Accelerator Driven System (100 MW$_t$, 5 MW Beam, 600MeV Protons)
Target and Core Configuration of Accelerator Driven System
A study was carried out to analyze and design a Lead-Bismuth spallation target for driving a subcritical assembly.

**Performance Parameters:**

- Produce the required neutron source with the appropriate spatial distribution to operate the subcritical multiplier.
- Protect the subcritical multiplier from the high-energy protons and neutrons.
- Contain the spallation products during normal and abnormal conditions.
- Achieve a long lifetime to satisfy the plant availability goal.
- Utilize a simple and fast replacement procedure for normal and abnormal conditions.
- Operate and fail safely to achieve the required plant performance.
Lead-Bismuth Spallation Target Design

Design Constraints:

- Utilize existing structural materials and engineering databases as much as possible.
- The coolant operating conditions are constrained to satisfy different engineering requirements.
- The coolant chemistry is closely controlled to reduce corrosion concerns.
- The structure temperature is constrained to insure satisfactory mechanical properties.
- The target diameter is minimized to maximize the utilization of the spallation neutrons, to simplify the target replacement procedures, to reduce the neutron losses in the beam direction, to decrease the shield volume, and to reduce the required number of the subcritical multiplier fuel assemblies.
- The target decay heat is removed by radiation, natural convection, and conduction to the shielding materials.
Several parametric studies and design iterations were performed to develop the current LBE target design including:

- Physics analyses
- Thermal hydraulic analyses
- Structural analyses including radiation effects
- Radiological analyses
- Safety analyses
- Target interface
- Mechanical design
- Maintenance procedure
- Leak detection procedure
Spatial Energy Deposition in the Lead-bismuth Eutectic for Different Proton Energies with a Uniform Proton Beam Distribution

Energy Deposition, W/cm³/µA/cm²

Depth in Lead-Bismuth Eutectic, cm

200 MeV
400 MeV
600 MeV
800 MeV
1000 MeV
Number of Neutrons per Proton and Neutron Percentage with Energy above 20 MeV as a Function of the Proton Energy from the Lead-bismuth Eutectic
Energy Deposition in the Lead-bismuth Eutectic as a Function of the Proton Energy Normalized per Incident Proton on the Right Axis and per Generated Neutron on the Left Axis

![Graph showing energy deposition as a function of proton energy.](image-url)
Generated Neutron Spectra for Different Proton Energies
Normalized per Generated Neutron from the Lead-bismuth Eutectic

Proton Energy, MeV
200
400
600
800
1000

n(E), n/MeV/generated neutron

Neutron Energy, MeV

10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
Comparison of the Lead-bismuth Neutron Spectrum Generated by Proton and the Fission Neutron Spectrum Normalized per Generated Neutron

![Graph showing comparison of LBE and fission neutron spectra](image)
Number of Generated Neutrons per Proton as a Function of the Buffer Thickness From the Lead-bismuth Eutectic Target for Different Proton Energies
# Target Design Example for 5 MW 600 MeV Proton Beam

## Proton Beam

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Power</td>
<td>5 MW</td>
</tr>
<tr>
<td>Current</td>
<td>8.33 mA</td>
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<tr>
<td>Proton Energy</td>
<td>600 MeV</td>
</tr>
<tr>
<td>Current Distribution</td>
<td>Uniform</td>
</tr>
<tr>
<td>Current Density</td>
<td>40 µA/cm²</td>
</tr>
</tbody>
</table>

## Engineering Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Steel Structural Material</td>
<td>HT9 or 316SS</td>
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<tr>
<td>Maximum Average Lead-Bismuth Velocity</td>
<td>2 m/s</td>
</tr>
<tr>
<td>Maximum Steel Surface Temperature</td>
<td>550 °C</td>
</tr>
<tr>
<td>Maximum Steel Temperature</td>
<td></td>
</tr>
<tr>
<td>HT9 Steel</td>
<td>550 °C</td>
</tr>
<tr>
<td>Type 316 Stainless Steel</td>
<td>600 °C</td>
</tr>
<tr>
<td>Minimum Lead-Bismuth Temperature</td>
<td>200 °C</td>
</tr>
<tr>
<td>Leakage Detection Capability</td>
<td></td>
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<tr>
<td>Passive Decay Heat Removal</td>
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</tbody>
</table>
# Beam Window Nuclear Responses for 40 µA/cm² 600 MeV Protons

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Energy deposition</strong></td>
<td>766.5 W/cm³</td>
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<tr>
<td><strong>Atomic Displacement</strong></td>
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</tr>
<tr>
<td>Neutrons</td>
<td>46.2 dpa/fpy</td>
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<tr>
<td>Protons</td>
<td>21.1 dpa/fpy</td>
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<tr>
<td>Total</td>
<td>67.4 dpa/fpy</td>
</tr>
<tr>
<td><strong>Helium Production</strong></td>
<td></td>
</tr>
<tr>
<td>Low energy neutrons &lt; 20 MeV</td>
<td>6 appm/fpy</td>
</tr>
<tr>
<td>High energy neutrons &gt; 20 MeV</td>
<td>50 appm/fpy</td>
</tr>
<tr>
<td>Protons</td>
<td>1437 appm/fpy</td>
</tr>
<tr>
<td>Total</td>
<td>1493 appm/fpy</td>
</tr>
<tr>
<td><strong>Hydrogen production</strong></td>
<td></td>
</tr>
<tr>
<td>Low energy neutrons &lt; 20 MeV</td>
<td>6 appm/fpy</td>
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<tr>
<td>High-energy neutrons &gt; 20 MeV</td>
<td>1010 appm/fpy</td>
</tr>
<tr>
<td>Protons</td>
<td>26753 appm/fpy</td>
</tr>
<tr>
<td>Total</td>
<td>27769 appm/fpy</td>
</tr>
</tbody>
</table>
Lead-bismuth Target Design

Proton Beam Direction

LBE Coolant Flow Directions

Target Region

Structural and Shielding Materials

Beam Window

Radial Direction

Bottom
Lead-bismuth Target Design
Buffer Analysis Conclusions

- The number of spallation neutrons per proton has low sensitivity to the buffer thickness.
- The number of spallation neutrons reaching the multiplier is reduced as the buffer thickness is increased.
- The peak nuclear responses in the structural material at the buffer boundary show a good linear fit with the reciprocal of the outer buffer radius.
- The helium to atomic displacement ratio at the buffer boundary is in the range of 0.1 to 0.3 appm/dpa. In fast reactor spectrum, this ratio is about 0.26 for HT-9.
- The analyses show that a 7-cm buffer thickness protects the structural material from the nuclear responses caused by the high energy neutrons (E> 20 MeV), does not impact the utilization of spallation neutrons, and has the required cross section area for the inlet and outlet coolant manifolds.
Thermal-hydraulics Parametric analyses were performed to study the effect of the different design parameters and choices on the target performance including the following design variations:

- Two structural materials (SS316 and HT-9),
- Coolant inlet temperature,
- Flow path with respect to the beam window,
- Conical and hemi-spherical beam windows,
- Geometrical variations in the inclination of the middle walls and the conic beam window,
- Beam power spatial distributions
The Thermal-hydraulics Analyses Conclusions

- The current design concept has a hemispherical beam window with a uniform thickness of 3.5 mm. All other structural components have a uniform thickness of 5 mm.

- The peak temperatures on the adiabatic and wetted surfaces of the beam window are 501°C and 340°C, respectively.

- The peak internal and surface temperatures of the middle wall are 456°C and 390°C, respectively.

- The outlet temperature of LBE is 280°C for an inlet temperature of 200°C.

- The total pressure drop in the target is 32 psi.

- Flow control methodologies are employed to increase the stability of the flow field.
Lead Bismuth Eutectic Target Contour Plots Showing

Fluid Velocity

Fluid Temperature

Structural Temperature Profiles
Conclusions

- A Lead-Bismuth Eutectic target design was successfully developed for generating neutrons to drive a subcritical assembly.

- The target design objectives and constraints were defined and satisfied.

- The target design concept has a coaxial geometrical configuration and HT-9 structural material.