Megawatt Class Spallation Target Development

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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 Target Station

Proton beam:
- CW
- 590 MeV
- \( \sim 1.4 \text{ mA} \Rightarrow 0.8 \text{ MW} \)
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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
MEGAwatt Pilot Experiment:

- Demonstrate the feasibility of a liquid metal target for high-power spallation and ADS applications
- Lead-Bismuth-Eutectic (LBE, $T_m=125^\circ$C)
- Increase the neutron flux at SINQ
MEGAPIE (Pb-Bi) Target Features

electromagnetic pumps
heat exchanger
central flow guide tube
safety hull
beam window
lower target assembly
MEGAPIE Target Operated Continuously for Four Months

First protons on target, August 14, 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)

<table>
<thead>
<tr>
<th></th>
<th>SINQ 2005</th>
<th>Err. (%)</th>
<th>MEGAPIE 2006</th>
<th>Err. (%)</th>
<th>ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICON</td>
<td>3.80E+8</td>
<td>~5</td>
<td>6.89E+8</td>
<td>~5</td>
<td>1.81</td>
</tr>
<tr>
<td>NEUTRA</td>
<td>2.59E+7</td>
<td>~5</td>
<td>4.80E+7</td>
<td>~5</td>
<td>1.85</td>
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<tr>
<td>EIGER</td>
<td>6.46E+8</td>
<td>~5</td>
<td>1.04E+9</td>
<td>~5</td>
<td>1.61</td>
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<tr>
<td>NAA</td>
<td>5.82E+12*</td>
<td>~5</td>
<td>1.04E+13</td>
<td>~5</td>
<td>1.79</td>
</tr>
</tbody>
</table>
**Improvement options for the solid Pb canneloni target**

- **Zr cladding** (replacing steel) done!  
  → 10-13%

- **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

Liquid Metal Target 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 \(\Rightarrow\) 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
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
- Thermalexpansion of the thermal expansion of mercury due to the contraction of micro bubbles
- Absorption against cavitation bubble by compressive pressure emitted from gas-bubble expansion.

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

Suppression
- Bubble diameter <50 µm
**Bubblers applicable to target**

Which bubbler is most suitable for mercury target conditions?

<table>
<thead>
<tr>
<th>Bubbler</th>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Venturi</strong></td>
<td>Difficult to control, D&gt;50 μm, High erosion risk, High pressure drop</td>
<td>![Venturi Image]</td>
</tr>
<tr>
<td><strong>Needle</strong></td>
<td>Controllable, D&gt;500 μm, Flow induced vibration, Erosion</td>
<td>![Needle Image]</td>
</tr>
<tr>
<td><strong>Swirl</strong></td>
<td>Controllable, D&lt;50 μm, Acceptable pressure drop</td>
<td>![Swirl Image]</td>
</tr>
</tbody>
</table>
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.
SNS Mercury Target

SNS Target Configuration

Hg Operating Parameters for 2 MW
- Nom Op Pressure: 0.3 MPa
- Flow Rate: 340 kg/s
- $V_{\text{max}}$ (In Window): 3.5 m/s
- Temperature:
  - Inlet to target: 60°C
  - Exit from target: 90°C
- Total Hg Inventory: 1.4 m³

SNS Ultimate Parameters
- 1 GeV protons
- 2 MW average beam power
- Pulse duration ~ 0.7 µs
- 60 Hz rep rate
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 \( \leq 4 \) 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 $\geq 1$ MW
  - MEGAPIE experiment completed in 2006; demonstrated $\sim 1$ 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