Bertrand Blau:: Head of Operations Group :: Paul Scherrer Institute

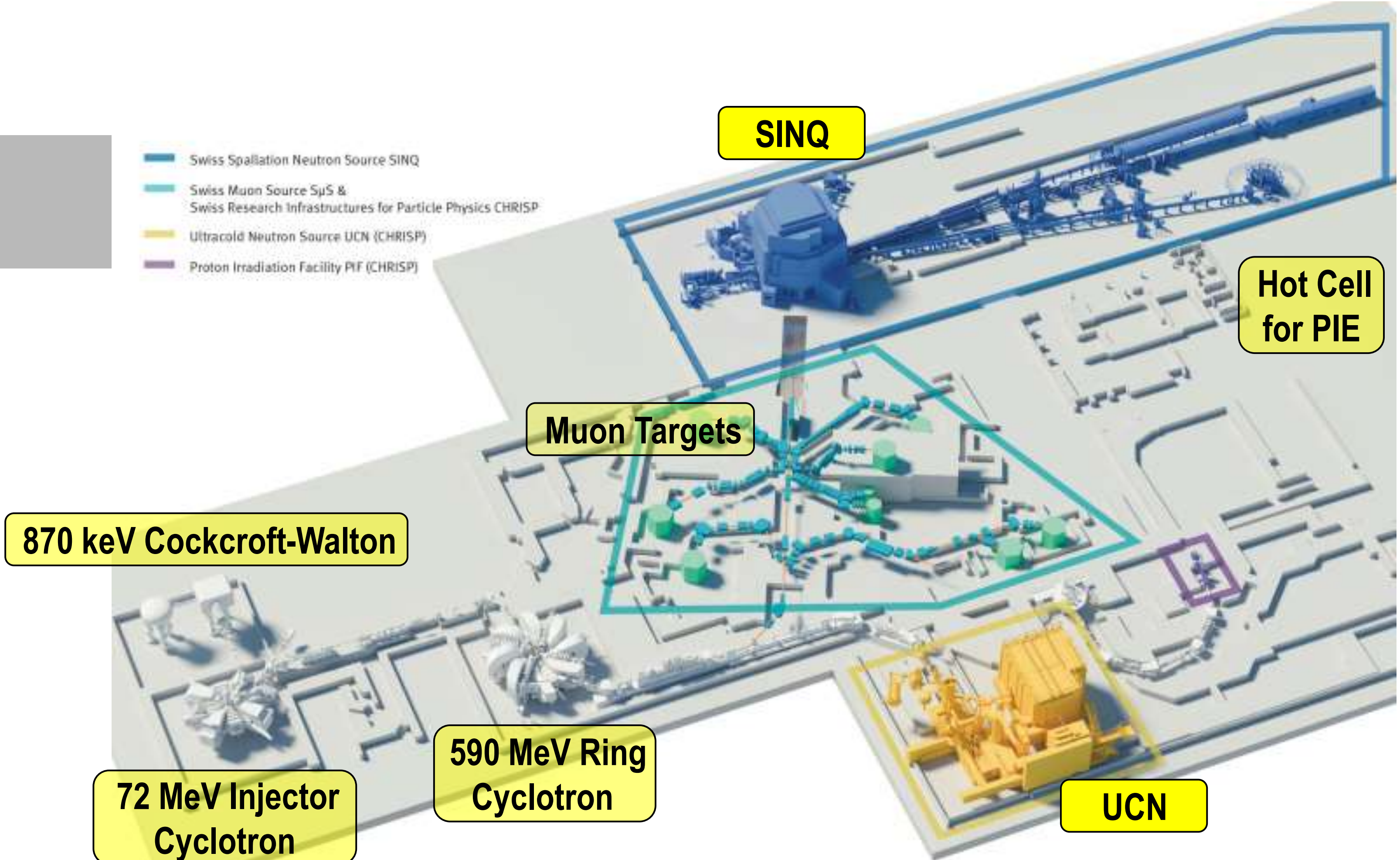
The SINQ Solid State Target: Lessons learned from a Recent Target Failure and the Experience Gained from an Improved Target Design

ICANS XXIV, 1st November 2023, Dongguan, China

Outline

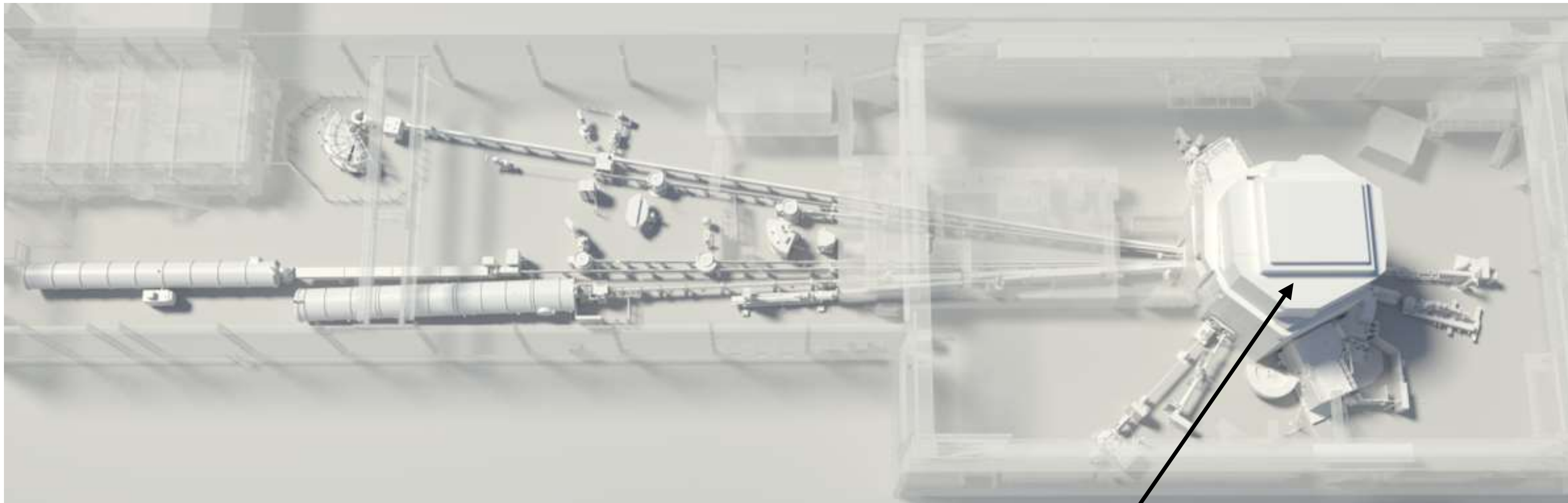
- Design of Mark IV Target
- Target Incident
- Design Improvements: Mark V Target
- Novel Beam Positioning System
- Neutron Radiography Results of Target Rods
- Summary

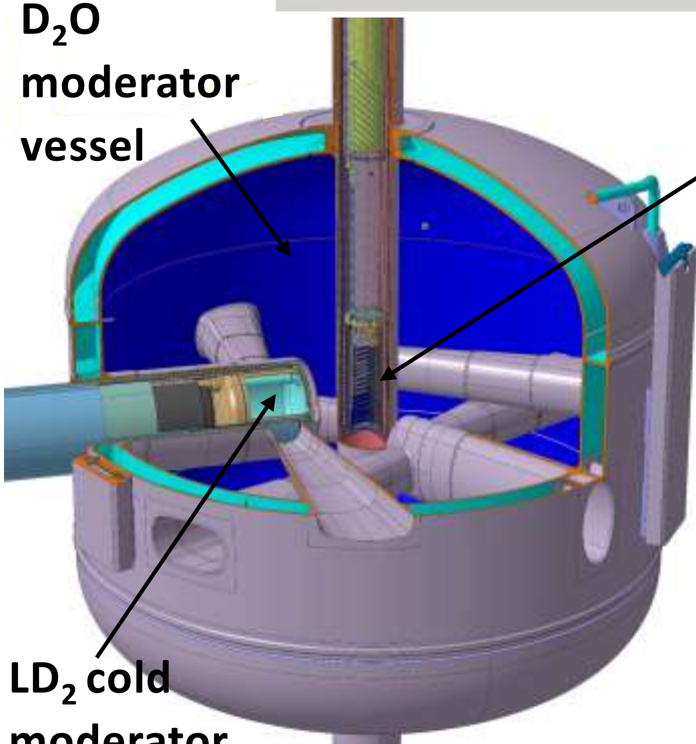
High Intensity Proton Accelerator Complex

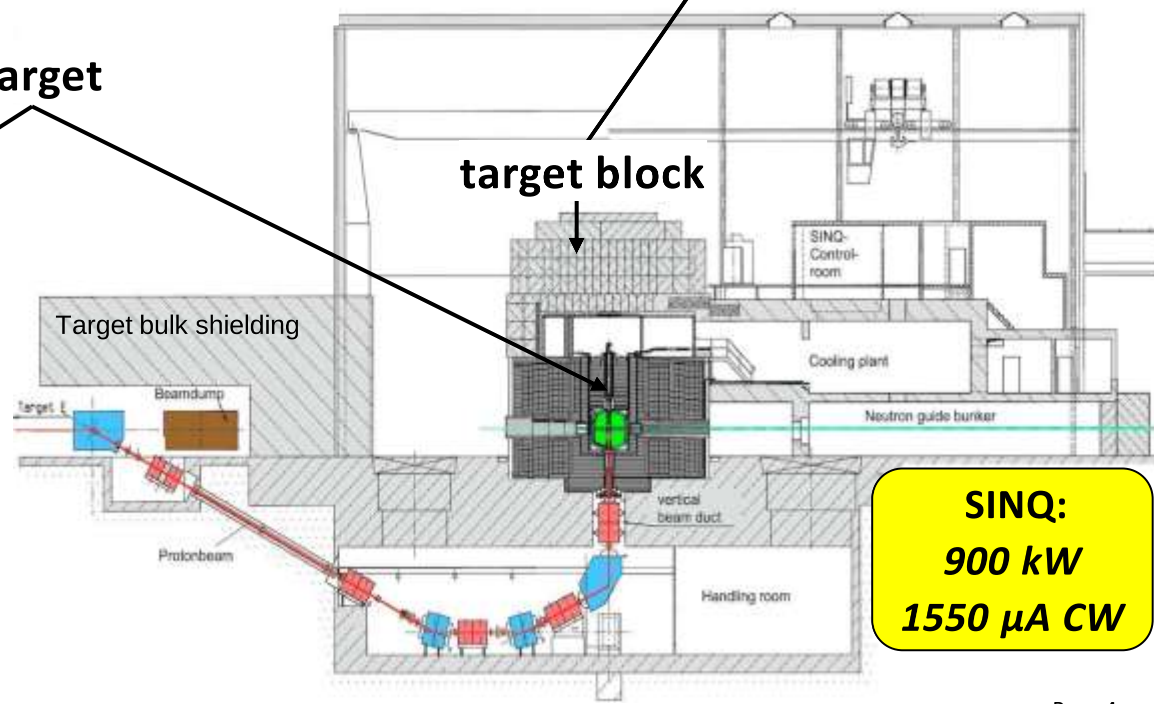


- Cyclotron based CW proton accelerator; max. beam power 1.4 MW
- Proton current: 2.2 mA (2.4 mA 2016)
- Multi-user facility: 1 IP station, 2 meson production targets, 2 spallation neutron sources

SINQ Target Station







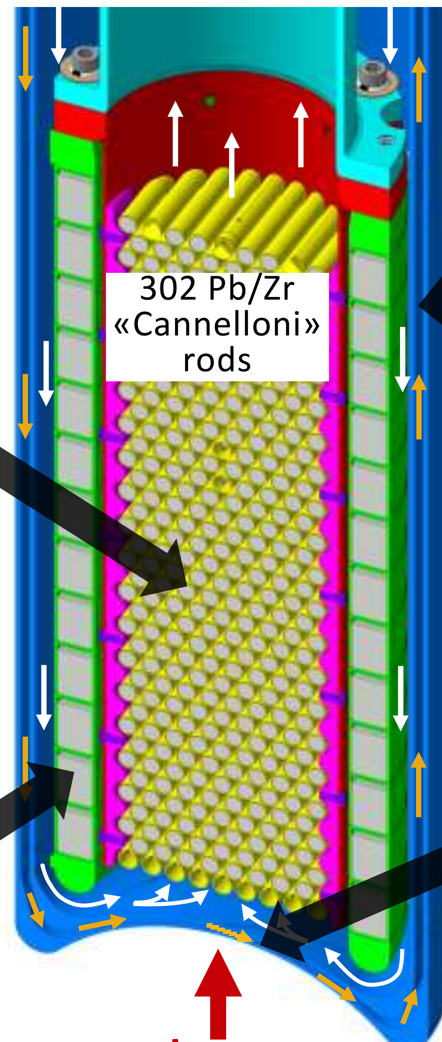
SINQ:
900 kW
1550 µA CW

SINQ Target Design (Mark IV)

length: 5 m

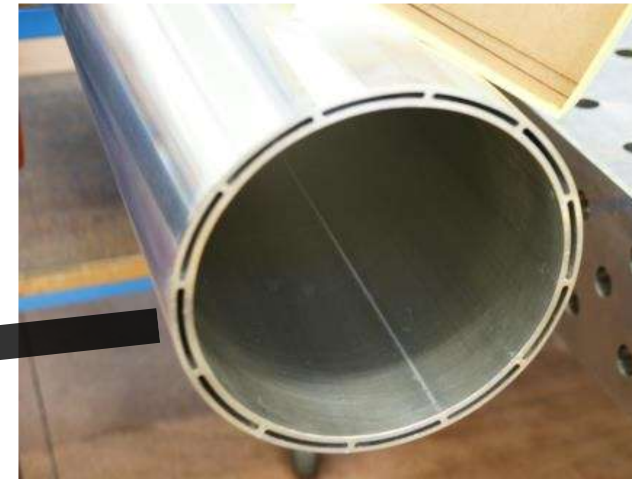
223 Cannelloni target rods:
Pb-filled Zr-tubes

Pb blanket/reflector



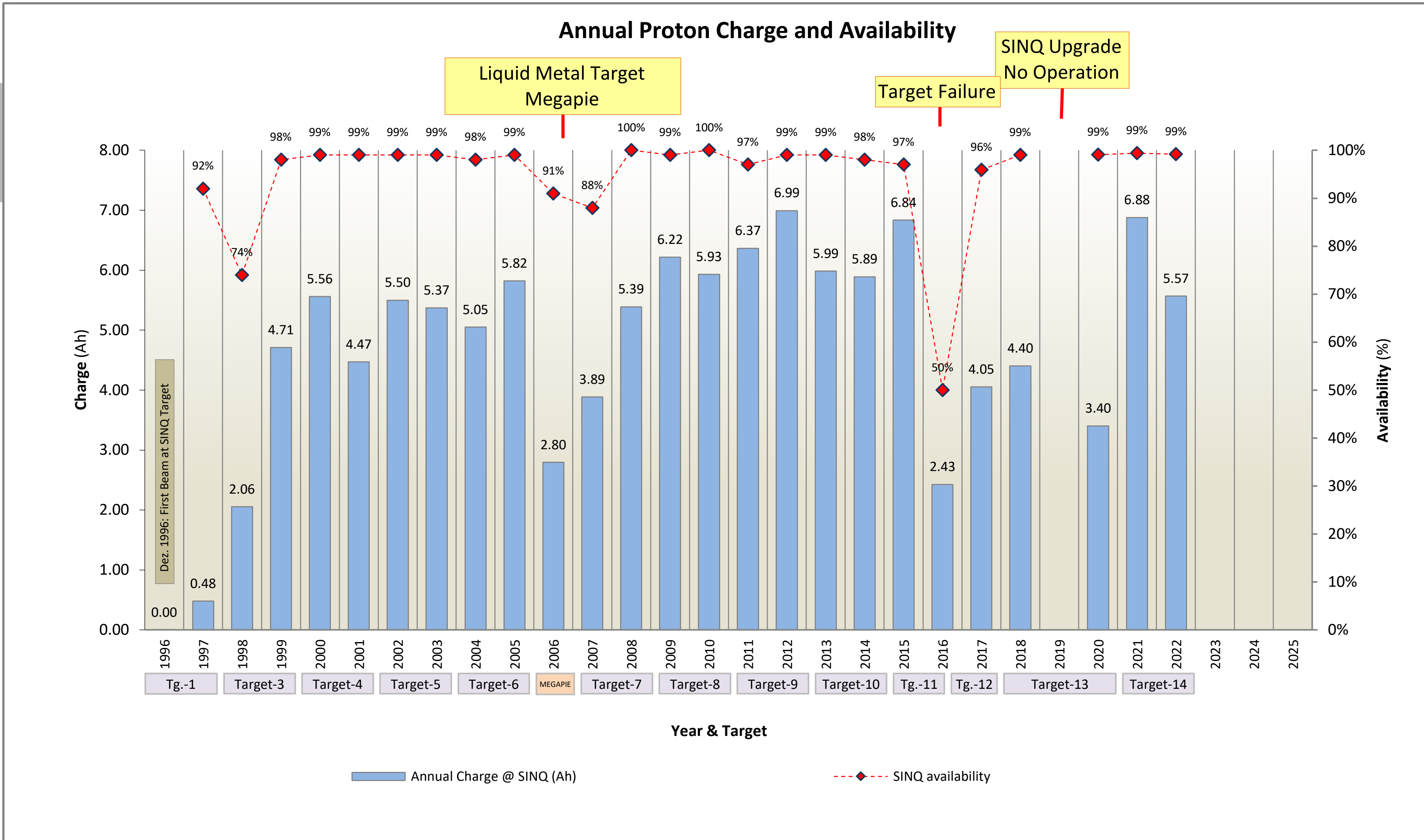
p-beam

double-walled safety shroud (AW-6060)



beam entrance window (AW-5754)

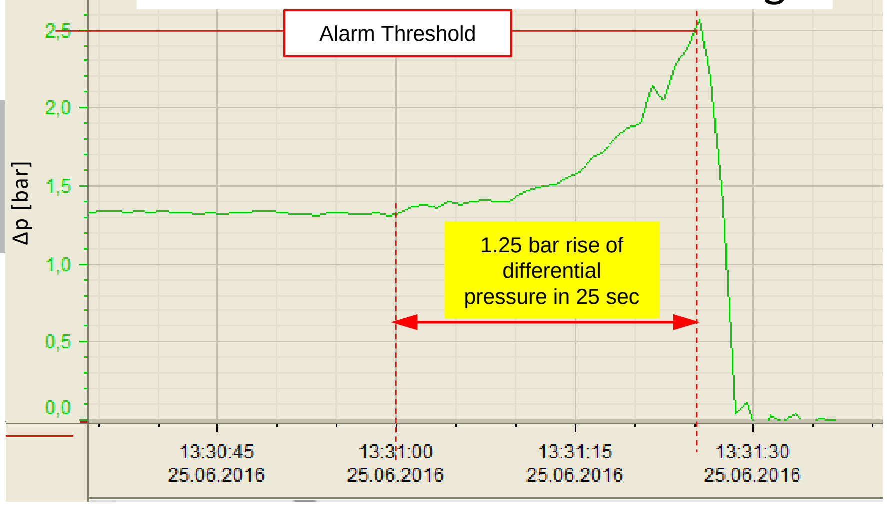
Complete SINQ Performance Statistics



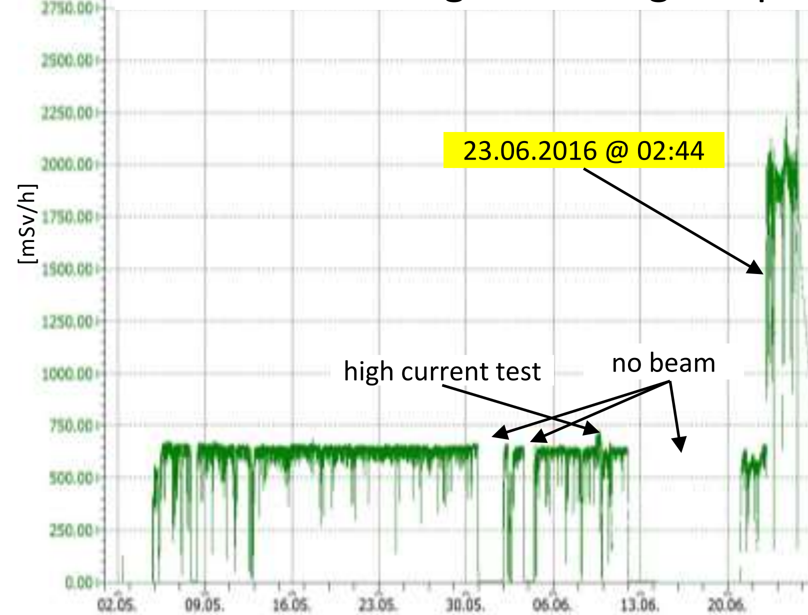
Average annual p-charge **5.07 Ah** Average annual operating hours **3'974 h**
Average annual availability **94.7%**

Symptons of the Incident

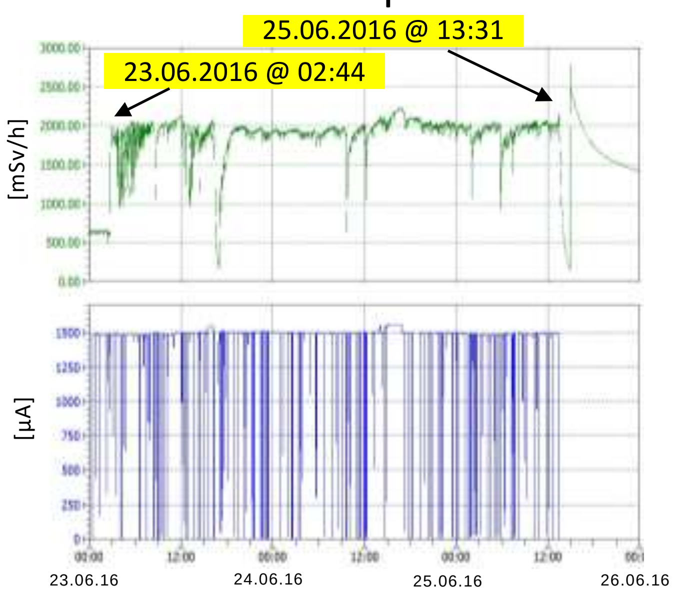
Differential Pressure across Target



Dose Rate at Target Cooling Loop



Dose Rate & p-Current



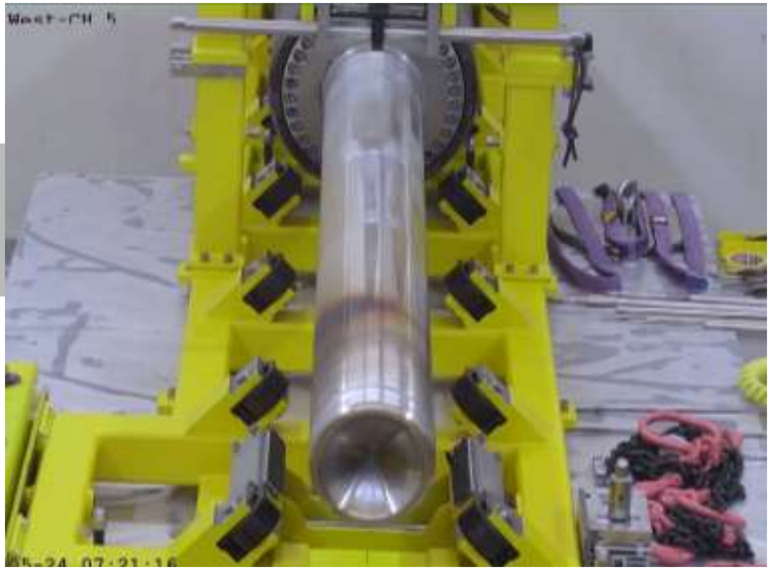
23.06.2016, 02:44

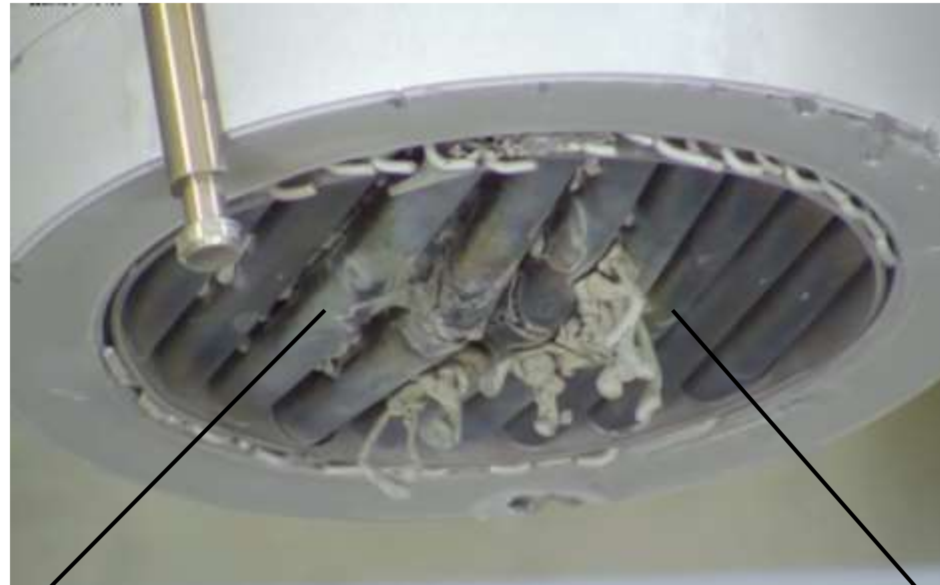
- Sharp increase in dose rate measured close to target cooling pipe
- Overfocussed p-beam

25.06.2016, 13:31

- Sharp rise in differential pressure of cooling water across target => severe blockage of cooling passage
- p-beam switched off

Disassembly and Visual PIE (May 2017)



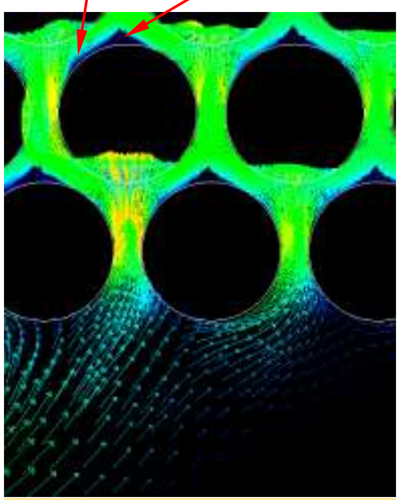


Lead Cross Section & Heat Removal

Despite 90% filling in virgin state, tube cross-section appears to be 100% filled after operation

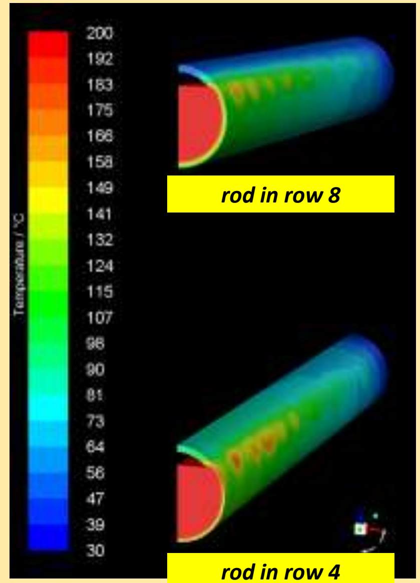
Flow separation

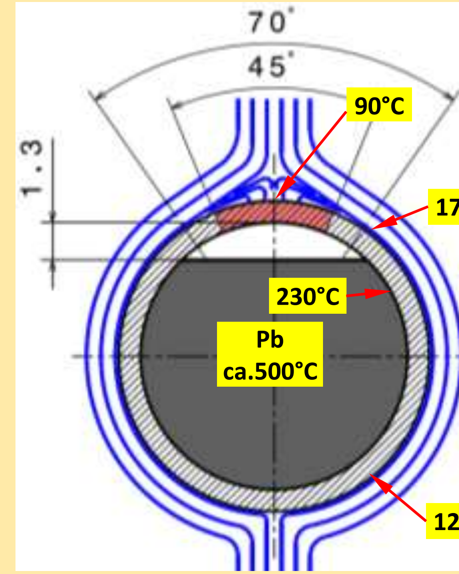
Dead Water Zone



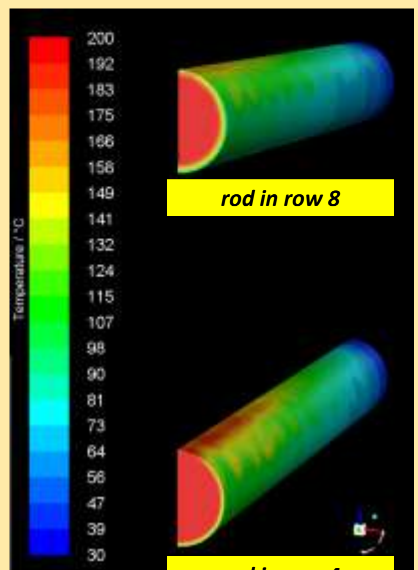
CFD simulation by S. Jollet (PSI)

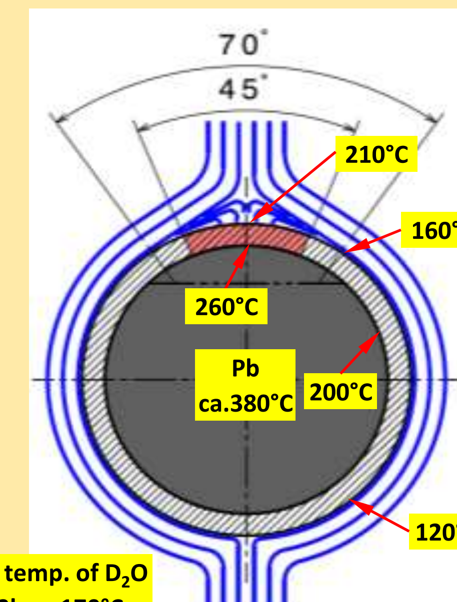
90% lead filling





100% lead filling





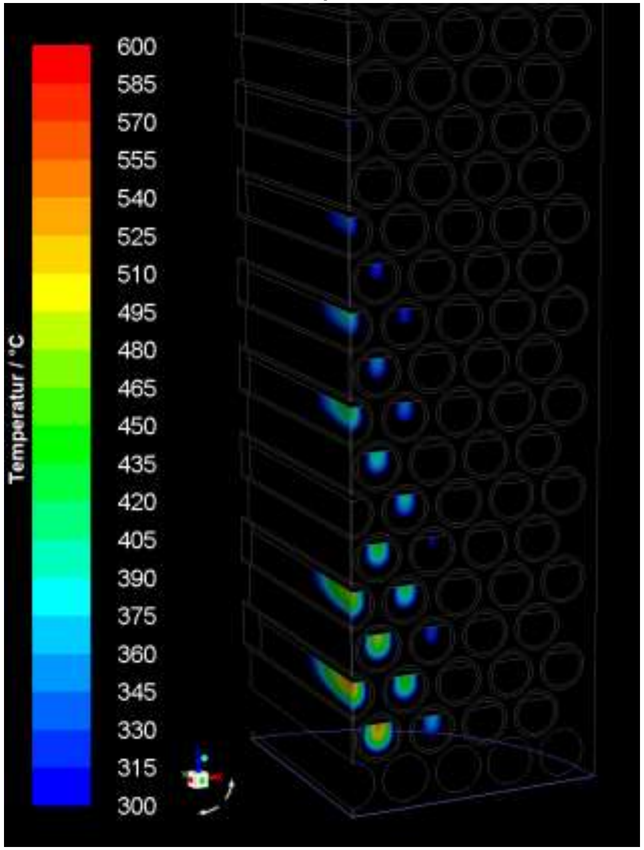
boiling temp. of D_2O at 7.2bar: 170°C

(FEM/CFD calc. by S. Jollet)

Improved Target Design (Mark V)

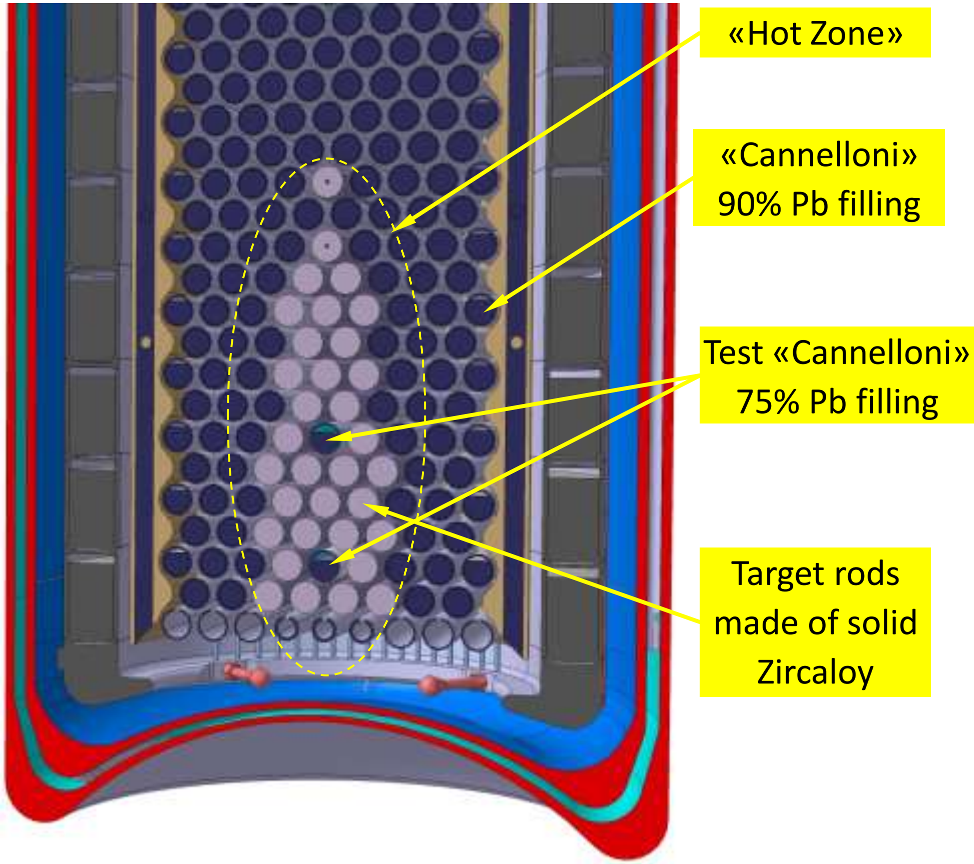
Replacement of 33 Cannelloni rods in «hot zone» by solid Zircaloy rods

target temperatures above 300°C from CFD simulation @ nominal current of 1500µA



(CFD calc. by S. Jollet)

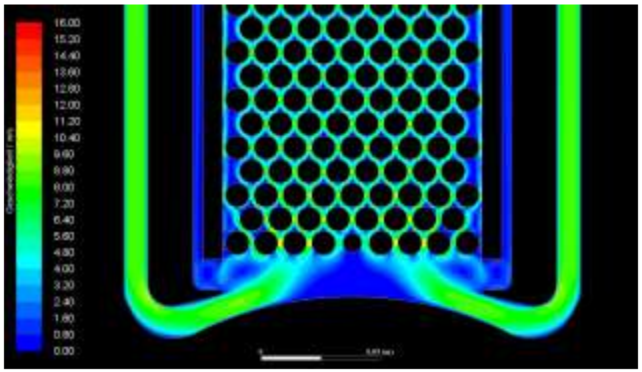
rod distribution



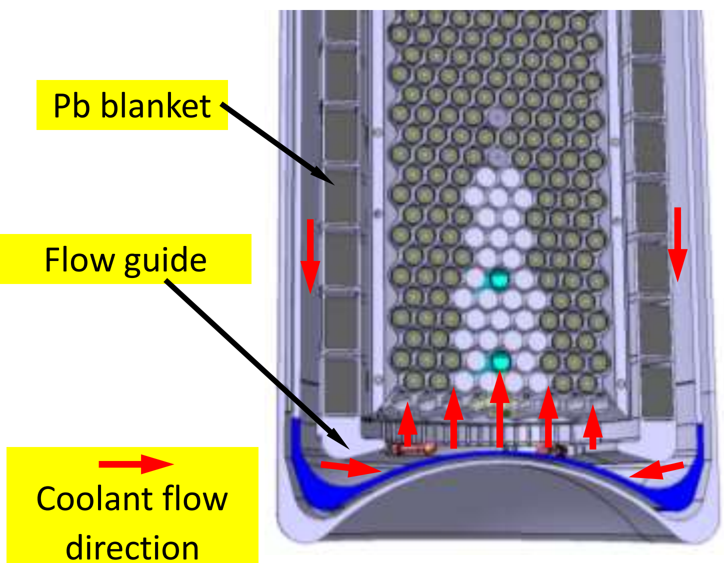
Improved Target Design (Mark V) - continued -

better flow distribution

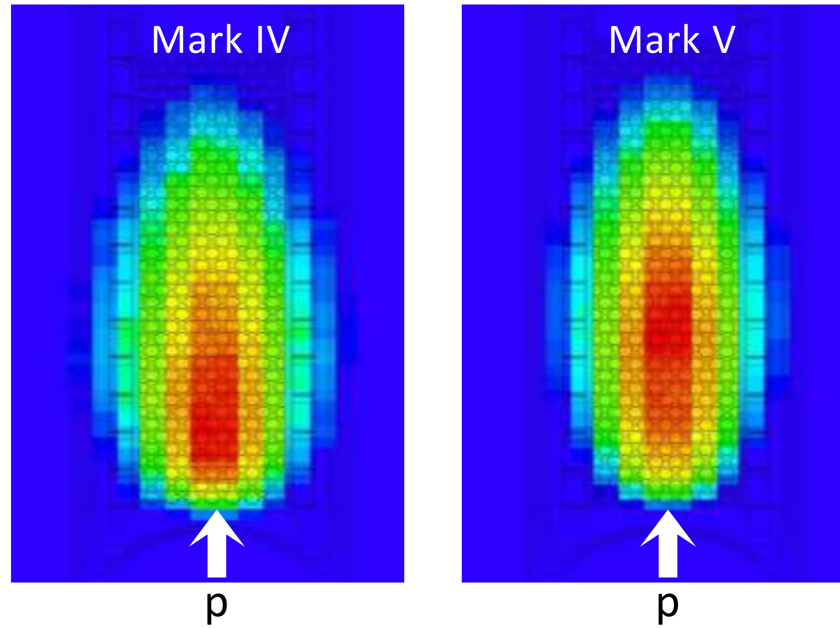
Coolant flow optimized



(CFD calc. by S. Jollet)



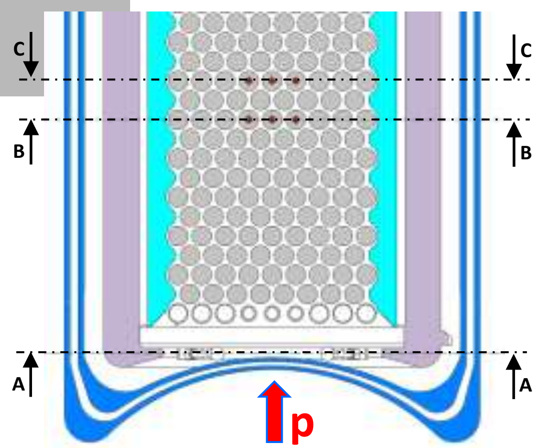
readjustment of target length



to compensate for the deeper penetration of the proton beam the target was elongated by 38 mm

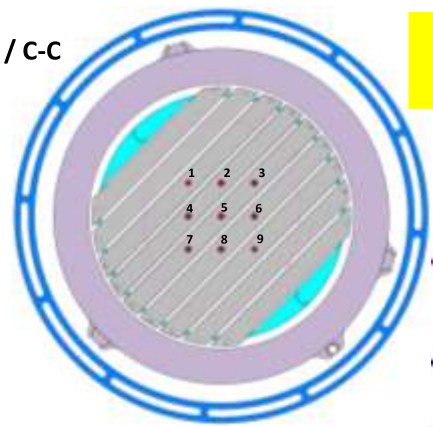
Improved Target Design (Mark V)
- further continued -

Temperature Beam Positioning System (TBPS)



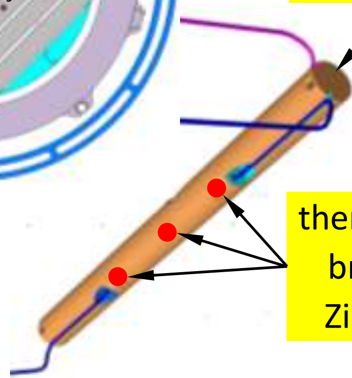
details of the TBPS
see poster #157
by J. Welte et al.

B-B / C-C



2 grids of
9 TC's each

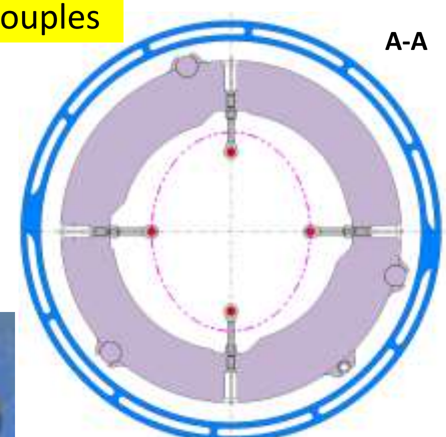
Zircaloy rod



thermocouples
brazed into
Zircaloy rod

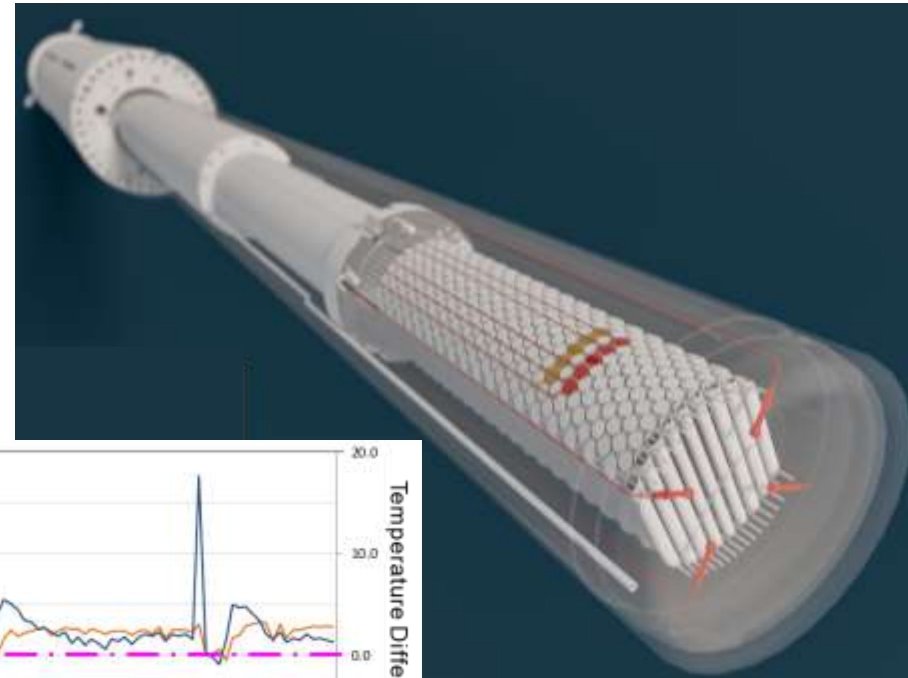
4 thermocouples

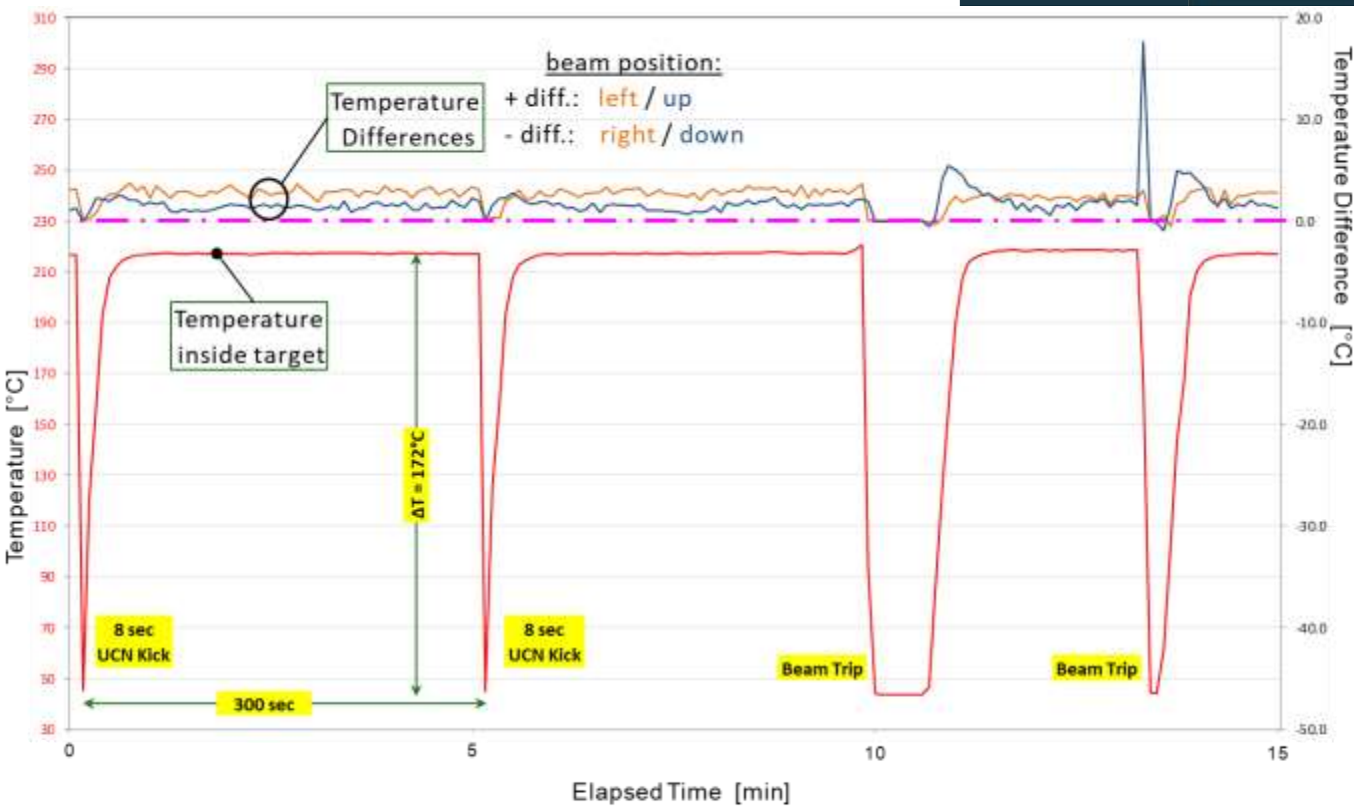
A-A



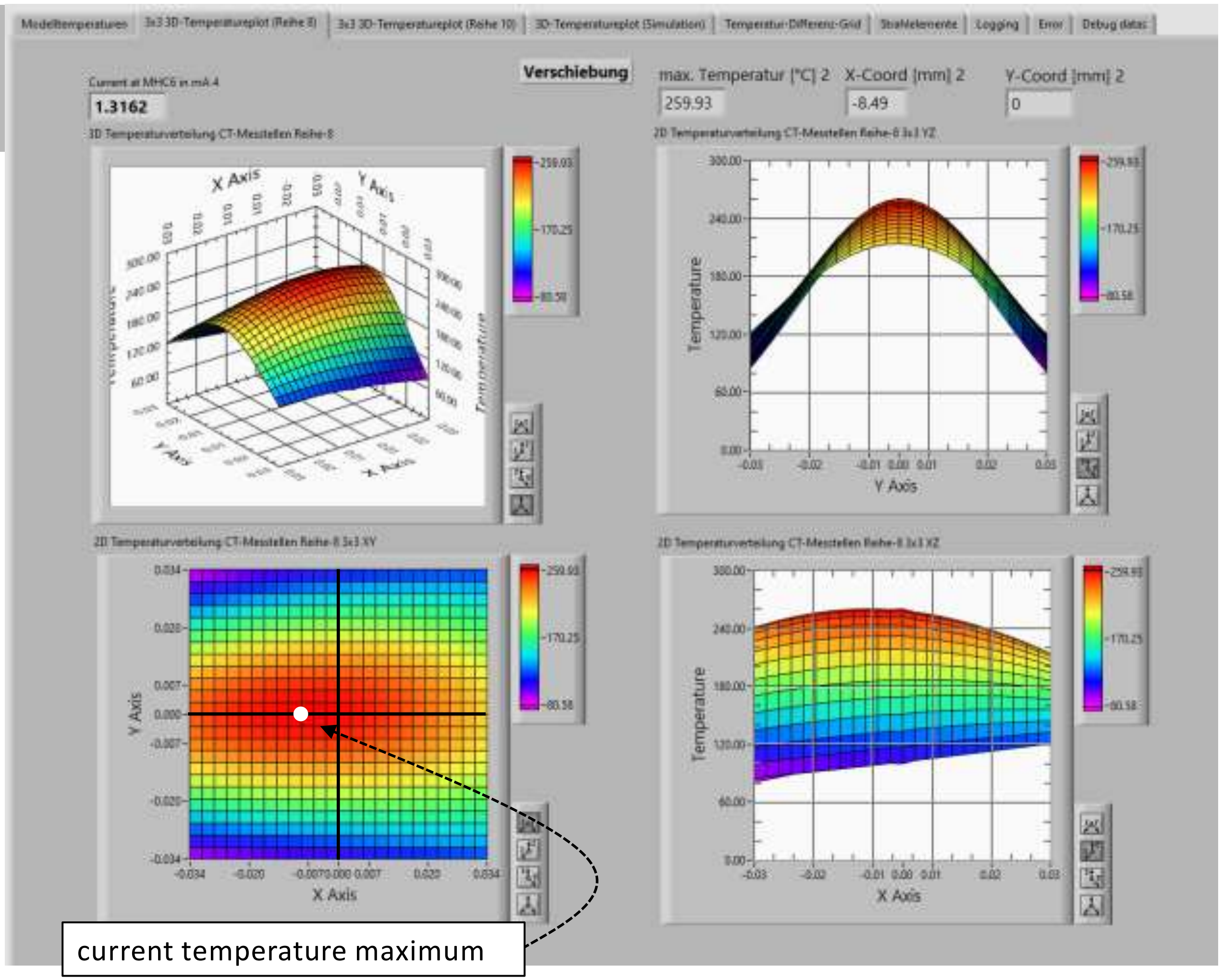
Zircaloy absorber

Sensitivity of new Temp. Measurement





example of an off-centered beam



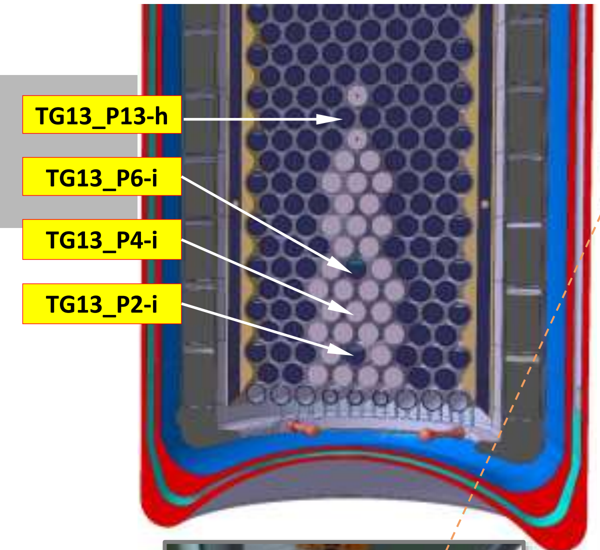
- beam position and shape monitored in real time in control room
- center of the beam continuously displayed in a coordinate system
- TBPS is now part of the automatic interlock system:
  22 temperatures sensors are constantly monitored and p-beam is automatically switched off as soon as any sensor's threshold is reached

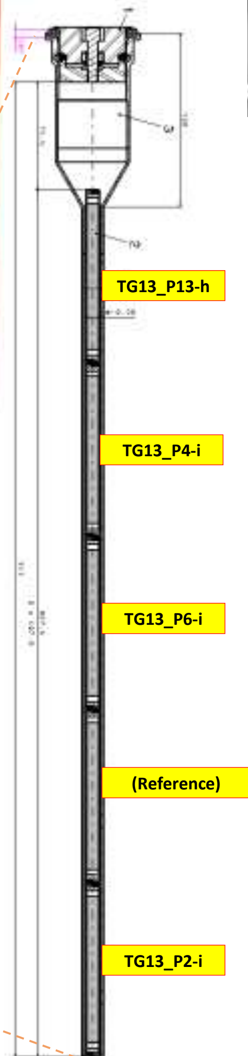
details see poster #157 by J.Welte et al.

NEURAP at NEUTRA Beamline

neutron radiography of heavily activated specimen (~1 Sv/h)

Target 13



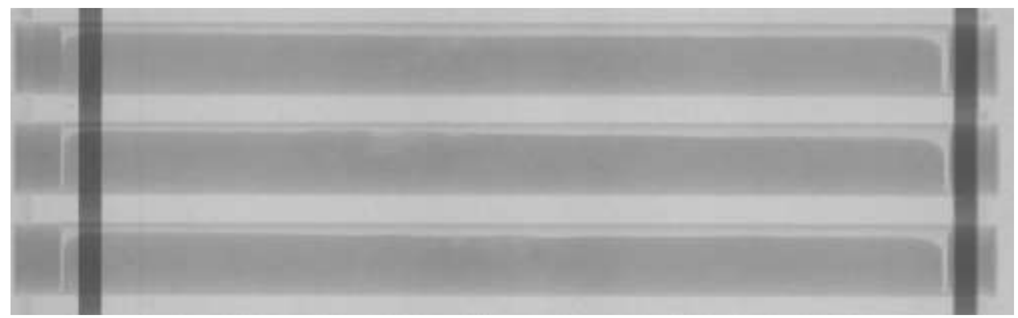


massive Zircaloy-2 rod (row 4)

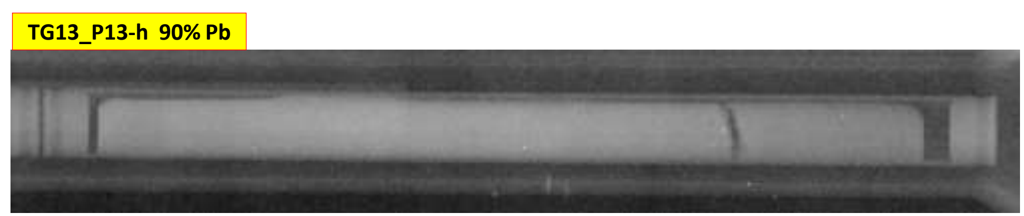
(radiography after 2y of use)

☑ as expected

Pb/Zr 'Cannelloni' with 90% Pb filling (row 13)



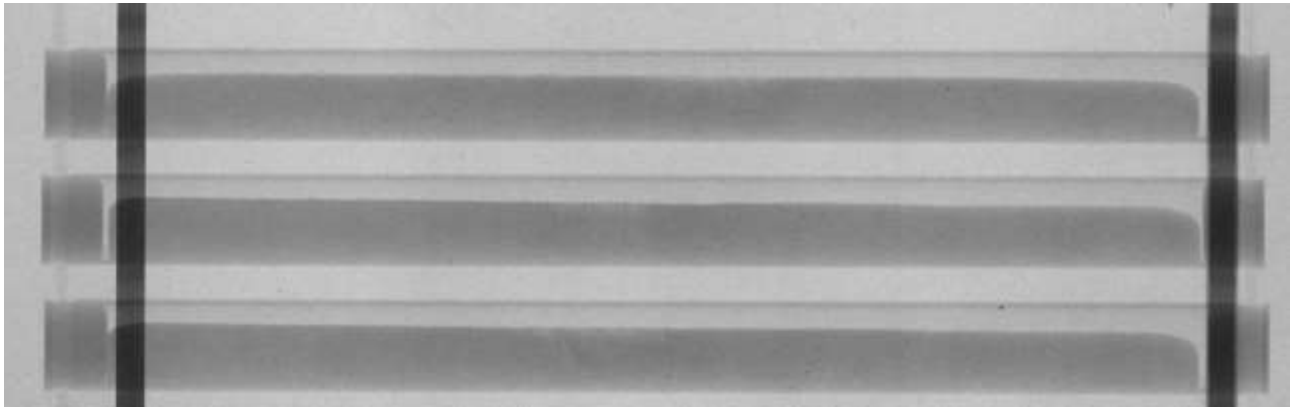
(radiography before use)



(radiography after 2y of use)

? crack unexpected

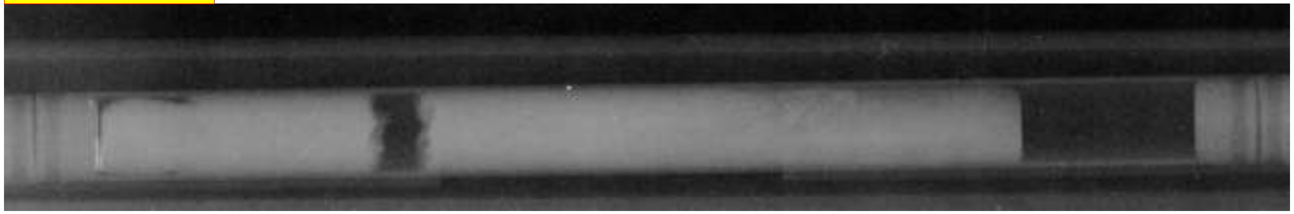
Radiography of Cannelloni rods w 75% filling



(radiography <u>before</u> use)

TG13_P6-i 75% Pb

Pb/Zr Cannelloni with 75% Pb filling (row 6)

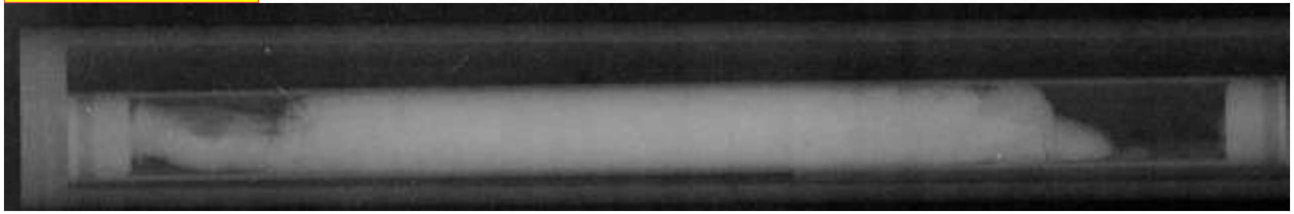


(radiography <u>after</u> 2y of use)

complete cross-section filled, big crack

TG13_P2-i 75% Pb

Pb/Zr Cannelloni with 75% Pb filling (row 2)



(radiography <u>after</u> 2y of use)

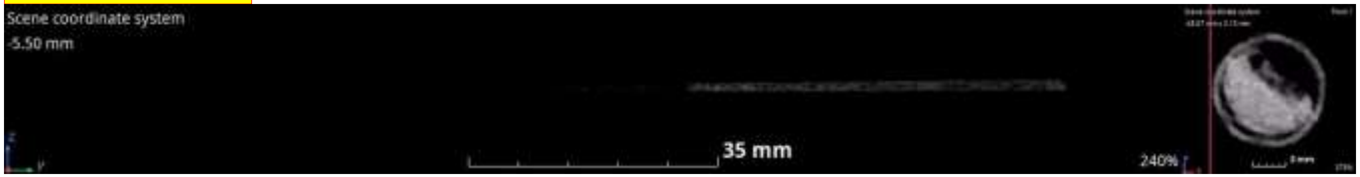
very inhomogeneous Pb distribution, see tomography!

Neutron Tomography

3D view of Pb-filling (false colours)

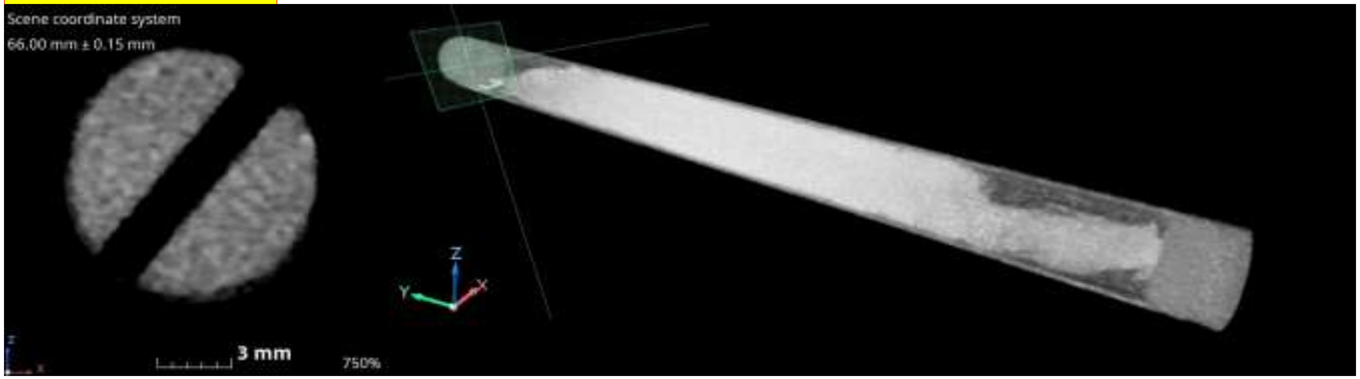
frontal view through rod with 75% Pb filling (row 2)

TG13_P2-i 75% Pb



axial view through rod with 75% Pb filling (row 2)

TG13_P2-i 75% Pb



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Summary

- first severe premature target failure in 2016 due to cracked Zircaloy tubes and subsequent discharge of liquid lead blocking cooling paths
- several actions were taken to prevent a similar event in the future
  - ✓ replacement of Cannelloni type rods by pure Zircaloy rods in the 'hot zone'
  - ✓ optimized coolant flow (flow concentration in vicinity of middle axis)
  - ✓ introducing grids of temperature sensors inside the target for monitoring the position and focus of the incident proton beam
  - ✓ implementation of a fast PLC system which triggers automatically a beam interlock as soon as any temperature sensor of the grid exceeds its individual upper limit
- no indication of any cracked target rods since the introduction of the new Mark V targets – so far!
- As part of PIE, neutron radiography and tomography of some target rods were carried out at the NEUTRA beamline at SINQ revealing that a local 100% filling of the Zr-tube cross section cannot be prevented in the 'hot zone'.

  => Massive Zircaloy rods are the better – i.e. safer – choice

My thanks go to my co-authors

- Sven Jollet
- Pavel Trtik
- Joerg Welte
- David Mannes

Thank you for your attention!