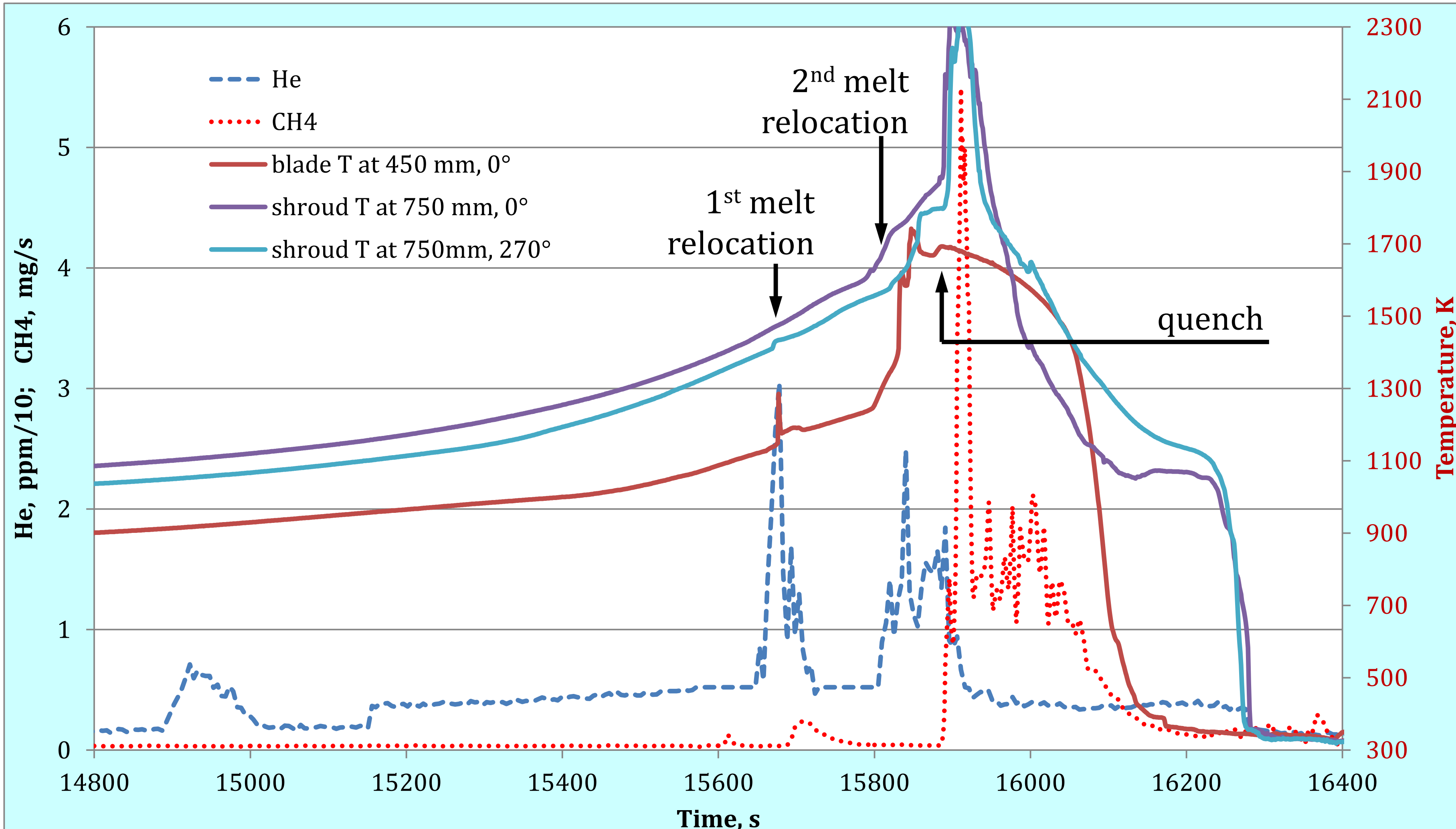
QUENCH-20 bundle surrounded by shroud: post-test view



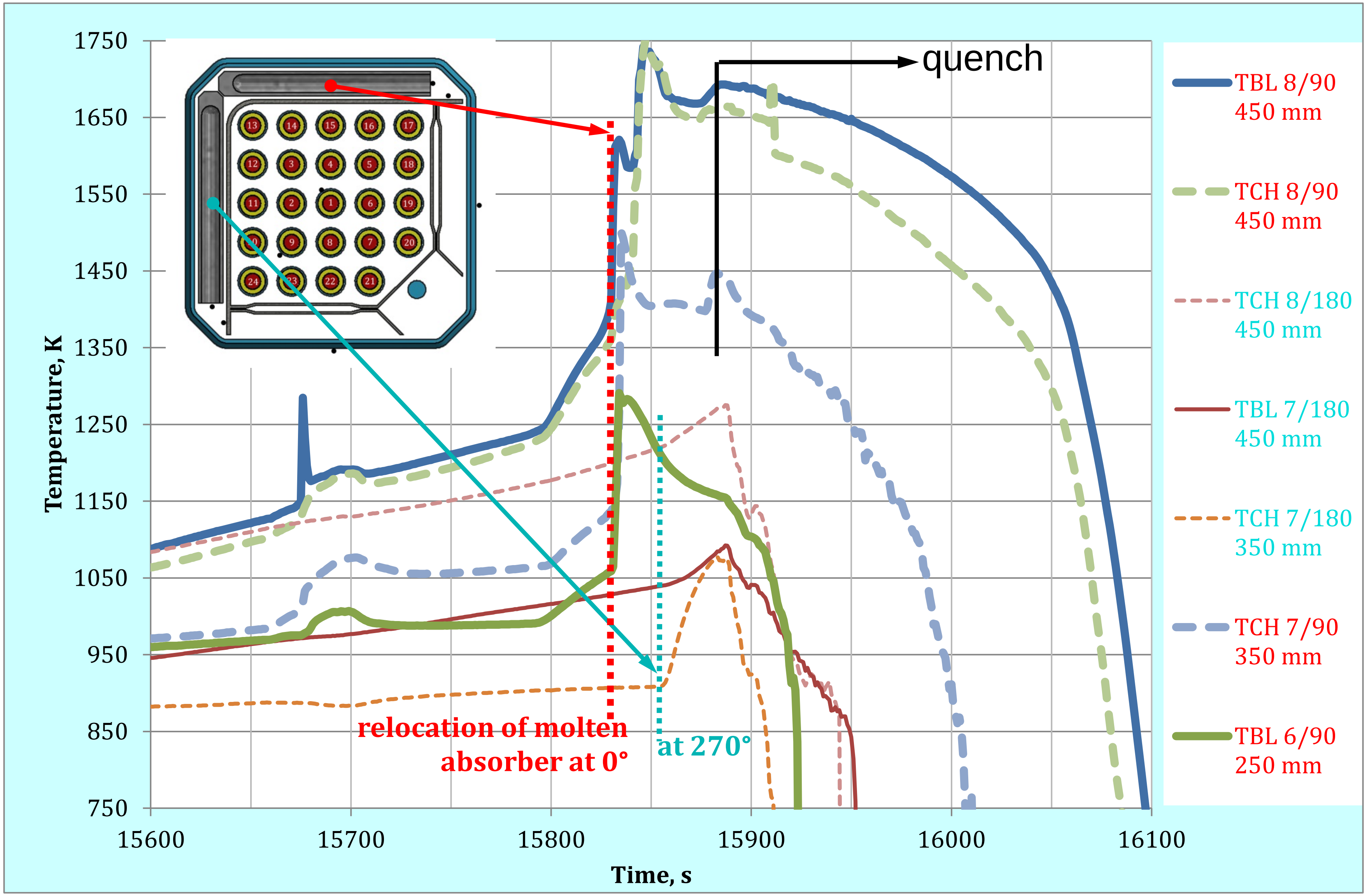


Strong degradation of absorber blades, channel box and shroud between elevations 650 and 950 mm at angle positions 0° and 270°

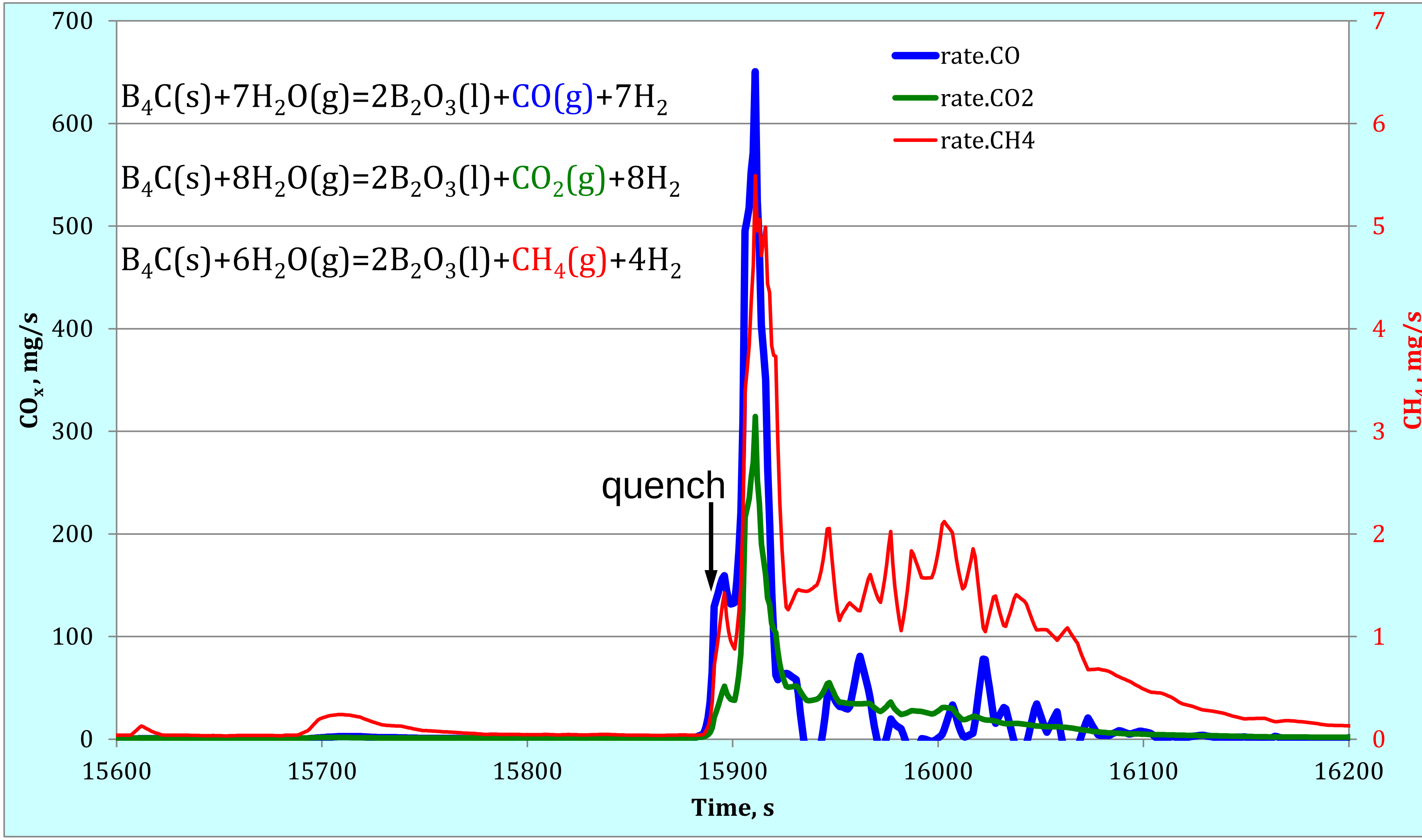
QUENCH-20: absorber melt formation at above 750 mm and relocation to lower elevations



QUENCH-20: absorber melt relocation from hottest bundle elevations to elevations 250-450 mm

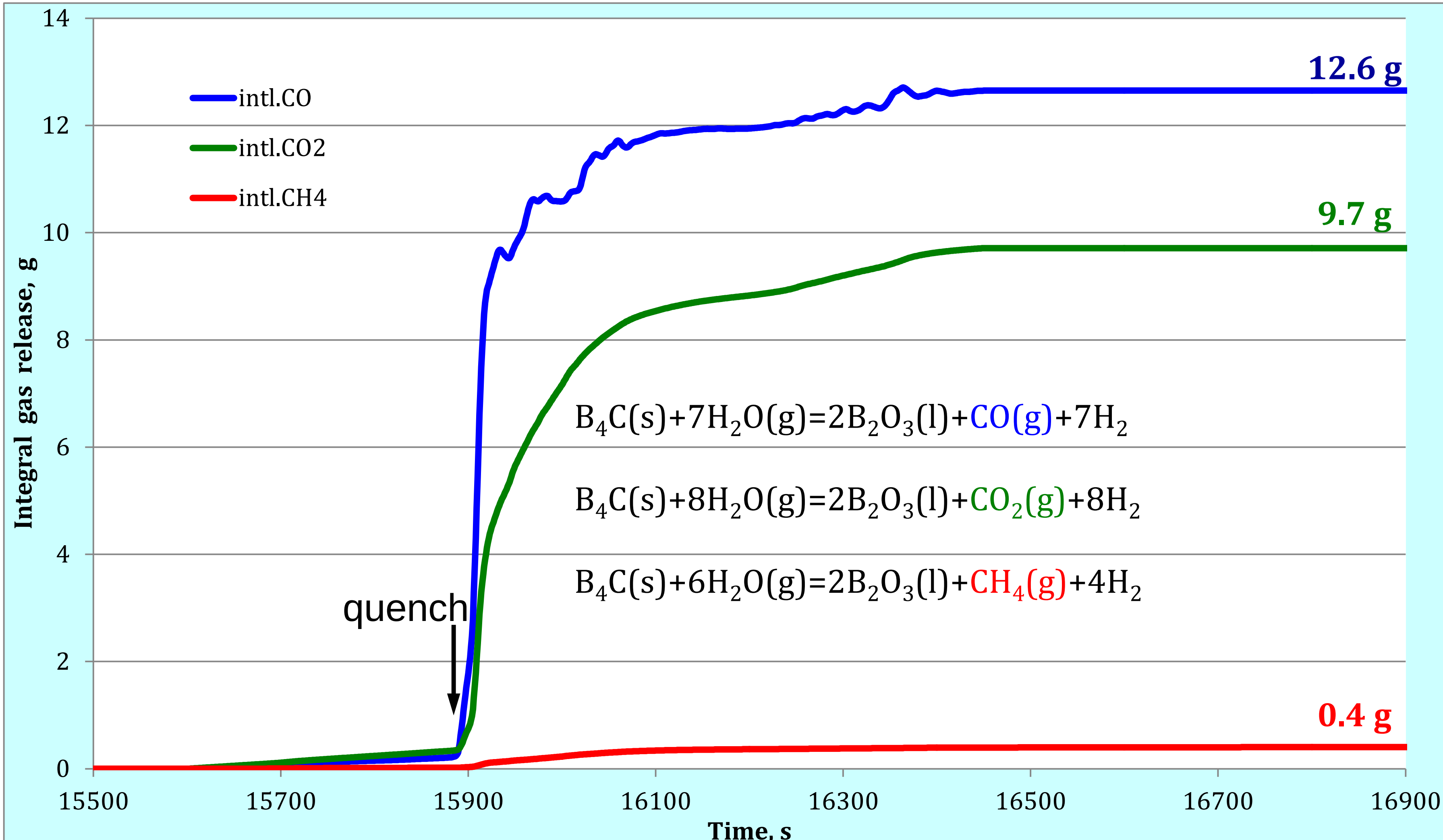


QUENCH-20: reaction of B_4C with steam



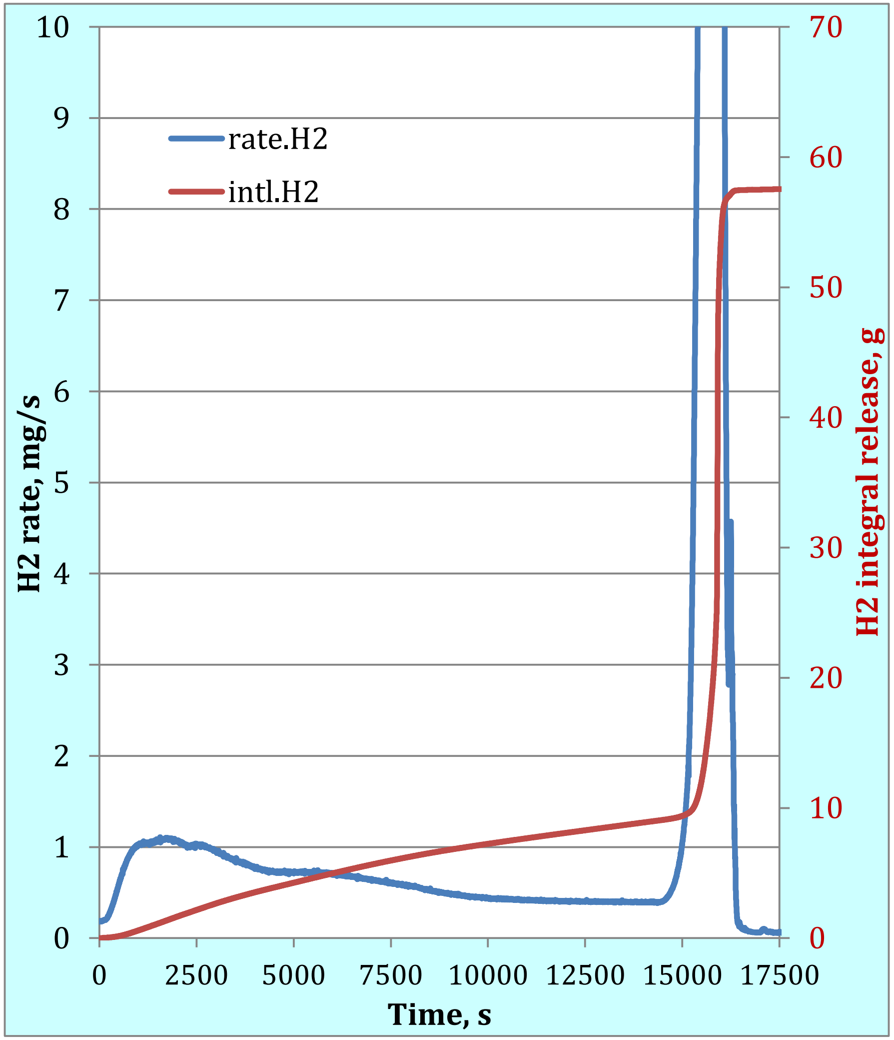
only small release of CH_4 before quench; CO and CO_2 formation firstly in the quench stage

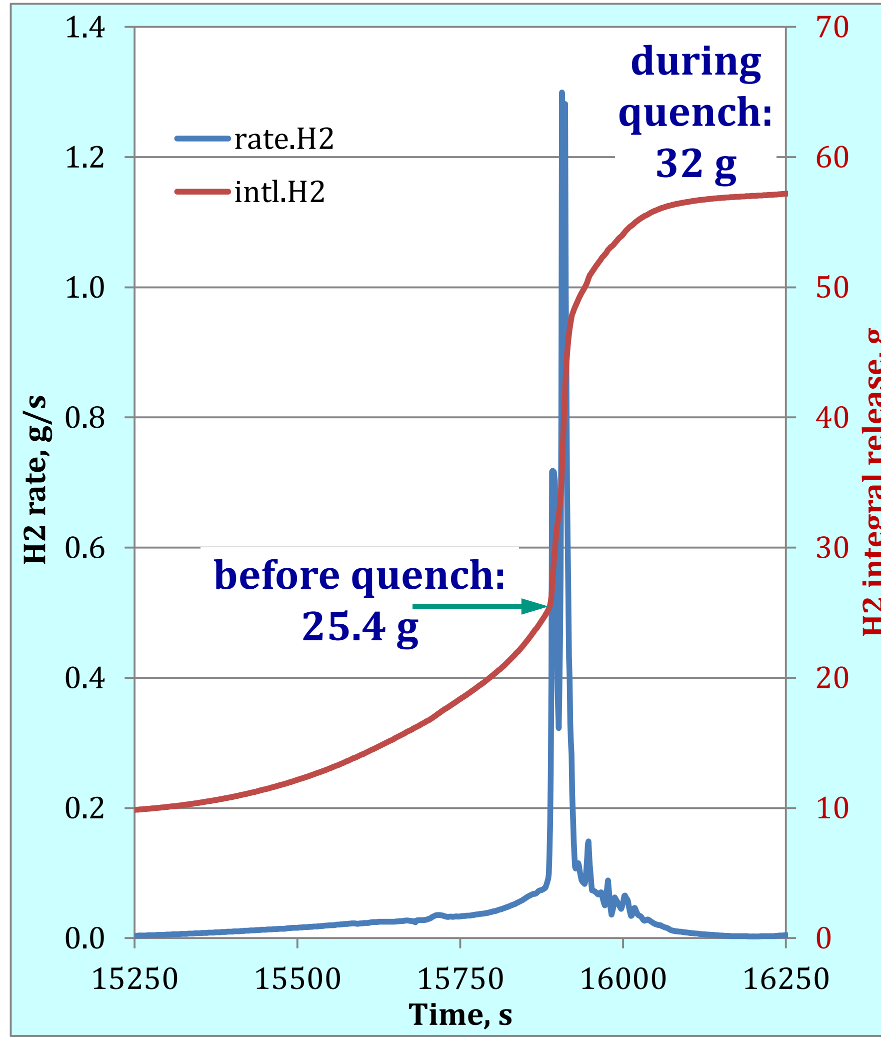
QUENCH-20: reaction of B_4C with steam, integral gas release



According to CO_x and CH_4 release: corresponding mass of B_2O_3 is 96.8 g; H_2 is 10.0 g

QUENCH-20: hydrogen release

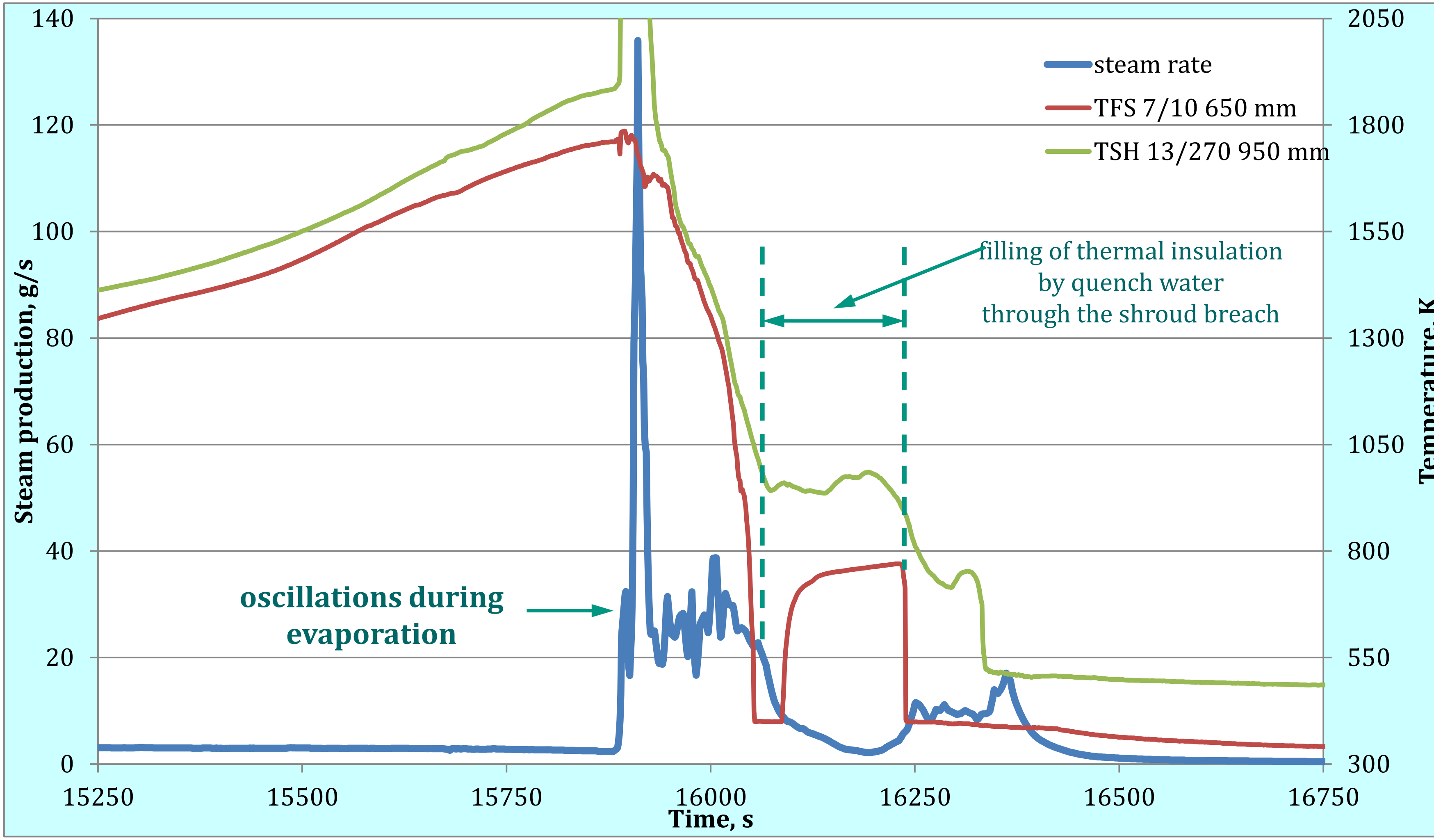




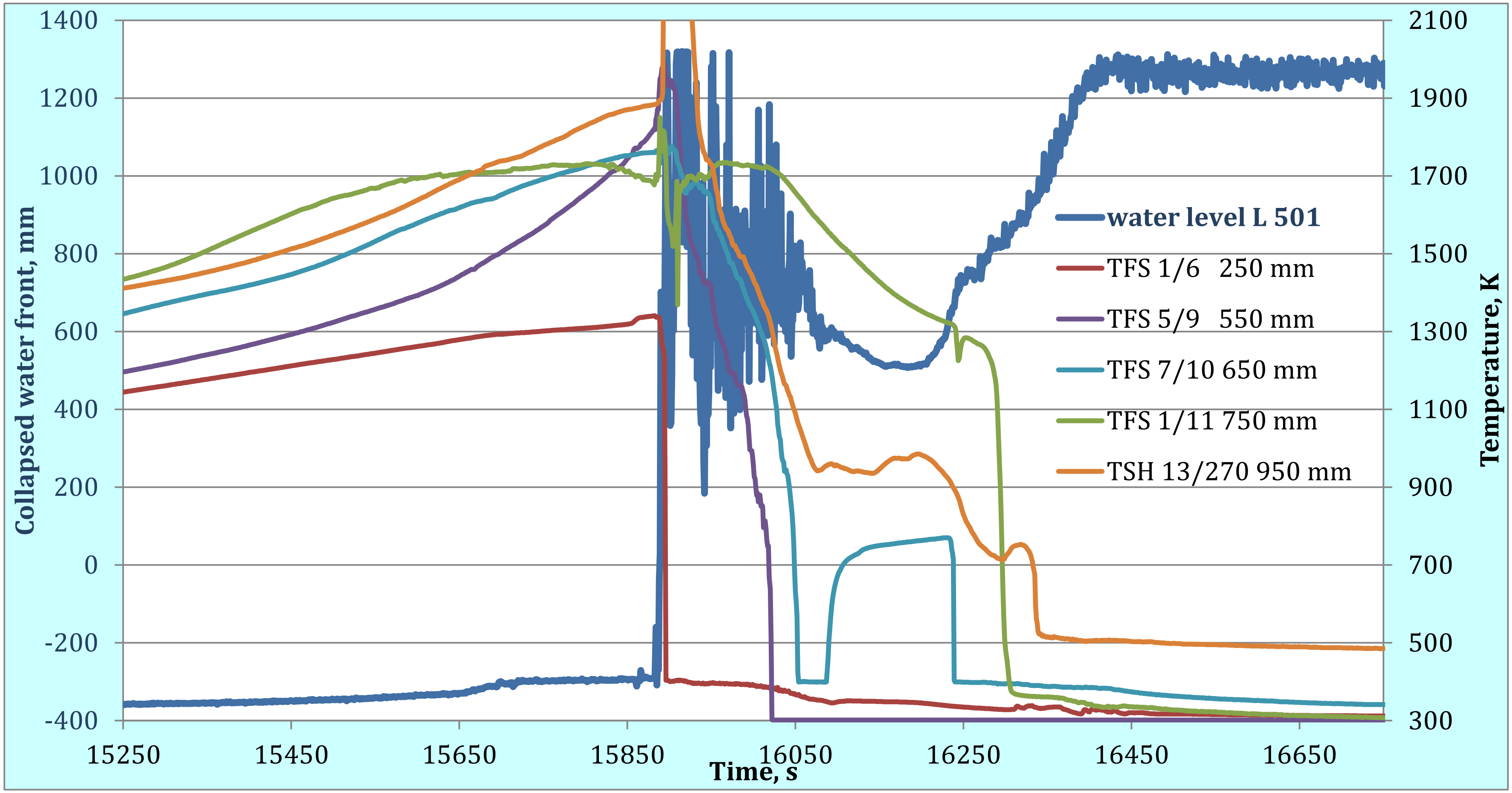
H_2 release during the whole test: 57.4 g;
before quench – interaction of steam with Zry,
during quench – steam interaction with Zry and absorber

H_2 release during quench:
22 g (from Zry and molten steel) +
+ 10 g (from B_4C)

QUENCH-20: steam production during the quench stage



QUENCH-20: filling of bundle with quench water and wetting of thermocouples



delayed cooling of the bundle (>450 s) due to filling of insulation annulus through the shroud breach at ≈550 mm

Summary and conclusions

- Experiment QUENCH-20 with BWR geometry simulation bundle was successfully conducted at KIT on 9th October 2019 in the framework of the international SAFEST project. The test bundle mock-up represented one quarter of a BWR fuel assembly with 24 electrically heated fuel rod simulators and B_4C control blade. The rod simulators were filled with Kr to inner pressure of 6 bar at peak cladding temperature of 900 K.
- The pre-oxidation stage in the flowing gas mixture of steam and argon (each 3 g/s) and system pressure of 2 bar lasted 4 hours at the peak cladding temperature of 1250 K. The Zry-4 corner rod, withdrawn at the end of this stage, showed the maximal oxidation at elevations between 930 and 1020 mm with signs of breakaway.
- During the transient stage, the bundle was heated to a maximal temperature of **2000 K**. *The cladding failures were observed at temperature about 1700 K and lasted about 200 s*. During the period of rod failures also the first absorber melt relocation accompanied by shroud failure were registered. *Massive absorber melt relocation was observed 50 s before the end of transition stage*.
- The test was terminated with the quench water injected with a flow rate of 50 g/s from the bundle bottom. Fast *temperature escalation* from 2000 to **2300 K** during 20 s was observed. The mass spectrometer measured *release of CO (12.6 g), CO_2 (9.7 g) and CH_4 (0.4 g) during the reflood as products of absorber oxidation; corresponding production of B_2O_3 should be 96.8 g .*
- Hydrogen production during the reflood amounted to **32 g** (57.4 g during the whole test) including 10 g from B_4C oxidation.

Acknowledgment

The QUENCH-20 experiment was performed in the framework of the SAFEST project in cooperation with Swedish Radiation Safety Authority (SSM), Westinghouse Sweden, GRS and KTH and supported by the KIT program NUSAFE. Personal thanks to Mr. Isaksson (SSM), Mr. Bechta (KTH), Mr. Hollands (GRS), Ms. Korske (Westinghouse) for their help and fruitful cooperation. The bundle materials and absorbers were provided by Westinghouse Sweden.

The authors would like to thank all colleagues involved in the pre-test calculations.

Thank you for your attention

http://www.iam.kit.edu/awp/666.php
http://quench.forschung.kit.edu/