Technical Issues for Cannelloni at High Power

High Power Targety Workshop, Malmö, May 2011

K. Thomsen, F. Heinrich, M. Butzek, J. Wolters, F. Sordo, A. Sander-Holm
Good experience motivates consideration and preliminary assessment shows promising performance of Cannelloni for ESS

NIMMA 625, 5-11 (2011), AccApp’11 Knoxville
Principal water-cooling circuit

1 pump
2 Target
3 decay tank
4 heat exchanger
5 expansion tank
6 filter
1 pump  
2 Target  
3 decay tank  
4 heat exchanger  
5 expansion tank  
6 filter
Good experience and simple calculation confirm modest required parameter values:

\[ Q = m \cdot c_p \cdot \Delta T \]

- \( Q \) ........ transported heat [ W ]
- \( m \) ........ massflow [ kg/s ]
- \( c_p \) ........ specific heat (water = 4190 J/kg K)
- \( \Delta T \) ........ temperature increase in coolant [ K ]

\[ 3 \text{ MW}_{\text{therm}} = 35.8 \times 4190 \times 20, \text{ i.e. } \Delta T = 20 \text{ K @ 36 l/s} \]

also radiological issues, handling, … are well known
Averaged and local convective heat transfer coefficients for the first few rows with a gap width of 1.5 mm, \( v = 1 \text{ m/s}, T_{\text{bulk}} = 40^\circ \text{C} \); coarse \( \kappa \) vs. fine SST CFX-models.

Water-cooling, limits

Water offers reserve:

"Shah"-relation for 0.75 m/s water flow at \( T_{\text{bulk}} = 40^\circ \text{C} \) and 5 bar for a single tube

Convective cooling

Convective heat transfer and pressure loss of cannelloni bundle with a gap width of 1 and 2 mm in cross-flow

G. Heidenreich

see presentation R. Milenkovic
Many configurations are possible, some examples:

0) crossflow, along beam direction, horizontal tubes, circular / rectangular geometry (SINQ, UCN)
1) „flat nose“, crossflow bottom up, horizontal tubes
2) „flat nose“, crossflow sideways, horizontal tubes
3) „flat nose“, crossflow sideways, vertical tubes
4) System layout on platform
5) Last step: continuously rotating wheel
6) …..
crossflow, along beam direction, horizontal tubes, circular / rectangular geometry (SINQ, UCN)

Well established, requires ~300 cm² cross-section
„flat nose“, crossflow bottom up, horizontal tubes

sideways connections are not in the way to the moderators
"flat nose", crossflow sideways, horizontal or vertical tubes

connections are even less in the way, (...continuous rotation)
(vertical tubes with essentially solid filling only)
System layout on platform

Starting in stepping mode allows for gradual build up of experience, qualification of new components in the peculiar spallation environment and for continual upgrades. The possibility of quickly swapping between inserts ensures maximum availability. Completing the remainders of the wheel with optimized reflector material could partly compensate for the lower density compared to more dense tungsten.

swapping targets at end of life (.....> continuous rotation)
Continuously rotating wheel(s)

Figure 53: Rotating target mounted on a water hydraulic bearing and drive unit featuring sliding rind seals (SNQ 1984)

Figure 51: Cross-flow low density configuration

cannelloni ...> panzarotti ...> canned tungsten blocks
Peak temperatures after pulse for cannelloni (conf.1) during 50 ms

Temperature Cannelloni external surface
Temperature Cannelloni internal surface
Temperature in Pb Center
Mean current density: 21.2 µA/cm²
\(\sigma_x \times \sigma_y = 50 \times 30 \text{ mm}\)
Mean current density: 42.4 µA/cm²
(for maximum loaded location)
\(\sigma_x \times \sigma_y = 50 \times 15 \text{ mm}\)

A wide / flat beam profile relaxes conditions significantly for any target
there are ways to improve on the reference beam:

**Reference conditions:**
- 5 MW, 2.5 GeV, 2mA (average),
- $\sigma_X=5\,\text{cm}$, $\sigma_Y=1.5\,\text{cm}$,
- duration 1 ms, repetition rate 20 Hz
- peak current density: $42.44\,\mu\text{A/cm}^2$

- adding 2 octupoles in HEBT already reduces peak by 35 %
- with a sophisticated multipole system a flat profile (+/- 7 %) over 200x50 mm can probably be achieved
Preliminary result: Cannelloni produce 82 % of LBE (H₂O coolant, lead filling)

see presentation L. Zanini
Replacing lead by tungsten increases density & brilliance and neutronic yield:

Example geometry full wheel:
- 100% tungsten
- 75% tungsten
- 75% tungsten & 25% light water
Cannelloni offer minimum risk and maximum safety

- Limited development required (14 years in SINQ)
- Very high availability proven / expected
- Water-cooling offers relatively convenient handling
- Cannelloni open widest options for improvements
  (e.g. Cannelloni on a wheel can handle > 5 MW)
- Low building-, operations- and decommissioning cost
- Licensing and public acceptance are relatively easy
- Price to pay: some initial reduction in neutronic yield
Suggested Further Steps:

• Simulations:
  Optimize Geometry / Coupling for Cannelloni Target
  (Target, Moderator, Reflector, Beam Lines, Shielding)

• Simulations & Experiments:
  Verify Cooling Limits in Representative Set-Up(s)

• Re-Assessment:
  Size of & Response to Repetitive Stresses

• Urge Linac to provide Least Pointed Beam Profile
Acknowledgements

G. Heidenreich, K. Geissmann, and many more
3 more slides on criteria / evaluation
## Cannelloni in the light of main Selection Criteria, OVERVIEW

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Pro</th>
<th>Con</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>X</td>
<td></td>
<td>Low, relatively conventional water cooling</td>
</tr>
<tr>
<td>(building, op., decom.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td>X</td>
<td>Limited, “diluted target“</td>
</tr>
<tr>
<td>Safety</td>
<td>X</td>
<td></td>
<td>High, lead, water and zircaloy make the least harmful inventory reasonable possible</td>
</tr>
<tr>
<td>Devel. Risk</td>
<td>X</td>
<td></td>
<td>Low, 14 years of SINQ experience</td>
</tr>
<tr>
<td>Availability</td>
<td>X</td>
<td></td>
<td>High, quick replacement on wheel</td>
</tr>
<tr>
<td>Maintainability</td>
<td>X</td>
<td></td>
<td>High, hands-on access to cooling circuits</td>
</tr>
<tr>
<td>Upgradeability</td>
<td>X</td>
<td></td>
<td>High, e.g. via wheel speed up to high power</td>
</tr>
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### Cannelloni in the light of main Selection Criteria, SAFETY

<table>
<thead>
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<th>Criterion</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Chemical toxicity</td>
<td>X</td>
<td></td>
<td>Relatively low, during operations limited Hg produced</td>
</tr>
<tr>
<td>Radio-toxicity</td>
<td>X</td>
<td></td>
<td>Relatively low, during operations limited Po produced</td>
</tr>
<tr>
<td>Release in op.</td>
<td>X</td>
<td></td>
<td>Low, only limited tritium</td>
</tr>
<tr>
<td>Release in acc.</td>
<td>X</td>
<td></td>
<td>Low, inventory well contained in tiny portions, low decay heat</td>
</tr>
<tr>
<td>Radiation exp.</td>
<td>X</td>
<td></td>
<td>Low, cooling with water</td>
</tr>
<tr>
<td>Handling</td>
<td>X</td>
<td></td>
<td>Most hands-on, only small inserts (or wheel) require relatively small hot cell and remote handling</td>
</tr>
<tr>
<td>Decomm. &amp; Disp.</td>
<td>X</td>
<td></td>
<td>Established, relatively easy</td>
</tr>
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### Cannelloni in the light of some more prop. Selection Criteria

<table>
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<th>Criterion</th>
<th>Pro</th>
<th>Con</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure tolerance</td>
<td>X</td>
<td></td>
<td>High, quick replacement (on wheel)</td>
</tr>
<tr>
<td>Flexibility</td>
<td>X</td>
<td></td>
<td>Example: SINQ, wheel opens many options</td>
</tr>
<tr>
<td>Public acceptance</td>
<td>X</td>
<td></td>
<td>High, (PSI experience)</td>
</tr>
<tr>
<td>Licensing</td>
<td>X</td>
<td></td>
<td>Comparatively easy, (PSI experience)</td>
</tr>
<tr>
<td>Damage potential to facility</td>
<td>X</td>
<td></td>
<td>Low, solid lead, water</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>X</td>
<td></td>
<td>Established, relatively easy</td>
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