PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

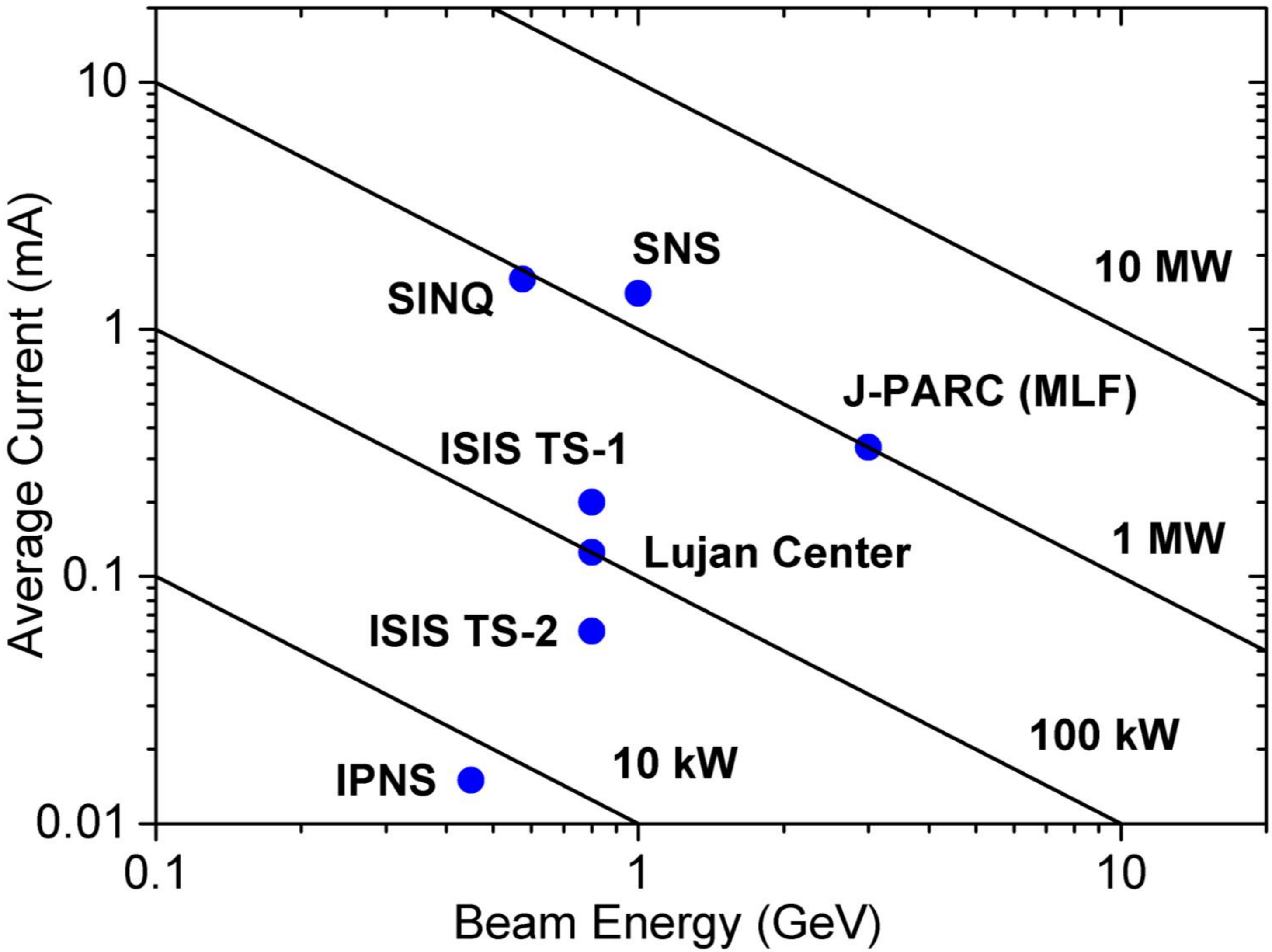
Spallation Target Developments

B. Riemer (ORNL), H. Takada (JAEA), N. Takashi (JAEA) and M. Wohlmuther (PSI)

Thorium Energy Conference 2013 (ThEC13),

27. – 31. October 2013, CERN, Switzerland

Spallation Neutron Sources

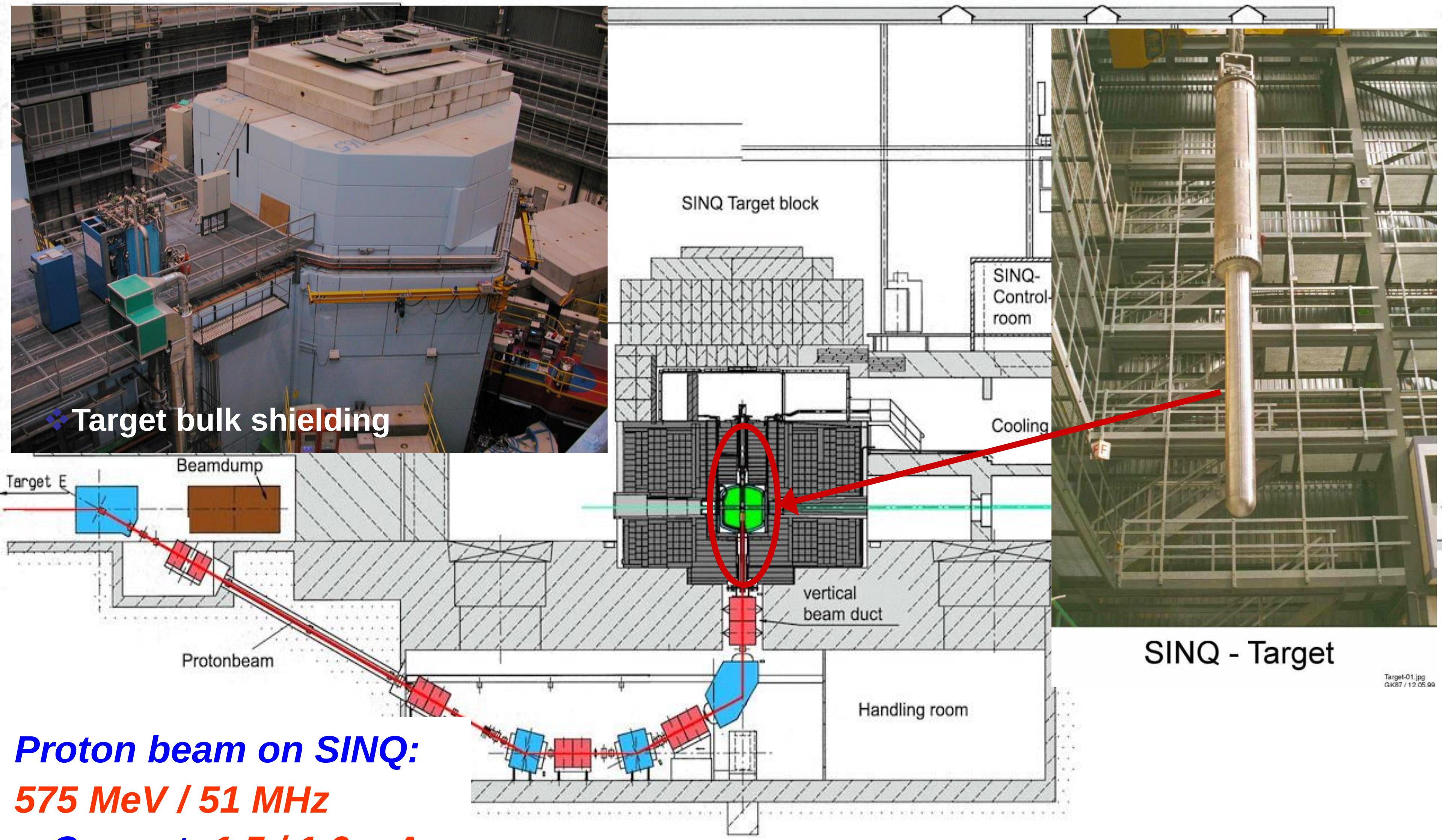


IPNS & KENS (not seen on the slide; I_{av}=6 µA @ 500 MeV) have been decommissioned.
New sources built in China (CSNS) and planned in Lund, Sweden (ESS).

Spallation Neutron Sources

Facility	Status / rep. rate	Energy	Target Type / Time structure	Coolant	Power Level [kW]	Additional Information
IPNS (ANL)	decom. 30 Hz	0.450	Solid SP	H_2O	7	Depl. U / W
ISIS TS 1 (RAL)	running 50 Hz	0.800	Solid SP	H_2O	100 - 200	Depl. U / Ta / W-Ta clad
ISIS TS 2 (RAL)	running 10 Hz	0.800	Solid SP	H_2O	48	W-Ta clad
Lujan Center (LANL)	running 20 Hz	0.800	Solid SP	H_2O	100	W
KENS (KEK)	decom. 20 Hz	0.500	Solid SP	H_2O	3	W-Ta clad
SINQ (PSI)	running 51 MHz	0.575	solid/liquid CW	D_2O/LBE	800 – 1000	Zr / Pb-SS clad / Pb-Zr clad / LBE
SNS (ORNL)	running 60 Hz	1.000	Liquid SP	Hg	1000	1.4 MW design
JSNS (J-PARC)	running 25 Hz	3.000	Liquid SP	Hg	1000	1.0 MW design

SINQ @ PSI



Proton beam on SINQ:

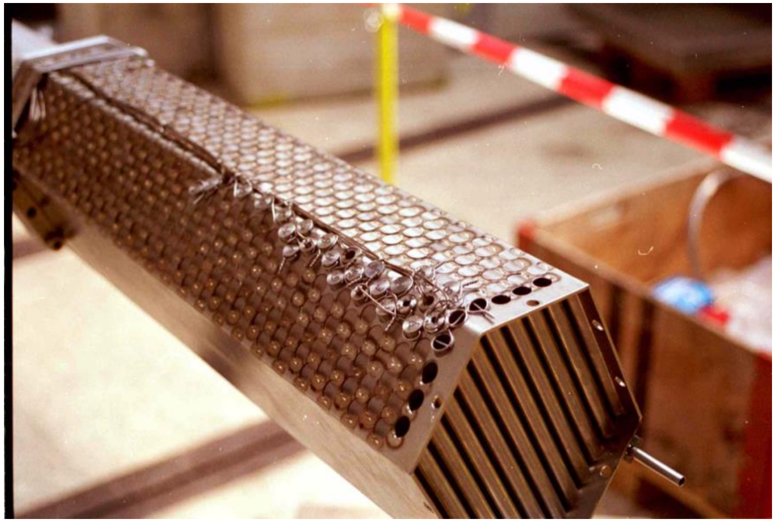
575 MeV / 51 MHz

p-Current: 1.5 / 1.6 mA

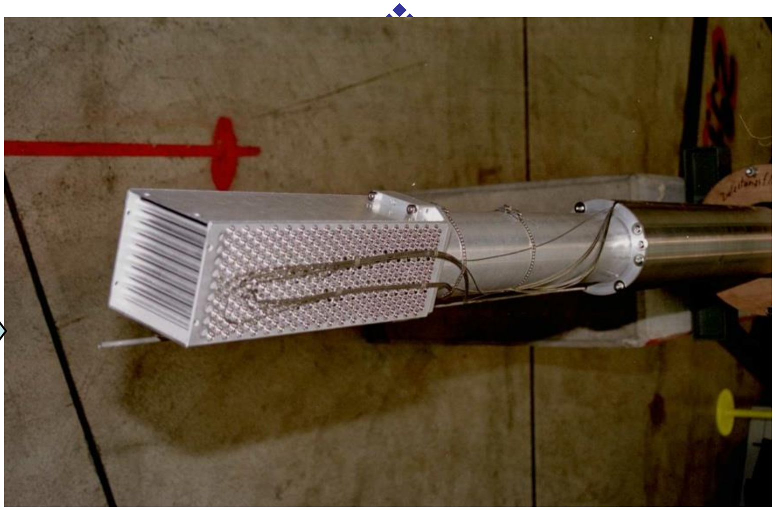
Power: 0.8 - 0.9 MW

Target Evolution at SINQ

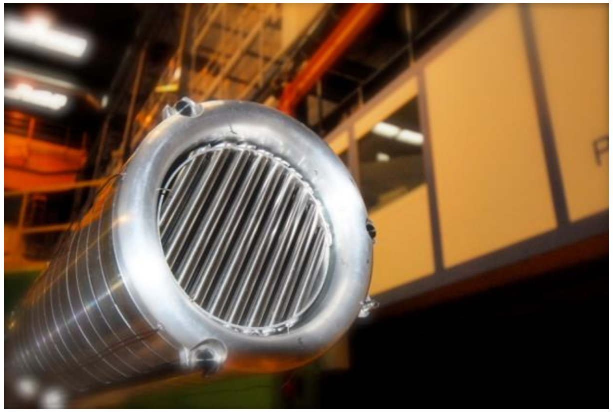
1997-1999: Target Mark I
Water-cooled Zircaloy rods



2000 - 2003:Target Mark II:
Lead rods, steel clad
42% increase in neutron yield



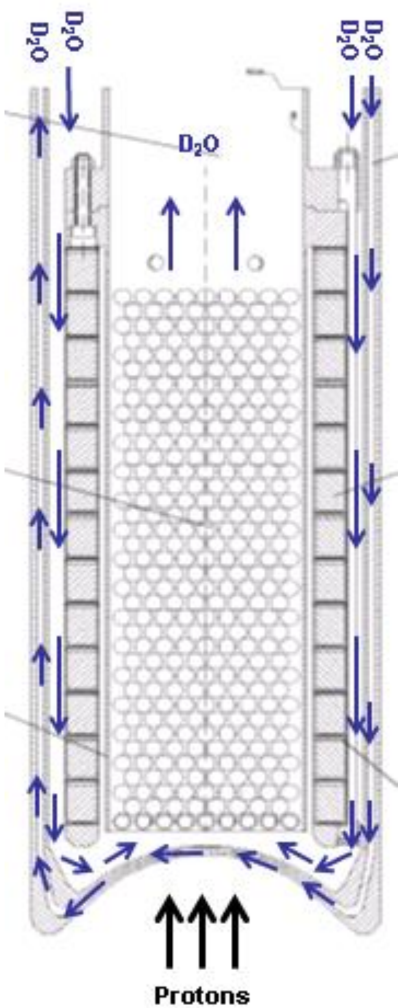
2004 – 2008:Target Mark III
hybrid Pb SS & Pb Zr-clad



2009 – present: Target Mark IV
Lead rods, with Zr clad, blanket

Aug - Dec 2006: **MEGA**watt **Pi**lot **E**xperiment:
Joint international initiative to design,
build, licence, operate and explore
a liquid metal spallation target
for 1 MW beam power (**Details next talk**)

Basic Design - MARK IV Target



Total Power Deposition in Target Assembly

~ 575 – 610 kW

Basic parameters – main loop

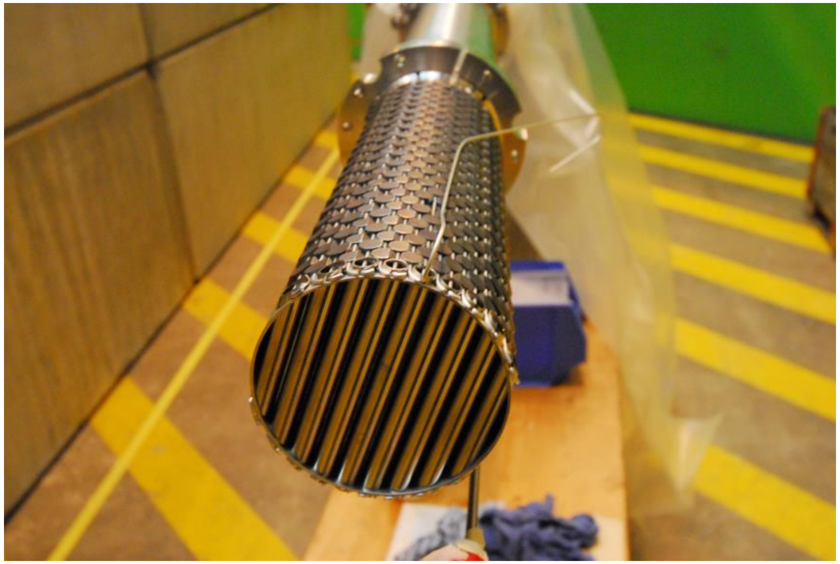
- Proton current: 1.5 – 1.6 mA
- Double Gaussian Beam Profile
  - σ_x=2.14 cm, σ_y=2.96cm
- Peak Current Density: 25 μA/cm^2/mA*
- D_2O Cooling: p_{stat}=8 bar
- Peak power deposition: 512 W/cm^3/mA
- D_2O inlet temp: 30ºC
- D_2O outlet temp: 70ºC

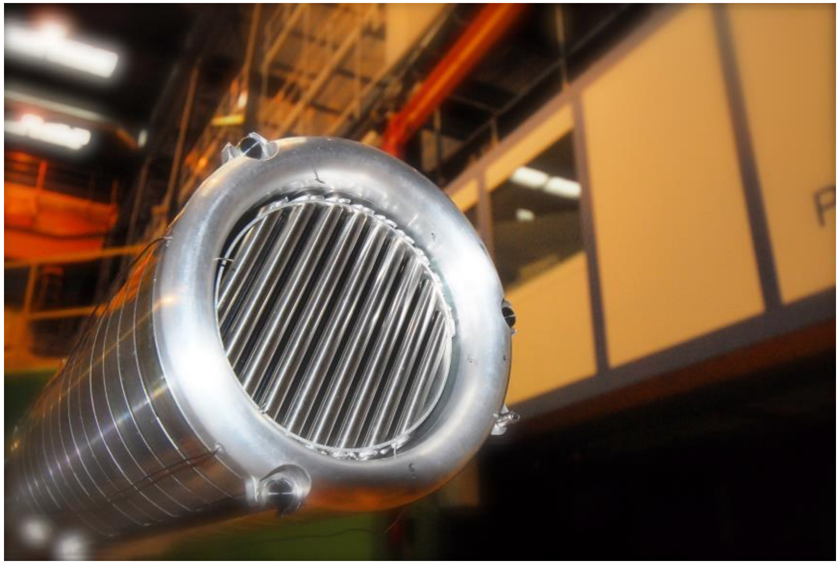
* no immediate damage at 70 μA/cm^2

Materials

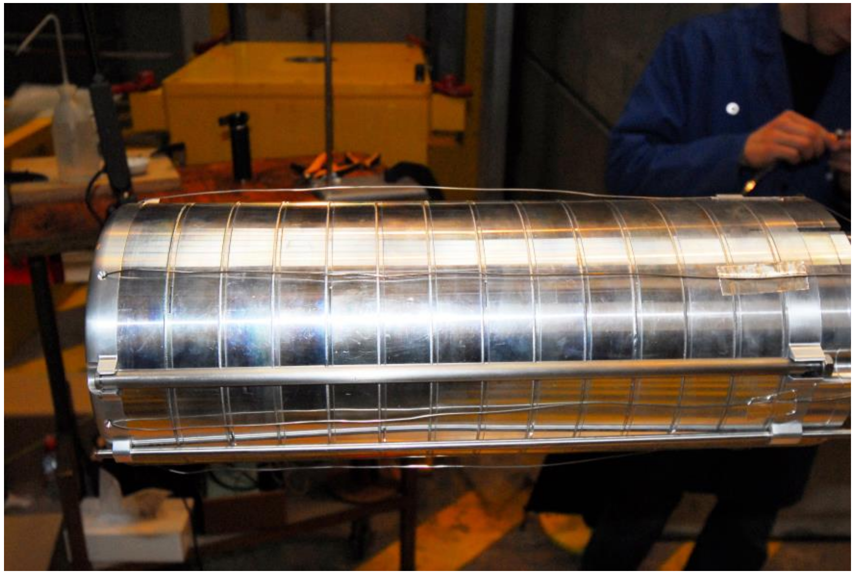
- Low neutron absorption cross sections (continuous, reactor-like source)
- Cladding material: Zircaloy II
- Main Target material: Pb (Sb-free)
- Blanket material: pure Al
- Safety Shroud: AlMg3
- Coolant: D_2O

SINQ MARK IV Target



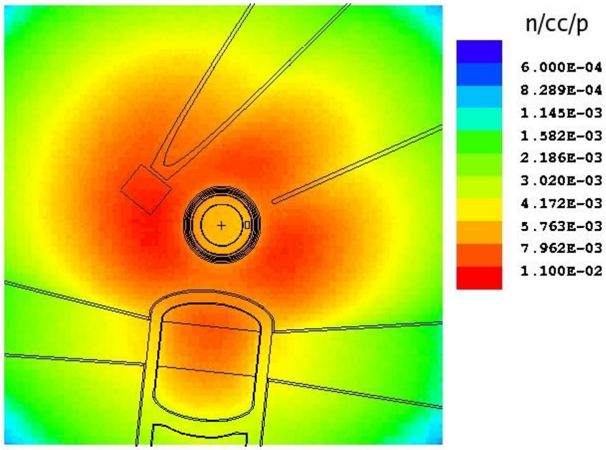


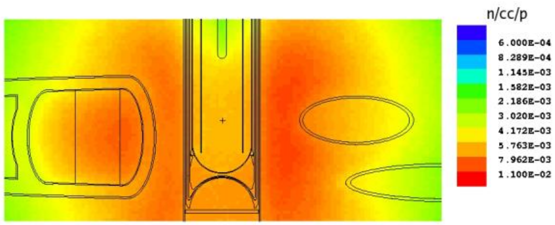
Up to now the targets have performed as predicted.
Currently investigations of on-line ‚health monitoring system' using TCs, vibration and acceleration sensors.



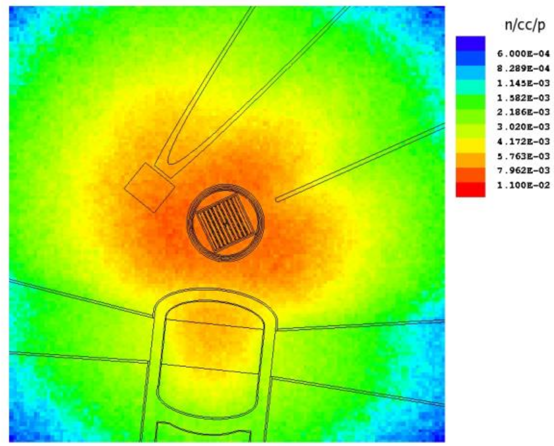
Neutronic Simulations

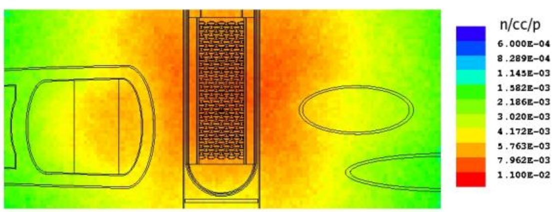
MEGAPIE



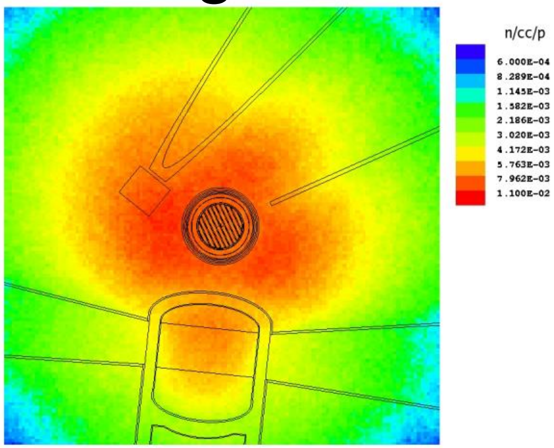


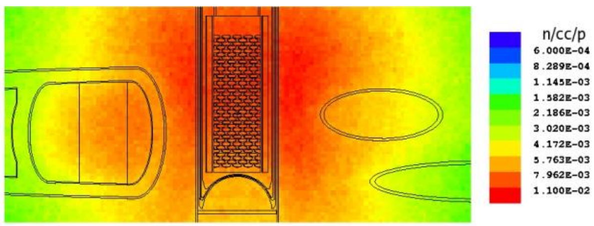
MARK III Target 7





MARK IV Target 8





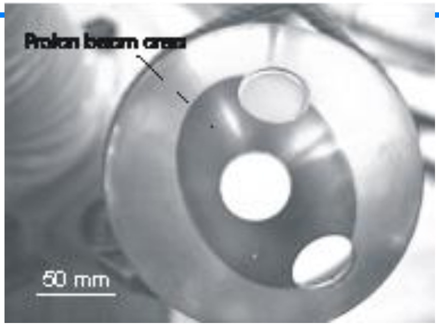
Simulated flux maps (MCNPX) of MEGAPIE, Target 7 (MARK III) and a MARK IV target

Simulated differences to Target 6 are: MEGAPIE (~1.80), Target 7 (1.20*), Target 8 (~ 1.60). *if STIP samples are included (1.10)

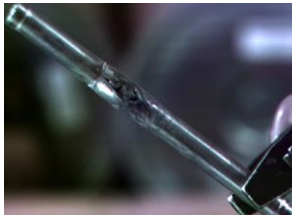
Lifetime, Damage & PIE

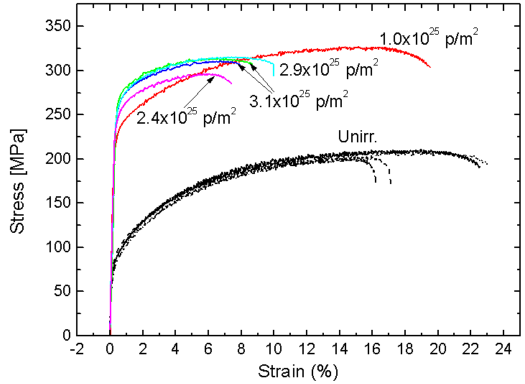
- Lifetime limiting component of SINQ target: AlMg3 safety shroud
  - Period of usage: limited to 2 years
  - Operation cycle (accumulated charge > 13 Ah):
    Beam on Target ~ April/May – Dec.
- Damage:
  - Embrittlement
  - Fatigue (due to interrupts / UCN)
- Failure of Cannellonis seldomn

AlMg3 BEW



Cannelloni Failure (T6)

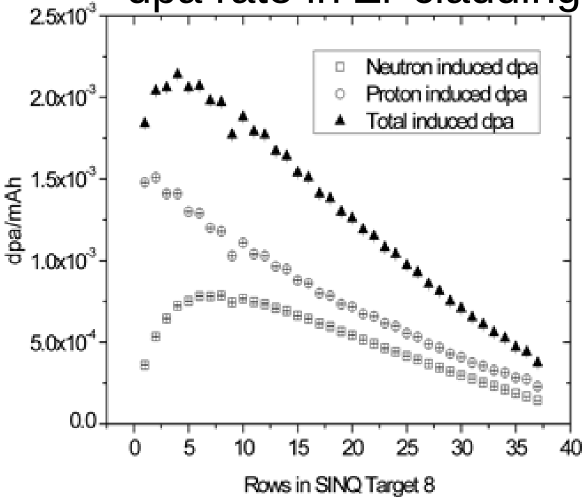




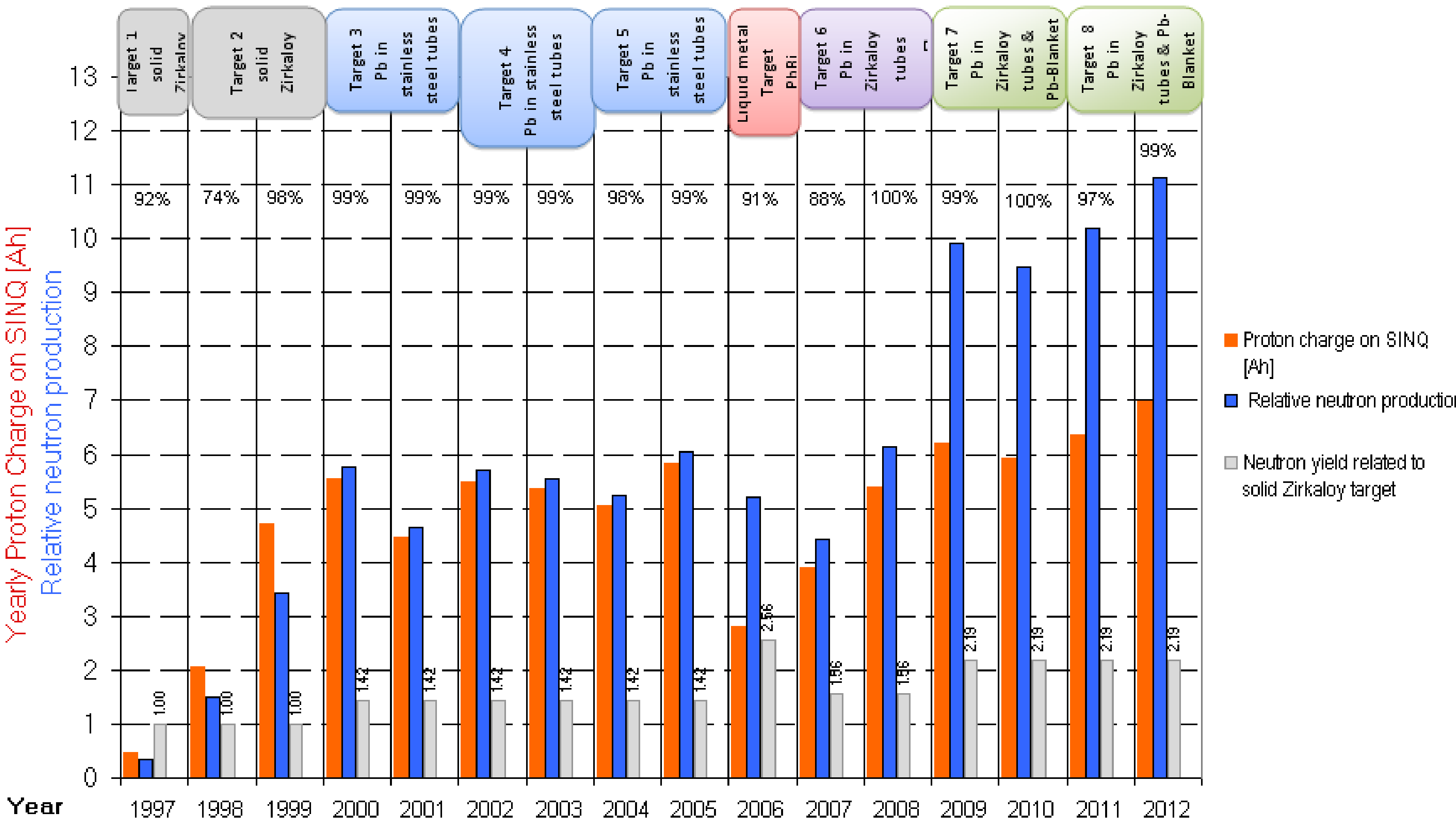
SINQ Target Irradiation Program (STIP)

- Miniaturized samples inserted into SINQ target(s)
- Position dependent damage rates
- Investigation after storage time (~ 2 years) & unpacking (complete remote handling)

dpa rate in Zr-cladding

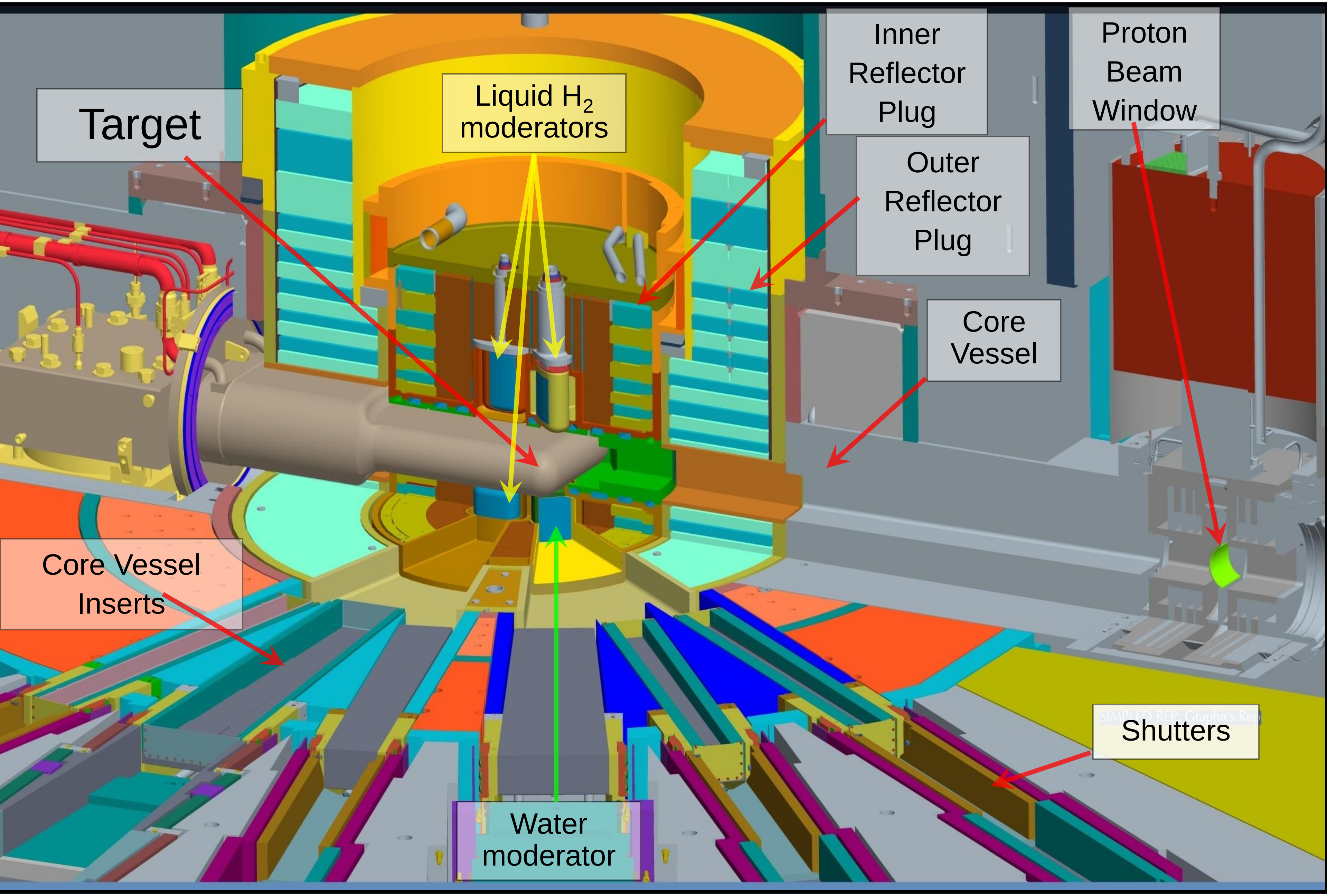


Operation Data of SINQ

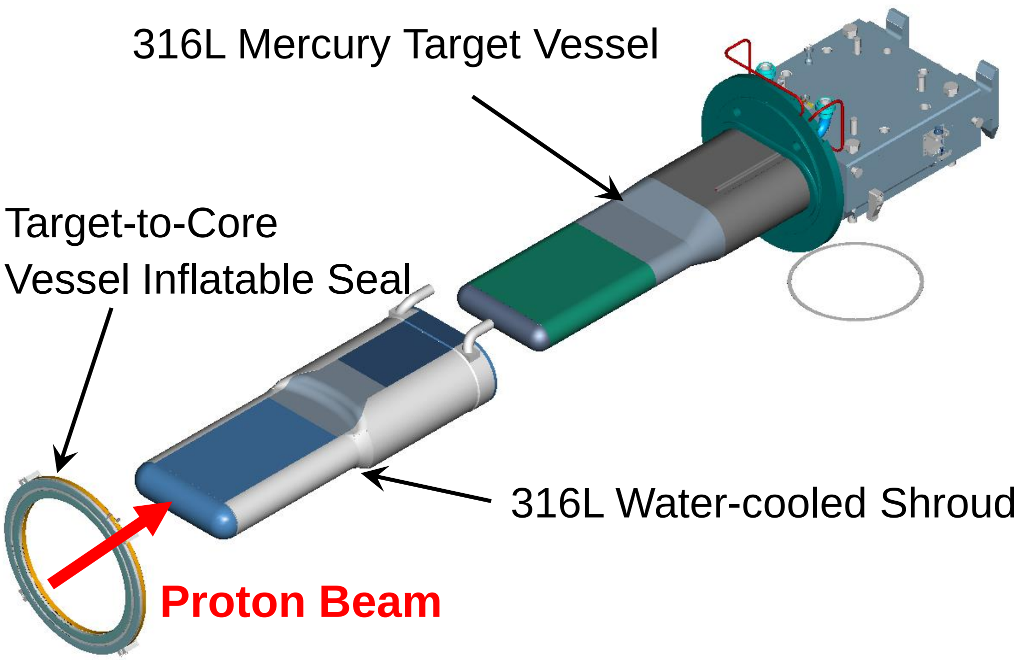


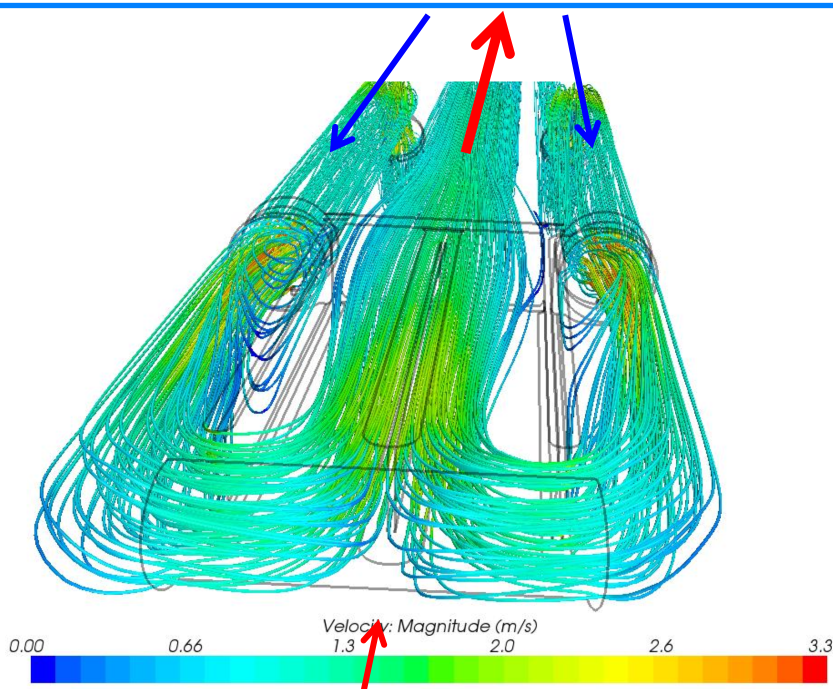
PAUL SCHERRER INSTITUT

Core of SNS target monolith

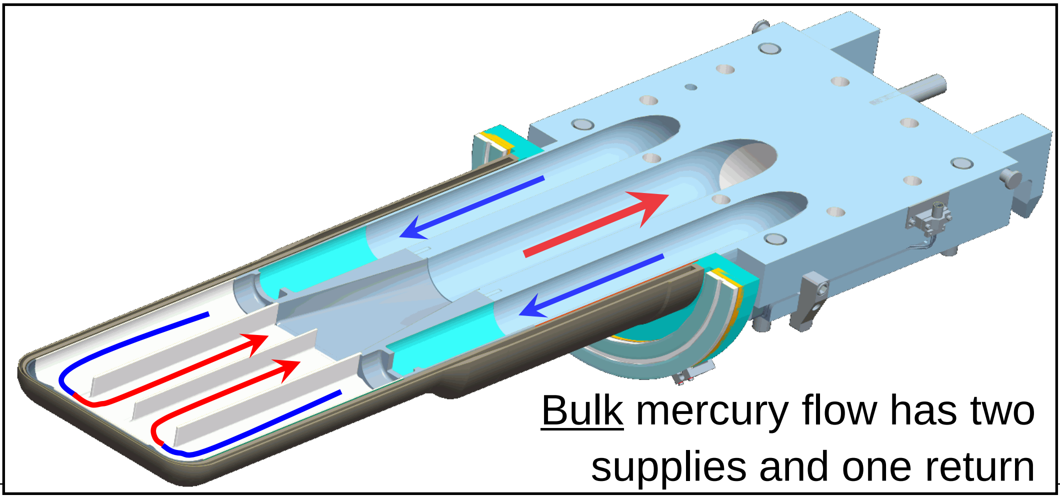


SNS Mercury Target Module

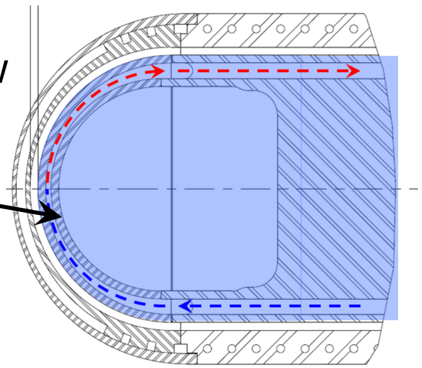




quasi-stagnation region at the center of the window



Channel Hg flow V_{max}: 2.4 ~ 3.5 m/s



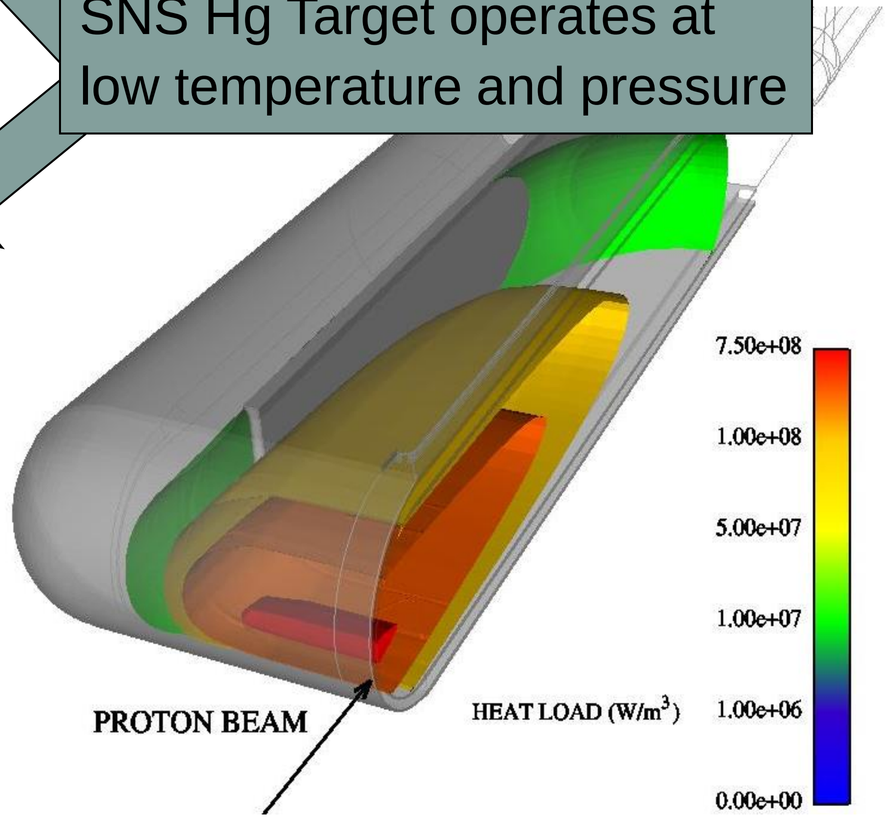
Mercury Loop Parameters @ 2 MW

Power absorbed in Hg	1.2 MW
Nom Op Pressure	0.3 MPa
Flow Rate	340 kg/s
V_{max} (In Window)	3.5 m/s
Temperature	
• Inlet to target	60ºC
• Exit from target	90ºC
Total Hg Inventory	1.4 m^3
Centrifugal Pump Power	30 kW

Peak power density in mercury ~ 800 MW/m^3 @ 2 MW

SNS Hg Target operates at low temperature and pressure

- Local pressure rise is 38 MPa (380 atm compared to static pressure of 3 atm!)*
- Mercury expansion and wave reflection at the vessel interface lead to tension in the mercury and cavitation

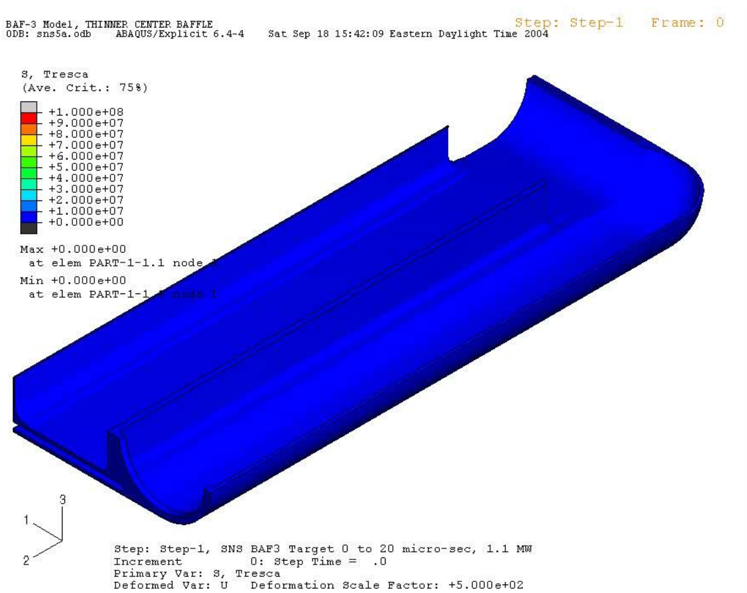


Pressure pulse effects on target vessel

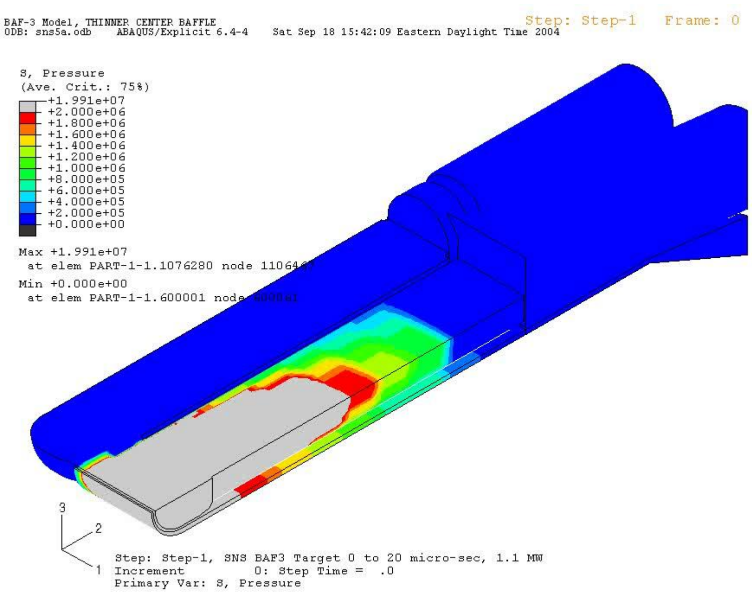
- Includes an empirical model for cavitation in mercury
- Benchmarked with Hg target test data obtain at LANSCE – WNR*
- Needed for estimating the fatigue life of the vessel

see B.W. Riemer / J. of Nuclear Mater. 343 (2005) 81–91

Vessel dynamic stress



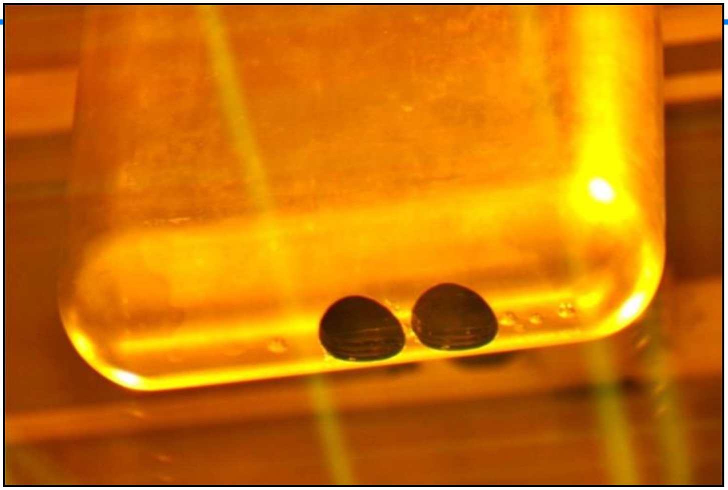
Mercury pressure evolution

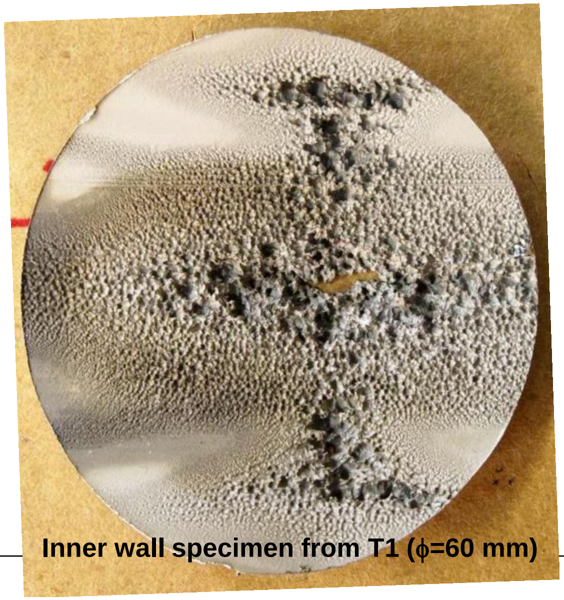


*LANSCE – WNR: Los Alamos Neutron Science Center – Weapons Neutron Research

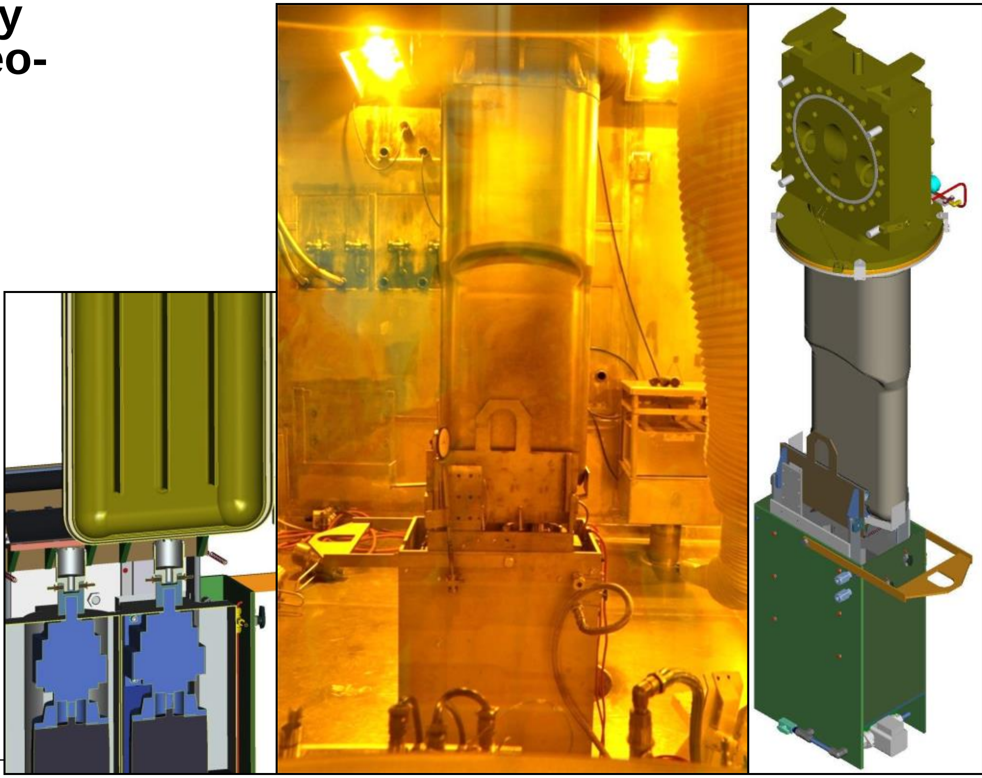
PIE of SNS Targets

- **Two to five cuts have been made in Targets 1-7**
  - **Remotely operated annular cutter**
- **Targets have been inspected using:**
  - **Through shield-window high-resolution photography**
  - **Direct photography of disk specimens**
  - **Internal examinations using security video cameras and articulating video-probes**





Inner wall specimen from T1 (ϕ=60 mm)

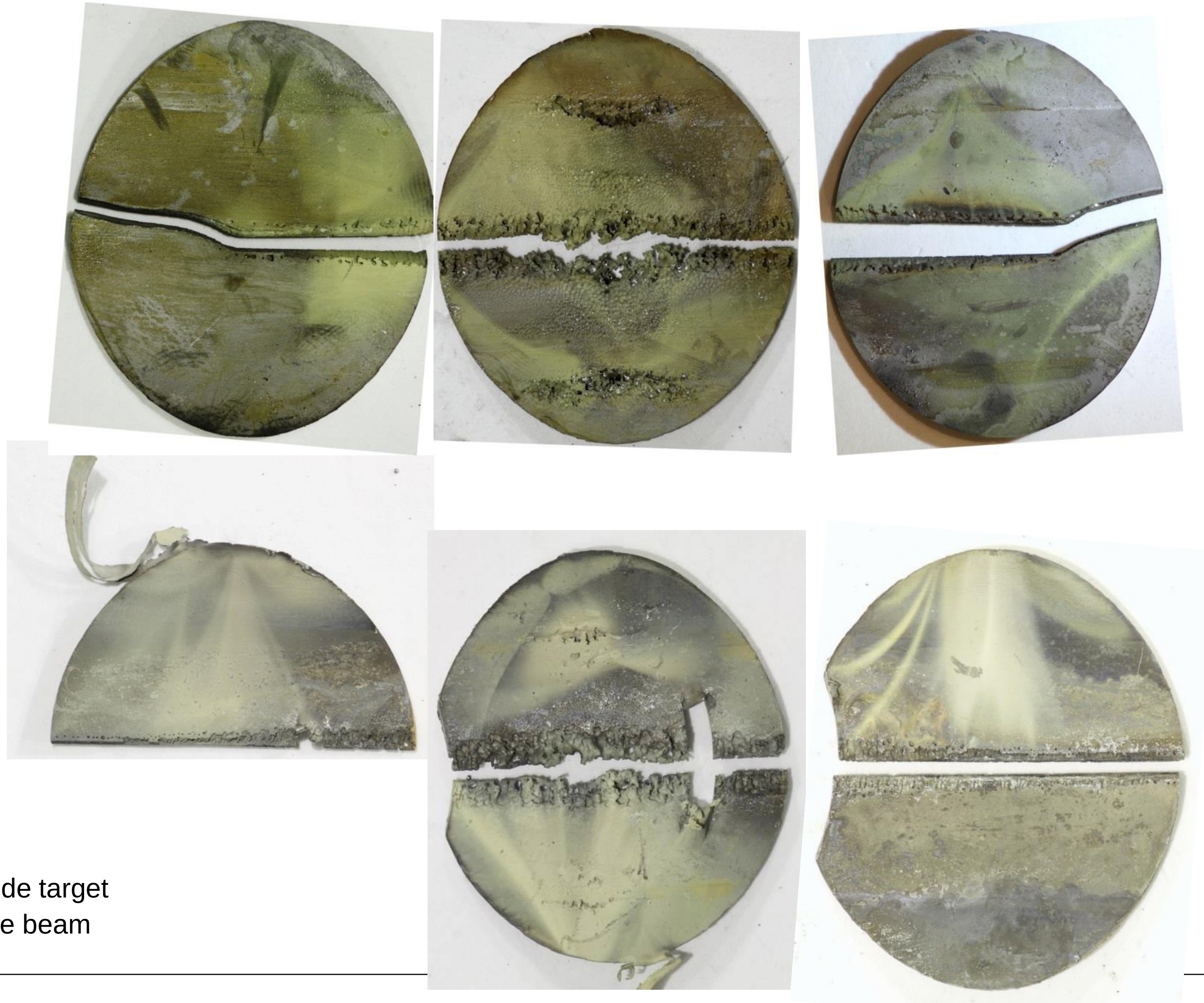


Cavitation-induced erosion on inner wall

Left offset | **Center** | **Right offset**

Target 4

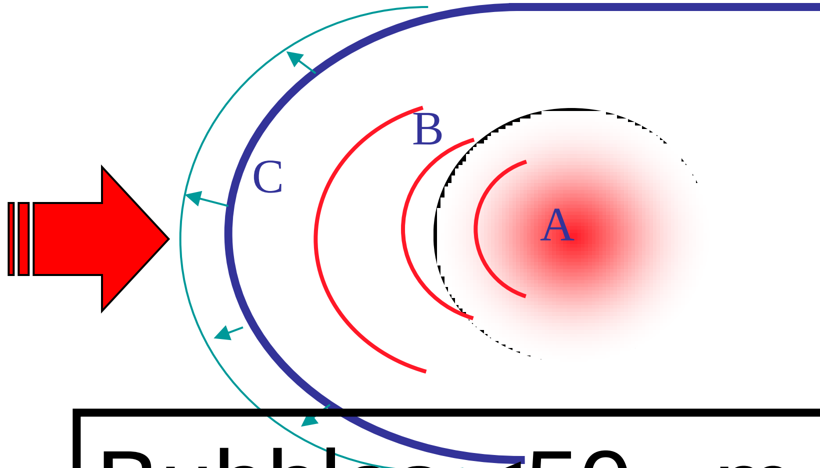
Target 5



View from inside target
looking into the beam

Bubble Injection to Mitigate Cavitation Damage

Close Collaboration between SNS & JSNS



3 mechanisms for each region

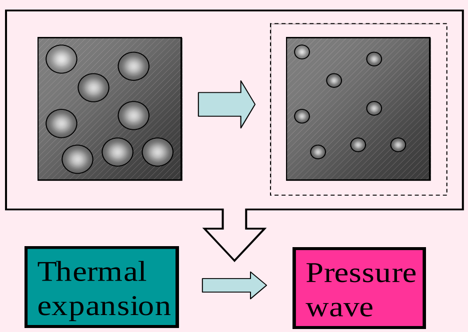
Center of thermal shock : A
Absorption

Propagation path : B
Attenuation

Negative pressure field : C
Suppression

Bubbles <50 μm

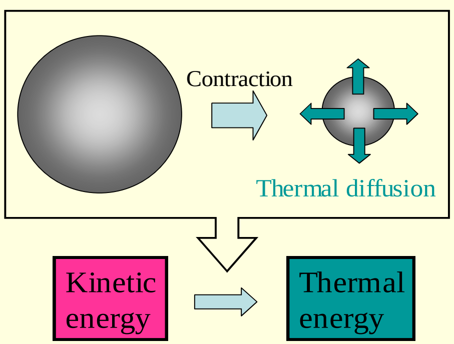
A



Absorption of the thermal expansion of mercury due to the contraction of micro bubbles

Absorption

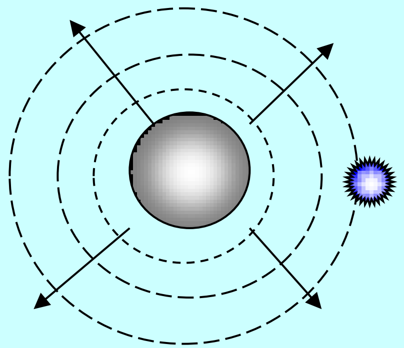
B



Attenuation of the pressure waves due to the thermal dissipation of kinetic energy

Attenuation

C



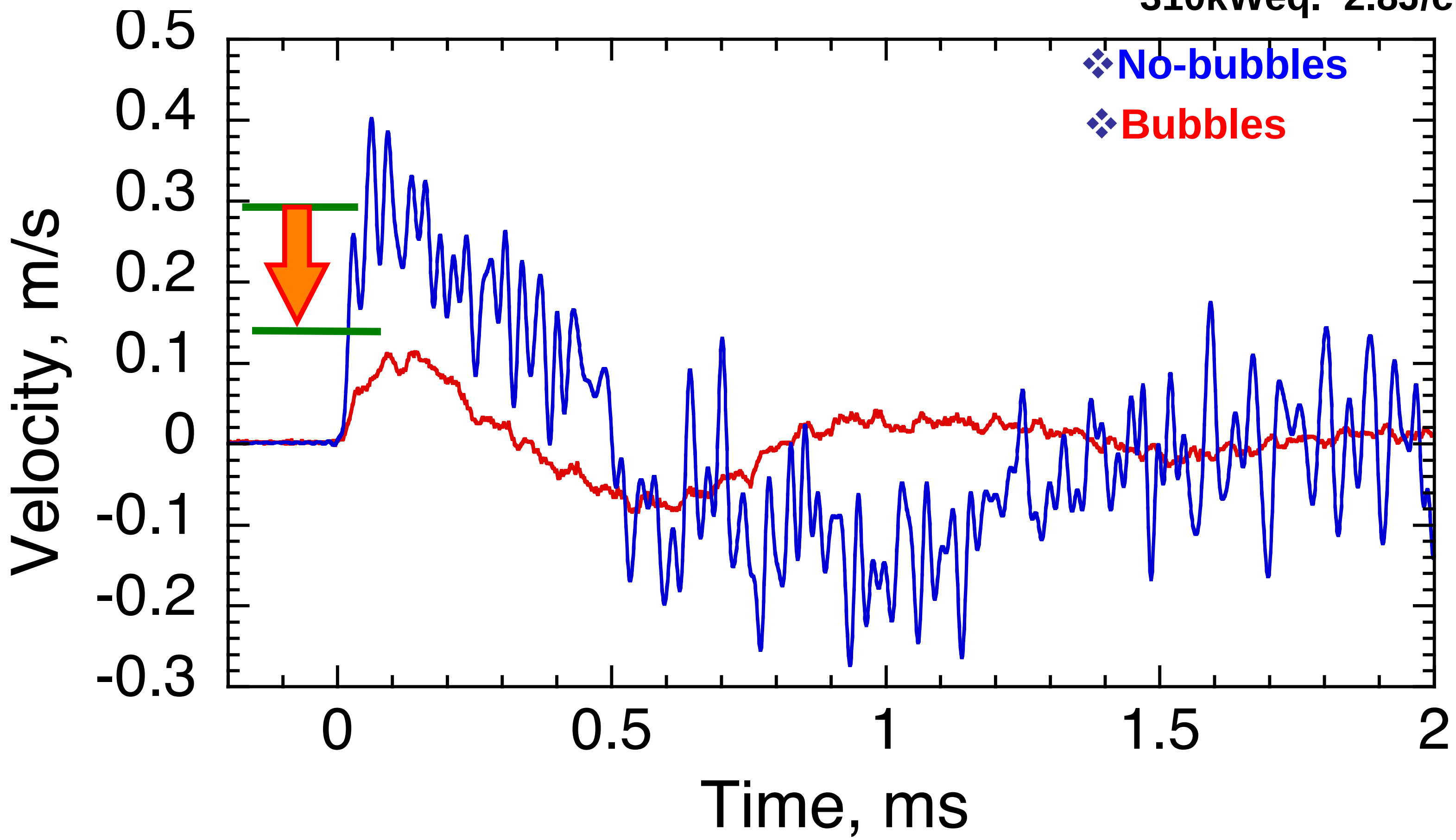
Suppression against cavitation bubble by compressive pressure emitted from gas-bubble expansion.

Suppression

Bubbling effect on vibration

Laser Doppler Vibrometer measurements at J-PARC (MLF) Target

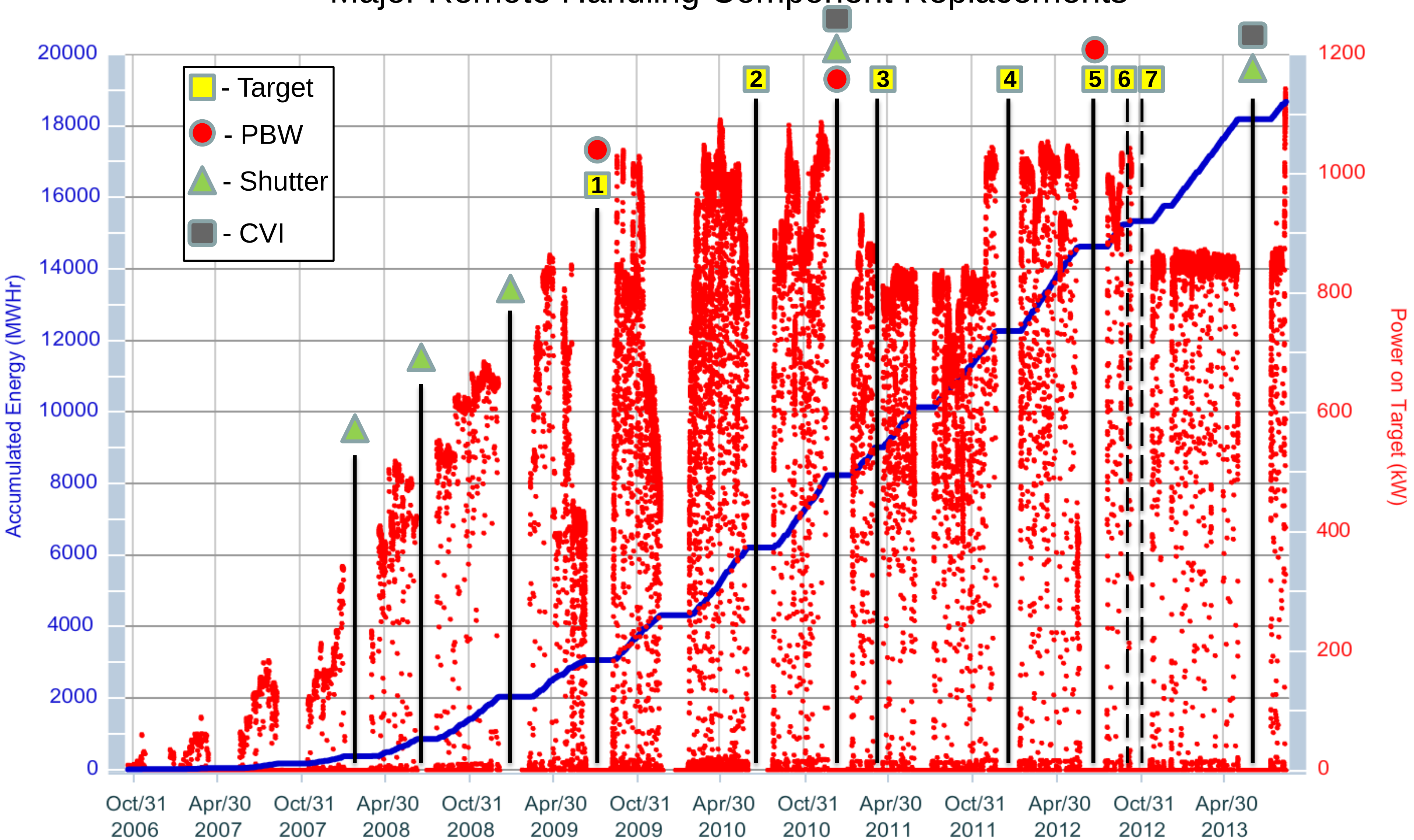
310kWeq. 2.8J/cm³/pulse



First peak is reduced; Same trends observed for the side wall vibration of the WNR experiment

Power on target & accumulated energy

Major Remote Handling Component Replacements



Acknowledgement

We would like to thank Ashraf Abdou, Michael Dayton, David McClintock and Mark Wendel from ORNL.

Moreover our thanks go to Werner Wagner, Kurt Geissmann, Frank Heinrich and the whole team of the PSI target development group.

Finally, ….

PAUL SCHERRER INSTITUT

PSI

Thank you for your attention.