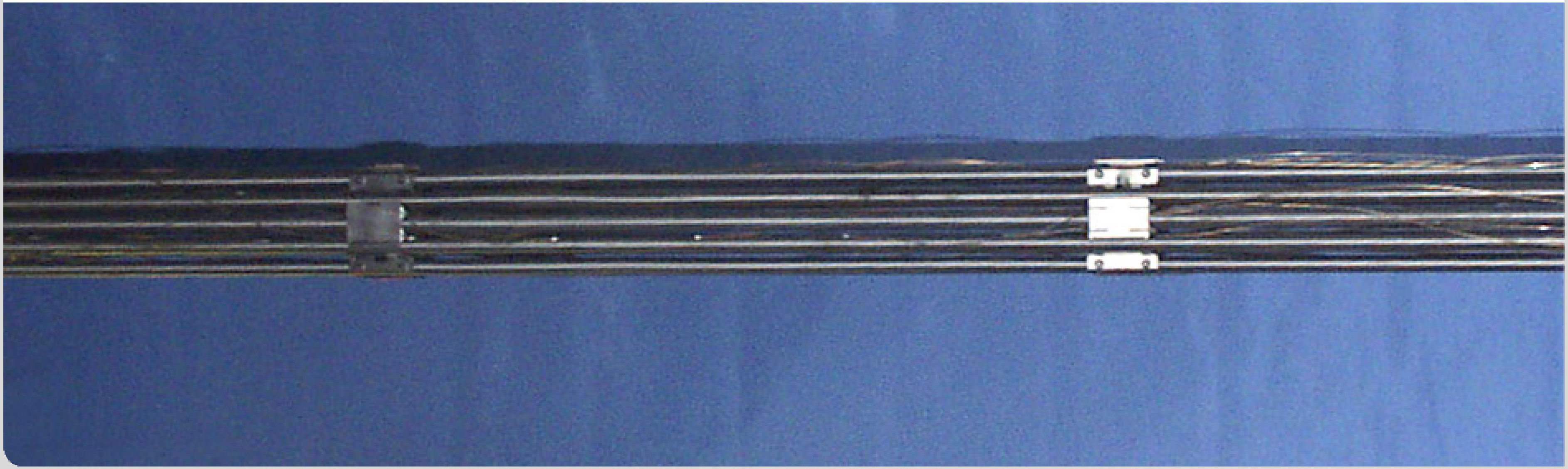
First results of the QUENCH-17 bundle test on debris formation

J. Stuckert, J. Moch, C. Rössger, M. Steinbrück, M. Große

presented by J. Stuckert

SARNET2: WP5-COOL Review Meeting

Institute of Apllied Materials



Objectives of the QUENCH-17 test

- **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**

Status of bundle preparation

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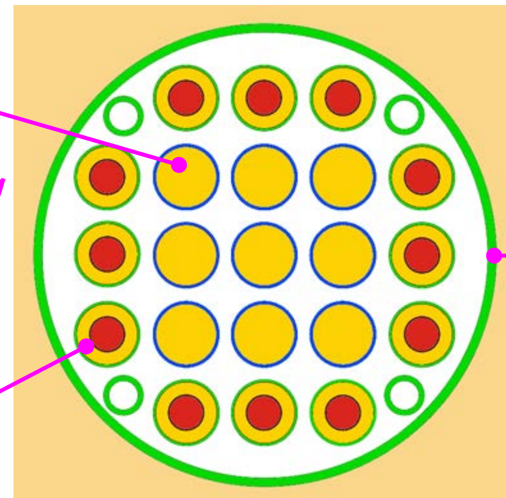
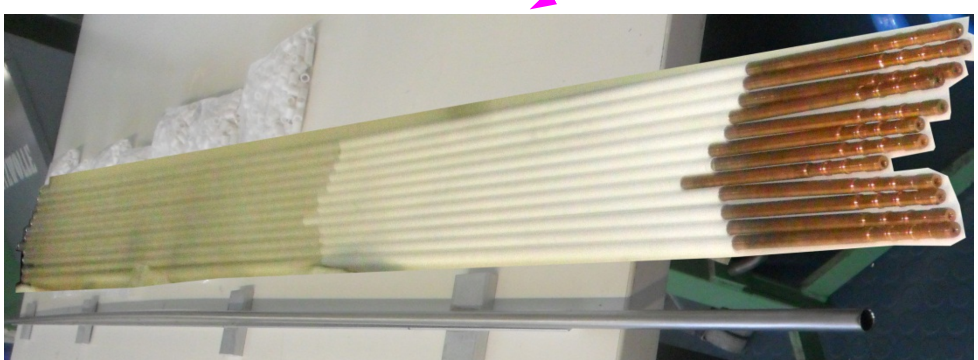
Zry cladding filled with ZrO_2 pellet segments and ZrO_2 powder

9 unheated rods with Zry-4 cladding



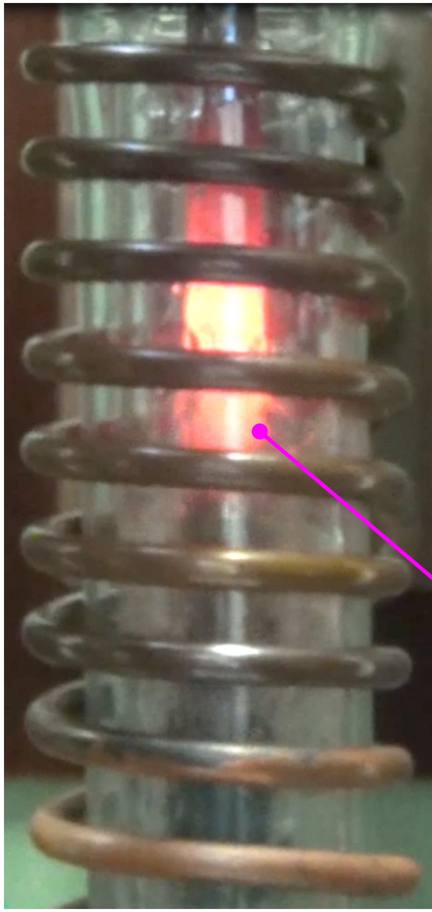
Hf shroud

12 heated rods with Hf cladding



Quench test with <u>completely</u> oxidized cladding filled with segmented pellets.

Oxidation at 1773 K during 11600 s, quench with water 80 g/h

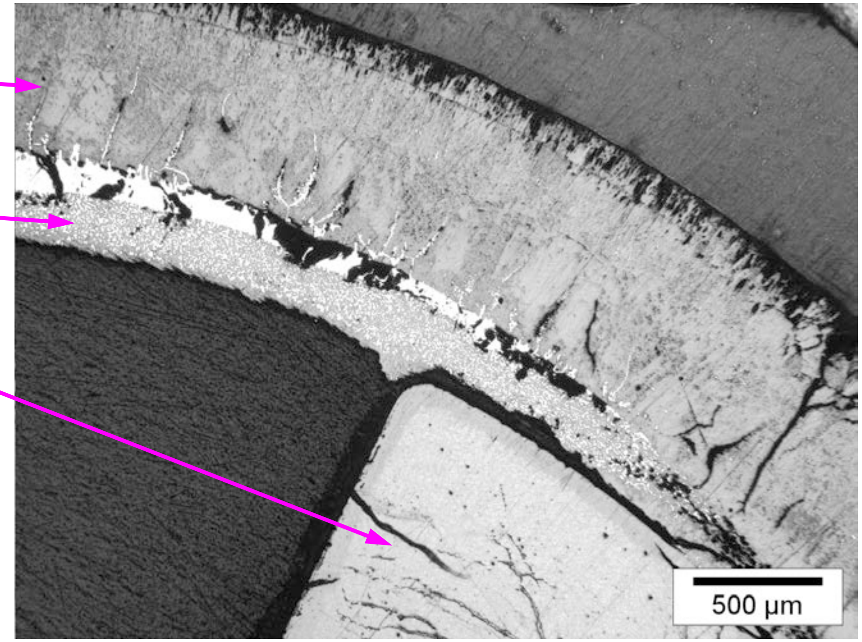


sample inside inductive furnace during quench

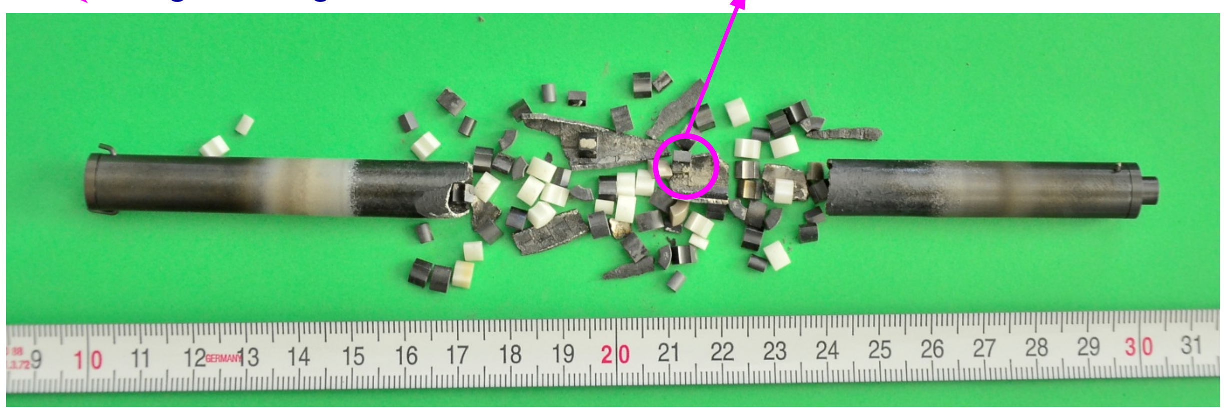
oxide

ZrO_2 powder reacted with clad metal

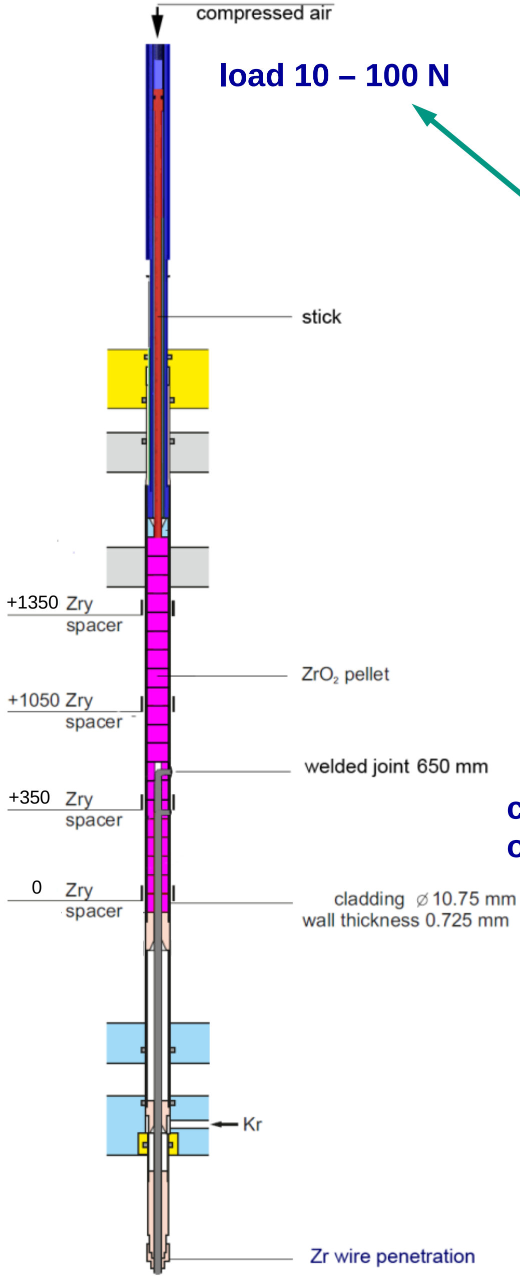
pellet segment



sample was destroyed during handling



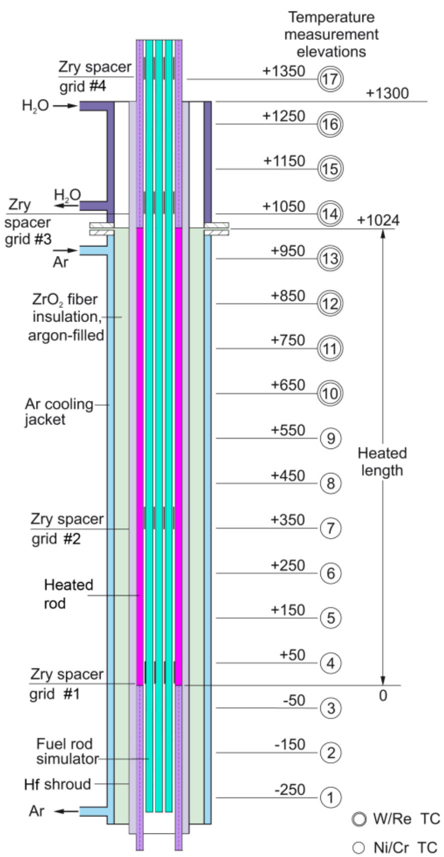
load 10 – 100 N

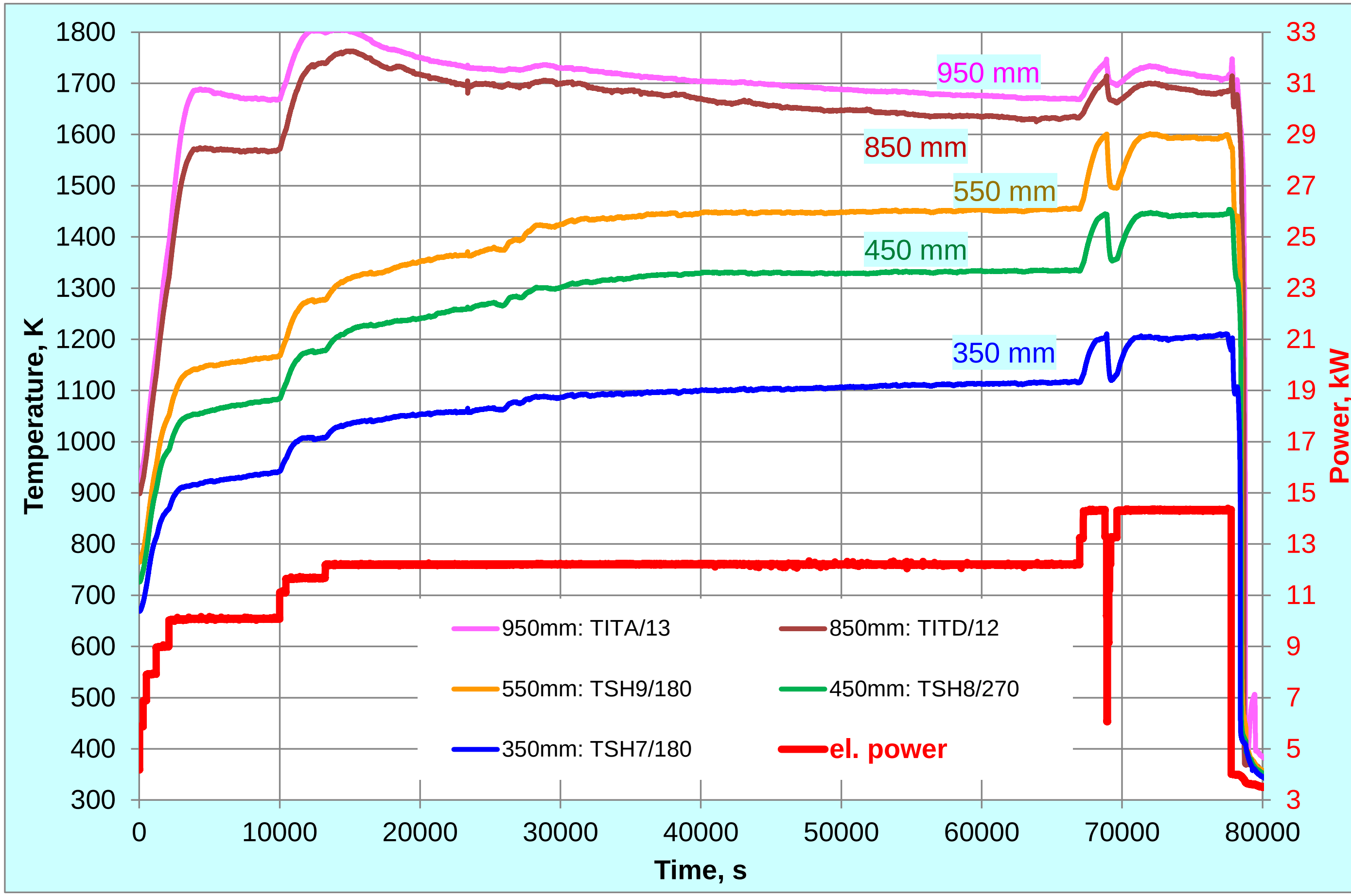


Two features of unheated test rods

check of through going oxidation

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

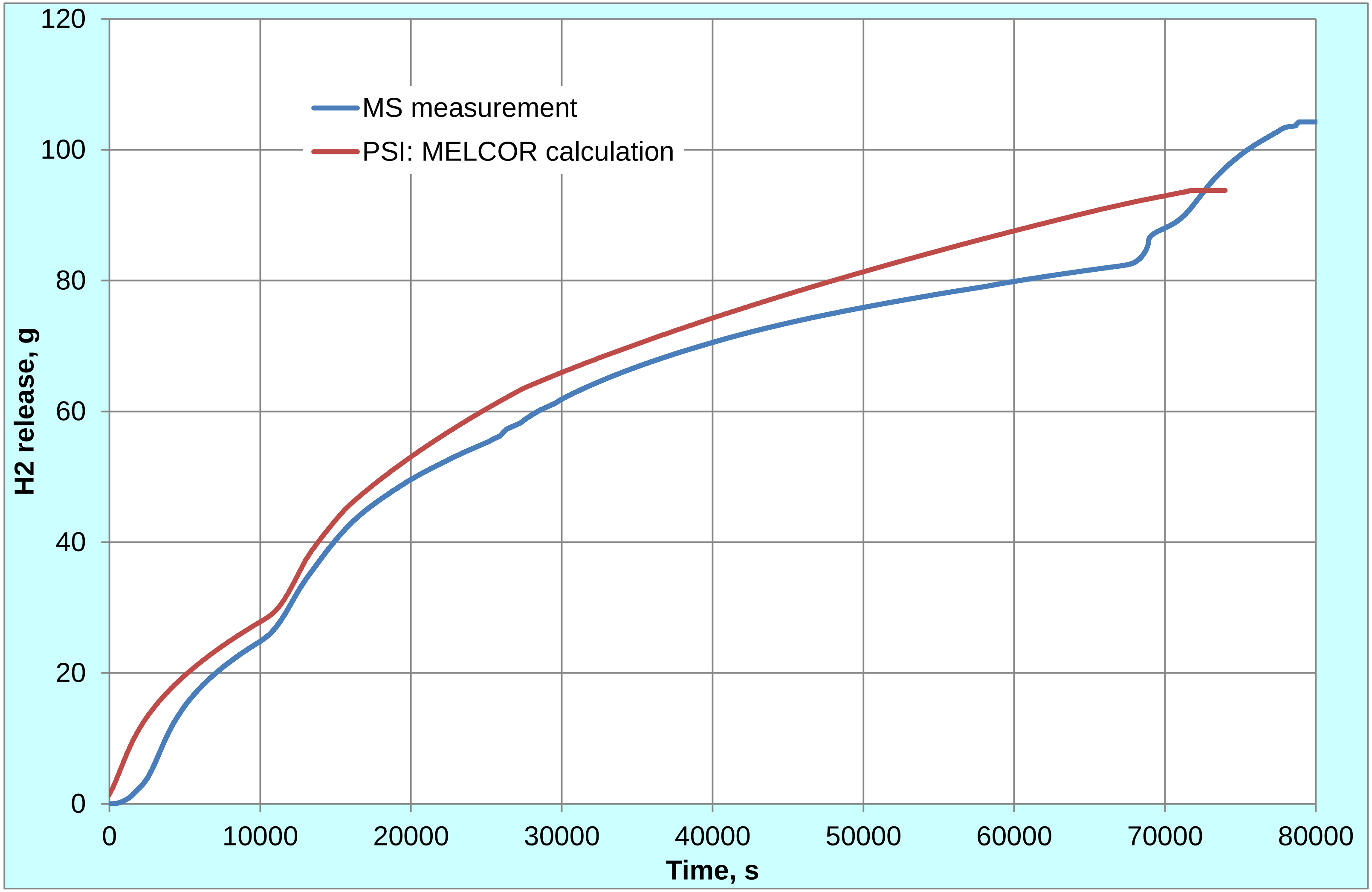




1) pre-oxidation stage with 2 g/s steam and 2 g/s Ar. Complete oxidation of Zry-4 clads between 650 and 1150 mm

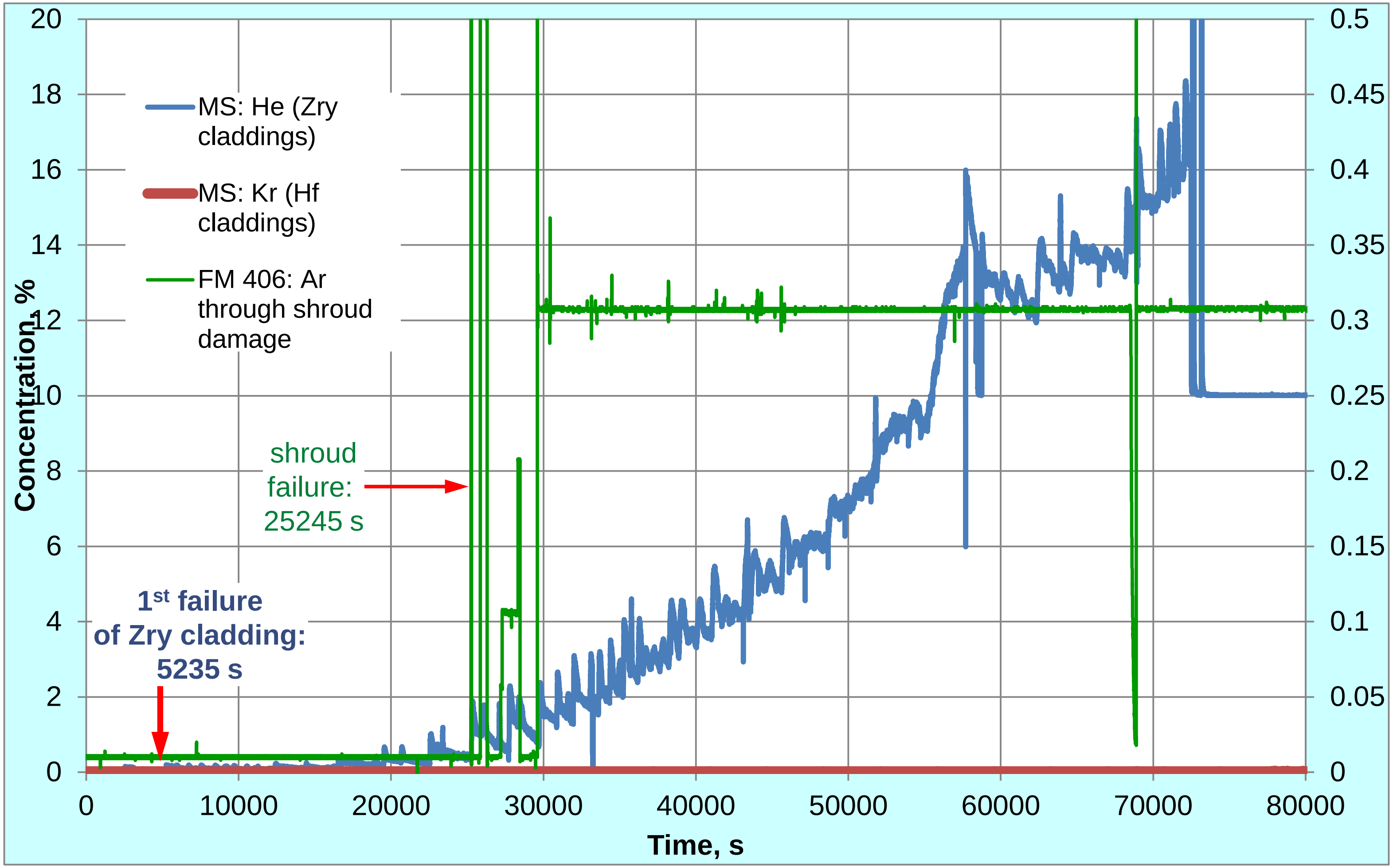
2) Test termination: reflood from bottom with water flow rate 10 g/s.

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



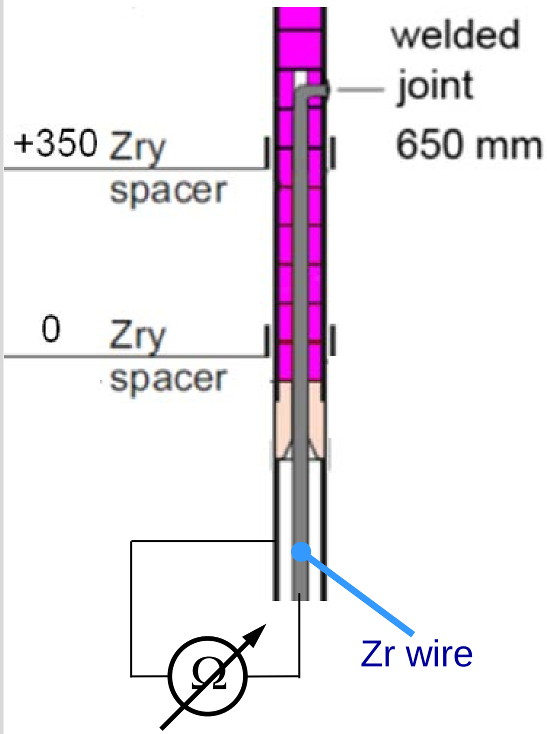
good correspondence with pre-test calculations

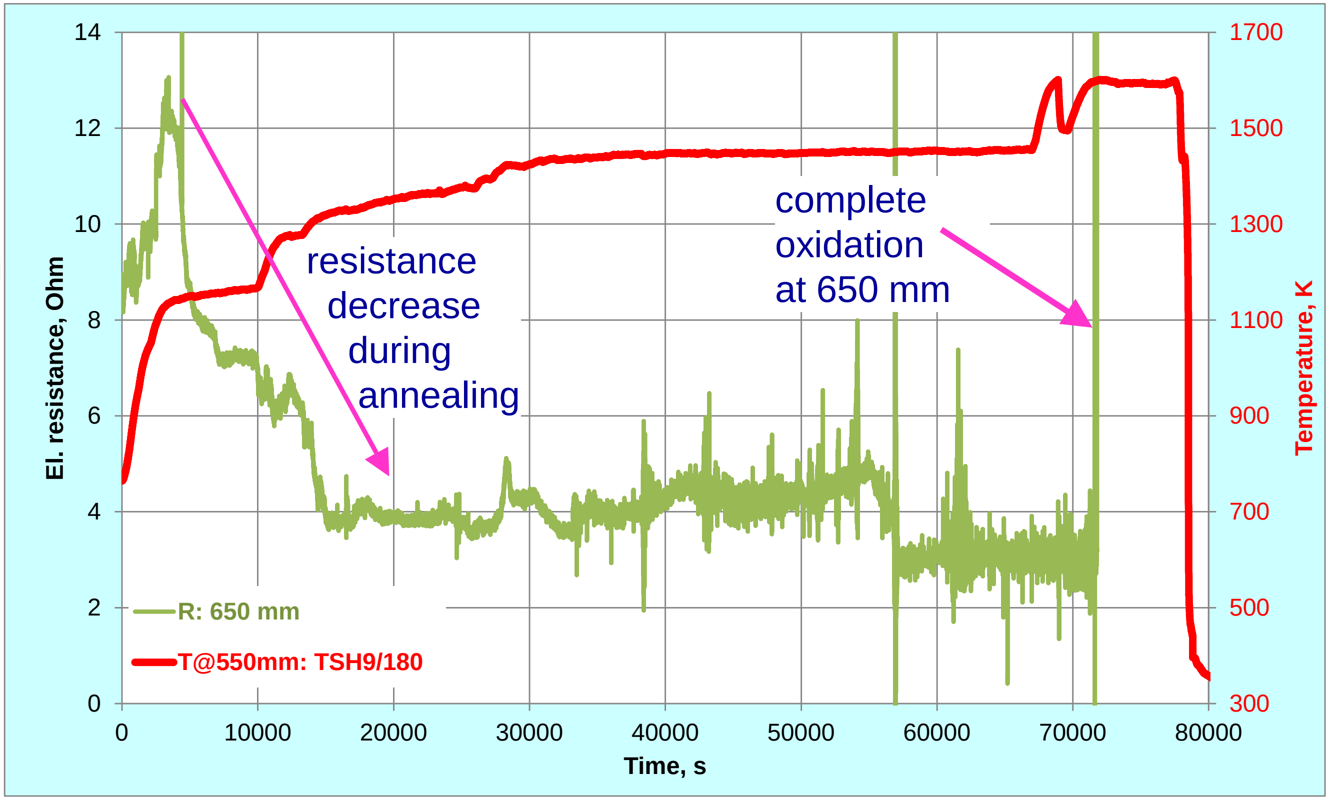
Failures of Zry claddings and Hf shroud



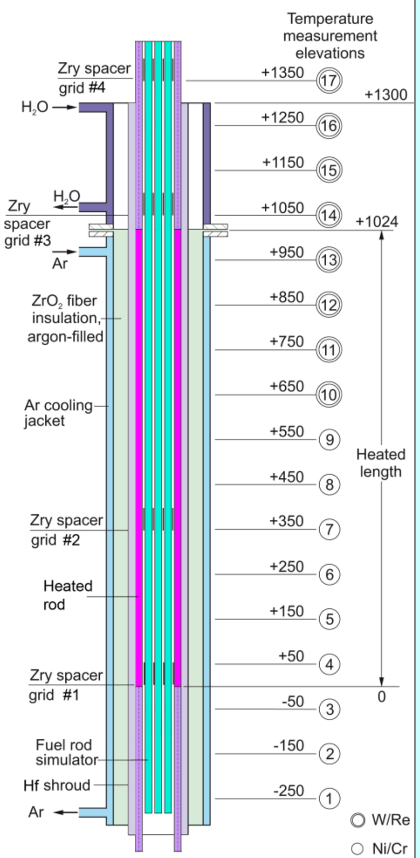
no failure of Hf claddings was registered

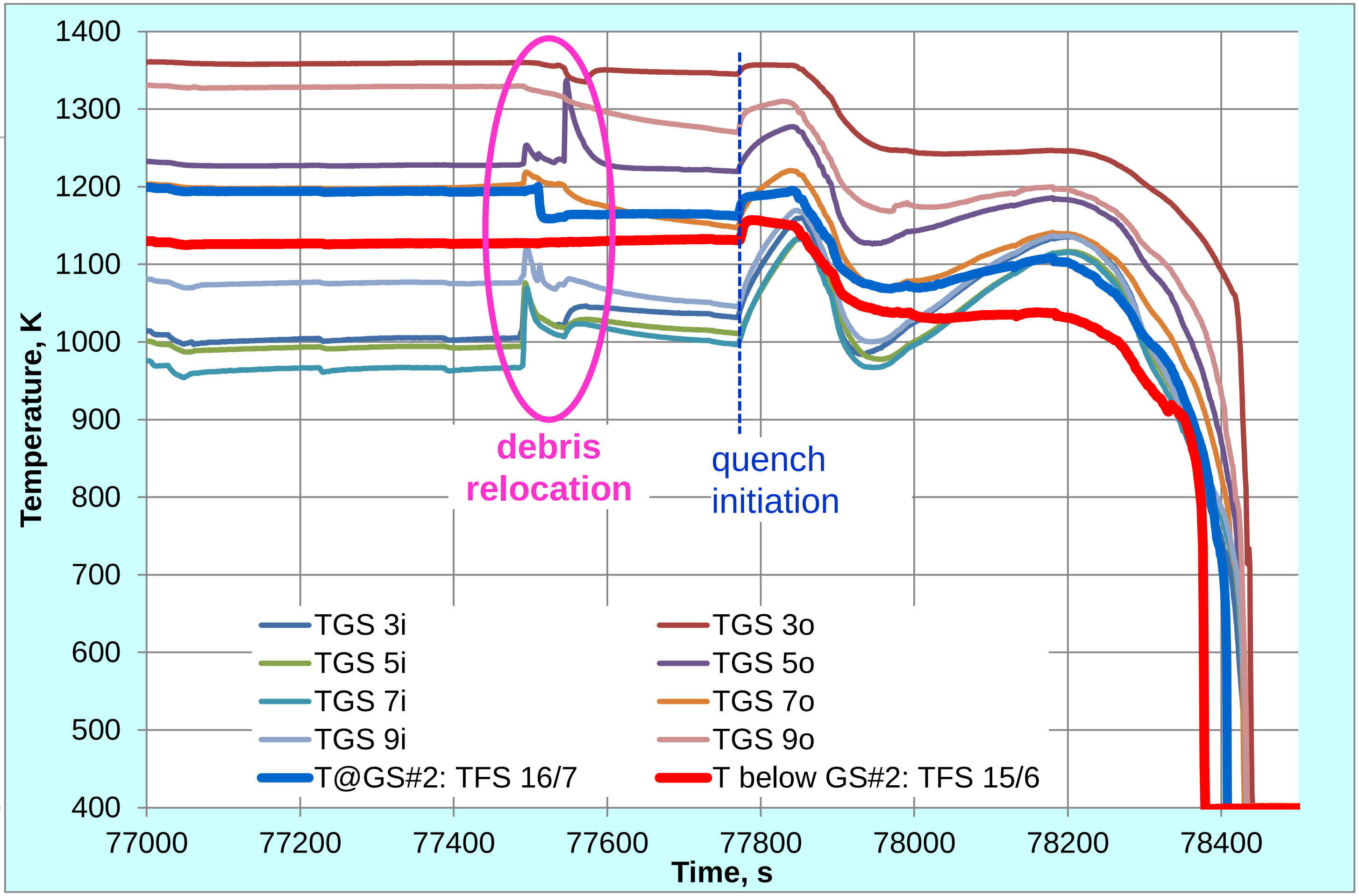
Indication of complete oxidation at 650 mm by el. resistance measurement



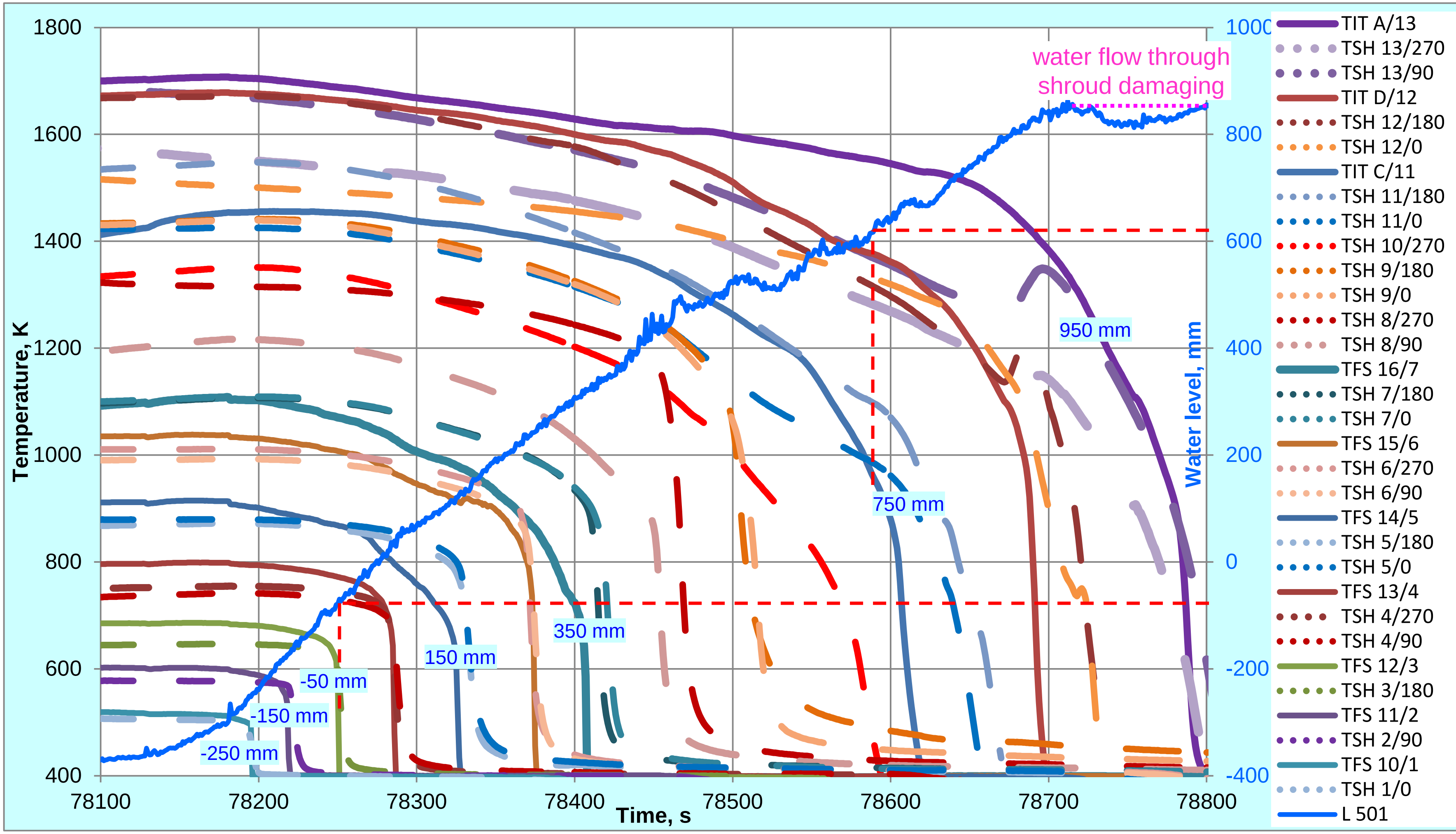


Indication of debris relocation to GS#2
(reaction of thermocouples TGS installed at the top of GS#2)

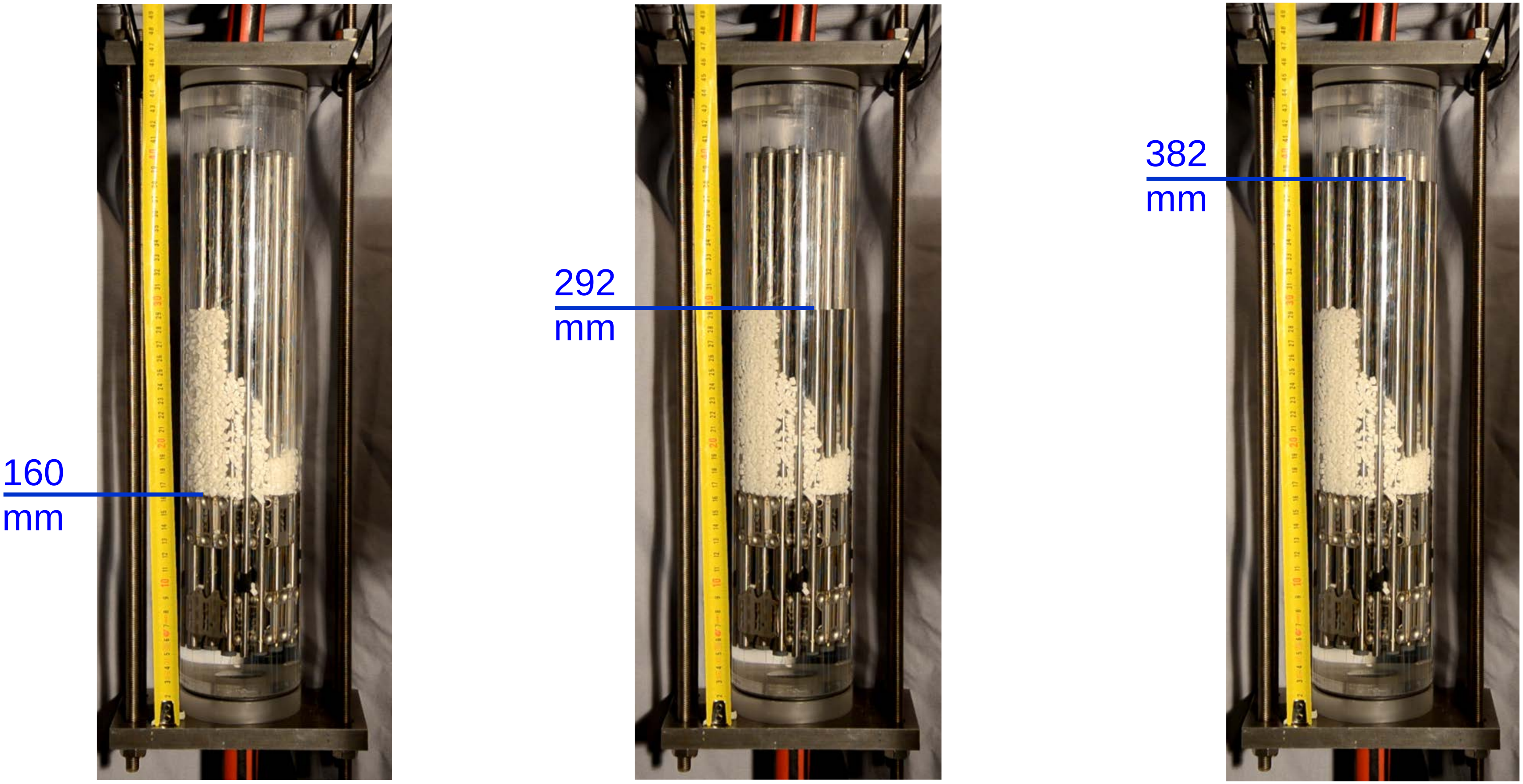




Quench phase: collapse water level and TC wetting



Reflood simulation with pellet debris inside 21-rod-bundle. Cold water flow rate 10 g/s



δt=27 s: **v = 5 mm/s**

δt=28 s: **v = 3 mm/s**

Quench phase: water level oscillations and evaporation rate

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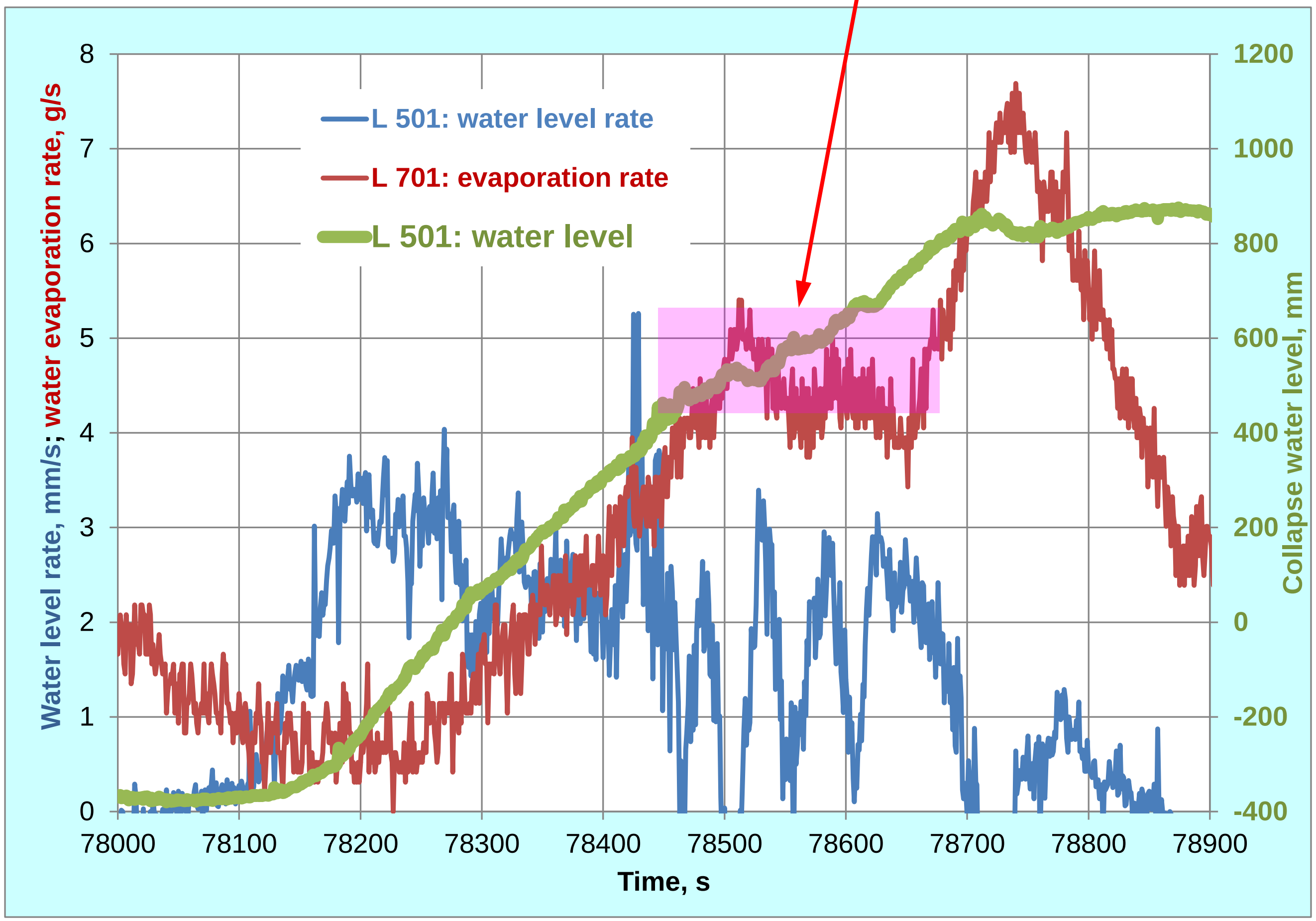
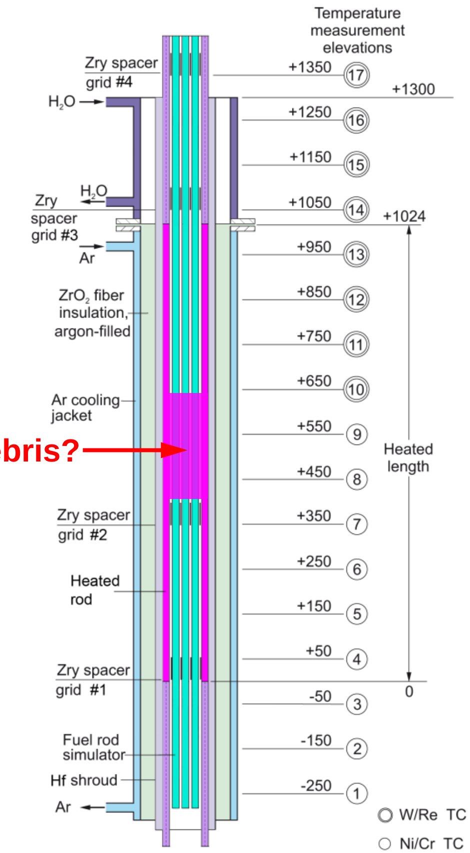
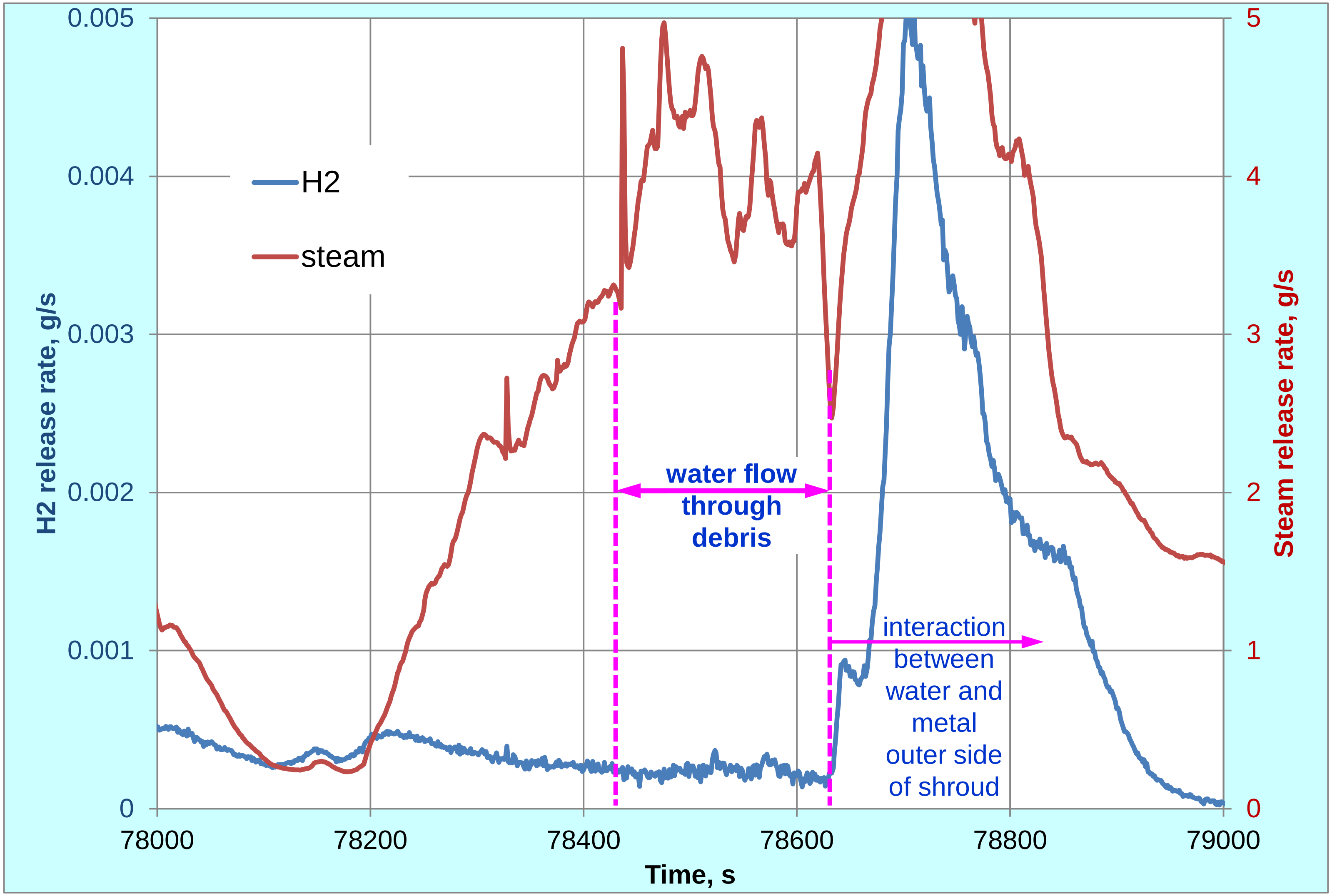
Constant evaporation rate.
Region of debris bed?



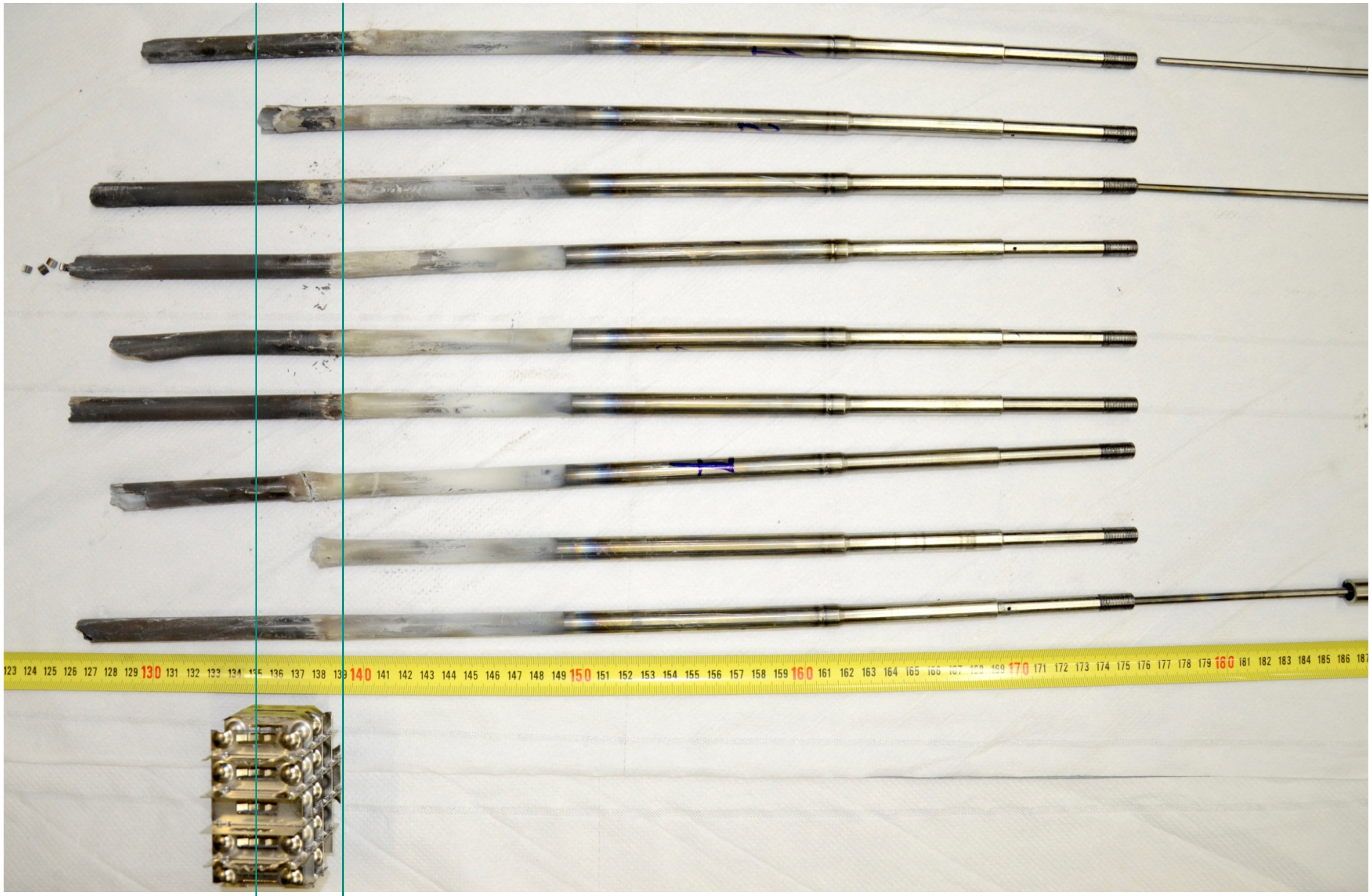
Debris?



Mass spectrometer measurements: no hydrogen production during water flow through debris



Upper parts of Zry claddings above 1200 mm



Endoscope observation of debris relocated to top edge of GS #3 (about 1100 mm)

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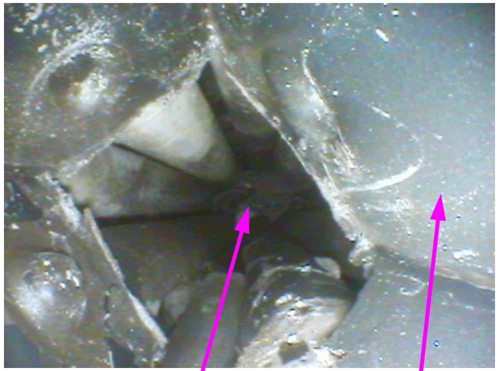
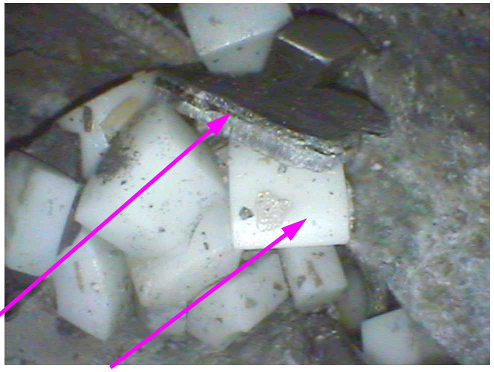
1. After pull-up of upper part of one Zry-4 rod (rod #2)

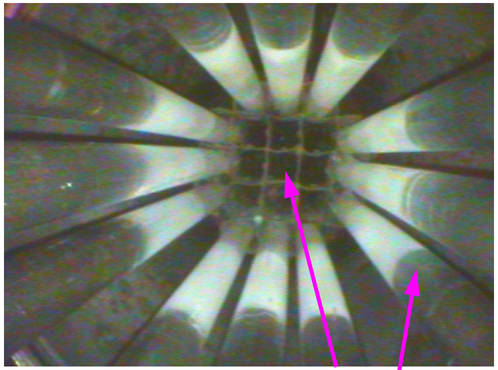


view of top of GS#3 through the position of rod #2 inside the GS#4 (1350 mm)

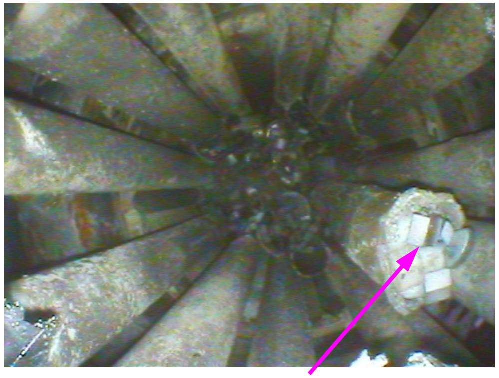


debris of oxidised cladding and pellets on the top of GS#3

2. After pull-up of upper parts of all nine Zry-4 rods



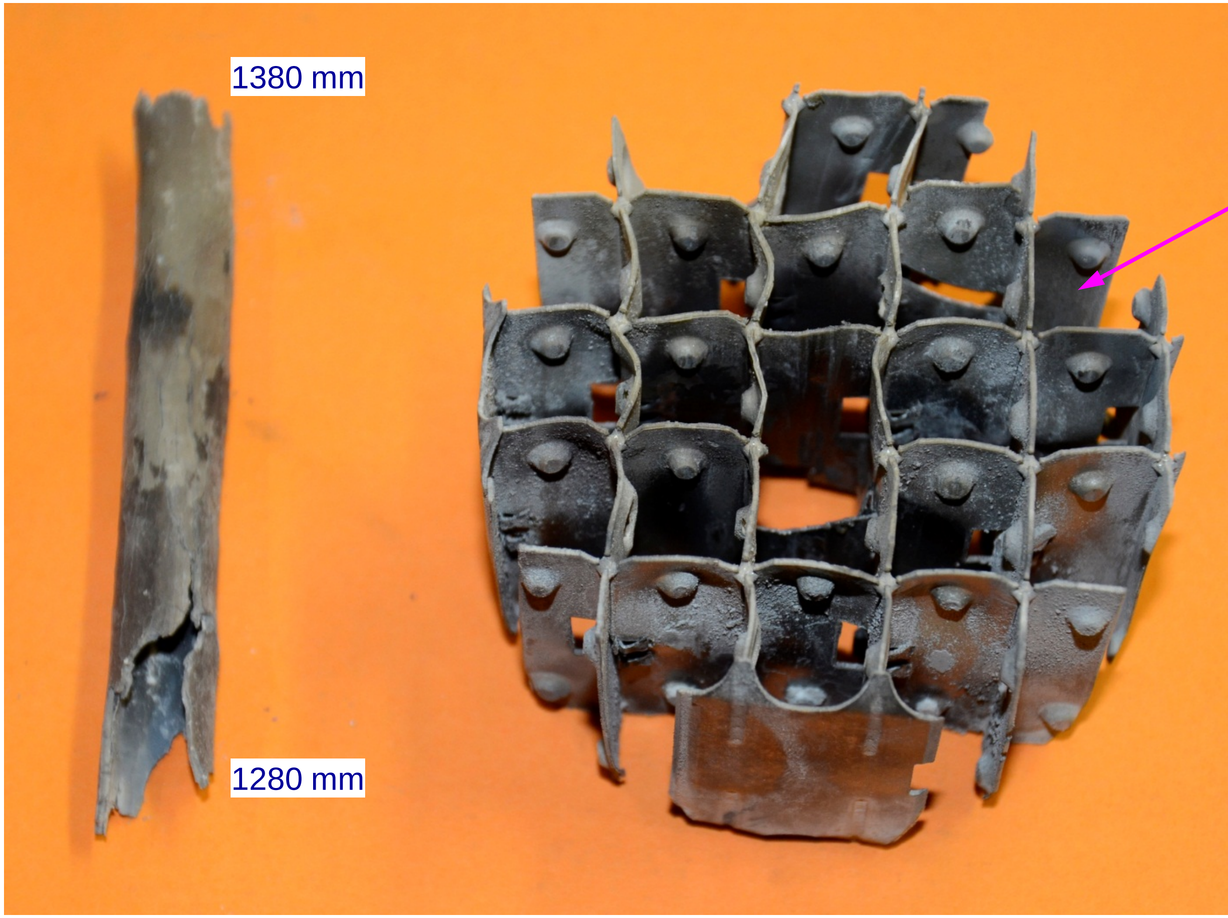
top view of GS#4 and twelve Hf claddings

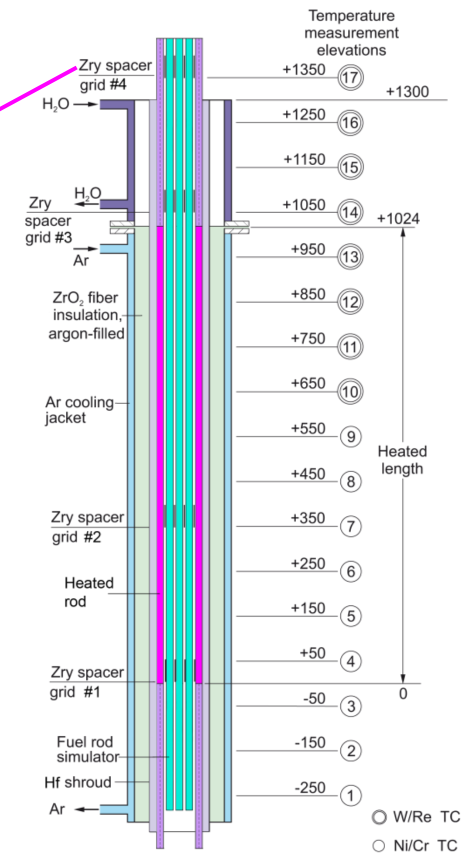


1200 mm: segmented pellets inside remnant of rod #8

1100 mm: debris relocated downwards from removed nine test rods

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





remnant of rod #8:
significantly oxidised

GS #4:
completely oxidised

Structure of oxidized Zry cladding at 1328 mm, T ≈ 1000 K. Stab #7.

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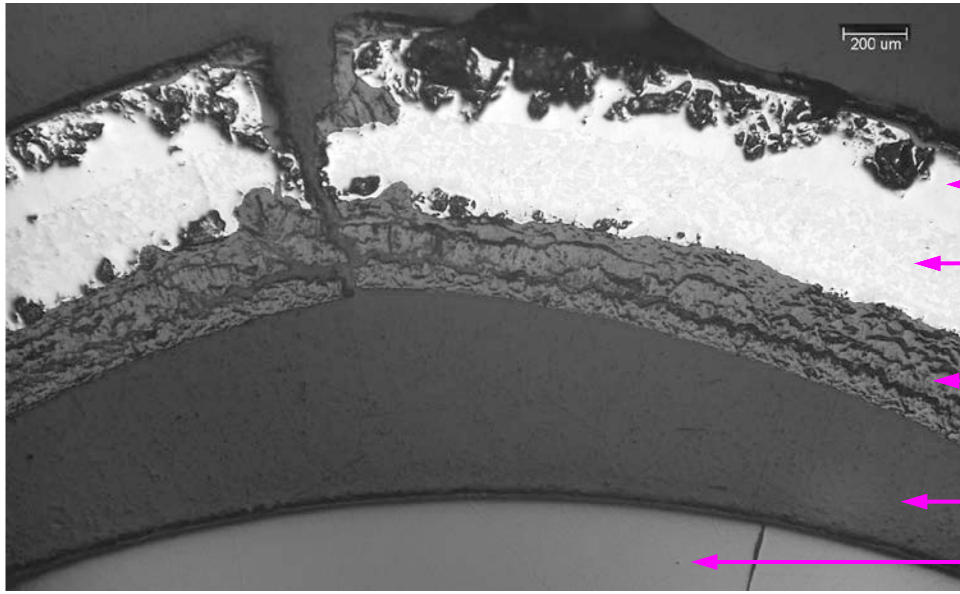


α-Zr(O)

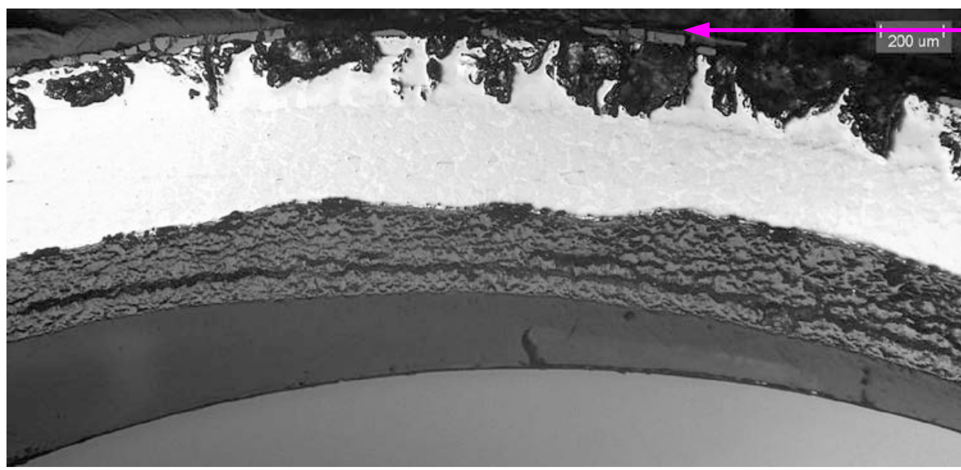
prior β-Zr

thick inner oxide layer

gap

upper not segmented pellet

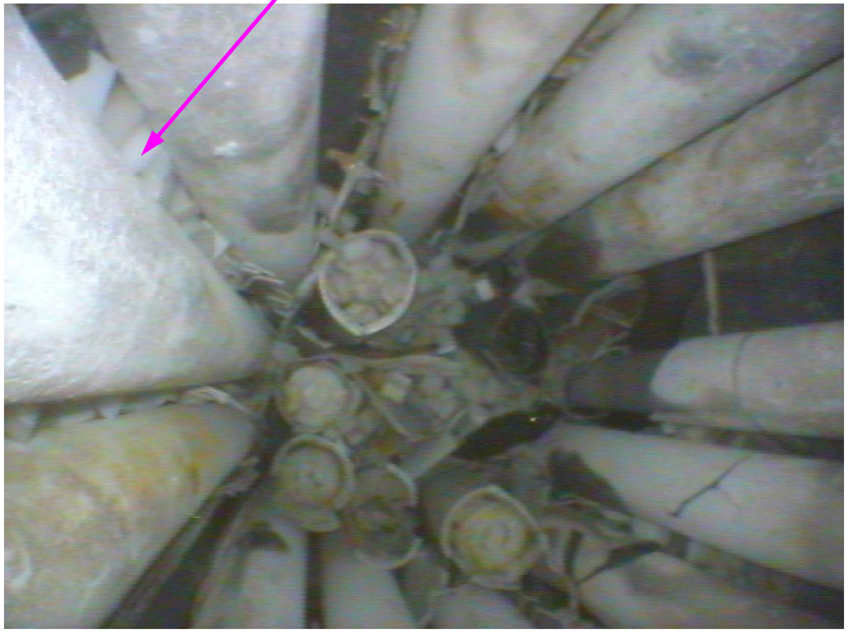
0°

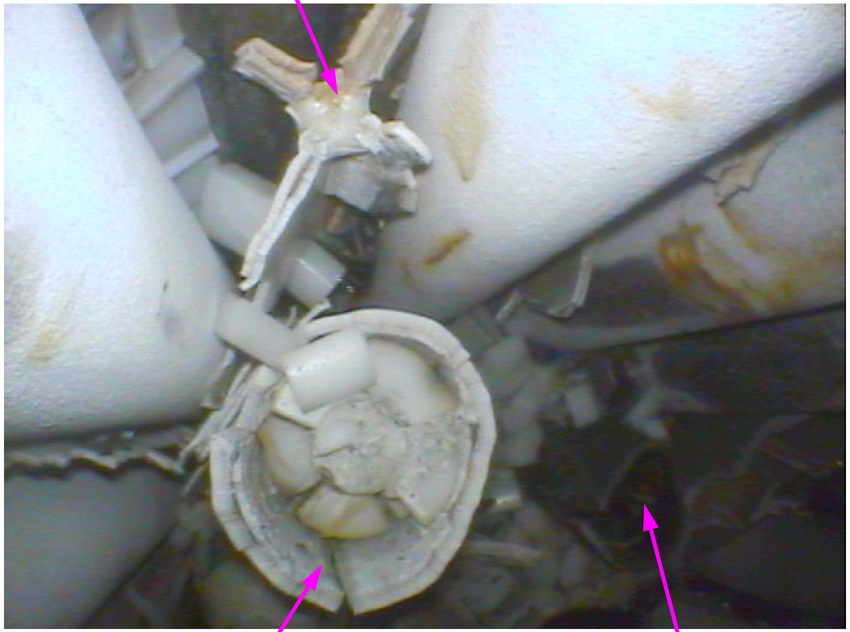


thin outer ZrO_2
(starvation, spalling?)

180°

Top view of grid spacer #3 (1090 mm)





Endoscope observation of debris relocated under GS #3 (about 1100 mm)

top view of empty rod #6

view through the empty cladding

blockage at elevation 910 mm

sintered pellets at 950 mm

pellet segments at 920 mm between Zry and Hf claddings

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

CONCLUSIONS

- 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)

- Hf claddings of heated rods were intact during whole test, Hf shroud was failed at 850 mm after 25000 s.

- First failure of Zry-4 cladding was registered at 5500 s. Noticeable internal oxidation was observed at upper bundle elevations.

- Mechanical impact on the end of pre-oxidation caused debris relocation to grid spacers at 1050 mm and 350 mm.

- Steam production rate was stagnated during propagation of flooding water through the debris collected above grid spacers at 350 mm.

- Some Zry-4 claddings were not significantly damaged; the pellet segments relocated from the failed rods were captured between corresponding neighbour rods.

- Ceramics debris collected at the top of spacer at 1050 mm consist of separate pellet segments and relatively large cladding segments.

- Tomographical and metallographical investigations of region above grid spacer 350 mm should give detailed information on the degree of bundle degradation.

Thank you for your attention

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