Minicooling Absorber Design and Performance

Dan Kaplan, IIT

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Outline:

1. Minicooling absorbers
2. Power dissipation and refrigeration cost
3. Heat transfer
4. Window design
5. Alternatives to LH₂
6. Conclusions
Minicooling:

- “Parameters version 2” calls for 2 minicooling absorbers preceded by beryllium plate (to absorb low-\(E\) protons):

<table>
<thead>
<tr>
<th>Absorber</th>
<th>Mat'l</th>
<th>Length (cm)</th>
<th>Radius (cm)</th>
<th>Power Diss. (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;0&quot;</td>
<td>Be</td>
<td>1?</td>
<td>30</td>
<td>?</td>
</tr>
<tr>
<td>1</td>
<td>LH(_2)</td>
<td>175</td>
<td>30</td>
<td>(\approx 5.5)</td>
</tr>
<tr>
<td>2</td>
<td>LH(_2)</td>
<td>175</td>
<td>30</td>
<td>?</td>
</tr>
</tbody>
</table>

- H. Kirk simulation results (from 12/18/00 video meeting):
ICOOL Simulation Results

Induction Linac Phase Rotation
Power dissipated in 1st mini-cool LH cell

Positive muon collection

<table>
<thead>
<tr>
<th>Power, KW</th>
<th>e</th>
<th>μ</th>
<th>π</th>
<th>K</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>positives</td>
<td>0.42</td>
<td>2.02</td>
<td>0.14</td>
<td>0</td>
<td>0.86</td>
</tr>
<tr>
<td>negatives</td>
<td>0.43</td>
<td>1.29</td>
<td>0.24</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

Total Power dissipated = 5.4 KW

Negative muon collection

<table>
<thead>
<tr>
<th>Power, KW</th>
<th>e</th>
<th>μ</th>
<th>π</th>
<th>K</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>positives</td>
<td>0.42</td>
<td>1.45</td>
<td>0.19</td>
<td>0</td>
<td>0.94</td>
</tr>
<tr>
<td>negatives</td>
<td>0.45</td>
<td>1.90</td>
<td>0.14</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

Total Power dissipated = 5.5 KW
Refrigeration Costs:

- 15´ bubble chamber had 6.7-kW refrigerator (J. Kilmer)

- 5.5-kW refrigerator:
  - capital cost: $>1M$ (J. Kilmer, FNAL)
    $\approx$ $1.7M$ (M. A. Green, LBNL)
    $\approx$ $2.5M$ (B. Norris, FNAL)
  
  - operating cost:
    Green: 5.5 kW at 20 K $\rightarrow \approx 660$ kW at room temp
    
    [cf. Kilmer: 15´ bubble chamber required
    
    $400$ hp (cooling) + $50$ hp (vacuum)] $\rightarrow 336$ kW
    
    $\Rightarrow$ operating cost @10¢/kWh: $\approx$ $130k$/yr (Green)
Heat Transfer:

- Peak dissipation much higher than average:

  ⇒ Need to assure adequate heat transfer from core to periphery

  Don’t know how to do this yet! Note that power/cm at upstream end is $>10 \times$ that proposed for SLAC E158, but power/cm$^3$ is $<10^{-2} \times$ E158

  ⇒ Probably feasible
Window Thickness:

• Assuming operation at 1.2 atm, hemispherical Al-alloy windows, and “canonical” safety factor of 4,

\[ t \approx 2 \frac{PR}{S} \approx 2 \times 0.12 \text{ MPa} \times 0.3 \text{ m} / 300 \text{ MPa} \approx 240 \mu\text{m} \]

(Determination of exact thickness awaits detailed design and finite-element analysis)

⇒ Given 175 cm of LH\(_2\) per absorber, this is unlikely to affect the beam significantly
Simpler Alternatives?

• Does it make sense to operate two “15´bubble chamber equivalents” for this purpose?

→ While capital and operating costs not show-stoppers, may want to minimize operational effort/safety concerns & maximize reliability

⇒ Why not minicool with water, liquid methane, solid lithium, or beryllium?
$\rightarrow \text{Li costs} \approx 5\% \text{ in } \mu/p, \text{ Be} \approx 10\%$

- could raise $B$ field to compensate?
Material Comparison:

<table>
<thead>
<tr>
<th>Mat'l</th>
<th>$\Delta E_{\text{min}}$ (MeV)</th>
<th>Length (cm)</th>
<th>$%X_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH$_2$</td>
<td>50</td>
<td>175</td>
<td>20</td>
</tr>
<tr>
<td>LiH</td>
<td>50</td>
<td>38</td>
<td>35</td>
</tr>
<tr>
<td>Li</td>
<td>50</td>
<td>57</td>
<td>37</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>50</td>
<td>49</td>
<td>45</td>
</tr>
<tr>
<td>Be</td>
<td>50</td>
<td>17</td>
<td>48</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>50</td>
<td>25</td>
<td>70</td>
</tr>
</tbody>
</table>

- Comments:
  1. Liquid methane somewhat better than beryllium?
  2. Liquids should give easier power handling by circulation
  3. Solids require liquid-cooling $\rightarrow$ perimeter cooling sufficient, or some water needed in beam region?
Heat Transfer Guestimate:

- Approximate as 2D problem with heat applied in small inner core:

\[ \Delta T \approx \frac{P}{2\pi k L} \ln \left( \frac{r_o}{r_i} \right) \]

(Neglect T dependence of k)

\[ k \approx 70 \text{ W/m} \cdot \text{K (Li)} \quad \text{and} \quad 200 \text{ W/m} \cdot \text{K (Be)} \]

say \[ P/L \approx 55 \text{ W/cm (conservative)} \]

\[ r_o/r_i \approx 5 \text{ (conservative?)} \]

\[ \rightarrow \Delta T \approx 20 \text{ K (Li)} \quad \approx 7 \text{ K (Be)} \]

⇒ Water-cooling around perimeter probably sufficient
Conclusions:

1. LH$_2$ minicooling appears feasible and affordable
2. LH$_2$ minicooling complicated and hazardous
   - will probably diminish facility reliability
3. Understanding heat transfer in LH$_2$ requires more study
4. Should consider alternatives (in future study?):
   - Li, LiH, CH$_4$, Be