PAUL SCHERRER INSTITUT

Design of Solid Spallation Targets at PSI

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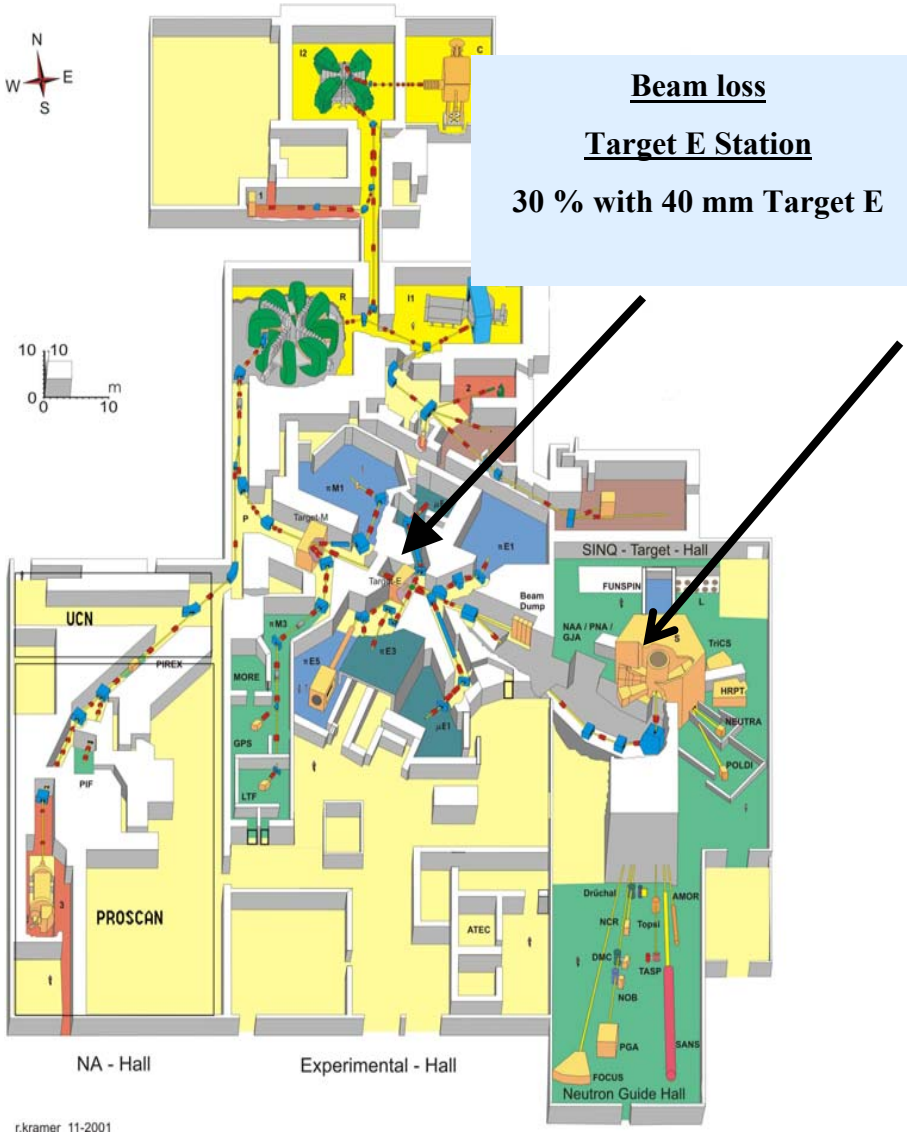
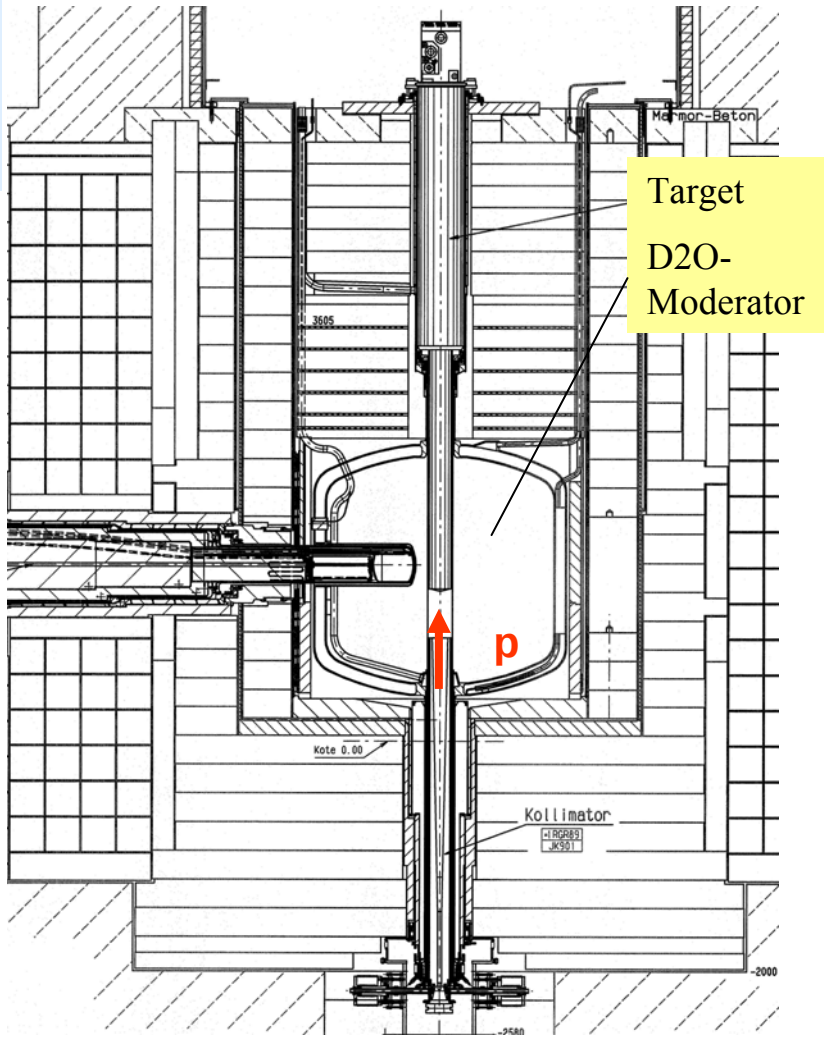
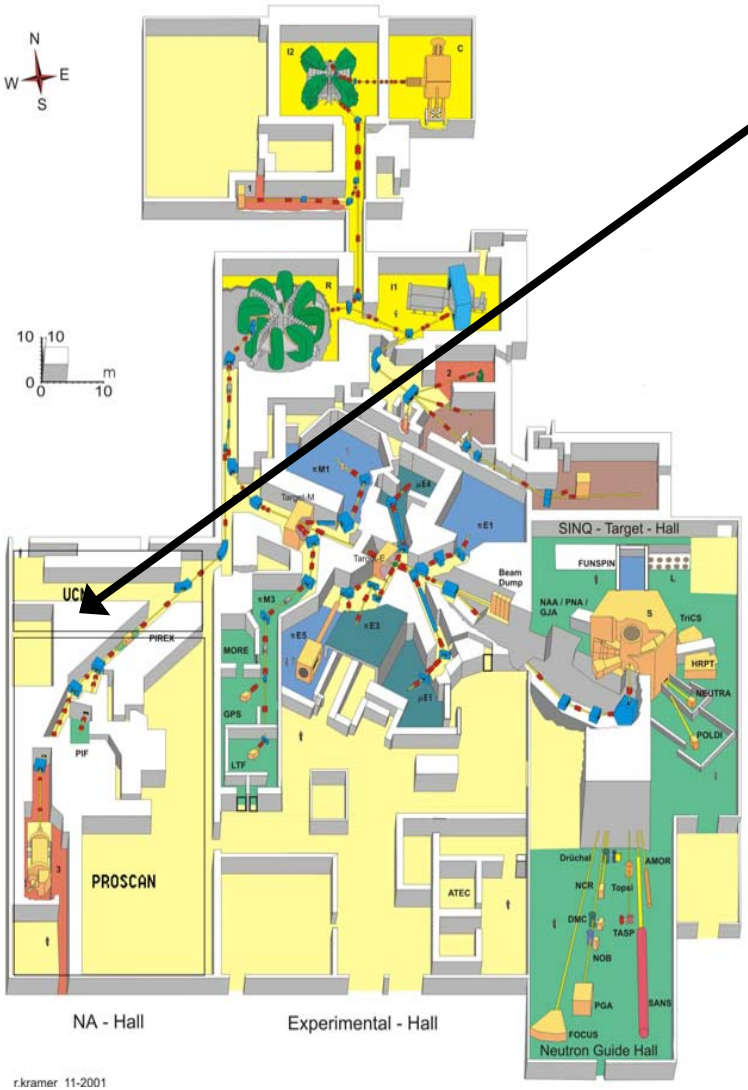
Neutron Spallation Sources at PSI (SINQ)



SINQ (DC-Operation) 570 MeV, 1.4 mA



Neutron Spallation Sources at PSI (UCN)



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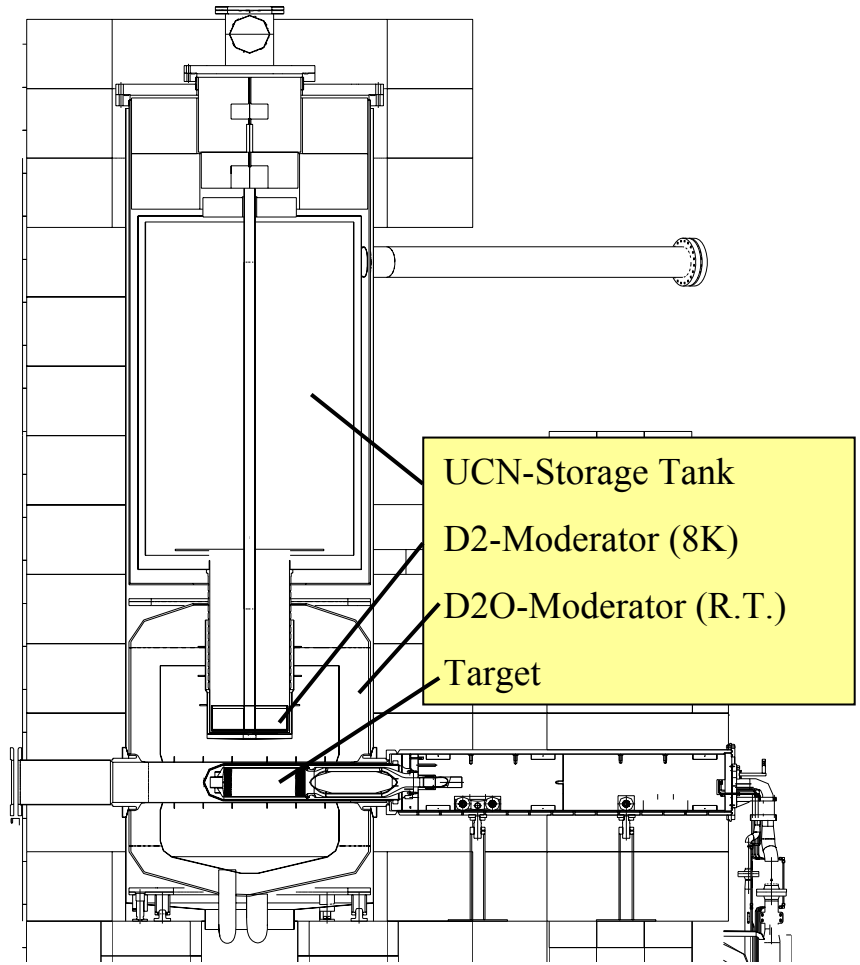
Ultra Cold Neutron Source UCN
(in construction) 590 MeV, 2 mA

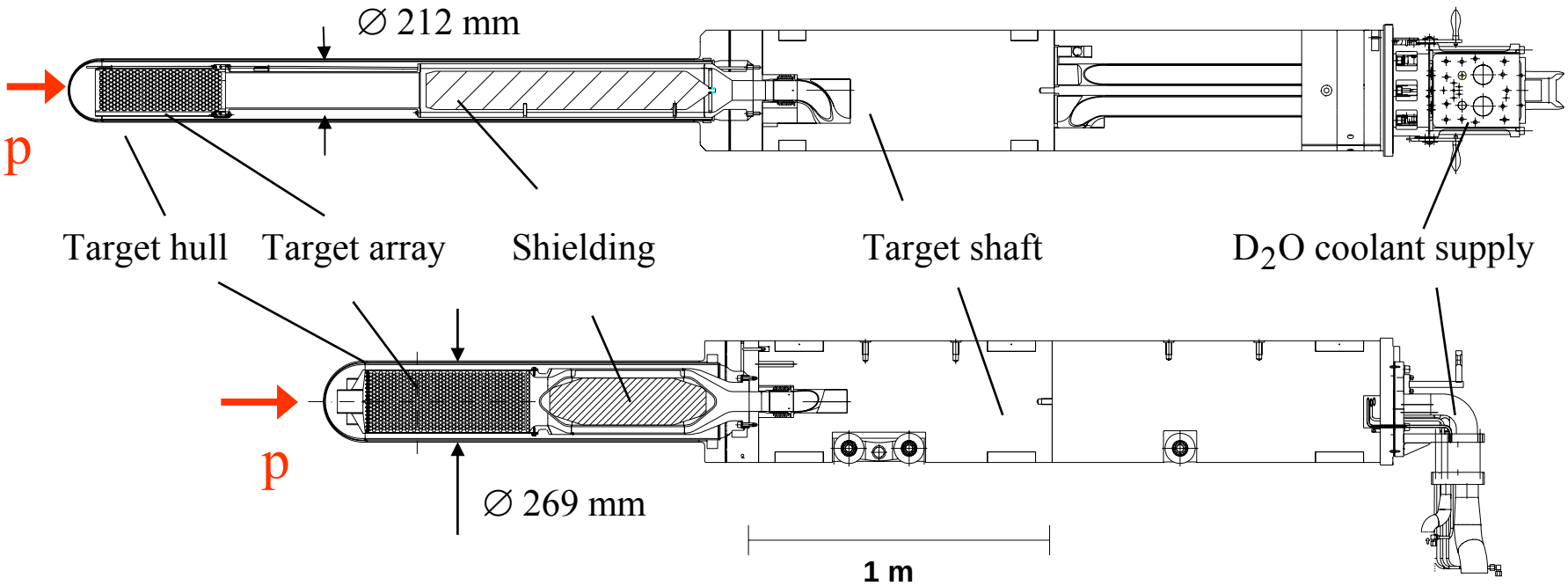


Layout of the SINQ & UCN Solid Targets

SINQ-Target:

Continuous operation: (1.4 mA 570 MeV)→ 0.8 MW beam power on target

Beam parameter: Gaussian beam spot (cut by collimator II); Peak current density ~35 μA/cm^2

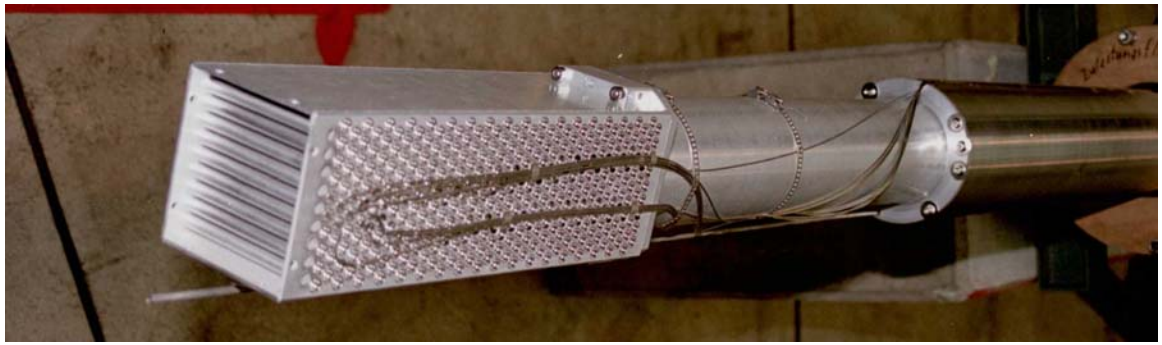


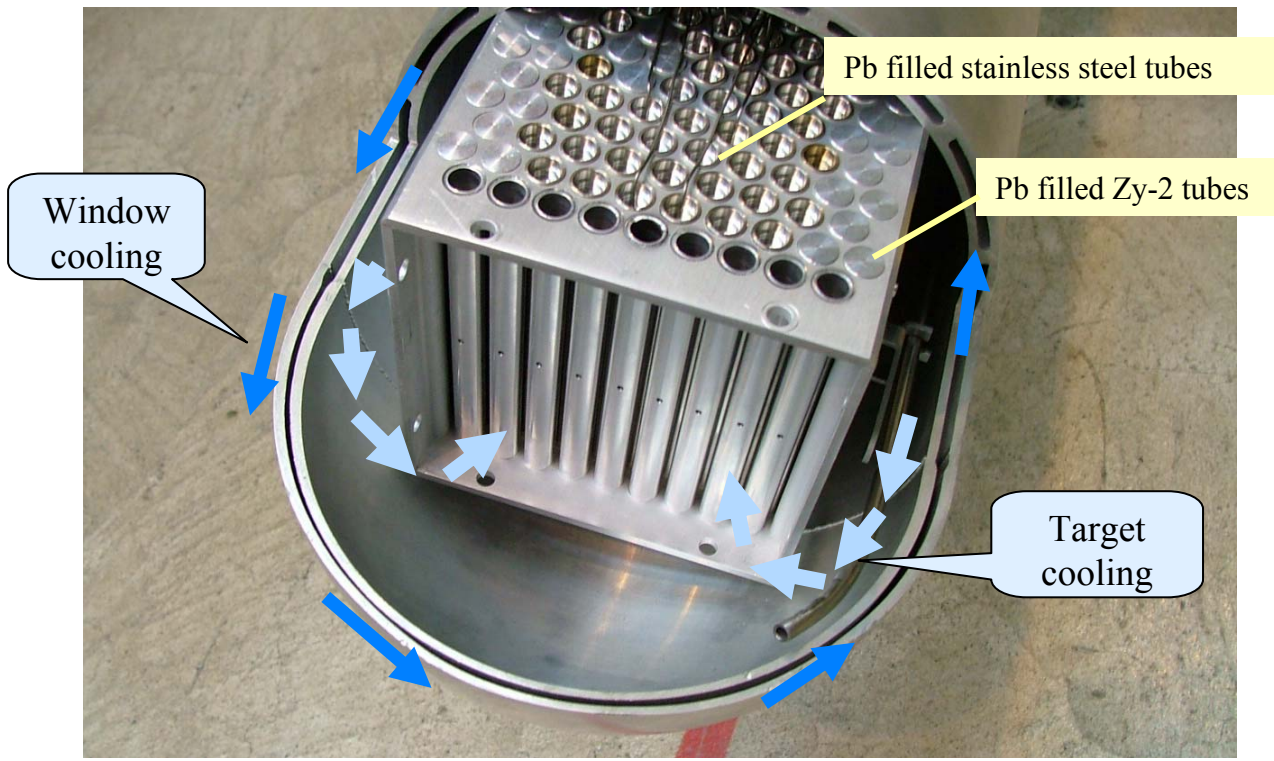
UCN-Target:

Pulsed operation: 8 seconds beam on (2 mA 590 MeV)→ 1.2 MW beam power on target; 1% duty cycle

Beam parameter: Gaussian beam spot (cut by collimator at R = 2.5 σ); Peak current density 20 μA/cm^2

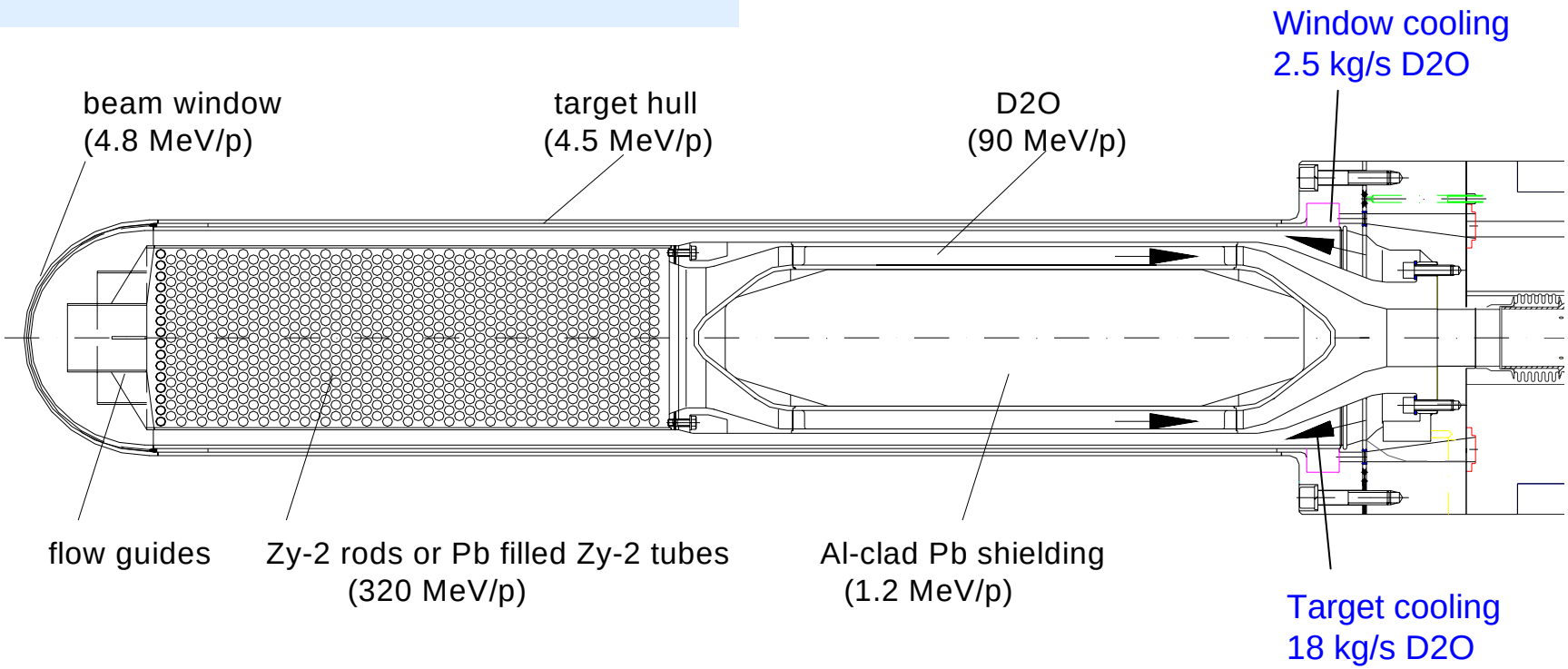
SINQ - Target




Pb filled stainless steel tubes
Pb filled Zy-2 tubes
Window cooling
Target cooling

UCN - Target

Power Deposition (590 MeV p-beam)



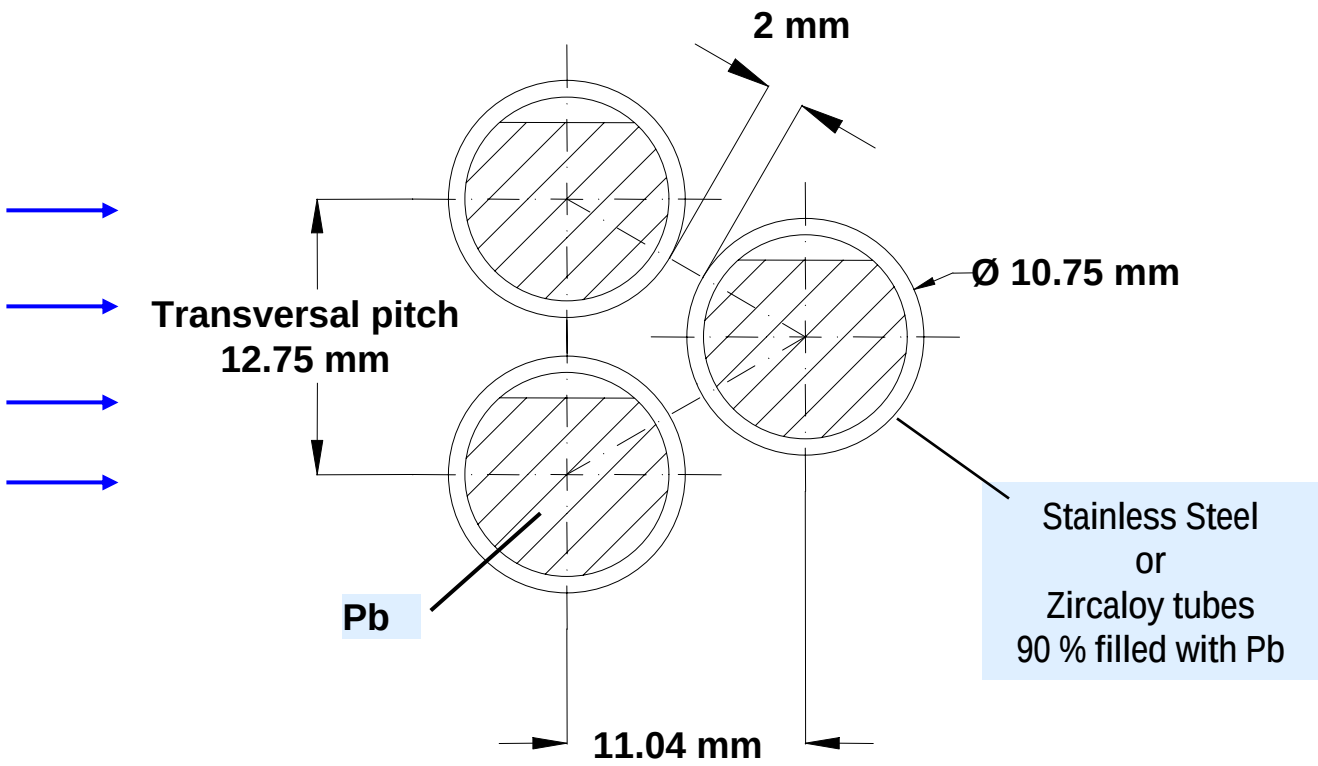
~70 % of the beam power deposited in the target assembly

Layout of the Target Array

V_{fluid} = 0.5 m/s

$\dot{dm}/dF$ = 500 kg/s/m²

Tb = 40°C



Target array options:	**SINQ:**	**UCN:**
I. solid Zircaloy rods	**1996/98**	
II. Pb filled Stainless Steel tubes	**1999/2005**	
III. Pb filled Zircaloy tubes	**2004/2005**	**> 2007**

Neutronic Performance

Relative thermal flux gain	Zy-2 rods (64.5% Zr, 35.5% D2O)	Pb-SS304-Cladding (48% Pb, 11.5% SS304, 34.9% D2O, 5.6% Void)	Pb-Zy2-Cladding (42.9% Pb, 16.7%Zr, 35.5% D2O, 4.9% Void)
UCN [1)]	1.00 *)	1.38	1.61
SINQ [2)]	1.00 *)	1.42	1.63 **)

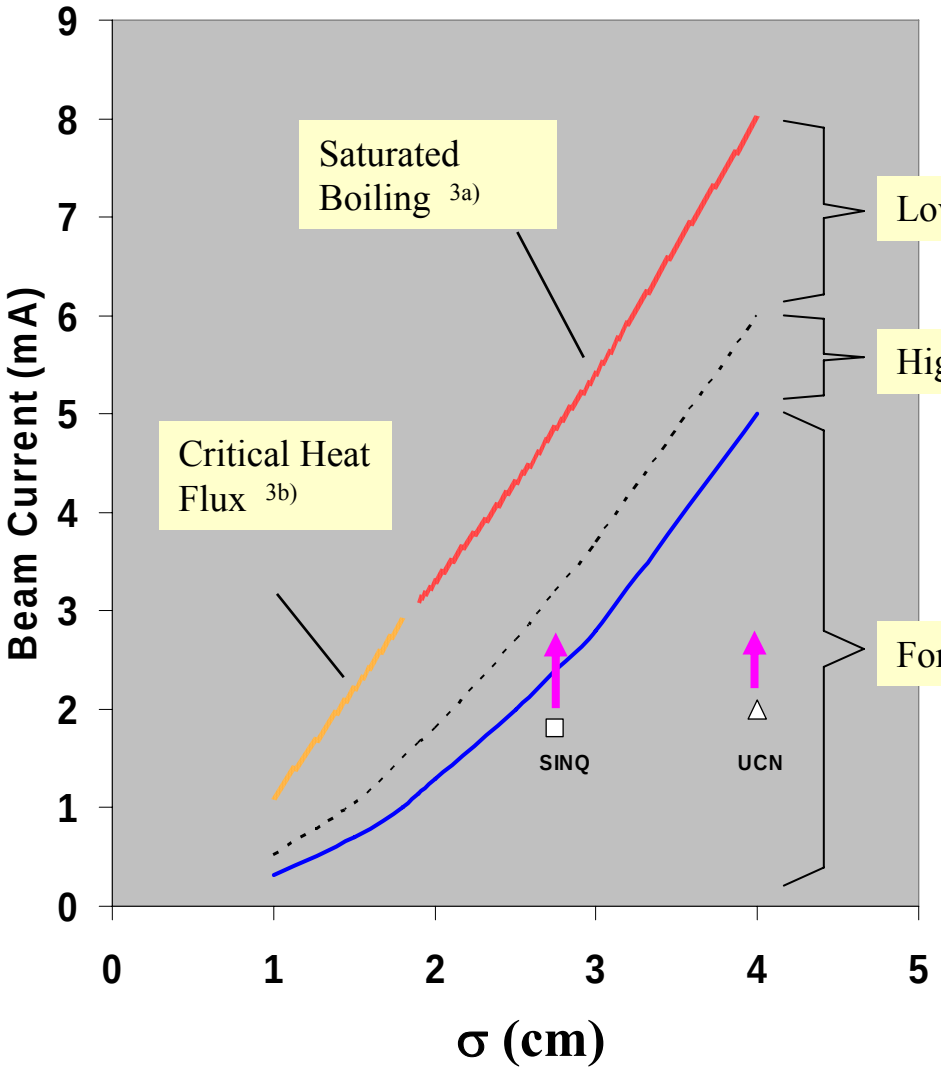
*) ~ $4.5 \cdot 10^{13}$ n/cm^2/s/mA

**) ~ 20 % flux gain for MEGAPIE

1) M. Wohlmuther, G. Heidenreich *Design and neutronic performance of the spallation target of the ultra-cold neutron source UCN at PSI*, ICANS-XVII, April 25-29, 2005 Santa Fe, New Mexico

2) E.J. Pitcher, J.R. Lebenhaft, E.H. Lehmann, *An Investigation of Neutron Spallation Targets in SINQ using MCNPX*, ICANS-XVI, Proceedings of ICANS-XVI, Düsseldorf-Neuss, Germany May 12-15, Vol. III, p.1191, ISSN 1433-559X (2003).

Thermo-hydraulic operating regime of the target array



V_{fluid} = 0.5 m/s

$\dot{m}/dF$ = 500 kg/s/m^2

p = 0.5 Mpa

T_{sat} = 150 °C

T_{bulk} = 40 °C

σ : Standard deviation of the Gaussian distributed beam

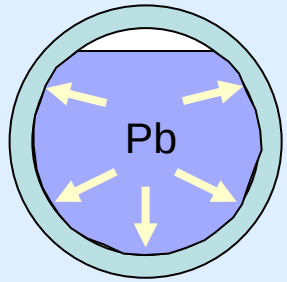
1) V. Gnielinski, VDI-Wärmeatlas,1998

2) M.M. Shah, Int. J. Heat and Fluid Flow Vol.5, No. 1,1984.

3a) M.Z. Hazan et al., J.Heat Trans. 103, 478 (1981).

3b) H.J. Ivey , D.J. Morris, UKAEA, AEEW-R137,1962.

Thermo-mechanical design of the Pb-filled tubes for pulsed operation in the UCN-target



Design steps:

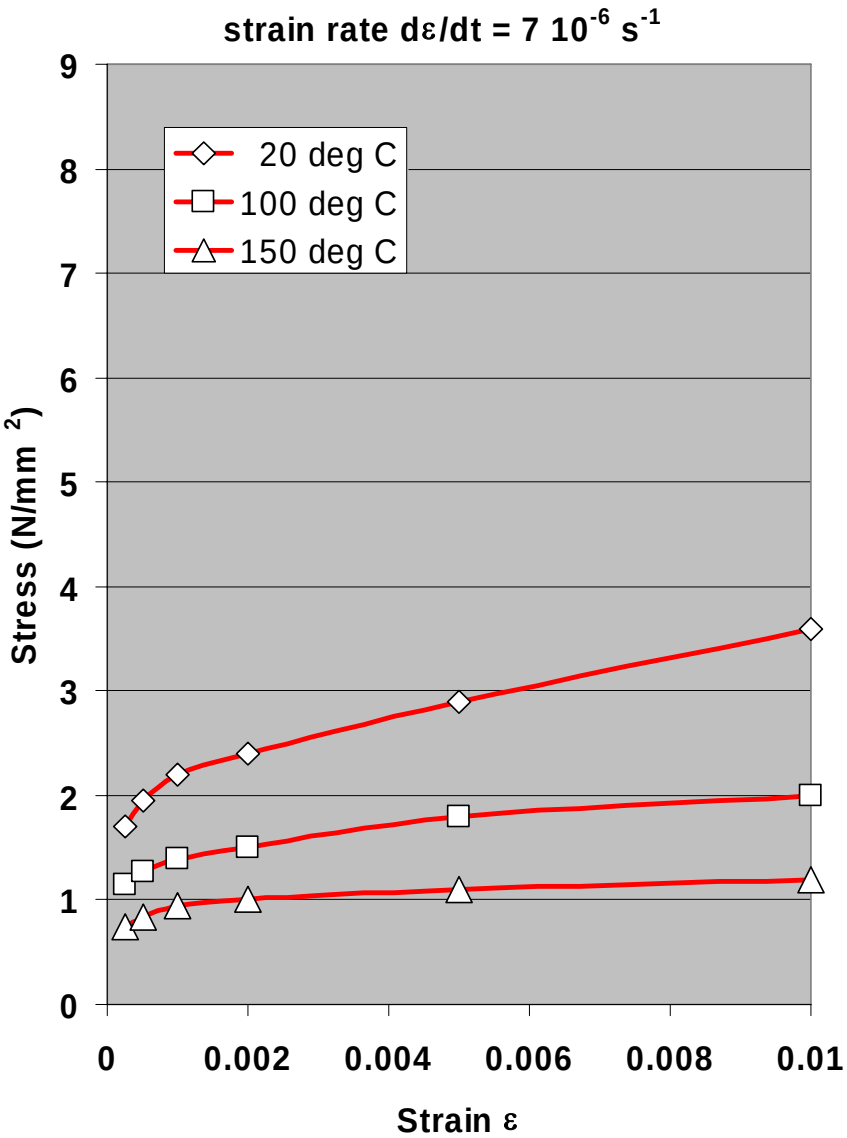
- Measurement of stress-strain relation of Pb

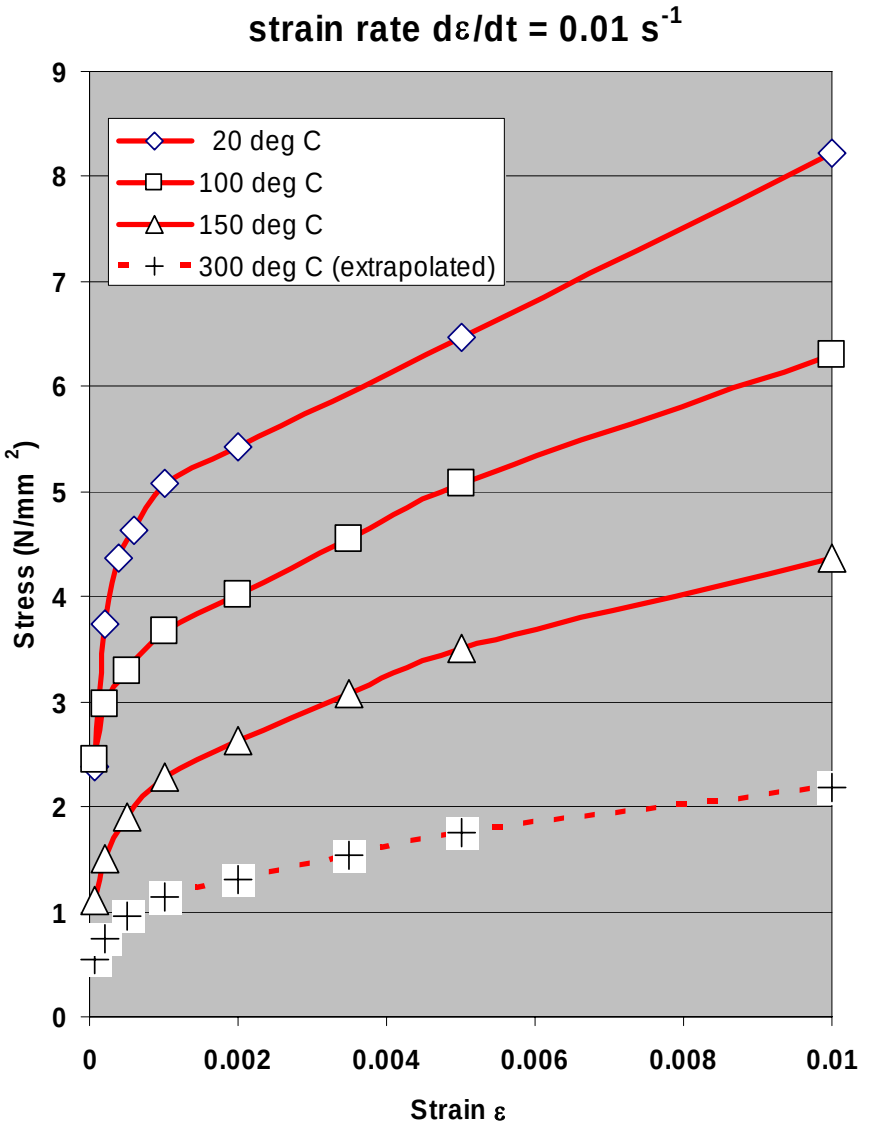
  $\Rightarrow \quad \sigma = f(T, d\varepsilon/dt)$

- Calculation of temperature response of Pb

- Calculation of stress response in the tube wall

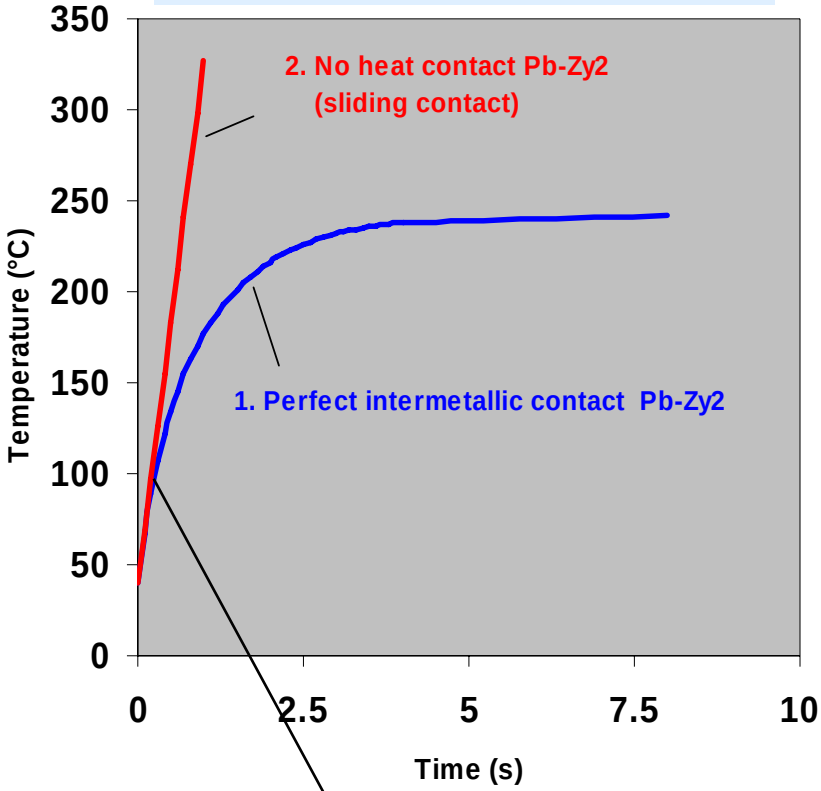
Measured stress-strain relations of Pb





Temperature & stress response due to the heat load by the proton pulse (peak current density 20 μA/cm²)

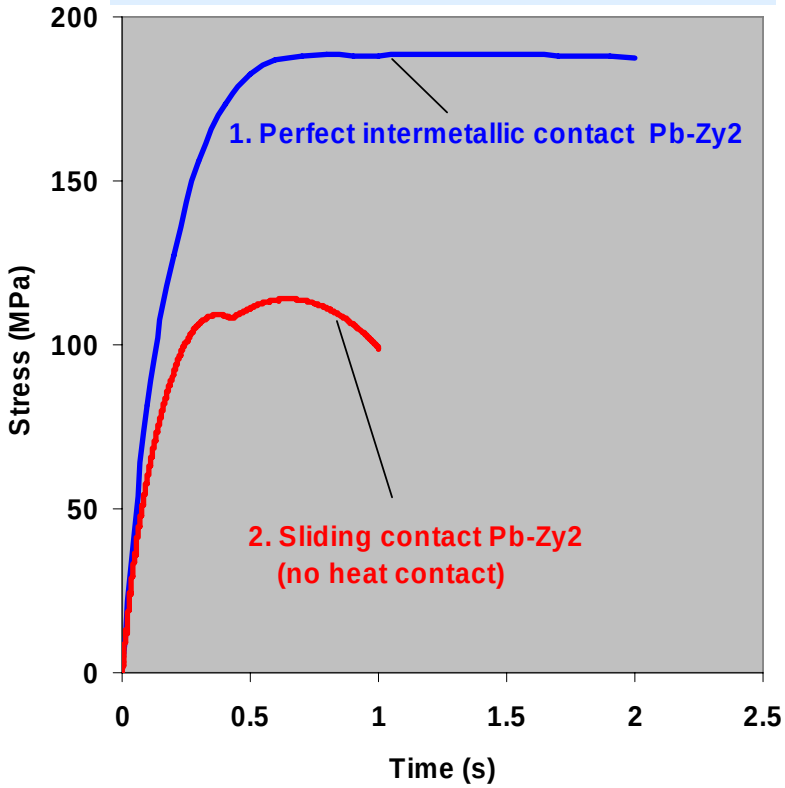
Temperature response of Pb



dT/dt = 300°C/s

⇒ strain rate: $d\varepsilon/dt = \alpha \cdot dT/dt = 0.01\ s^{-1}$

Stress response of Zy-2 cladding

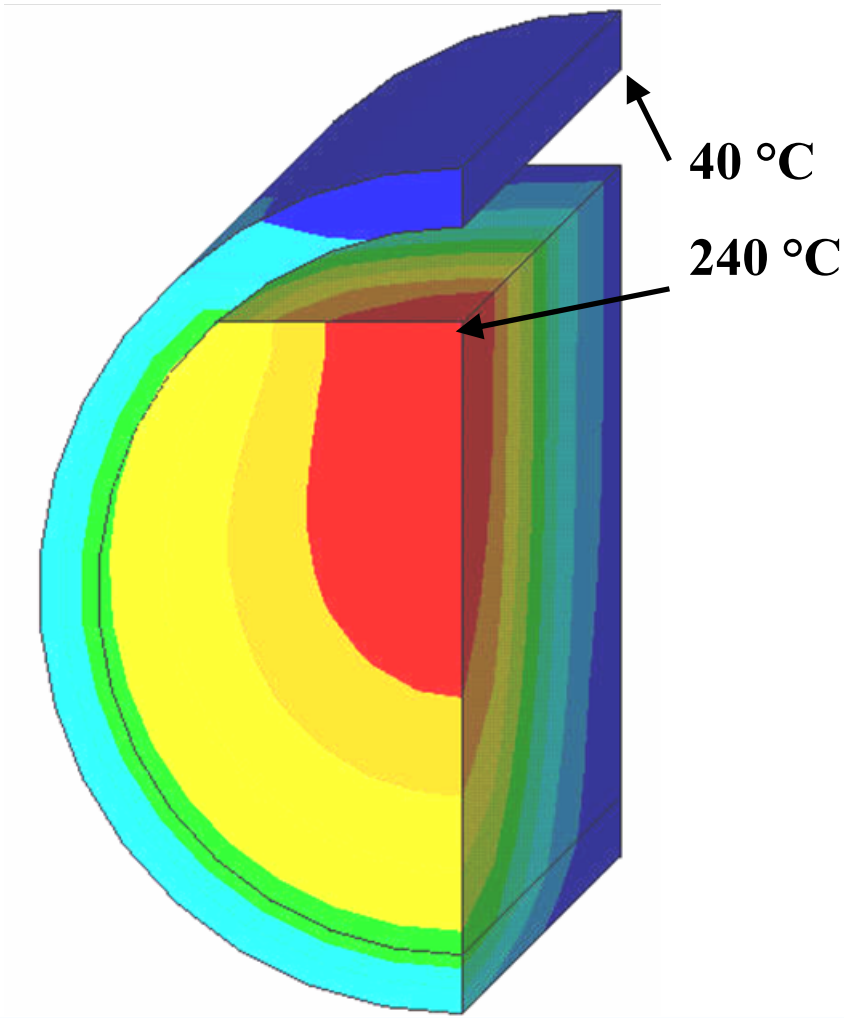


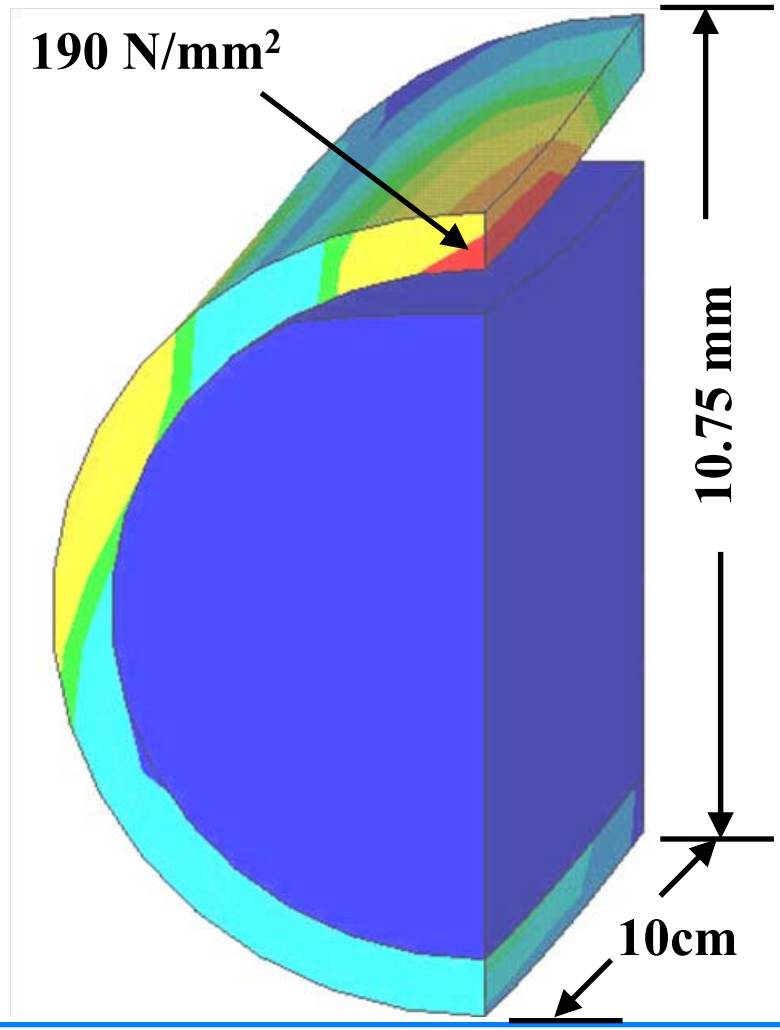
Fatigue limit(10^6 cycles) of Zy-2 :

⇒ **235 N/mm² (20 °C)**

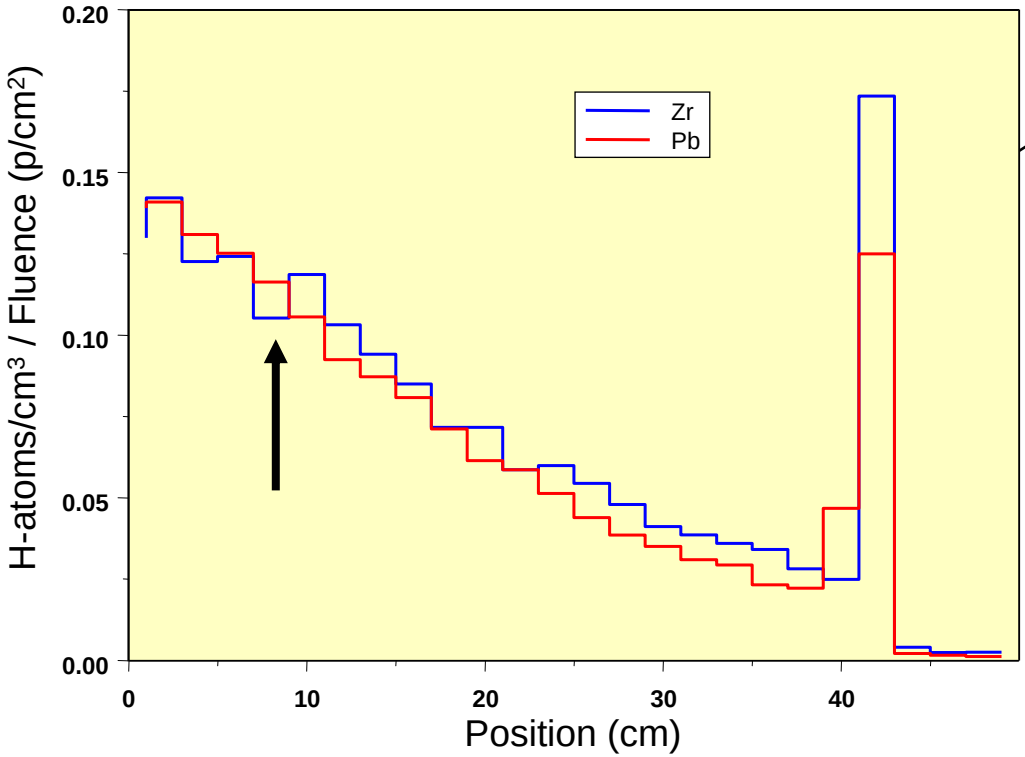
K.U. Snowden et al., J. Nucl. Mat. 67,p.215, 1977.

Temperature & stress distribution





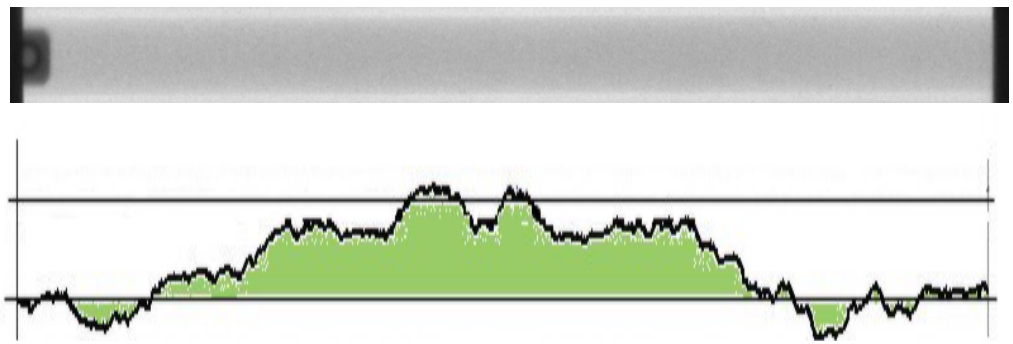
Hydrogen production in the target array



LAHET Calculation :

Peak values for Pb-filled Zr-tubes **per year (10 Ah)**:

UCN: ~ 3 wppm
SINQ: ~ 500 wppm



Neutron Radiography Method *):

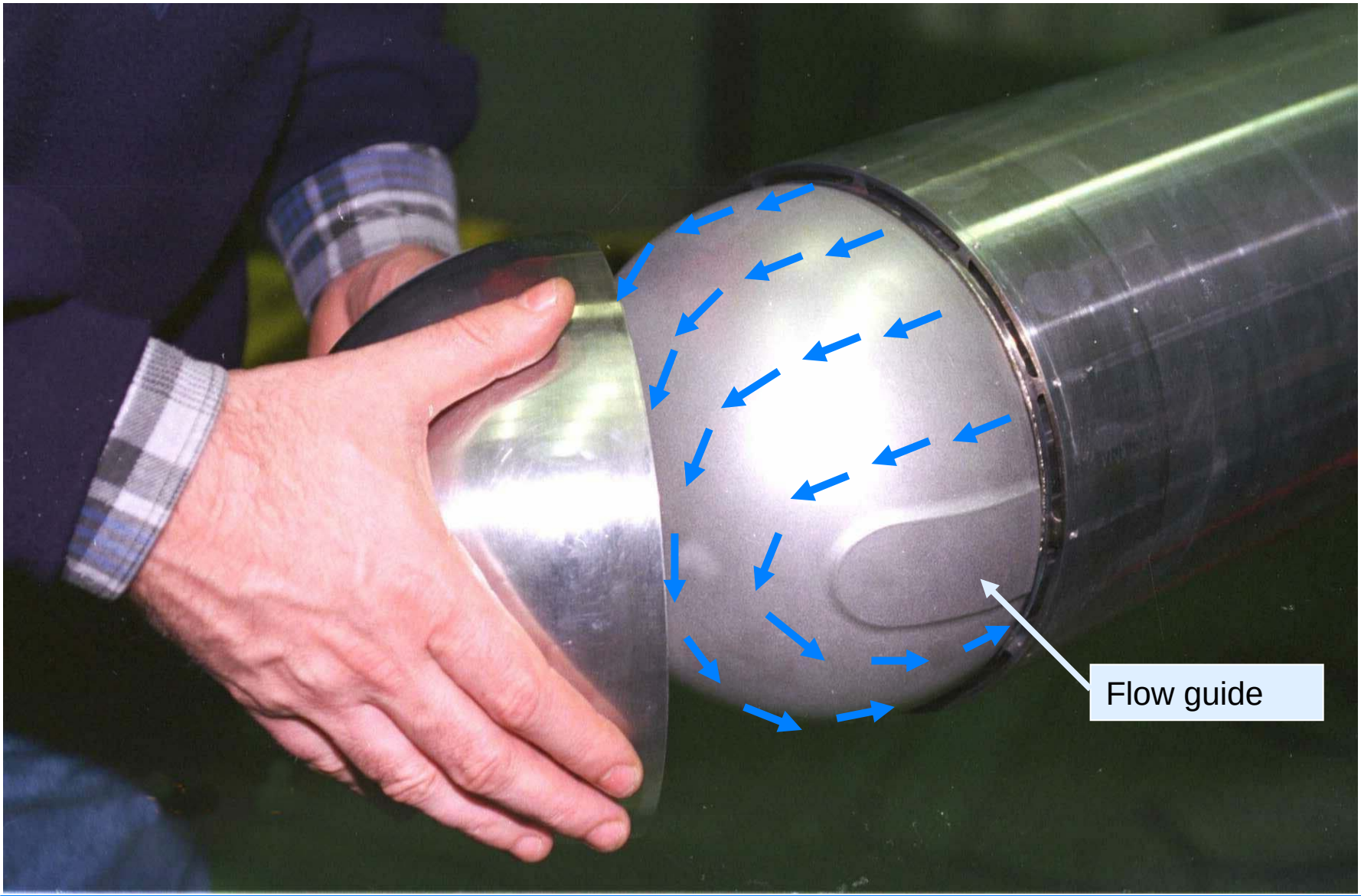
Measured peak value of hydrogen content for a Zr-rod irradiated at position 8 cm in SINQ.

~ 70 wppm H / $3 \cdot 10^{21}$ p/cm²

⇒ 0.1 (atoms/cm³) / (p/cm²)

*) E. Lehmann, PSI

Beam window design

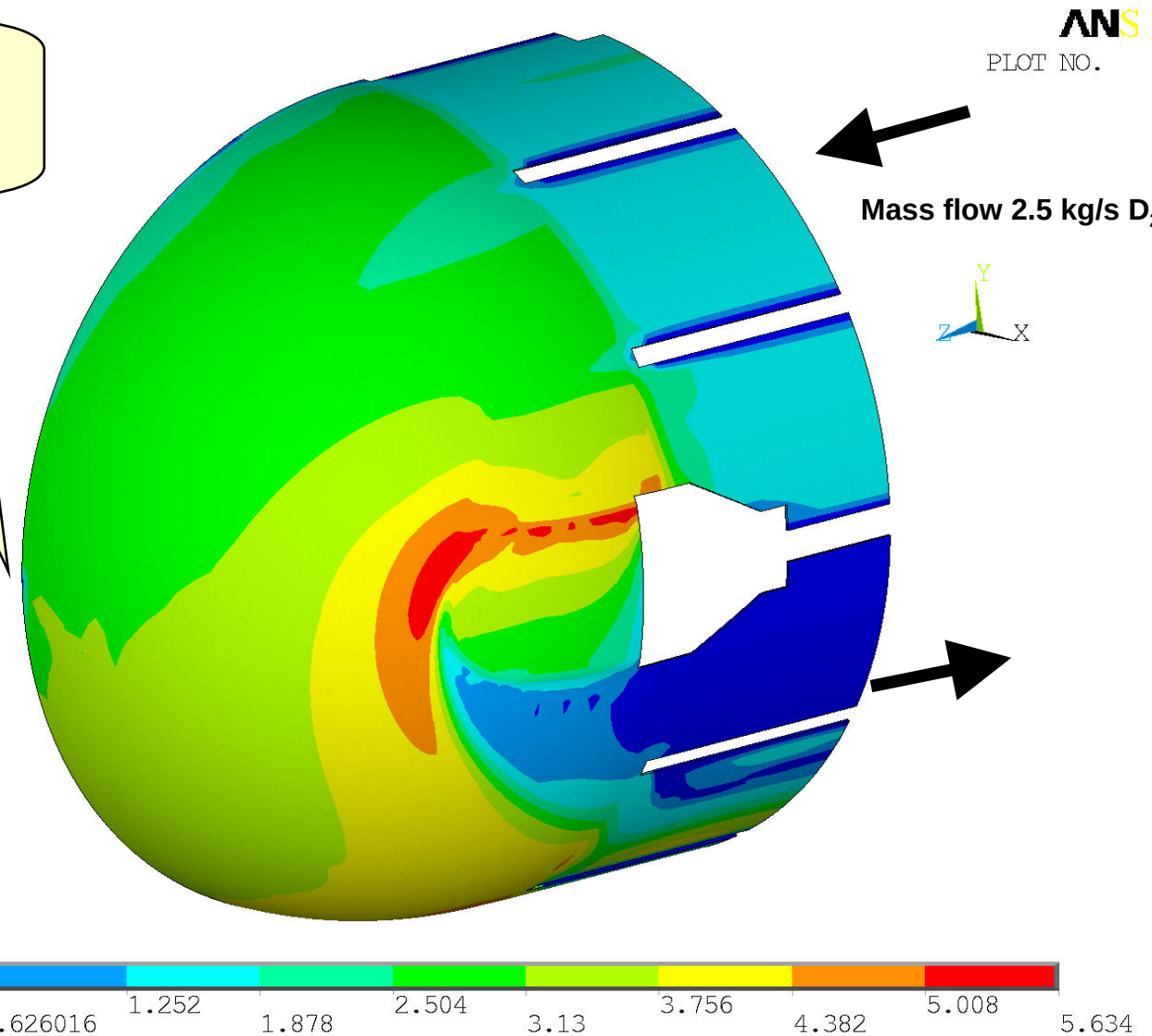


CFD - Analysis

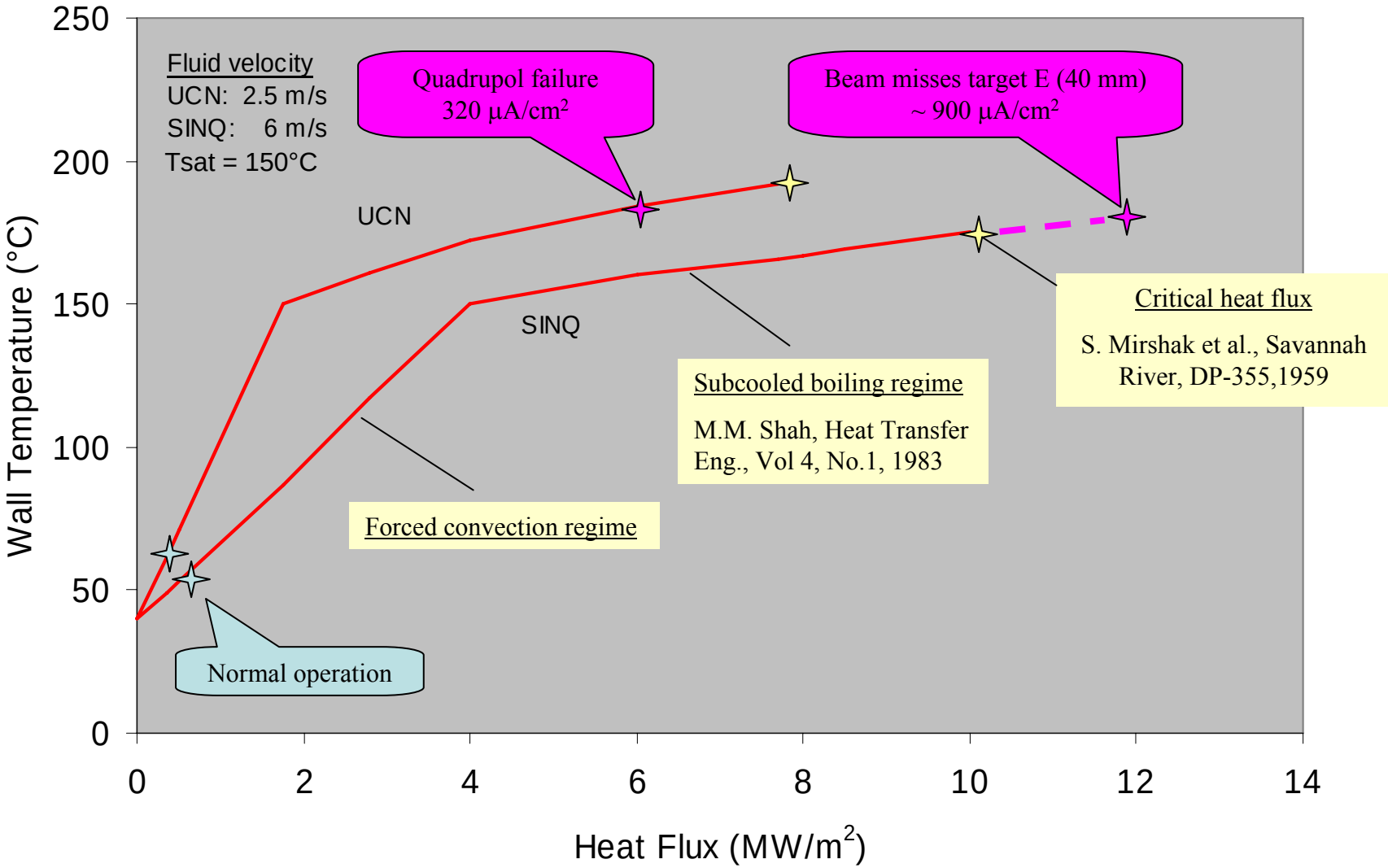
Fluid velocity at window center

UCN : 2.5 m/s

SINQ : 6 m/s



Thermo-hydraulic operating regimes of the UCN and SINQ window



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Thank you for your attention !