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Wir schaffen Wissen – heute für morgen

The SINQ solid spallation target – operational experience and recent improvements

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Paul Scherrer Institut, Switzerland

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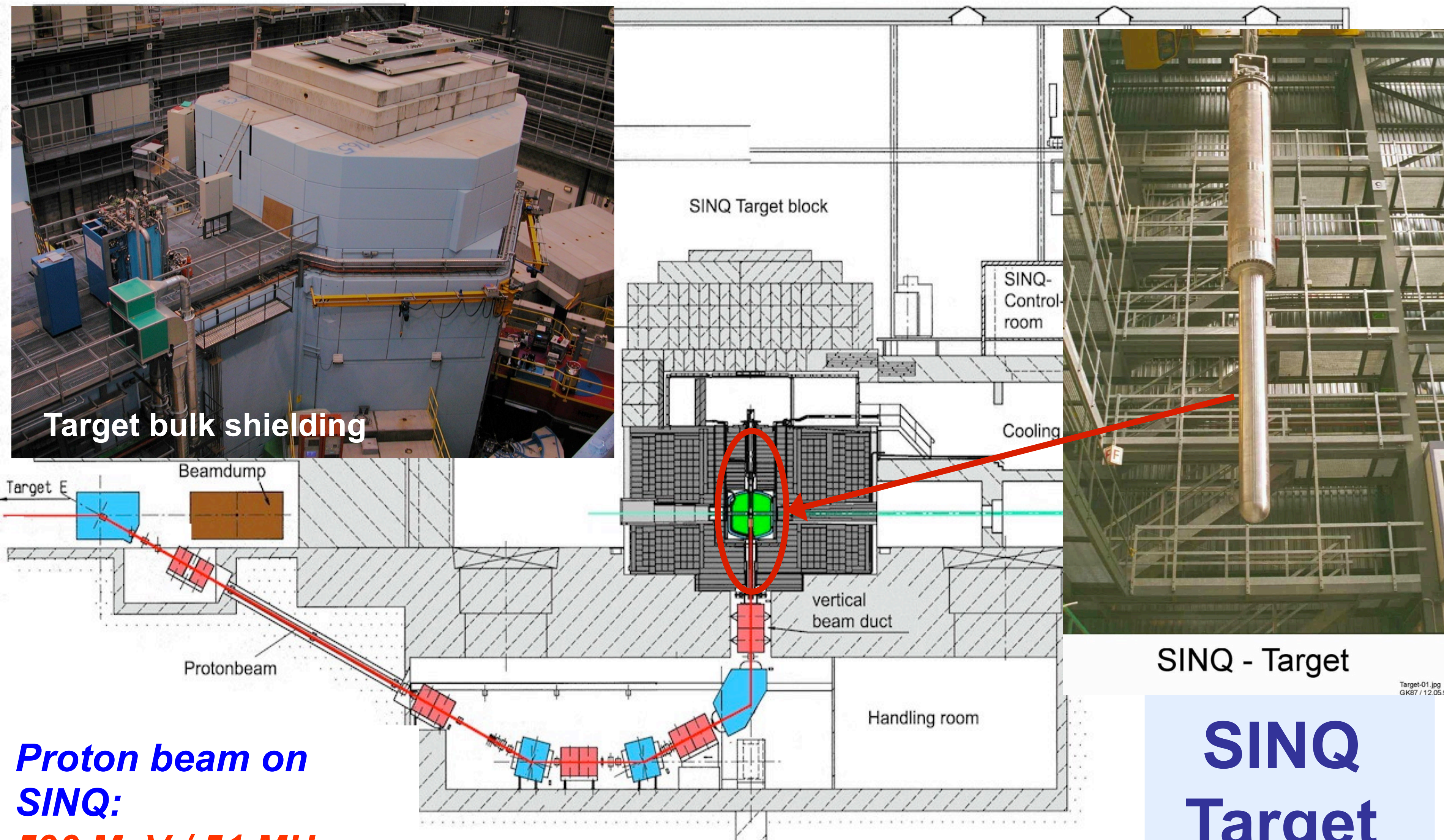
SINQ Target Station



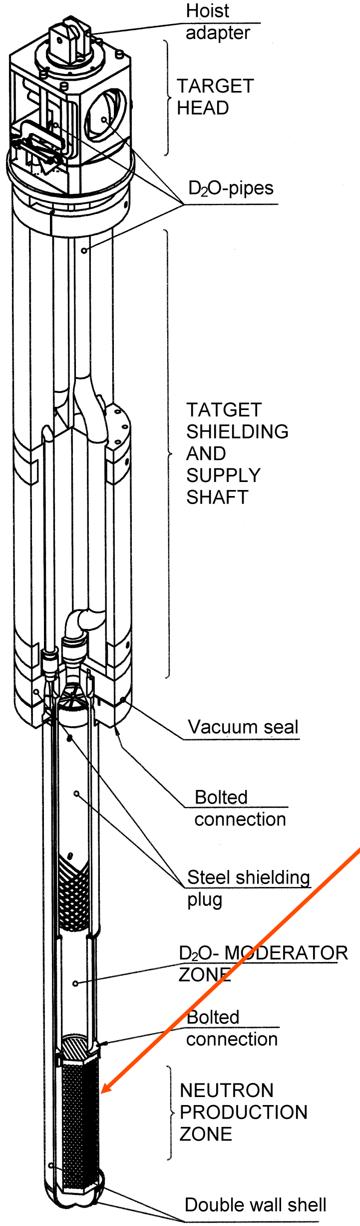
SINQ - Target

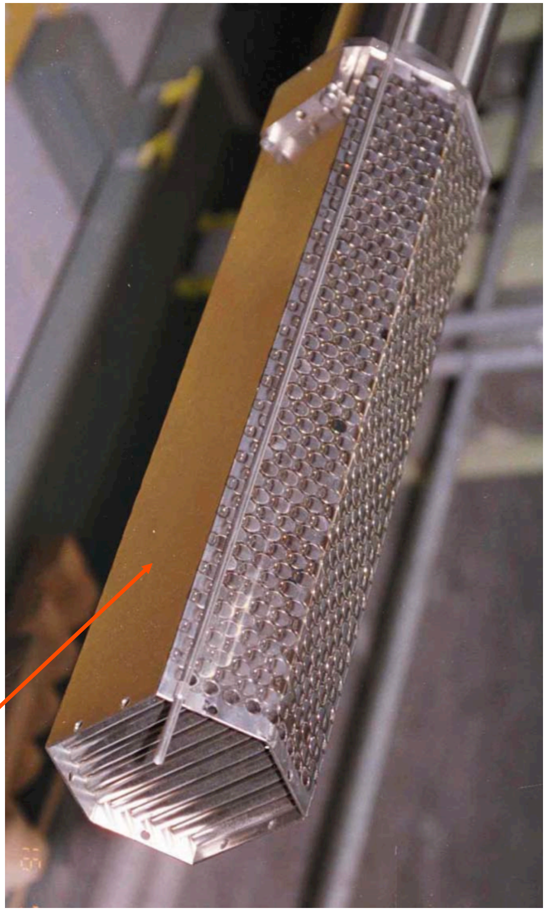
Proton beam on SINQ:
590 MeV / 51 MHz
p-Current: 1,5 mA
Power: 0.9 MW

Outline

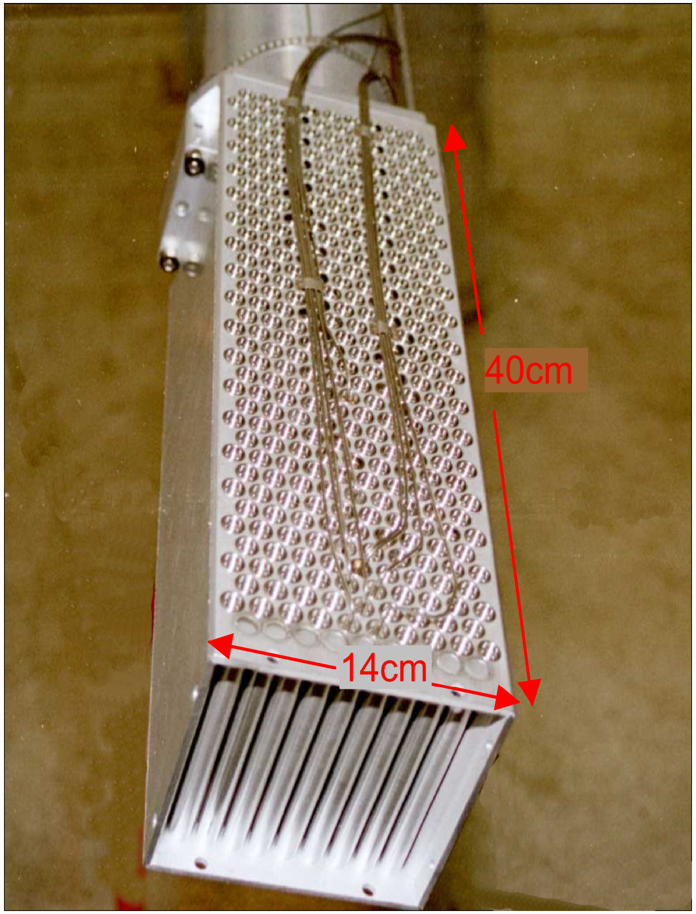
- Development initiatives for the (solid) SINQ spallation target
  - a view back in history
- Materials qualification, addressing
  - cladding tubes for the solid Pb-target
  - STIP: the SINQ Target Irradiation Program
  - ....⇒ targeting at the MEGAPIE liquid metal target
- Conclusion

SINQ targets



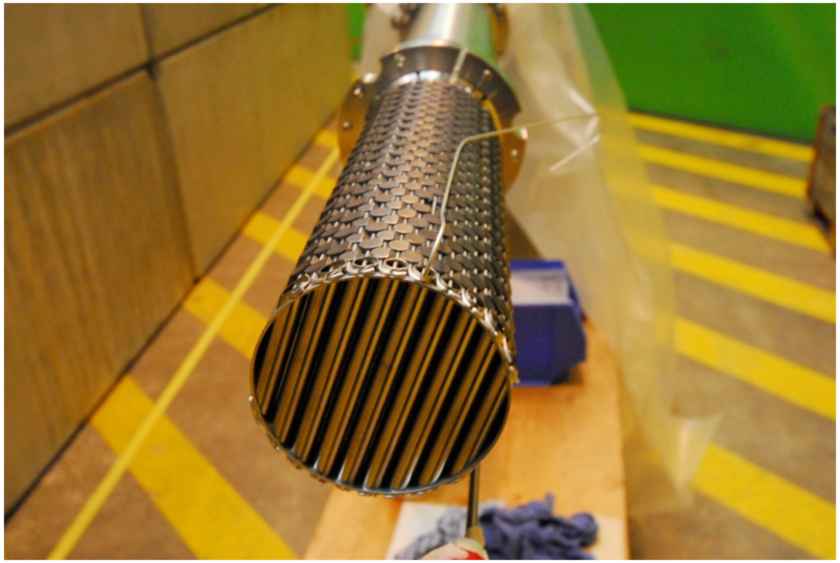


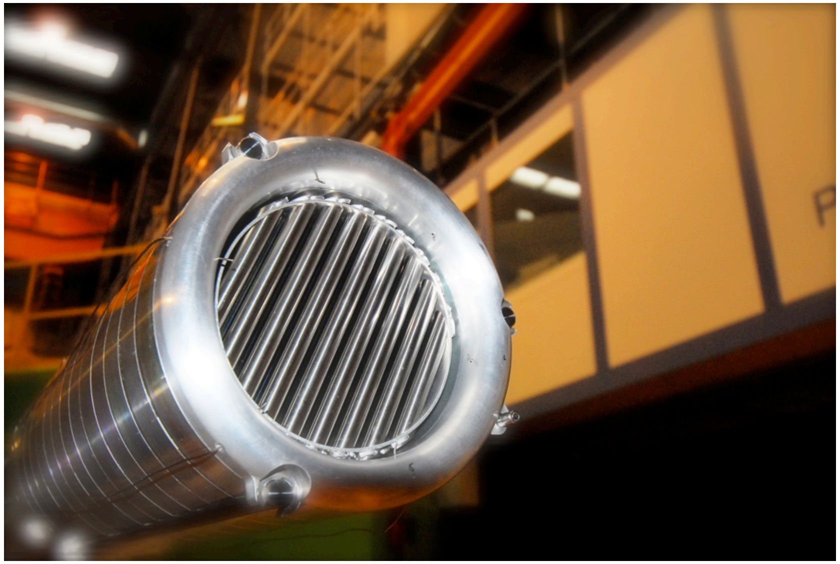
Start-up target: solid Zirkaloy rods 1997-1999

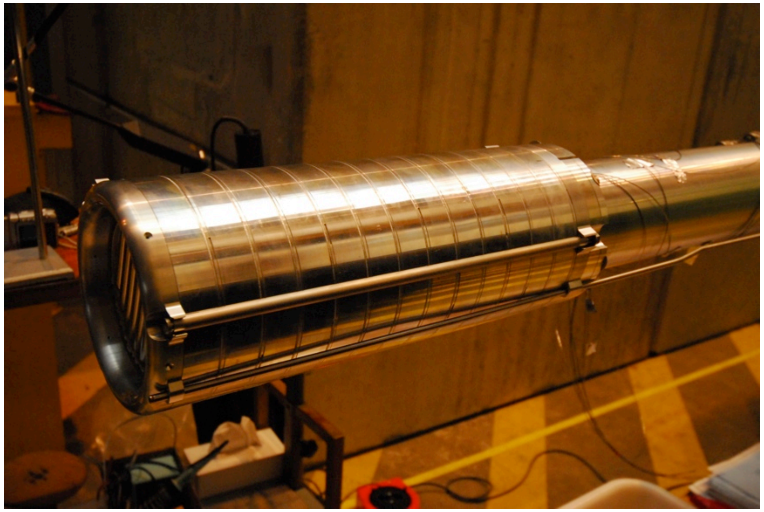


Lead-'Canneloni' Target in stainless steel cladding 2000-2005: ⇒42% more neutrons

The new Zr-Pb compact ‚cannelloni‘ target for SINQ



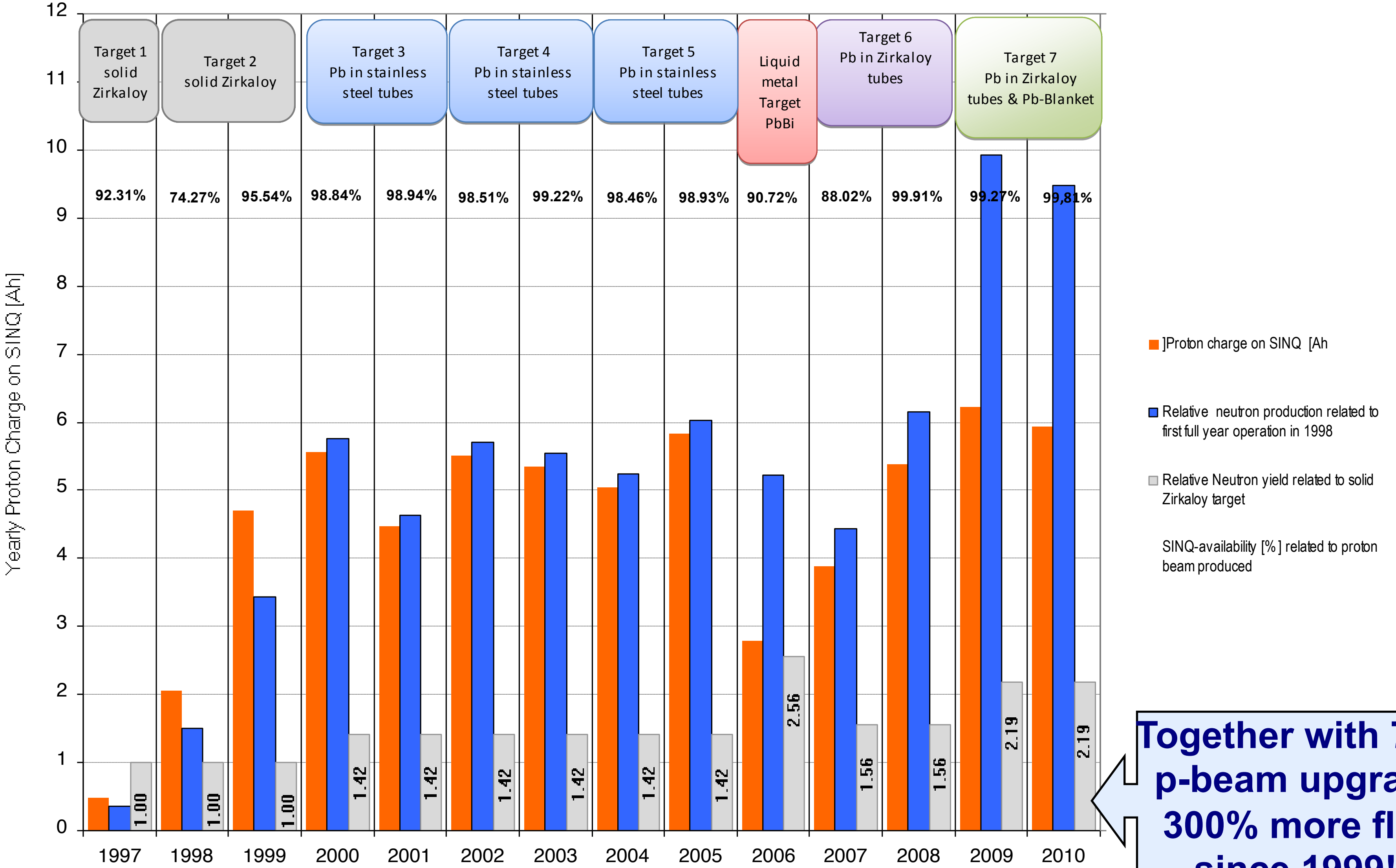




operation started April 2009

60% increase in neutron yield !!

SINQ neutron production statistics 1997-2010



Together with 75% p-beam upgrade 300% more flux since 1999!!

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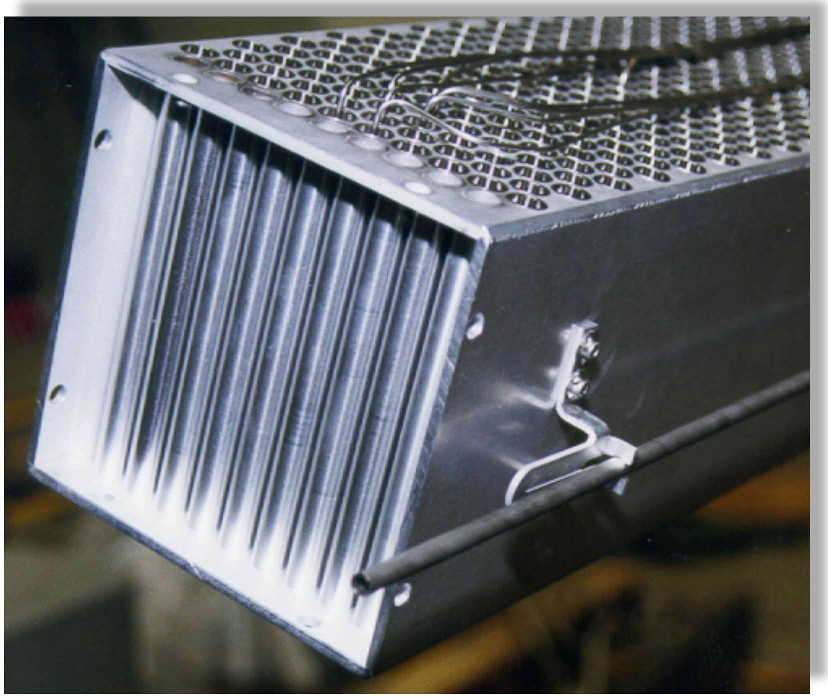
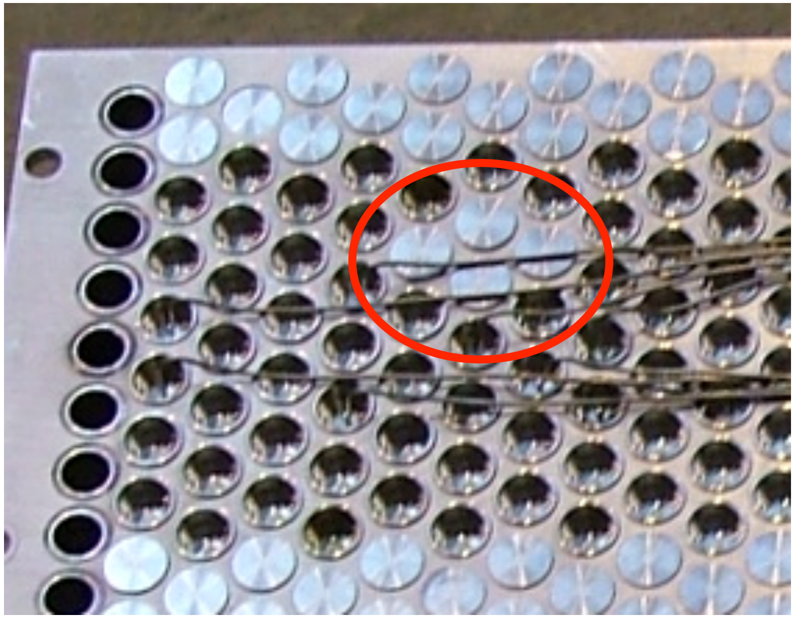
Qualifying Zircaloy for canning

Concern: Degradation by hydride formation

2002/3: SINQ-Target 4 (Mark III) with stainless steel canning

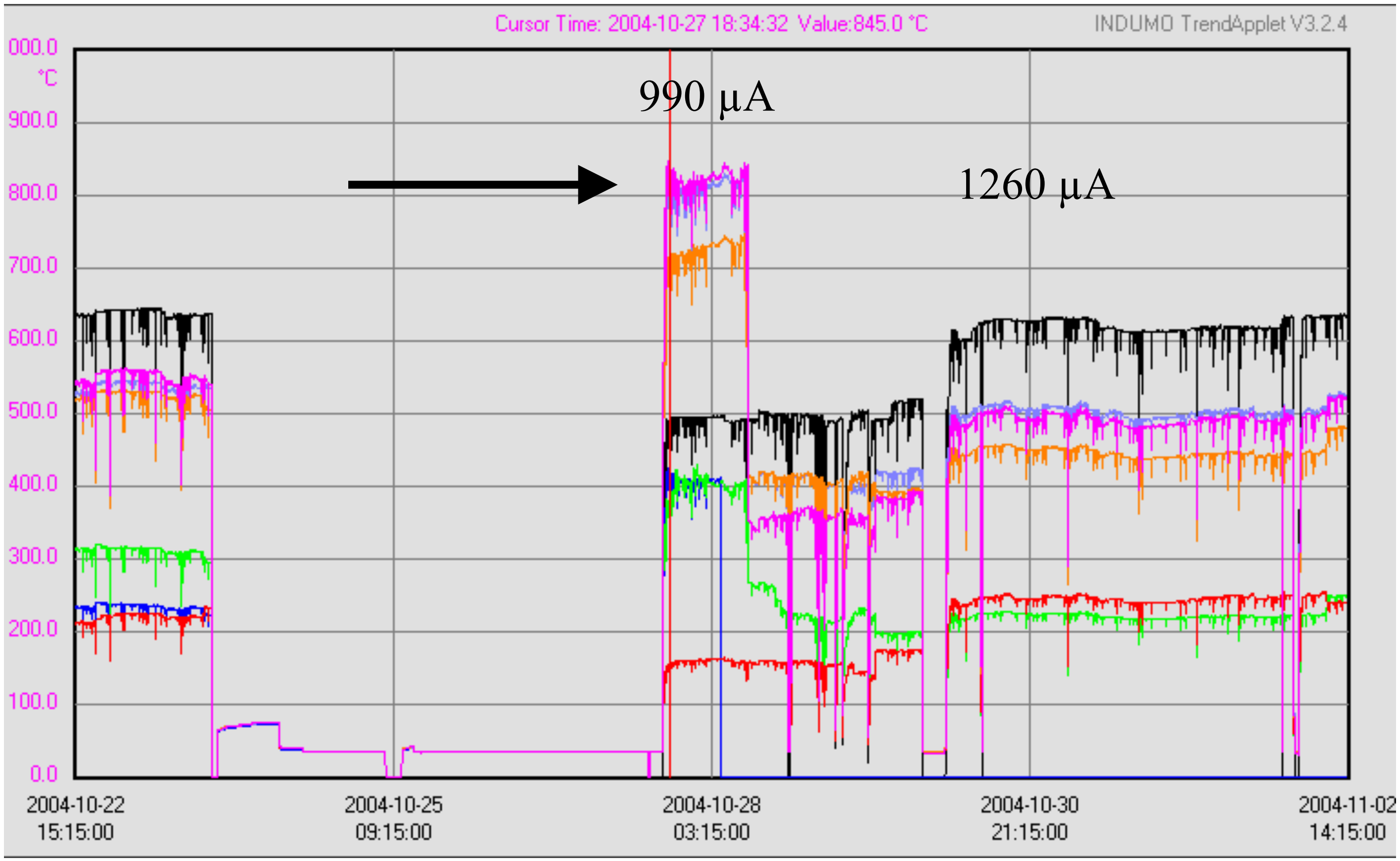


2004/5: SINQ-Target 5 with Zircaloy clad test tubes



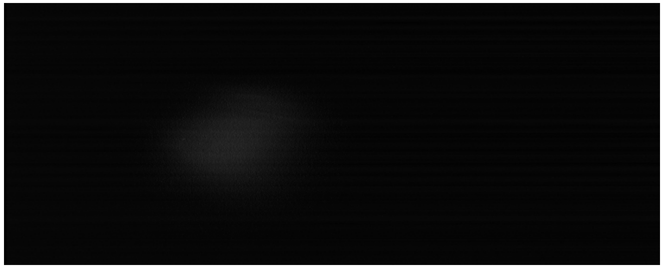
Target temperature recording

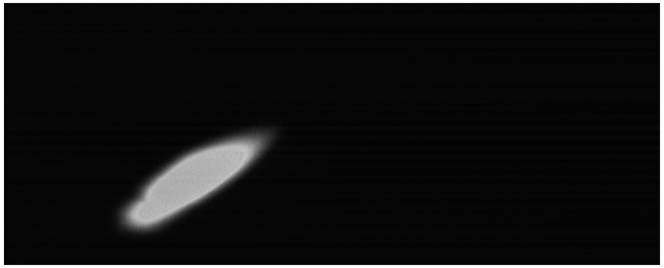
Temperatures during an unintended beam focussing, October 2004

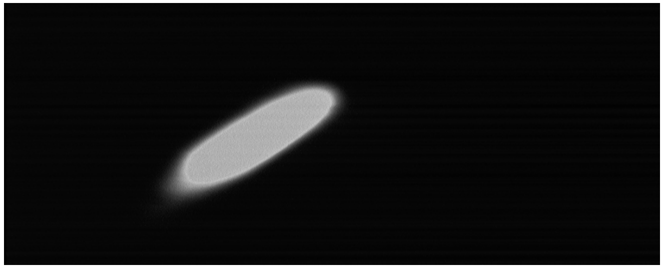


VIMOS: optical visualisation of the beam footprint in front of the SINQ beam window

VIMOS insert with **Tungsten mesh**







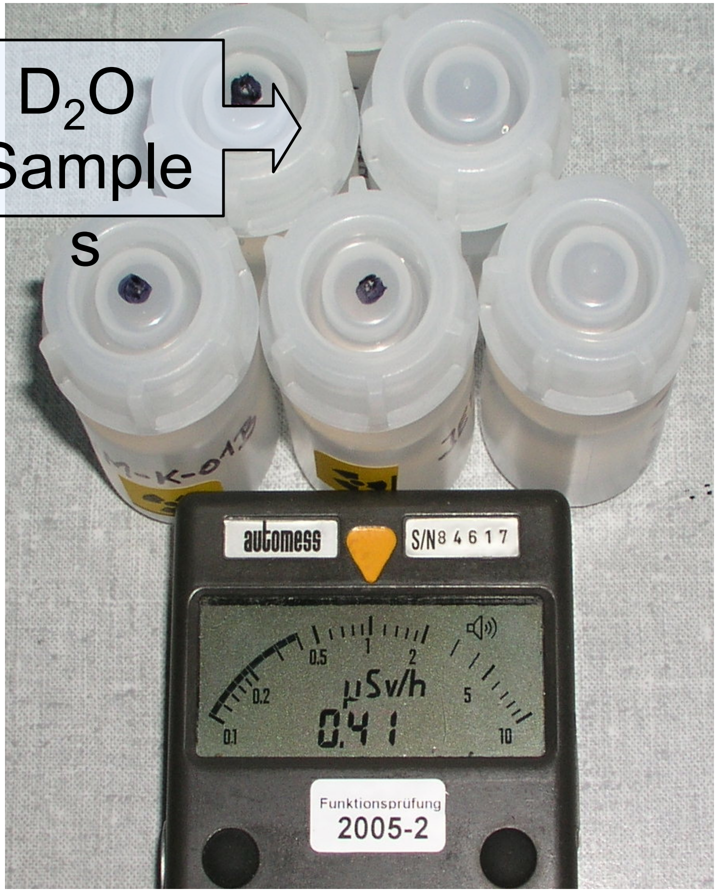
light spot from a focused beam caused by a wrong quadrupol parameter setting

(October 2004)

VIMOS observed the incident,
but was still in test phase, not yet set ‚sharp'

Oct.-Dec. 2005: High Activity in Target Coolant

D_2O Samples

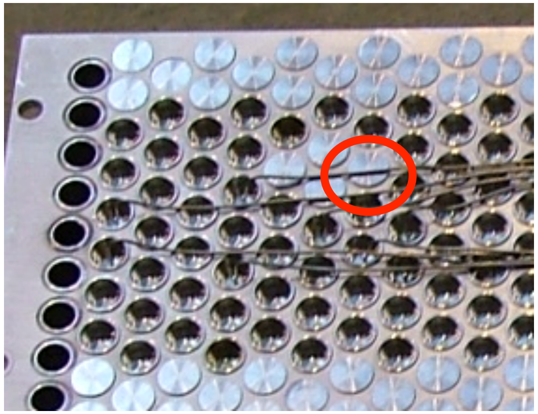


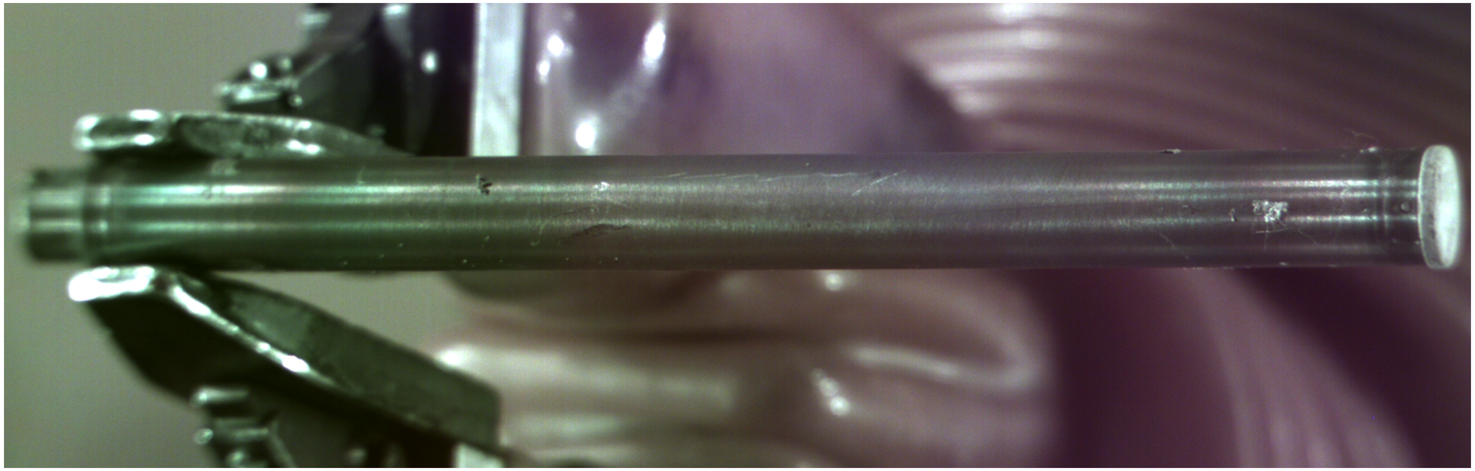
Nuklid	Aktivität	MUS	Bezugsdatum
H-3	7.56 GBq/kg	5%	23.12.2005
BE-7	630400. Bq/l	3%	23.12.2005
MN-54	942.4 Bq/l	21%	23.12.2005
CO-58	379.5 Bq/l	42%	23.12.2005
RB-84	1514. Bq/l	47%	23.12.2005
SR-85	1528. Bq/l	23%	23.12.2005
ZR-95	3313. Bq/l	14%	23.12.2005
NB-95	6782. Bq/l	12%	23.12.2005
RU-103	5188. Bq/l	10%	23.12.2005
SB-124	3670. Bq/l	9%	23.12.2005
XE-127	252700. Bq/l	1%	23.12.2005
HF-175	2074. Bq/l	67%	23.12.2005
RE-184	24060. Bq/l	7%	23.12.2005
OS-185	26290. Bq/l	4%	23.12.2005
IR-192	8730. Bq/l	5%	23.12.2005
AU-195	37300. Bq/l	9%	23.12.2005
HG-203	24980. Bq/l	3%	23.12.2005
BE-7	29500. Bq/l	3%	23.12.2005

Searching for the object of failure

Zr-clad rod:

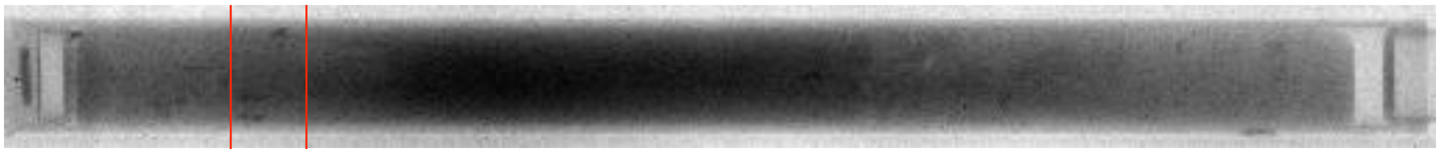
visual inspection after 2 years in SINQ (>10Ah of accumulated proton charge):



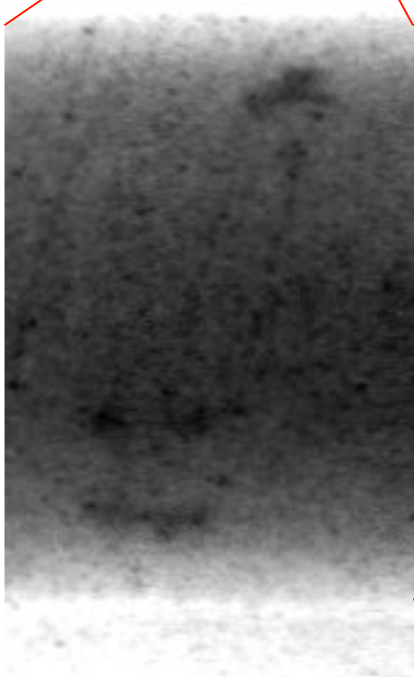


Searching for the object of failure

Neutron tomography: Zr-clad test rod

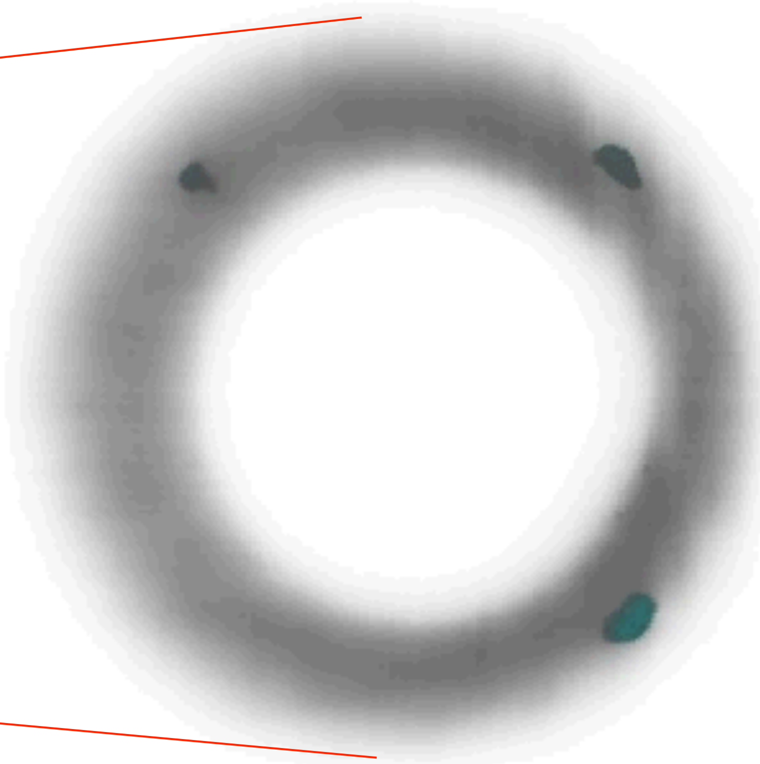


tomography reconstruction

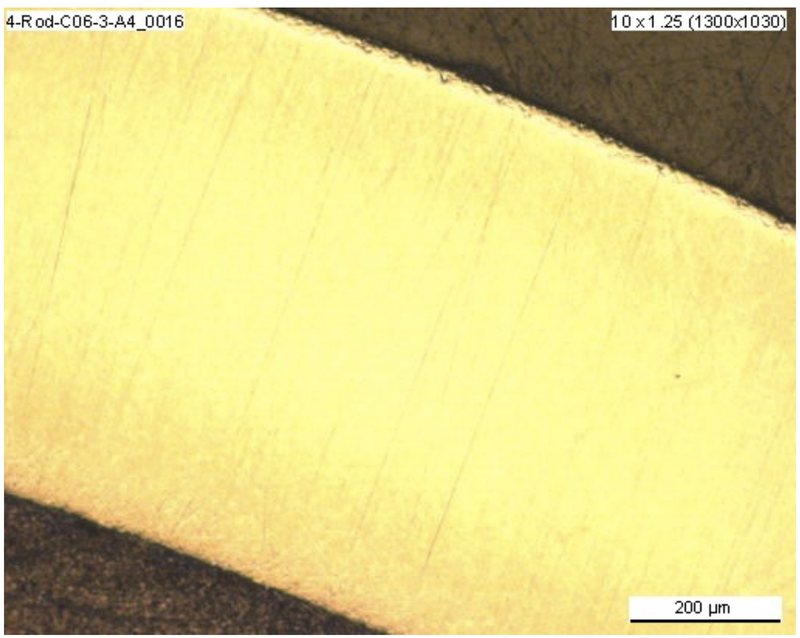


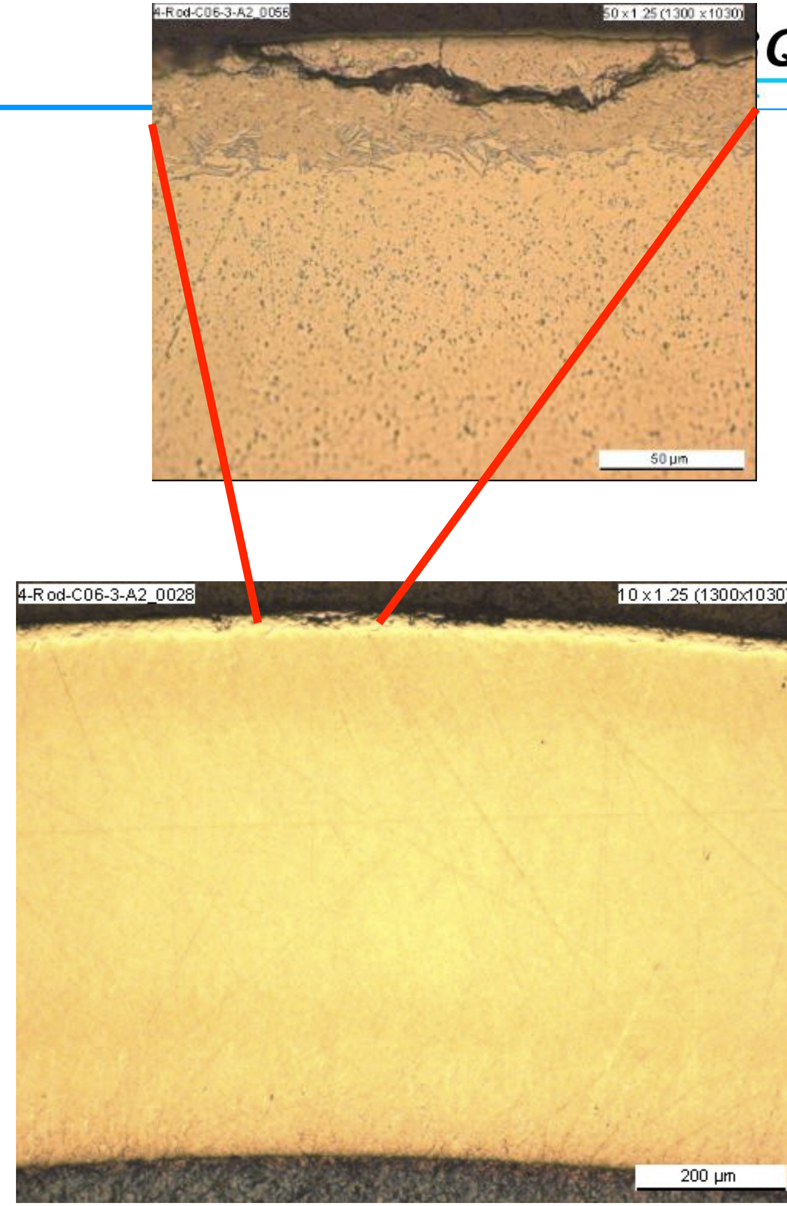
strongly neutron
attenuating spots:

spot location
outside
of cladding wall

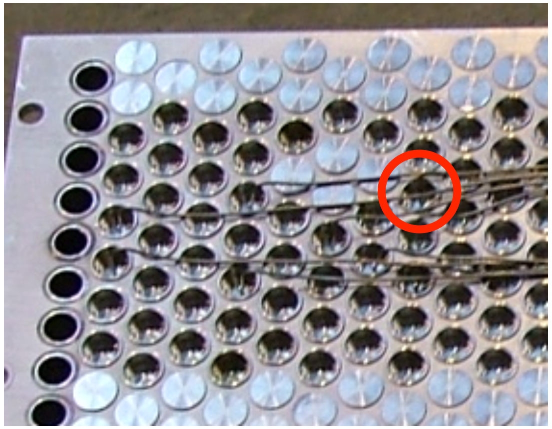


Metallographic investigation:
Zr-rod 06-3

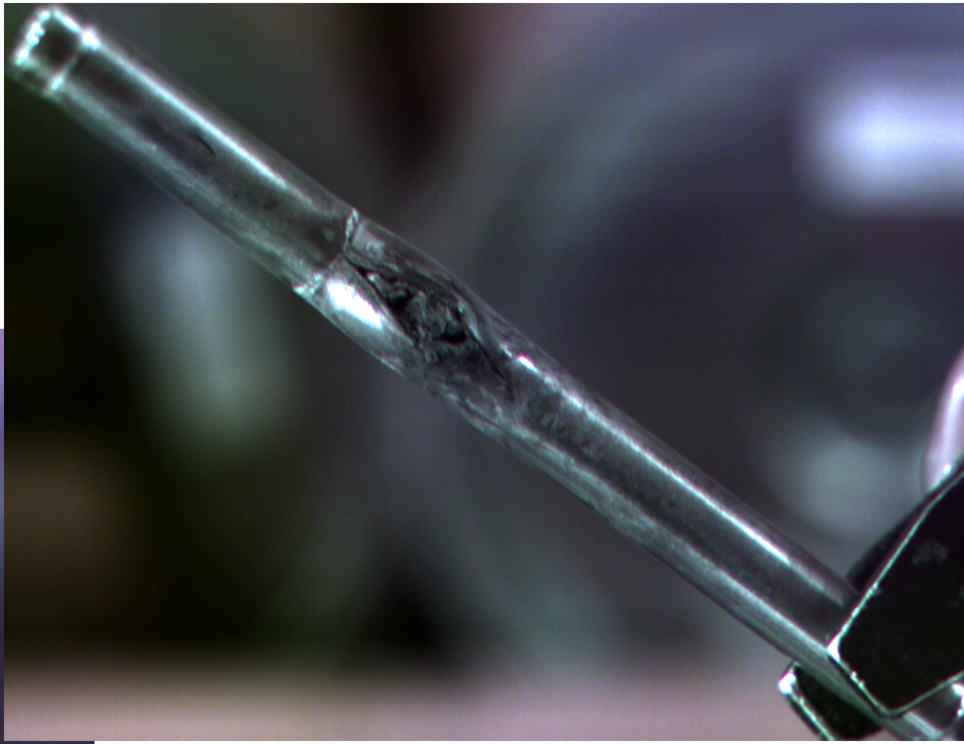


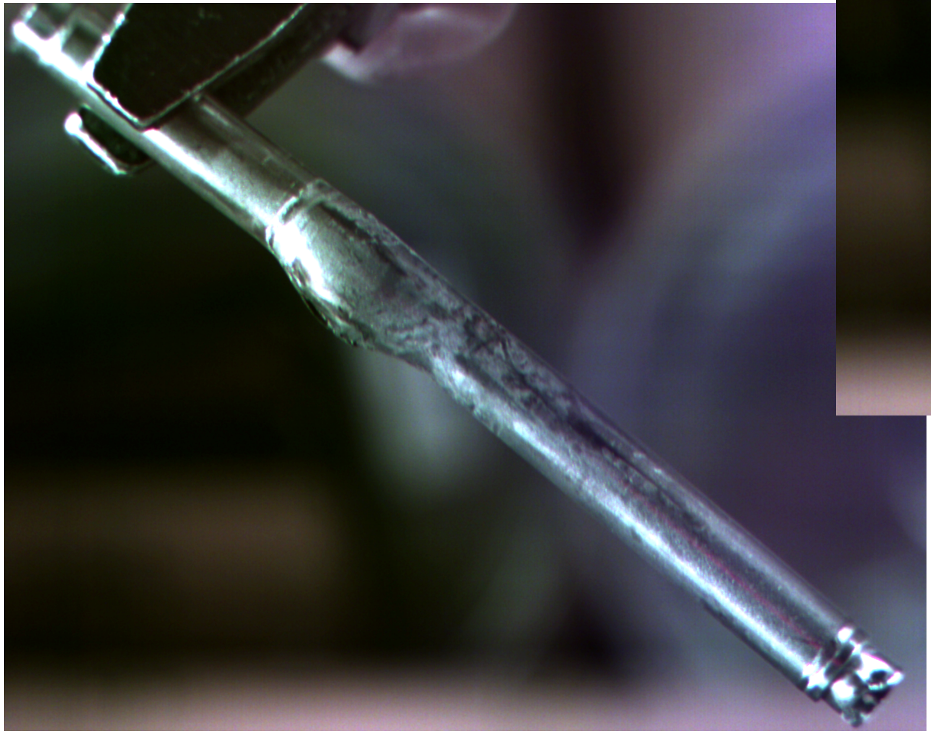


Searching for the object of failure

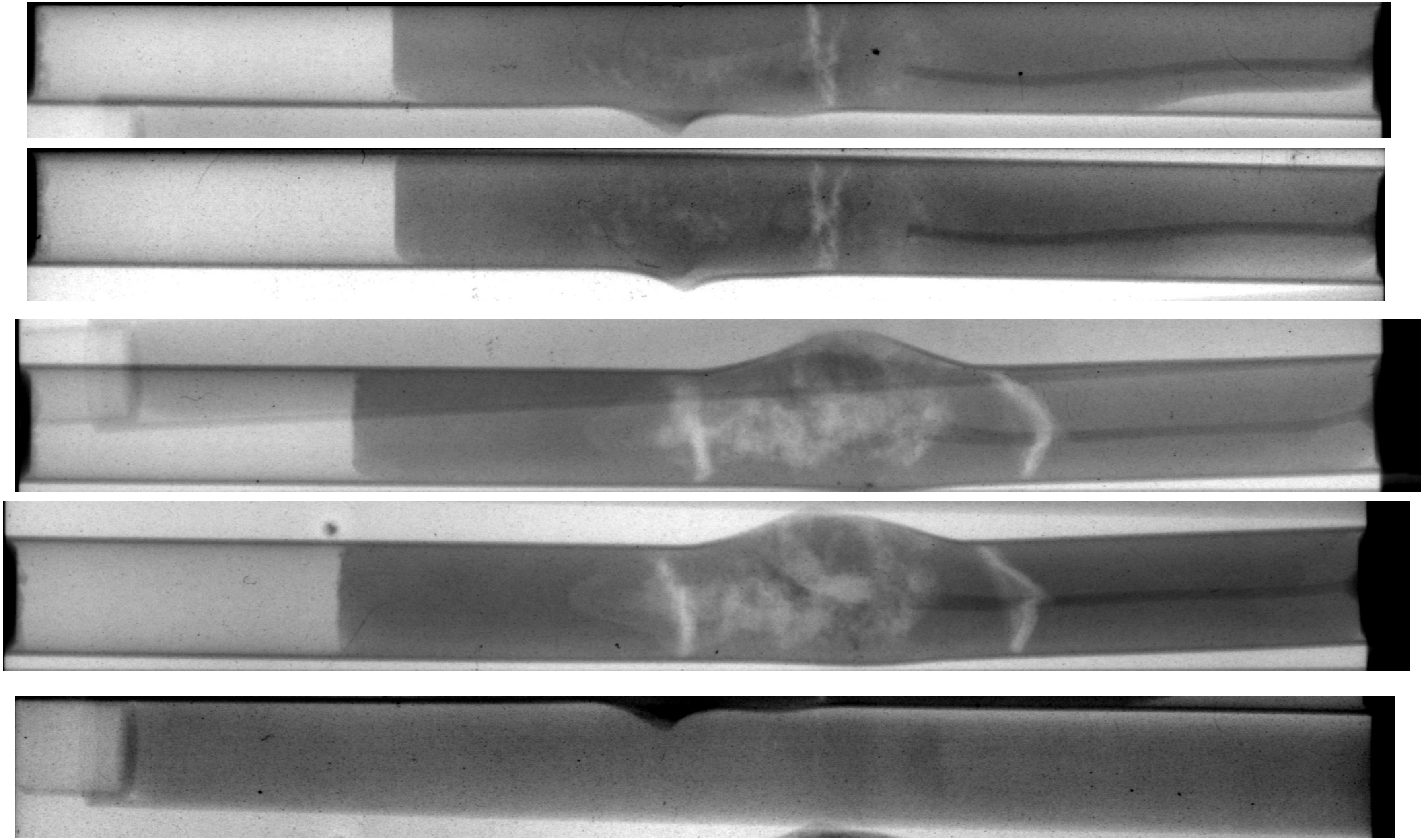


….adjacent steel-clad rod





Neutron radiographs from damaged (steel-clad) target rods



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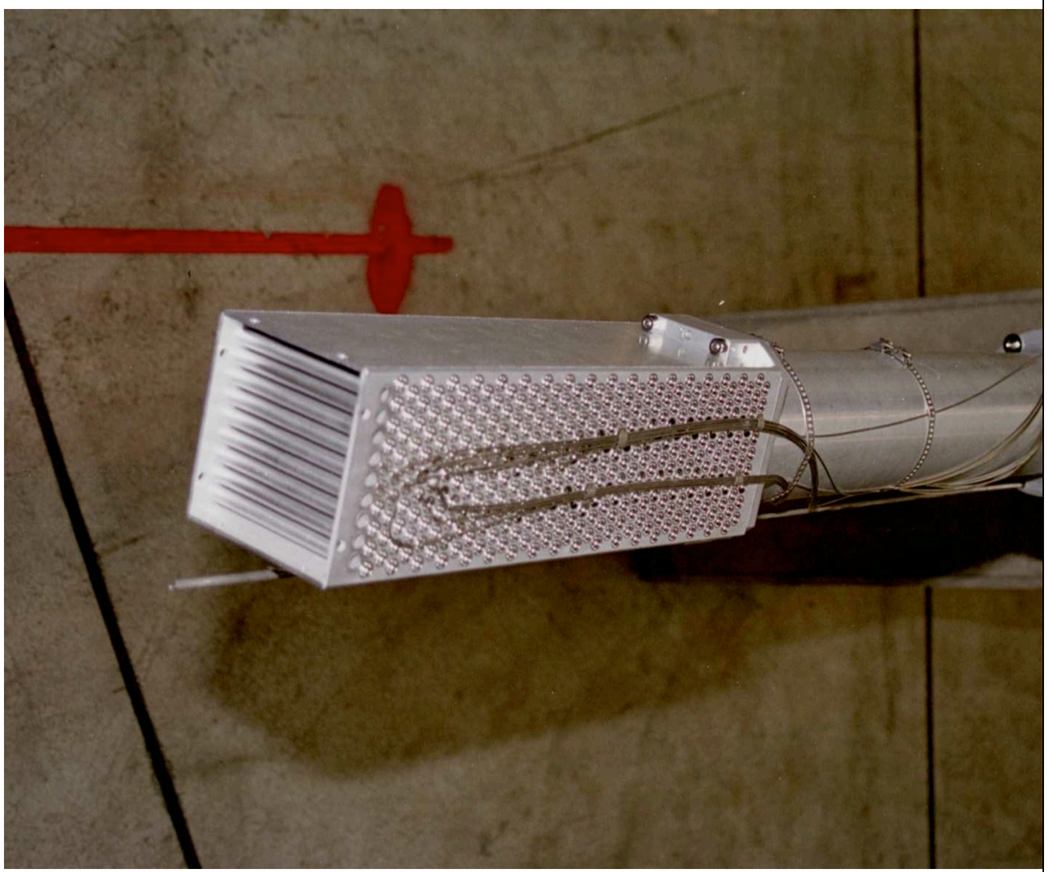
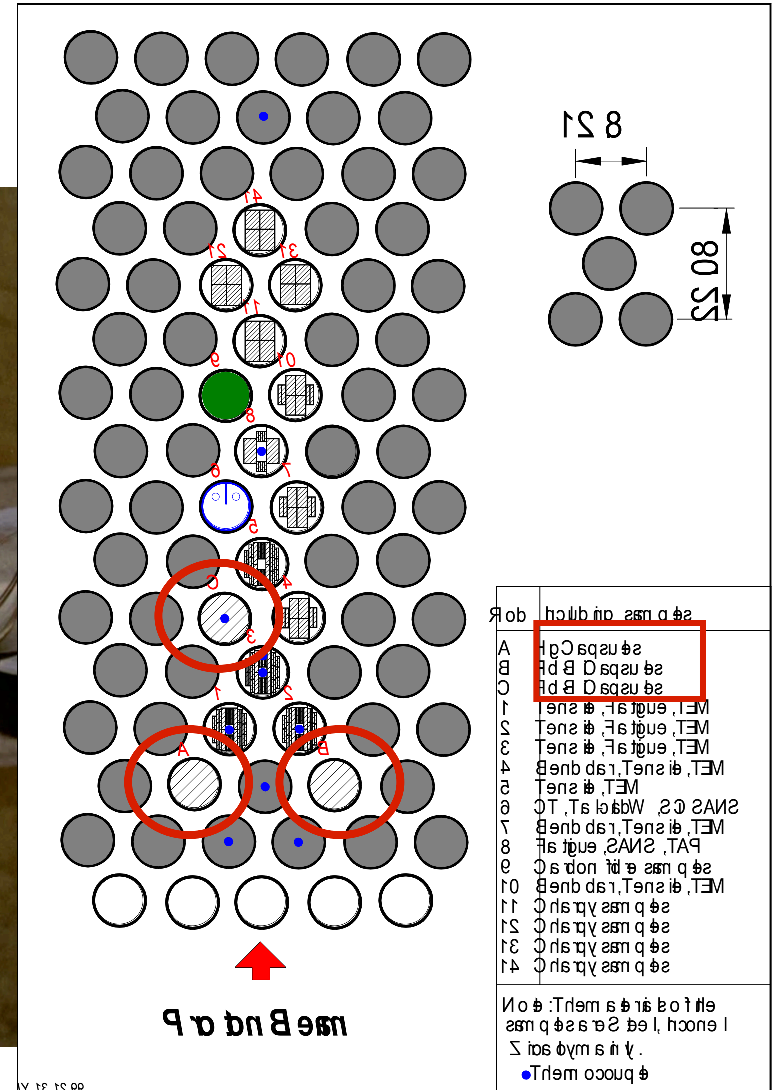
  - ….$\Rightarrow$ targeting at the **MEGAPIE liquid metal target**
- Conclusion

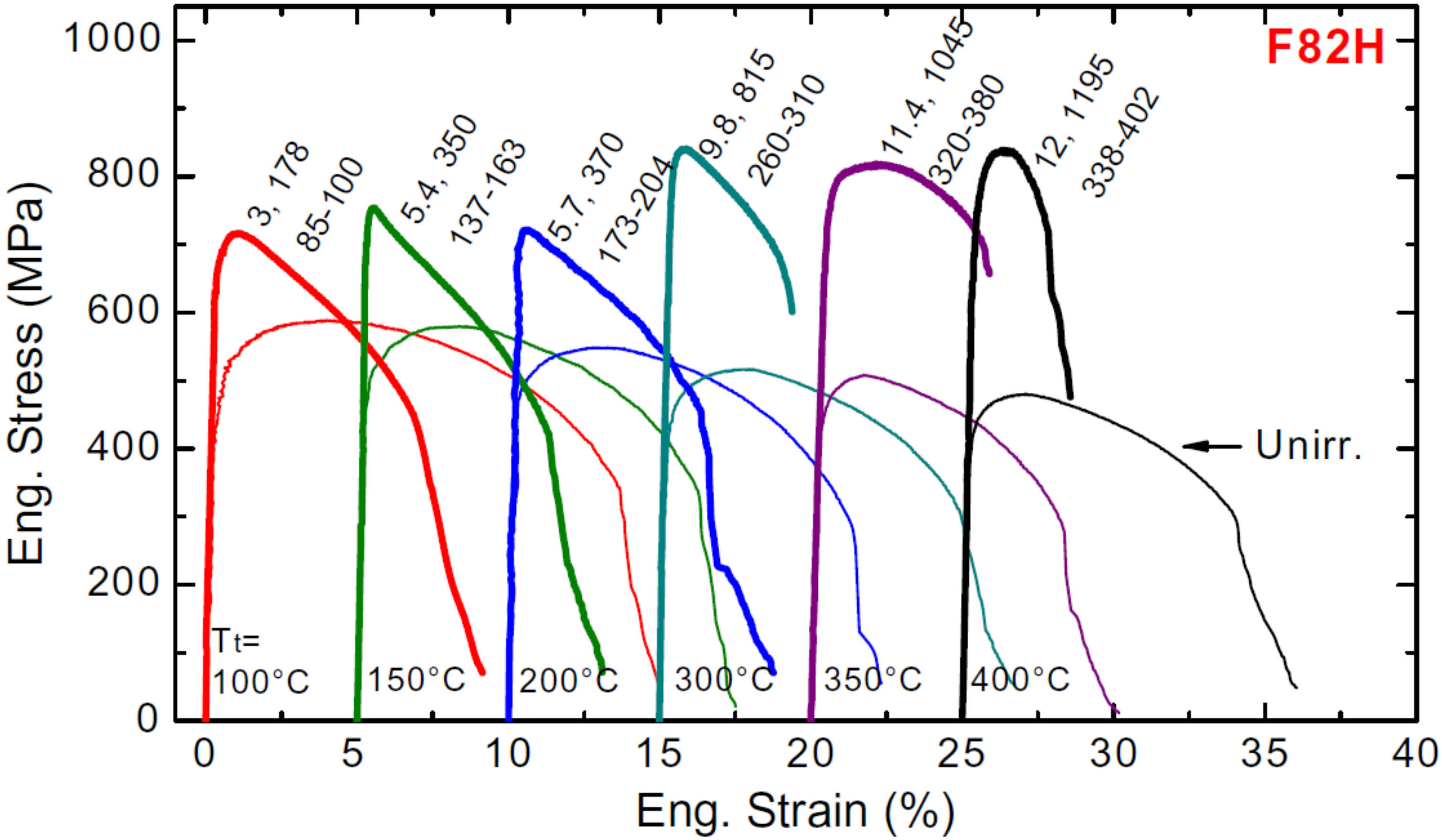
Target 4, carrying thermocoulpes and STIP samples: The SINQ Target Irradiation Program



STIP samples loading plan



Selected STIP results: FM steels – tensile properties

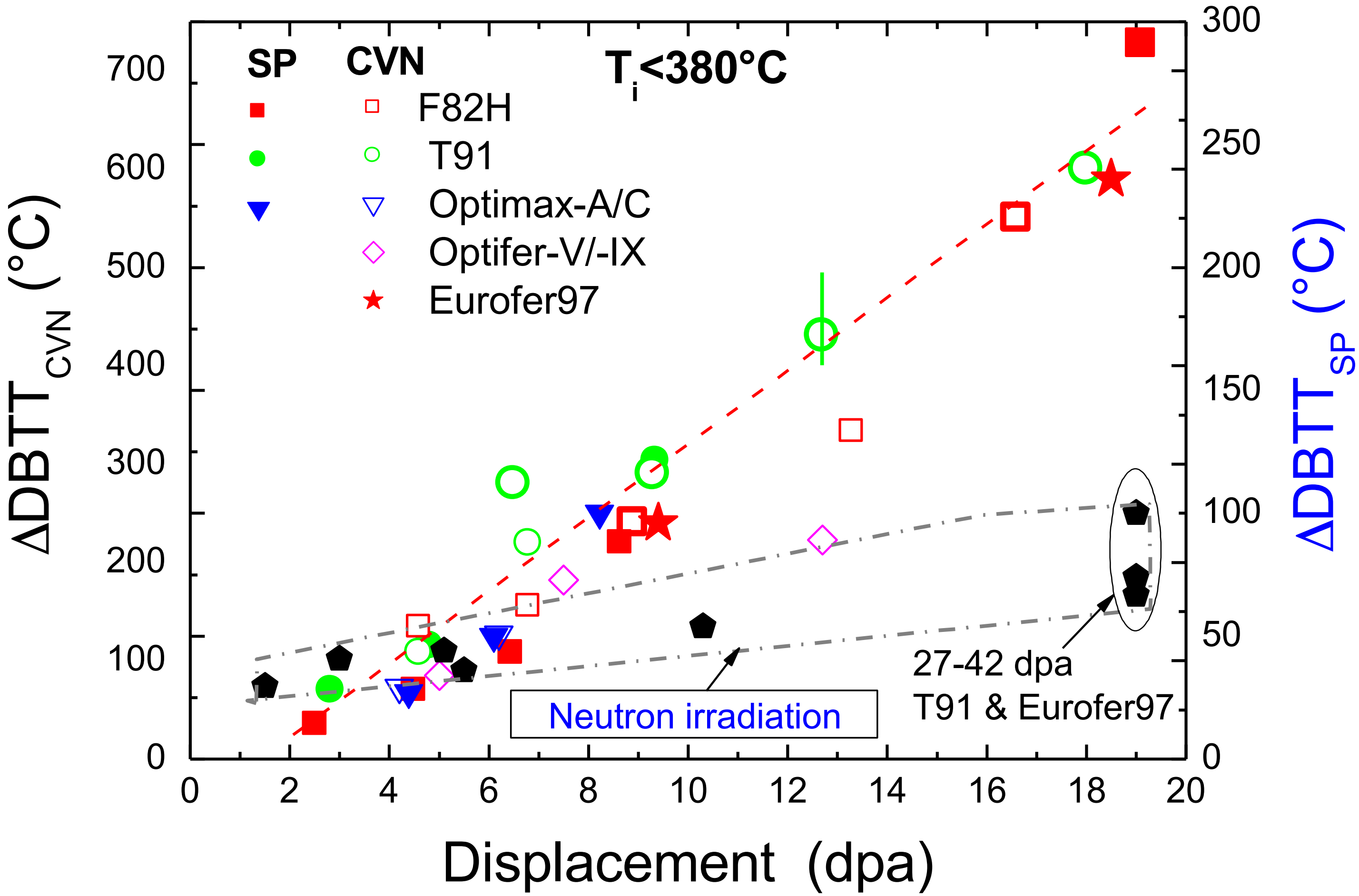


Irrad. >1dpa/<400°C: almost no uniform elongation left

Dai, et al. JNM, 377 (2008) 115.

Selected STIP results: FM steels – DBTT shift

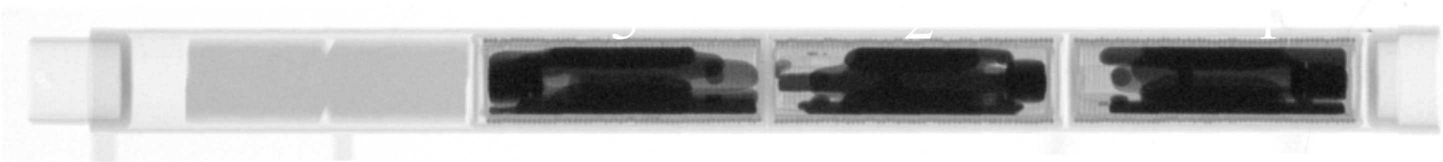
$\Delta DBTT_{SP} = 0.4\ \Delta DBTT_{CVN}$



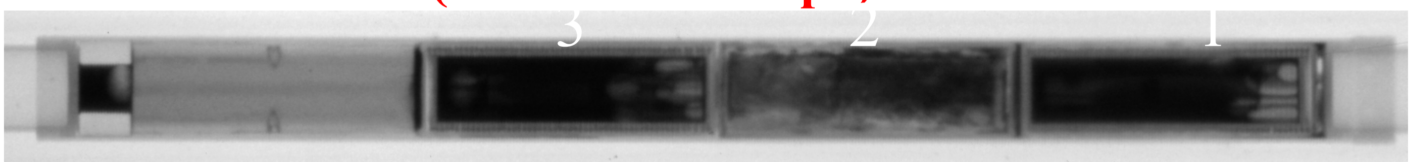
Neutron irradiation data: (1) Klueh et al, J. Nucl. Mater. 218 (1995) 151; (2) Hu et al. STP 1046 (ASTM, 1990), p.453; (3) Alamo, Euromat2007.

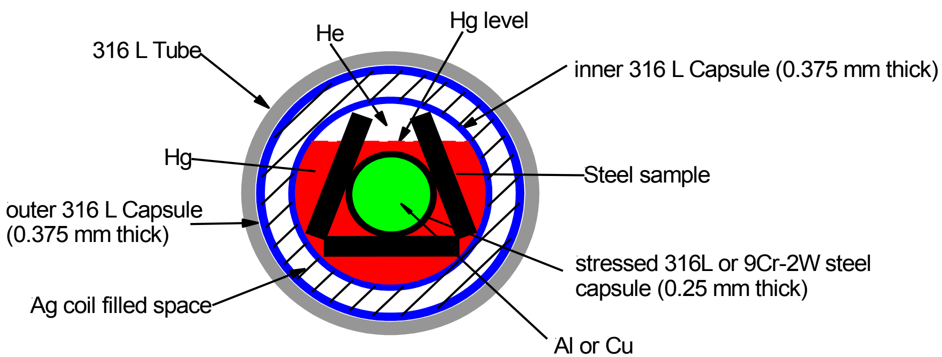
Example 1: Steel samples in Hg containing capsules

Before irradiation



After irradiation (max dose: 19 dpa)



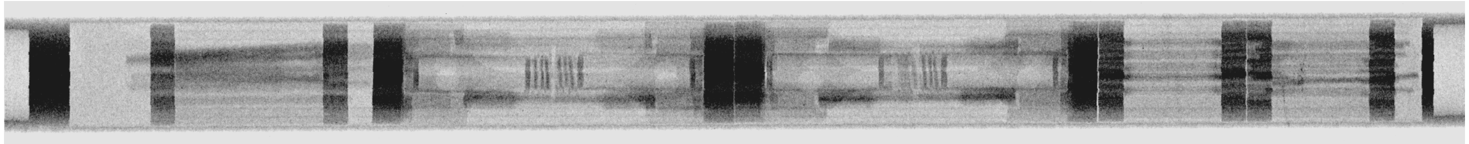


Target Rod A:
contains three Hg (about 19 g in total) filled SS 316 L capsules for studying irradiation assisted corrosion effects of Hg on two kinds of steels.

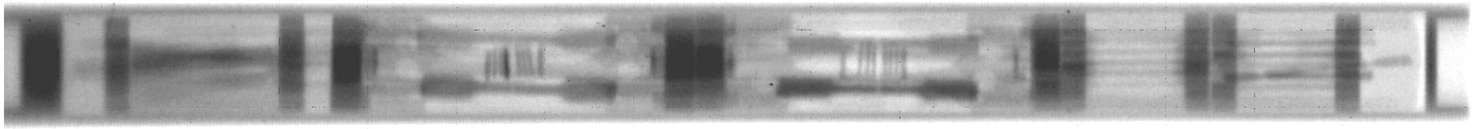
Neutron radiography revealed that one of the central Hg capsules which had received the highest dose was penetrated and leaking

Example 2: Steel samples in LBE, T_m=125°C

Before irradiation



After irradiation (max dose: 18.6 dpa)

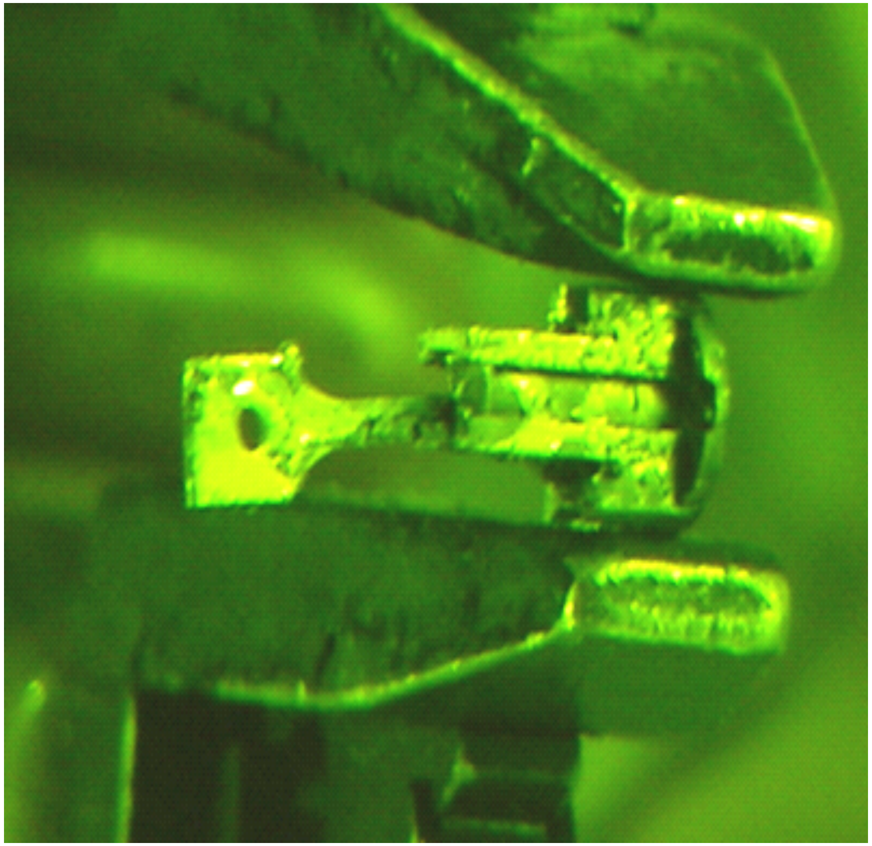


Target Rod B
contains a PbBi (about 38 g) filled T91 capsule. Inside PbBi there are about 50 test samples for studying irradiation assisted corrosion effects of PbBi on different kinds of materials.

Neutron radiography showing the samples (small tensile samples and TEM discs) in Pb-Bi are still existing, even at the highest irradiation dose

Approaching a lifetime assessment for a liquid metal target window:

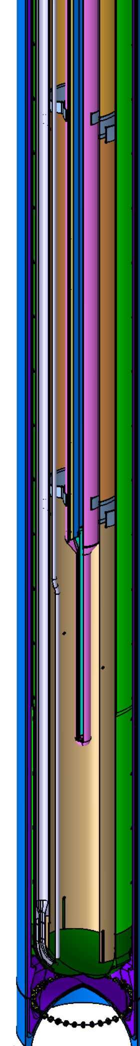
T91 steel tensile specimen after 2 years of irradiation (12 dpa) at 210 to 250°C:
NO severe LBE corrosion, **NO** evident failure.



…a necessary prerequisite for the design and licensing of MEGAPIE, the liquid metal (LBE) target project

MEGAPIE MEGAwatt Pilot Experiment:

a joint international initiative to built and operate a liquid metal (LBE) spallation target at 1 MW beam power



AlMg3 safety hull

T91 beam window

primarily driven by ADS initiatives for wast transmutation

Operated in SINQ in 2006 for 4 months

A none-too-pleasant incident:

Heat exchanger failure in the D_2O moderator system

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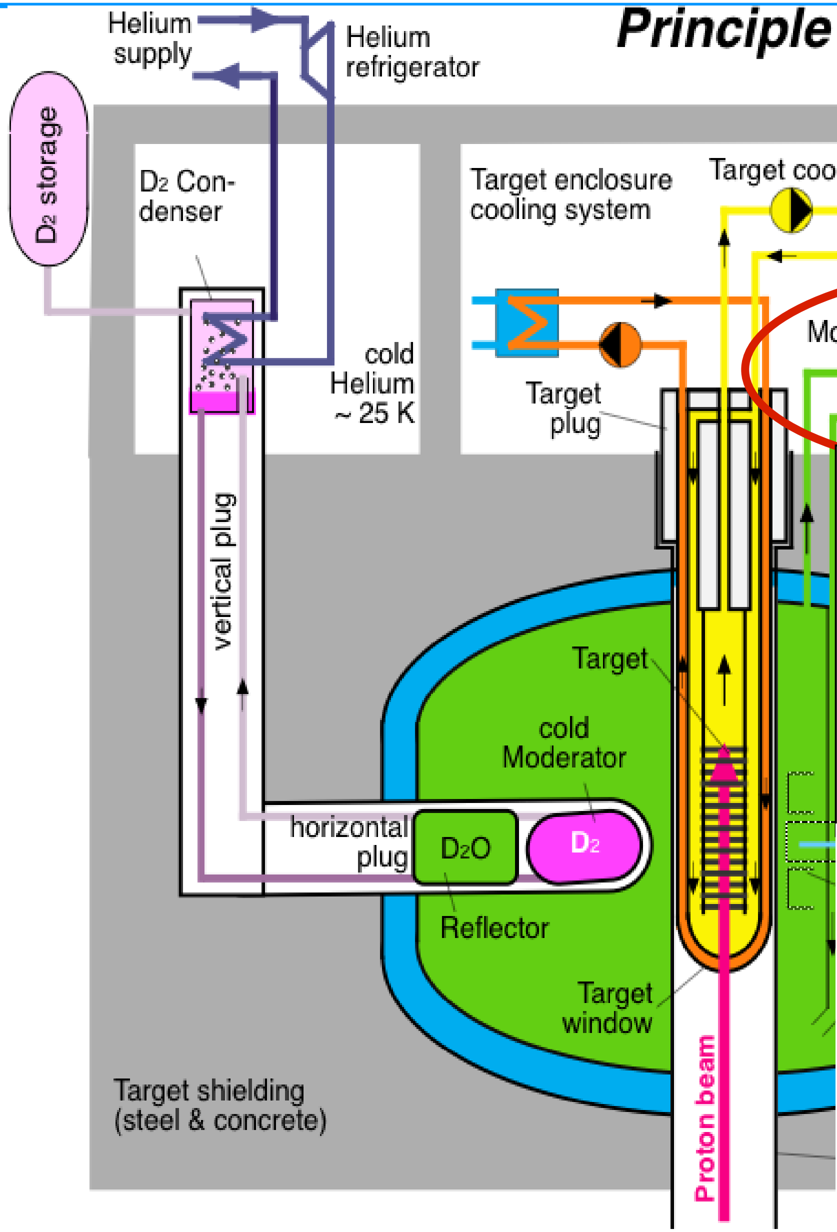
ASQ

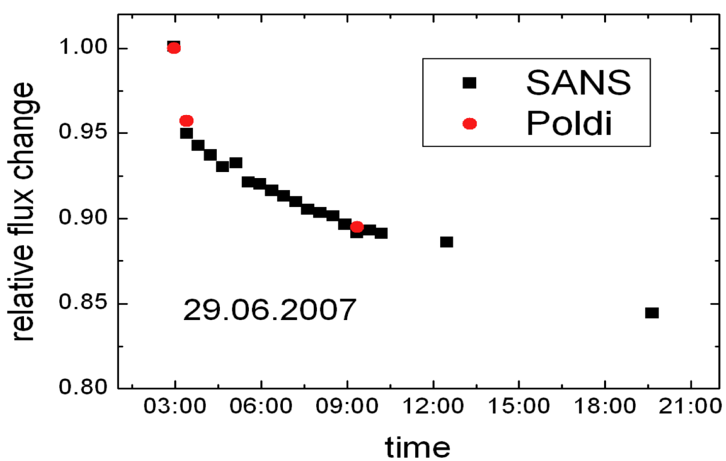
Principle of the SINQ Systems



June 29, 2007
Heat exchanger leak

Consequences:

- **Infiltrating D_2O contaminated the 125 m^3 secondary H_2O loop with 6 GBq Tritium and 55 MBq ^7Be**
- **Visa versa: H_2O infiltrating the D_2O moderator reduced the neutron flux by 30%**



He leaktest of repaired Moderator HX

Remedial actions

- Repair moderator HX
- Modestly drain and replace the contaminated H_2O
- Install an intermediate (uncontaminated) D_2O loop
- Recover the reduced neutron flux

….by (ingeniosly) exchanging the degraded D_2O moderator coolant with ('clean') target- and targetwindow coolant D_2O.

…which needed only 600 l fresh D_2O to be replenished into the ~6 m^3 containing moderator system

Summary

During 14 years of operational experience:

SINQ spallation target development is an on-going effort at PSI

- **…aiming for optimised neutron yield, longer lifetime, higher-power sustainability ….**
- **…goes along with an extensive Materials Qualification Program: STIP**
- **…is actively conducting post-operation inspection/investigation**
- **…where neutron imaging is a most valuable tools**

……..and was very successful so far

Thank you for your attention