Megawatt Class Spallation Target Development

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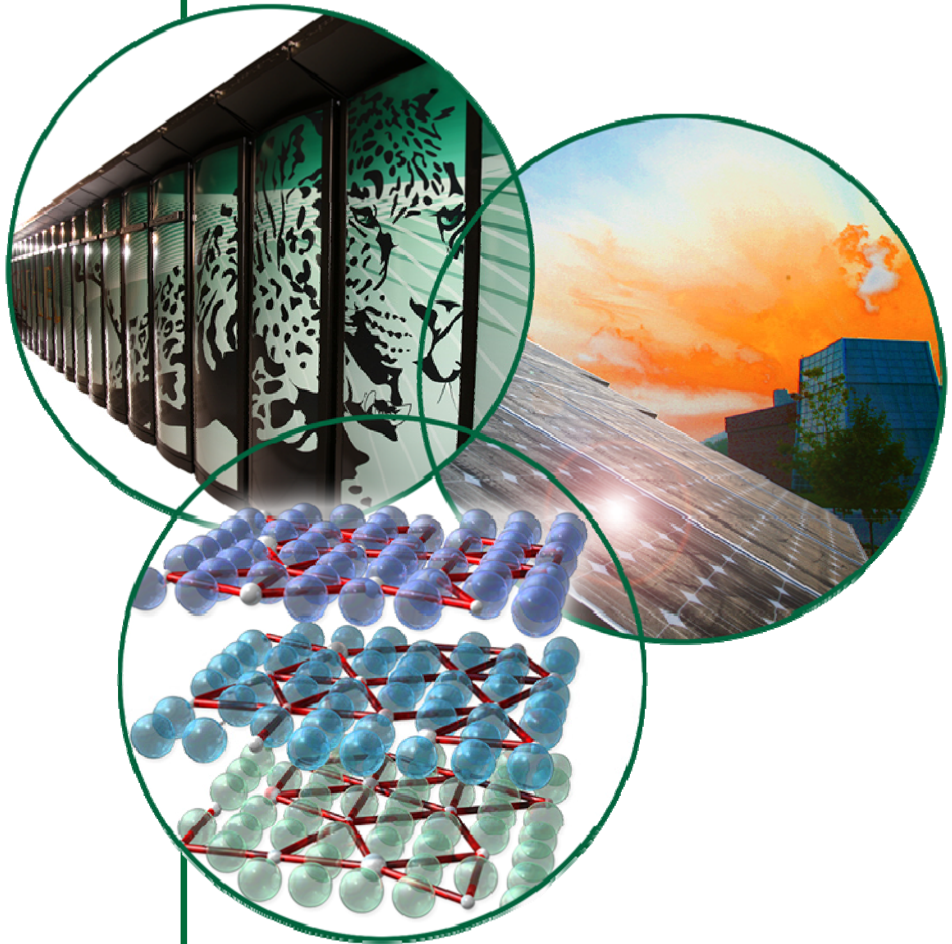
PAC09

May 5, 2009



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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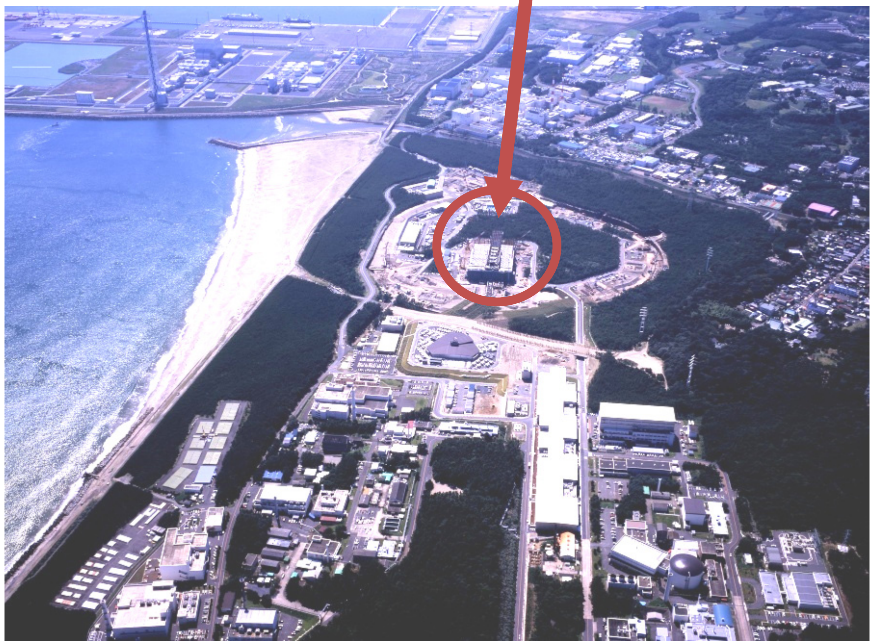
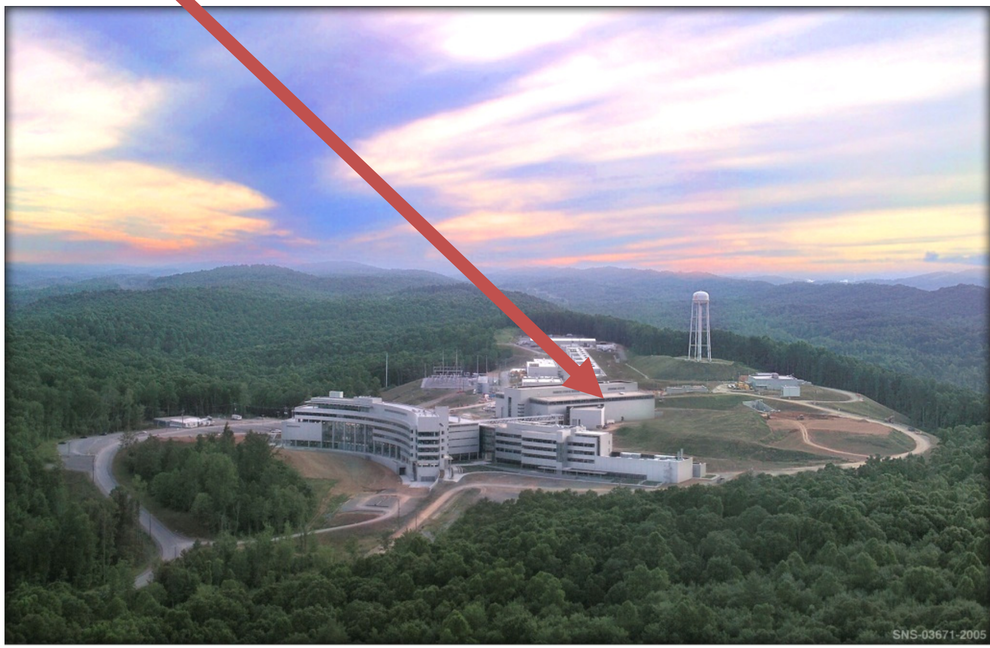
MW-Class Spallation Targets

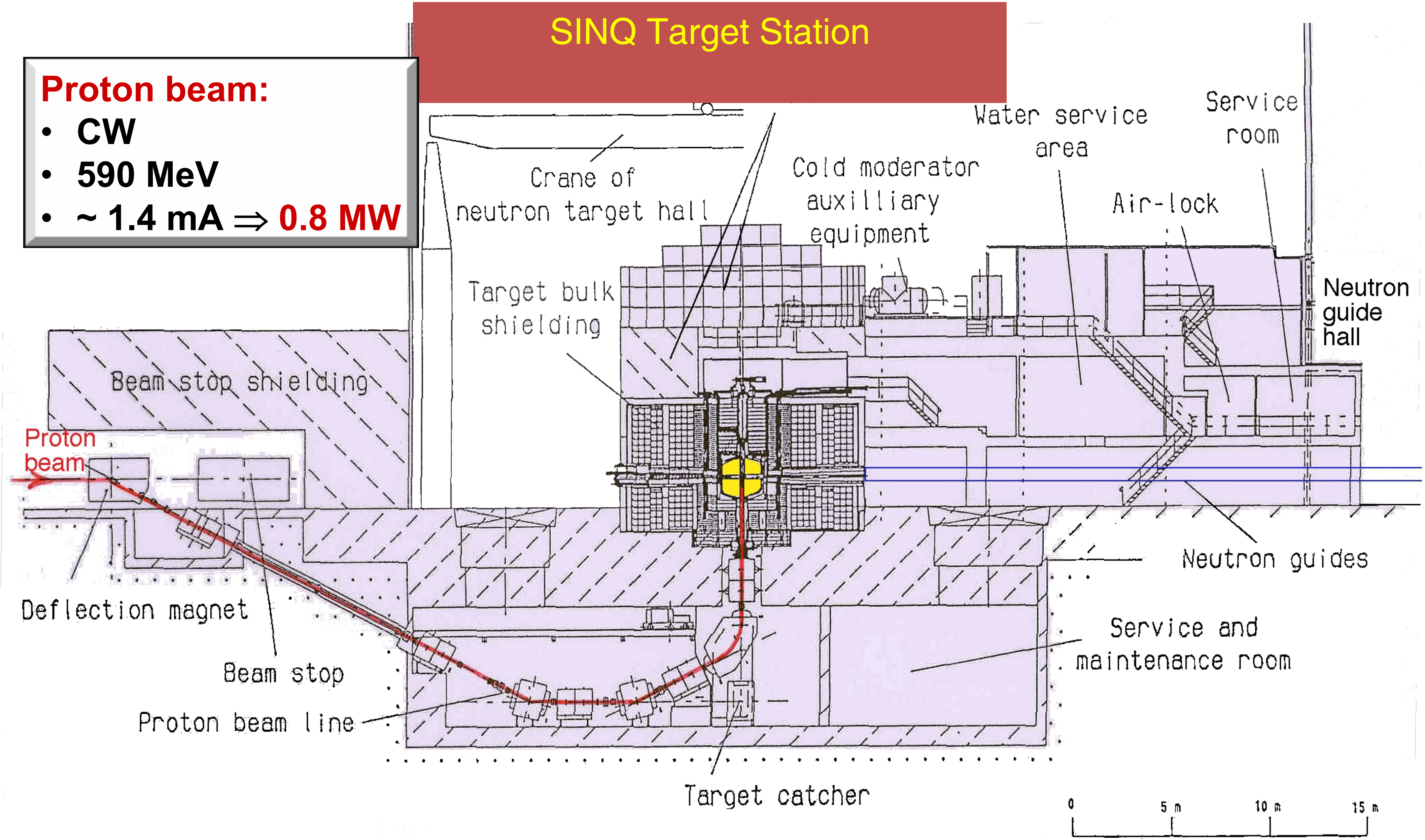
- SINQ at the Paul Scherrer Institut (PSI)
- SNS at the Oak Ridge National Laboratory (ORNL)
- JSNS at the Japan Atomic Energy Agency (JAEA)





SINQ Facility

Proton beam:
- **CW**
- **590 MeV**
- **~ 1.4 mA ⇒ 0.8 MW**



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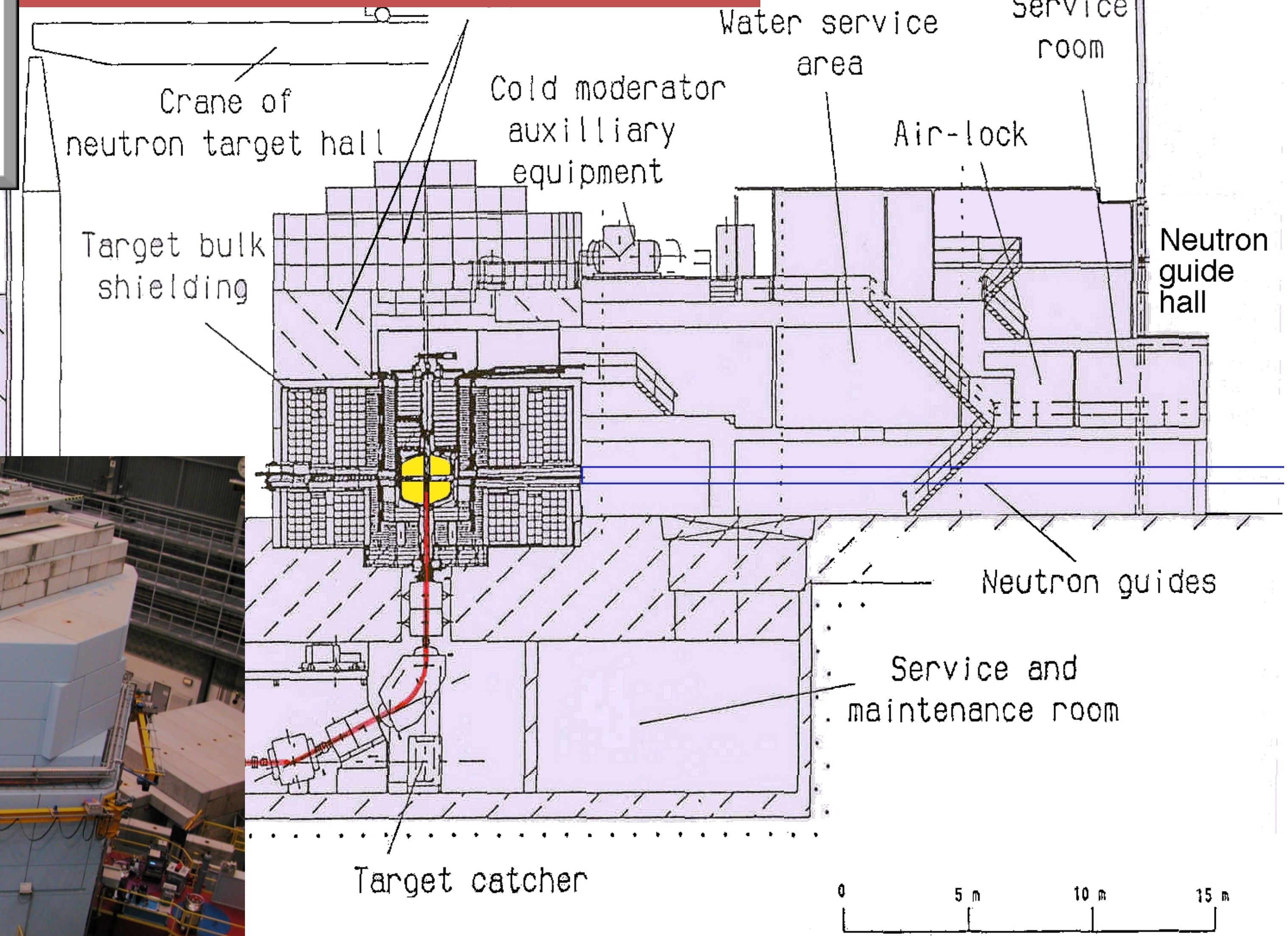
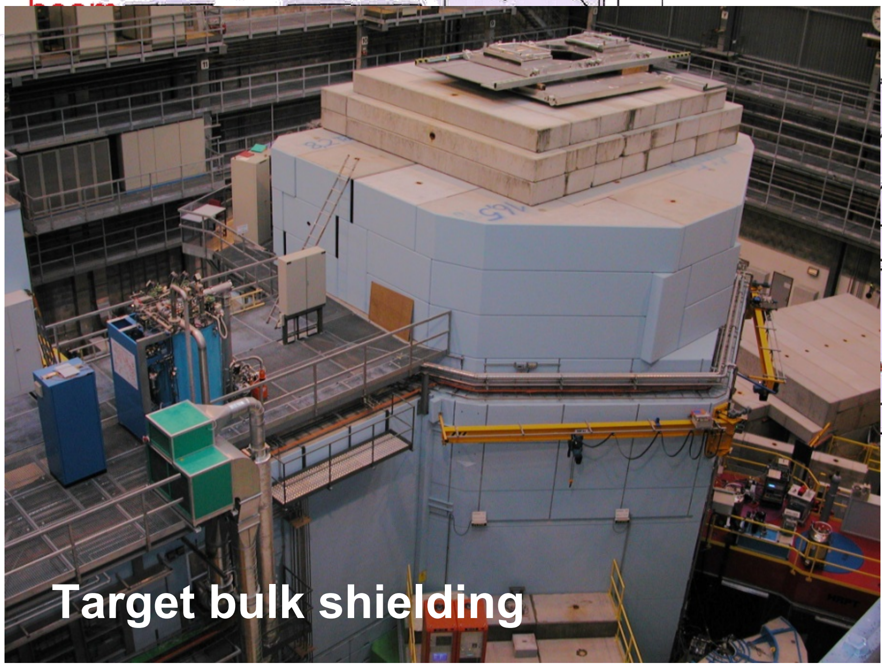
SINQ Target Station





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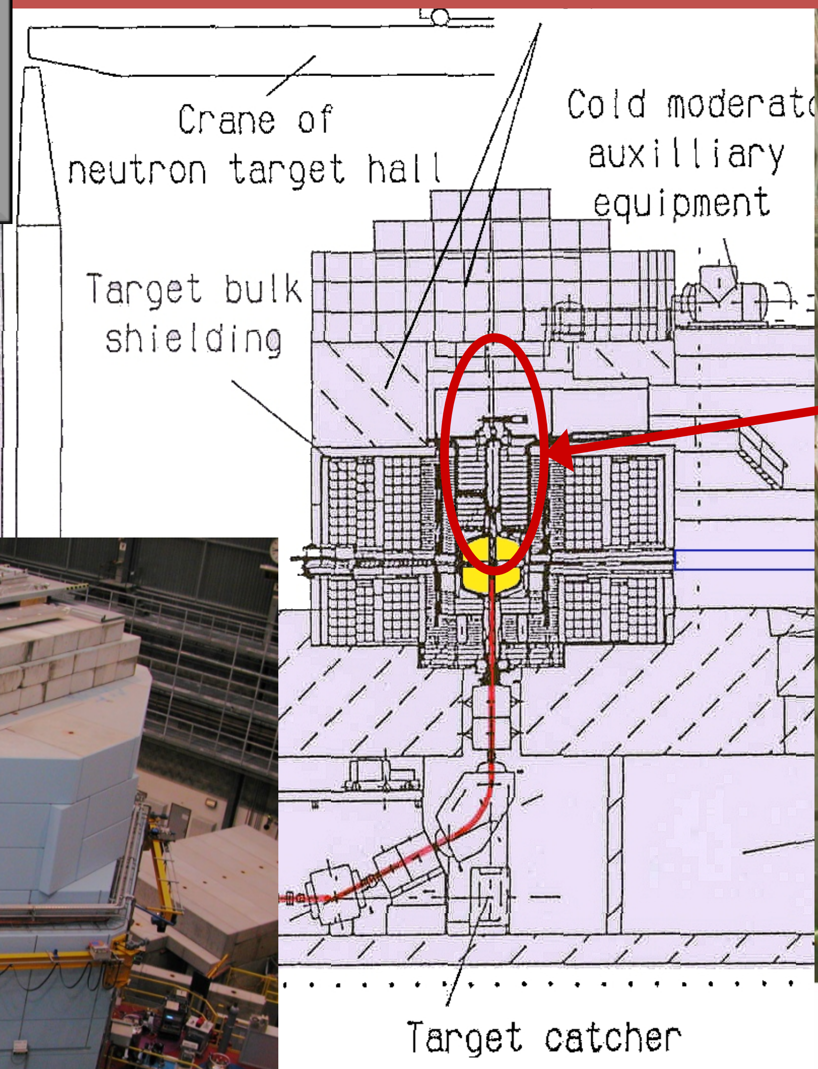
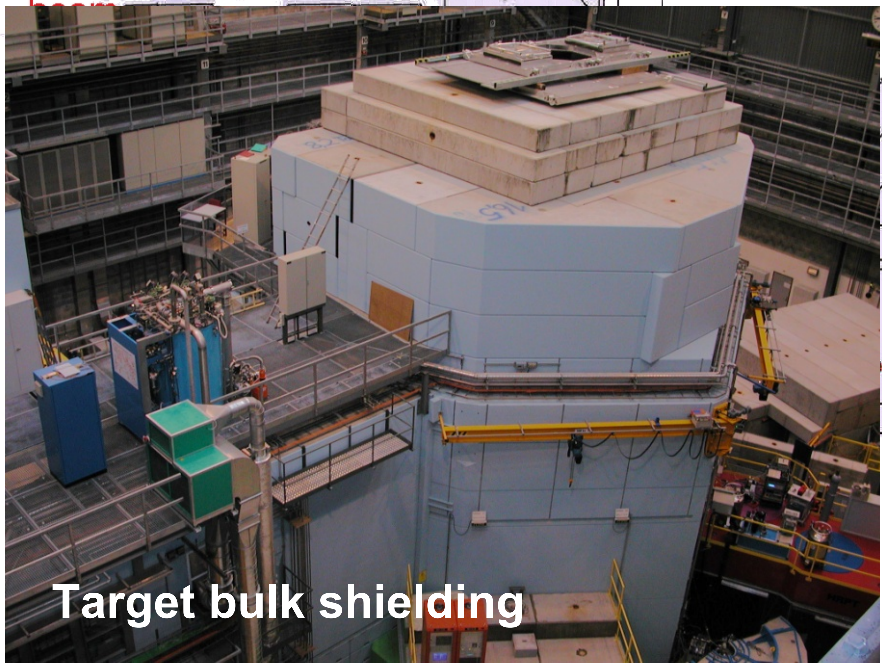
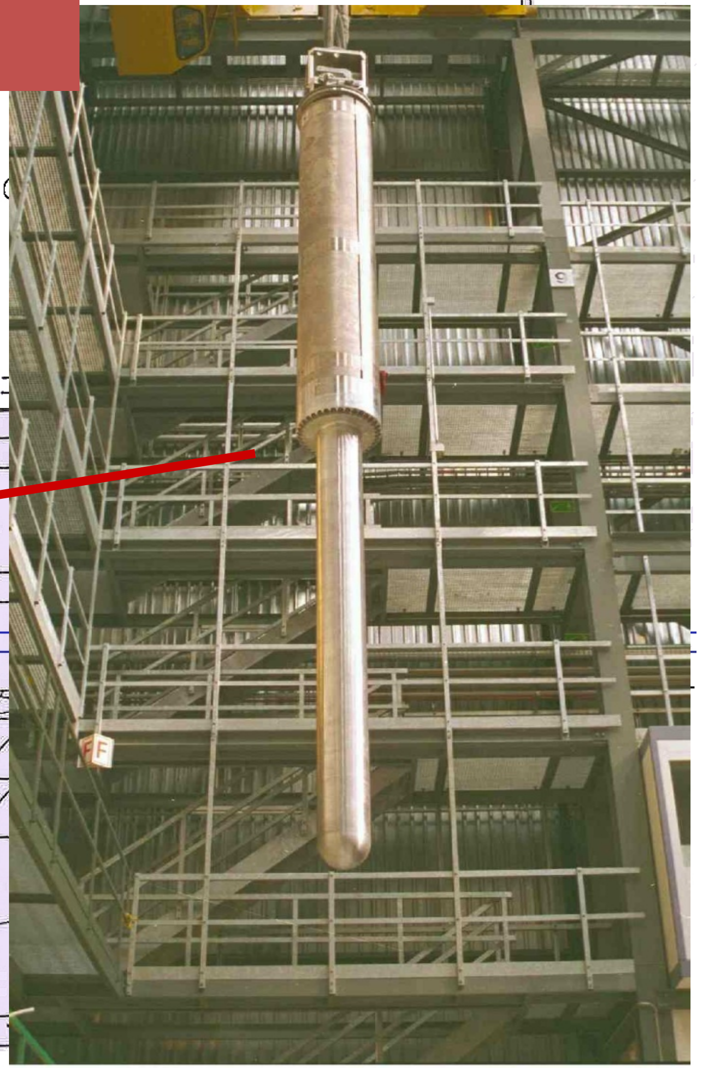
SINQ Target Station





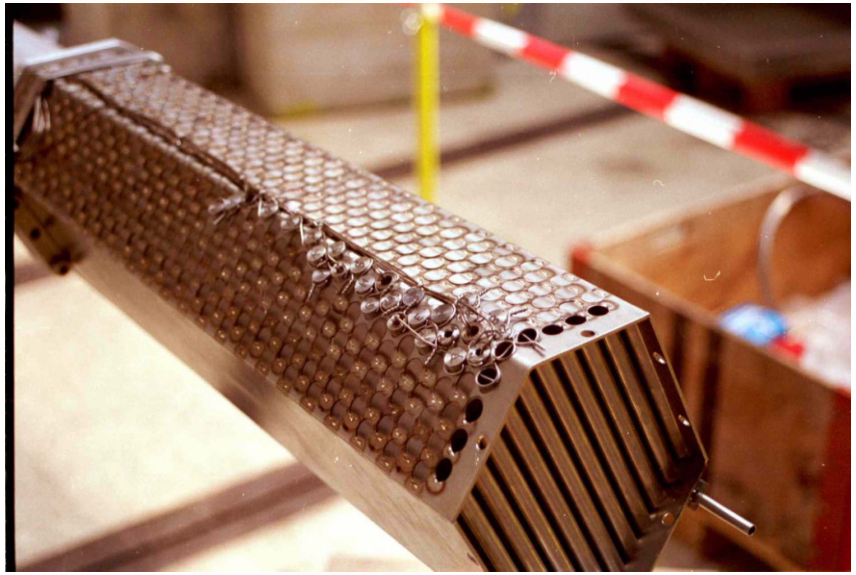


SINQ - Target

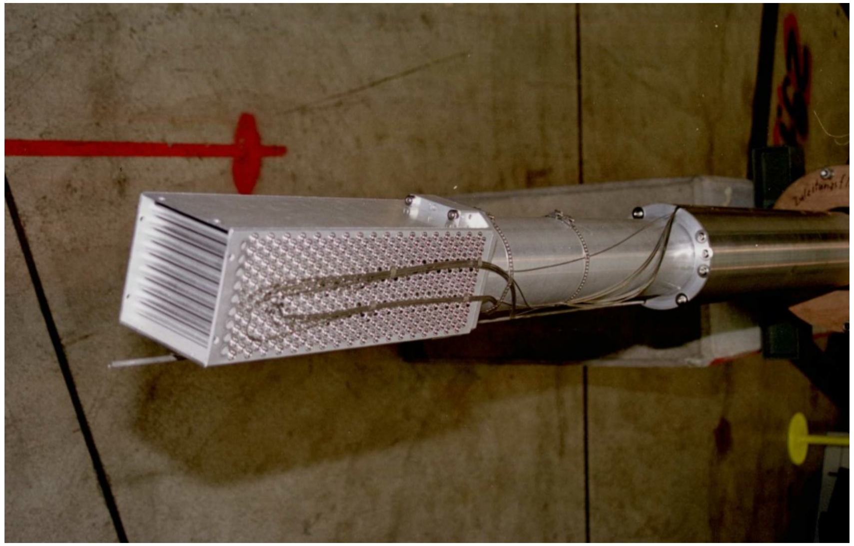
Target-01.jpg
GK87 / 12.05.99

Target Evolution at SINQ

1997-1999: SINQ Target Mark 2
Water-cooled Zircaloy rods



Since 2000:SINQ-Target Mark 3:
Lead rods, with steel clad
42% increase in neutron yield



Aug- Dec 2006: MEGAwatt Pilot Experiment:

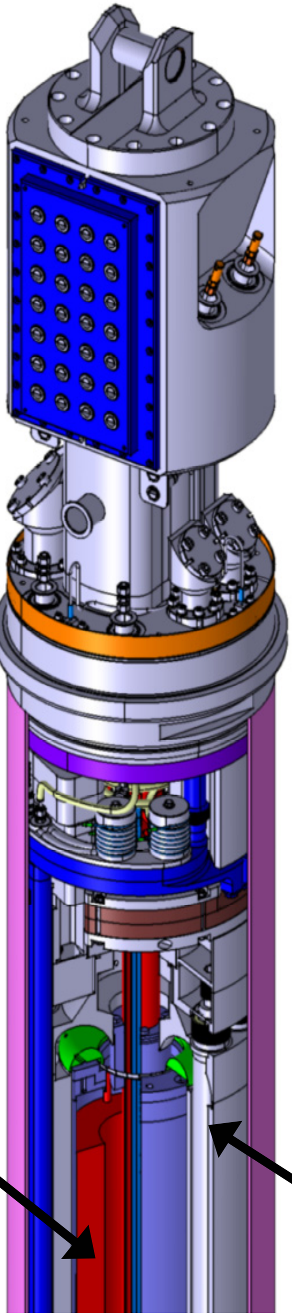
- **Joint international initiative to design, build, licence, operate and explore a liquid metal spallation target for 1 MW beam power**

MEGAPIE
A liquid metal target for SINQ

MEGAwatt Pilot Experiment:

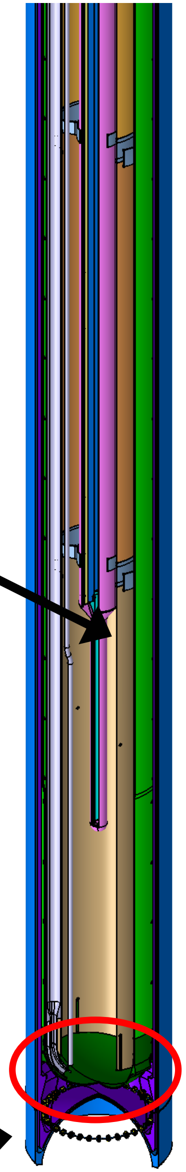
- Demonstrate the feasibility of a liquid metal target for high-power spallation and ADS applications
- Lead-Bismuth-Eutectic (LBE, T_m=125°C)
- Increase the neutron flux at SINQ

MEGAPIE (Pb-Bi) Target Features



electro-
magnetic
pumps

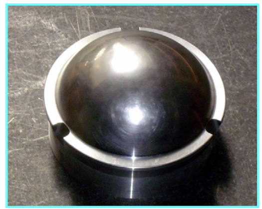
heat
exchanger



central flow
guide tube

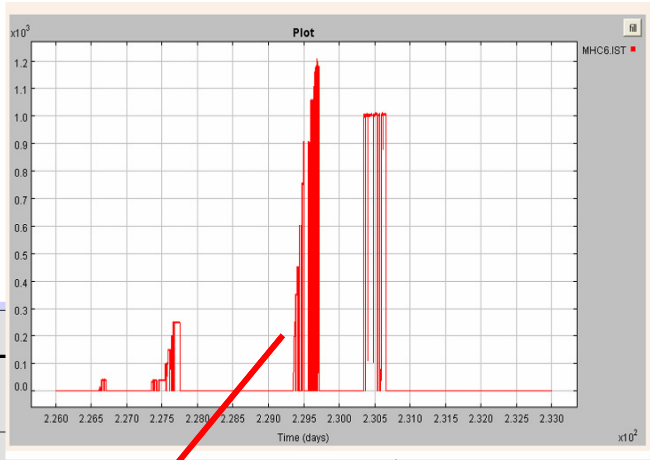
safety
hull

lower target
assembly



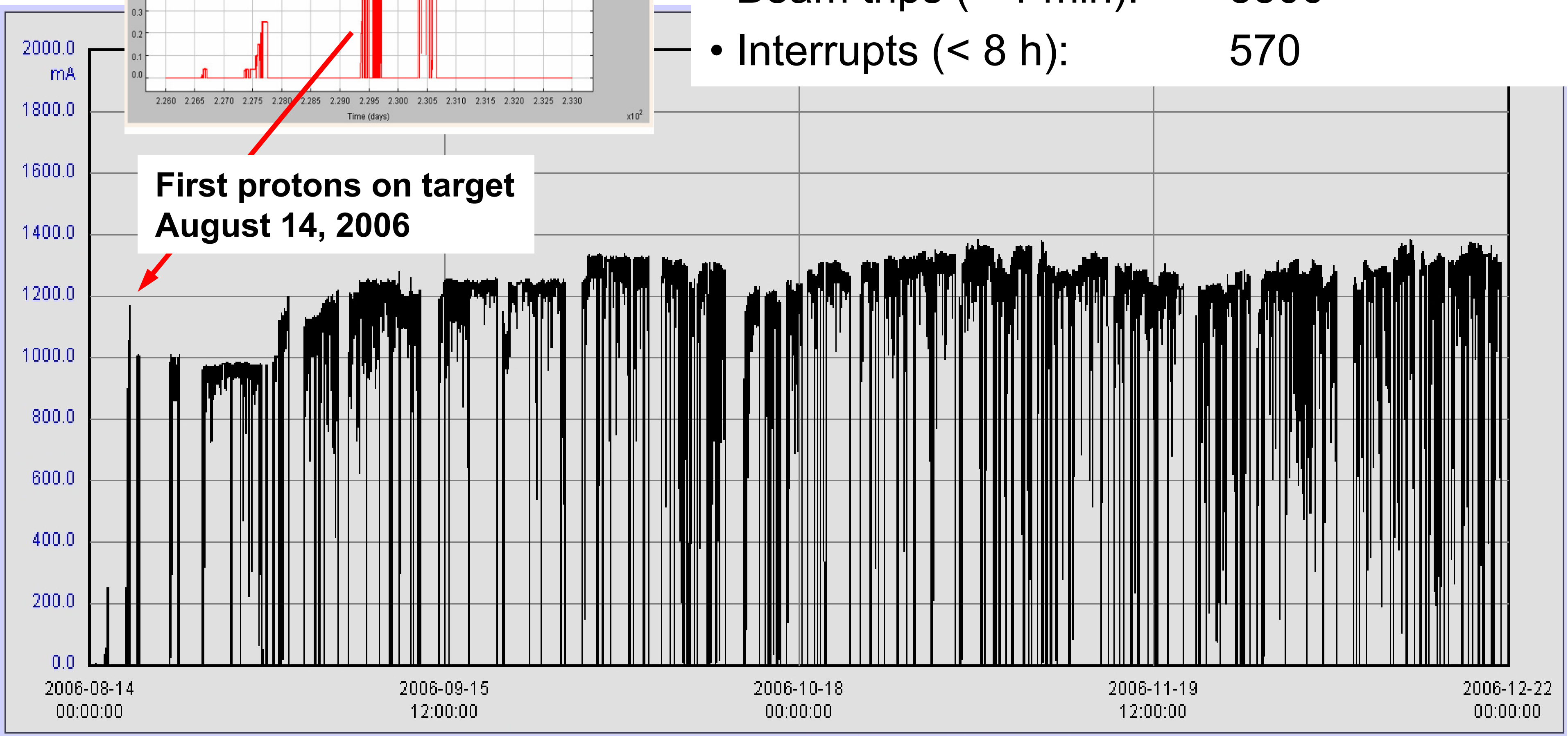
beam
window

MEGAPIE Target Operated Continuously for Four Months



Beam On Target: Aug 14 – Dec 21, 2006

- Accumulated charge: 2.8 Ah
- Peak Current: 1400 μA
- Beam trips (< 1 min): 5500
- Interrupts (< 8 h): 570

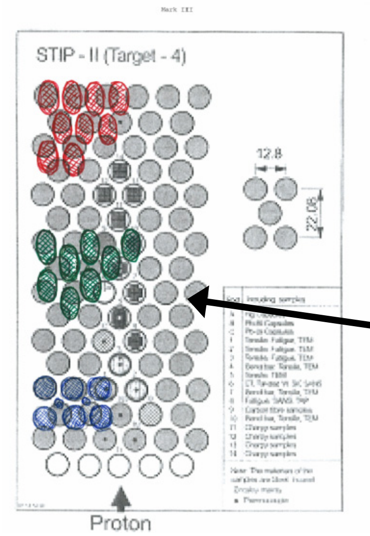


MEGAPIE Target Enhanced SINQ Neutron Flux

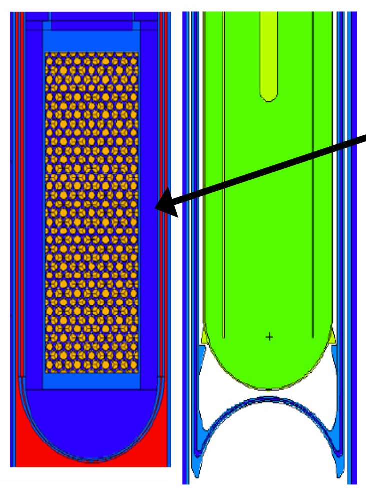
Fluxes measured by Au foil activation (in neutrons/cm^2/s/mA)

	SINQ 2005	Err. (%)	MEGAPIE 2006	Err. (%)	ratio
ICON	3.80E+8	~5	6.89E+8	~5	**1.81**
NEUTRA	2.59E+7	~5	4.80E+7	~5	**1.85**
EIGER	6.46E+8	~5	1.04E+9	~5	**1.61**
NAA	5.82E+12*	~5	1.04E+13	~5	**1.79**

Improvement options for the solid Pb canneloni target



Scetch from Knud Thomsen



(predicted) gain

- **Zr cladding** (replacing steel) → **10-13%**
  done!
- **compaction:** closer rod-packing (2mm gap ⇨ 1mm), oval rod shape ? → 5%
- **thinner tube wall** (0.75 mm ⇨ 0.5 mm) → 5%
- **Pb-reflectors** filling the gap around the canneloni structure → 10%
- **inverted calotte** of safety hull → 5%
- **No** (or less) **STIP samples** → 10%

~45%

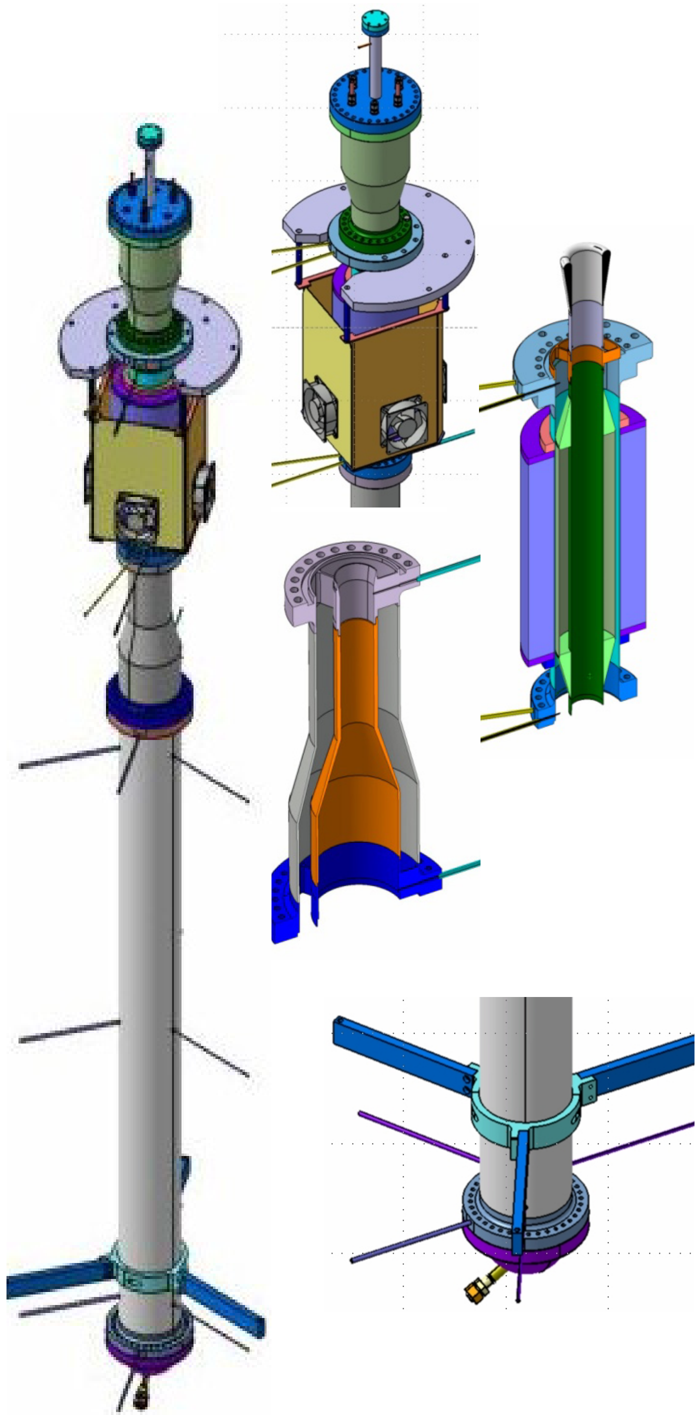
ULTIMATE GOAL: LIMETS

<u>Liquid Metal Target</u> for routine operation at SINQ

- **Only *one* flow path (no separate bypass)**
  - ***One* efficient EMP, at the cold side (down-stream) of the heat exchanger**
- ***New* heat removal concept (no oil)**
- **Reliable/functional sensors**
- **Improved heating and insulating system**
- **Desirable option: fit for liquid lead temperatures**

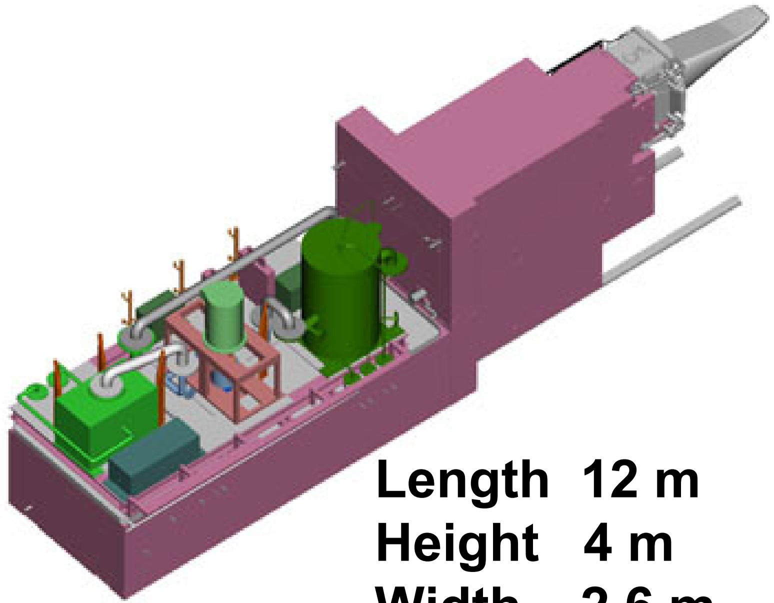
LiMeTS mock-up design (stage 1)

- **Modular design** allowing testing of different concepts heat exchangers, EM pumps, etc.
- Design phase underway

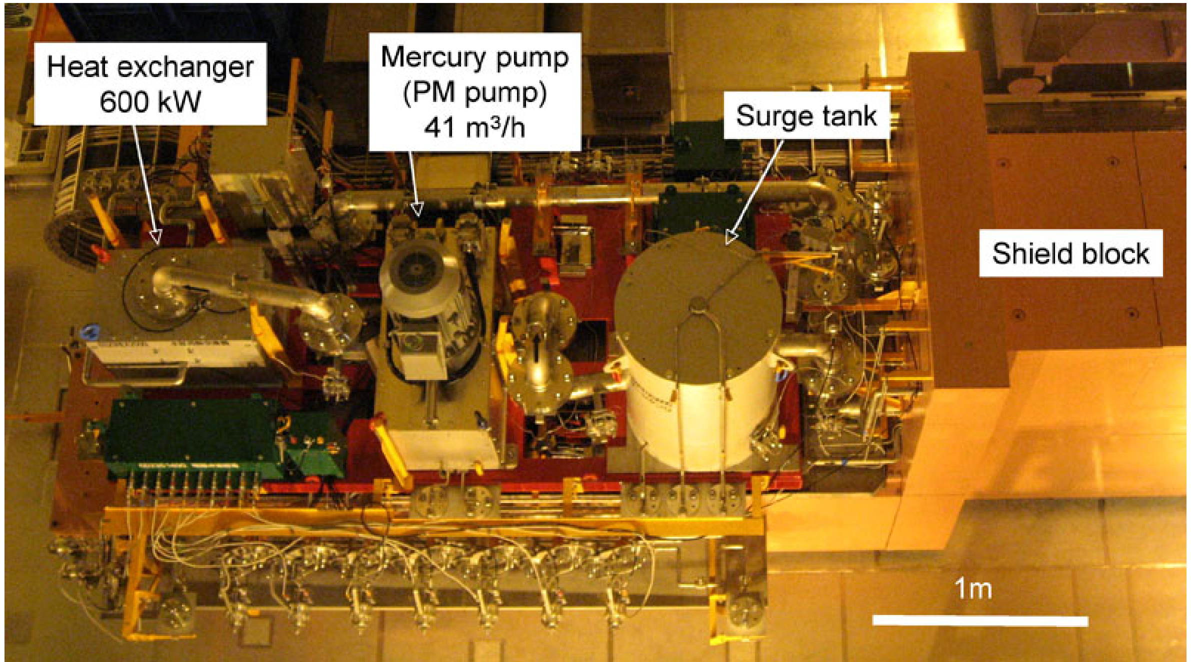


JSNS Hg Target

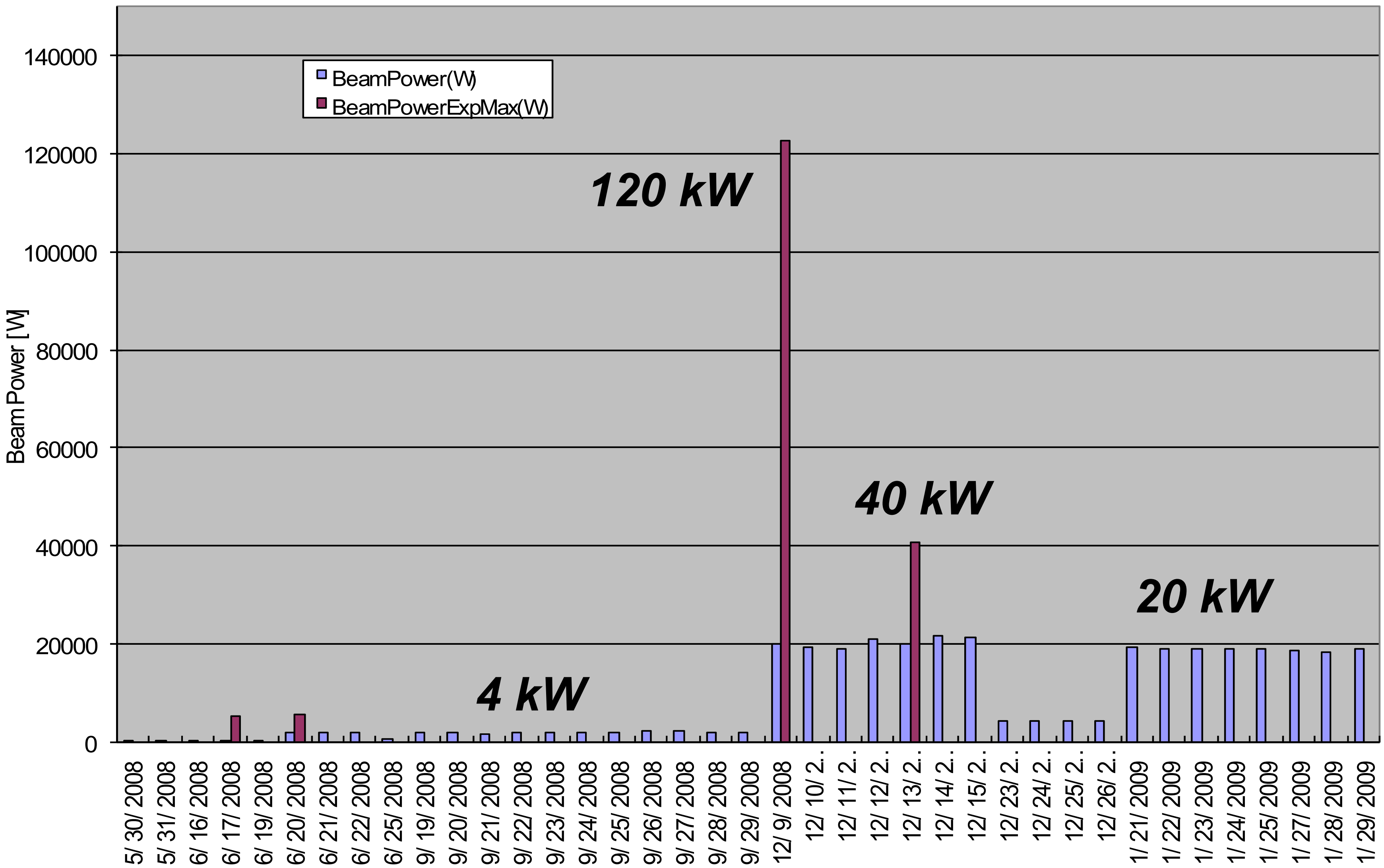
- Proton Beam (design parameters):
  - 3 GeV, 25 Hz rep rate, 0.33 mA ⇒ 1 MW
- Hg Target:
  - Cross-flow type, with multi wall vessel
  - Hg leak detectors between walls
  - All components of circulation system on trolley
  - Hot cell : Hands-on maintenance
  - Vibration measuring system to diagnose pressure wave effects



Length 12 m
Height 4 m
Width 2.6 m
Weight 315 ton



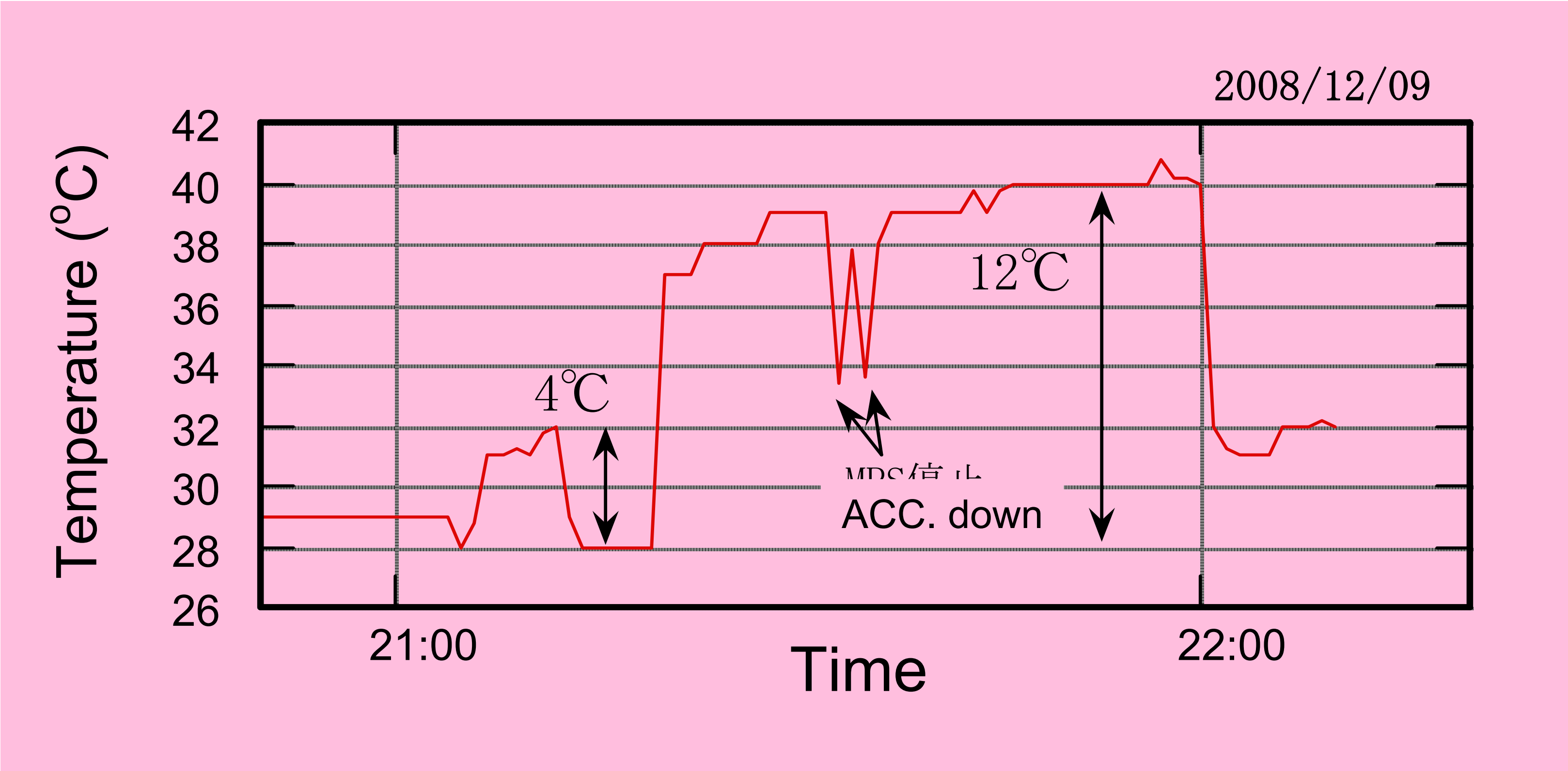
Beam power on target at 25 Hz



- 20 kW steady operation in Feb. 2009
- So far, max power 120 kW

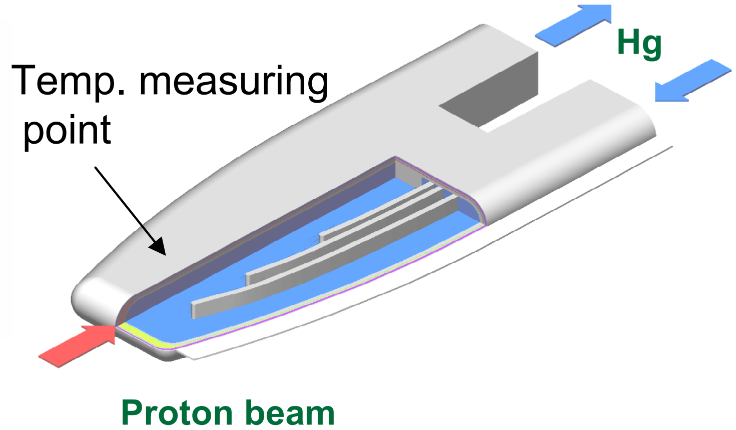
Oak Ridge National Laboratory

Target design confirmation at 120 kW

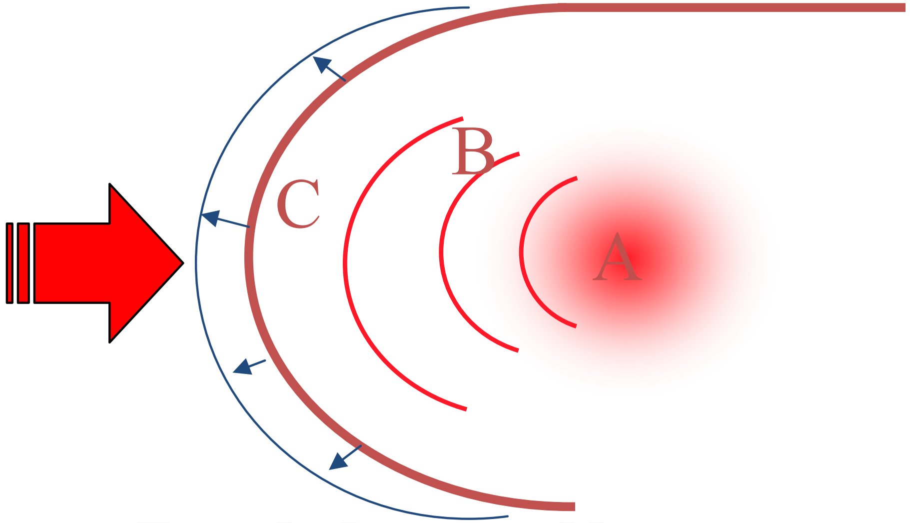


Confirmed Hg circulation system performance

- EM pump
- Heat exchanger
- Sensors



Bubble Injection Needed to Mitigate Cavitation Damage



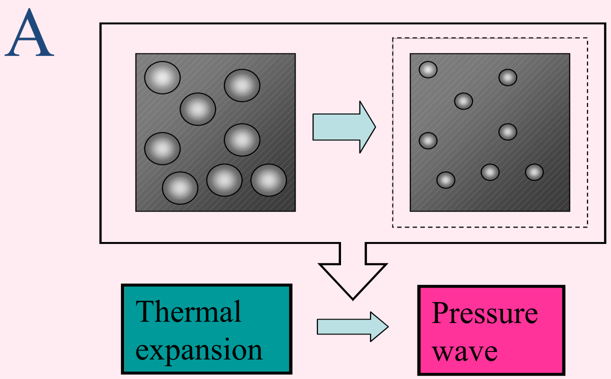
3 mechanisms

Center of thermal shock : A
Absorption

Propagation path : B
Attenuation

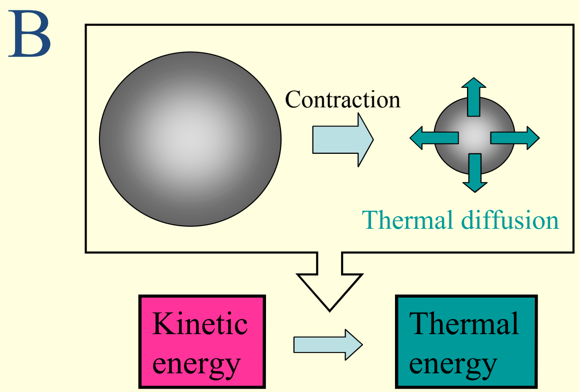
Negative pressure field : C
Suppression

Bubble diameter <50 μm



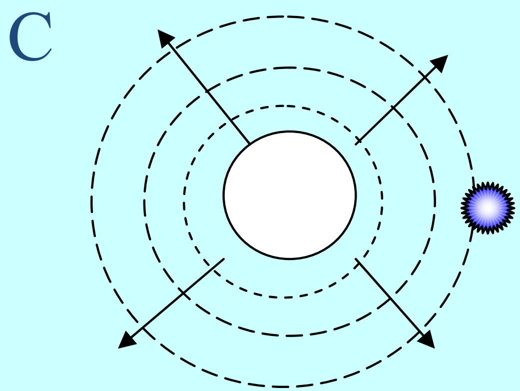
Absorption of the thermal expansion of mercury due to the contraction of micro bubbles

Absorption



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

Attenuation



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

Suppression

Bubblers applicable to target

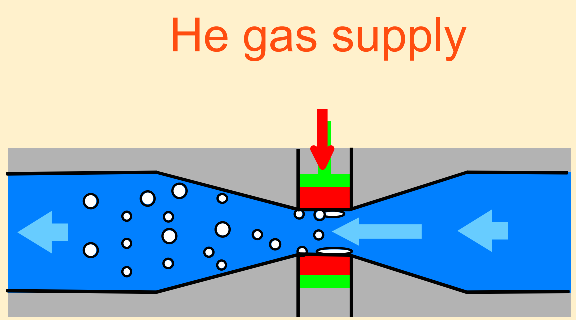
Which bubbler is most suitable for mercury target conditions?

Venturi

Difficult to control, D>50 μm

High erosion risk

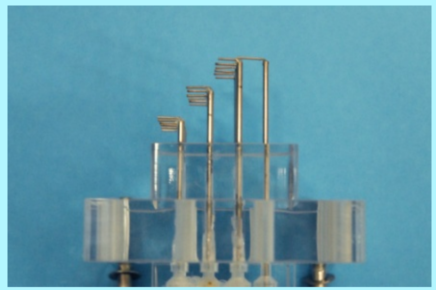
High pressure drop



Needle

Controllable, D>500 μm,

Flow induced vibration, Erosion



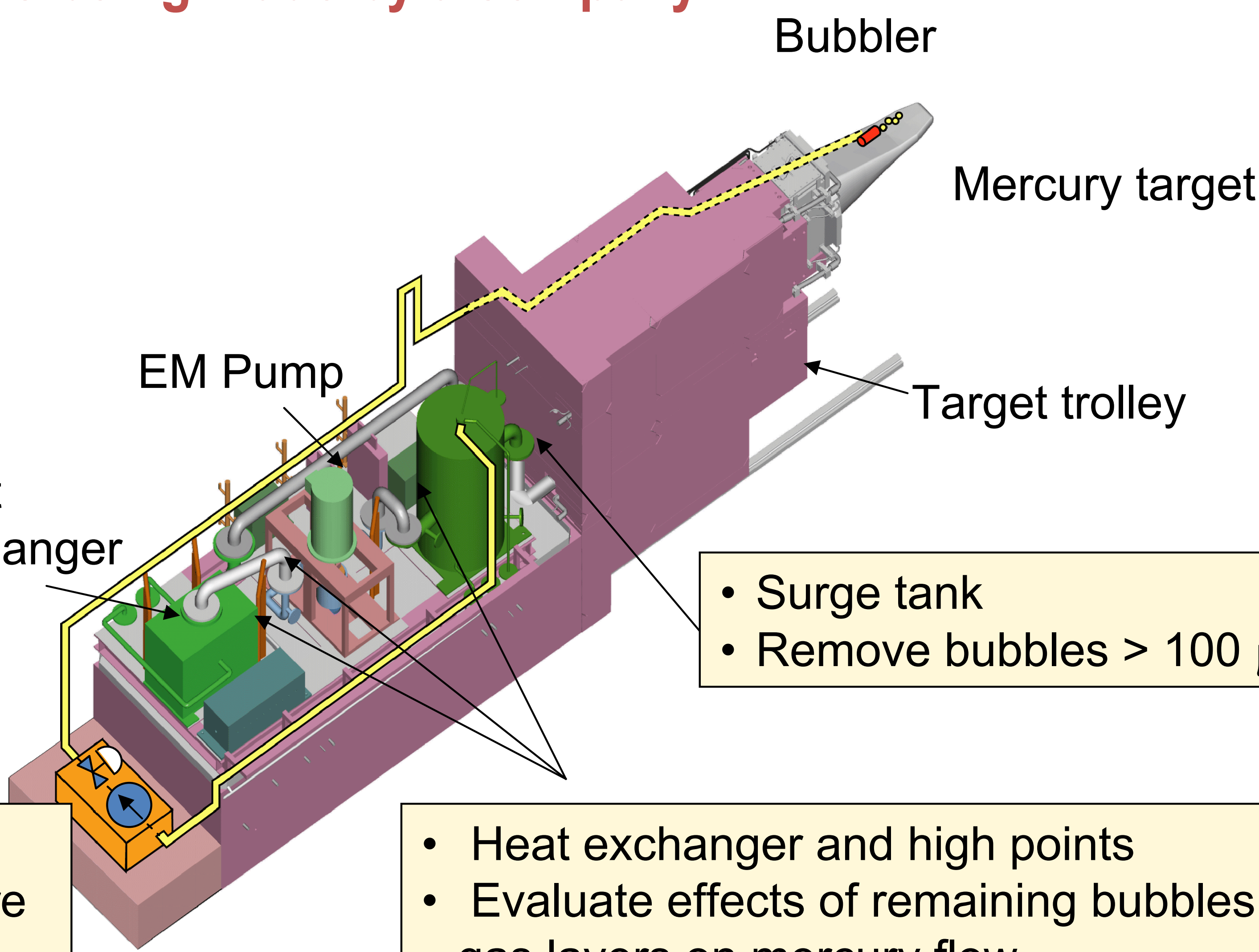
Swirl

Controllable, D<50 μm,

Acceptable pressure drop

Gas supply system for bubblers

- Component tests will be carried out in water and mercury loops
- Concept design is being made by a company



- Surge tank
- Remove bubbles > 100 μm

- Gas supply system
- Control gas pressure and flow rate

- Heat exchanger and high points
- Evaluate effects of remaining bubbles or gas layers on mercury flow

Strong Collaboration Between JSNS and SNS on Hg Target Development

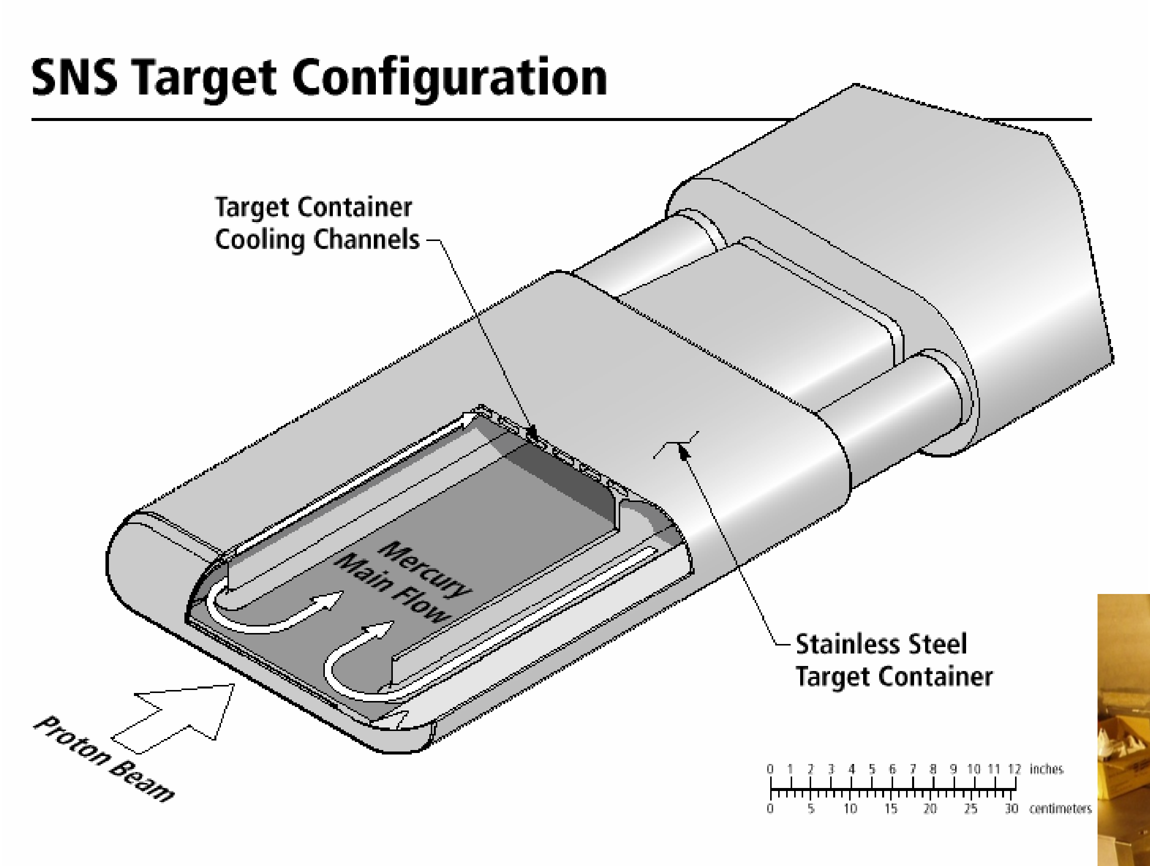
- Facilities for cavitation damage characterization and mitigation tests:
  - Off-line tests
    - JAEAs impact testing apparatus (MIMTM)
    - ORNLs full-scale Hg loop (TTF)
  - In-Beam Tests at LANLs WNR facility
- Characterize bubbles, measure mitigation effects, etc.

MIMTM

WNR

TTF

SNS Mercury Target

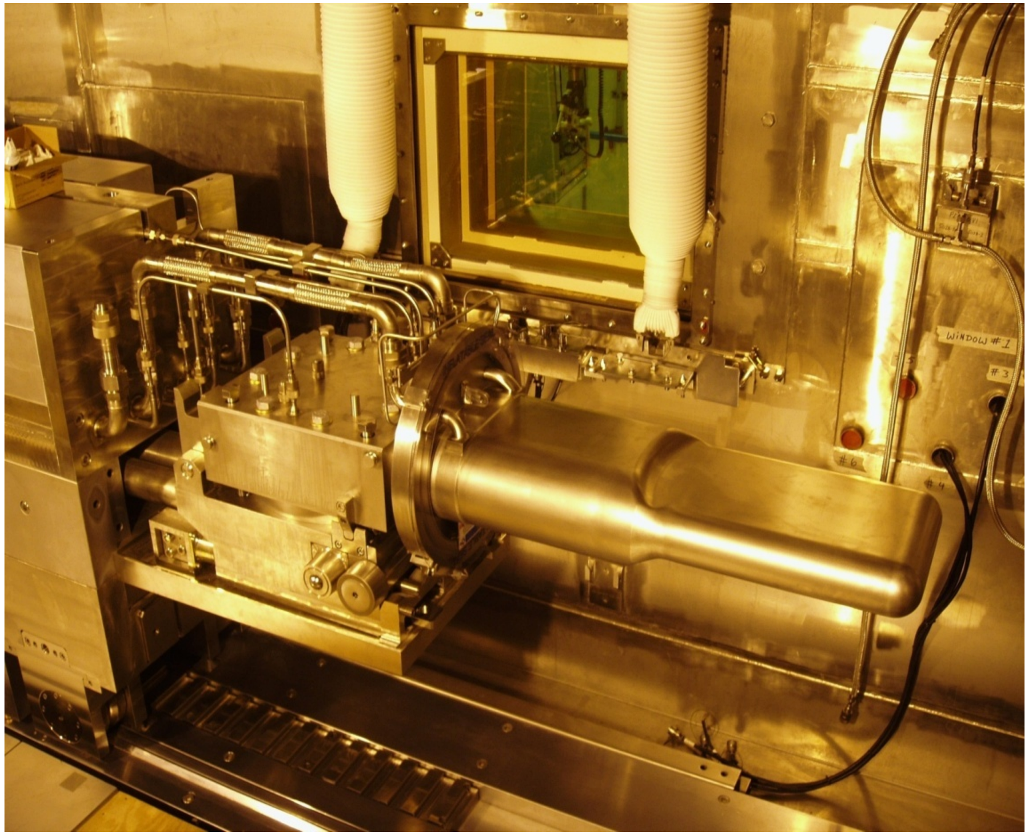


SNS Ultimate Parameters

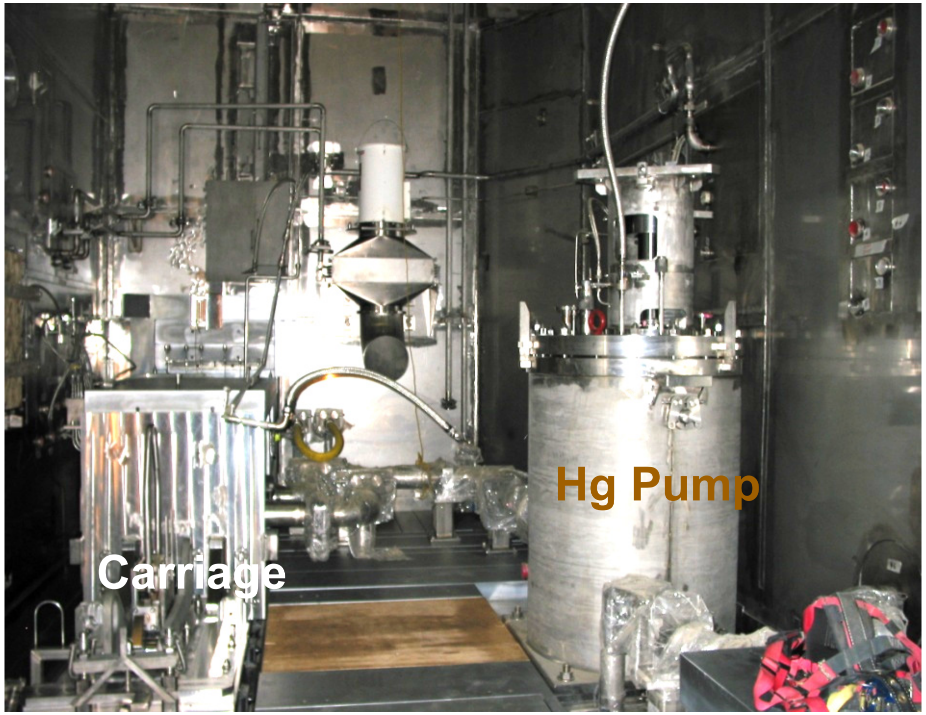
- 1 GeV protons
- 2 MW average beam power
- Pulse duration ~ 0.7 μs
- 60 Hz rep rate

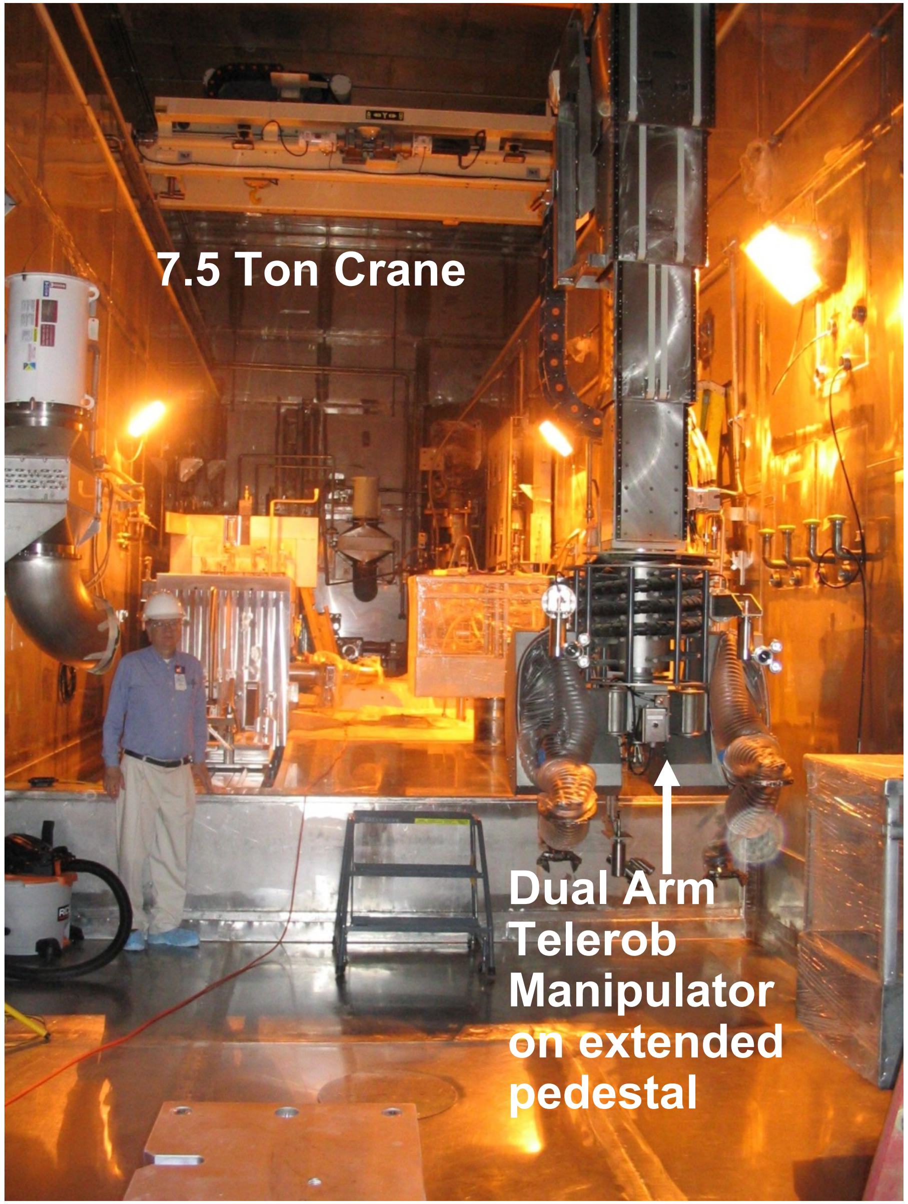
Hg Operating Parameters for 2 MW

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



Target Service Bay



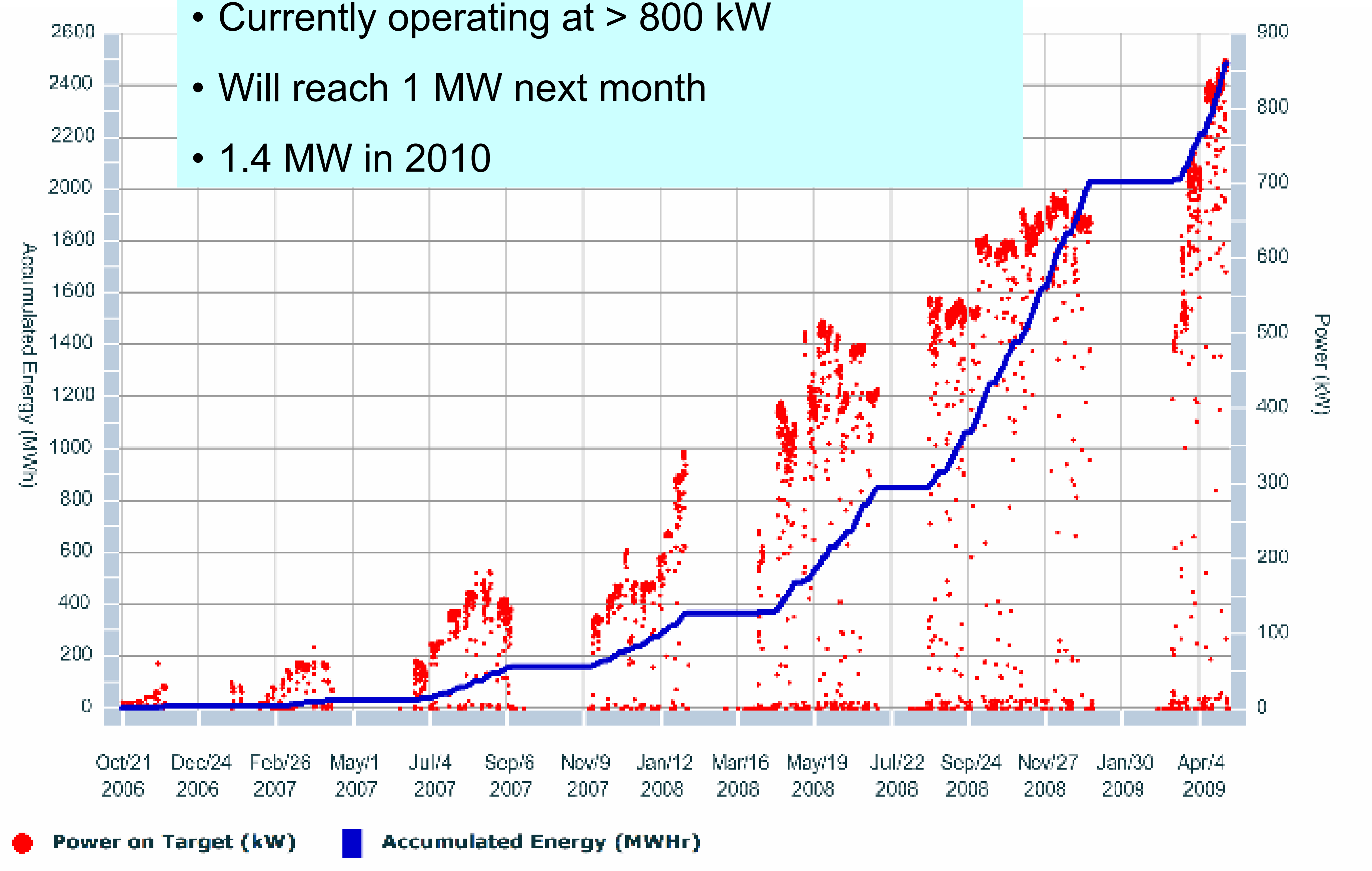


Target Service Bay

- Stainless-steel lined
- 4 window workstations
- 8 through-the-wall manipulators
- 7.5 ton crane
- Pedestal mounted manipulator
- Shielded transfer bay

SNS Power Ramp-Up

- Currently operating at > 800 kW
- Will reach 1 MW next month
- 1.4 MW in 2010

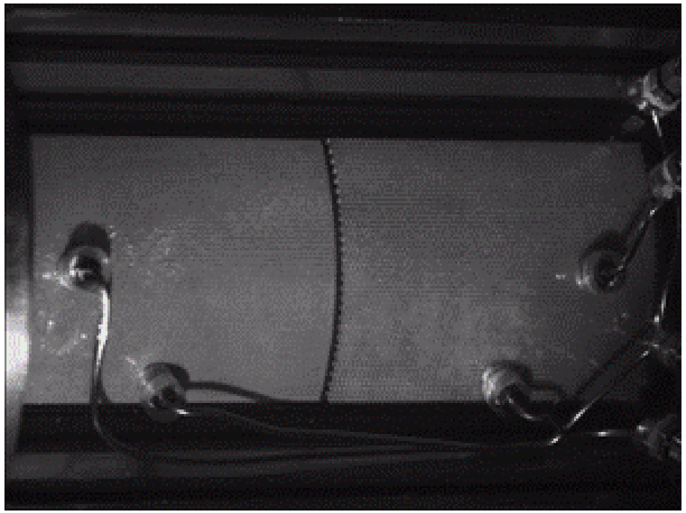


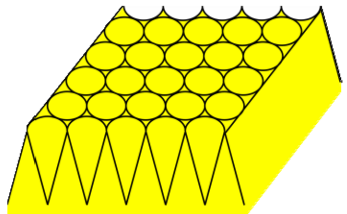
SNS Mercury Target Status and Plans

- Target module lifetime remains uncertain
  - Original target has surpassed goal of 5 dpa!
    - However, much of this fluence achieved at low power
  - Plan to run the first few targets to end-of-life, i.e., mercury leaks from primary container to its water-cooled shroud
    - But will remove in July 2009 shutdown if target survives until then (9 dpa)
- Post-Irradiation Examination (PIE)
  - Received tools
  - Arranged to examine target vessel samples in ORNL hot cells

SNS Mercury Target Status and Plans (continued)

- Nearly ready to implement diagnostic to view beam profile on target
  - Luminescent coating on front of target module viewed with optical system
- 1st spare target module staged for replacement, 2nd and 3rd spares at SNS
  - Strategy: Operate at power with ≤ 4 target replacements per year
- R&D program focused on finding means to extend lifetime





Concluding Remarks

- MEGAPIE, SNS, and JSNS projects successfully implemented liquid metal targets designed for ≥ 1 MW
  - MEGAPIE experiment completed in 2006; demonstrated ~ 1 MW reliable operation
  - SNS operating at 800 kW; ramp-up to 1.4 MW in 2010
  - JSNS demonstrated 120 kW; plan to ultimately achieve 1 MW
- SINQ pursuing more optimal solid targets in the near term and Pb-Bi (or Pb) targets for the longer term
- Cavitation damage remains a concern for short pulse sources with liquid metal targets
  - Target lifetime remains uncertain, but reasonably long lifetime established for SNS at 800 kW – limit remains to be discovered
  - Strong R&D collaboration between SNS and JSNS
- Future projects considering target alternatives for high power applications
  - SINQ, CSNS, ESS, SNS-STS, MTS
  - Liquid metal or rotating solid targets seem to be favored options