Gas Injection at SNS

Accelerator Safety Workshop 2018

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Outline

• Introduction to SNS and its Target
• Background – Need for gas injection
• Safety Analysis
• Regulatory Path
• Summary
The SNS is a complex machine that performs well – overall system reliabilities (excluding targets) > 90%

- The SNS machine has over 100,000 control points and cycles ~5.2 million times a day

- Power (and base neutron flux) is the product of:
  - Peak Current
  - Chopping Fraction
  - Beam Energy
  - Pulse Length
  - Repetition Rate

2.5 MeV  
186 MeV  
~1 GeV

Credit: K. Jones
The target provides neutrons to 24 beam lines

Figure: D. McClintock
There are now 18 instruments in the user program along with one operated by Office of Nuclear Physics.
Mercury enters through side supply passages and returns through the center return passage

Figure Credit: D. McClintock
Fatigue Stress and Cavitation Cause Target Failures

- **Giga-cycles** of fatigue stress in the mercury vessel over desired target lifetime.
- **Pitting & erosion damage** to the vessel caused by mercury cavitation.
- Pulse stresses and erosion rate increase with higher power.

Fig. 1. Samples cut from the centers of beam entrance windows from used targets T5, T8 and T9. Each curved disk sample is approximately 60 m in diameter. The top row images are from the inner window on the surface facing the bulk mercury volume; the bottom row images are of the outer window on the surface facing mercury cooling flow channel.

<table>
<thead>
<tr>
<th>Target</th>
<th>Energy (MW·h)</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5</td>
<td>2362</td>
<td>935</td>
</tr>
<tr>
<td>T8</td>
<td>3750</td>
<td>851</td>
</tr>
<tr>
<td>T9</td>
<td>4195</td>
<td>1033</td>
</tr>
</tbody>
</table>

Credit: B. Riemer
Target Module Injects Gas via Small Orifices

- The gas injection system uses micro orifices to inject gas at a measured rate into the mercury loop.

- The orifices work on the principle of “choked flow,” where the gas flow rate levels off after the gas reaches sonic velocity going through the hole.
  - This provides a stable flow to multiple gas injection sites to help generate many small bubbles in the mercury flow.
Integration of Safety in Design

• Facility safety became involved during preliminary design phase.
  − Conceptual design chosen – orifice bubblers in target module inlets.

• Weekly coordination meetings provided frequent opportunities to provide feedback to design team from a facility safety perspective.

• Safety Analysts co-located with Engineering.

• Testing could be developed to evaluate the physical credibility of phenomena.
Helium venting through Hg
Target Mercury - Radiation Hazard

- ~300 gallons (16T) target mercury used throughout life of facility.
- Spallation/activation produces radioactive nuclei that accumulate in target mercury.
  - ~42.5 GW-hrs total power history ≈ 318g Hg converted
- Most of the ASE controls are focused on preventing the release of target mercury.
Helium Supply Design

- High Bay
- Service Bay
- Mercury Offgas Treatment System
- Helium Supply System
- Mercury Loop System
- Gold Amalgamation Room
- Gas Panel
- Mechanical Room
- MOTS Room
Helium Supply Design

High Bay

Gas Panel 9

Service Bay

Helium Supply System

Mercury Loop System

Mercury Offgas Treatment System

Gold Amalgamation Room

Gas Panel Mechanical Room

MOTS Room
Gas Accumulation Analysis

• Testing in a prototypic loop indicated that apparent mercury level rises in the pump tank due to gas displacement.
  – Geometric differences between the prototypic and actual loop made the degree of accumulation in the actual loop uncertain.

• Excessive rise in mercury level could result in mercury leaving the Service Bay via the off-gas system.

• An existing control prevented this condition during loop fill operations by establishing a high point in the off-gas connection.
Relative Elevations

- 204.8" Penetration from GLS cavity to Service Bay
- 121" MOTS Loop Seal
- 14.3" Underside of Lid
- 0" Target Centerline
- -83.6" Top of Heat Exchanger Outlet
Relative Elevations

- 204.8" Penetration from GLS cavity to Service Bay
- 121" MOTS Loop Seal
- 93.2" Burst Disk Opens
- 42.3" Burst Disk Location
- 14.3" Underside of Lid
- 0" Target Centerline
- -83.6" Top of Heat Exchanger Outlet
Transient Bubble Expansion

- Bubble accumulates low in the loop, thus expands as it rises.
- Potential to displace mercury more rapidly than burst disc can remove it.
- Transient analysis necessary to ensure no overflow.
Transient Bubble Expansion

• Analysis showed that a restriction in the vent path was necessary.

• Orifice sized to ensure no mercury escapes Service Bay for bounding case.

• Credited Controls
  – Rupture disk
  – Orifice
  – Loop seal
Regulatory Path

- Positive USI
- Safety Assessment Supplement
- Supplemental ASE – DOE Approved
- ARR
- DOE Authorizes Commissioning
Outcome

- In October 2017, SNS successfully commissioned gas injection into the mercury process loop.
- System response was very favorable.
Outcome

- Significant reductions in measured stress/strain on the target module.
Summary

• Integration of Safety and Design
• Safety analysis identified credited controls
• Successful ARR, DOE authorizes commissioning
• Successful commissioning
• Significant strain reduction - success