The SNS target module fits within the upper and lower portions of the Inner Reflector Plug.
The target module consists of four basic components:

- Target-to-Shell Jacket
- Water Shroud
- Target-to-Core Vessel Inflatable Seal
- Mercury Vessel
The target has three mercury supply channels and one common return channel.
The mercury target module has two key functions

- Deliver mercury to the appropriate location at the end of the accelerator between the neutron moderators in order to optimize neutron production for instruments
- Contain mercury in the event of a leak of the primary mercury vessel so that surrounding components are not damaged (equipment protection)
  - Sole purpose of the Water Cooled Shroud
- The Mercury Target Module (Water Cooled Shroud and Mercury Vessel) carries no credited safety function
  - Both vessels may leak Hg without impact on the SNS safety basis
The SNS target performed reliably from 2006 until Target 6 installation during the summer 2012 outage

- Original target lifetime estimates were as short as 2 weeks
- Only one expected end of life during operations (T3)
- Lifetimes of ~2500 MW-hours, the original desired target life
Sensors indicated mercury in the interstitial space of T6 on September 22, 2012 (~690 MW-hours of operation)

• Many questions, but still have 3 targets
• Return to operations and perform a detailed evaluation of the issue
  – Sensor issue, cavitation issue, etc.
• Exceptional effort to return to operations in record time
Sensors indicated mercury in the T7 interstitial space on October 11, 2012 (~100 MW-hours of operation)

• Complete evaluation and measured response required

• Possible causes:
  – Sensor malfunction (common mode)
  – Operational issue (beam density, beam position, energy, etc.)
  – Installation issue (bolt torques, seal integrity, etc.)
  – Manufacturing issue (weld integrity, tolerances, etc.)
  – Material issue (material specification, material processing, etc.)

• Daily meetings with progress tracked in each of these areas
We looked at all elements of the target life cycle
The manifold block provides access for limited internal video examination - probe lifetime is limited by radiation dose rates.
Videoscope examination revealed an issue

- Bore-scope examination of T6 indicates:
  - A feature of interest in the window flow tube manifold entrance
  - Confirmation of a leak path between the interstitial space and this location in the window flow tube by injecting snoop liquid and observing bubbles
The mercury vessel pressure boundary requires 5 welds for integrity

- Flange (not shown) is not part of mercury boundary
- Weld 1 (EB) is internal and attaches the bulk flow front window
- 5 mercury pressure boundary welds (3 EBW, 2 TIG)
The leak appeared to be at a weld joint on the outer boundary of the mercury vessel for T6.

Leak appears to be at this weld joint.
Careful examination of T7 was the next step

• Cannot assume a common mode failure
• Some tests must be performed before the target is removed (i.e., before there is access for videoscope inspection)
  – Verify leak detector indications at the rear carriage connection using test cable system
  – Verify leak detector indications on the target module connection using test cable system
  – Connect a tight pressure test system to the T7 interstitial space and perform a pressure check while attached to the carriage
• In addition, reviews of the QA packages for T7 were initiated (T6 review was previously initiated)
Videoscope of T7 showed a similar leak in the mercury window flow inlet

• Down to 2 targets, and a common mode failure identified
  – Do the remaining targets have this issue?

• Need to understand the exact nature of the leak
  – Manufacturing defect, operations induced, etc.
Preparation for operations and QA of suspect area became top priority

- There are three target manufacturers: Metalex (MTX), Major Tool (MTM), and Oak Ridge Tool (ORTE) – we have received and used only MTX (6/6) and MTM (3/1) targets

- Working with ORTE that has targets in fabrication to expedite the process and provide close quality assurance oversight

- Preparing the second spare target (MTM-003) for use (fluorescent nose coating for target imaging system)

- Carefully evaluating condition of available spare target (MTM-002) that is ready for installation

- In-depth evaluation of different techniques for removal of the water shroud from Targets 6 and 7 to allow direct examination of the mercury vessel boundary
What happened on T6 and T7?

- Identifiable factors
  - Transition cover plate was installed offset from design condition
  - There was not enough weld in the failed joint on the transition cover plate
  - The weld in the failed joint was not a full penetration weld
  - NDT is difficult in this area
Analysis of the offset joint weld reveals credible evidence to why it failed

- Plate offset leads to reduced weld thickness / penetration
- New analyses of mercury vessel show cover weld stress dependency on weld penetration
- At ~50% weld thickness / penetration, stress goes up quickly
- Operating stresses are higher than previously estimated, but not high enough to cause failure at startup → fatigue suggested
Fatigue Fracture of Cover Plate Weld

- Lack of weld penetration results in initial crack at leak location
- Beam pressure pulse causes high cycle (~1 x 10^8 cycles for T6 and ~2 x 10^7 T7) alternating stress, which could grow crack
- Based on empirical data, no crack growth predicted if weld penetration 45% or better however with less weld, failure predicted in under ~200 hours at 1MW beam power.

No crack growth below Critical $\Delta K$ but ~10 days or less lifetime predicted if crack growth ensues
Videoscope examination of the prepared target (MTM-002) showed it suffered a similar weld issue

- Returned to the manufacturer
- Decision to remove the water shroud, repair the weld, and re-weld the water shroud in place
- On schedule for a July 2013 return
- More from Peter Rosenblad tomorrow
Target 8 (MTM-003) was more robust than T6 and T7 based on evidence of as-designed weld

- Mitigating factors based on analysis of the transition joint
  - The fit-up of the transition cover plate appears to be as-designed in inspection videos
  - There is evidence of weld penetration in the videos – Level 3 inspector has also reviewed video of the inside of the joints and finds them acceptable
  - Additional stress analysis shows T8 meets our design criteria
  - Additional QA performed with support from HFIR
Several Steps were taken to prevent this type of failure from recurring

- Removal of the joint, i.e. EDM machining of the flow cavity
- Thickening of material around the suspect areas to reduce stress
- Additional hold points during fabrication and assembly
- Additional inspection of weld joints; additional NDE examination and visual examination from the inside and outside of the joints
- Additional Quality Assurance support for both on-site inspections and off-site documentation review
- FMEA completed; lessons learned document initiated
First target from Oak Ridge Tool delivered and on site with increased QA emphasis

ORTE-001 Target Module mounted on e-beam weld tooling just prior to final weld pass

Final machining of ORTE-001 for mounting the inflatable seal
ORTE-002 and 003 are on schedule for FY14 delivery

Mercury vessel front bodies, 002 and 003, with windows welded in place; ready for Kolsterizing

Mercury vessel transitions in final phases of clean-up
Jet Flow Target design incorporates features to reduce damage

- Establishes 2+ m/s uniformly flow over inner wall bulk surface
  - Protect inner wall → maintain channel flow integrity and its mitigating effects on outer wall against damage
- Channel flow depth is kept at 2 mm to maintain high flow speed across beam entrance window
- Initiated procurement for two Jet-Flow targets
Jet flow target delivery schedule for Jan 14 and June 14

- Trapezoidal plate eliminated
- Removable water shroud for improved issue detection
Status of target supply

• Currently, we have the operating target and one spare (on the shelf and ready)

• Five targets in various states of manufacture
  – MTM-002 in repair (7/13)
  – ORTE-002,-003 (2/14, 6/14)
  – Two jet flow targets (2/14, 6/14)

• Historical consumption rate is 2 targets per year at 1 MW
  – Without accounting for premature failures

• Time to manufacture is more than 1 year

• More detailed information from Peter tomorrow
Summary

• Previously reliable target operation was interrupted by a common mode target manufacturing issue

• Exceptional effort by operations team and engineering staff resulted in quick determination and correction of the issue
  – Working to rebuild spare target inventory

• Three pronged approach
  – Modified design to improve manufacturability
  – Strengthened analysis to identify and address weakness
  – Increased QA oversight seeking “perfect” manufacturing
Back up
Location of Leaks in Targets 6 & 7 Were Located Using an Articulating Videoprobe

- An articulating videoprobe was inserted into the window-flow supply passage of Targets 6 & 7 and the leaks in were discovered using “Snoop” leak indicator.