SNS target challenges and progress

Presentation to

SNS Accelerator Advisory Committee

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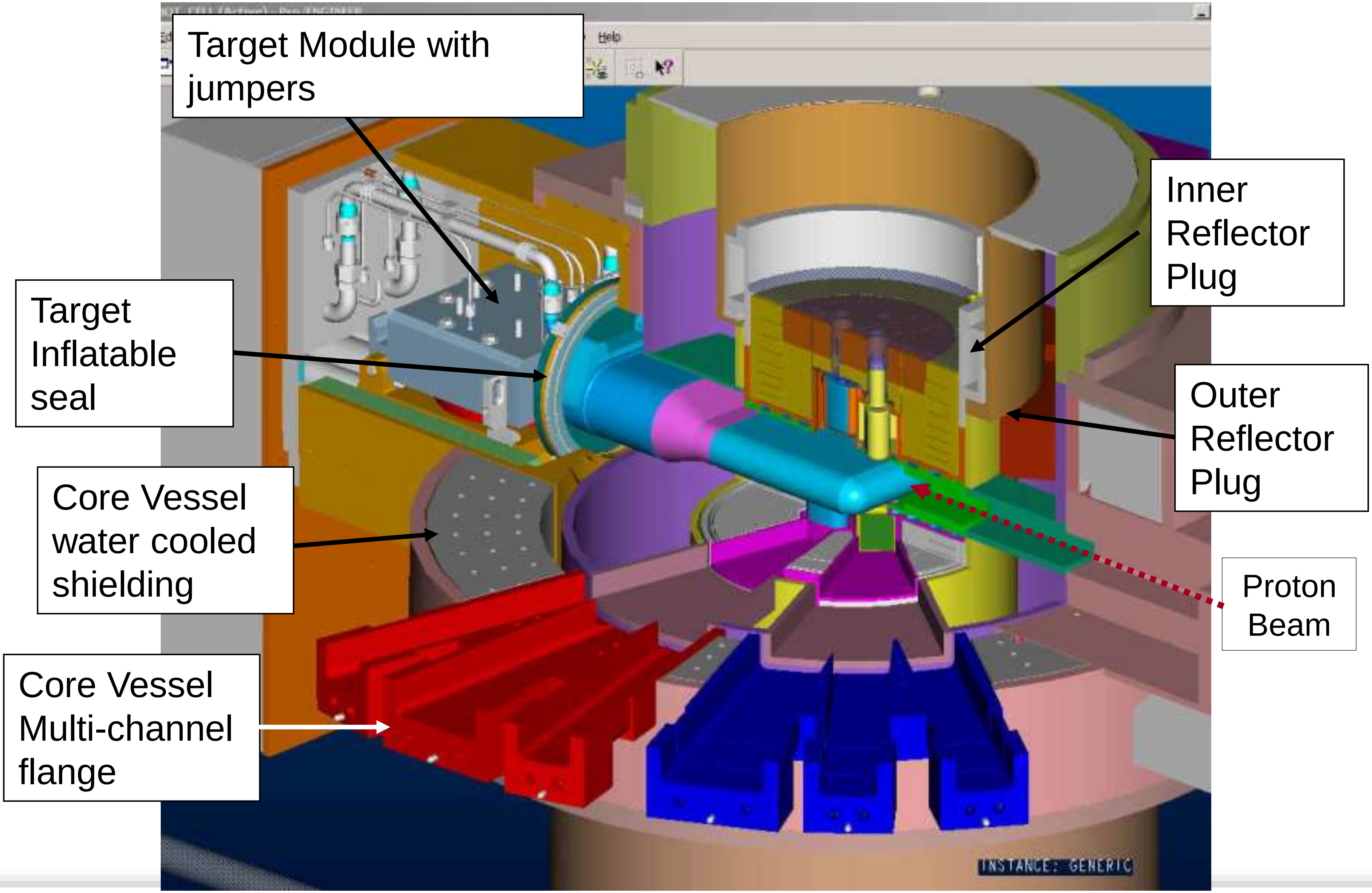
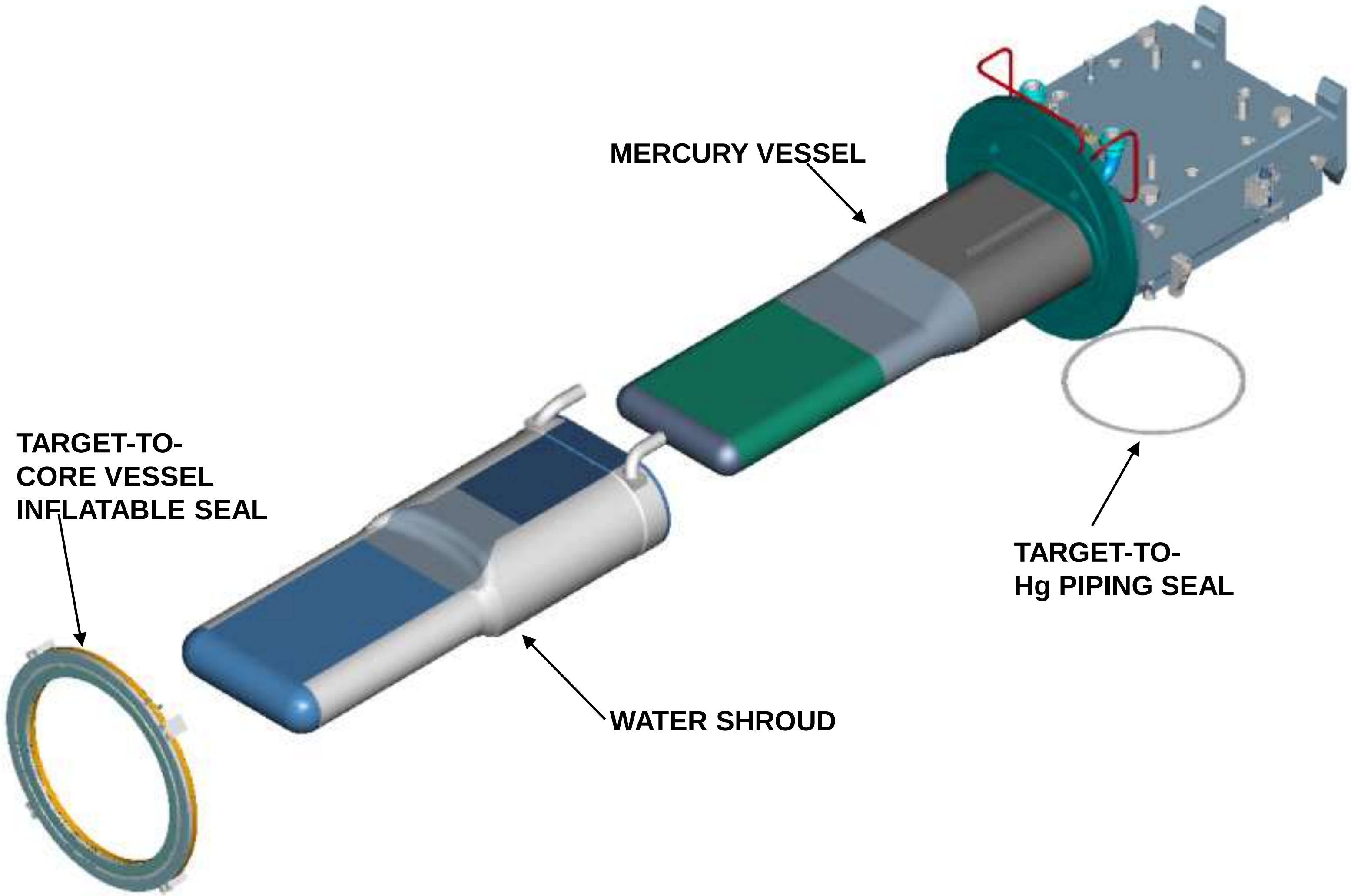
Oak Ridge, Tennessee
May 7, 2013

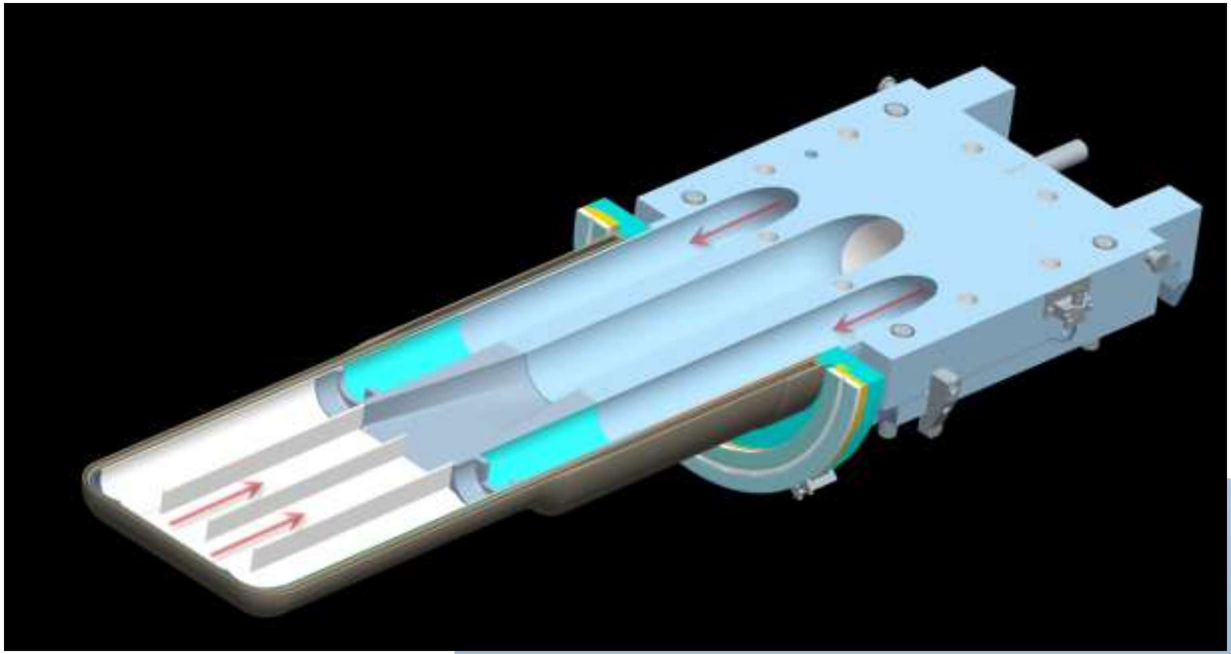
The SNS target module fits within the upper and lower portions of the Inner Reflector Plug

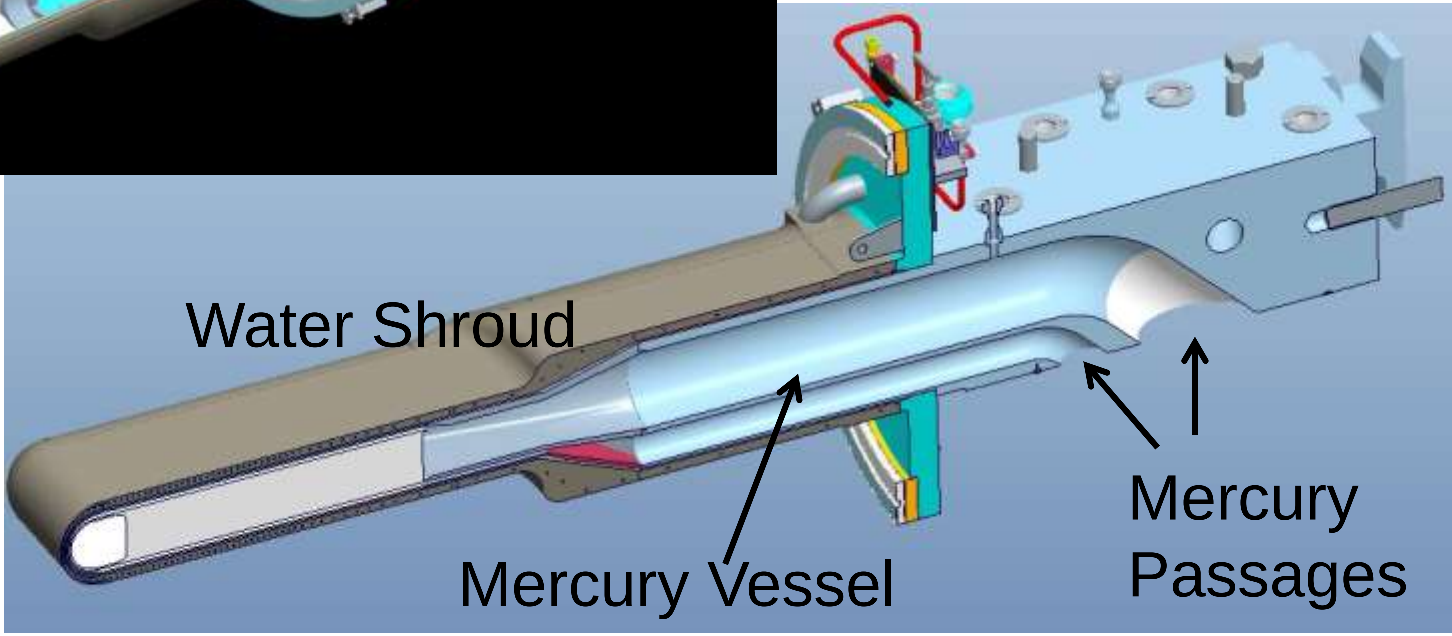


The target module consists of four basic components



The target has three mercury supply channels and one common return channel



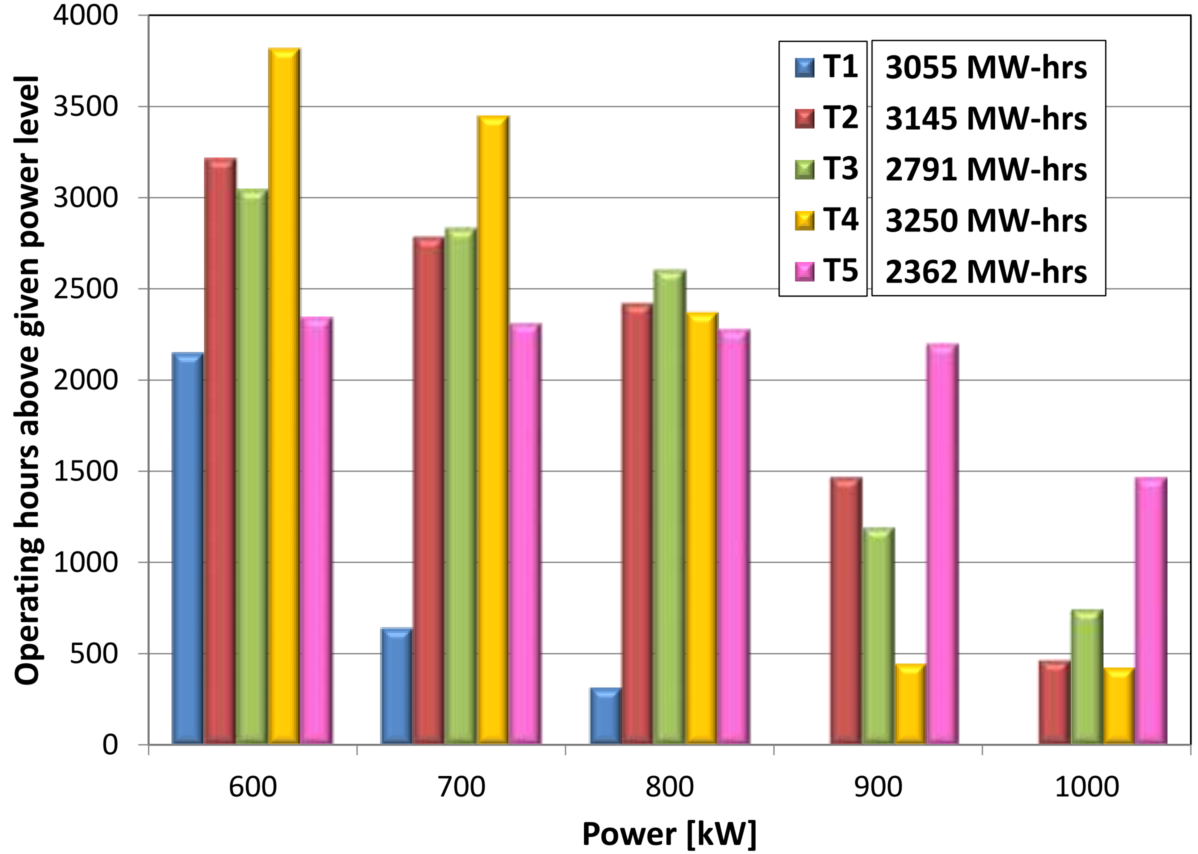


The mercury target module has two key functions

- 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

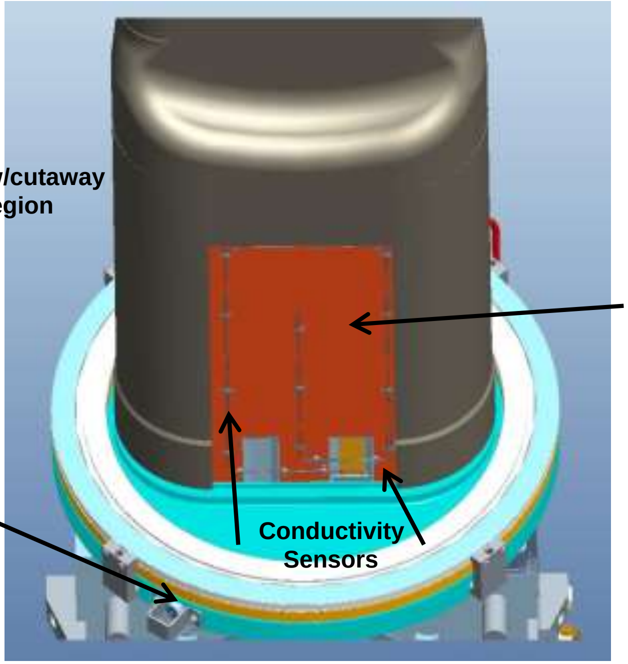
The SNS target performed reliably from 2006 until Target 6 installation during the summer 2012 outage

- 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)

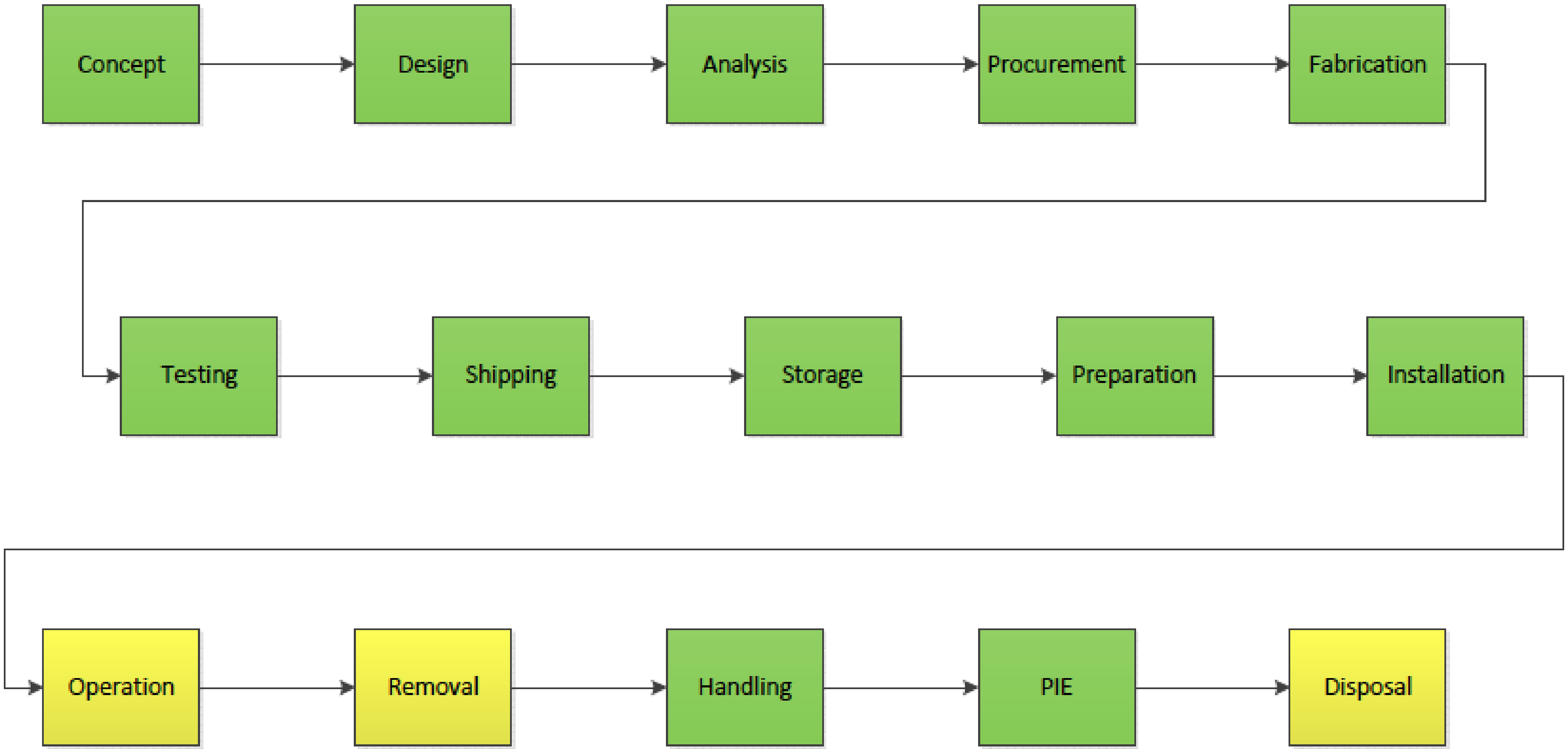
- Many questions, but still have 3 targets
- Return to operations and perform a detailed evaluation of the issue
  – Sensor issue, cavitation issue, etc.
- Exceptional effort to return to operations in record time



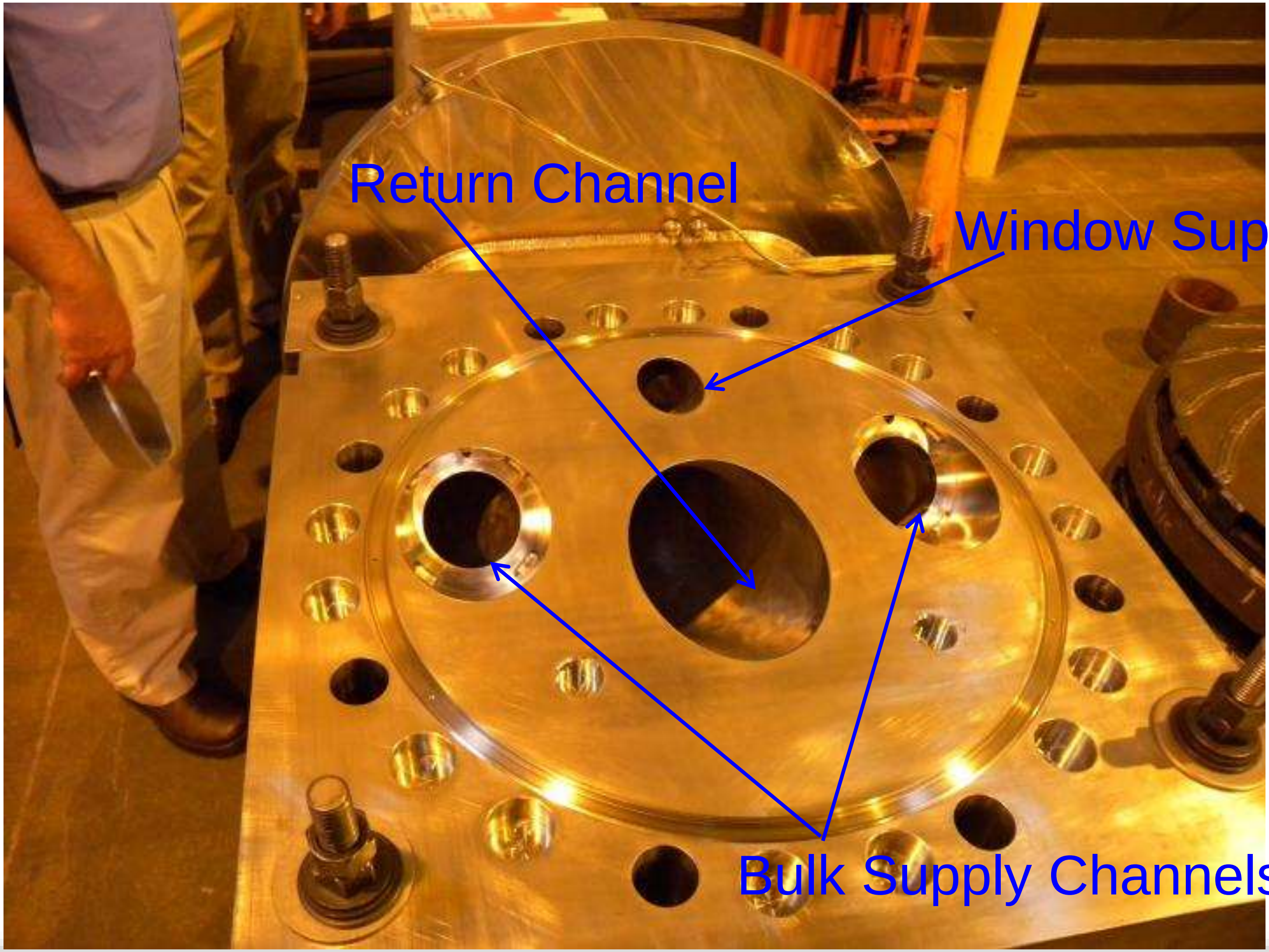
Sensors indicated mercury in the T7 interstitial space on October 11, 2012 (~100 MW-hours of operation)

- 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

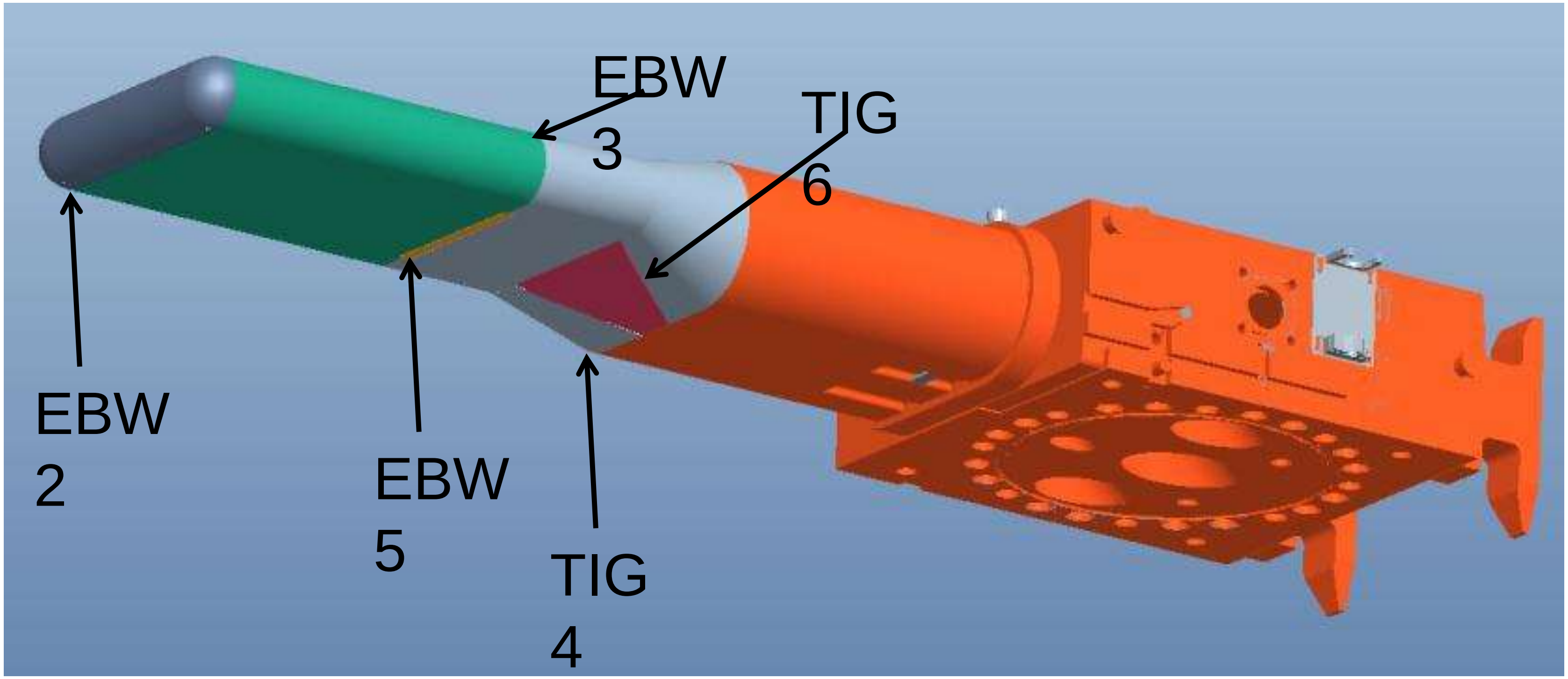


Videoscope examination revealed an issue

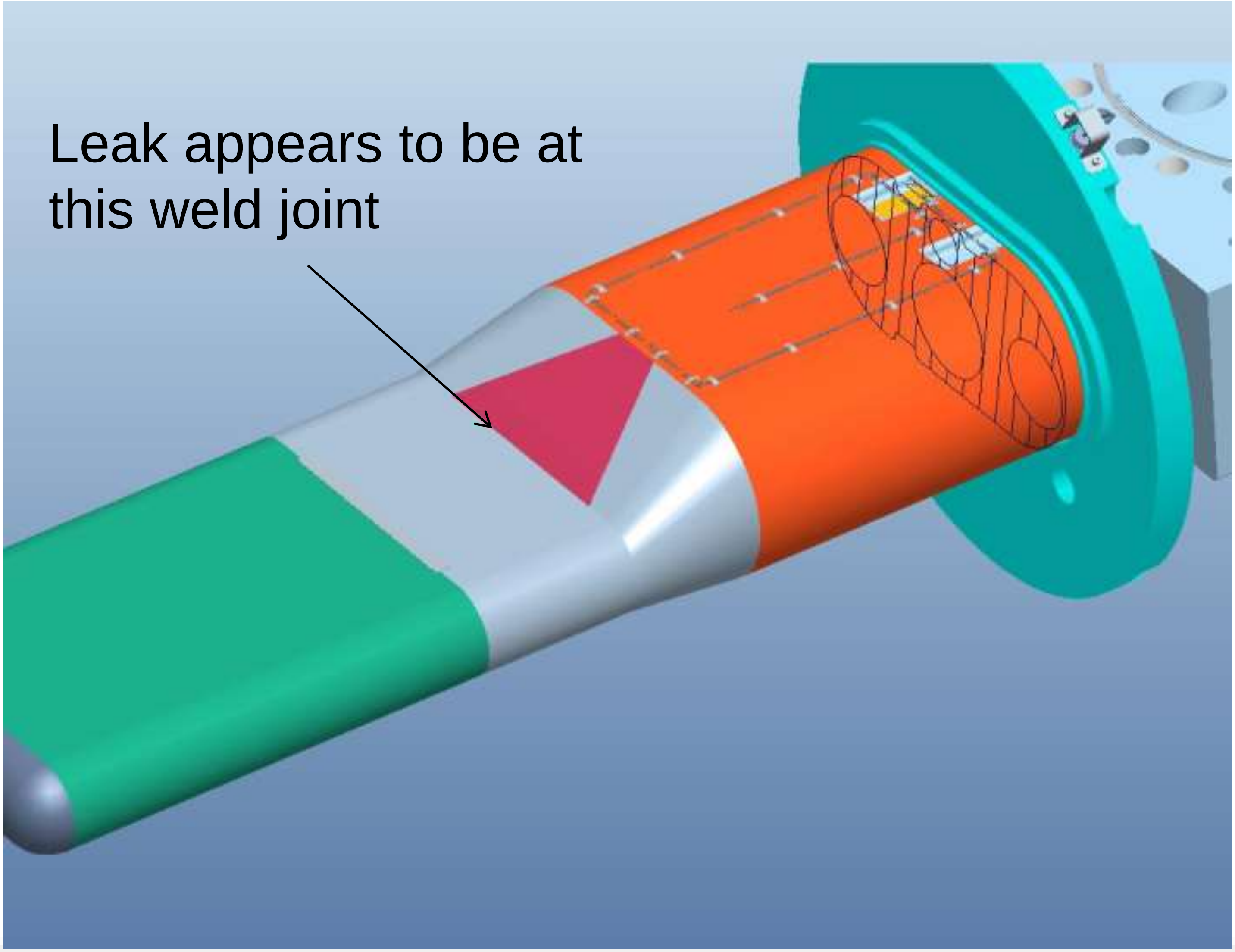
- Bore-scope examination of T6 indicates:
  - A feature of interest in the window flow tube manifold entrance
  - Confirmation of a leak path between the interstitial space and this location in the window flow tube by injecting snoop liquid and observing bubbles

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



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

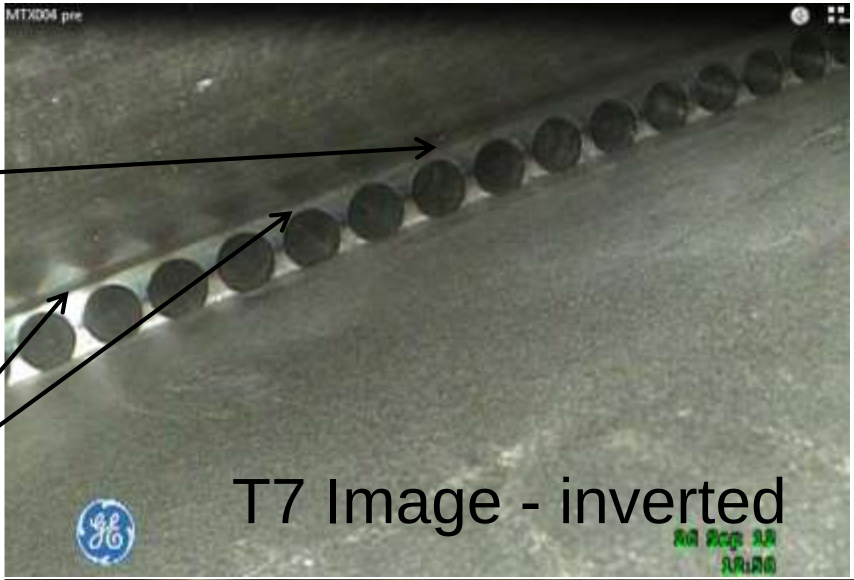
- Down to 2 targets, and a common mode failure identified
  - Do the remaining targets have this issue?
- Need to understand the exact nature of the leak
  - Manufacturing defect, operations induced, etc.

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

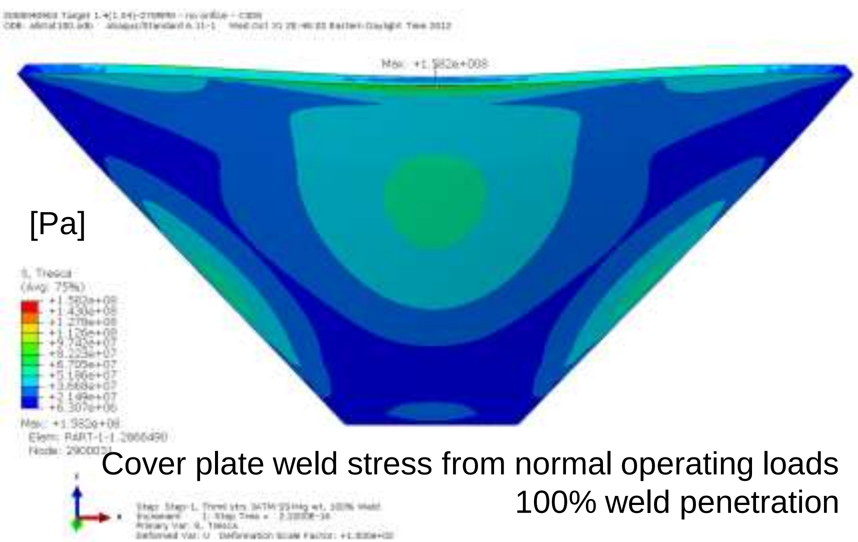
What happened on T6 and T7?

- 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

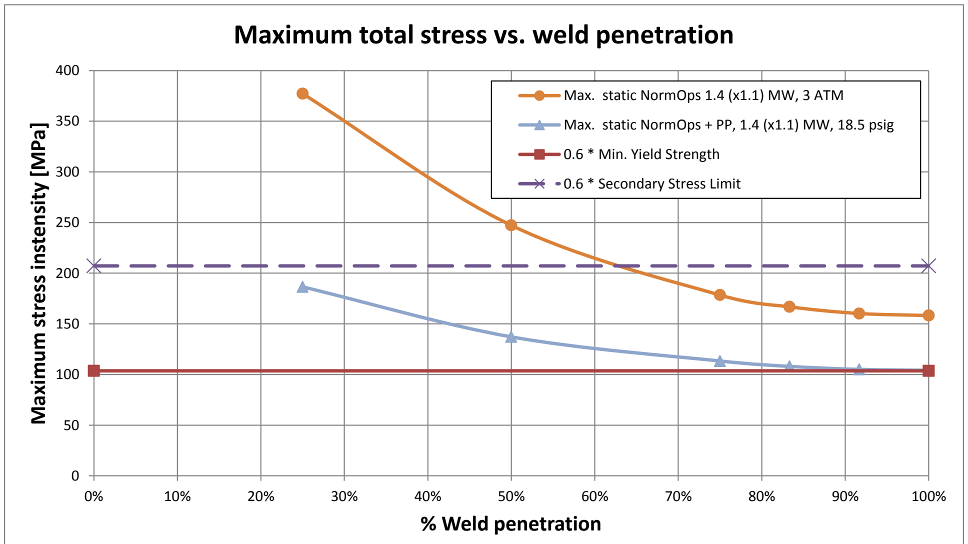


Analysis of the offset joint weld reveals credible evidence to why it failed

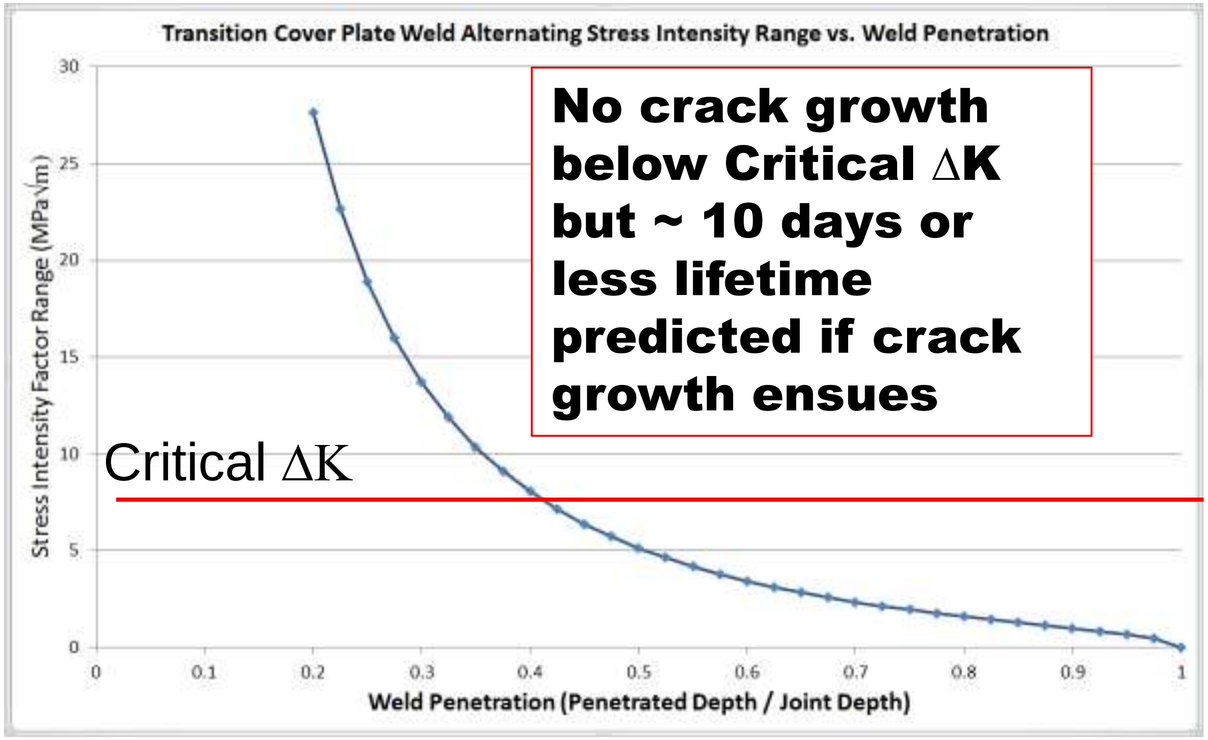
- Plate offset leads to reduced weld thickness / penetration
- New analyses of mercury vessel show cover weld stress dependency on weld penetration
- At ~50% weld thickness / penetration, stress goes up quickly
- Operating stresses are higher than previously estimated, but not high enough to cause failure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



Cover plate weld stress from normal operating loads
100% weld penetration



Fatigue Fracture of Cover Plate Weld



- Lack of weld penetration results in initial crack at leak location
- Beam pressure pulse causes high cycle (~1×10^8 cycles for T6 and ~2×10^7 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.

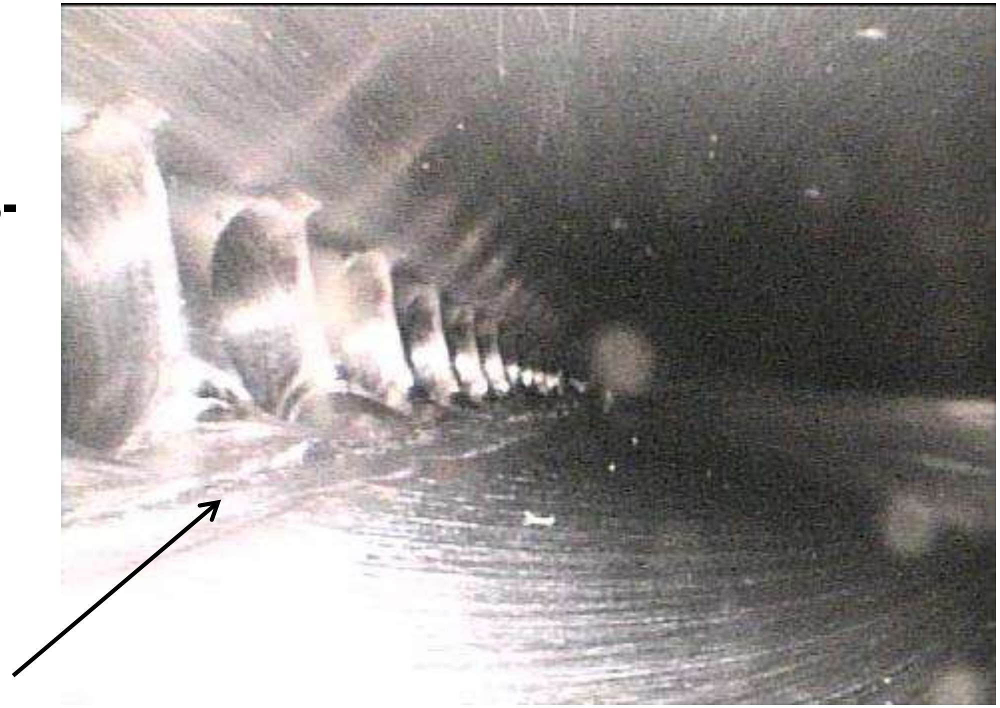
Videoscope examination of the prepared target (MTM-002) showed it suffered a similar weld issue

- 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

Less than full penetration

Target 8 (MTM-003) was more robust than T6 and T7 based on evidence of as-designed weld

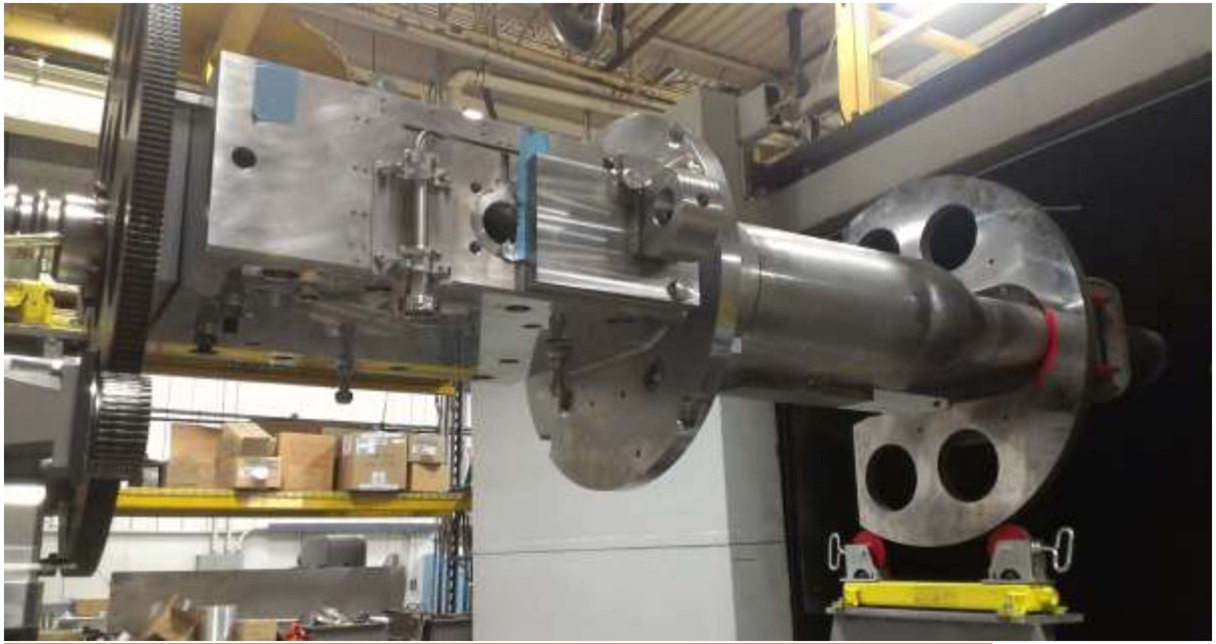
– **Mitigating factors based on analysis of the transition joint**
  - **The fit-up of the transition cover plate appears to be as-designed in inspection videos**
  - **There is evidence of weld penetration in the videos – Level 3 inspector has also reviewed video of the inside of the joints and finds 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

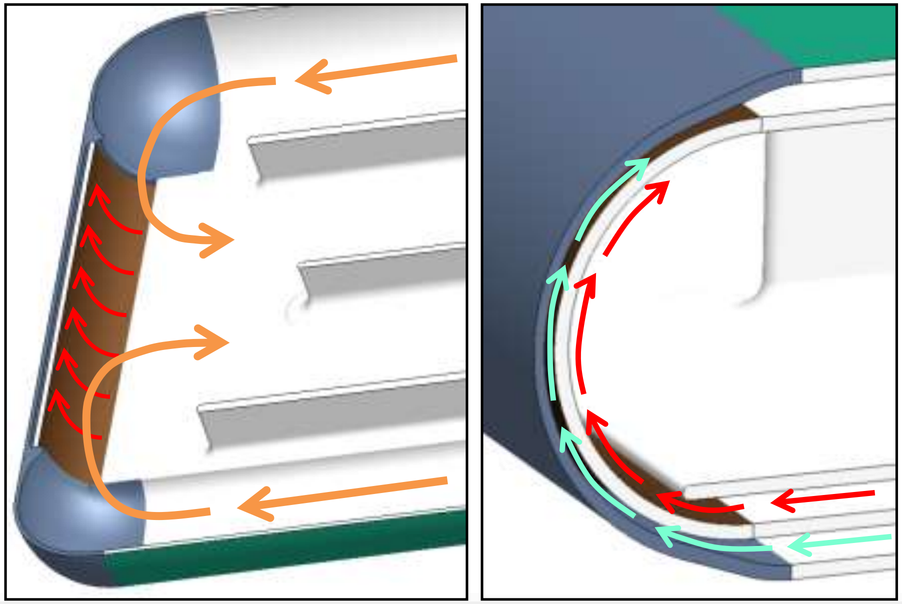
ORTE-002 and 003 are on schedule for FY14 delivery

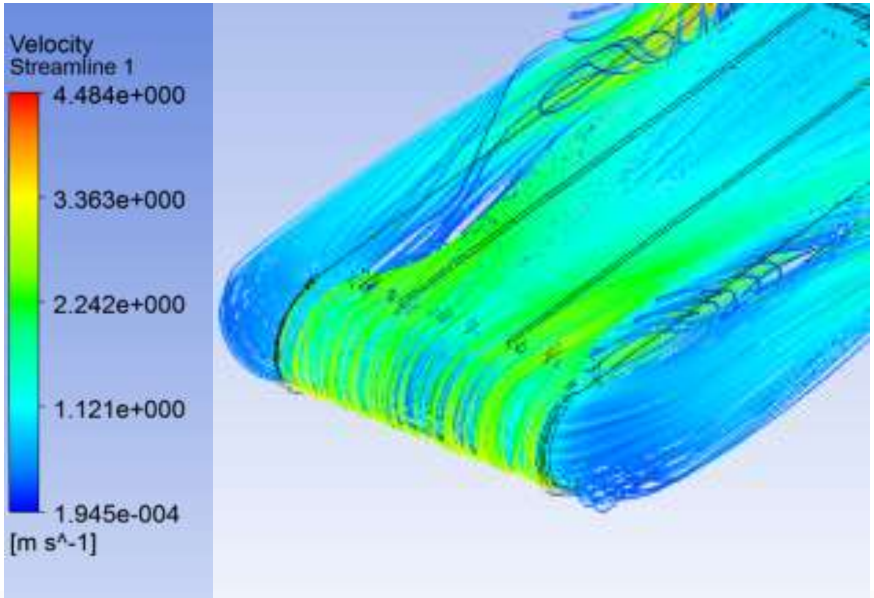
Mercury vessel front bodies, 002 and 003, with windows welded in place; ready for Kolsterizing

Mercury vessel transitions in final phases of clean-up

Jet Flow Target design incorporates features to reduce damage

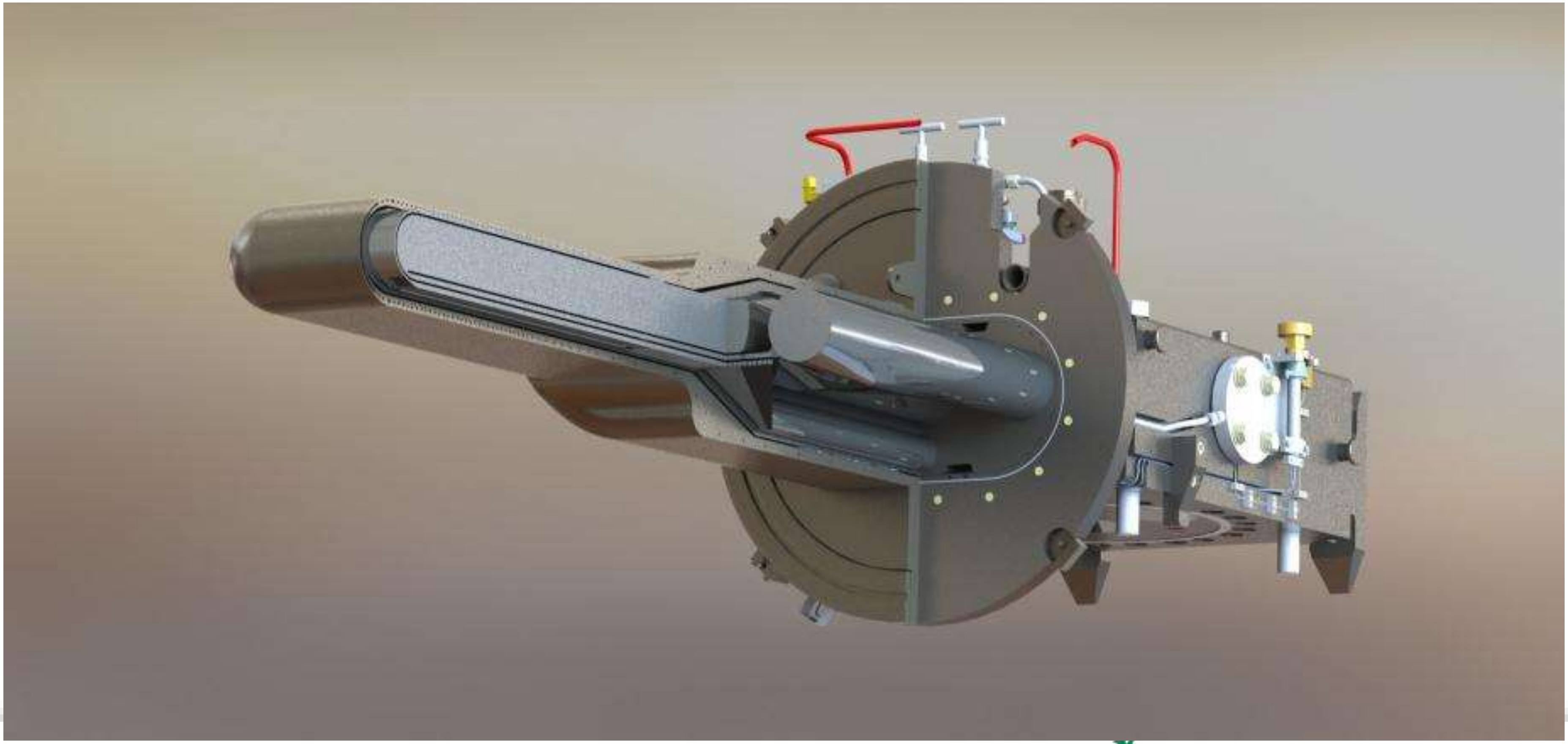
- Establishes 2+ m/s uniformly flow over inner wall bulk surface
  - Protect inner wall → maintain channel flow integrity and its mitigating effects on outer wall against damage
- Channel flow depth is kept at 2 mm to maintain high flow speed across beam entrance window
- Initiated procurement for two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

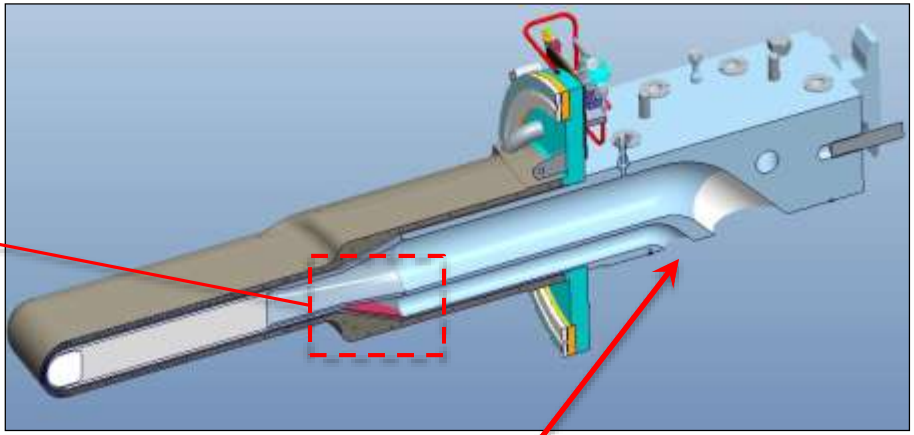
Summary

- 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**



Mercury Window Flow Supply Passage