Target Systems for the Spallation Neutron Source

Presented by
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at the
High-Power Targetry for Future Accelerators
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The Spallation Neutron Source

- Partnership of 6 labs (LBL, LANL, JLAB, BNL, ORNL, and ANL) under direction of ORNL
- World’s most powerful neutron science facility
- $1.4B project, with completion in 2006
- Pulsed proton beam creates neutrons by spallation reaction with Hg target
SNS Project

Technical Parameters

- Beam power  > 1 MW
- Beam energy  1 GeV
- Pulse repetition rate  60 Hz
- Pulse length  700 ns
- Neutron beam ports  24

Status

- Overall project is 68% complete and within budget and schedule constraints
  - $1.4B and June 2006 completion
  - Target Systems is 60% complete
- Overall project design is 92% complete
  - Target Systems design is 100% complete
Technical Scope of Target Systems

- **Target**
  - Mercury
  - Replaceable Vessel

- **Moderator**
  - Wing configuration
  - One ambient water
  - Three cryogenic supercritical $\text{H}_2$

- **Reflector**
  - Be

- **Vessel Systems**
  - Encloses components that need to be replaced routinely

- **Target Systems Shielding**
  - Steel
  - Vertical Shutters

- **Target Systems Utilities**
  - Heavy & light water
  - He and vacuum

- **Remote Handling Systems**
  - Target module
  - Mercury process equipment
  - Reflector/moderator plugs
  - Proton beam window
  - Shutters/Inserts

- **Local I&C**

- **Beam Dumps**
  - LINAC dump
  - Ring injection dump
  - Ring extraction dump

- **Neutronics and shielding analysis**
  for entire SNS complex

The Hg target, shielding, and maintenance systems will be a Nuclear Facility that must be designed in accordance with appropriate safety requirements.
Global View Of The SNS Target and Scientific Instrument Station

- Bulk Shielding, Shutters, Moderators, Reflectors, Hg Target, Neutron Guides
- Maintenance Systems
- Proton Beam
- Neutron Scattering Instruments
- Test Stand
- Utility Vault

SNS Experimental Facilities

Oak Ridge
Target Region Within Core Vessel

- Target Module with jumpers
- Outer Reflector Plug
- Target Inflatable seal
- Core Vessel water cooled shielding
- Core Vessel Multi-channel neutron guide flange
- Moderators
Target Systems Installation Has Started

- Equipment installation occurs while the building is being constructed
- Major components have been installed
  - Base plate
  - Outer liner
  - Inner and outer support cylinders
  - Drain tanks and Bulk shield liner drain line
  - Shield blocks
CFD Results Predict Recirculation Zone Near Flow Baffles
### Mercury Loop Parameters @ 2 MW

- **Power absorbed in Hg**: 1.2 MW
- **Nominal Operating Pressure**: 0.3 MPa (45 psi)
- **Flow Rate**: 340 kg/s
- **Vmax (In Window)**: 3.5 m/s
- **Temperature**
  - Inlet to target: 60°C
  - Exit from target: 90°C
- **Total Hg Inventory**: 1.4 m³ (20 tons)
- **Pump Power**: 30 kW
- **Reynolds Number**: $1.4 \times 10^6$ bulk flow
- **Pr**: 0.014

*SNS Hg Target operates at low temperature and pressure*
Target R&D Program Has Addressed Key Design and Operational Issues

• Steady state power handling
  – Cooling of target/enclosure window - wettability
  – Hot spots in Hg caused by recirculation around flow baffles

• Thermal Shock
  – Pressure pulse loads on structural material
  – Cavitation induced erosion (so-called pitting issue)

• Materials issues
  – Radiation damage to structural materials
  – Compatibility between Hg and other target system materials

• Demonstration of key systems:
  – Mercury loop operation
  – Remote handling
Three Thermal-Hydraulic Loops Were Constructed to Develop the Mercury Target

Mercury Thermal Hydraulic Loop (MTHL)
- Wettability
- Design data for target window
- Corrosion/erosion test

Water Thermal Hydraulic Loop (WTHL)
- Recirculation zone
- Flow stability

Target Test Facility (TTF)
- Full-scale loop
- Final CFD benchmark
- Verify Hg process equipment
- Operational experience
Rapid heating process leads to large pressure pulse in mercury

- Peak energy deposition in Hg for a single pulse = 13 MJ/m³
  - Peak temperature rise is only ~ 10 K for a single pulse, but rate of rise is 14 x 10⁶ K/s!
- This is an isochoric (constant volume) process because beam deposition time (0.7 µs) << time required for mercury to expand
  - Beam size/sound speed ~ 33 µs
- Local pressure rise is 34 MPa (340 atm compared to static pressure of 3 atm!)
Cavitation Bubble Collapse Leads to Pitting Damage

- Large tensile pressures occur due to reflections of initial compression waves from steel/air interface.
  - These tensile pressures break (cavitate) the mercury.
  - Damage is caused by violent collapse of cavitation bubbles under subsequent interaction with large compression waves.
- A series of tests were conducted at LANLs WNR facility to examine sensitivity of pitting damage to various parameters, materials, and mitigation schemes
  - 100 - 1,000 pulses
  - Stagnant Hg inside closed targets
  - Examined highly polished surfaces before and after irradiation to quantify damage
- Extrapolation to > $10^8$ pulses performed using off-line pressure pulse tests
Summary of WNR Pitting Tests

- Several test cases showed significantly reduced erosion on the front wall specimen.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Normalized Erosion*</th>
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<tr>
<td>Gas layer near surface</td>
<td>0.06</td>
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<tr>
<td>Bubble Injection</td>
<td>0.25</td>
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<td>Kolsterized surface</td>
<td>0.0008</td>
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<tr>
<td>1/2 Reference Power</td>
<td>0.09</td>
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* Erosion relative to reference (2.5 MW) case
Summary of Pitting Erosion Tests

Using this data, the estimated Mean Depth of Erosion at 1 MW for 2 weeks < 50 µm.

This is judged to be acceptable, but improvements must be pursued.
High Power Target Development Plans

- Plans are integrated with Japanese and European collaborators
- Examine irradiation damage resistance of Kolsterised layer
  - Measure hardness of specimens irradiated to ~ 1 dpa on HFIR
- Perform bubble injection tests on TTF in collaboration with ESS team and Univ of Tennessee (Fall 2003)
  - Measure bubble lifetime, saturation level, and pressure pulse attenuation
  - Examine performance of Hg loop with bubbles
- Perform in-beam tests with flowing Hg and bubble injection
  - Fabricate and test Hg loop in FY2004; perform in-beam tests in FY2005
    - Measure strain and pitting attenuation
Load Frequency and Mercury Contact Do Not Affect Fatigue Endurance Limits

Material - 316 LN

- Alternating Stress, MPa
- Cycles to Failure

- Test discontinued

\[ R = \frac{\text{Minimum Stress}}{\text{Maximum Stress}} = 0.1 \]

- 10Hz in Air
- 10Hz in Mercury
- 0.1Hz in Mercury
- 1.0Hz in Air
- 0.1Hz in Air
- 1.0Hz in Mercury
Tensile Data for Spallation Conditions Fall within the Range of Reactor Database

Uniform Elongation
Database: Type 316 SS, Irradiated and Tested at 0 ~ 200°C

Data from LANSCE-irradiated specimens
Remote Handling Demonstration Tests Drove Design Improvements

- Target module handling procedure successfully demonstrated.
  - Used to check-out remote handling tools, handling fixtures, hot cell crane, and manipulators
  - Many design revisions to enable or simplify remote handling implemented based on results of mock-up tests
### Target Systems’ Schedule

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- **R&D**:
  - R&D Final Report
  - Issue TTF Summary Report

- **Design**:
  - Title I Rev
  - Decision Point for Hg or Solid Target
  - Complete Shutter Fab

- **Procure & Fab**:
  - Award Utility Sys Procurement
  - Complete Core Vessel Fab

- **Install**:
  - Hot Cell Access
  - Load Hg

- **Test**:
  - All beam dumps ready for beam
  - Ready for Beam on Target

- **Commission**:
  - Complete Sub-Project Acceptance Test
Concluding Remarks

• SNS Target Systems Design and R&D efforts are complete
  – Verified Hg “wettability” and flow stability
  – Gained operational experience with prototypical loop and equipment; avoided mistakes on SNS (leaky valves, cavitation, …)
  – Most critical remote handling issues addressed by constructing mockups and performing tests
  – Materials irradiation and compatibility issues addressed in separate tests
    ▪ Combined effects of irradiation with mercury and stress remain uncertain
  – Considerable progress has been made on the pitting issue, however significant uncertainties and associated risks remain
    ▪ Further R&D and target design efforts are underway within the framework of an international collaboration

• SNS Target Systems installation has commenced