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High Power Targets for Accelerator Applications

G.S. Bauer
Forschungszentrum Jülich, Germany
g.bauer@ill.fr

High Power Accelerator Applications

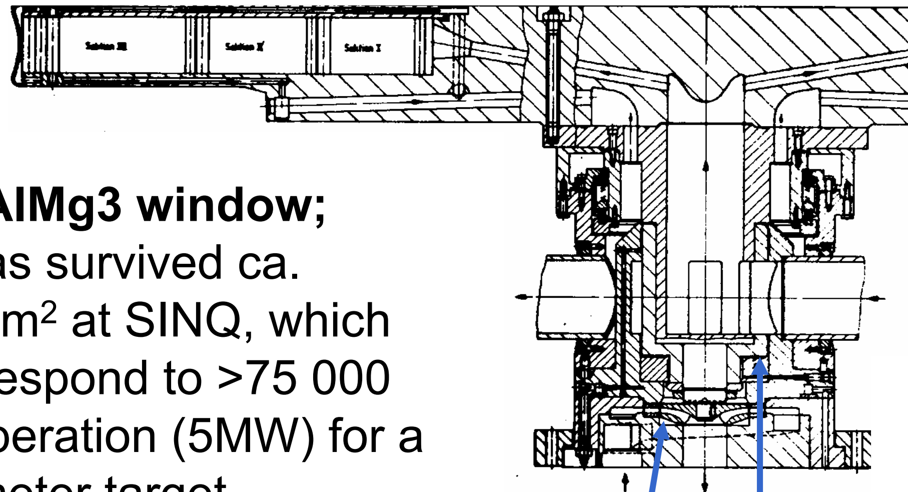
- Spallation Neutron Sources
- Radiation Effects facilities
- ADS (Subcritical Assemblies)
- Radioactive beam facilities
- Neutrino Factories

are now looking at a proton beam power between 1 and 10 MW,
- often in pulsed mode (!)

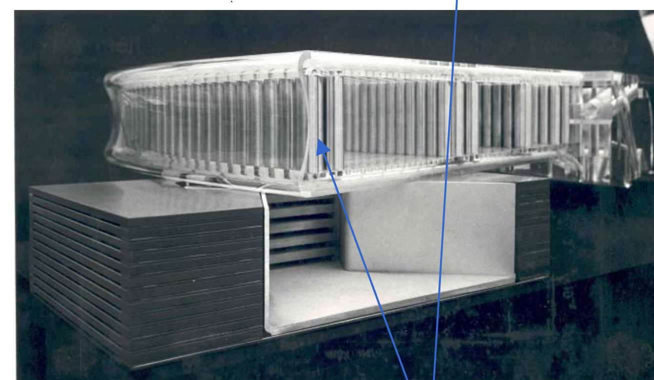
The Problem

- At 5 MW of beam power about 2.5 MW will be deposited in the target material.
- For a beam footprint of ca 100 cm^2 and parabolic intensity distribution (I_{peak} ca. 80 $\mu A/cm^2$) this leads to a peak power density of ca. 2.5 kW/cm^3.
- The resulting temperature increase in a heavy metal (Hg) is about 25 K in 20 ms (e.g. 1 pulse at 50 Hz operation).
- Removing this heat in a stationary situation requires either high coolant fraction (thin target plates), high temperature (risk of boiling) or a moving target.

The SNQ (5 MW) Rotating Target Concept
(1980)

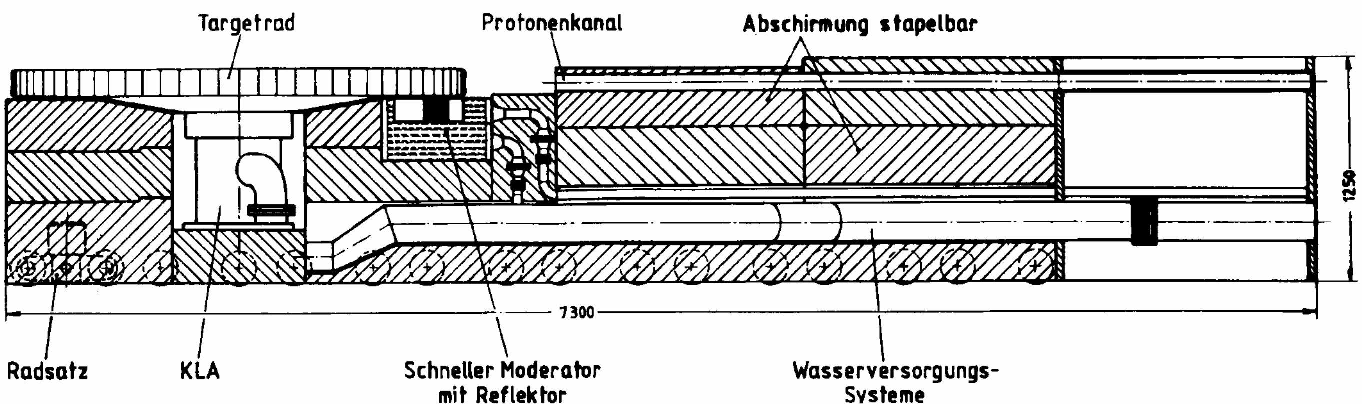


Rotating AlMg3 window; material has survived ca. 200 mAh/cm² at SINQ, which would correspond to >75 000 hours of operation (5MW) for a 1.5 m diameter target



Water turbine

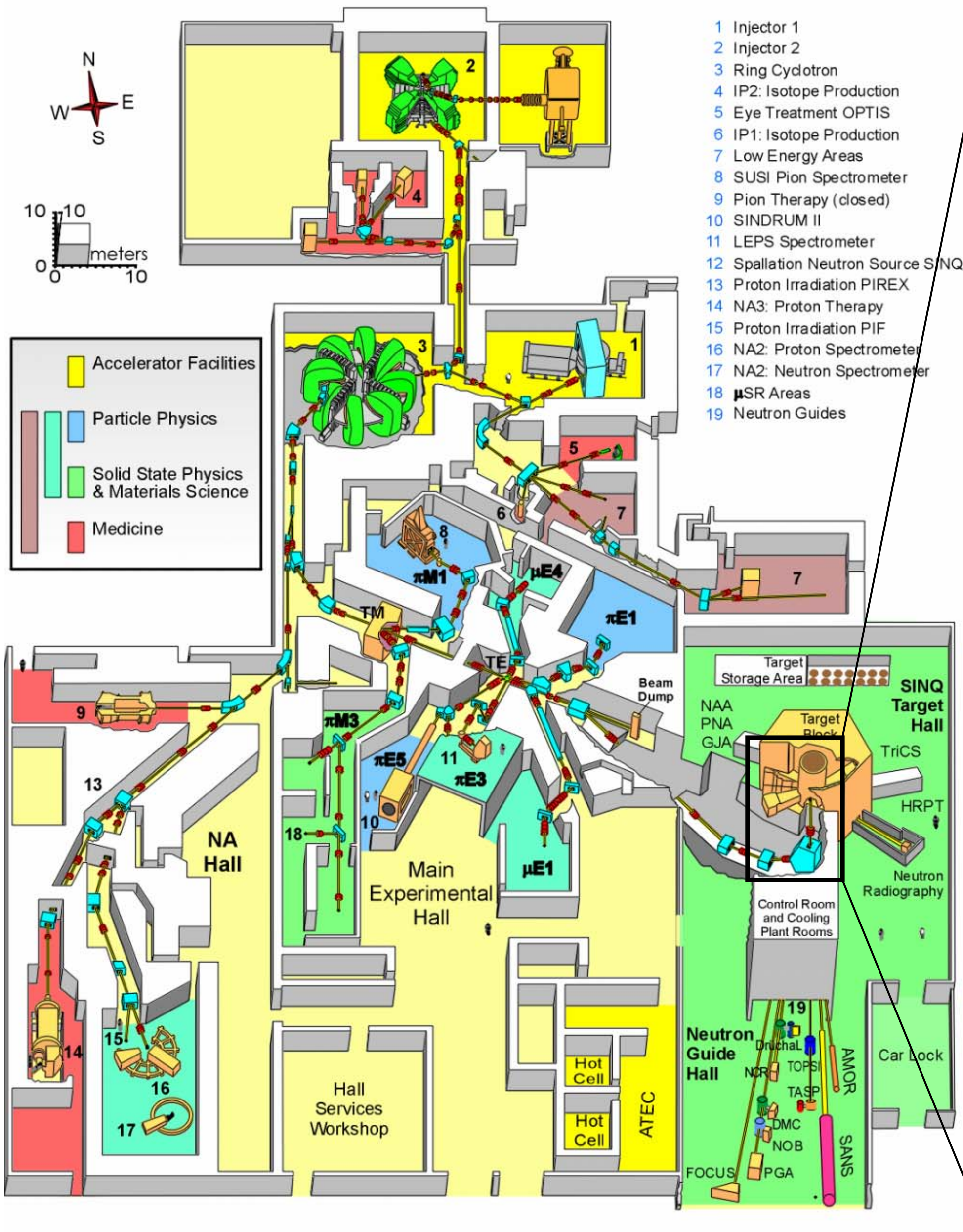
Hydraulic bearings



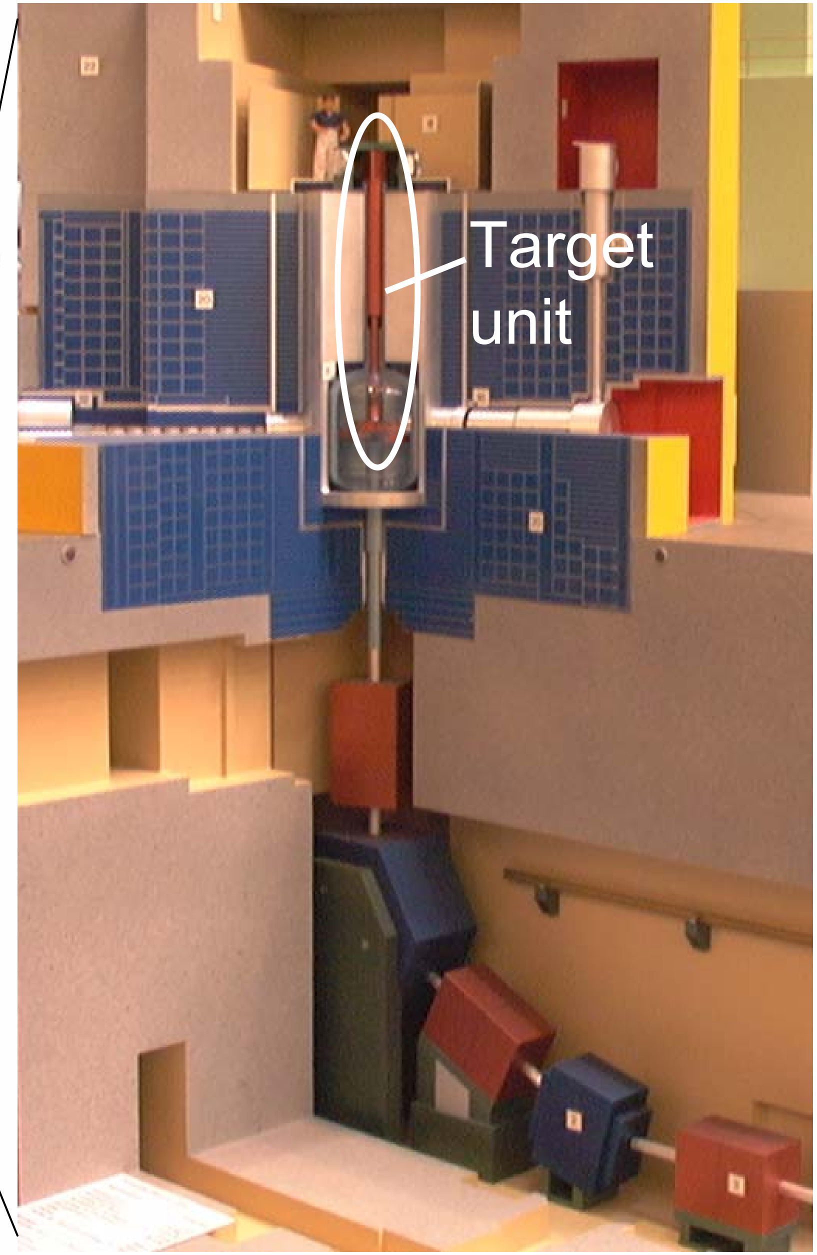
Target rods:
Pb in Al tubes,
surface cooled

alternatively:
W, edge cooled

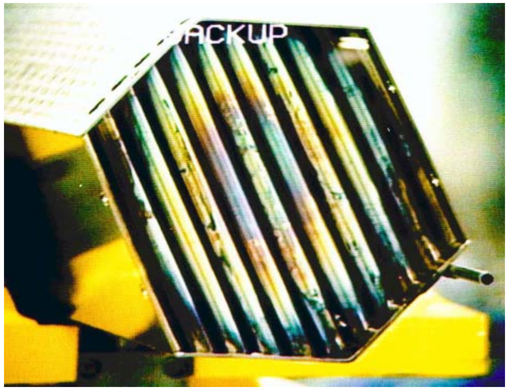
PSI Proton Beam Research Facilities t Model of the SINQ Target Block



Walter/Heyck - Jan. 1998 -Hallenplan



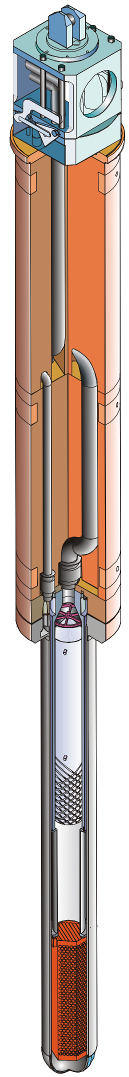
The SINQ Rod Target



Target Mk 1
(Zircaloy)
after 0.5 Ah
water
purification off

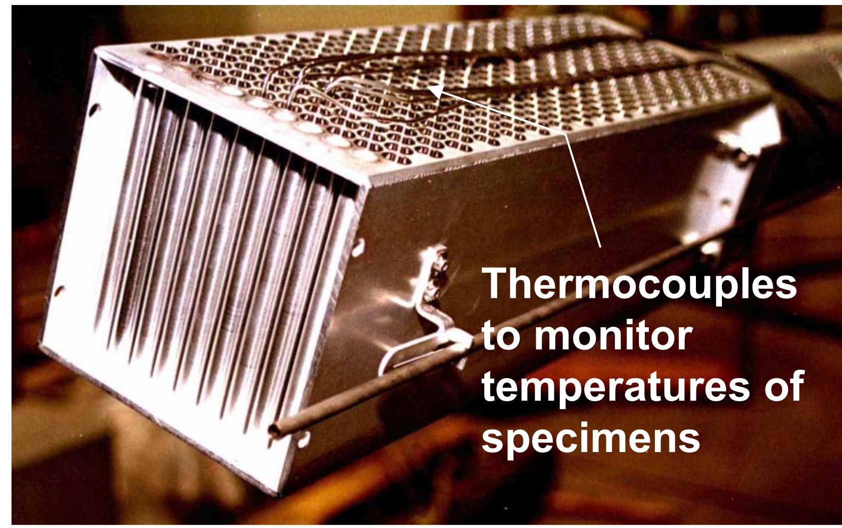
Target Mk 2
(Zircaloy)

Removed after 6.8 Ah of beam
(water purification on)



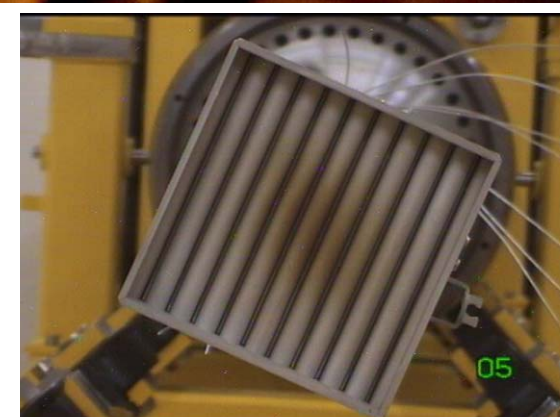
Incident proton beam

Target Mk 3
(lead rods in SS-tubes,
bottom row empty Al-tubes)

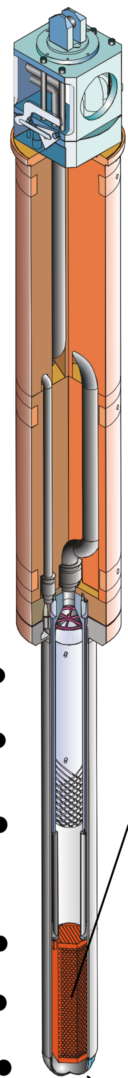


Thermocouples to monitor temperatures of specimens

Exposed
to 10 Ah
of beam;



Radiation Effects Research with SINQ

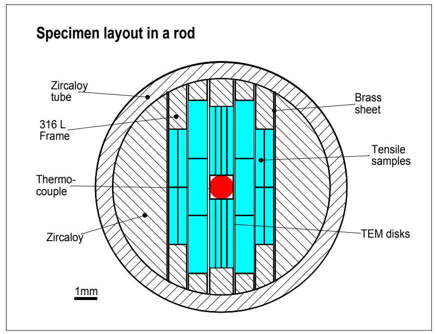


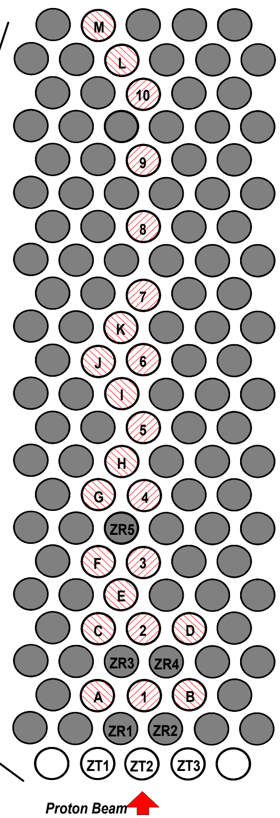
2 years of operation (6.8 Ah)

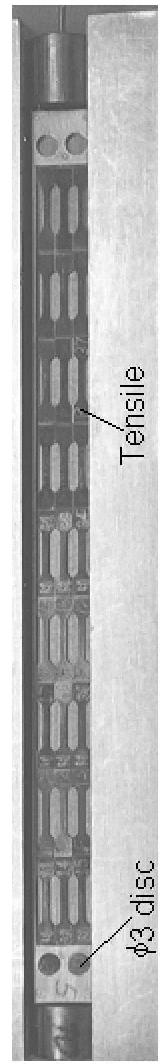
cooling time: 10 months

Incident proton beam

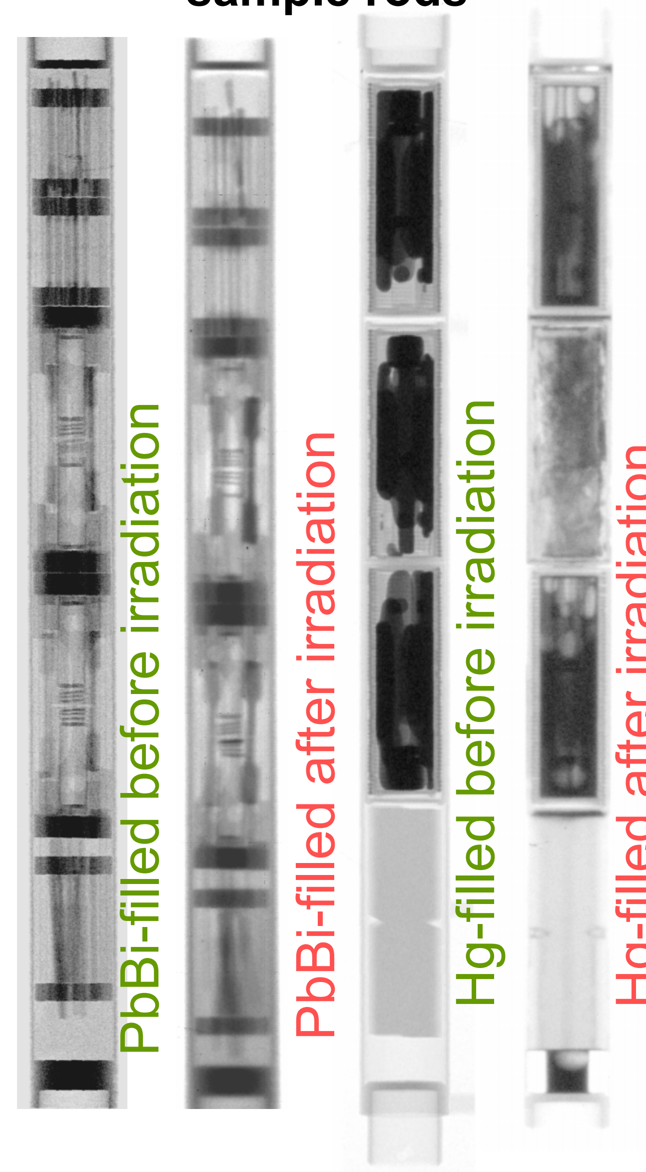
Rod with test specimens



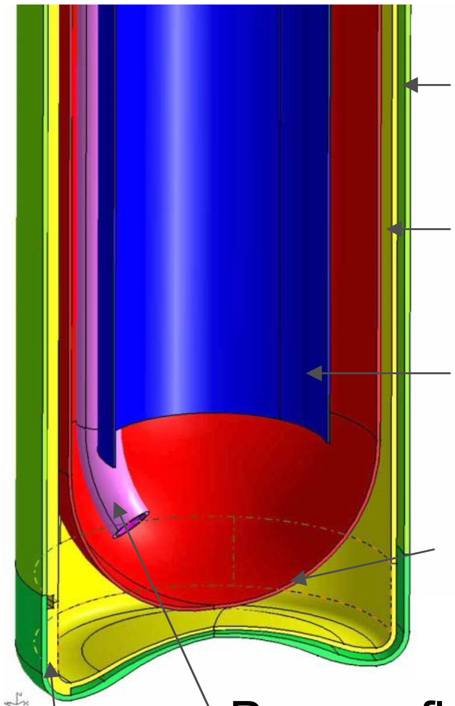


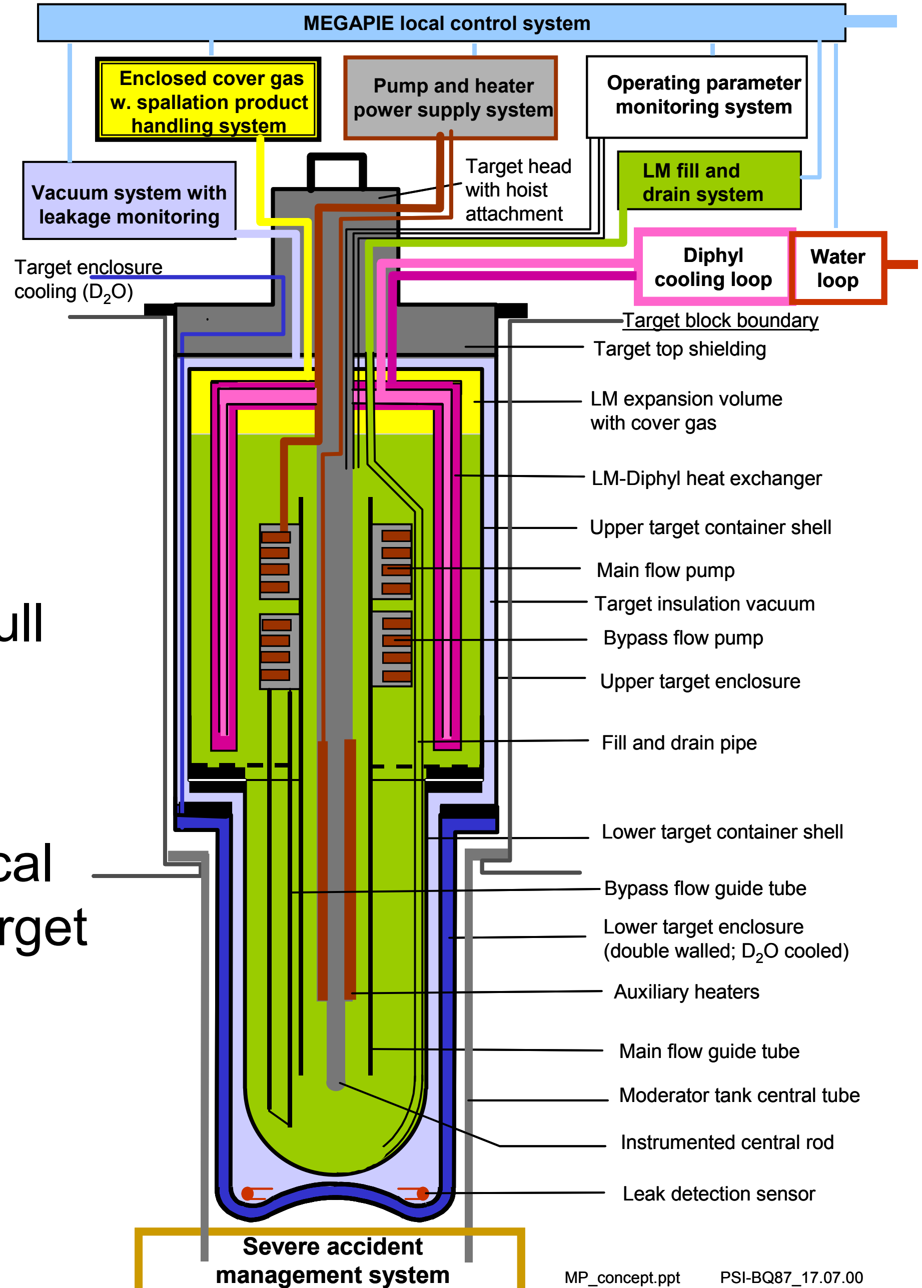


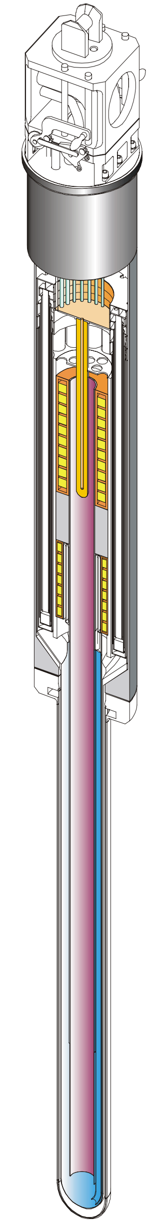
Neutron radiographs of sample rods



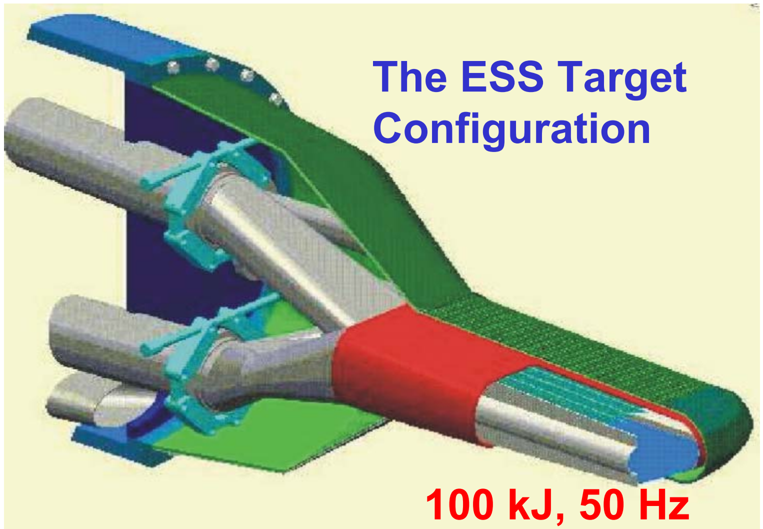
The SINQ PbBi MEGAPIE Target

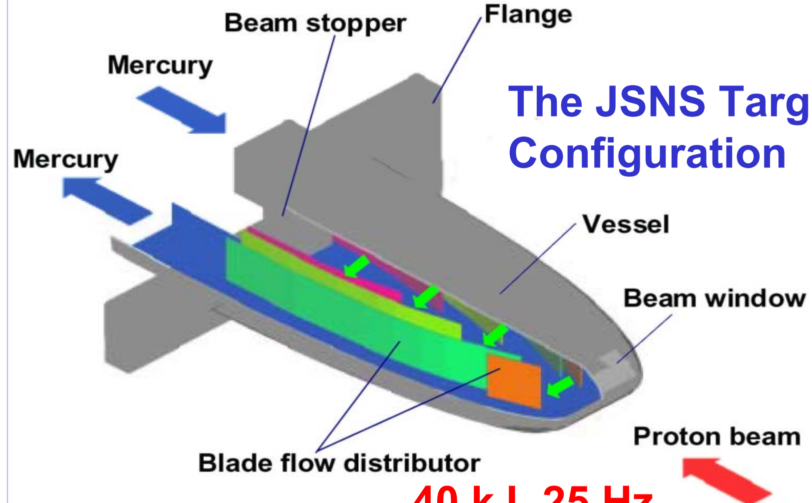






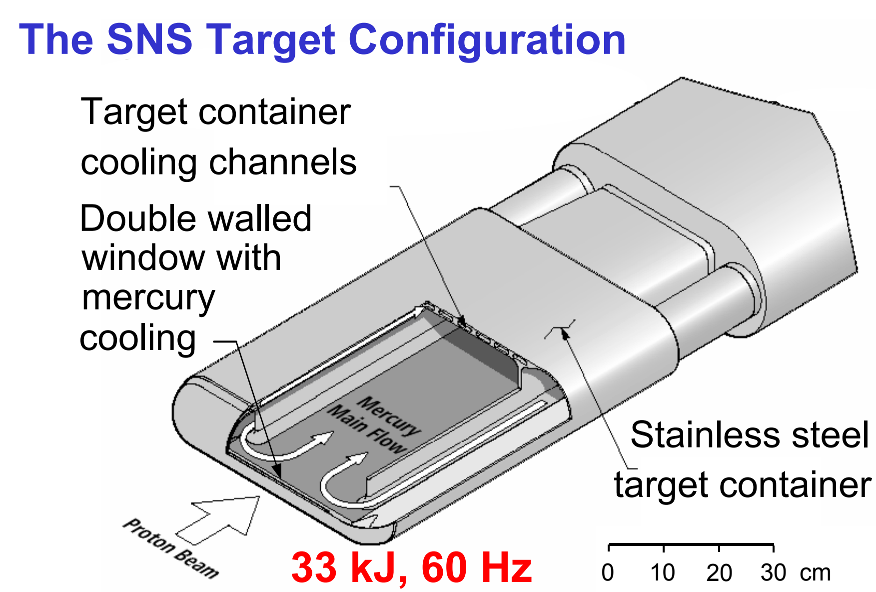
The ESS-SNS-JSNS Hg Target Concept



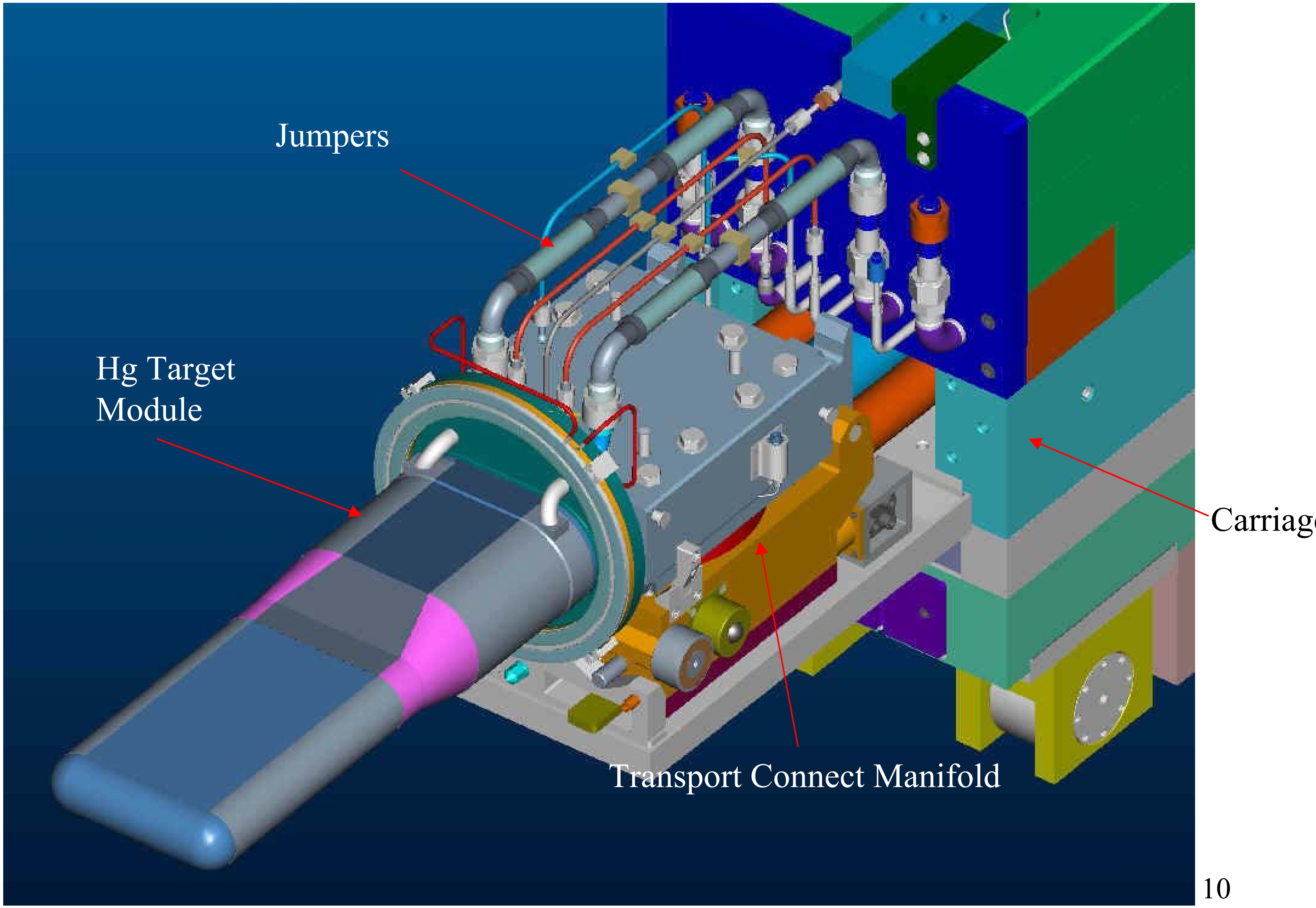


ESS (5 MW), SNS (2 MW) and JSNS (1 MW) all use liquid mercury targets enclosed in steel shells, albeit with different internal flow distributions.

In all cases the target vessel is surrounded by a secondary hull to contain the mercury in case of a leak in the primary container

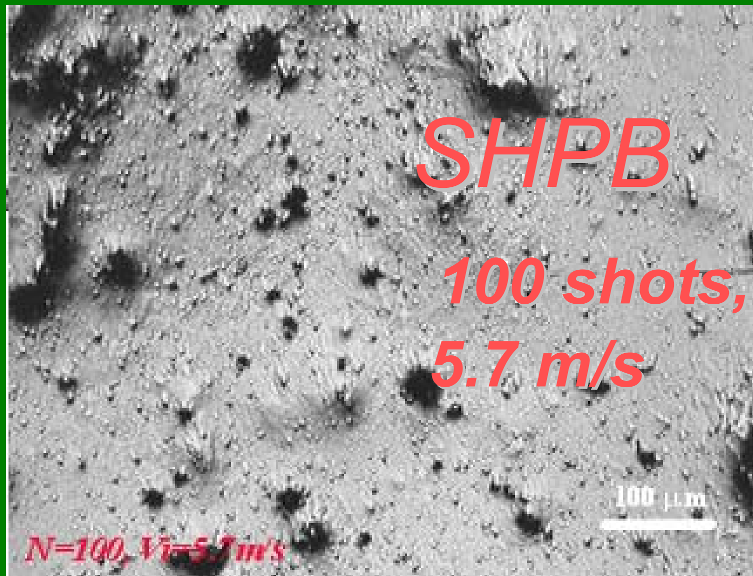


SNS Mercury Target Module

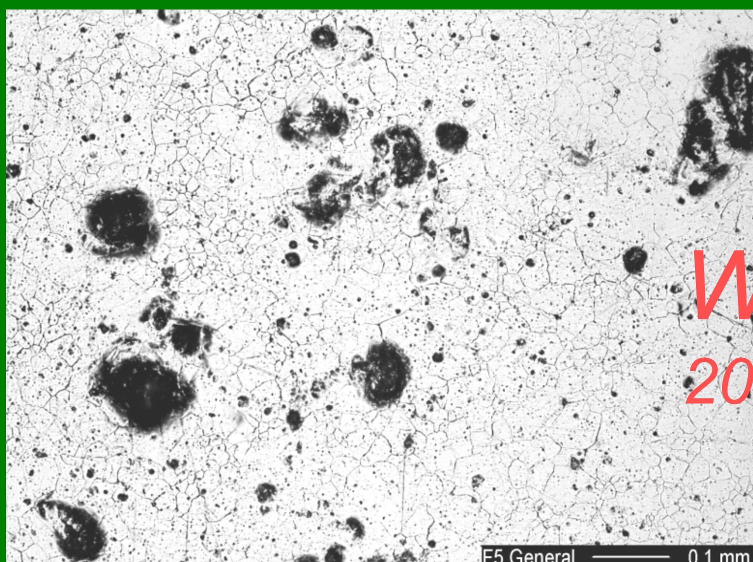


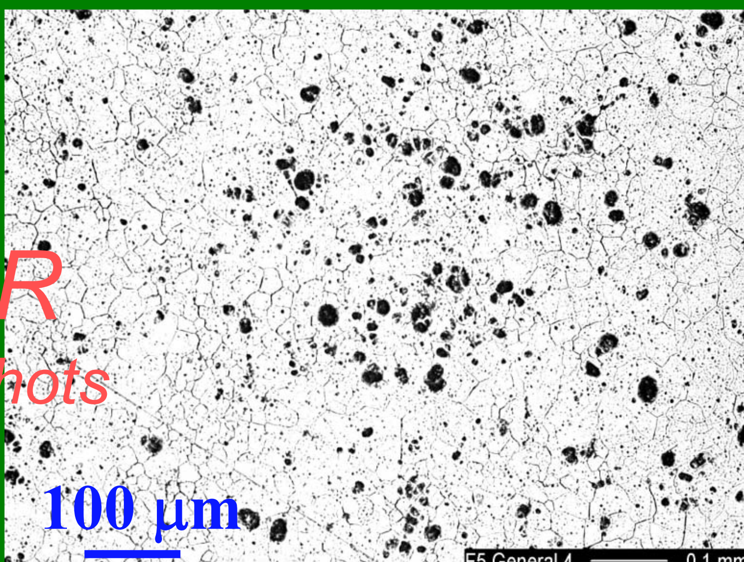
Cavitation-Erosion („Pitting“) by Pressure Pulses

Out of beam



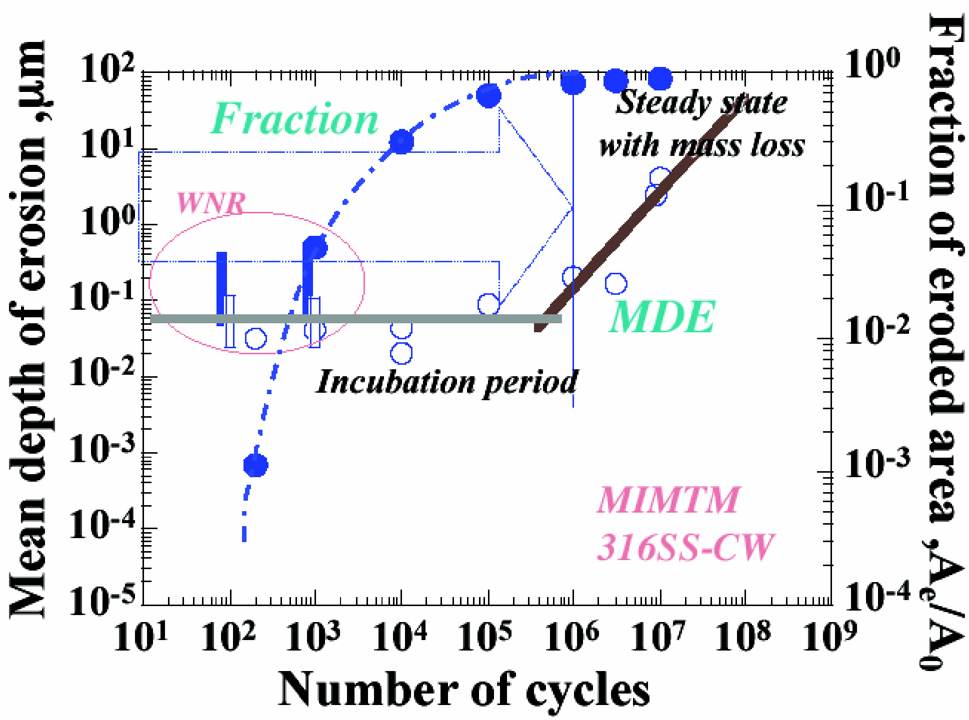
800 MeV proton beam



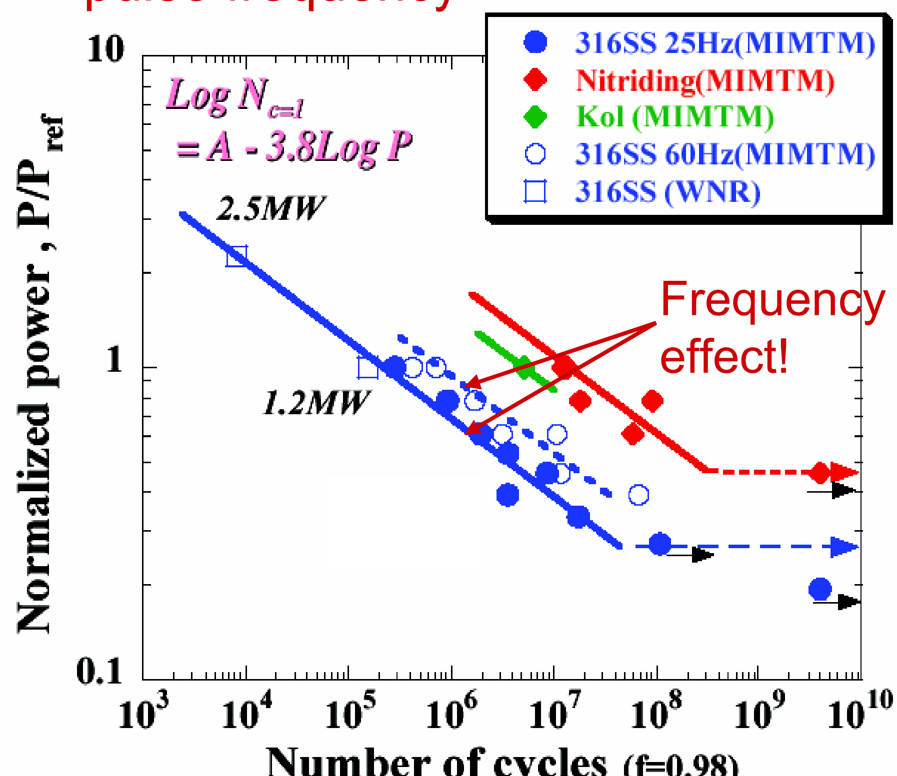


CE Research with Magnetic Impact Device

(MIMTM, M. Futakawa et al., JAERI)

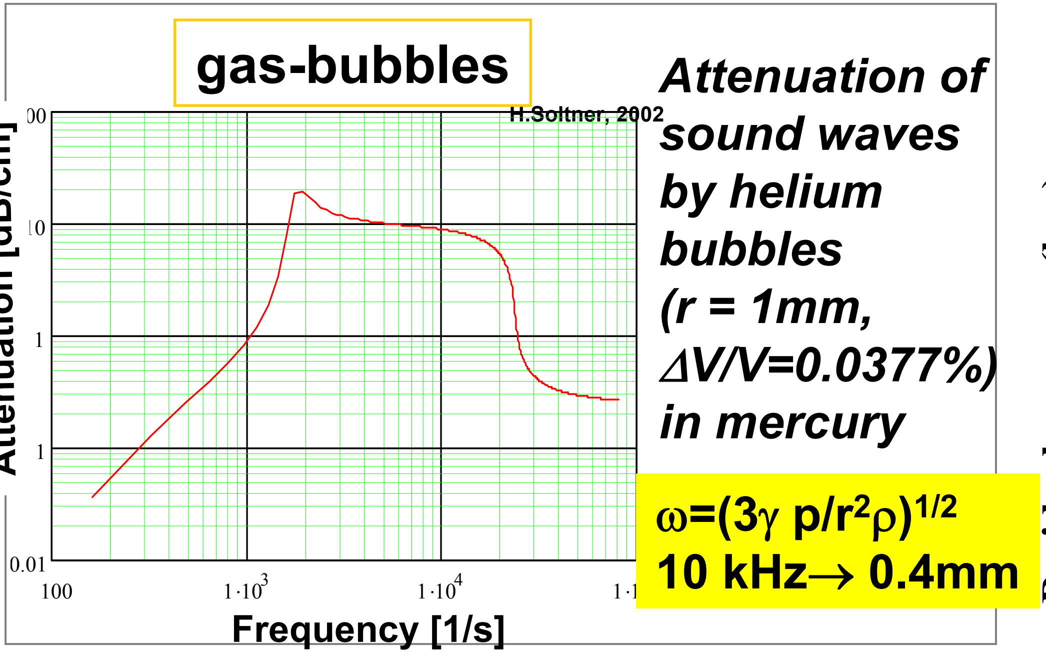


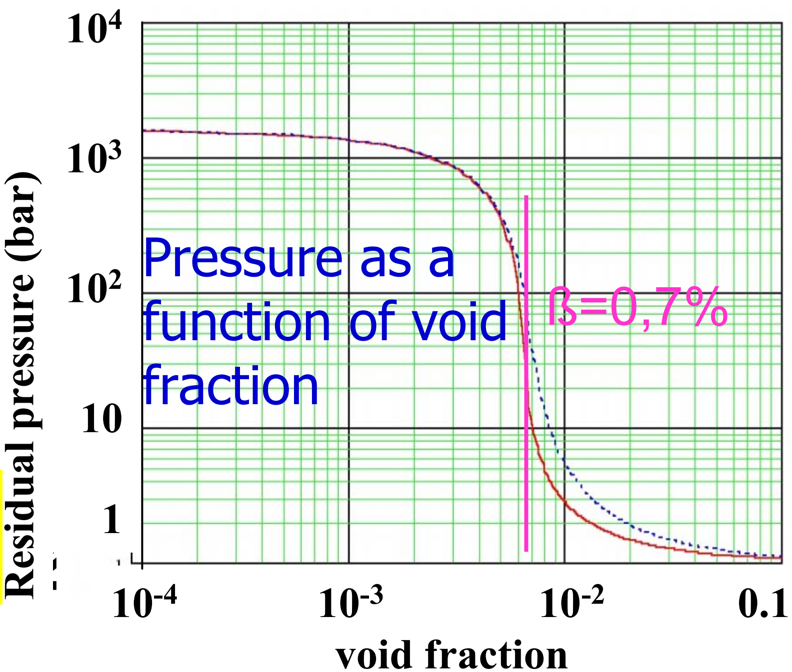
The number of cycles to onset of mass loss depends on impact power, surface treatment and pulse frequency



Mass loss in cavitation erosion (CE) sets on, once the surface is nearly fully covered with pits

Pressure Wave Mitigation by Gas Bubbles

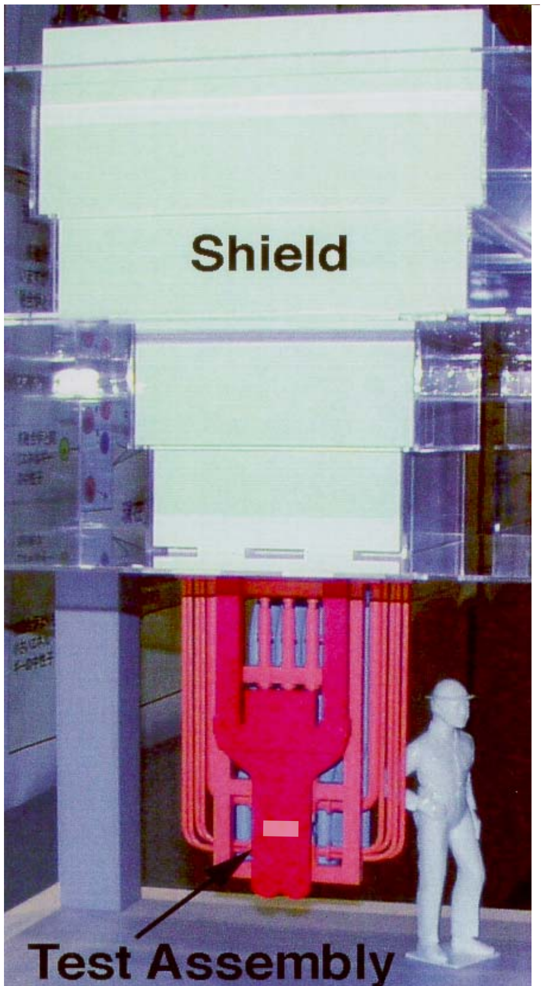


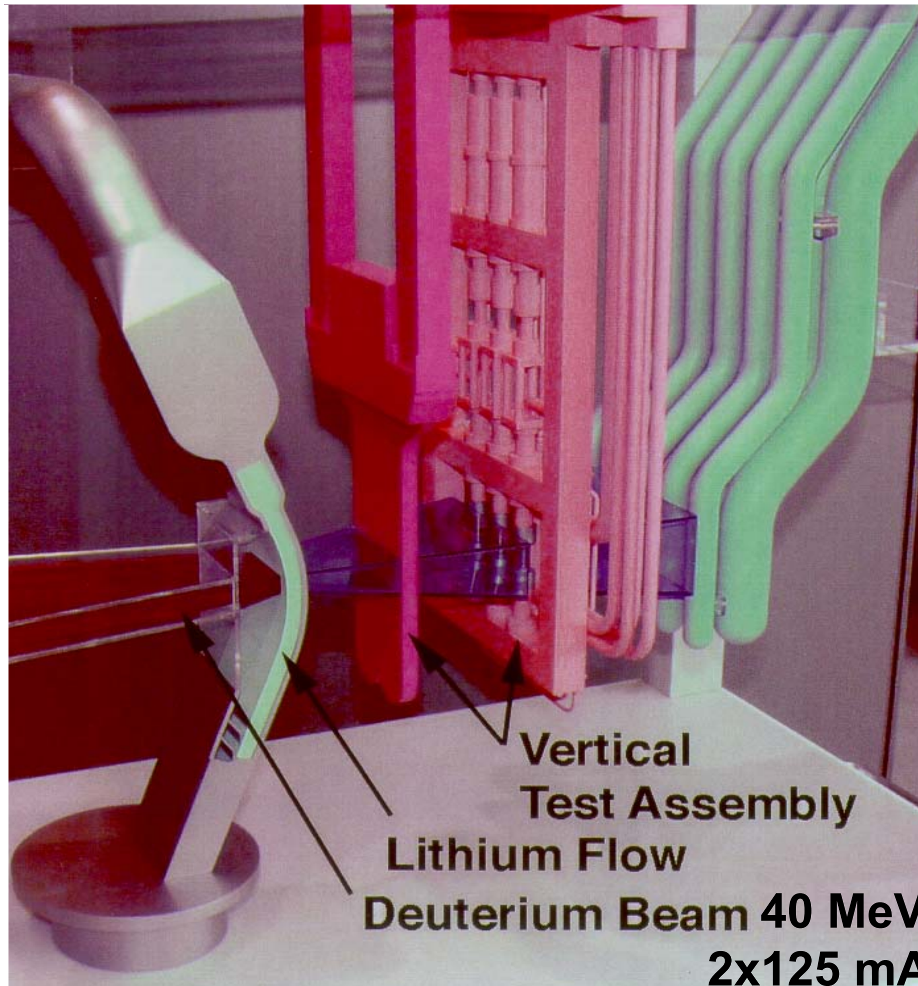


- A small amount of bubbles of the right size can attenuate a travelling pressure wave
- A sufficiently large volume fraction of bubbles can substantially reduce the peak pressure
- Bubble injection techniques are under development

The IFMIF Flowing Li Target Concept

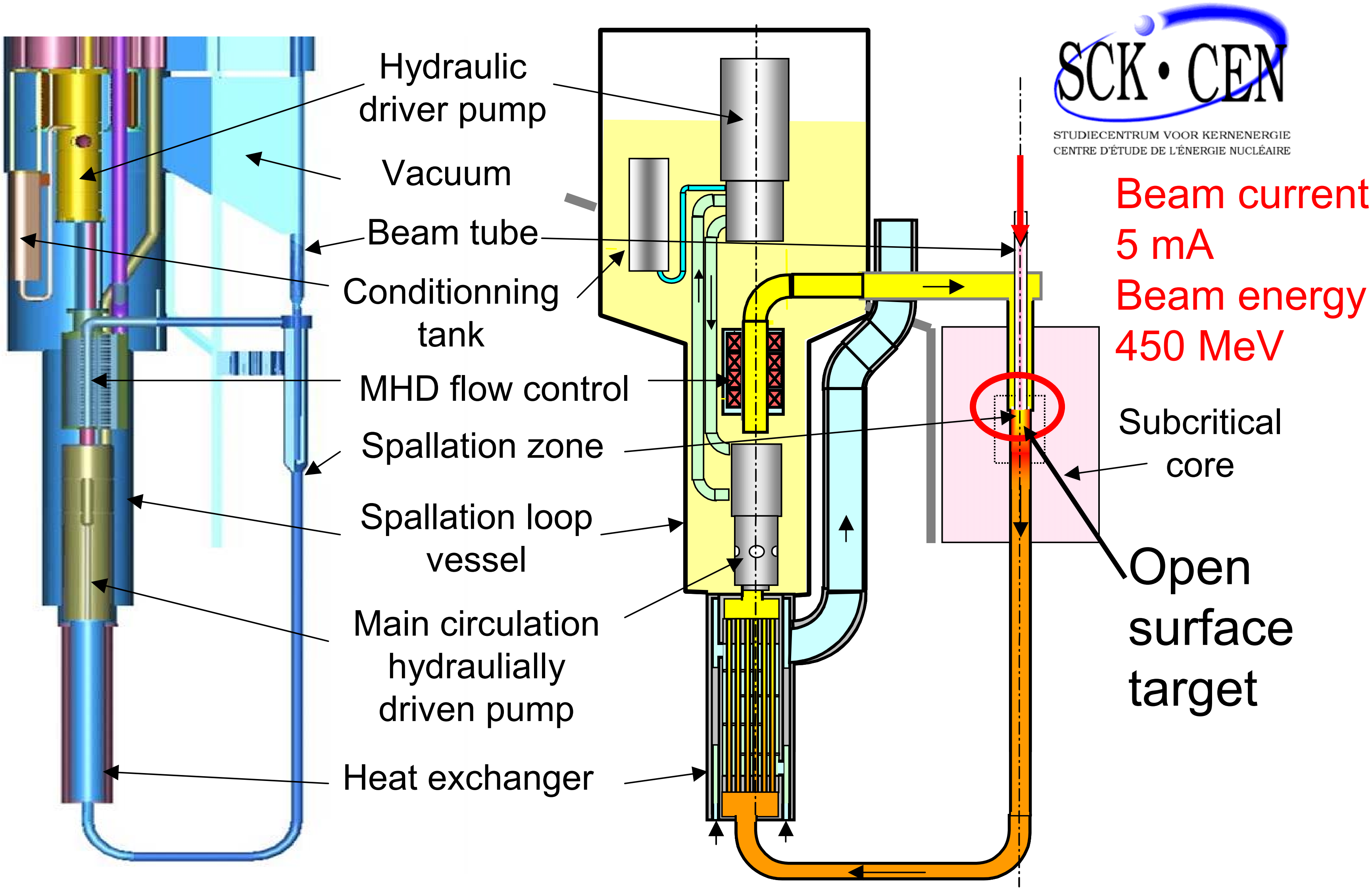
Generation of ca. 14 MeV neutrons by stripping of D on Li



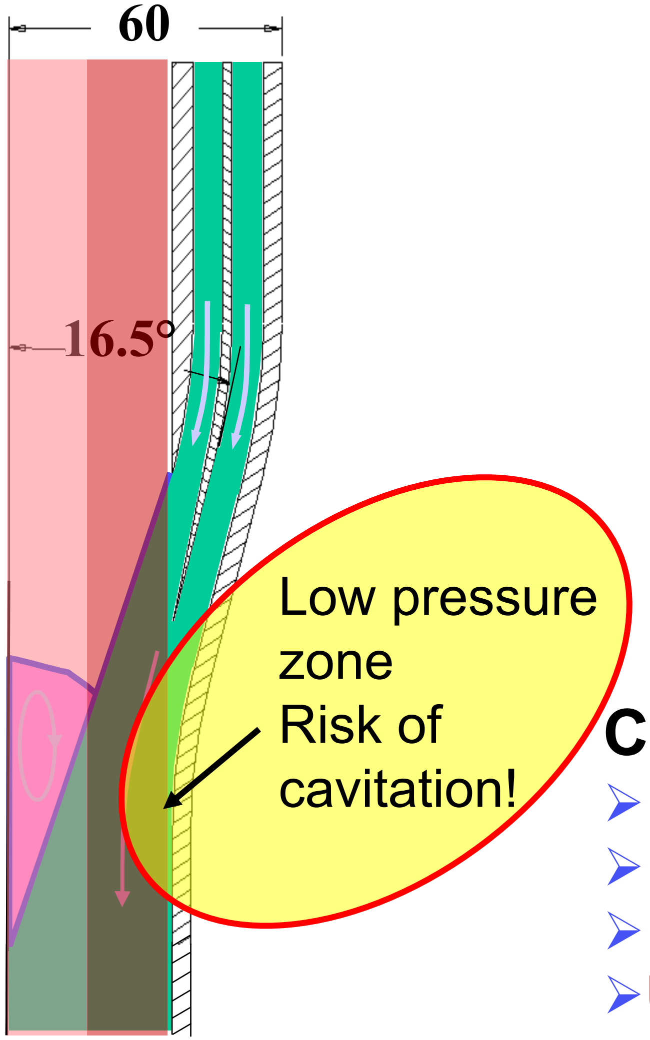


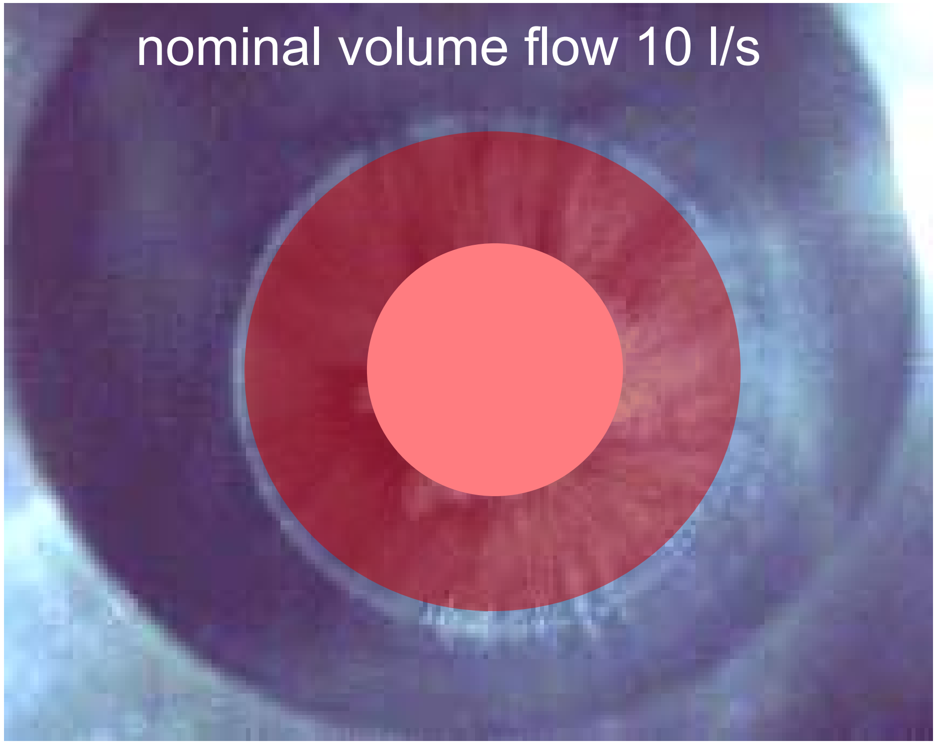
40 MeV,
2x125 mA
Footprint 20x5 cm^2

MYRRHA Spallation Target PbBi Loop



MYRRHA Spallation Target
Flow Experiment with Mercury

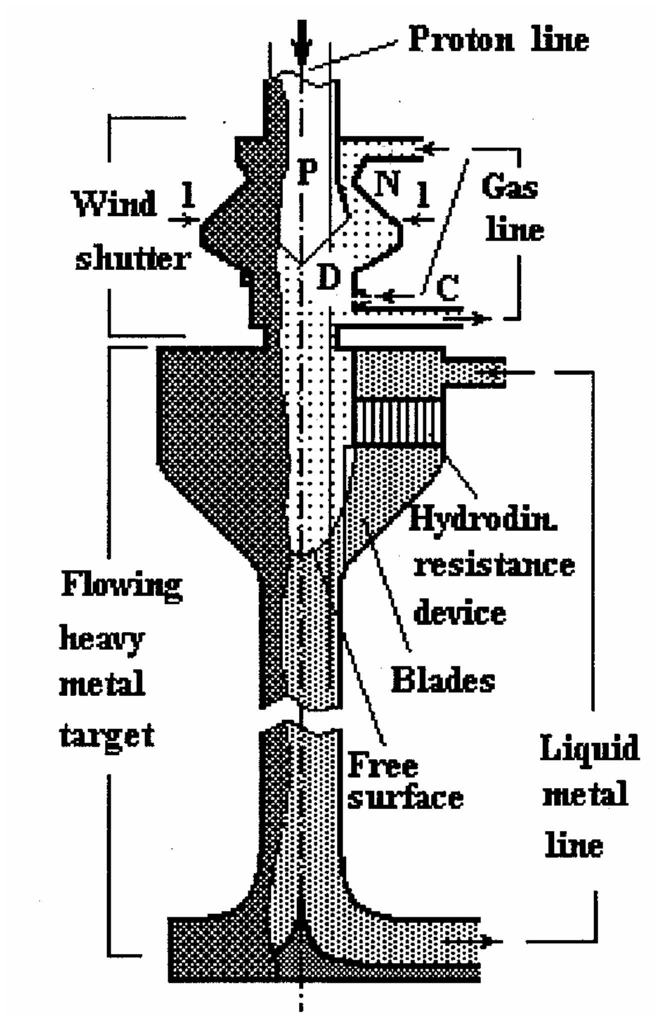




Close to desired configuration !

- intermediate lowering of level
- some spitting
- axial asymmetry
- Use “hollow” beam ?

Windowless Target: ISTC-17 Study*

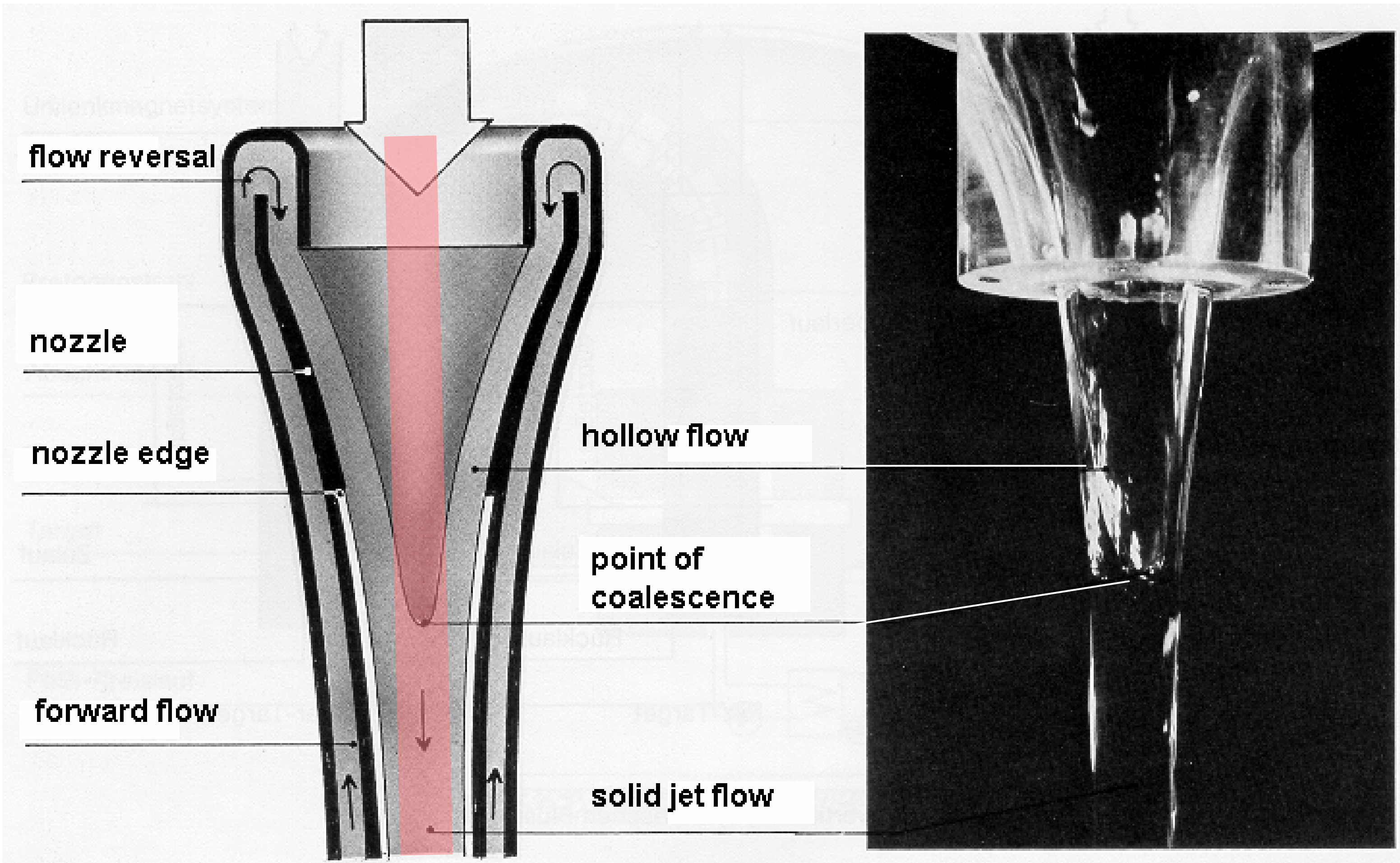


- Design goal: 20 MW_b
- Flow guided on outside
- Gas pressure above free surface found necessary to prevent cavitation; supersonic gas jet proposed
- Forced coalescence point; risk of recirculating zone; “swirl" (angular momentum) imposed by blades will not solve this problem

**Belyakov-Bodin et al. Kalmar 1996*

Windowless Target: The SNQ Study

" Free Falling Jet "

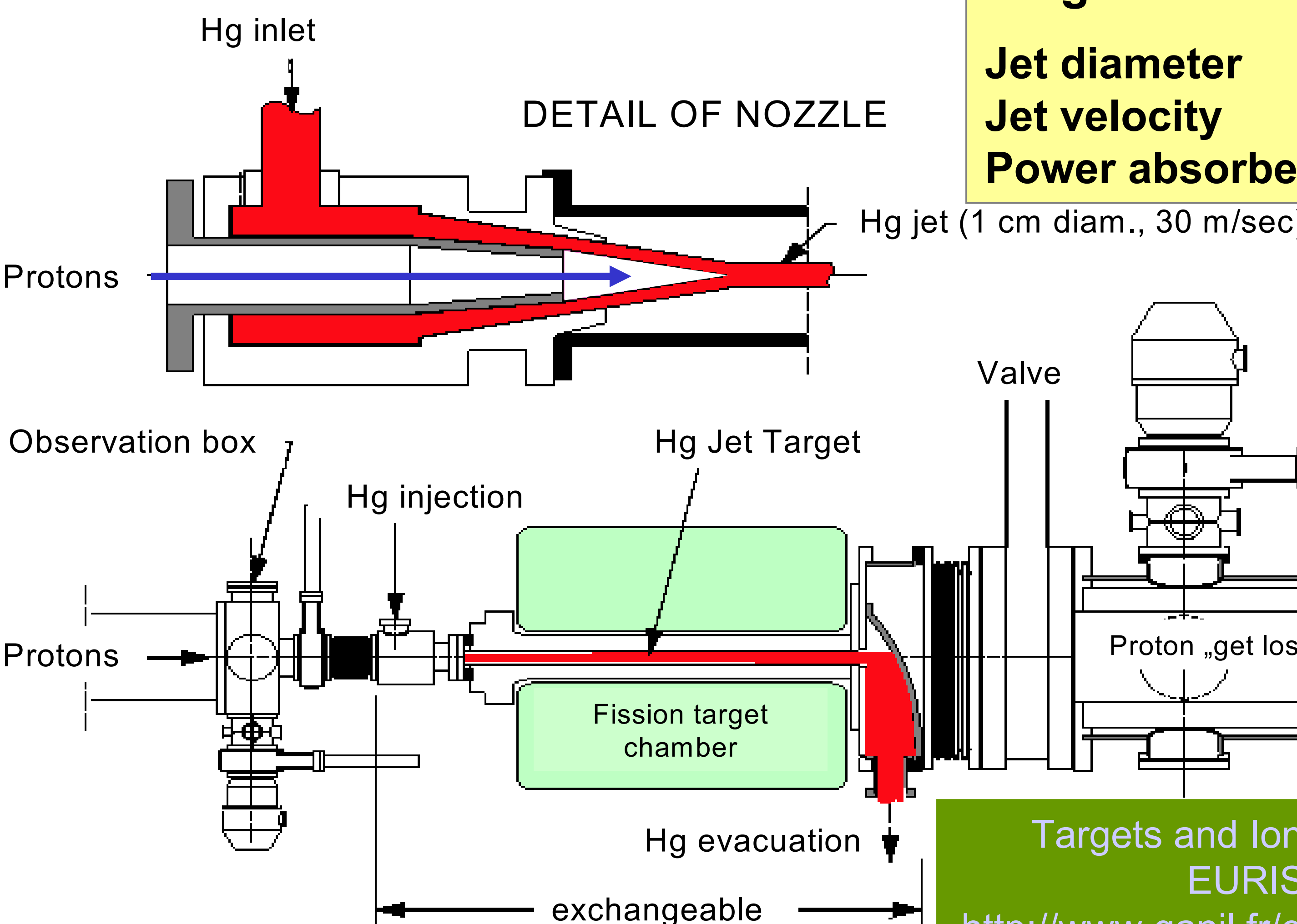


Schematic and water model of a windowless target studied at FZK, (KfK) 1981

The EURISOL Hg Jet Target Concept

Target Parmeters:

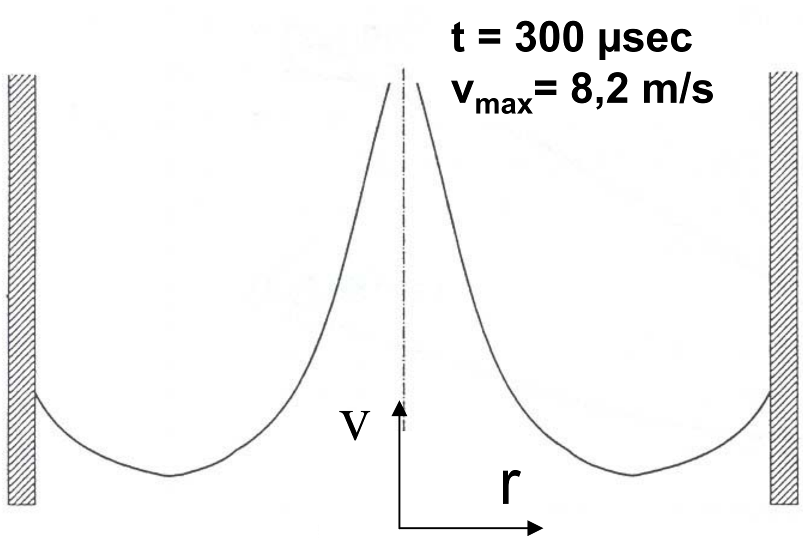
Jet diameter 1 cm
Jet velocity 30 m/sec
Power absorbed 1 MW +



Targets and Ion Sources for EURISOL
http://www.ganil.fr/eurisol/index.html

Free Surface Under Pulsed Operation

Calculated result for a power deposition of 60 kJ in 1 μsec in a 20 cm diameter target (beam diameter 10 cm, parabolic)



Velocity distribution on the (initially flat) surface of a <u>laterally confined</u> liquid PbBi target 300 μsec after pulsed power input *

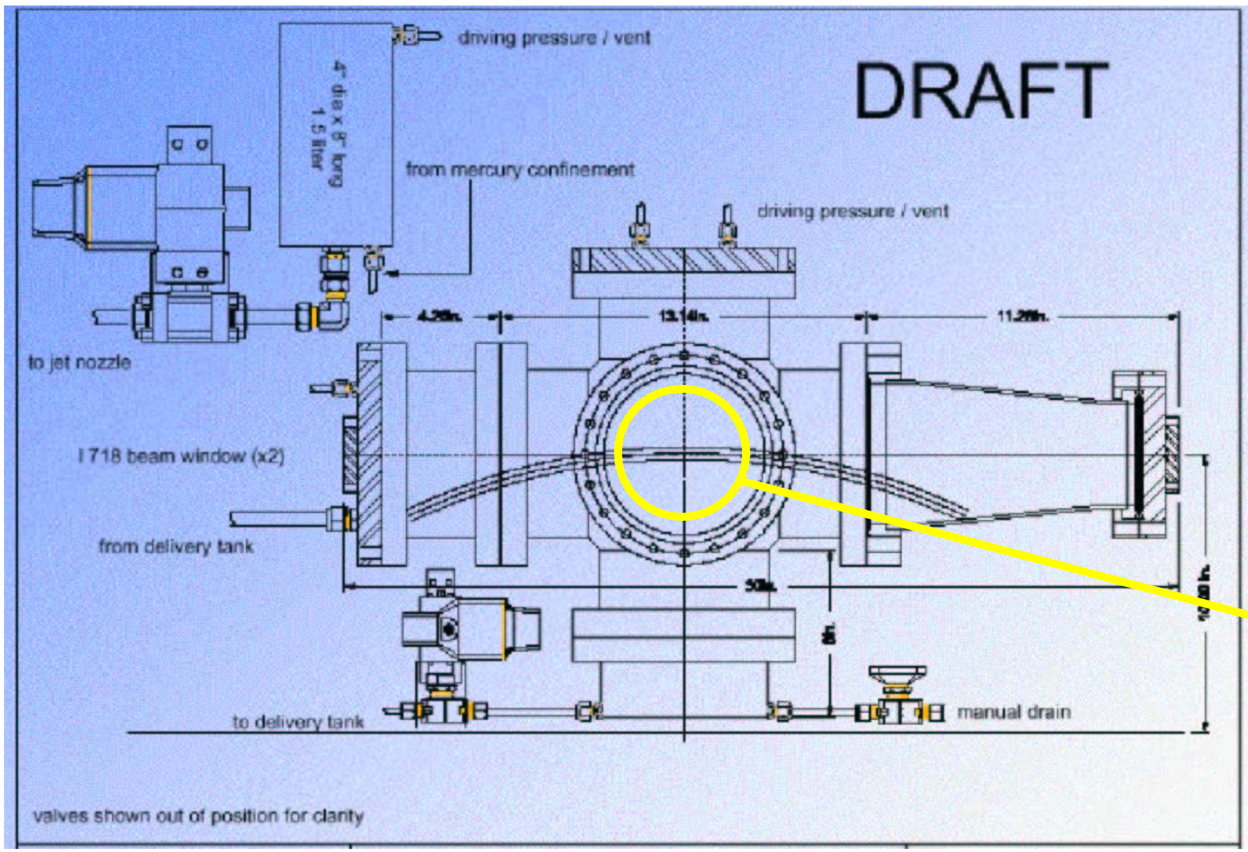
•Focusing effect!!

•Liquid would ultimately rise up to 3.4 m and return after 1.7 sec under the influence of gravity

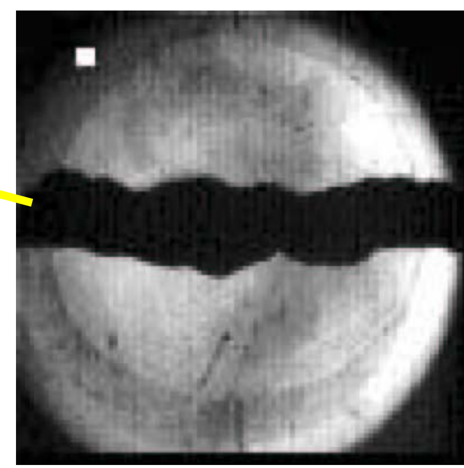
*K. Skala and G.S. Bauer, Proc ICANS XII, pp. 559-571 (1995)

The NuFact Hg Jet Target Experiment

POP Test at BNL E-951, K. Mc Donald, H. Kirk, A. Fabich, J. Lettry



POP-Test at 1/100 of ultimate power density and 1/10 of required jet speed



Pulsed operation ! (50 Hz)

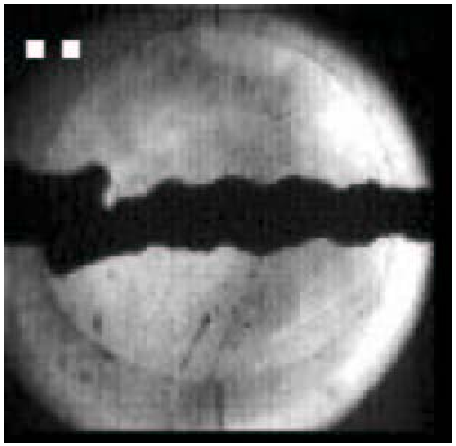
The NuFact Hg Jet Target Experiment

POP Test at BNL E-951, K. Mc Donald, H. Kirk, A. Fabich, J. Lettry

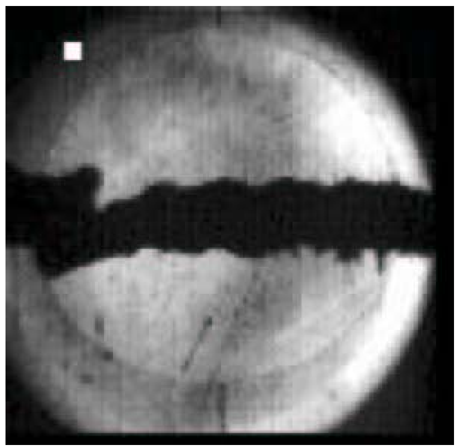
Event #11, April 25, 2001

Hg-Jet:

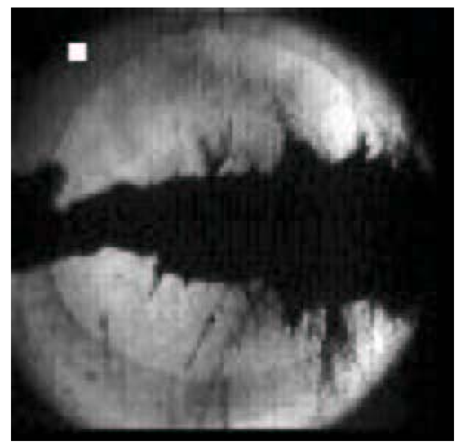
diameter 1.2 cm
velocity 2.5 m/s
perp. velocity: ca 5m/s



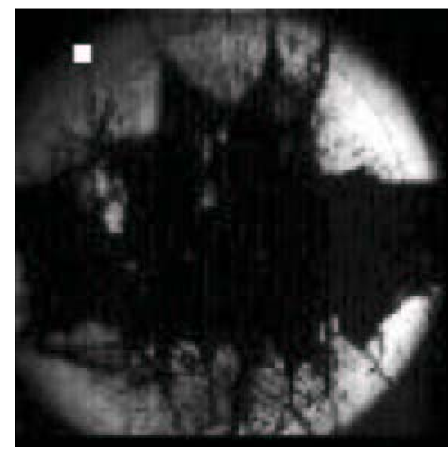
0.00 ms



0.75 ms



4.50 ms



13.00 ms

$2{,}7 \times 10^{12}$ protons
100 nsec
t_0 ca. 0,45 ms

Concluding Remarks

- Medium Energy Accelerators (around 1 GeV) are now reaching a power level of several Megawatts, which makes it increasingly difficult to devise condensed matter targets for efficient production of secondary particles.
- While stationary solid, water cooled targets can be used up to 1-2 MW_b, liquid metal targets of various deigns are being considered for higher power beams.
- Their application at high power, in particular in short pulse facilities does, however, still require a fair amount of R&D work.