LOCA IFA650-4: Fuel relocation study

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The PIE of IFA 650-4:

Characterisation of fuel relocation phenomenon shall give:

- **Knowledge of the balloon size and of the axial clad deformation profile**

  (maximum radial deformation, axial extent of the balloon)

- **Crack length and opening** (in relation with fuel ejection outside the rod)

- **Fuel relocation data**:

  -fuel particle size distribution

  -filling ratio

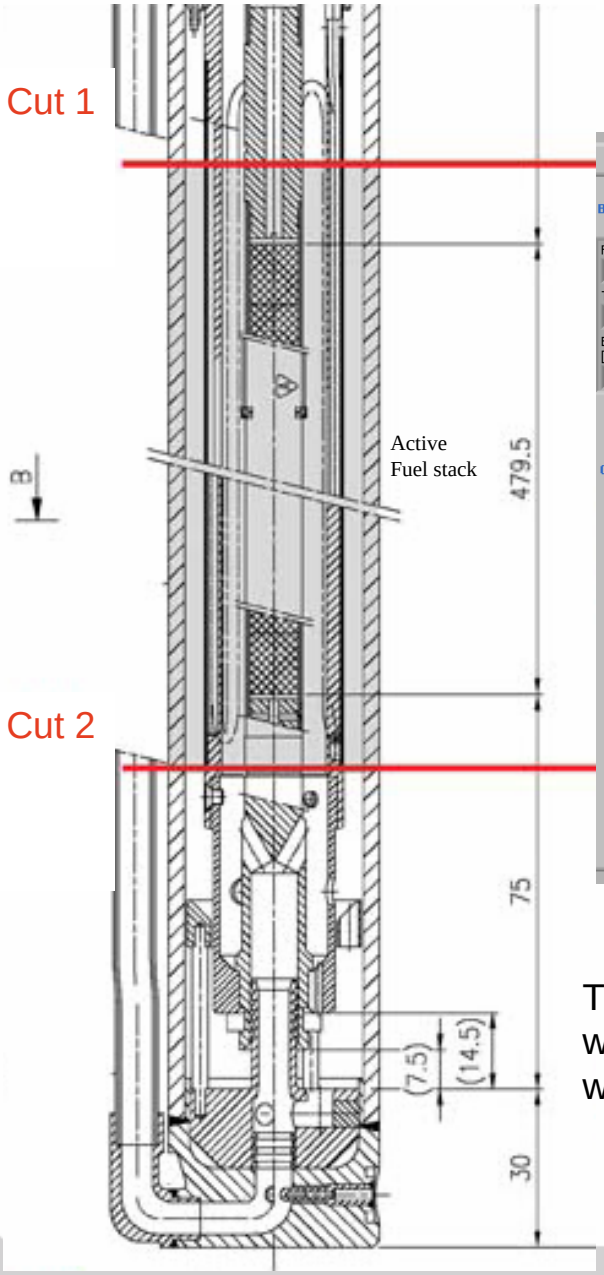
  -fuel mass ejected outside the rod

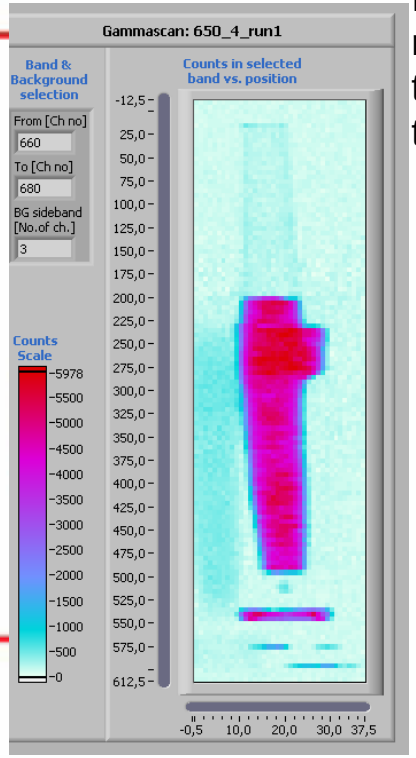
  -length of the remaining zone without fuel

- **Clad oxide thickness** at the middle of the balloon and at both ends

- **Micro-hardness** determination (not possible)

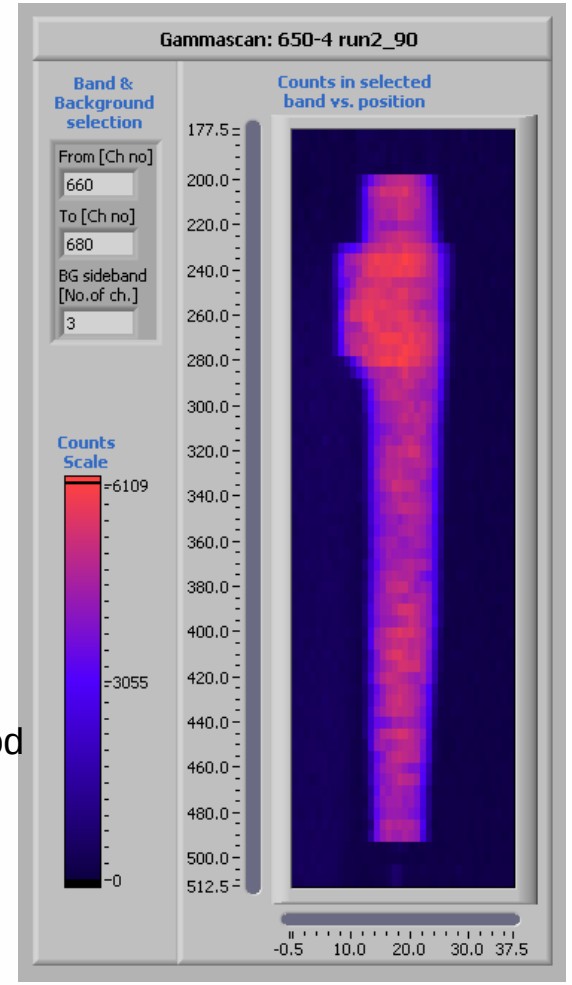
- **Quantification of the fuel mass that has been ejected from the rod** (agreement on method is needed)





Approx. 19 cm of fuel stack are missing from the upper part of the rod. The length that originally was filled with fuel is indicated by the slight activity registered above the highly active (red) part around the balloon. Some fuel has fallen to the bottom of the flask.

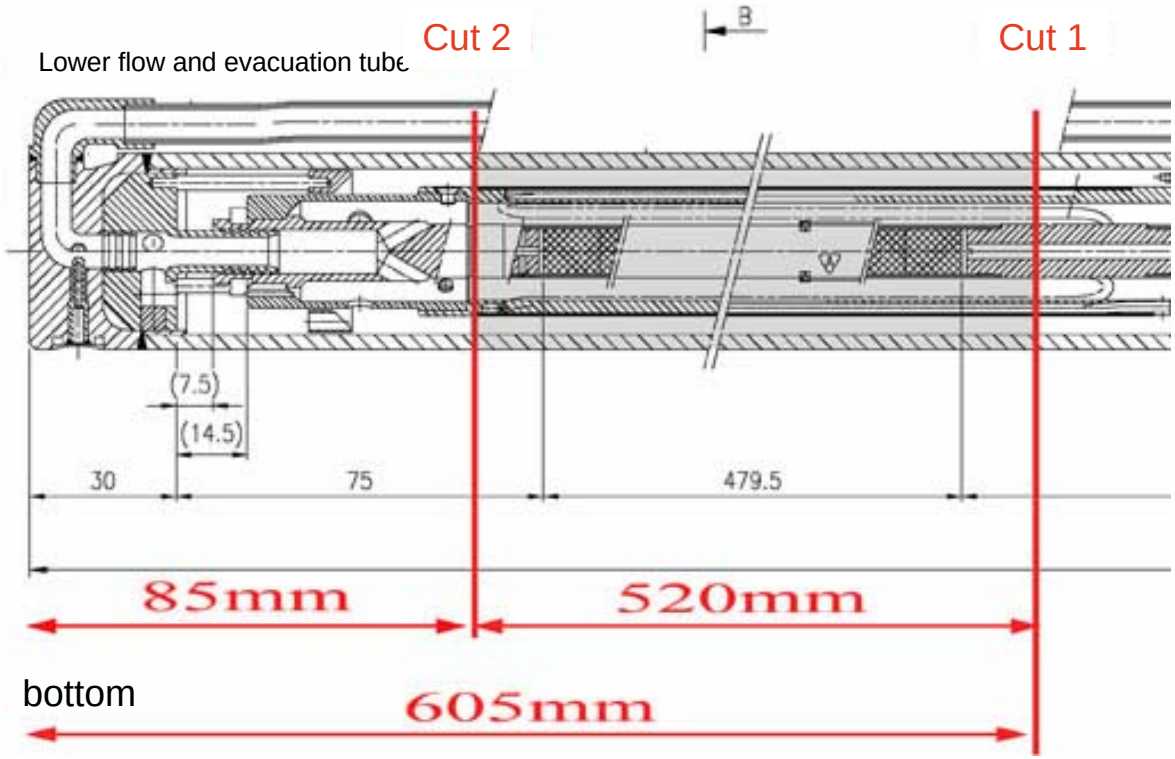
LOCA induced burst with fuel relocation

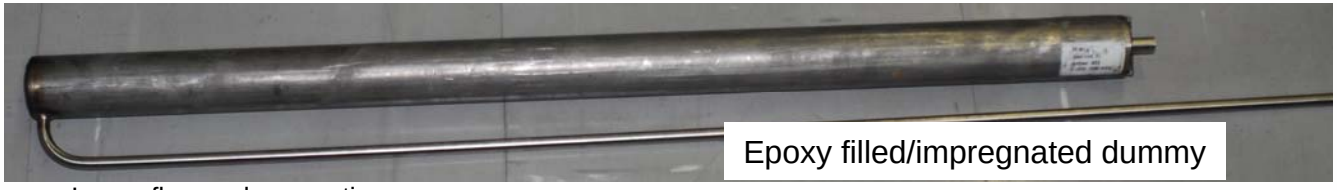


This image only shows the part of the rod with remaining fuel. The rod was turned by 90 degrees for the scan.

Stabilizing the LOCA induced fuel relocation

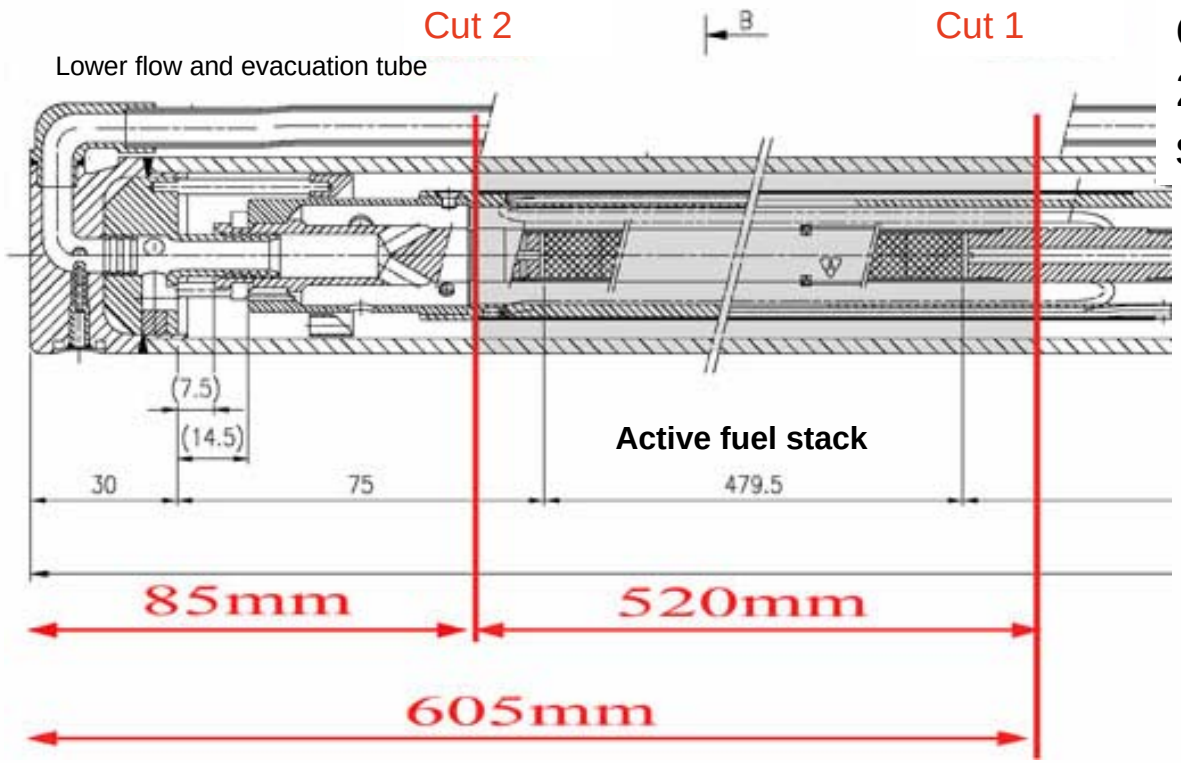
* Epoxy filling of dummy fuel element. Epoxy injection from lower end, gas outlet top.





Lower flow and evacuation tube

Cutting study of epoxy filled fuel element dummy in hot cell



Cut 1 & 2: on each end, 20 mm off the active fuel stack (Circle saw)

Lower flow and evacuation tube

Example: Cut 1 at 605mm

Cut 3: Removal of pressure flask in a length of 520 mm for metallographic precision cutting of active fuel stack

*Cutting with hollow saw in epoxy between D_{inner} Pressure Flask and D_{outer} El. Heater (260 mm from each end)

Technical data:

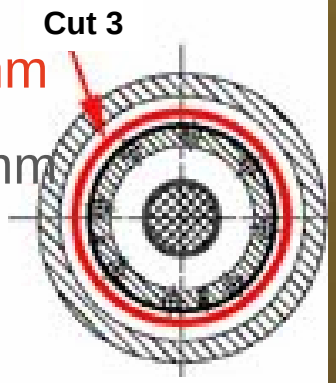
D_{outer} Pressure Flask:40mm

D_{inner} **Pressure Flask:**34mm

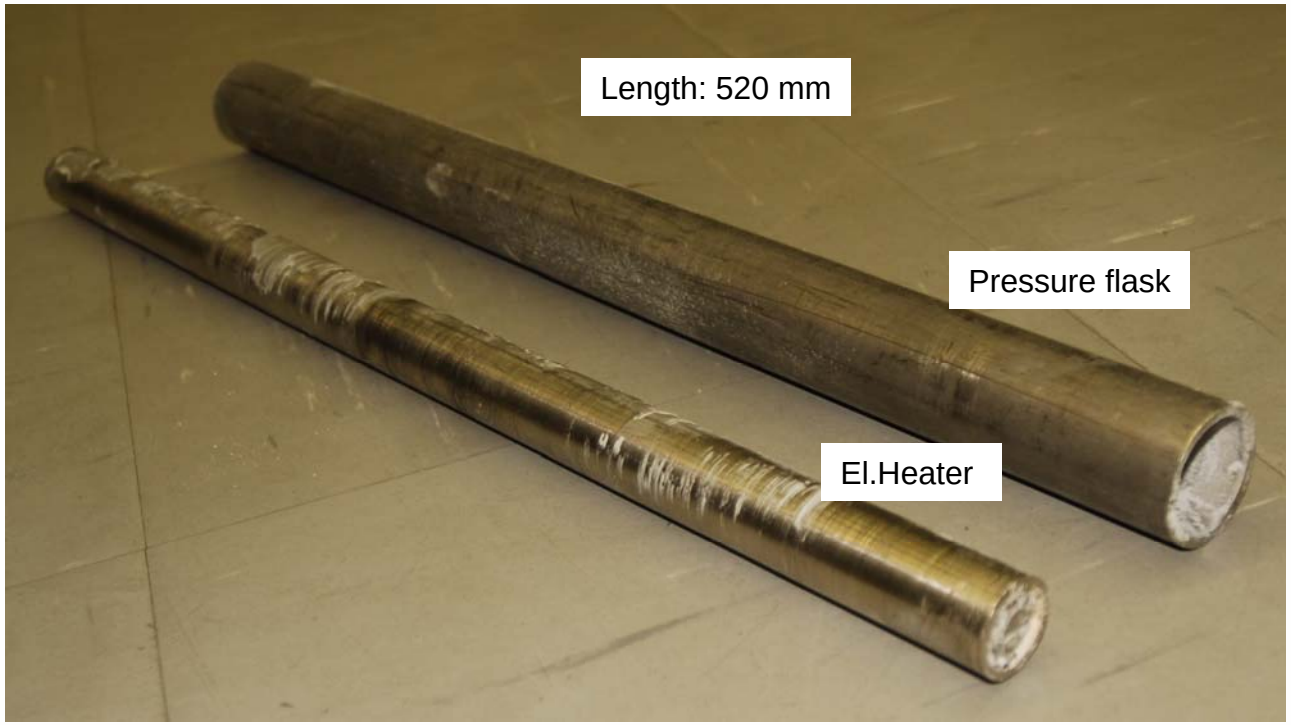
D_{outer} El. Heater:26 mm

D_{inner} El. Heater: 20 mm

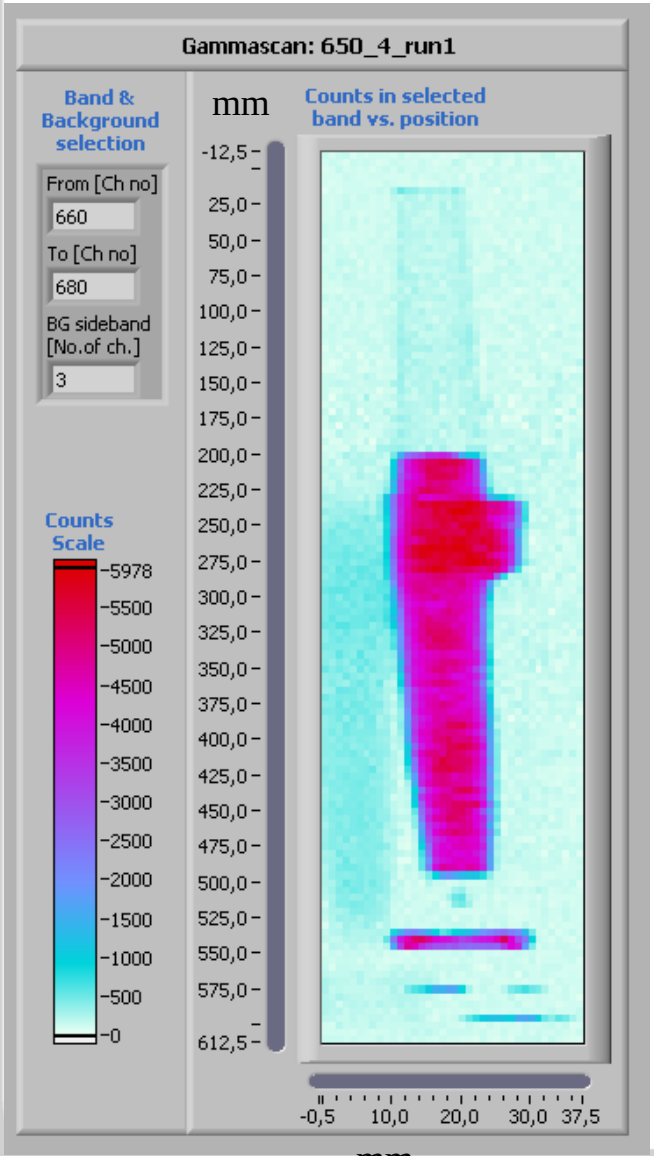
D_{outer} Rod segment: >10.8mm<20mm$_{burst}$



Removed pressure flask prior to sampling for fuel relocation study



Examinations levels according to the objectives



•The examination levels are based on the gamma scanning.

•Radial cuts to allow determination of clad straining;

Cutting levels:

Upper part:

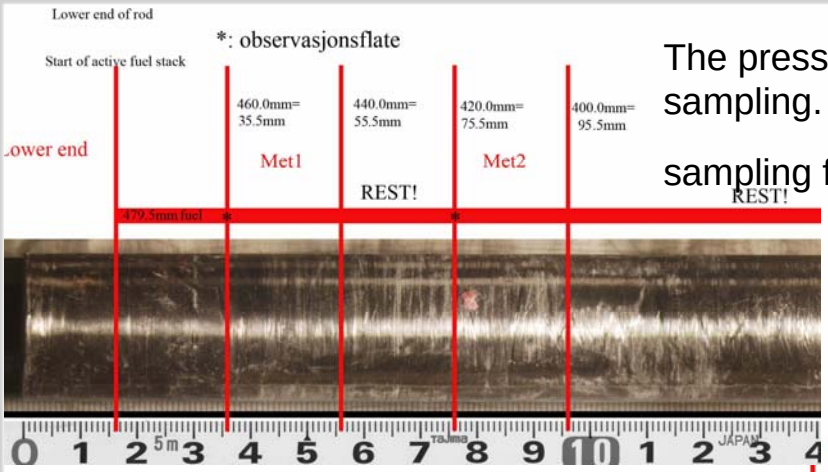
2 cuts at levels 25mm for reference (undeformed zone) and at 180 mm (axial profile of deformation)

Balloon zone (200-280mm) (balloon size and maximum deformation) **:**

4 cuts at the levels 210, 235 , 255 and 275mm

Zone with relocated fuel outside the balloon zone :

3 cuts at levels 325, 420 and 460 mm

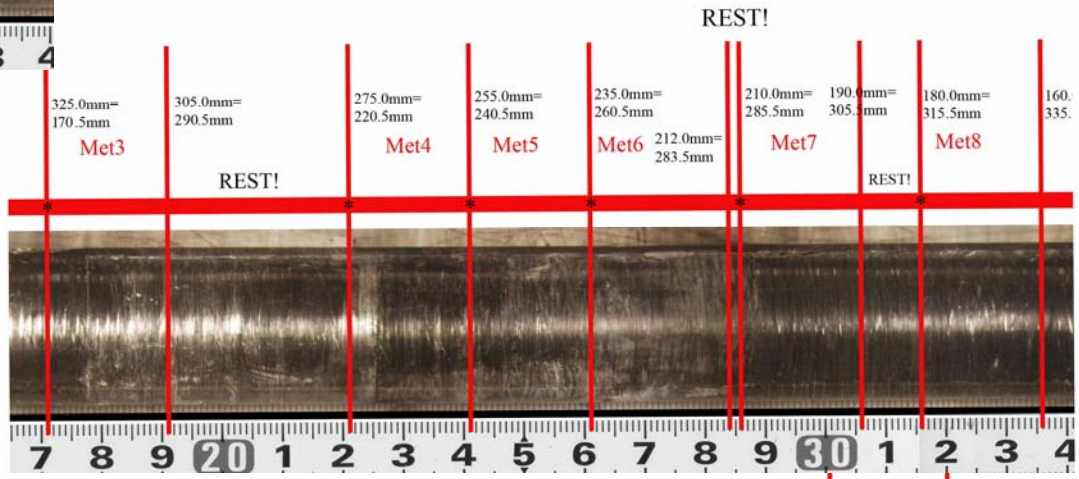


The pressure flask of the test element is removed for metallographic sampling. Visual inspection photos show the heater surface prior to

sampling for fuel relocation study

Zone with relocated fuel outside the balloon zone : 3 cuts at levels

325 mm / Met3, 420 mm / Met2, 460 mm / Met1



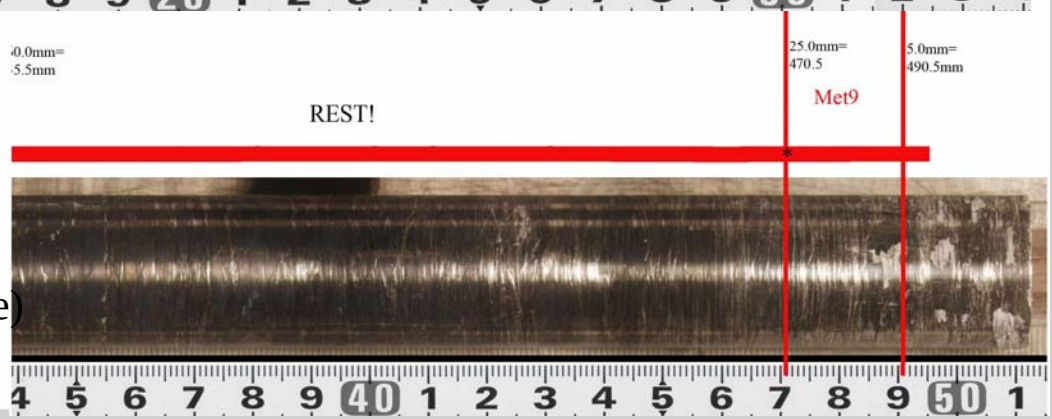
Balloon zone (200-280mm) (balloon size and maximum deformation) **:** 4 cuts at the levels

210 mm / Met7,

235 mm / Met6,

255 mm / Met5,

275mm / Met4



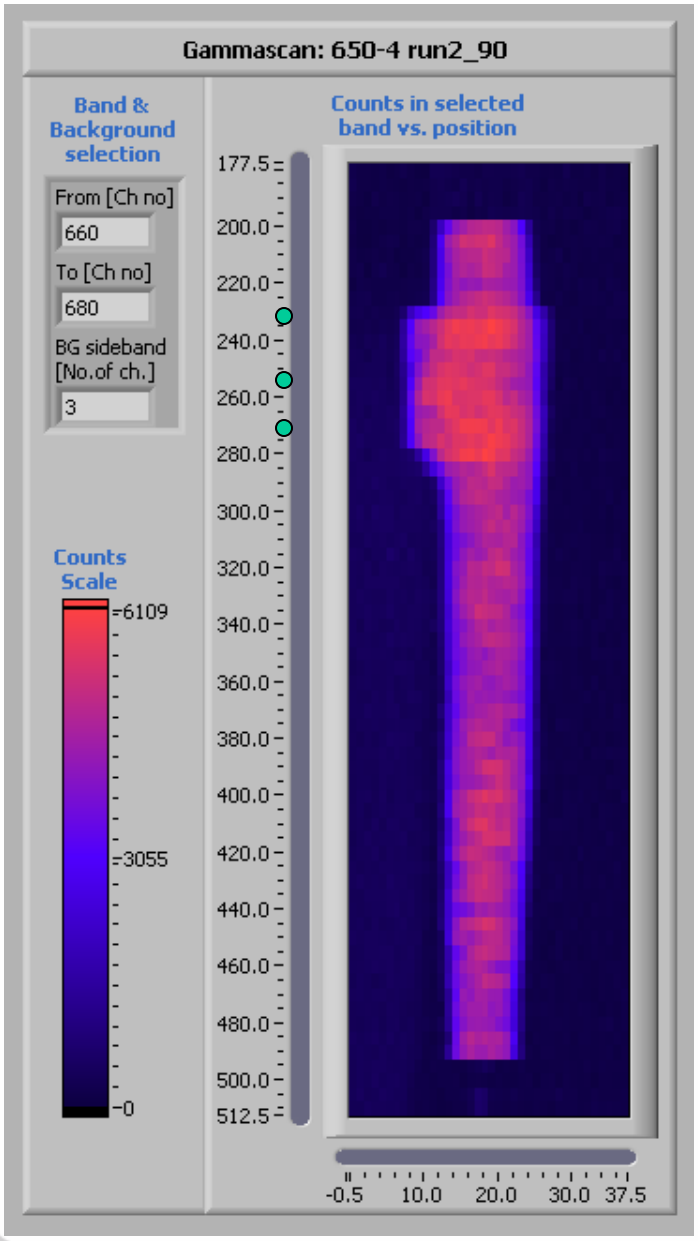
Upper part: 2 cuts at levels

25 mm / Met9 for reference (undeformed zone)

180 mm / Met8 (axial profile of deformation)

Low speed cutting machine with cutting discs

- Cubic BN disc (Buehler), ∅102mm,d:0.3mm - 8 hrs per cut, worn out after 1 cut
- High speed milling disc, ∅100mm,d:0.6mm - 9 hrs per cut, worn out after 3 cuts
- Diamond cutting wheel (Struers), ∅102mm,d:0.3mm - 3 hrs per cut, worn out after 3 cuts



Balloon zone (200-280mm) (balloon size and maximum deformation) **:** 4 cuts at the levels

210 mm / Met7,

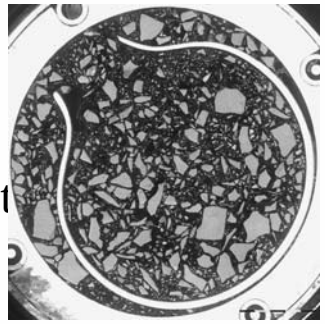
235 mm / Met6,

255 mm / Met5,

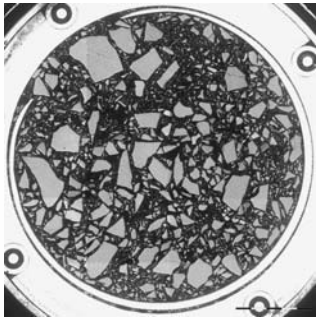
275mm / Met4

Ballooning&burst with fuel pellet fragmentation. Fuel fragments inside and outside the clad.

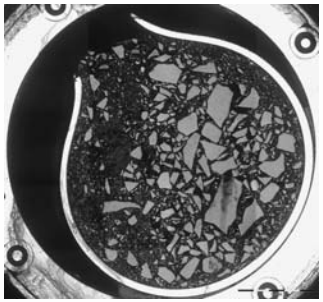
Fuel fragments were stabilised by epoxy impregnation



Met6
L_{Circe}:50 mm
Wall thickness
Min: 300 µm
Max: 522µm
Oxide
do: 12µm
di/fracture: 3-5µm



Met5
L_{Circe}:53 mm
Wall thickness
Min: 160µm
Max: 520µm
Oxide
do: 10µm
di/fracture: 3-5µm

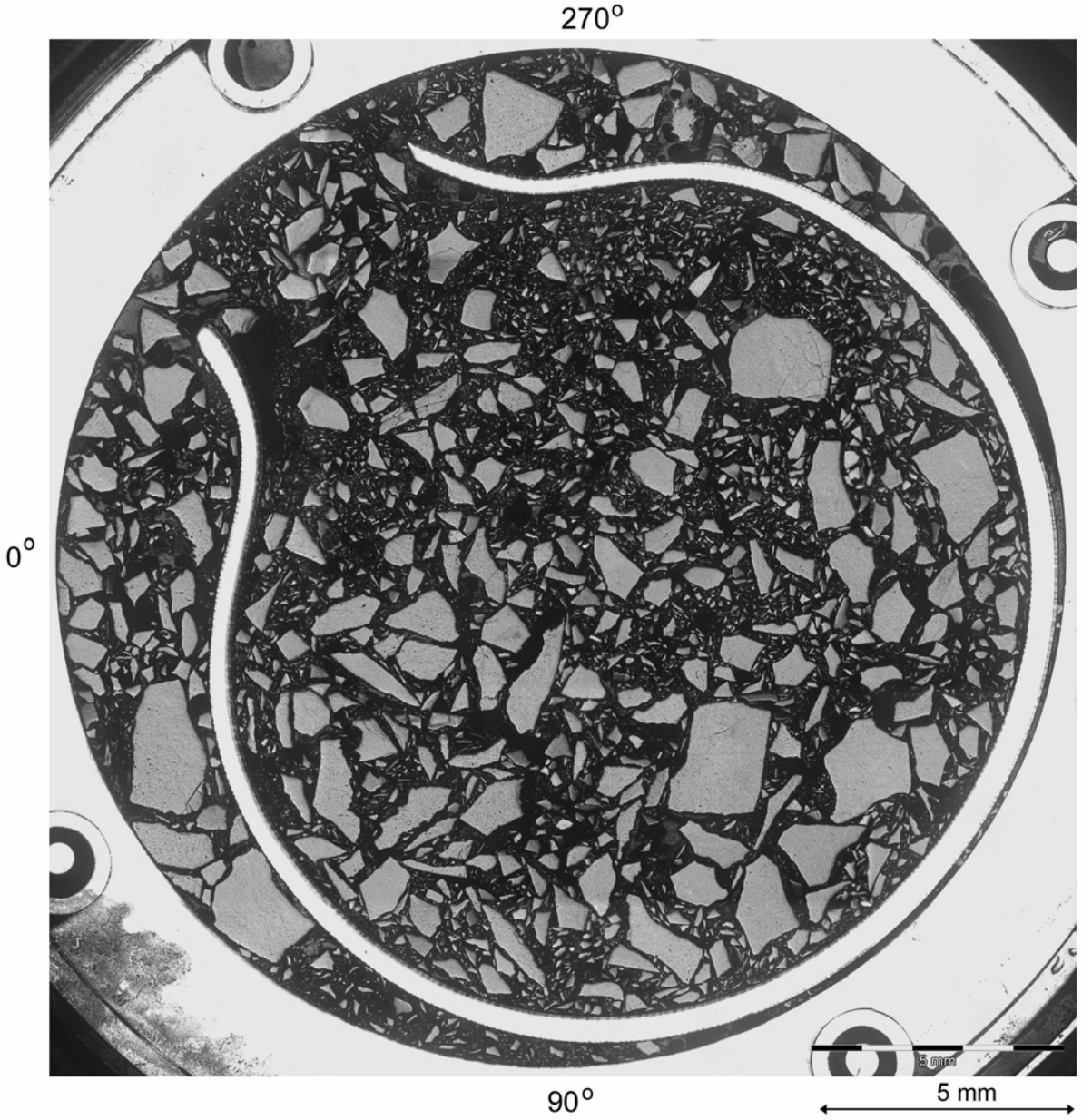


Met4

L_{Circe}:49 mm
Wall thickness
Min: 345µm

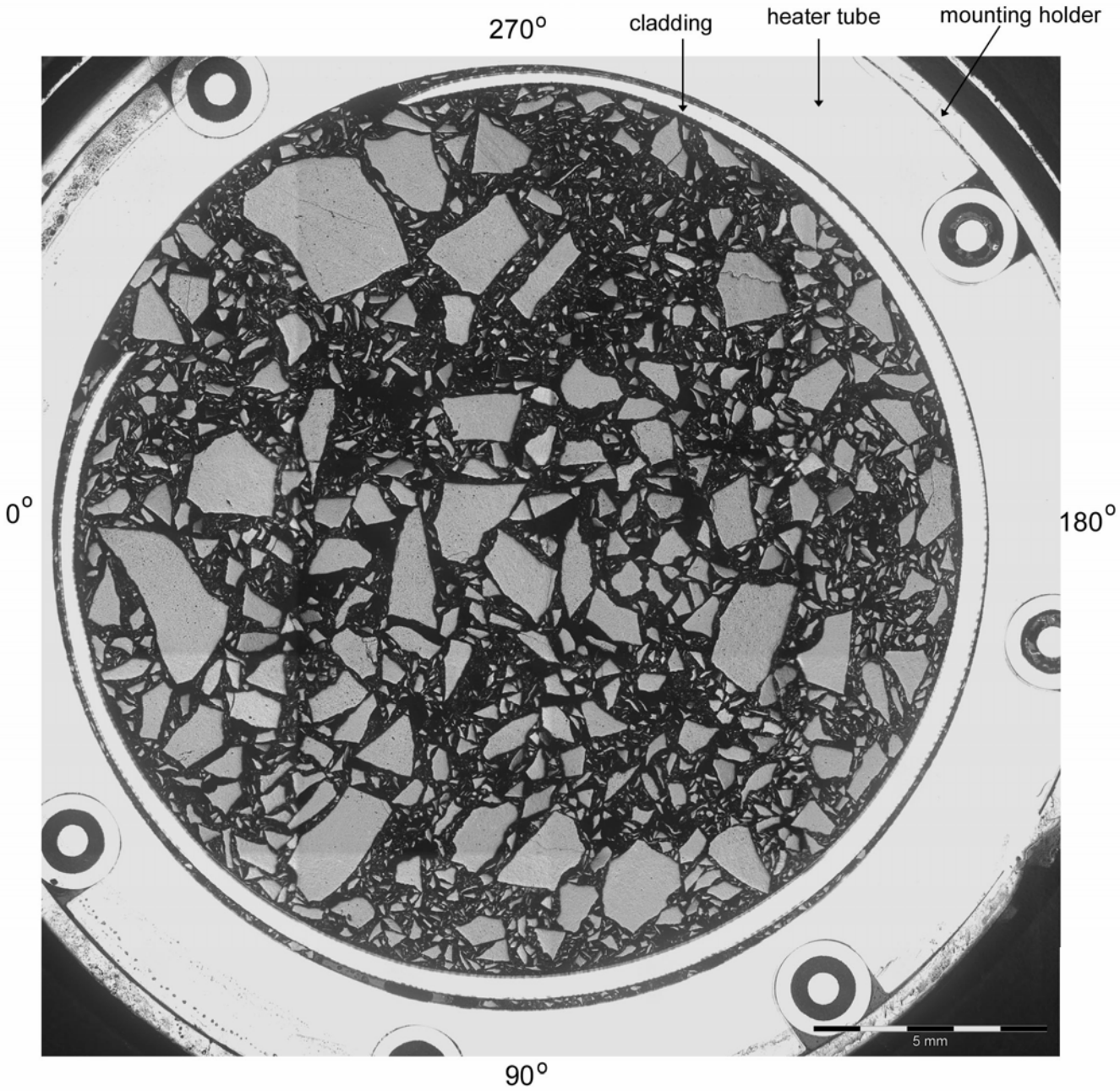
Max: 523µm

Oxide
do: 11µm
di/fracture:3-5µm



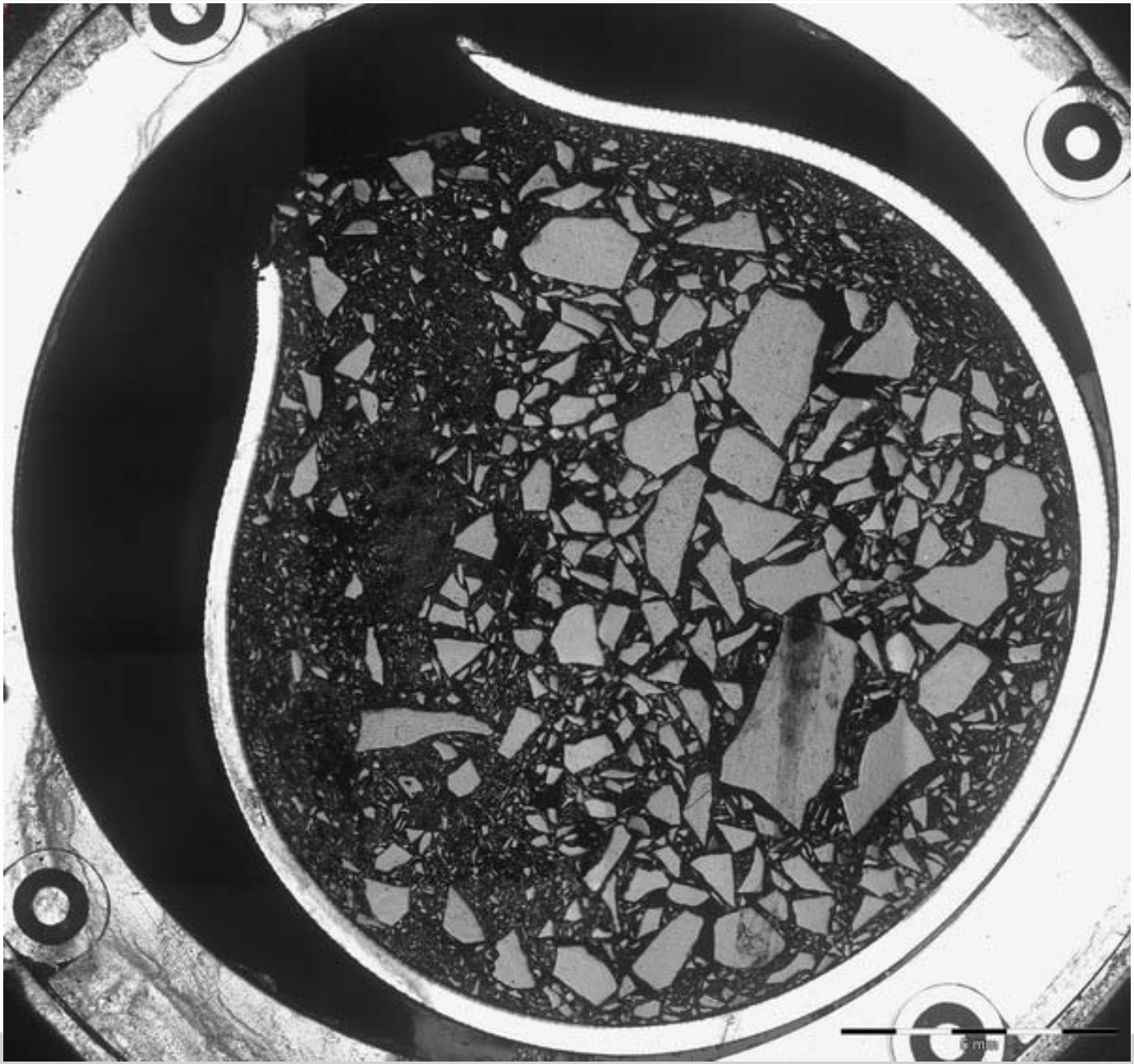
Macrograph showing the transverse cross section of IFA-650-4 ar axial position 235.0 mm from upper end of fuel stack (Met6).

- In the burst zone the fuel is fragmented (fragment Ø≤2mm).
- Fuel particles were blown out when the rod burst.
- Fuel particles /fragments are relocated outside between cladding and inner heater wall.



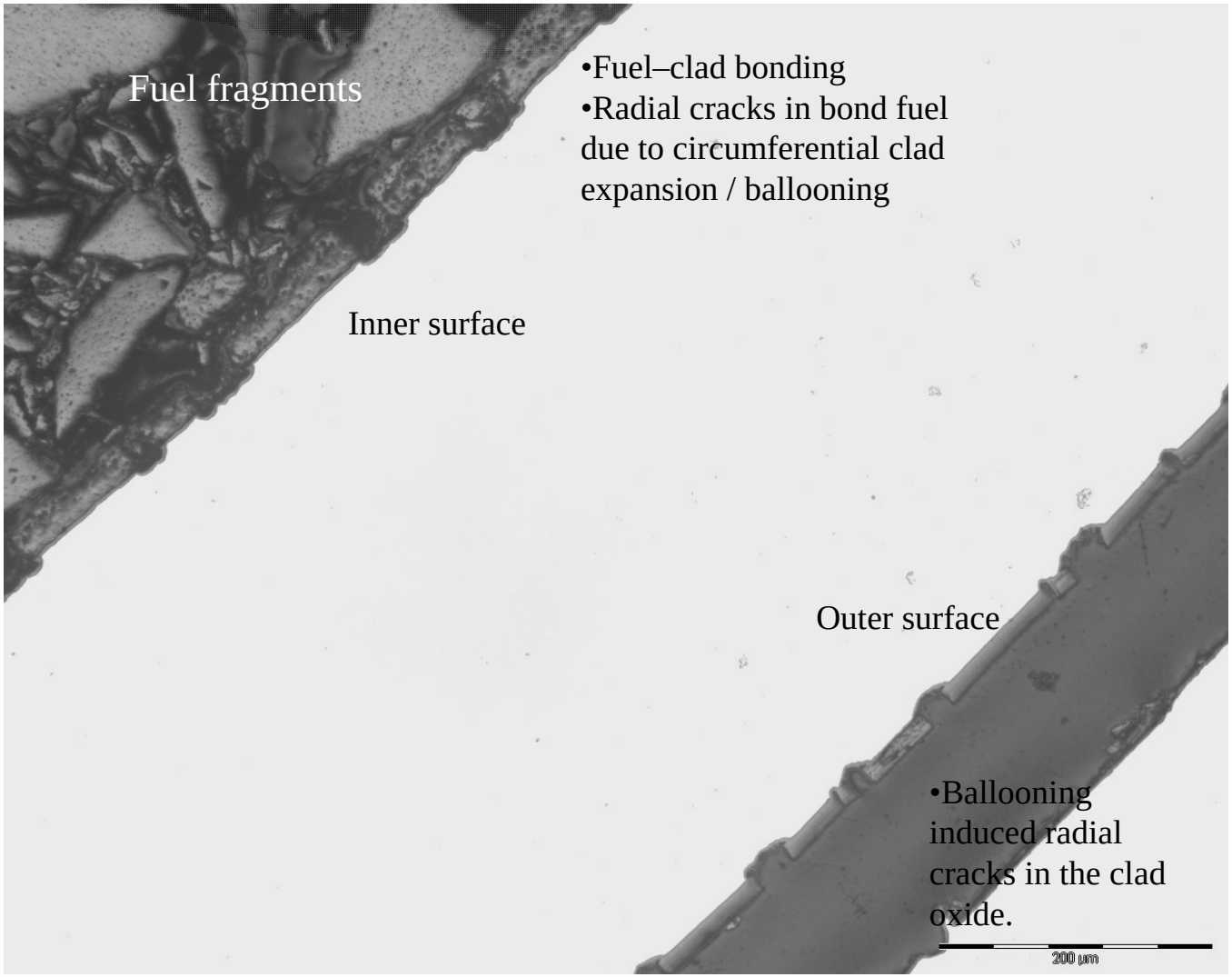
Macrograph showing the transverse cross section of IFA-650-4
at axial position 255.0 mm from upper end of fuel stack (Met5)

- Fuel was blown out when the rod burst opened.
- Fuel particles were fixed by epoxy injection
- The ballooning itself fills the free space on the inner side of the heater tube.



Met4
275mm

•The max ballooning / burst fills the inside of the heater.

• The max ballooning hindered majored fuel particle/ fragment relocation from the upper to the lower part of the rod

Oxides on cladding