Activation Assessment of the SNS STS

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Outlay

• Introduction
• SNS second target station
• Moderators optimization
• Heating, radiation damage and activation
• Final remarks
Introduction
Second target station

- short (<1 μs) proton pulses
- 1.3 GeV protons
- 10 Hz repetition rate
- 466 kW beam power
- stationary compact target W plates cladded with Ta
- beam footprint ~ 30 cm² (90% of the beam)
- 22 instruments projected

STS will be optimized for high intensity and high resolution long wavelength neutron applications.
Second target station

- Stationary plate-type
- 17 plates (Ta clad W)
- 30 cm total length
- 1.5 mm D$_2$O cooling channels between plates
- Plate thicknesses vary to limit peak temperature in plate < 250°C, peak surface temperature < 110°C
Three moderators will provide neutrons to 22 instruments.
Moderator optimization procedure

Main components:

- **MCNPX**
- **Mcnp_pstudy** [1]
- **Run_mcnpx**
- **Optimizer**
  - (optimization routines by Mockus[2])

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Moderator optimization

Point detectors used to calculate fluxes at 10 m from the moderators

FOM for coupled moderators

\[
FOM = \int_0^{5\text{meV}} \text{max}_t(\Phi(E, t)) dE
\]

FOM for decoupled moderators

\[
FOM = \int_0^{E_0} \int_{t_o(E)}^{t_o(E)+\Delta t(E)} \Phi(E, t) dt \ dE - \int_0^{E_0} \int_{t_o(E)+\Delta t(E)}^{\infty} \Phi(E, t) dt \ dE
\]

\[
t_o(E) = \frac{\Delta x}{\sqrt{\frac{2E}{m_n}}}
\]

\[
\Delta t(E) = \begin{cases} 
\frac{2.5}{E^{0.482}} \mu s & \text{for hydrogen} \\
45 \mu s & \text{for water}
\end{cases} 
\]

\[
E_0 = \begin{cases} 
10 \text{ meV} & \text{for hydrogen} \\
50 \text{ meV} & \text{for water}
\end{cases}
\]
Optimization parameters for the cylindrical moderator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBH</td>
<td>39.4</td>
</tr>
<tr>
<td>MBR</td>
<td>41.1</td>
</tr>
<tr>
<td>PMLR</td>
<td>21.4</td>
</tr>
<tr>
<td>PMLB</td>
<td>23.2</td>
</tr>
<tr>
<td>PMLT</td>
<td>21.4</td>
</tr>
<tr>
<td>TZP</td>
<td>-88.0</td>
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</tbody>
</table>

Viewed moderator faces:
- two 3 cm x 3 cm
- one 3cm x 6 cm
Optimization parameters for the top upstream box moderator

<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>CBMBL</td>
<td>84.0</td>
</tr>
<tr>
<td>CBPMXB</td>
<td>21.1</td>
</tr>
<tr>
<td>CBPMXT</td>
<td>18.4</td>
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<tr>
<td>CBPMYB</td>
<td>12.6</td>
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<tr>
<td>CBPMYT</td>
<td>8.48</td>
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<tr>
<td>CBPML</td>
<td>24.2</td>
</tr>
<tr>
<td>CBPMT</td>
<td>21.4</td>
</tr>
<tr>
<td>CBDZ</td>
<td>0.0, (-37.2)</td>
</tr>
</tbody>
</table>

Viewed moderator face:
- one 5 cm x 5 cm
Optimization parameters for the top downstream decoupled moderator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCMBL1</td>
<td>21.3, (25.0)</td>
</tr>
<tr>
<td>DCMBL2</td>
<td>22.5, (25.0)</td>
</tr>
<tr>
<td>DCMVD</td>
<td>8.96</td>
</tr>
<tr>
<td>DCDY</td>
<td>10.1, (4.89)</td>
</tr>
<tr>
<td>DCDZ</td>
<td>16.2, (13.2)</td>
</tr>
</tbody>
</table>

Viewed moderator face:
- one 7 cm x 7 cm (H₂O)
- one 7 cm x 7 cm (H₂)
STS coupled para-H$_2$ moderators exhibit ~13 to 10 times higher brightness relative to the FTS coupled moderators (FTS at 2 MW).
STS decoupled moderator:
- para-$\text{H}_2$ moderator $\sim 3$ times
- $\text{H}_2\text{O}$ moderator $\sim 4$ times
higher brightness relative to the FTS decoupled moderators (FTS at 2 MW).

STS decoupled moderators are not in optimal location.
Cooling with D$_2$O possible; with flow velocity $\sim$ 10m/s, and plate peak temperature $\sim$ 250 °C (inside) and $\sim$ 110°C at the surface. Exit pressure $\sim$ 3 bars provides adequate margin from boiling.
Heating rates around STS target

At > 0.001 W/cc active cooling is needed
Dpa rate in steel; vertical cut through STS

Red isoline marks the region of 10 dpa per 40 years of operation (for steel)
Dpa rate in target beam window (stainless steel)

Proton:
Max. 5.41 dpa/y

Neutron:
Max. 5.72 dpa/y

Estimated target window lifetime ~ 11 months (at 5000 h/year)
Aluminum proton beam window: He production rate and dpa rate

Max. He production rate: $\sim 890$ appm/y;
Estimated lifetime: 2.3 years;
Neutron contribution negligible

Max dpa rate: $1.54$ dpa/y;
Estimated lifetime: 26 years;
Neutron contribution $\sim 12\%$. 
Burnup of Cd decoupler and poison plates

Estimated lifetime:
side decoupler ~3.2 years;
poison plate ~4.6 years;
1 mm Cd assumed

Simple estimates based on initial burnout rate only.
Target decay heat rate versus decay time

Decay heat is high, dominated by tantalum at \( t > \sim 12 \) minutes

![Graph showing decay heat rate versus decay time with different materials and decay times.

**Target:**
- tungsten 23.6 kg
- SS 17.1 kg
- tantalum 2.7 kg

**Decay heat:**
- 500 W at \( \sim 97 \) d
- 300 W at \( \sim 220 \) d

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Gamma-ray source intensity versus decay time

Tantalum dominates gamma-ray source intensity at $t > \sim 1$ minute
Target hazard relative to DOE Cat-3 threshold

Dominant contribution from tungsten at all times.

Graph showing the fraction of DOE CAT-3 over decay time (s). The graph includes lines for Total, Tungsten, Tantalum, Tungsten + Tantalum, and Stainless Steel Shroud, with key points marked at 1 minute, 1 hour, 1 day, 1 month, and 1 year.
Final remarks

• Preparatory work for STS at SNS is proceeding well

• For the STS considerably higher moderator brightness is predicted at 0.477 MW operation relative to the FTS at 2 MW
  • Coupled moderators ~ 10 - 13 times higher brightness
  • Decoupled moderators ~ 3 - 4 times higher brightness
  • Instrument requirements will drive final moderator design
  • Advance moderator concepts may be included

• Based on radiation damage to the target window the target lifetime is ~ 11 months
  • Radiation damage to tantalum and tungsten likely not limiting, but will be considered in future work

• Decay heat and radionuclide inventory of the spent target is much higher than for FTS
  • Despite small mass Ta dominates target decay heat and gamma-ray source