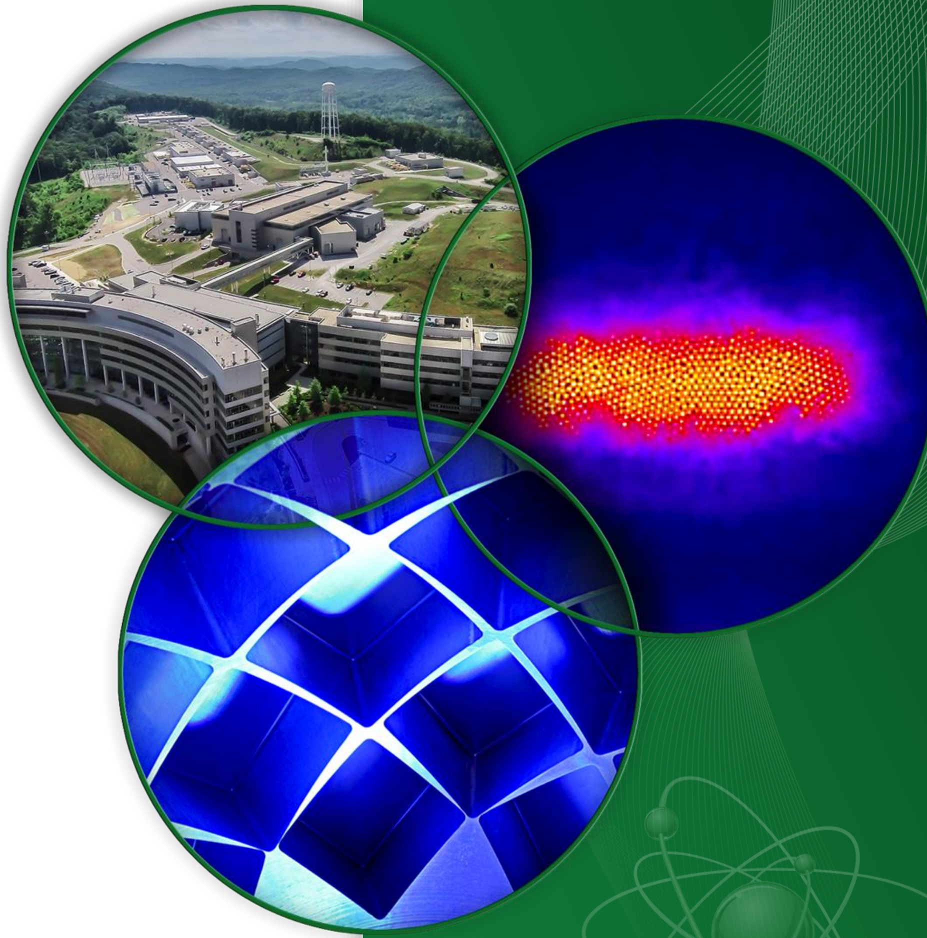
DOE Target Review Summary



J. Galambos

SNS AAC Review

March 24-25, 2015

ORNL is managed by UT-Battelle
for the US Department of Energy

Oak Ridge National Laboratory | Spallation Neutron Source

Outline

- Target failures: brief history
- Leak reactions
- Directions towards understanding and mitigating leaks: proposals and review reccomendations

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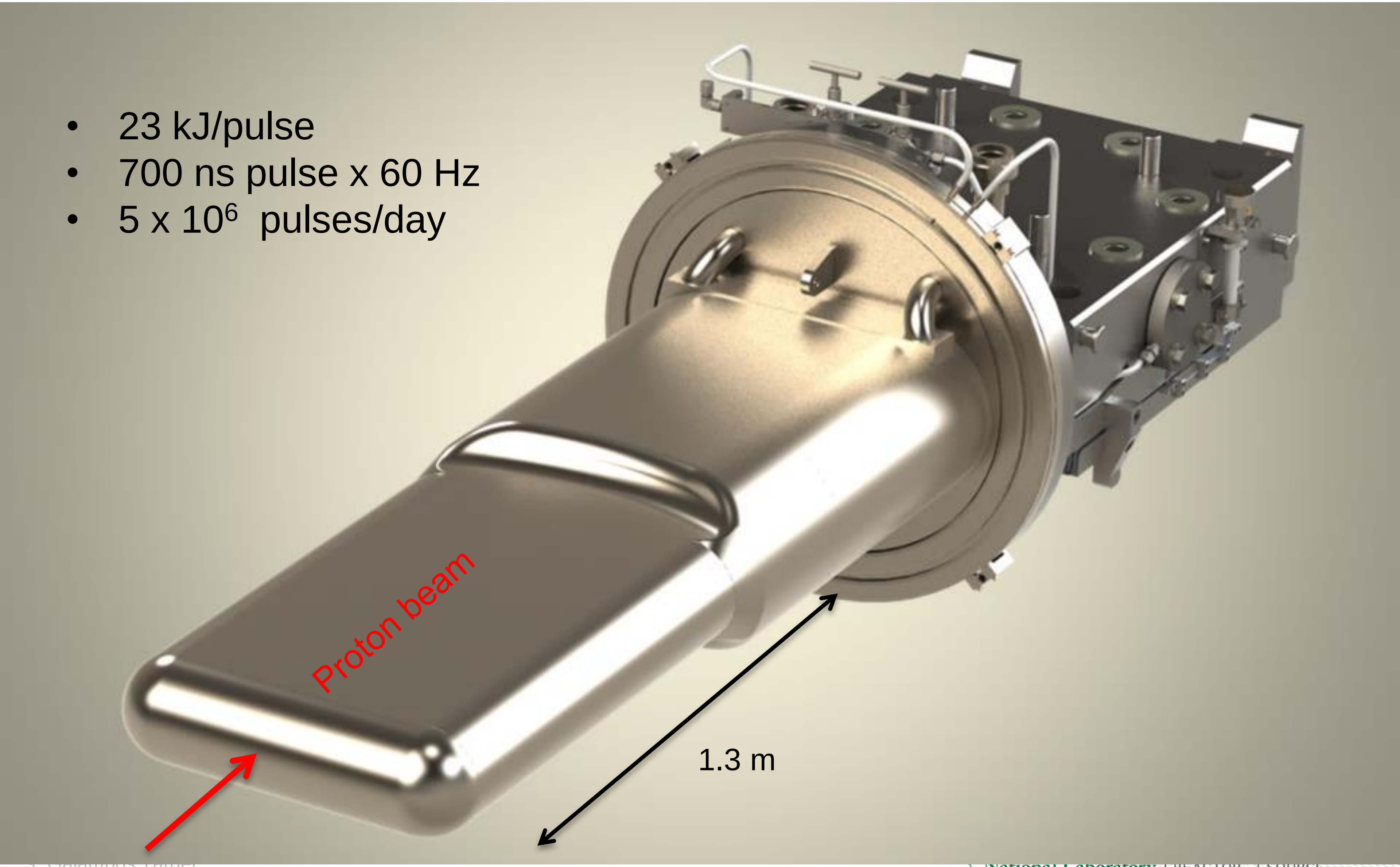
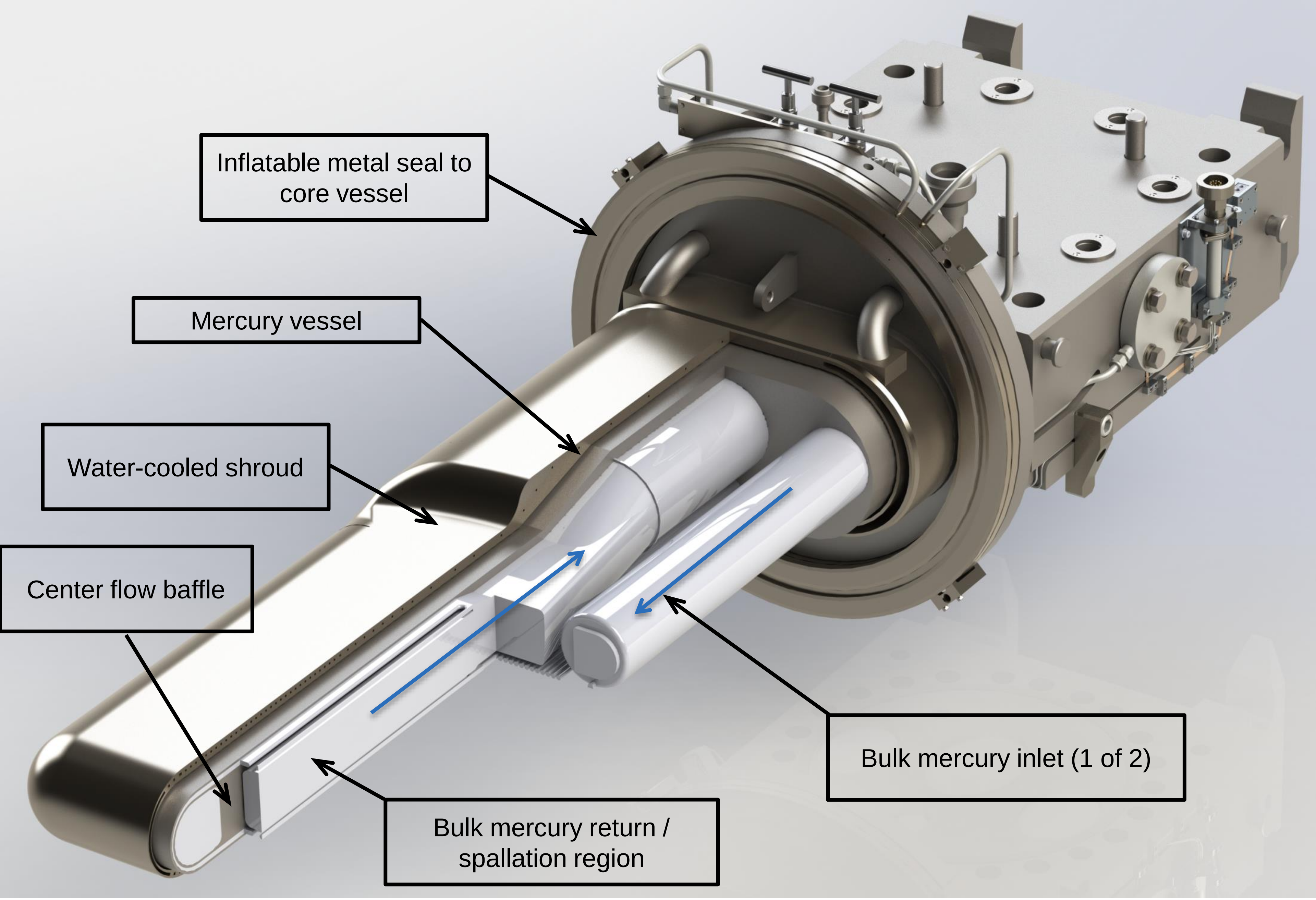
First-of-a-kind design: MW class, mercury and short-pulse

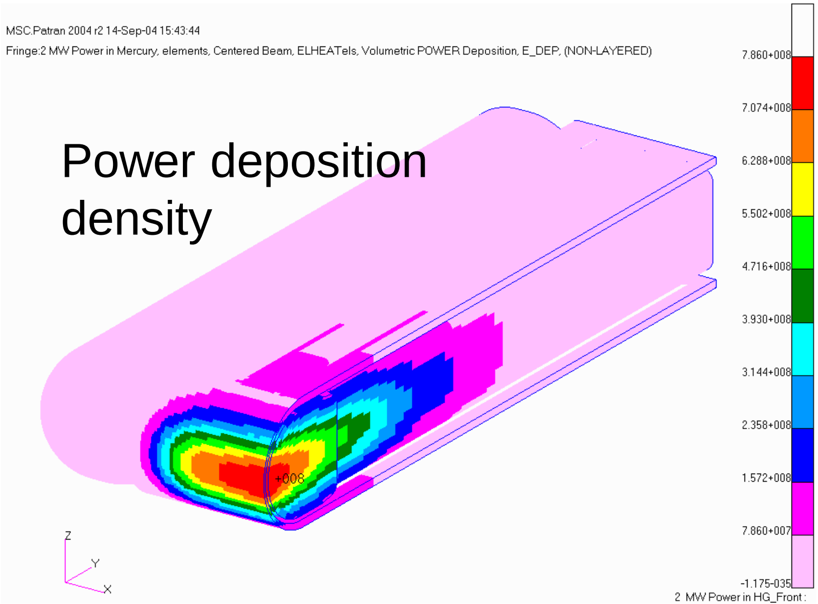
- 23 kJ/pulse
- 700 ns pulse x 60 Hz
- 5 x 10^6 pulses/day



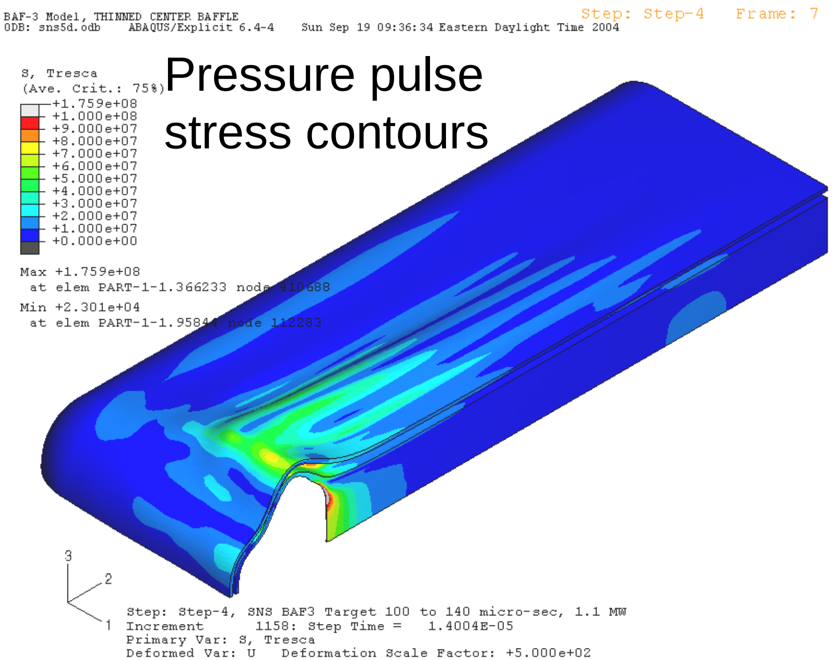


Inflatable metal seal to core vessel
Mercury vessel
Water-cooled shroud
Center flow baffle
Bulk mercury inlet (1 of 2)
Bulk mercury return / spallation region

Highest Power Density in Target Nose

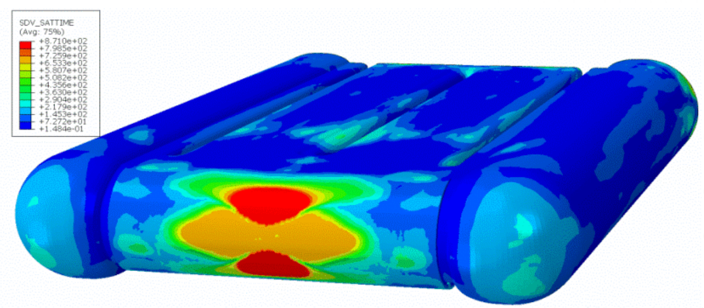


Power deposition density



Pressure pulse stress contours

This is where the design focus originally was



Cavitation damage potential

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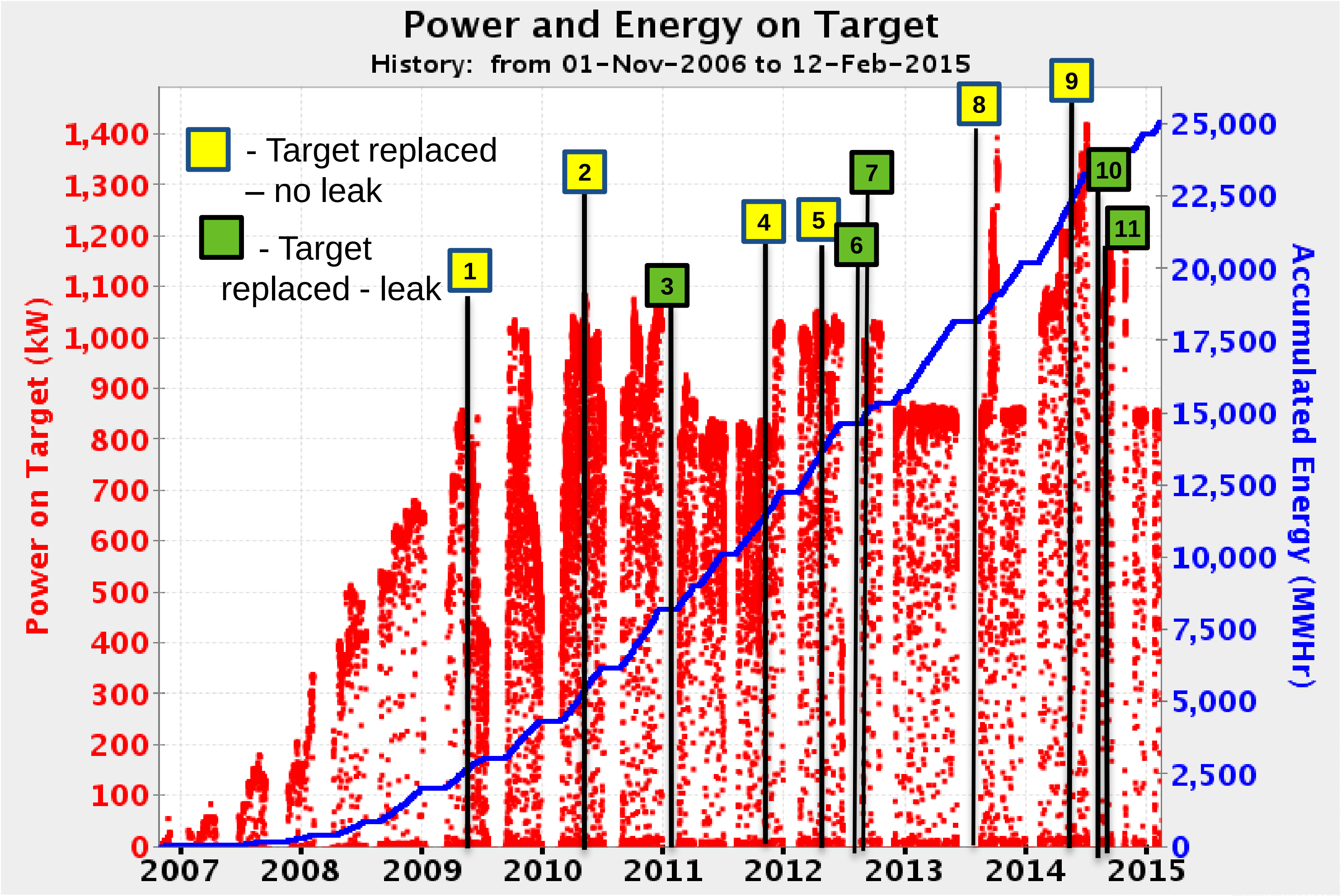
SNS Beam Power and Target System Change History



- 5 out 11 targets leaked before scheduled replacement

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Target Lifetime History

Target	Exposure (MW-hrs)	Avg. Power (MW)	Failure
1	3065	379	
2	3145	771	
3	2791	845	???
4	3252	782	
5	2362	938	
6	617	916	Transition cover plate weld
7	98	943	Transition cover plate weld
8	3750	851	
9	4195	1033	
10	601	1052	Front / transition weld
11	167	1116	Transition cover plate weld

<u>Premature failures</u>

- Understand failure location.
- Working on understanding the cause / mitigation

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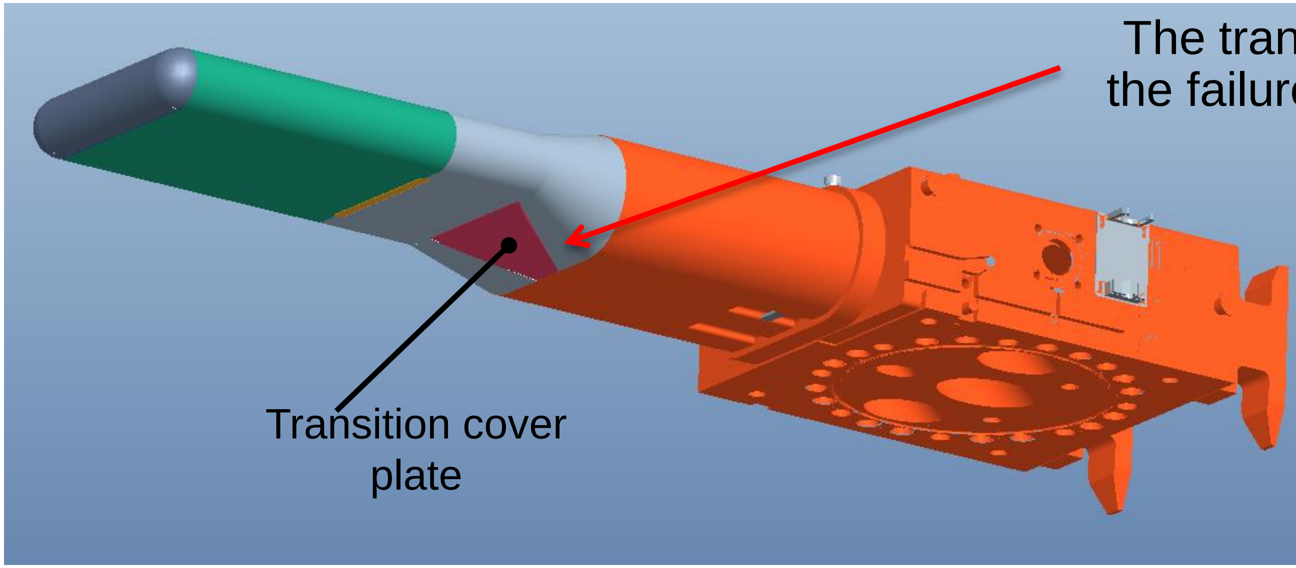
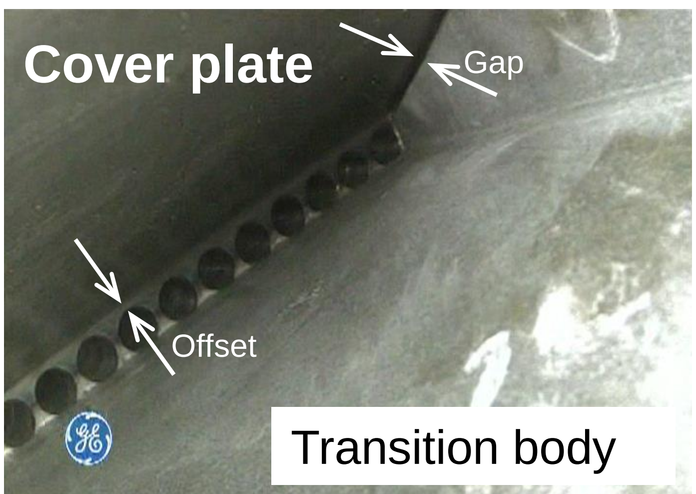
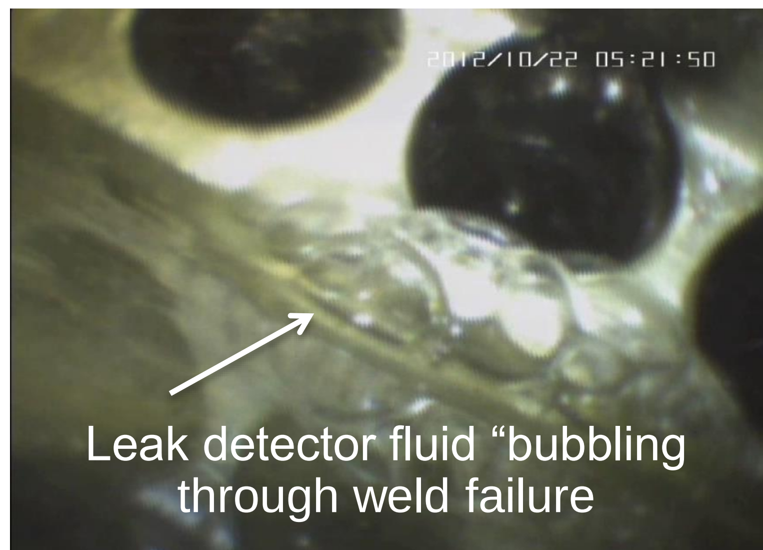
Target 6&7 Leaks: Transition Plate Weld



The transition plate weld was the failure point for targets 6, 7 (2012)

Bad fit-up for targets 6 and 7





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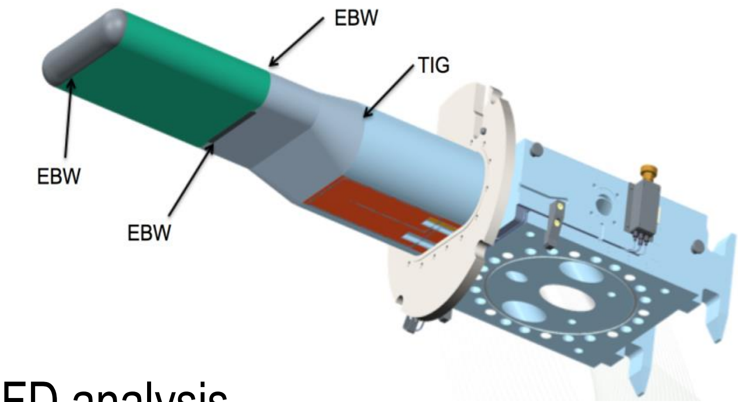
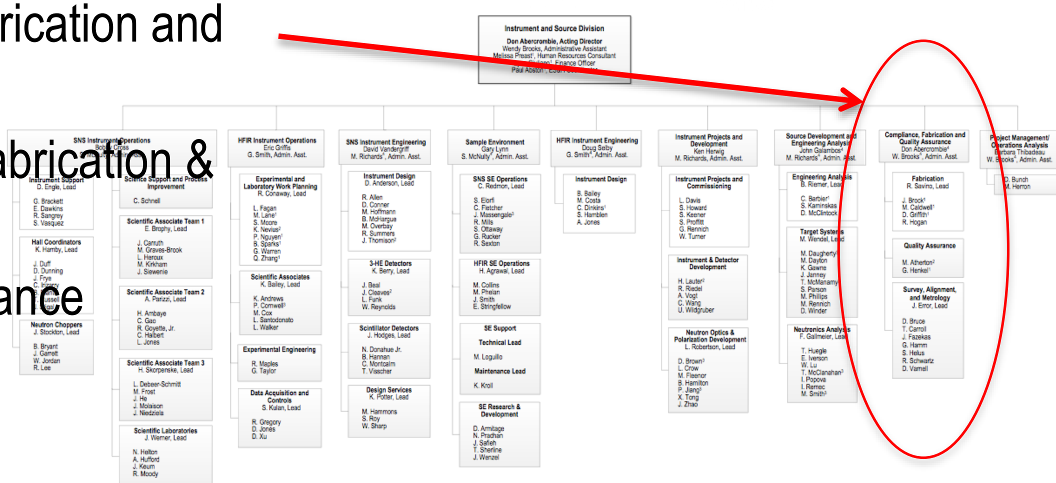
2012 Target Leak Reaction

- Both targets 6 and 7 had visible offsets (manufacturing deviations) in the failure region.
  - Eliminate the transition plate in future targets



- Reduce operating power to 850 kW
- Design basis review
  - Independent review of design basis, stress and CFD analysis
- Fabrication Q/A
  - New ISD group: "Compliance, Fabrication and Q-A"
    - Increased oversight on target fabrication & Q-A
    - Increased vendor non-conformance requests



2013 AAC Recommendation

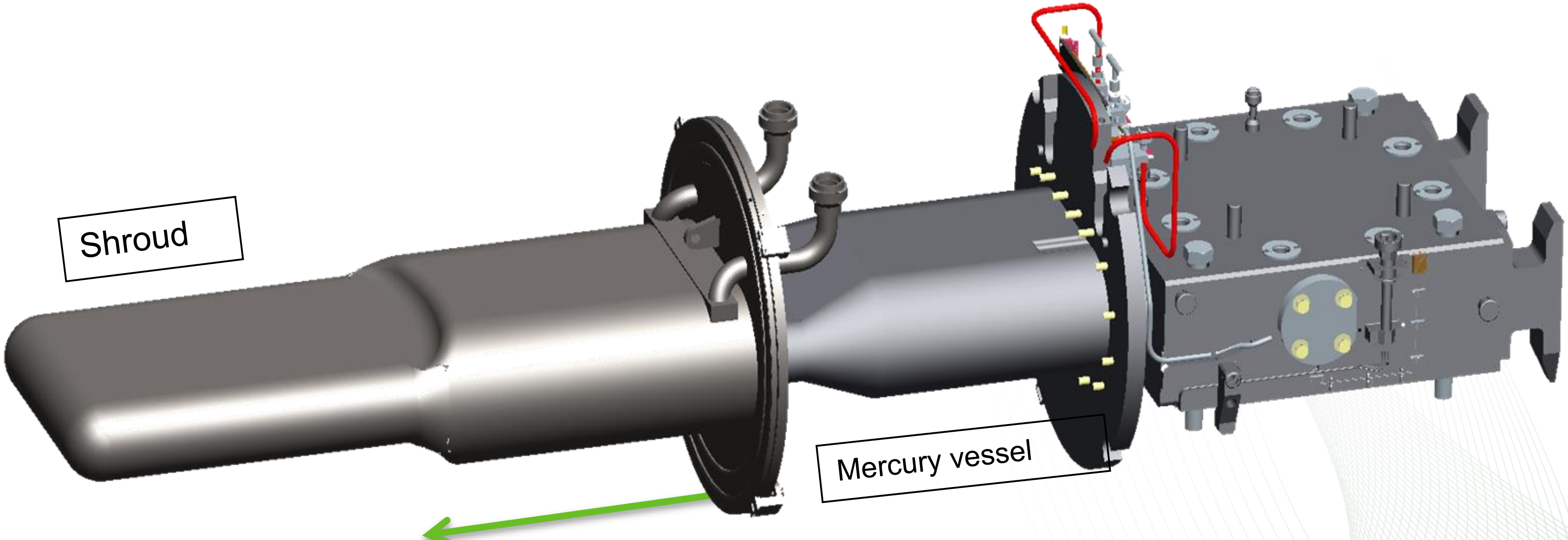
24. The target failures can be traced directly to a lack of appropriate quality assurance during both the design analysis and the fabrication stages of the target manufacture. In addition, the delay in completing the manufacture of the next Inner Reflector Plug can also be attributed to inappropriate quality assurance. Quality assurance procedures should be improved to avoid future delays and deficiencies in target station performance.

Response:

- *Created a Fabrication / Q-A group*
- *Increased vendor oversight*
- *Increased non-conformance requests*

Design Change 1: Bolt-on Water Shroud

- Original targets had a welded on outer water shroud
  - Limited post irradiation inspection
- Bolt on shroud allows removal in SNS hot-cell
  - Facilitates leak detection
- T10 (failed October 2014) was the first target to incorporate a bolt-on shroud



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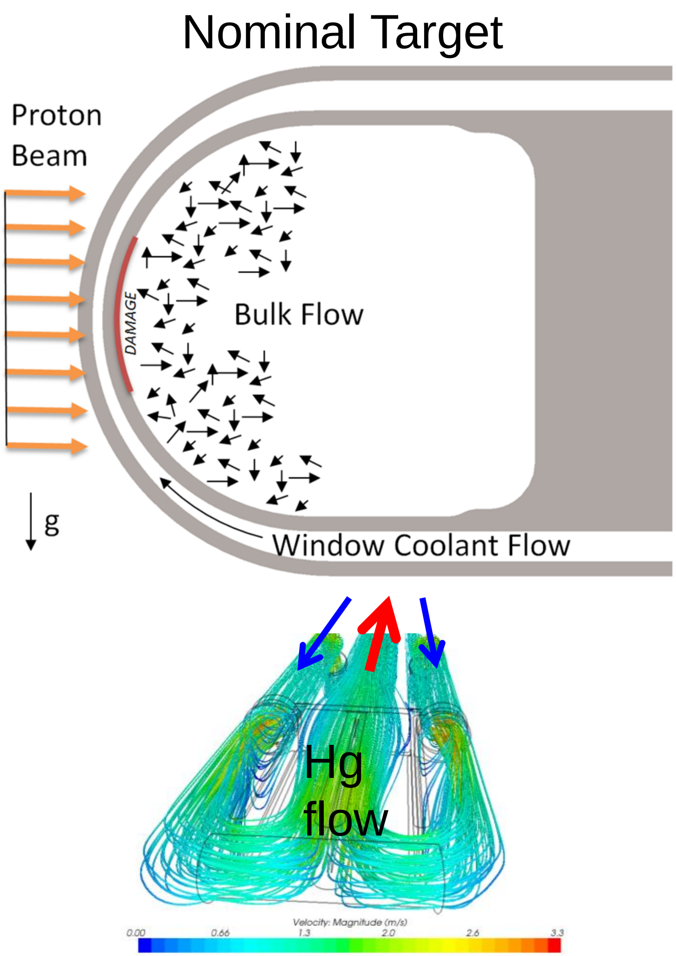
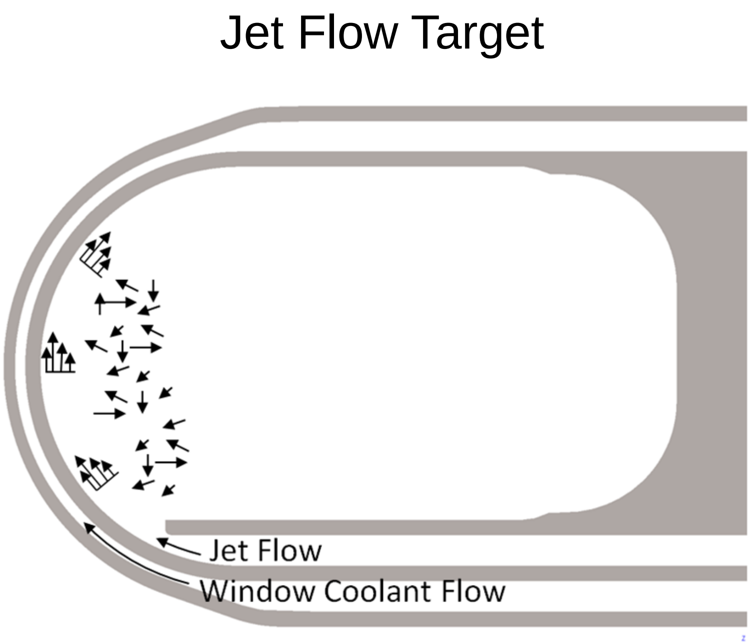
Design Change 2: Jet-Flow Target





- Nominal target has a mercury flow stagnation zone on the inner wall
- Jet flow provides flow along this surface with additional “jet” Hg flow path
  - Aimed to reduce cavitation erosion

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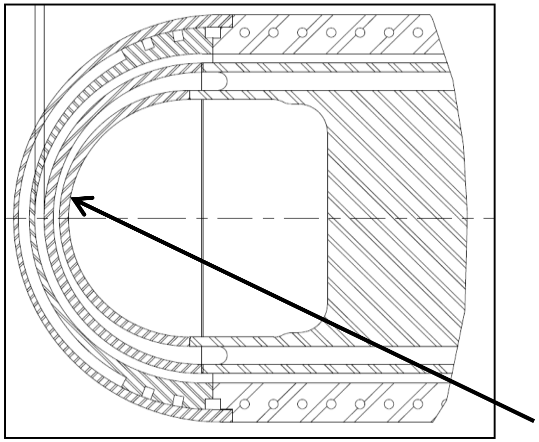
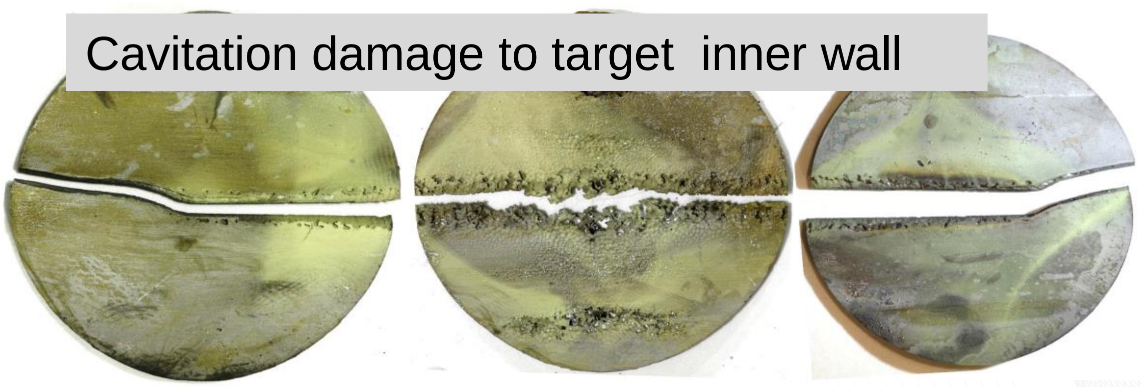
Cut-outs from Target Inner Wall





- Outer Hg wall has shown only minimal evidence of cavitation damage

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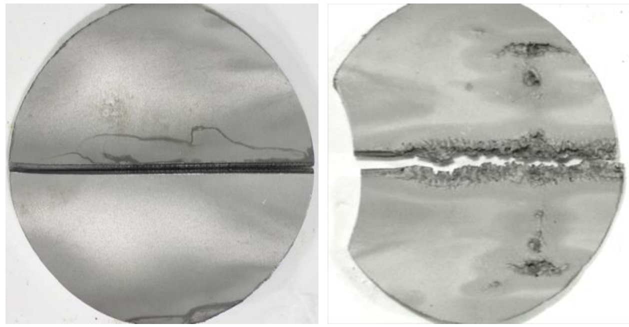
Aside: Jet Flow Does Mitigate Cavitation Damage

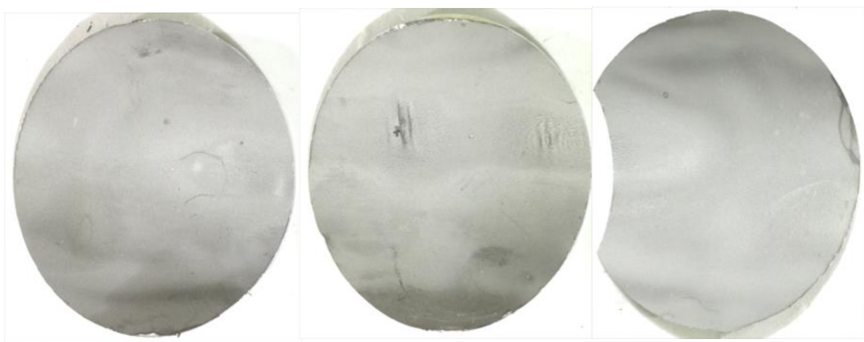
Inner Wall of Beam-entrance Region

Target 6
(original design)



617 MW-hrs, P_{av} = 916 kW

Target 10
(Jet-flow)



601 MW-hrs, P_{av} = 1052 kW

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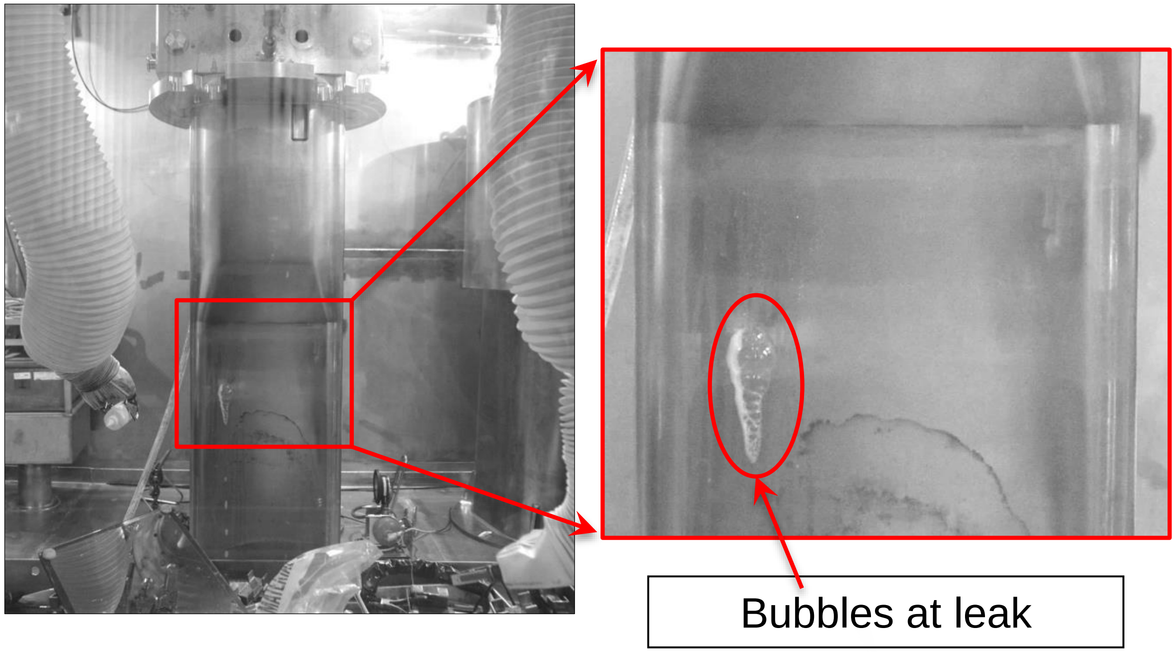
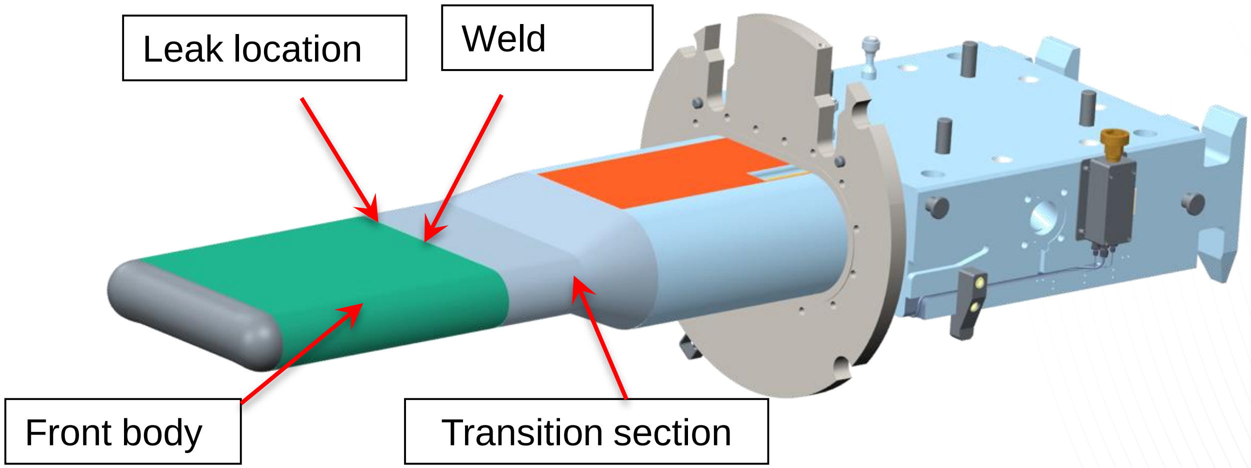
9/11/2014: Leak in Target 10

- Target 10 was the first jet-flow target, removable shroud target
  - Stopped jet-flow fabrication
- Leak located Dec. 4
  - Weld between front body and transition section cracked





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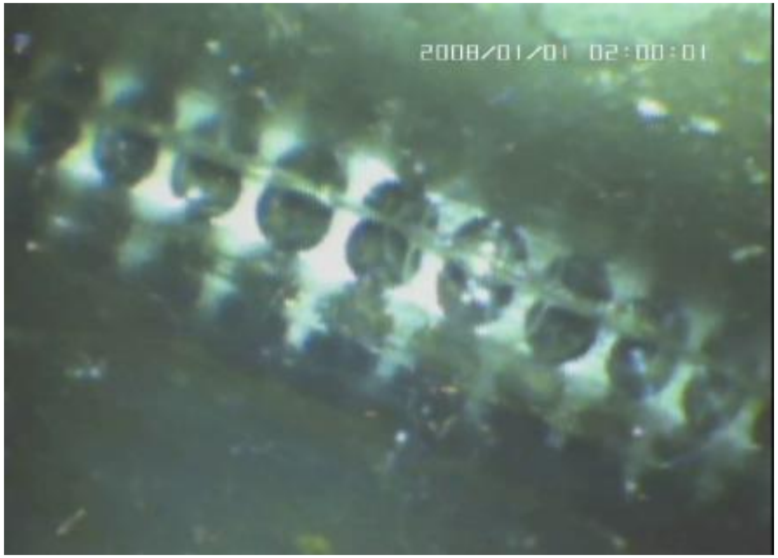
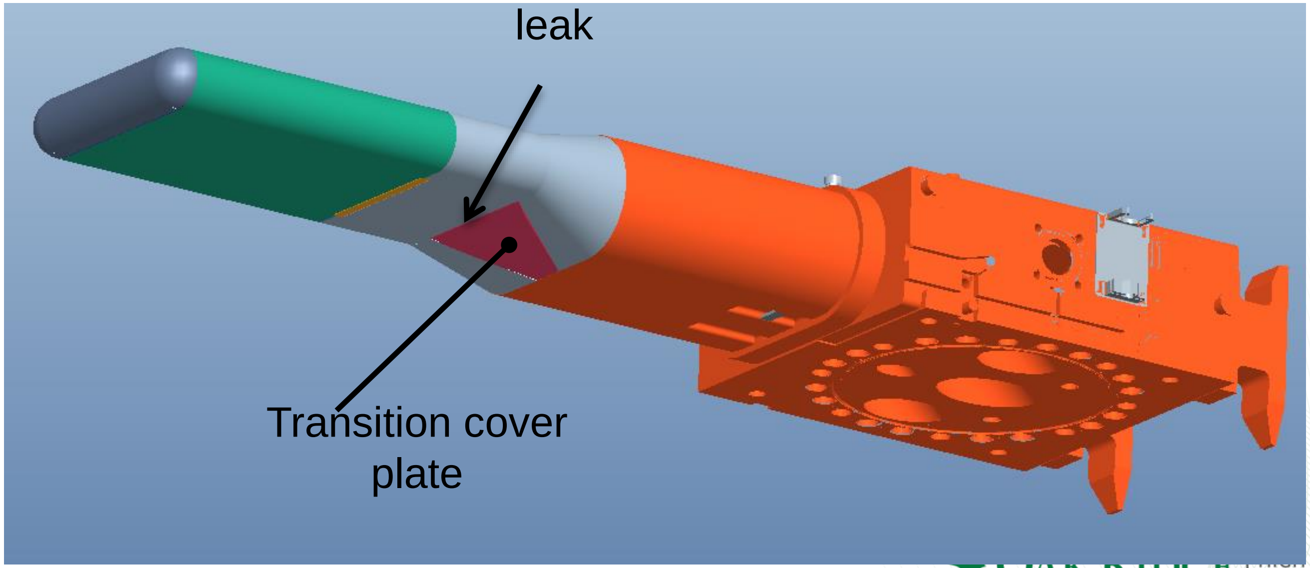
10/26/2014: Leak in Target 11

- Original style target
- Leaked at the transition plate weld
  - Same location as targets 6 and 7 (“Deja-vu”)
  - Leak located Nov. 13, 2014
- Not a fit-up issue, as in target 6 & 7





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2014 Target Leak Reaction

- Created a series of panels with lab assistance
  - Target replacement
  - Locate leaks
  - Target design and analysis
  - Target fabrication
  - Material effects
  - Failure area sample extraction
  - Target history / comparisons
- Reduced power level (1.2 MW to 850 kW)
- DOE OS Independent Review Feb. 24-25, 2015

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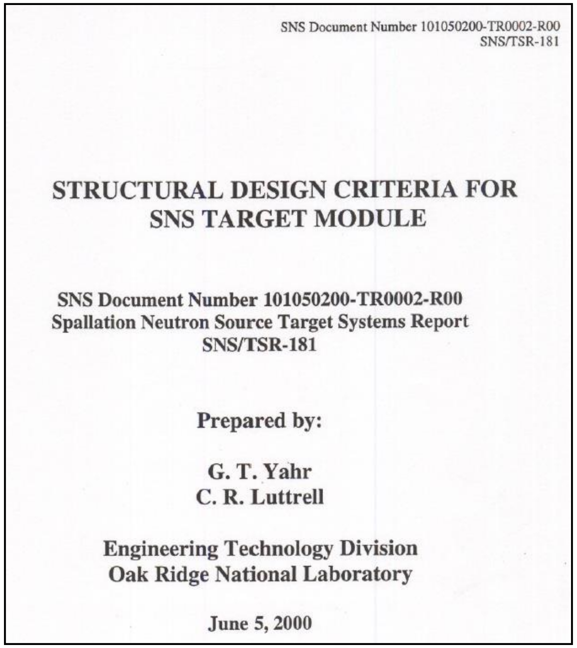
Stress Analysis / Design Basis

- Target design criteria (circa 2000) based on ASME Boiler and Pressure Vessel Code, Section III Division 1, Subsection NB, and Section VII, Division 2
- ASME fatigue evaluation methodology revised in ~2007
  - Current code requires weld fatigue “knock-down” factors for weld type, surface finish, inspection capability, ….
- New tools available for fatigue analysis



SNS Document Number 101050200-TR0002-R00
SNS/TSR-181

STRUCTURAL DESIGN CRITERIA FOR
SNS TARGET MODULE

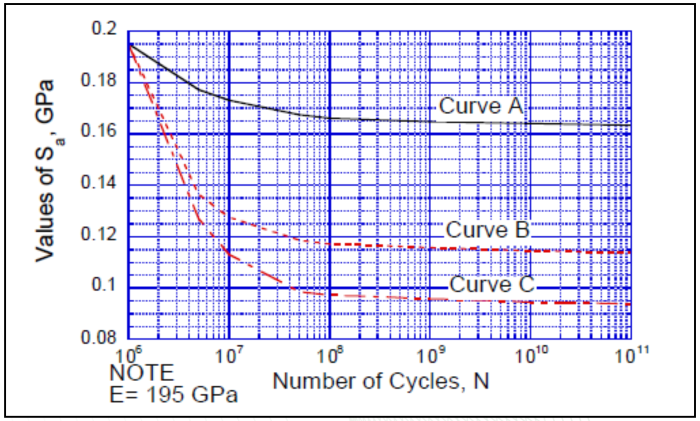
SNS Document Number 101050200-TR0002-R00
Spallation Neutron Source Target Systems Report
SNS/TSR-181

Prepared by:

G. T. Yahr
C. R. Luttrell

Engineering Technology Division
Oak Ridge National Laboratory

June 5, 2000



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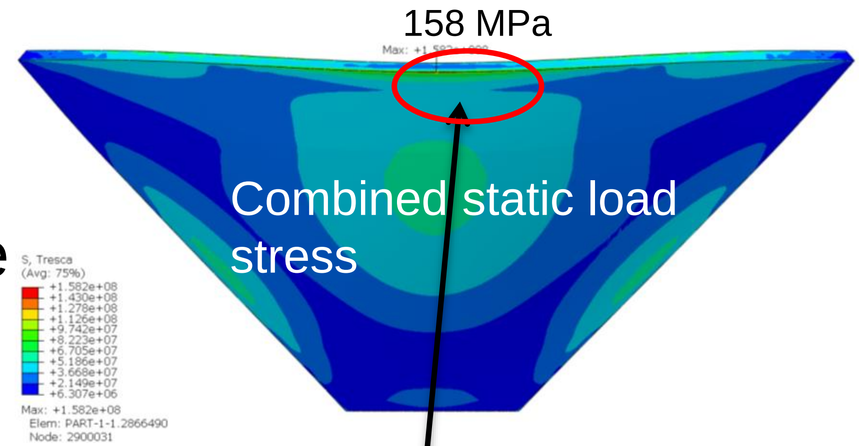
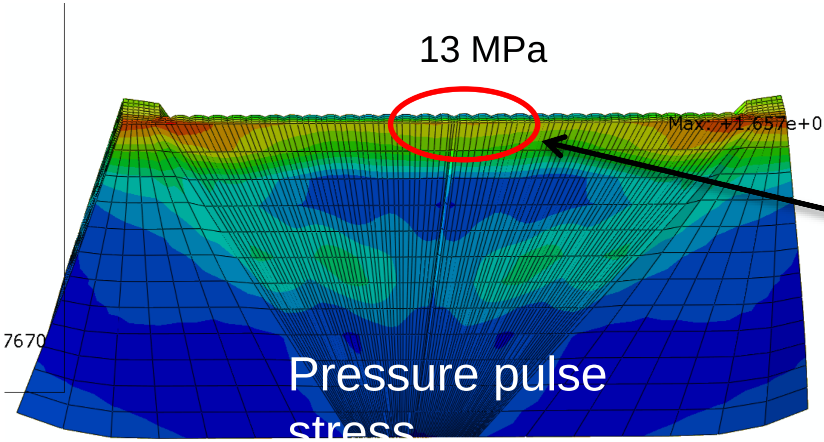
Target Analysis

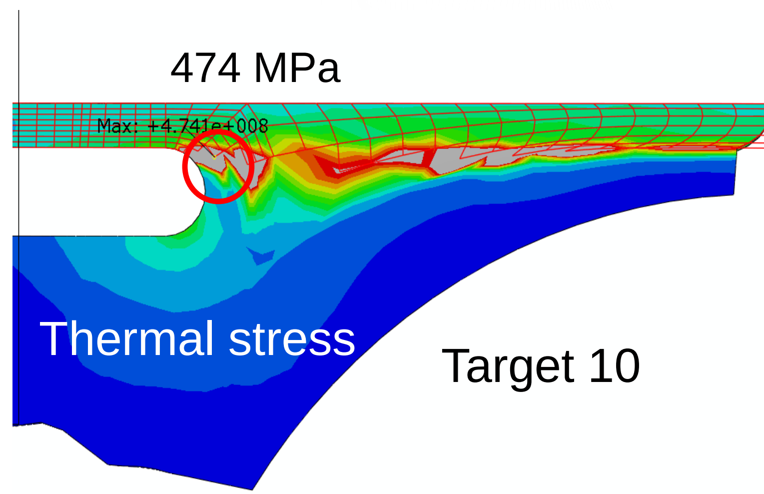
- What do stresses look like at the failed welds?
  - Target 11 (trapezoidal plate weld):



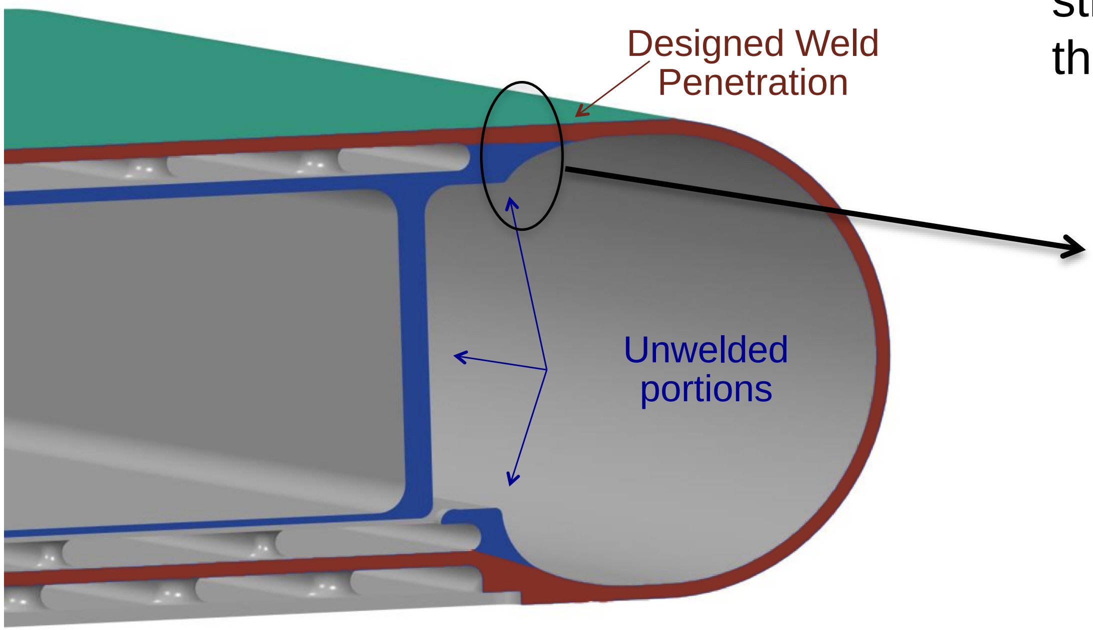


Target 11: stress not high at the failed weld – within limit, if weld is good

  - Target 10 (front/transition weld)
    - At this target region, thermal stress has a stronger influence



Front-Transition Weld Cross Section Concern



Partial penetration results in a stress concentration at the root of the weld

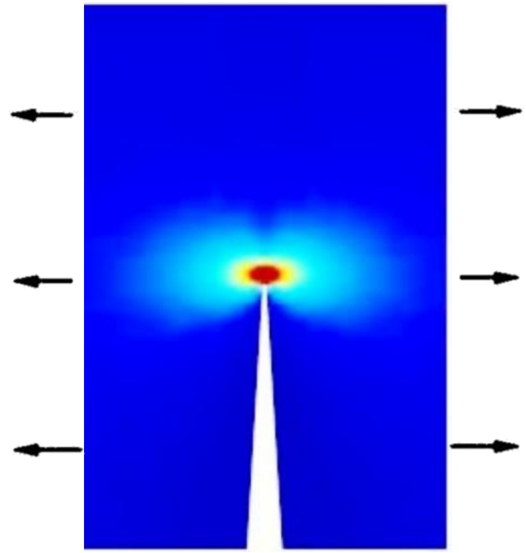


Image from Kroon, Computational Mechanics, Vol. 49, No. 1, 2012,

- Redesigning this transition region is planned
  - Avoid partial penetration
  - Allows for more inspect-able welds
  - But will permit mixing of bulk/window channel Hg flow

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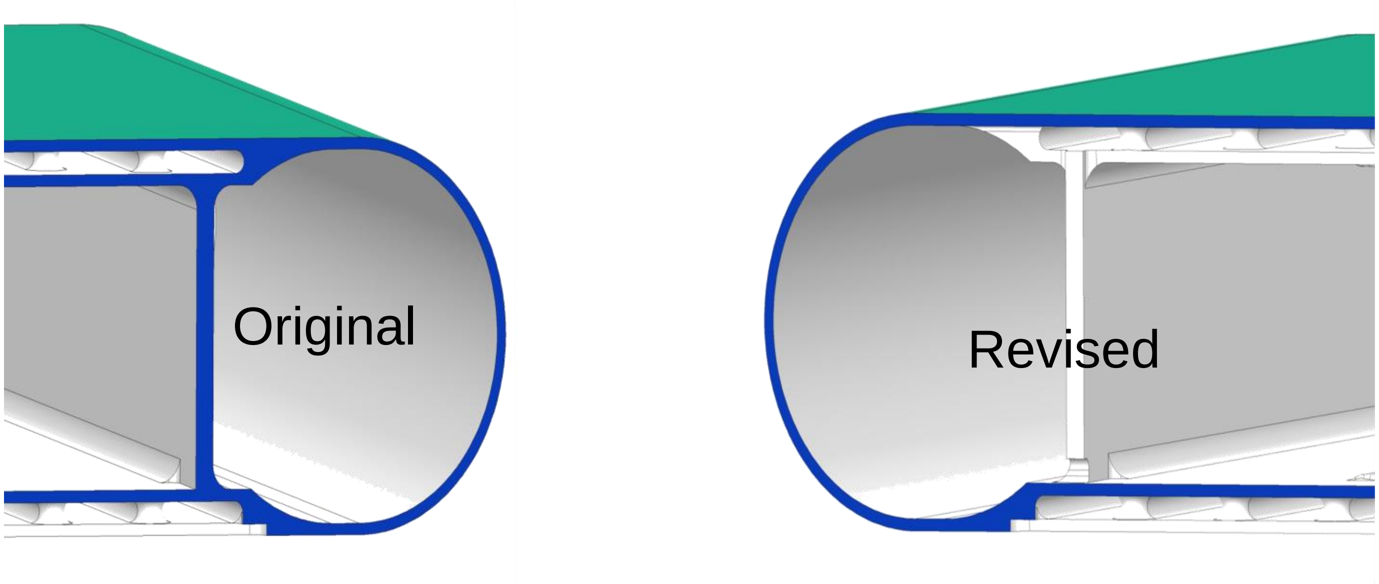
Modifications to Original Target



- Benefits
  - Full penetration weld.
  - Radiographs possible all around weld.
  - Compatible with analysis.
  - Removes contact ambiguity on abutting faces.
  - Preliminary results indicate this reduces the loads on weld at failure location.

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2015 DOE Review Recommendation

- *Re-design the transition-body to front-body weld area (EBW3) (including more realistic modeling of the new design) beyond the modification of targets in queue (FY16 targets) to move the weld-line away from discontinuities, ensure complete penetration, and allow for NDE.*

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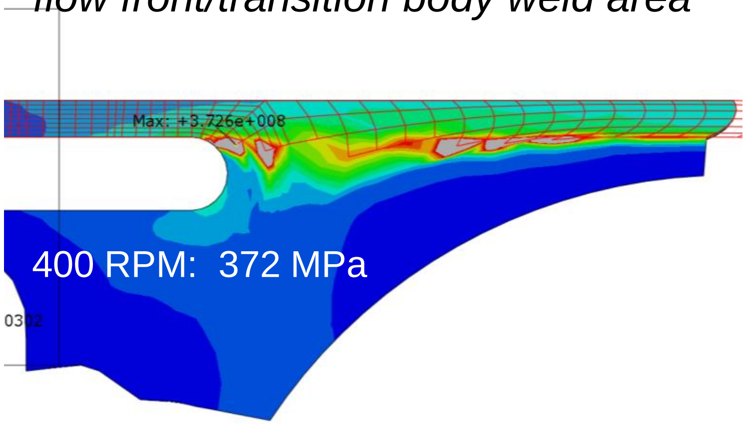
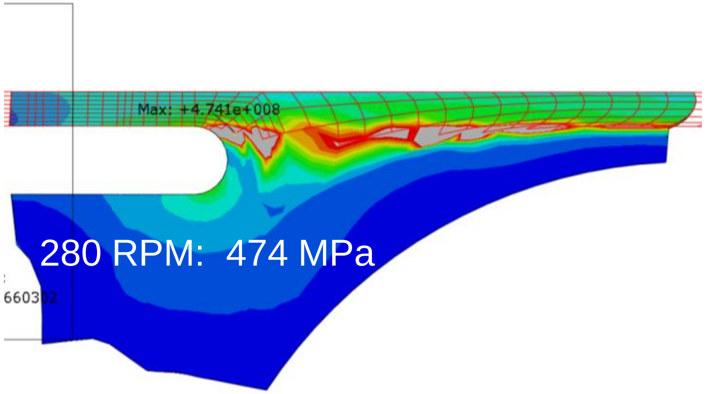
Thermal Stress Mitigation

- Increasing the mercury pump speed reduces the thermal stress
  - Larger reduction for jet-flow than for original design
- However there is an increase in Hg pressure
  - Higher stress at the transition plate
  - Concern for Hg pump grease
- Negatives outweigh positive for original design with transition plate, but will reconsider for the jet-flow

Thermal stress comparison at the jet-flow front/transition body weld area





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2015 DOE Review Recommendation

- Investigate running at higher pump speeds to evaluate the cost/benefit case for target survival versus pump/seal survival.
- Improve the design to reduce thermal stresses on welds.

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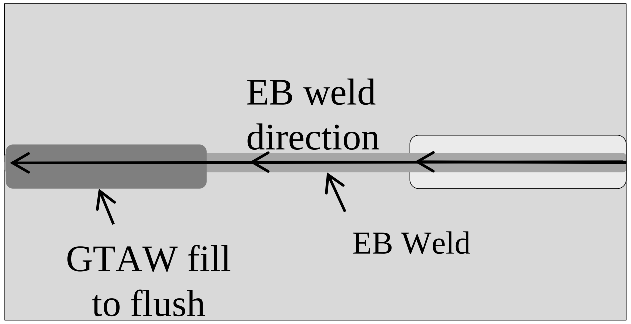
Fabrication Questions

- Weld questions
  - Kolsterizing® surface treatment
  - TIG backfill of e-beam weld
  - Samples being prepared for testing



- Relieve manufacturing induced residual stress at the front/transition body weld
  - Kolsterized layer must be kept below 300°C

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2015 DOE Review Recommendation

- *Clearly understand the implications of not post heat treating during the fabrication process. Consider limiting the portions of the target treated by Kolsterization in order to stress relieve as many welds as possible.*

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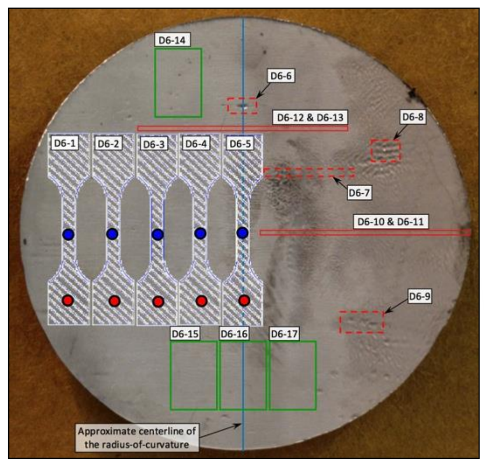
Sample High Exposure Targets

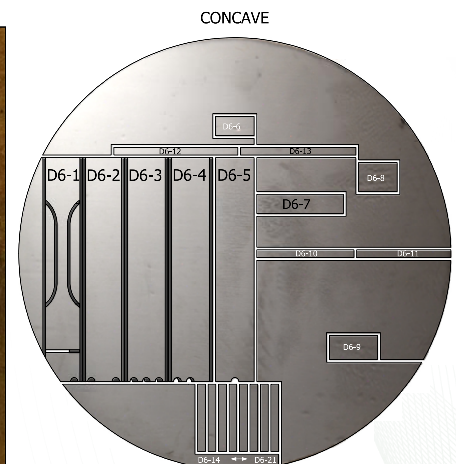
- Cut tensile test samples from nose of targets with high exposure and measure yield, ductility, hardness, …
- Use as a basis to extend target lifetime
  - Done for targets 1 and 2
  - Planning Target 9 tests (4195 MW-hrs)

Example: Disk 6 from Target 2

After Cleaning



Specimen Map



EDM Machining Map

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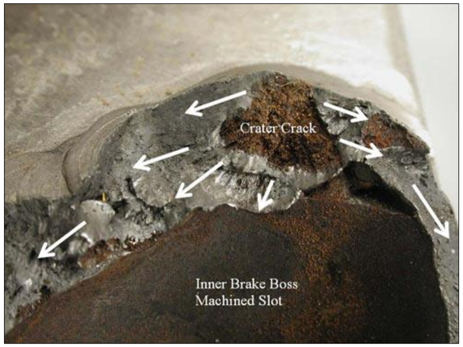
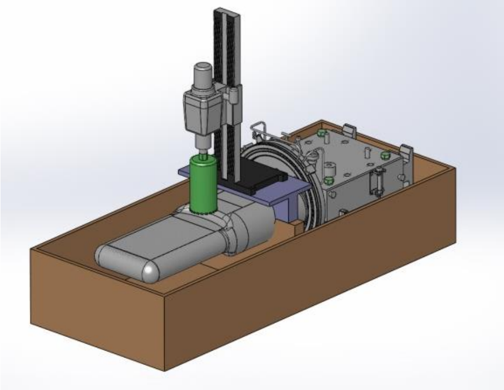
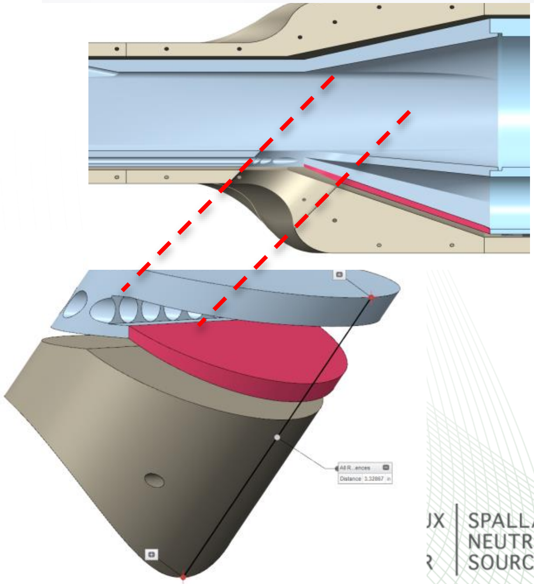
Sample and Analyze Failed Welds (T10 and T11)

- Microscopy on failure region can shed light on failure mechanism
  - Crack morphology, fracture mode
- Extract and analyze the highly activated target material
  - Investigating a simple / lower-cost option for sample extraction
  - Develop technique for cutting and examining failed welds
- Need to avoid congesting the target service bay
  - Temporary storage capability of target-11 is needed

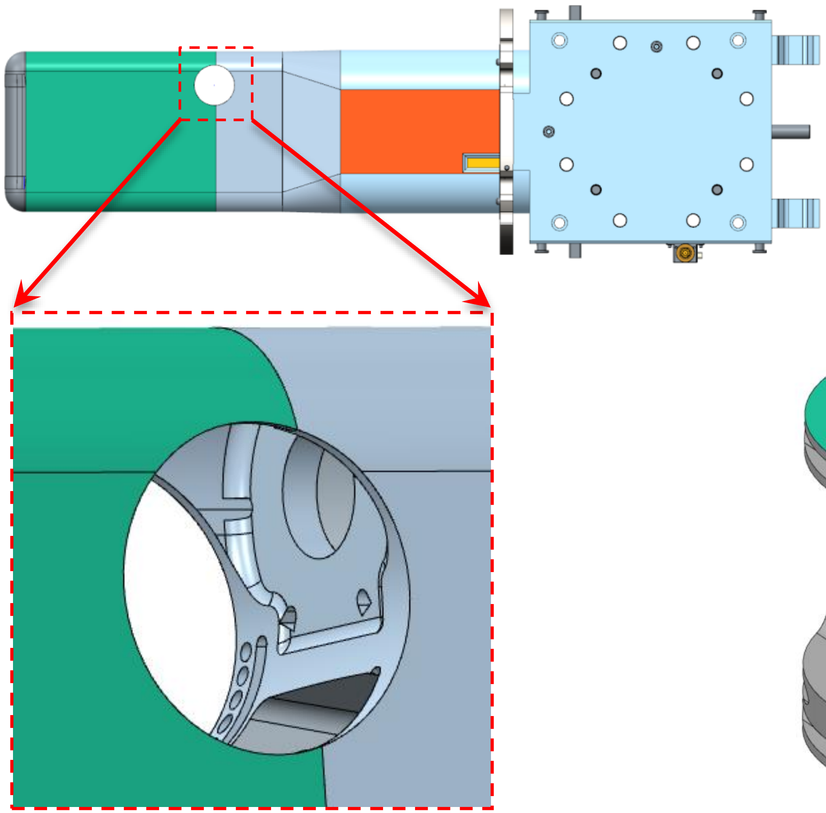






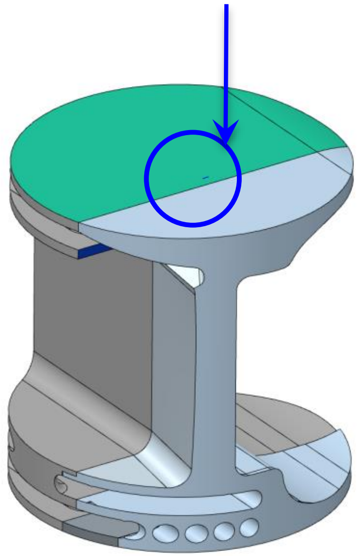
The Target 10 Leak Sample Removal

- Use annular cutters with carbide teeth for target front samples
- Sampling method and equipment being developed for Target 10
  - Need to “remote-ize” procedure



Sample of Target 10 Leak Location

Approximate Leak Location



Characteristic test cut

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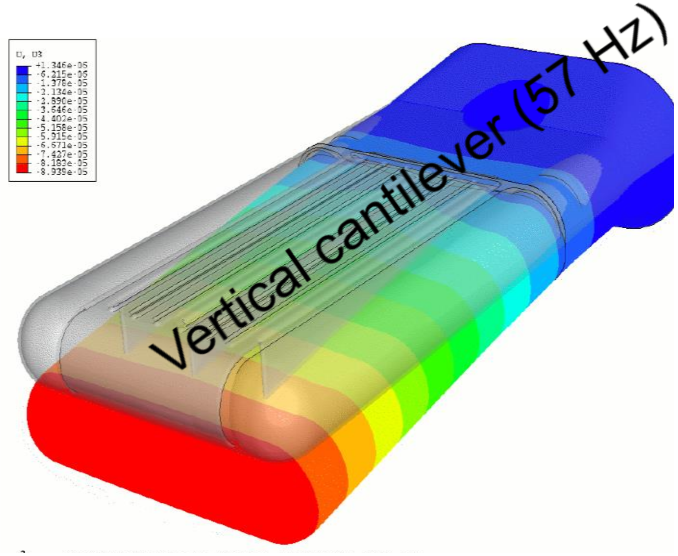
Recommendations

- 2015 DOE Target Review
  - *Continue PIE efforts with high priority – on all 3 targets*
- 2013 AAC Recommendation 25
  - *In order that users and the sponsor understand the problems based on the uncertainties relating to the lifetime of targets, the communication between the SNS accelerator management, and users and the sponsor is essential. R&D on target design should be carried out to reach the high power stable operation, and avoid the risk of unscheduled outages. PIE gives a lot of worthwhile information relating to pitting and irradiation damage and is an essential element to improve target reliability and target service life extension*

Instrument Targets

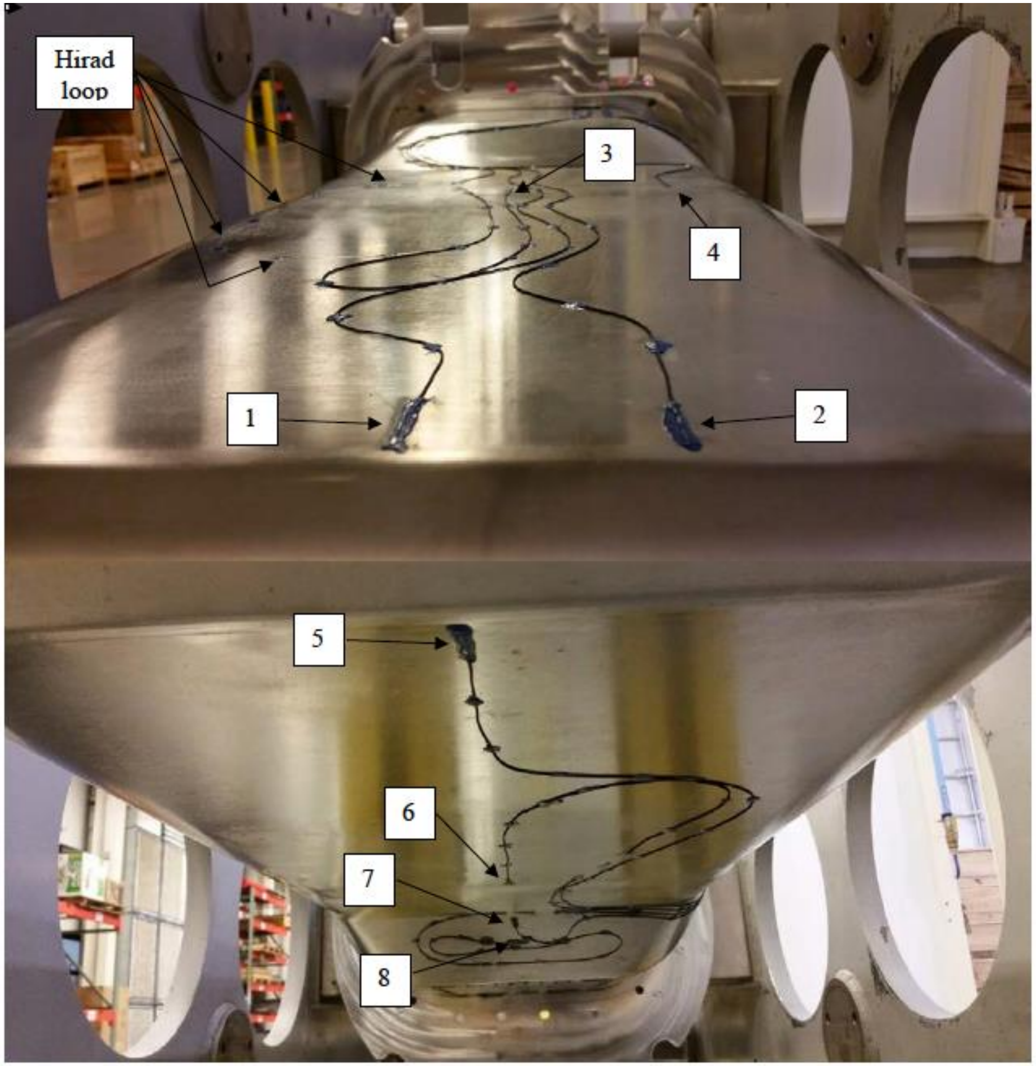
- Target modal analysis
  - Targets are designed to avoi resonances at 60 Hz harmor
  - Are models right?
- Measure vessel movement
  - Install fiber optic strain sensors on the vessel
  - Gas injection precursor



Instrument Targets

- Effort is underway to instrument the next installed target
- 8 sensors installed week of March 1
  - Strain sensors and high-radiation fiber test

Sensor locations



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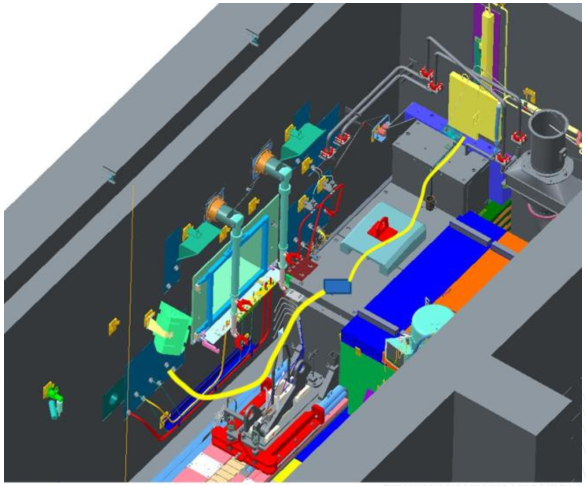
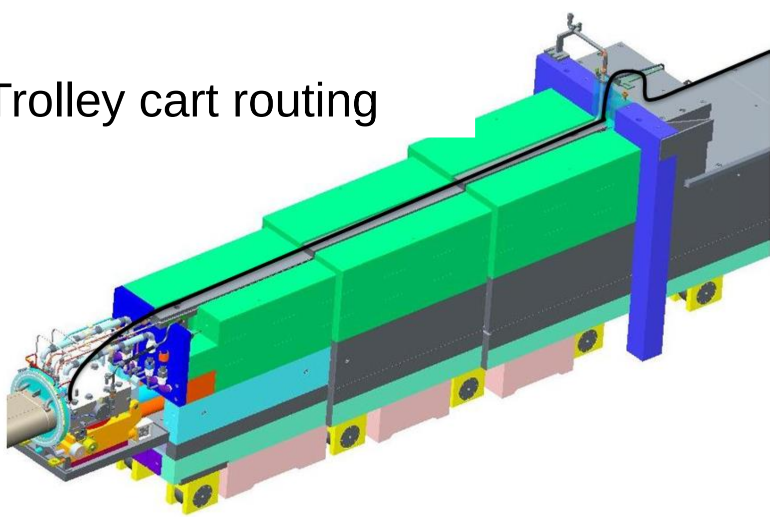
Instrument Targets

- Concerns:
  - Modifying target to accept new cables
    - New sensors cannot compromise Hg leak detection
  - Service bay impacts
  - Sensor / cable lifetime
    - Optimize beam turn on strategy

Service bay routing



Trolley cart routing



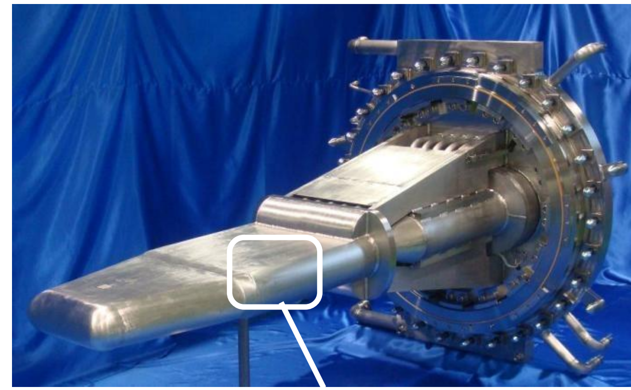
2015 DOE Review Recommendation

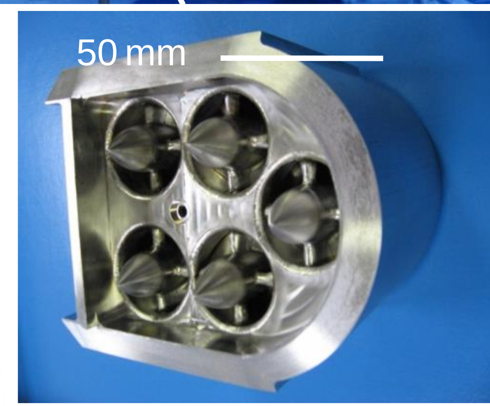
- Proceed with plan to install fiberotic strain gauges in the near term and develop LDV system like J-Parc on the longer term..

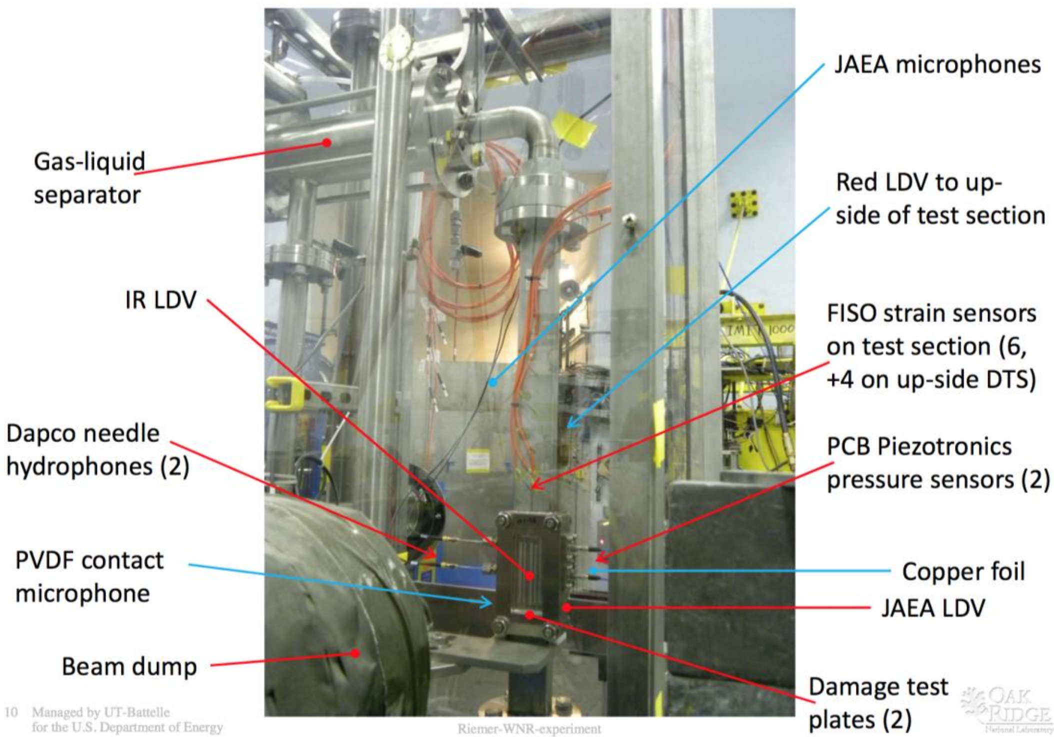
Gas Injection: Effective Pressure Wave Mitigation

J-PARC gas injector
T. Naoe et al, ACCAP 2013

- Absorb/attenuate pressure wave energy
- Mitigate cavitation damage
- Soften flow-induced vibrations
- Reduce dynamic stresses in the target



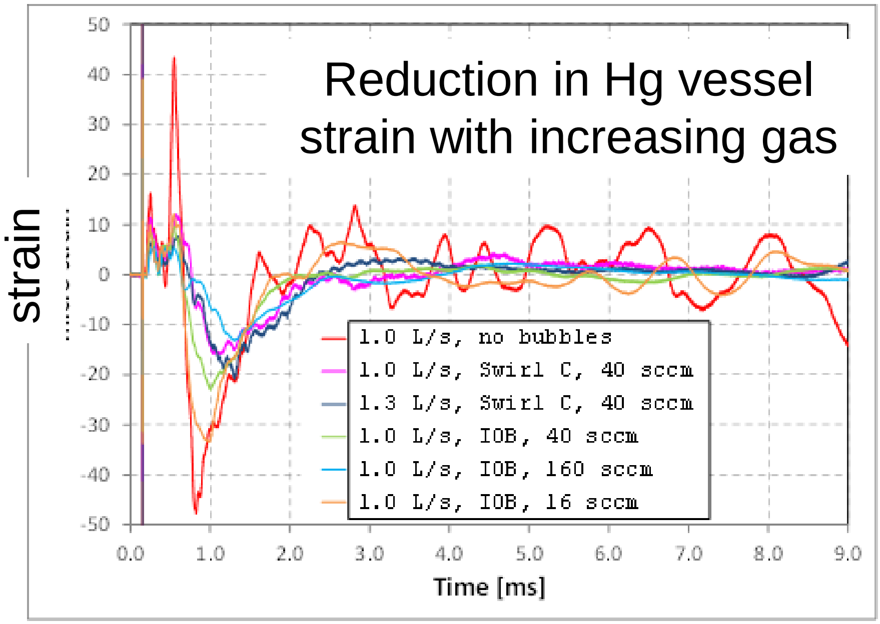




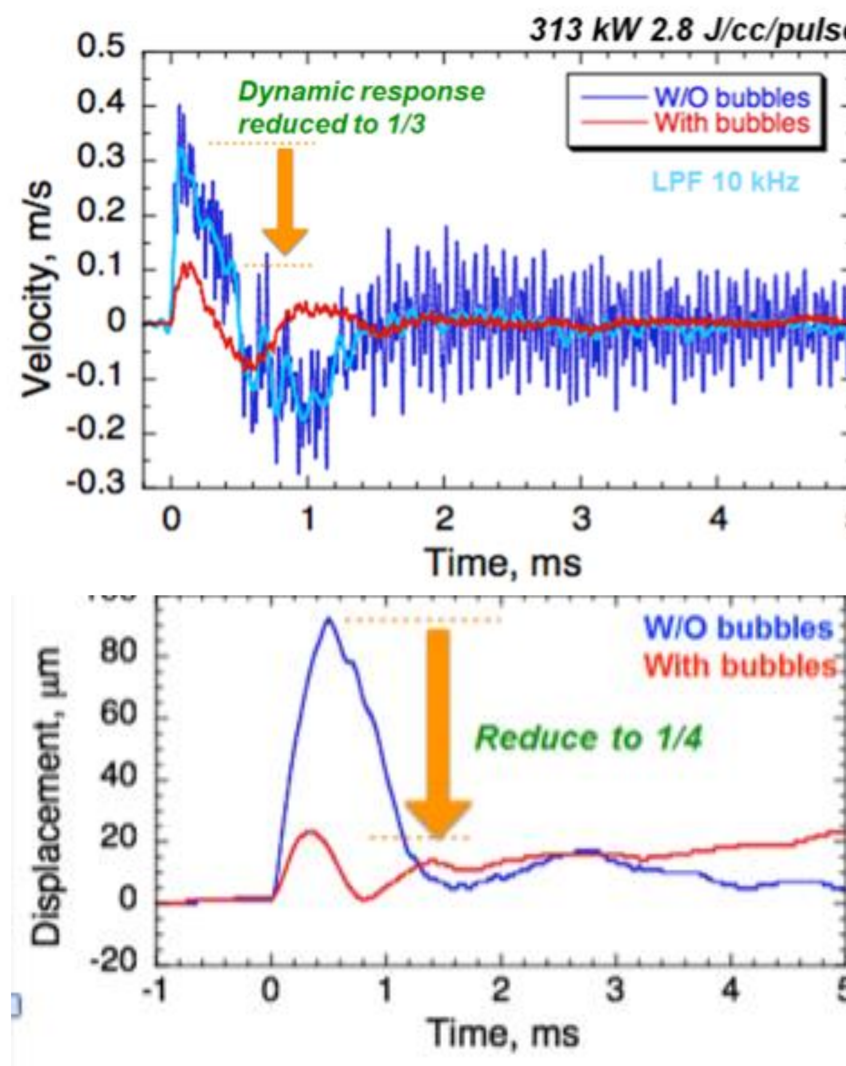
SNS Experiment at LANSCE (Riemer et al.)

Gas Bubble Mitigation

B. Riemer et al.



T. Naoe, J-PARC



- Gas injection into the Hg measurably reduces target vessel stress !

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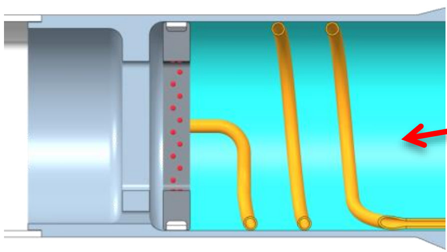
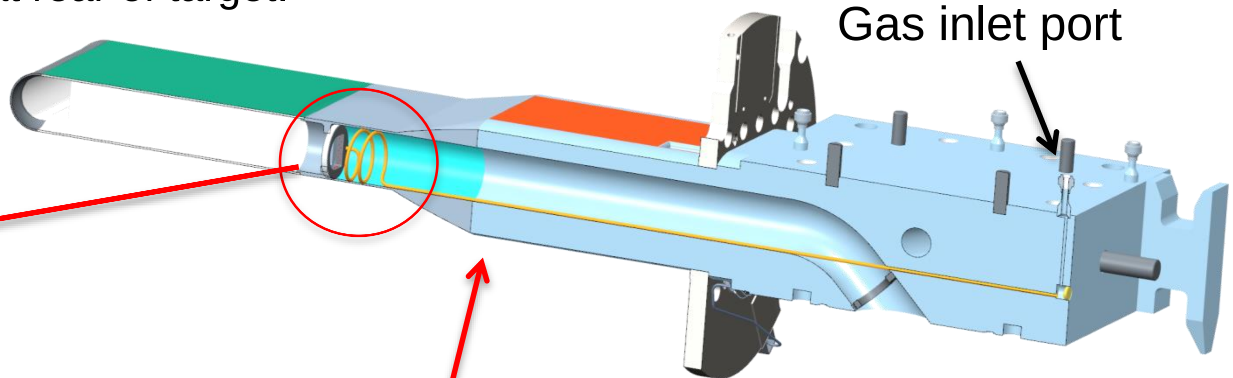
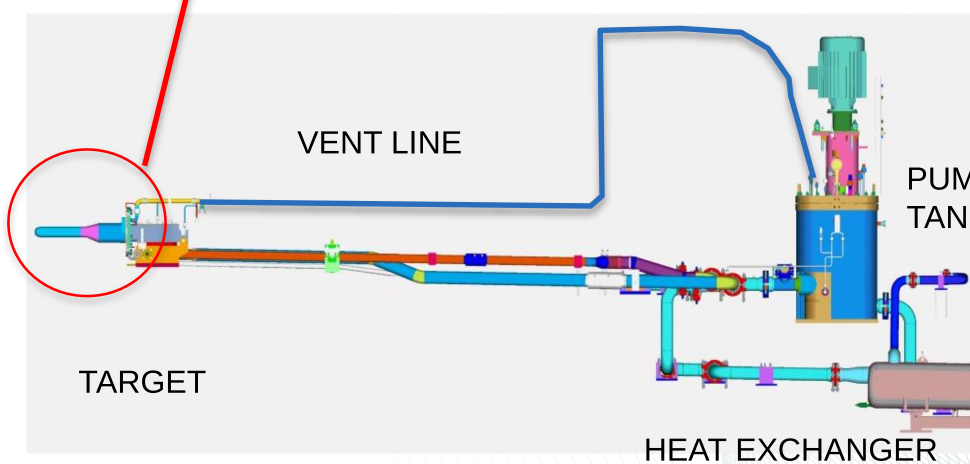
Gas Bubbler Short-term Retrofit Concept

- Machined assembly would provide 100 psi gas pressure to all orifices in one bulk return from common supply.
- Gas fed through new gas ports at back of target.
- Gas connections added at rear of target.





~ 1 year, $ 1M to implement



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Recommendations

- 2015 DOE Review
  - *R&D to develop effective bubble populations in the required regions of the target to mitigate high-cycle pulse stresses, while avoiding negative gas layer conditions, is recommended.*
  - *Implement in the near term a helium bubble injection system with gas injection ratio >10^{-4} and mean bubble radius <10 µm, but not at the expense of weld area re-design and reduction of thermal stress efforts.*
- 2013 AAC Review
  - *Although the jet flow gives the possibility to mitigate the pitting damage, the fatigue damage combined with pitting damage will ultimately dominate because the tensile stress increases with increasing beam power. The typical example is the cracking of the baffle plate. Gas bubbling in mercury reduces the magnitude of the pressure waves, which reduces both cavitation damage and fatigue damage. The development of gas injection concepts should be carried out under the collaboration with JSNS. The TTF mercury loop at SNS is valuable to carry out the R&D related to gas injection.*

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Projected Target Inventory

Assumes 2 targets/year consumption

	Fall 14	Winter 14/15 Shutdown	Spring 15	Summer 15 Shutdown	Fall 15	Winter 15/16 Shutdown	Spring 16	Summer 16 Shutdown	Fall 16	Winter 16/17 Shutdown	Spring 17	Summer 17 Shutdown	Fall 17	Winter 17/18 Shutdown	Spring 18	Summer 18 Shutdown
Installed:	MTM-002		MTM-002		MTX-009		MTX-010		MTX-008(JF)		MTX-011(JF)		MTX-013		MTX-012(JF)	
Spares: ↓	ORTE-003		ORTE-003		ORTE-003		ORTE-003		ORTE-003		ORTE-003		ORTE-003		ORTE-003	
			MTX-009		MTX-010		MTX-008(JF)		MTX-013		MTX-013		MTX-012(JF)		FY16-1	
					MTX-013		MTX-013		MTX-011(JF)		MTX-012(JF)		FY16-1		FY16-2	
							MTX-011(JF)		MTX-012(JF)							

FY16 Fabrication

Original target front/transition modifications

Jet-flow target front/transition modifications

Updated design criteria, fatigue analysis, …

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2013 AAC Recommendation

- *27. In light of the long lead time to manufacture targets, additional orders should be placed soon so as to sustain a reliable supply of spares.*

  - 6 targets were in fabrication chain during 2014 failures

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Target Replacement Rhythm

- Present strategy is to replace targets during planned major outages, as they approach a material radiation damage limit
  - Typically have some remaining margin when we replace targets
- Extend the target exposure
  - Introduce short target change outages to accommodate running to full exposure limit
  - Perform tests on previously exposed target samples to measure radiation damage – increase exposure limit
  - Be prepared to change a target quickly
    - We have cross trained staff
  - Neutron production contingency time to reschedule experiments ?

2015 DOE Review Recommendation

- *Consider introducing mid-term outages that offer flexibility to change out targets more frequently.*

Additional 2015 DOE Review Recommendations

- *Consider assigning priorities, with greater resolution to distinguish between all those tasks currently rated high.*
- *Consider removing the center baffle or re-designing to allow more flexing of the front body during the pressure pulse*
- *The same argument (aside from modal analysis) holds for the inner window. Consider re-design of inner window to allow more flexibility to damp the pressure pulse*
- *Pursue jet flow as planned, but not at the expense of bubble injection or weld/baffle re-design efforts.*

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Summary

- We know where the latest two failed targets leaked
- Steps towards understanding why welds failed
  - Analyze failed welds, instrument targets, sample weld specimen tests, update analysis tool
- Stress mitigation steps
  - Design changes, gas injection, relieve manufacturing stress, increase Hg Flow

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