New STIP PIE plan for tungsten and conceptual study for PIECE

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Target Division

www.europeanspallationsource.se
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The ESS Machine Layout

Target

Linear proton accelerator

Neutron science systems
ACCSYS: A 5 MW SCRF Linac

Design Drivers:
- High Average Beam Power: 5 MW
- High Peak Beam Power: 125 MW
- High Availability: > 95%

Key parameters:
- 2.86 ms pulses
- 2 GeV
- 62.5 mA peak
- 14 Hz
- Protons (H+)
- Low losses
- Minimize energy use
- Flexible design for future upgrades
For better neutronic performance, the spallation volume must have high neutron production density.

- Spallation material shall have high atomic number
- Spallation material shall have high density
- The material must be affordable, preferably with operational track records at other spallation sources.
Spallation Material

- Pure tungsten is chosen to be the spallation material at ESS:
  - Lower DBTT than W-10%Re for DPA > 0.3 [H. Ullmaier, F. Carsughi, NIM-B 101, 1995]
  - Higher thermal conductivity than other W-alloys [M. Rieth et al, Tech-Rep.-KIT]
  - Tantalum has a higher volumetric decay heat and lower neutron production density.
ESS Spallation Target

- Rotating tungsten target
  - Helium coolant at 1.0 MPa
  - Wheel diameter: 2.5 m
  - Tungsten slabs in 36 segments
  - Rotation speed: 23.3 rpm
Issues on tungsten material at ESS

- Thermal fatigue caused by beam pulses and beam trips
- Tungsten oxidation and release of radioisotopes
- Radiation Damage:
  - Reduced or no ductility
  - Reduced thermal conductivity

<table>
<thead>
<tr>
<th></th>
<th>Unirradiated</th>
<th>As irradiated</th>
<th>1050°C 1 h</th>
<th>1200°C 1 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile yield stress [MPa]</td>
<td>580</td>
<td>150</td>
<td>260</td>
<td>810</td>
</tr>
<tr>
<td>Total elongation [%]</td>
<td>10</td>
<td>*</td>
<td>*</td>
<td>4</td>
</tr>
</tbody>
</table>

Effect of irradiation on tensile strength at 500 C (T_{irrad}=700 C, ~2 dpa) [H. Ullmaier, F. Carsughi, NIM-B 101, 1995]

[J. Linke et al. First meeting of CRP on irradiated tungsten, Vienna, 26-28 Nov 2013]
SINQ Target (Y. Dai)

Proton beam

Cooling water (D2O)

AlMg3 container

$\sigma_x \sim 3.5 \text{ cm}, \sigma_y \sim 2 \text{ cm}$

~360 Pb rods with SS / Zy-2 tubes
Proton and neutron flux distribution (Y. Dai)
# PIE Plan using STIP (SINQ Target Irradiation Program) tungsten specimens

<table>
<thead>
<tr>
<th>STIP</th>
<th>Irradiated Period</th>
<th>Total p&lt;sup&gt;+&lt;/sup&gt; Charge</th>
<th>Tungsten Type</th>
<th>Dimension</th>
<th>Quantity</th>
<th>Irradiated Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>STIP-V</td>
<td>2007-2008</td>
<td>9.83 Ah</td>
<td>Rolled W for CSNS</td>
<td>60 × 8 × 1 mm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>2</td>
<td>5-28 dpa at 100-800 °C</td>
</tr>
<tr>
<td>STIP-VI</td>
<td>2011-2012</td>
<td>13.16 Ah</td>
<td>Rolled W from Goodfellow</td>
<td>27 × 5(6) × 0.5 mm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>52</td>
<td>5-25 dpa at 100-600 °C</td>
</tr>
<tr>
<td>STIP-VII</td>
<td>2013-2014</td>
<td>-</td>
<td>Rolled W from a Chinese company</td>
<td>bend bar</td>
<td>10</td>
<td>5-35 dpa at 100-600 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>rod with HIP’ed cladding</td>
<td></td>
<td>9</td>
<td>5-35 dpa at 100-600 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>HIP’ed full rod</td>
<td></td>
<td>1</td>
<td>5-35 dpa at 100-600 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>canned full rod</td>
<td></td>
<td>1</td>
<td>5-35 dpa at 100-600 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>HIP’ed W from KIT</td>
<td>bend bar</td>
<td>5</td>
<td>5-35 dpa at 100-600 °C</td>
</tr>
<tr>
<td>STIP-VIII</td>
<td>2015-2018</td>
<td>-</td>
<td>To be defined by June 2014</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
7 Pieces of tungsten sheets in Rod 5 of STIP-5 (Y. Dai)

The 5 larger pieces are about 15-20 mm long.
2 Pieces of tungsten samples in Rod 3 of STIP-5 (Y. Dai)
Samples from the 2 Pieces of tungsten sheets in Rod 3 of STIP-5 (Y. Dai)

~ 6x small bend samples
Size: 8x2x1 mm

Tensile samples
For the 5 larger pieces, one 6mm diameter disc and 4-6x bend samples of 8x2 mm will be cut from each piece.
Irradiate W samples in STIP-VI (Y. Dai)
Irradiation: 2011-2012, PIE: 2016 -
Irradiate W samples in STIP-VII (Y. Dai)
Irradiation: 2013-2014, PIE: 2016 -
Summary: STIP tungsten specimens

• A series of STIP tungsten specimens PIEs are planned.

• The PIEs will be supplemented by small-scale cold and hot materials tests.
  – Fatigue tests
  – Oxidation tests in inert gas
  – Thermal cycling tests
  – Coating evaluation
  – Tungsten release factor
Irradiation Module Feasibility Study
Irradiation Module Feasibility Study
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Irradiation Module Feasibility Study

- Four locations are identified for implementing irradiation modules for materials research.
- The passive modules in the beryllium reflector and in the spallation target are within the allocated budget.

<table>
<thead>
<tr>
<th>Location</th>
<th>Dominant particles</th>
<th>Estimated dose rate</th>
<th>Estimated He appm/dpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal moderator</td>
<td>Fast neutrons</td>
<td>7-14 dpa/GW-d</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Target upstream</td>
<td>Fast neutrons with halo protons</td>
<td>2-8 dpa/GW-d</td>
<td>10 - 100</td>
</tr>
<tr>
<td>Beryllium reflector</td>
<td>Thermal neutrons</td>
<td>1.0E22 n/cm²/GW-d</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Spallation target</td>
<td>Protons and fast neutrons</td>
<td>1.0 dpa/GW-d</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>
Feasibility of PIE Cells at ESS
Summary

• A series of PIEs are planned on STIP tungsten specimens.

• Conceptual design of irradiation modules are under way.
  – A low budget modules will be realized during the construction phase.

• Conceptual design of PIE cells are under way.
  – Space allocation with appropriate preparation for the floor loading will be done during the construction phase.

• The feasibility/justification of chip irradiation facility is under investigation.