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Institute for Applied Materials

Results of the QUENCH-DEBRIS Test

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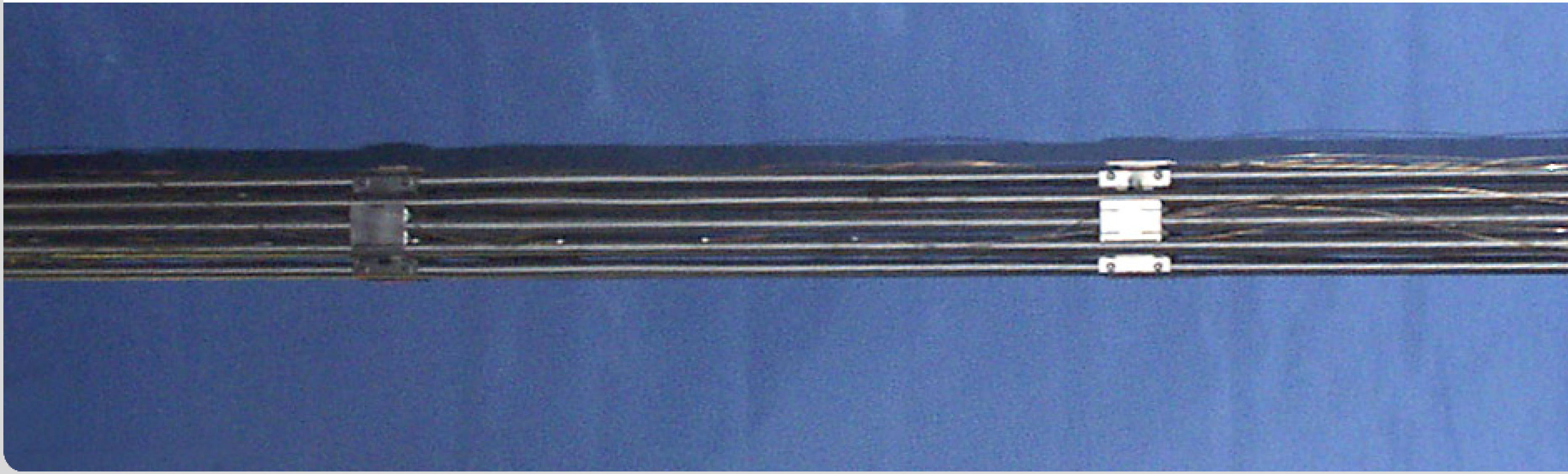
Institute for Applied Materials; Program NUKLEAR



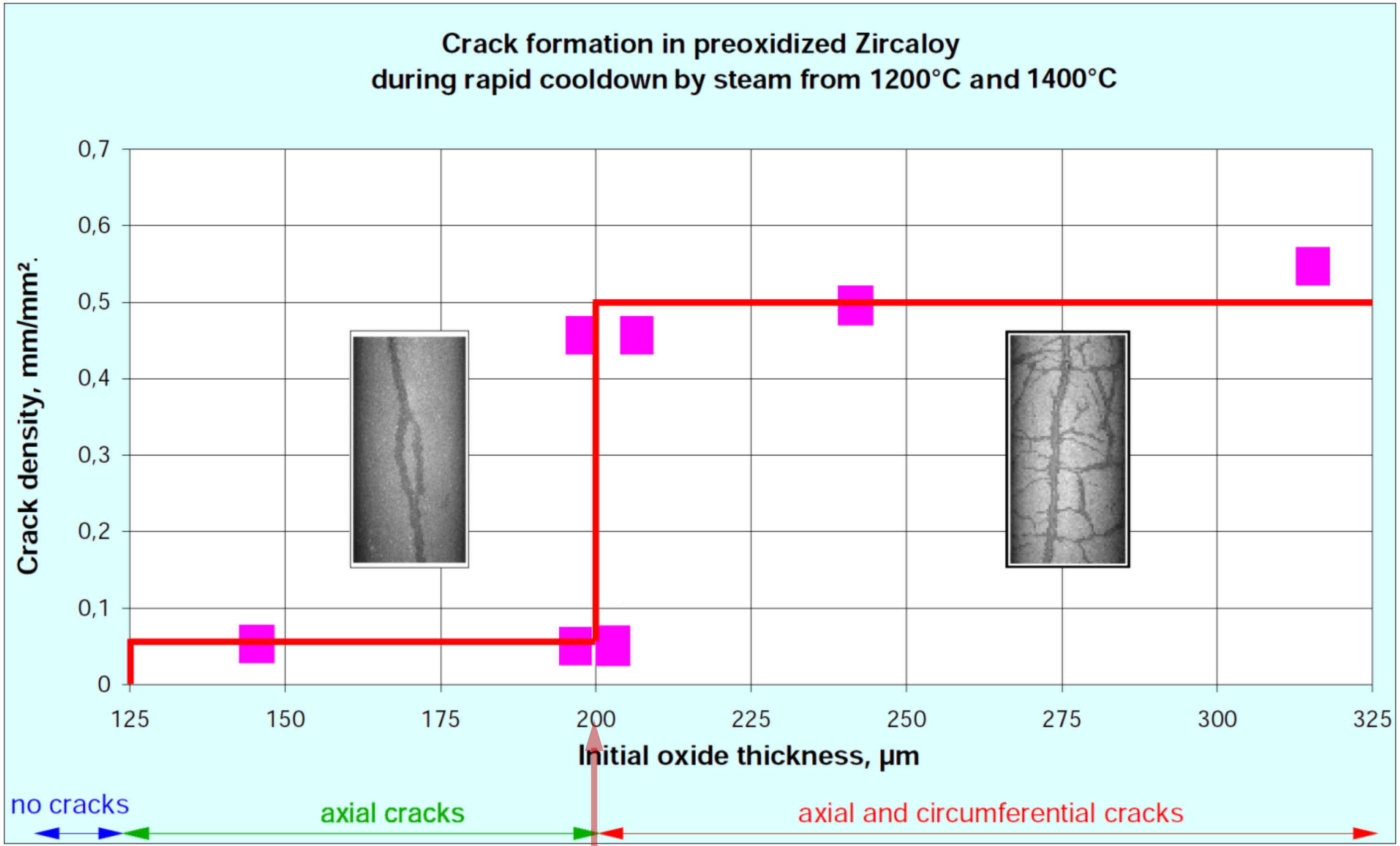
Objectives

- **investigation of debris bed formation for bundle with completely oxidised Zry-4 claddings filled with segmented pellet simulators**

- **investigation of cooling of degraded bundle during the water reflood from bottom**

Formation of through going cracks in cladding quenched from high temperatures

/ http://bibliothek.fzk.de/zb/berichte/FZKA6013.pdf /

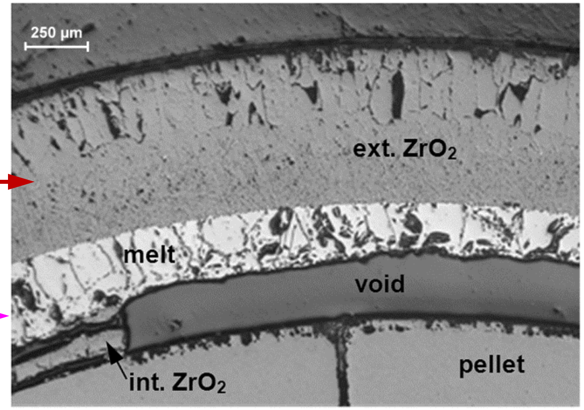


Formation of crack net for oxide layer thicker than 200 µm

Melt capture between oxidised cladding and pellet

thick stable oxide

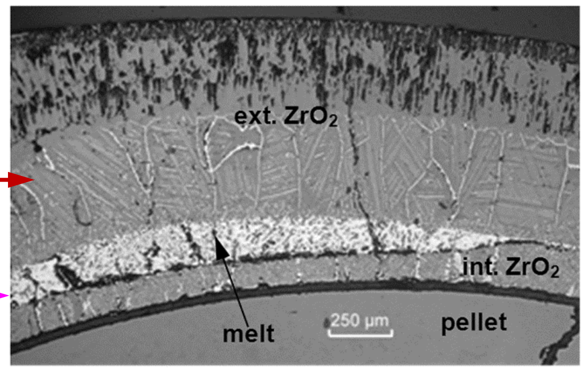
captured melt



QUENCH-06

thick stable oxide

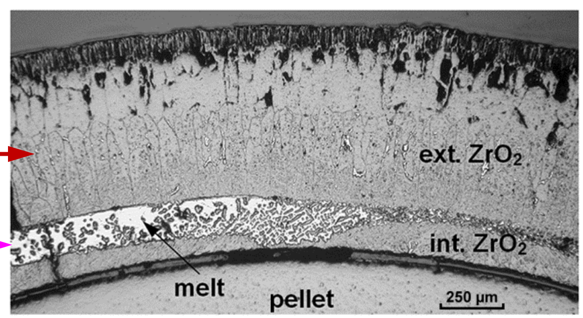
captured melt



QUENCH-14

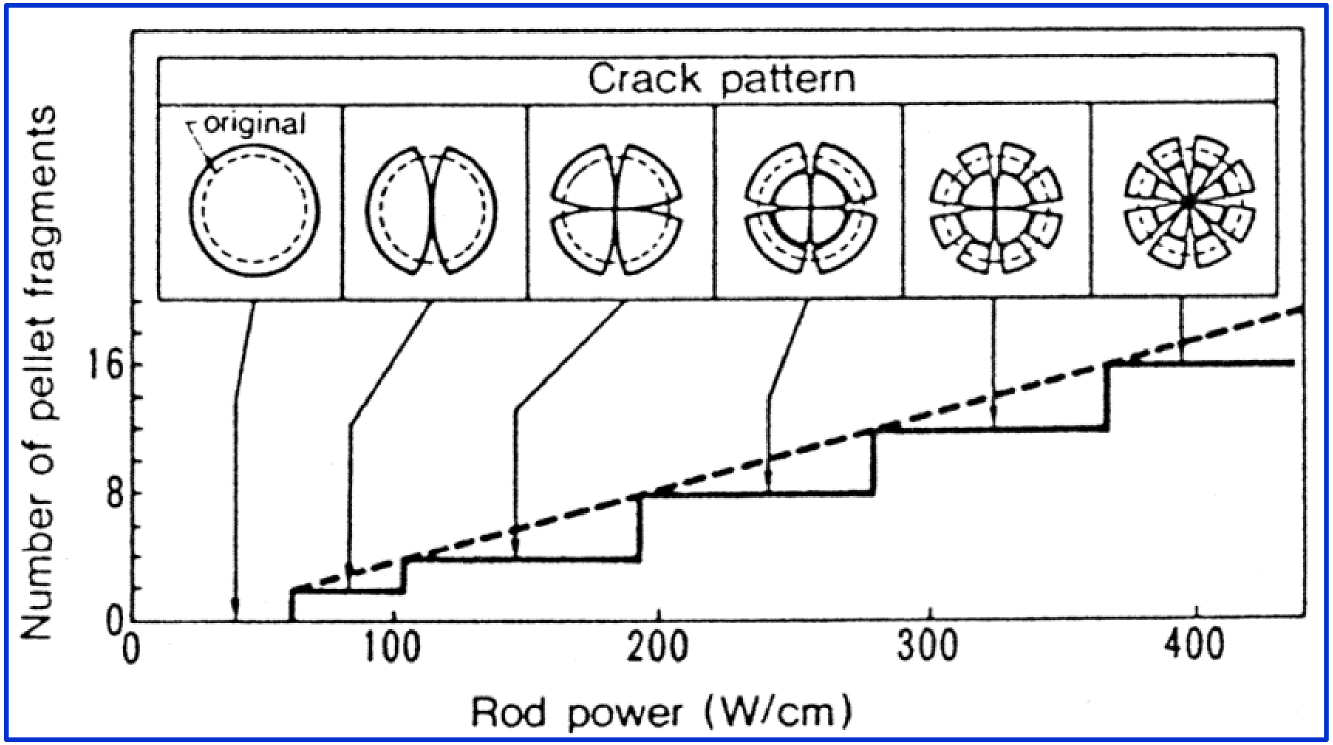
thick stable oxide

captured melt



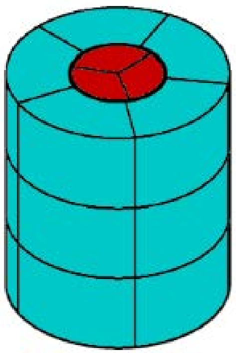
QUENCH-15

Fuel pellet segmentation during operation



Cracking and relocation behavior of nuclear fuel pellets during rise to power

M. OGUMA. Nucl. Eng. and Des., 76 (1983), 35-4



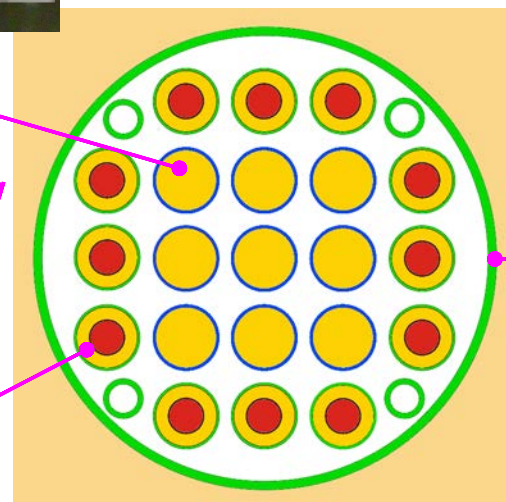
ZrO_2 pellet simulator for QUENCH-DEBRIS:

8*3=24 segments

Test bundle preparation

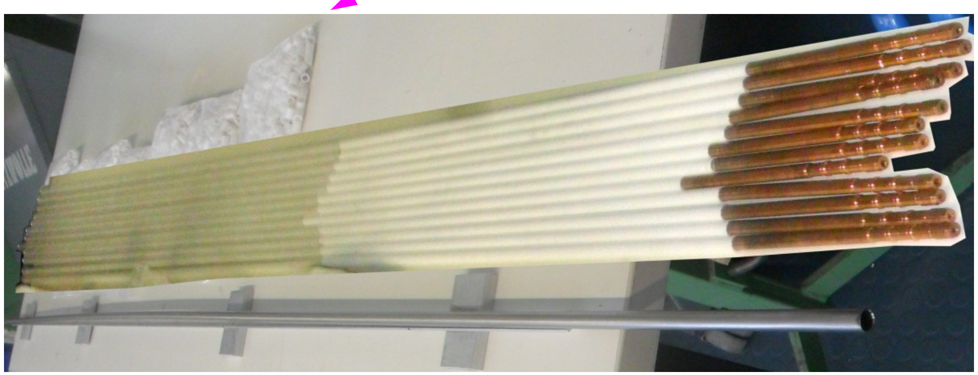
Zry cladding filled with ZrO_2 pellet segments and ZrO_2 powder

9 unheated rods with Zry-4 cladding

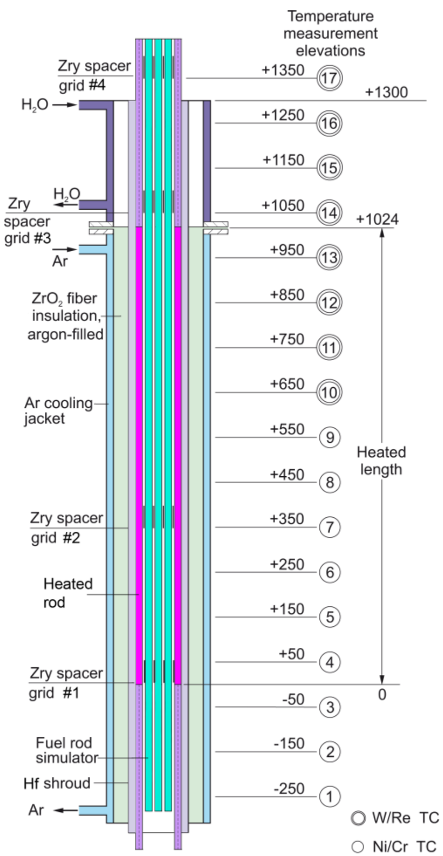


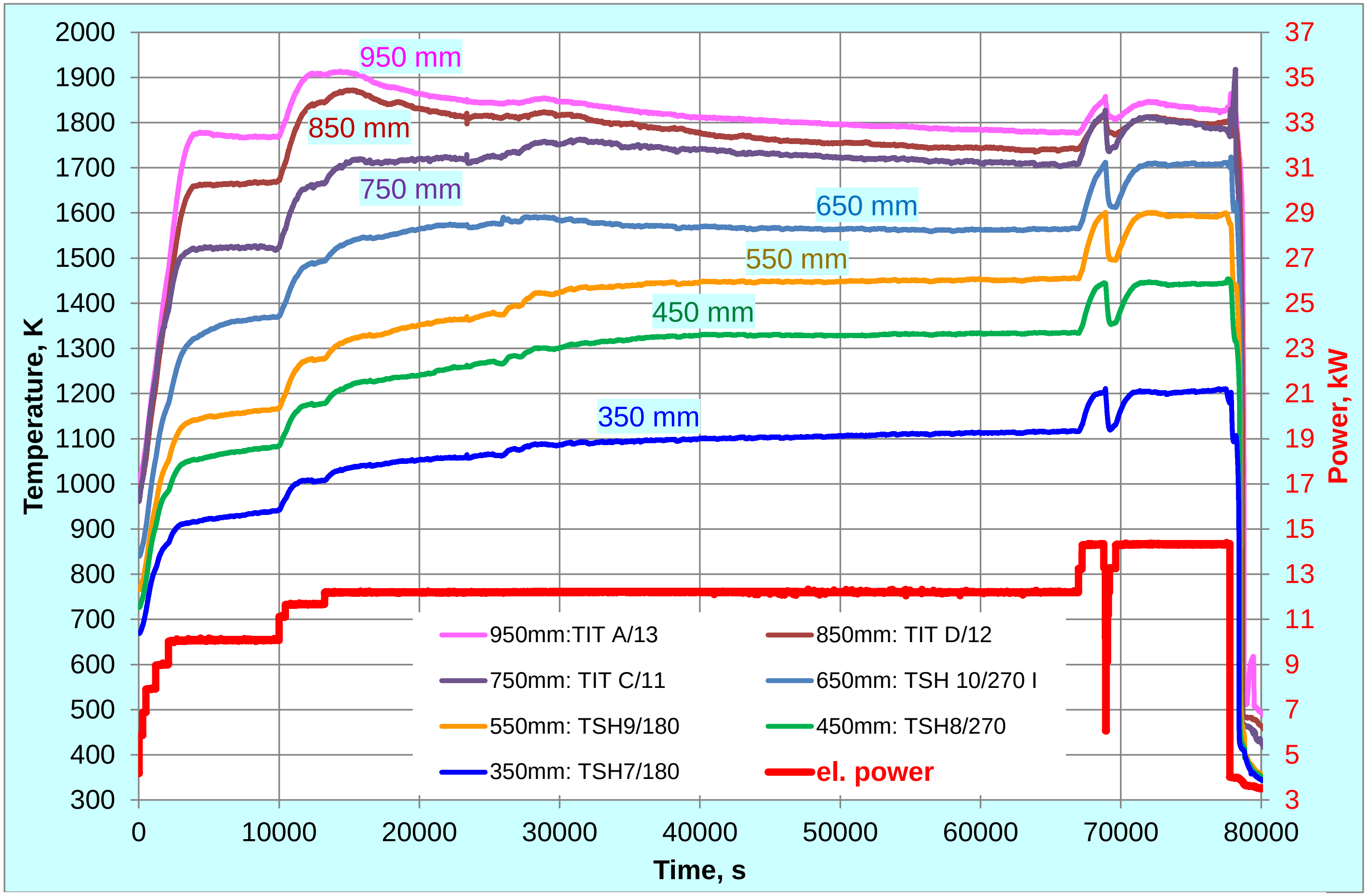
Hf shroud

12 heated rods with Hf cladding



Test scenario: el. power and TC readings at different elevations

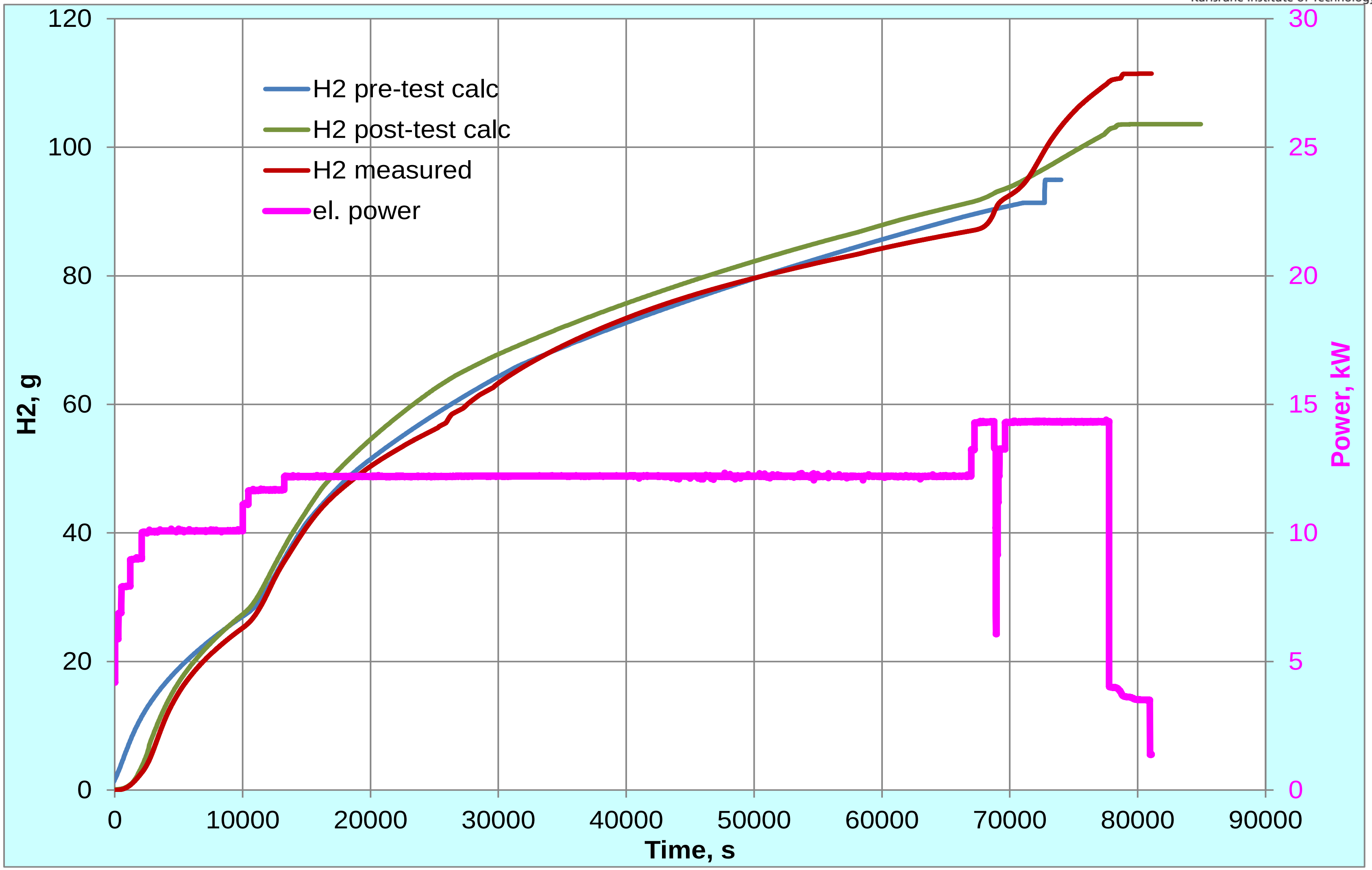




1) **pre-oxidation stage with 2 g/s steam and 2 g/s Ar. Complete oxidation of Zry-4 clads between 650 and 1150 mm**

2) **Test termination: reflood from bottom with water flow rate 10 g/s.**

Integral criterion of bundle oxidation progression: hydrogen release during oxidation of Zry and Hf parts



the course of the experiment closely followed the pre-test prediction

Indication of debris relocation to GS#2 (reaction of thermocouples at the top of GS#2) after mechanical impact on the bundle top

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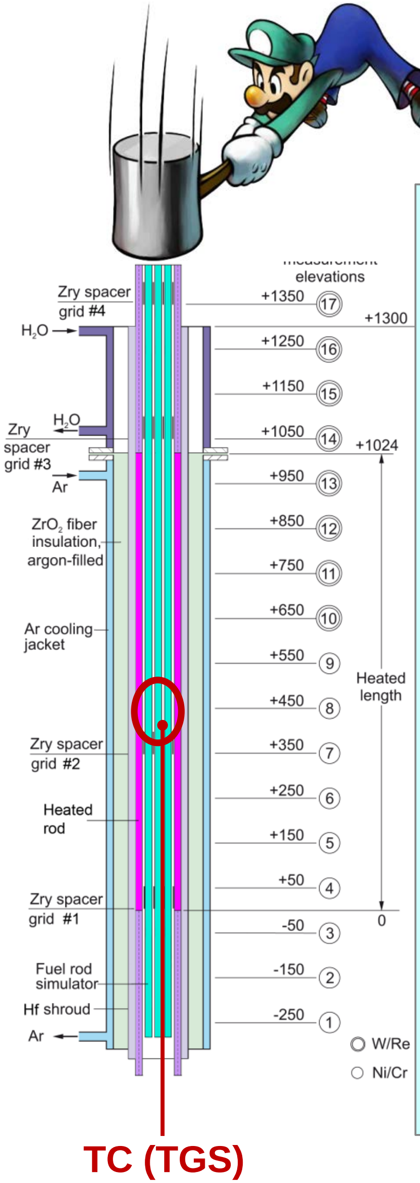
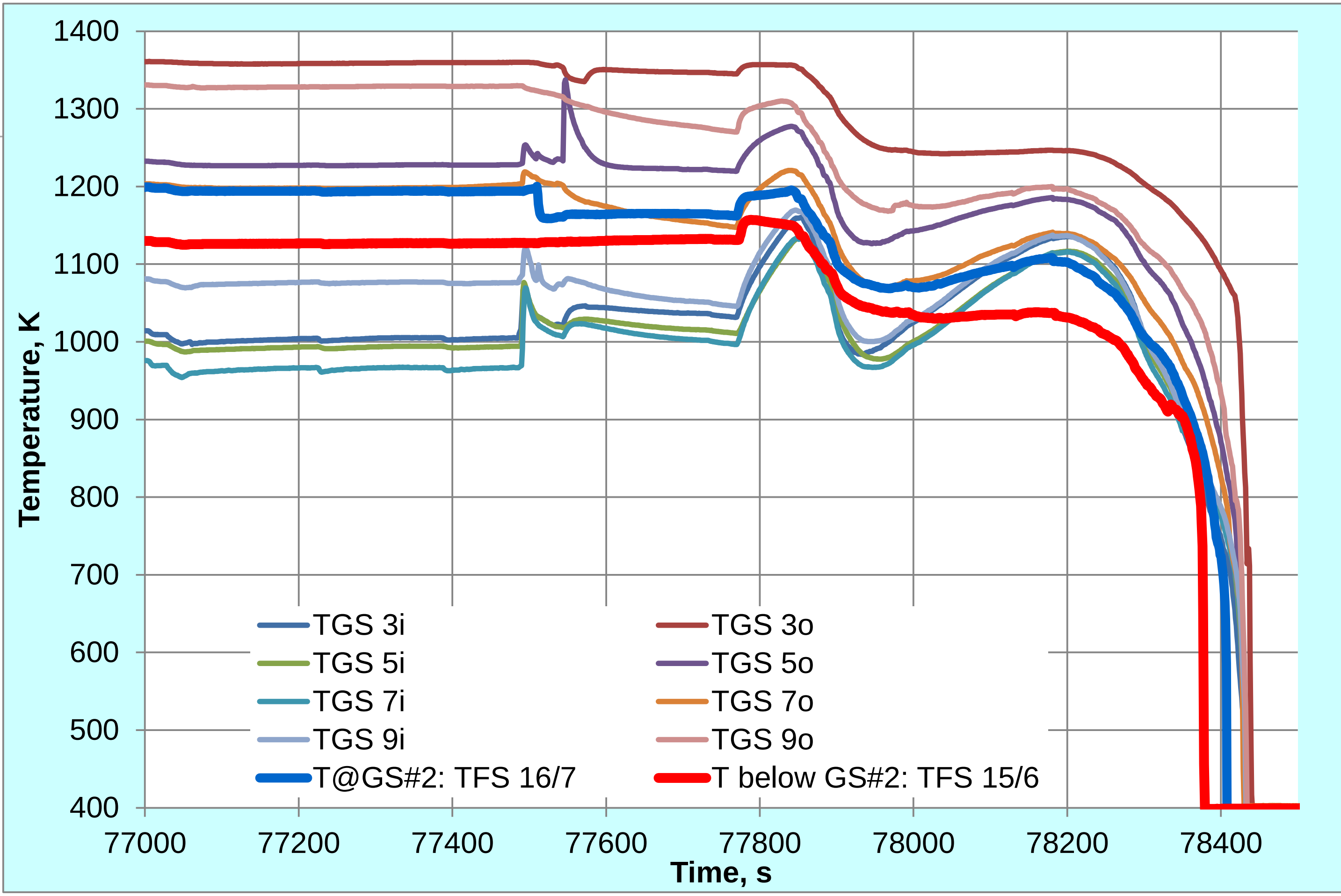
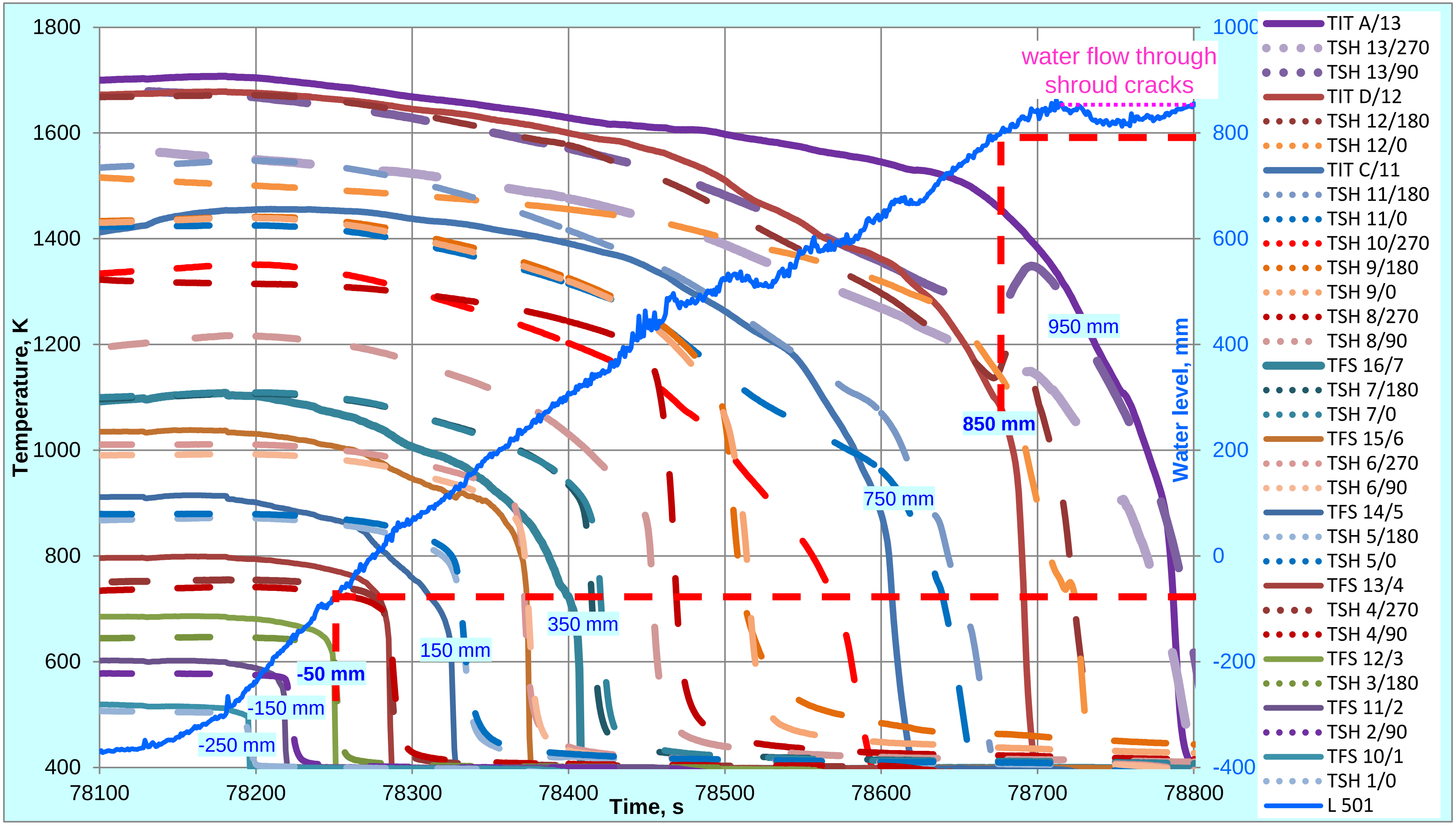


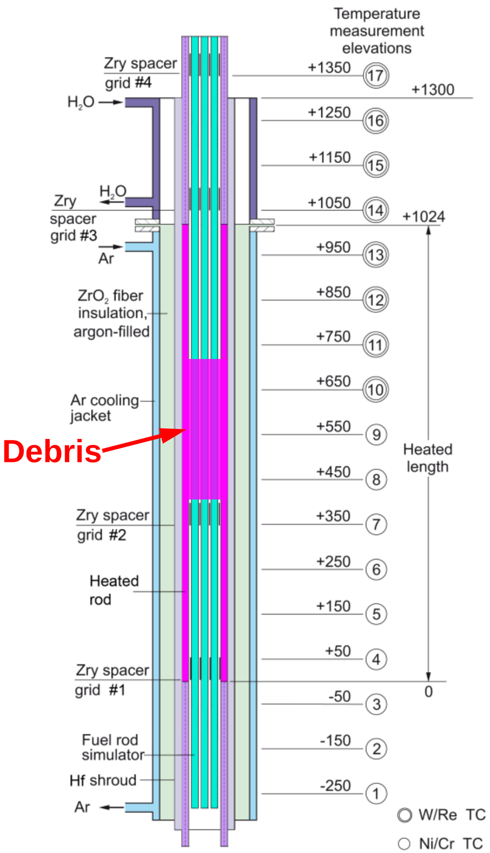


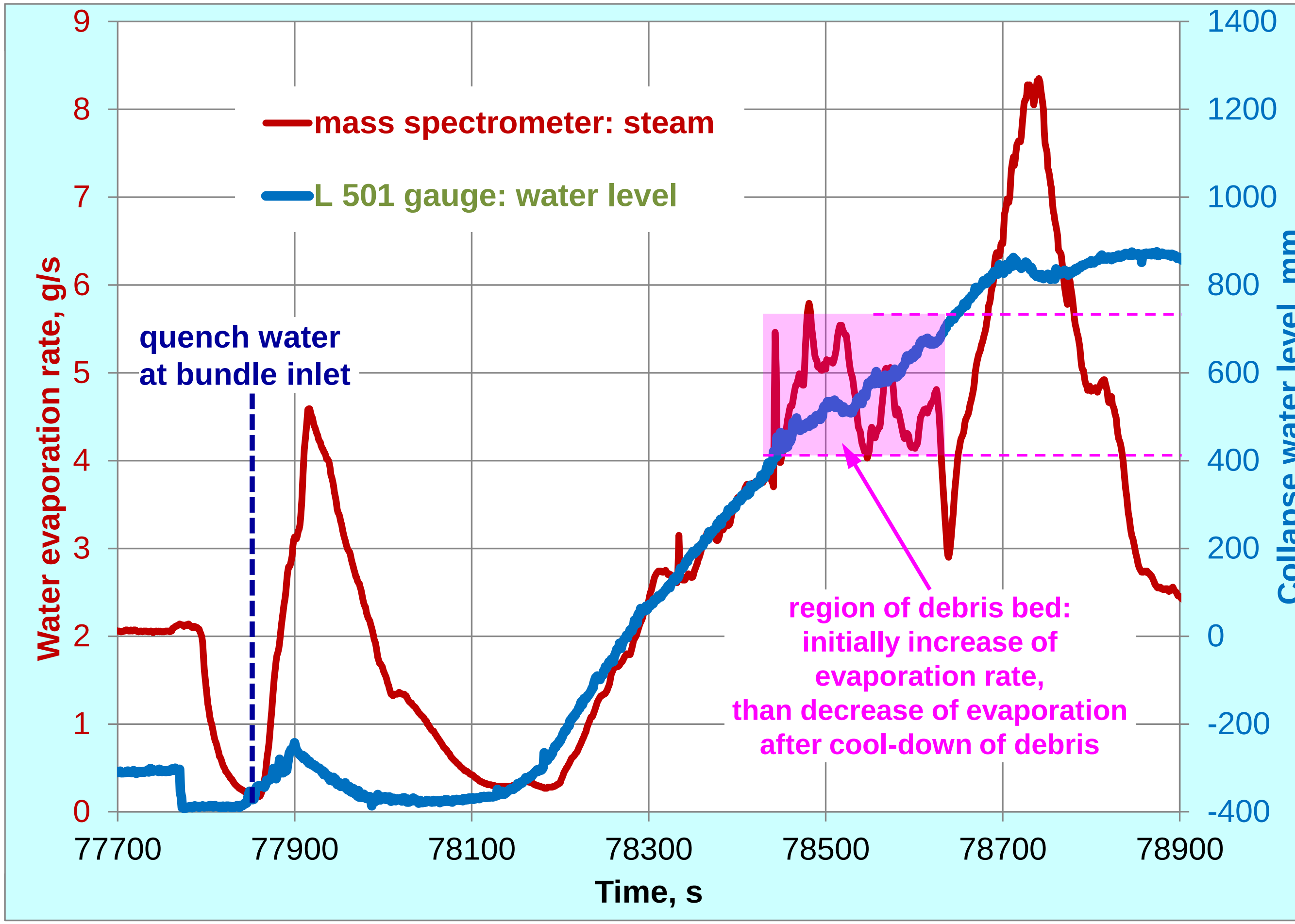
Quench phase: collapse water level and TC wetting



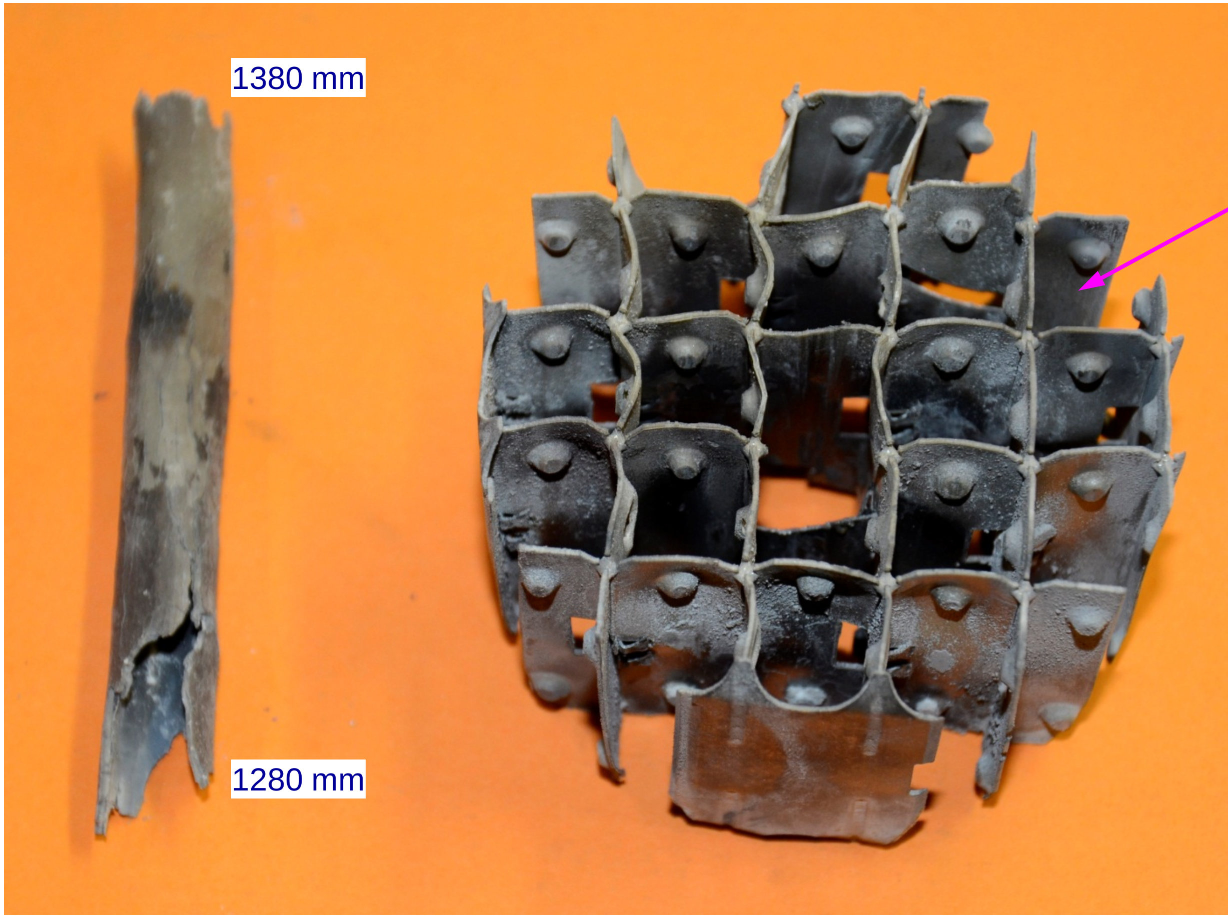
TC wetting at high elevation by 2-phase fluid

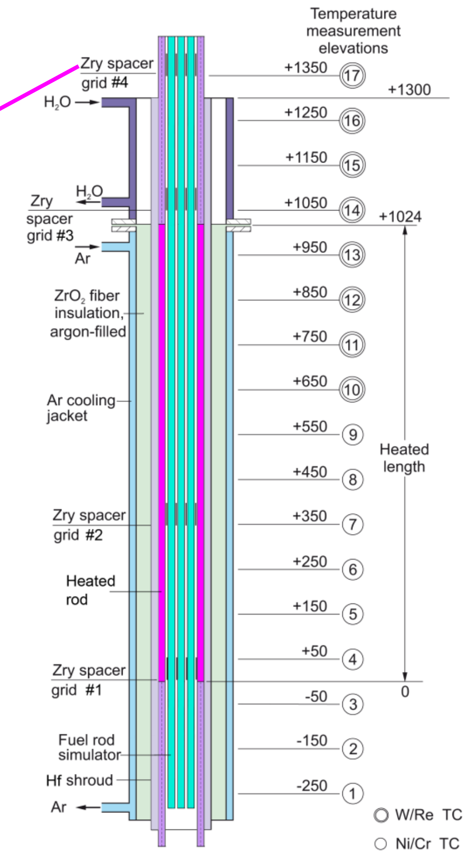
Quench phase: water level oscillations and evaporation rate





Withdrawn grid spacer #4 (1350 - 1390 mm) and remnant of cladding





remnant of Zry clad #8:

significantly oxidised

Zry-4 GS #4 (highest elevation):

completely oxidised

Endoscope observation of debris relocated under GS #3

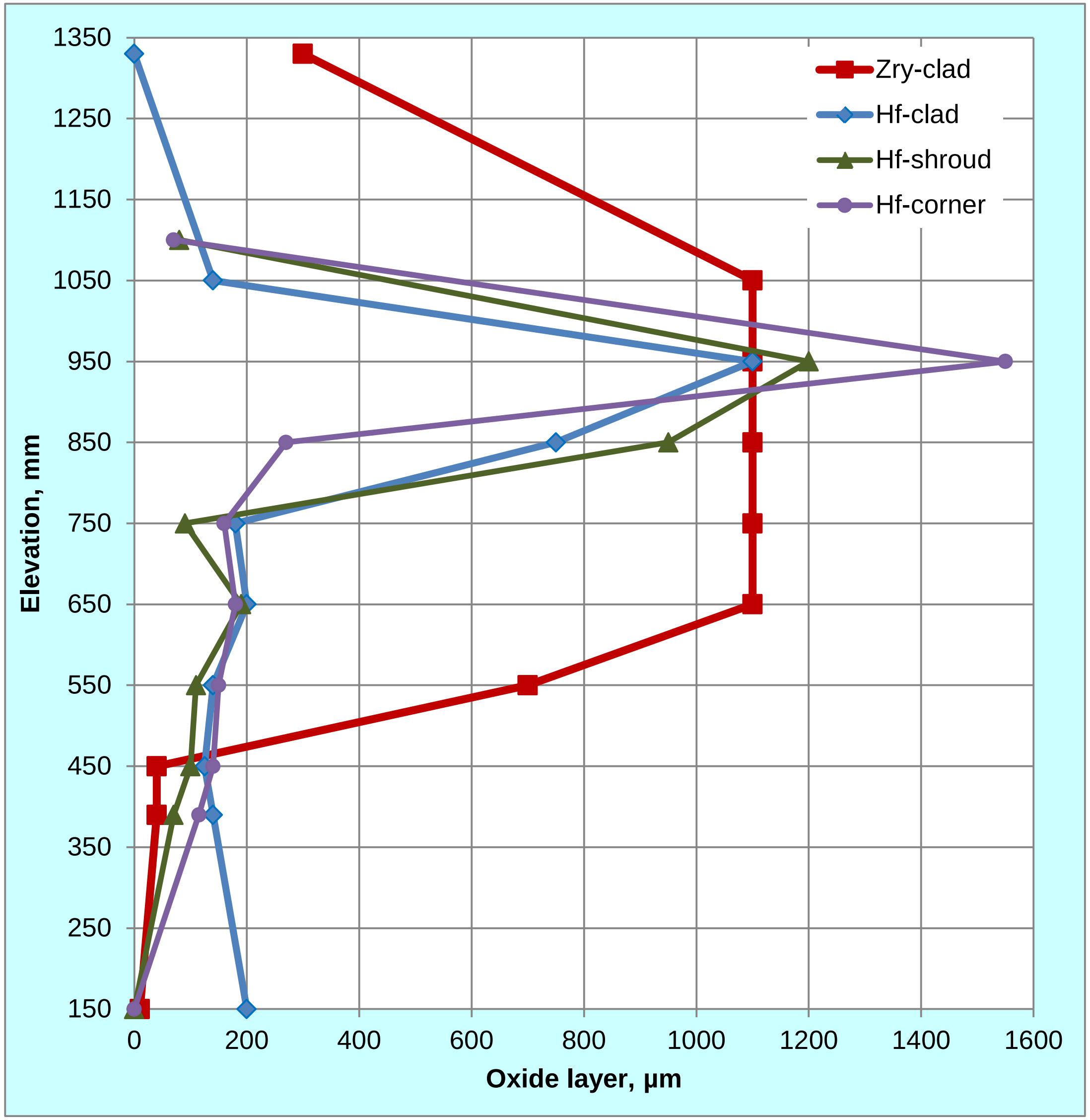
sintered pellets at 950 mm

pellet segments at 920 mm
between Zry and Hf claddings

blockage at elevation 910 mm

Debris collected at the top of grid spacer #3 (1090 mm)

Axial distribution of oxide layers



Elevation, mm	**ZrO_2, µm**	HfO_2-clad, µm
150	**10**	200
390	**40**	140
450	**40**	125
550	**700**	140
650	**1100**	200
750	**1100**	180
850	**1100**	750
950	**1100**	1100
1050	**1100**	140
1330	**300**	0

Elevation, mm	HfO_2-shroud,µm	HfO_2-corner, µm
150	0	0
390	70	115
450	100	140
550	110	150
650	190	180
750	90	160
850	950	270
950	1200	1550
1100	80	70

Structure of claddings at 390 mm: local effects due to debris; T_{long}=1200 K

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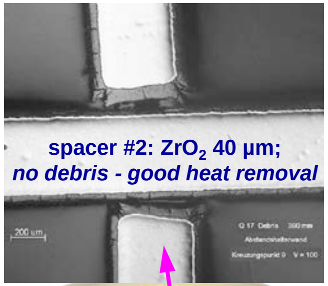
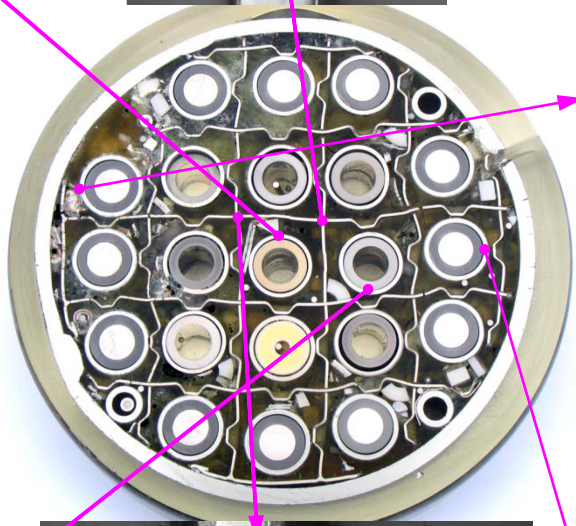
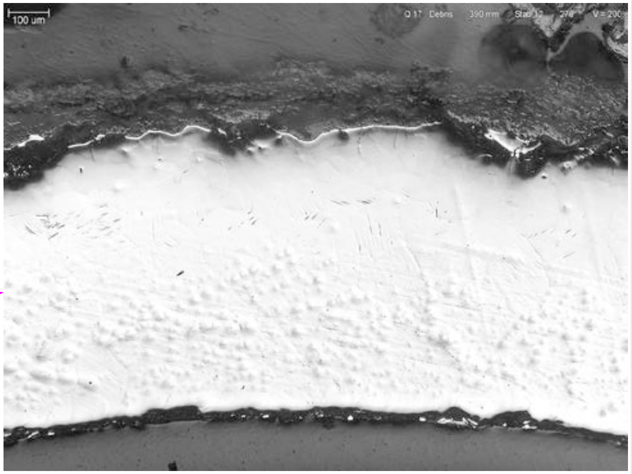
rod #1: outer ZrO_2 90 µm; inner ZrO_2 5 µm;
inhibited heat removal due to debris → higher T → thicker ZrO_2



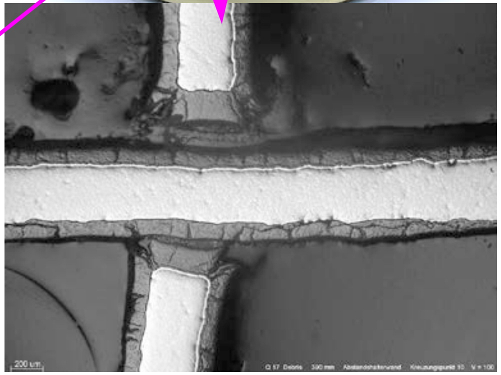
spacer #2: ZrO_2 40 µm;
no debris - good heat removal



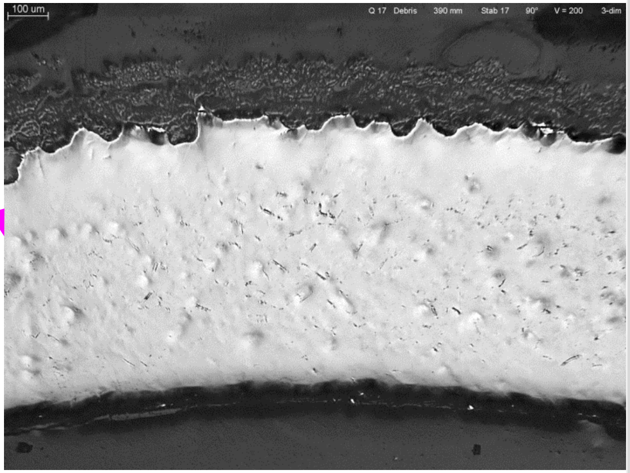


rod #12: outer HfO_2 140 µm, breakaway;
α-Hf(O) 300 µm

rod #6: outer ZrO_2 25 µm; α-Zr(O) 50 µm;
no debris → good heat removal

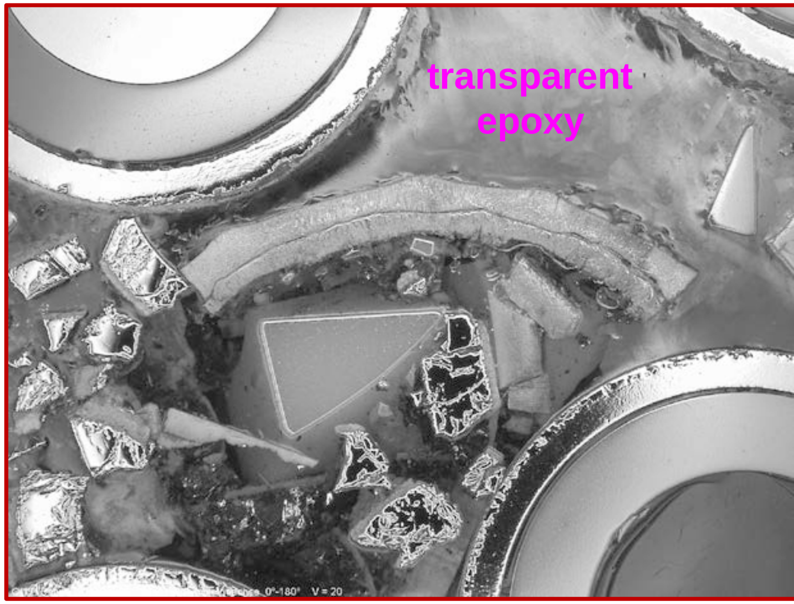


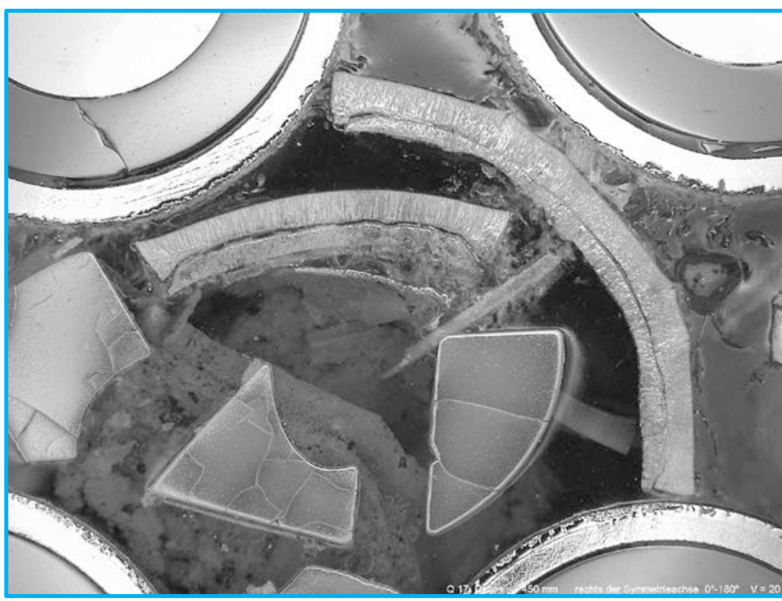
grid spacer #2: ZrO_2 120 µm;
inhibited heat removal due to debris

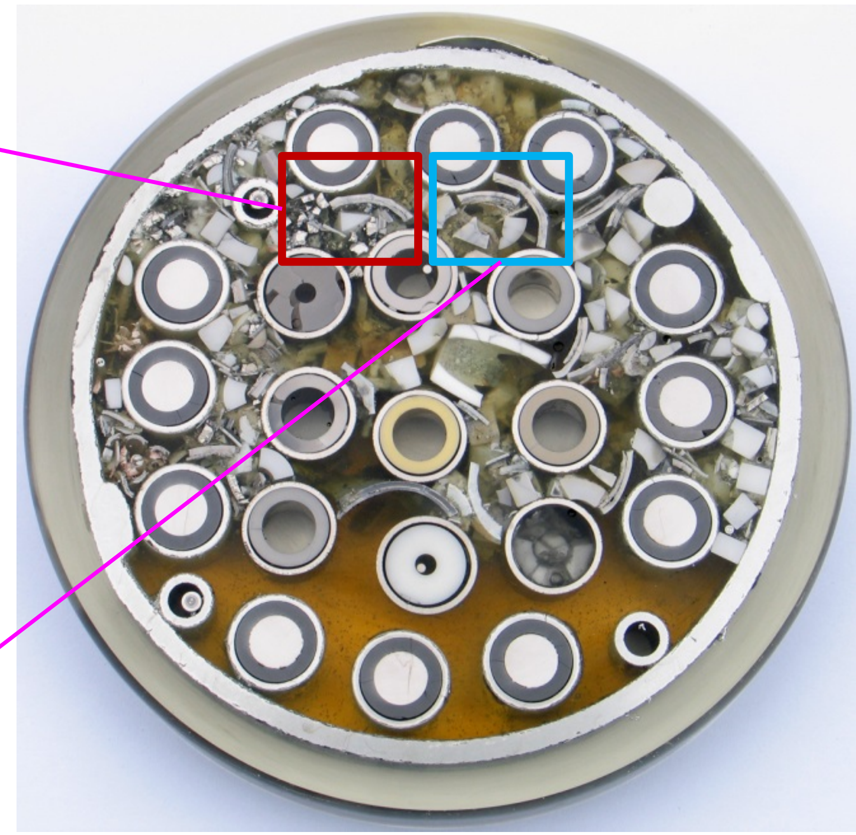


rod #17: outer HfO_2 140 µm, breakaway;
α-Hf(O) 150 µm

Debris regions at elevation 450 mm

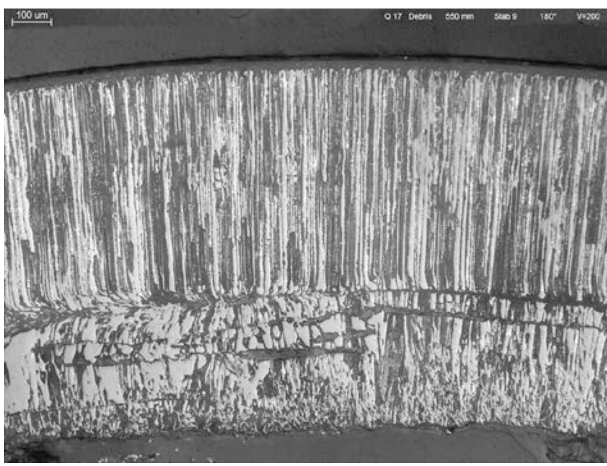




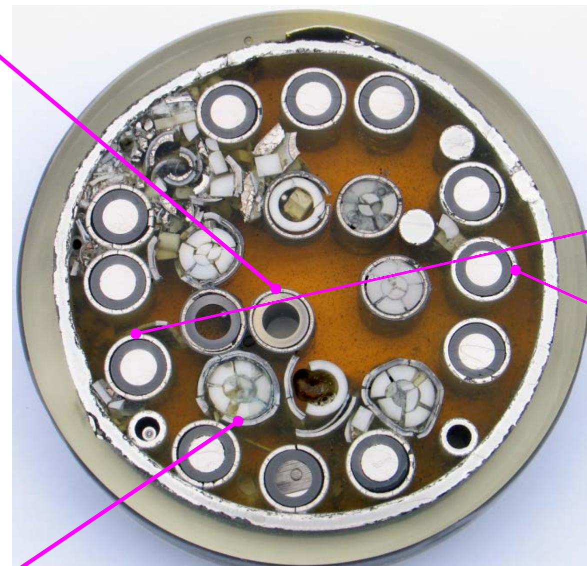


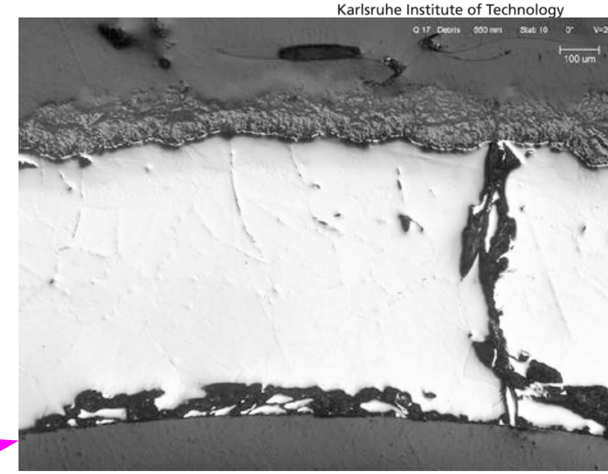
Structure of claddings at 550 mm: local effects due to debris; TFS 18/9 $_{long}$=1400 K

rod #1 (similar to #2 - #6):
outer ZrO_2 220 µm; inner ZrO_2 70 µm;
through-going crack



rod #9 (similar to #7 and #8):
completely oxidised



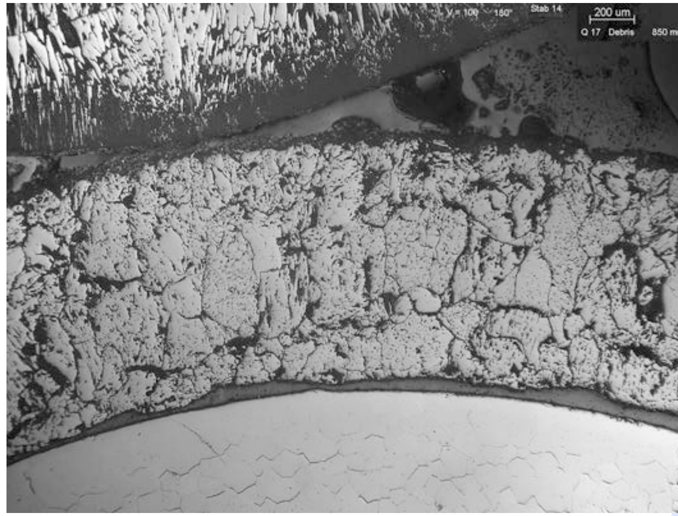


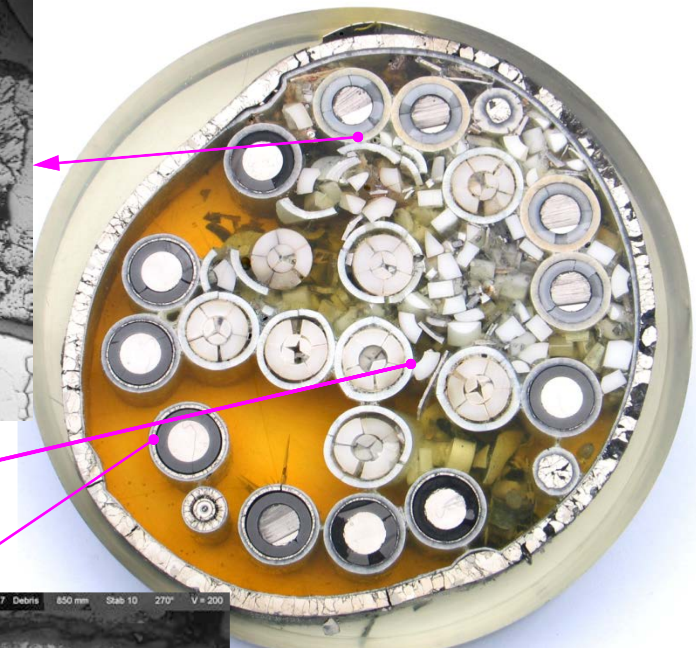
rod #10: outer HfO_2 120 µm, breakaway
α-Hf(O) remnant

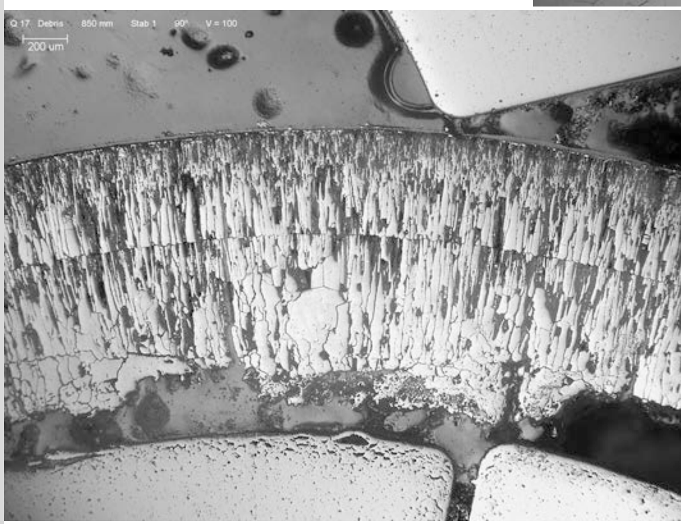
rod #17: outer HfO_2 160 µm, breakaway
α-Hf(O) remnant

Structure of claddings at 850 mm: local effects due to debris; TIT D/12$_{long}$=1750 K

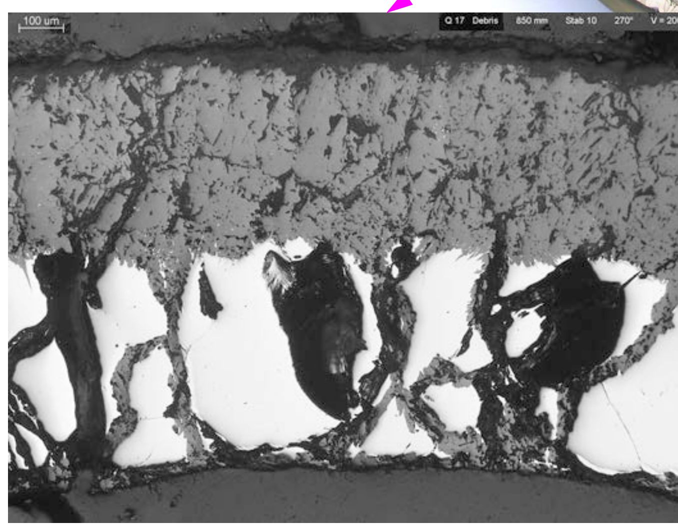
Hf rod #14 (similar to rods inside debris zone #13, 15 – 18): completely oxidised





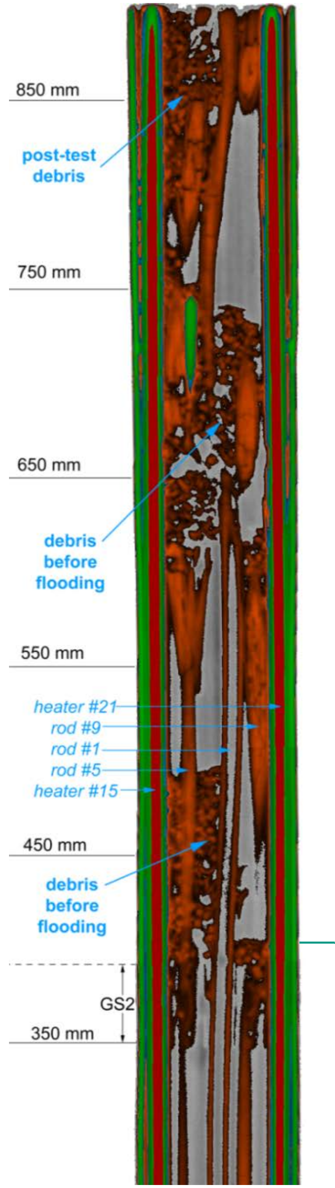


completely oxidised rod #1 (similar to other Zry rods)

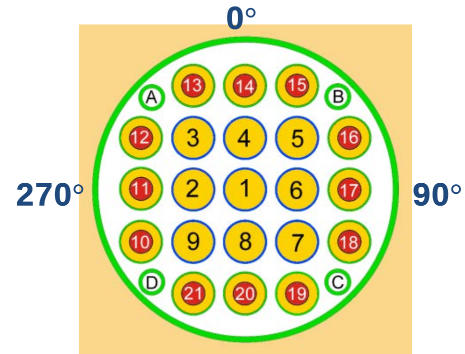


Hf rod #10 (similar to rods in zone without debris #11, 12, 19 – 21): HfO_2 450 µm; α-Hf(O) 460 µm; through-going cracks

X-ray tomography

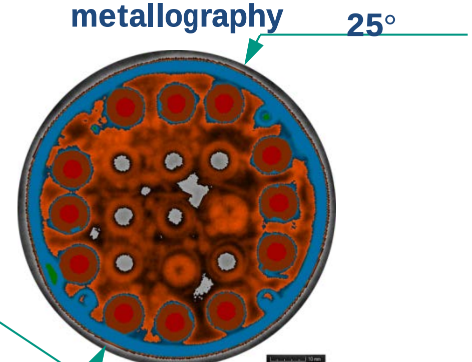


scan 25° - 205°



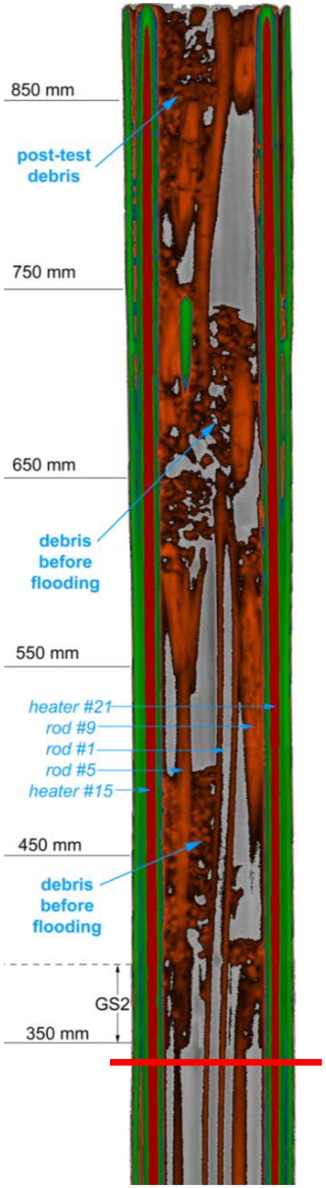
bundle composition

cross-section at 400 mm: metallography



cross-section at 400 mm: tomography; **cooling channel blockage 85%**

X-ray tomography: debris formed before flooding above grid spacer GS2



scan 25° - 205°

Movie: debris between 392 mm (GS top) and 765 mm

Summary

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• The QUENCH-17 bundle test with 9 unheated internal rods (Zry-4 claddings) and 12 heated external rods (Hf claddings) was performed in two stages: 1) long pre-oxidation stage (78000 s) at T_{pct}=1750 K with complete oxidation of Zry-4 claddings between about 650 and 1150 mm, 2) reflood stage with slow flooding from bottom (10 g/s, or about 3 mm/s through the debris bed).

• Different kinds of Zry and Hf cladding oxidation were observed depend on temperature: breakaway of relative thin oxide layers at lower temperatures and regular thick oxide layers at higher temperatures. Despite complete oxidation of claddings their mechanical integrity was mostly not damaged.

• Mechanical impact on the end of pre-oxidation caused debris relocation to grid spacer at 350 mm. Some Zry-4 claddings were not significantly damaged. Ceramics debris collected at the top of grid spacers consist of separate pellet segments (eff. D ≈ 3 mm) and **relatively large linear cladding segments (> 10 mm)**.

• Steam production rate was strongly **oscillated** during propagation of flooding water through the debris collected above grid spacers at 350 mm.

• The **porosity** of debris bed is **significant**, no dense packing of debris particles was observed. **Large empty volumes** formed due to bending of rods. The maximum cooling channel **blockage** was about **85%**.

• Impact of heterogeneous debris bed on reflooding remains open question. Detailed analysis of the reflood is planned in the near future to examine the latter question.

Acknowledgment

The authors would like to thank Mrs. U. Peters, Mrs. U. Stegmaier and Mrs. J. Laier for intensive work during test preparation and post-test investigations

Thank you for your attention

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