SNS Mercury Target Development

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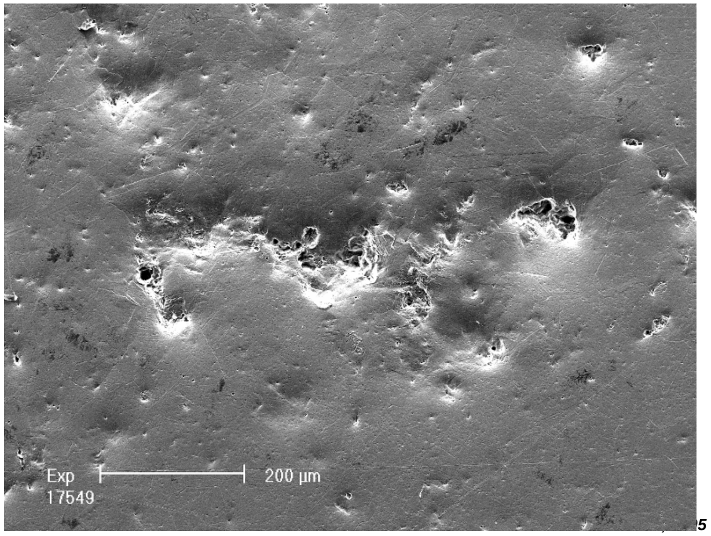
October 10-14, 2005

Oak Ridge, Tennessee

SNS *Project* Target R&D Ended in FY2002

- Steady state power handling
  - Cooling of target window - wettability
  - Hot spots in Hg caused by recirculation around flow baffles
- Thermal Shock
  - Pressure pulse in mercury & structural response of target vessel
- Materials issues
  - Radiation damage to structural materials
  - Compatibility between Hg and other target system materials
  - Fatigue properties of SS316LN in Hg
- Demonstration of key systems:
  - Mercury loop operation
  - Remote handling
- Cavitation damage erosion



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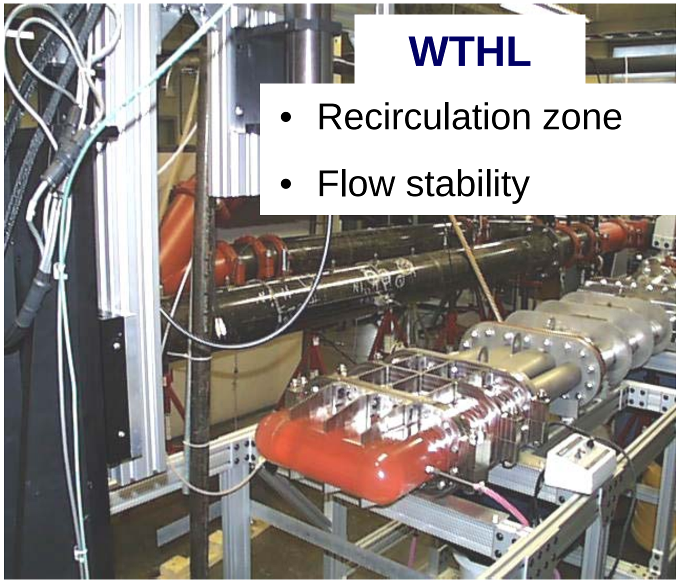


WTHL

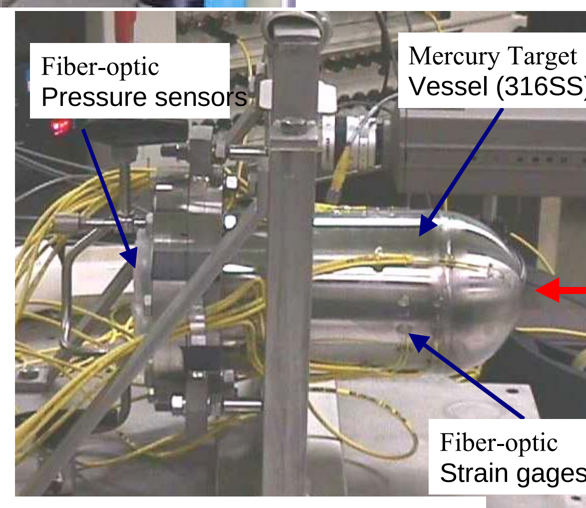
- Recirculation zone
- Flow stability

MTHL

- Wettability
- Design data for target window

TTF

- Final CFD benchmark
- Verify Hg process equipment
- Operational experience



In-Beam Hg Target Tests

SNS Mercury Target Development
Proton Beam Experiments

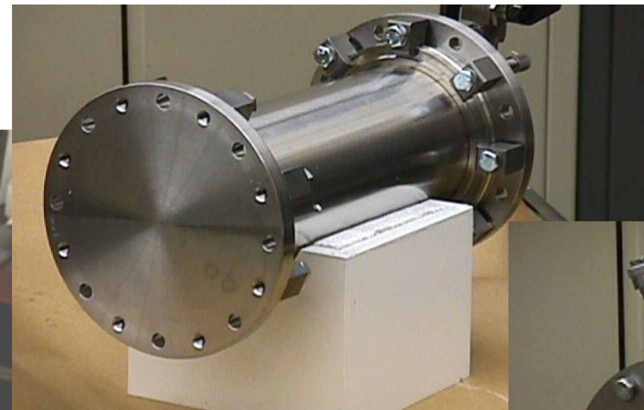
- Thermal shock experiments at BNL conducted under **ASTE collaboration** (SNS, J-Parc, ESS).
  - Strain, pressure, energy deposition, shielding
  - Large, cylindrical target
  - AGS proton beam: 24 GeV
  - Experiments in 1997, 1999, 2001

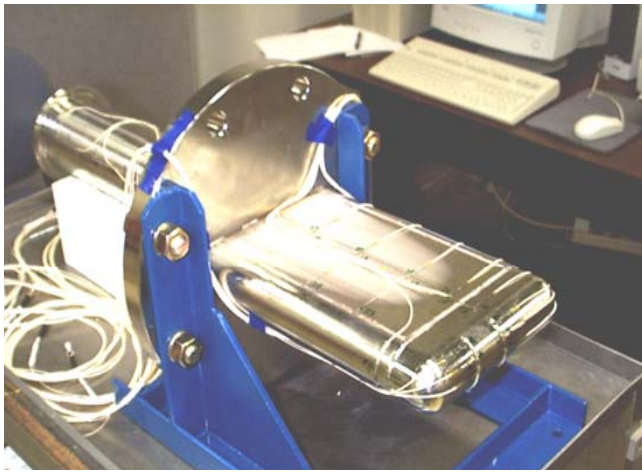
- Experiments at **LANSCE – WNR**
  - Strain, pressure, energy deposition, cavitation damage
  - Multiple target geometries
  - WNR beam: 800 MeV
  - Experiments in 1997, 1999, 2000, 2001 (July & Dec.), 2002 and 2005

Various Mercury Targets Have Been Used in WNR In-beam Tests

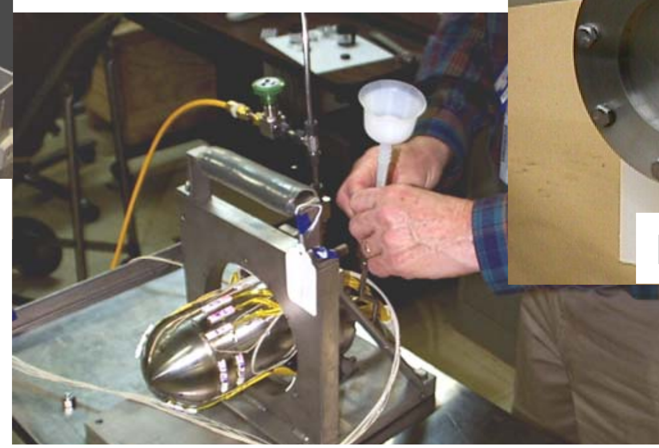
- Measure vessel strains for single-pulses

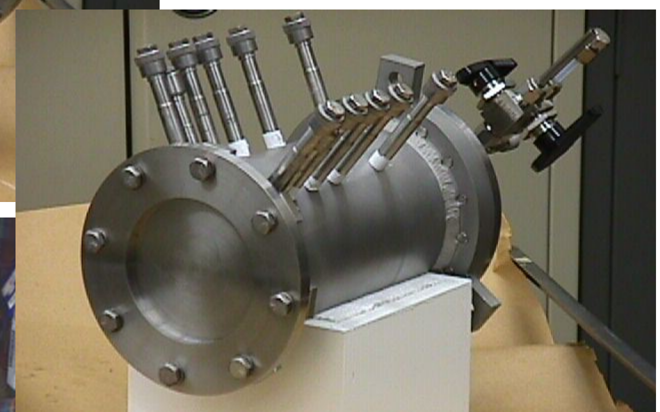
Large Effects Target





Prototypical Shape Target



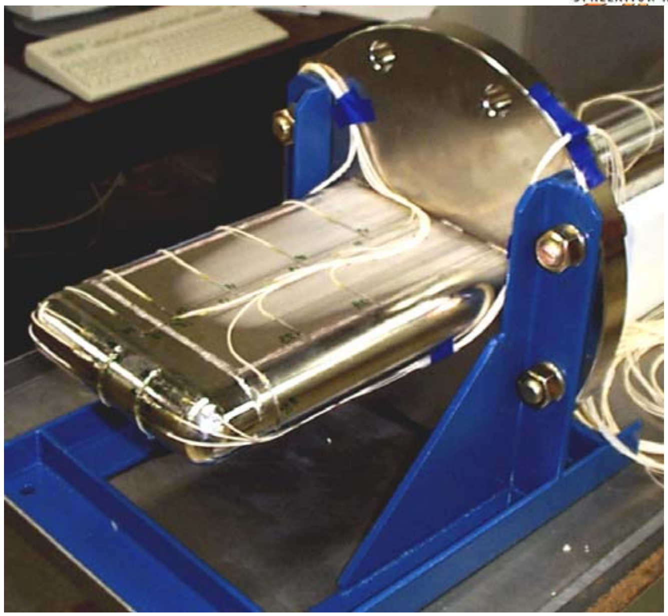


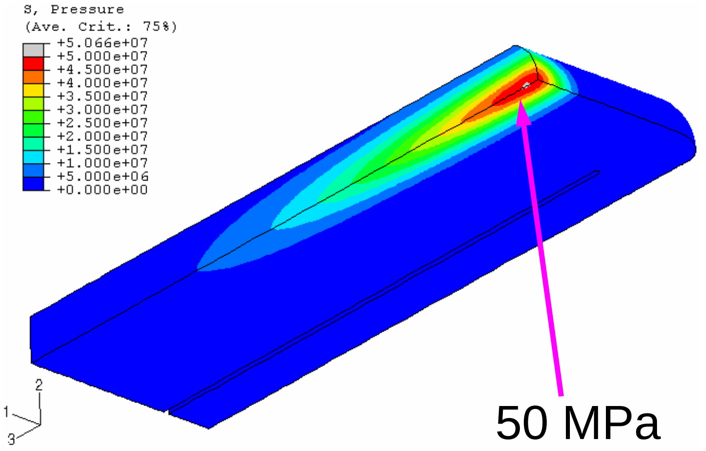
Energy Deposition Target

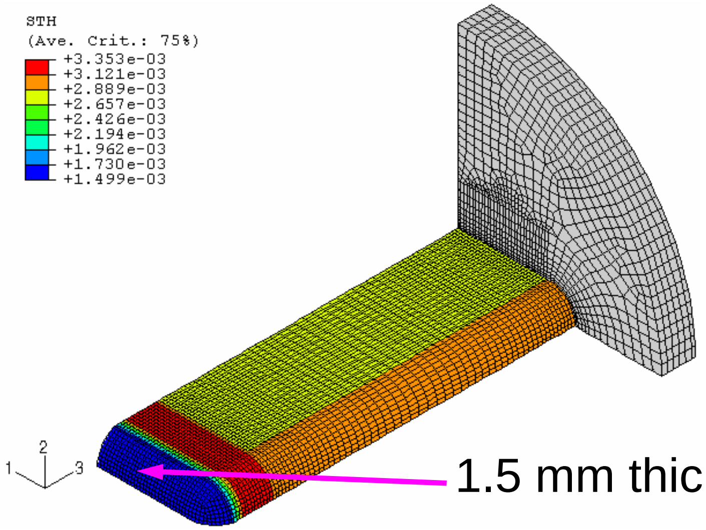
Axisymmetric Target

Benchmark of structural response simulation: Prototypic Shape (PS) targets

- One – half scale to SNS target.
- Strain levels similar to SNS.
- Internal flow baffles; stagnant Hg.
- Thin beam window; single wall.
- 25 strain sensors.
- Quarter symmetry, 3D model.

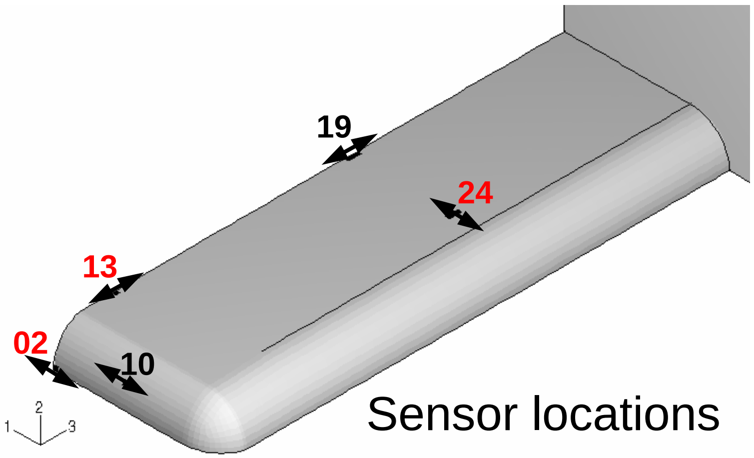


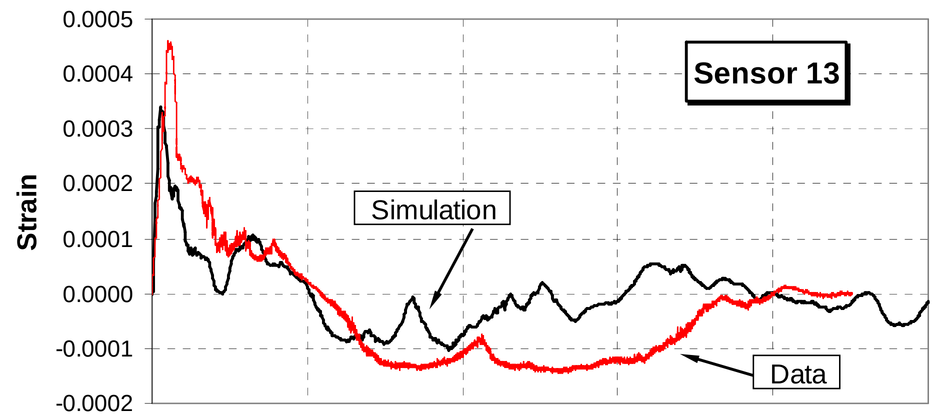


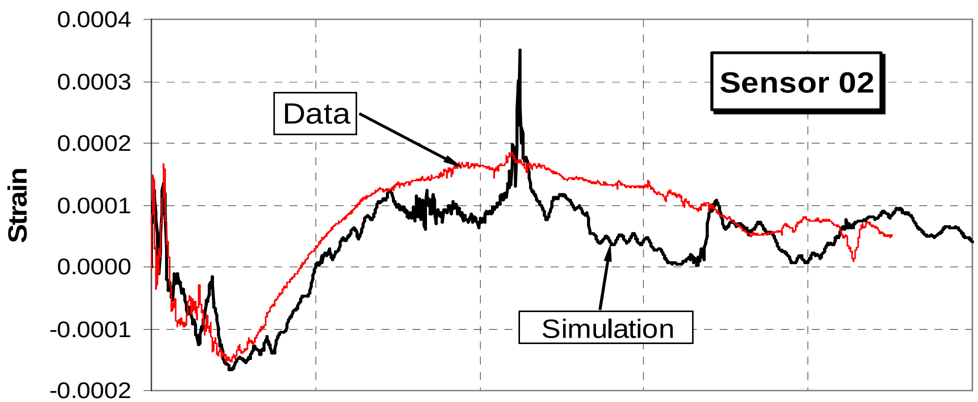


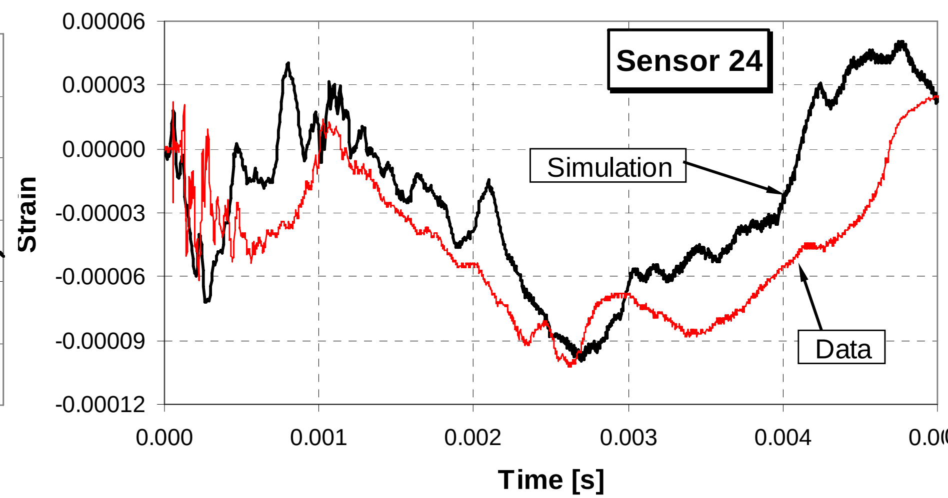
PS Target simulation strains agree reasonably well with data

- Simulation technique includes behavior to simulate mercury cavitation.
- Results are sensitive to cavitation threshold.
- Technique employed for SNS Target structural evaluation.







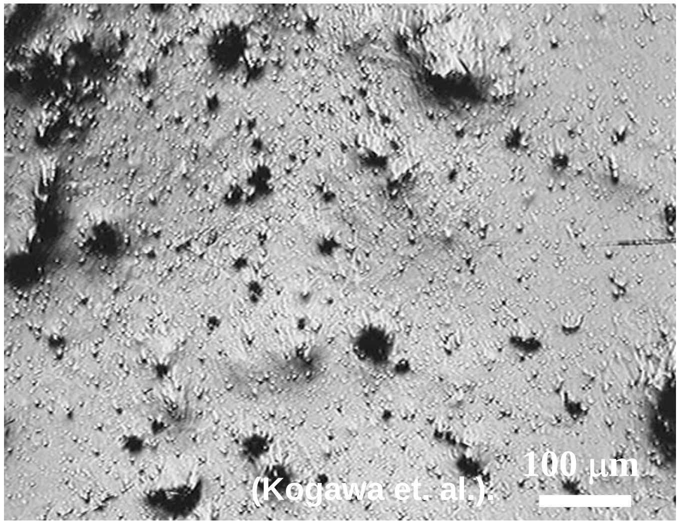


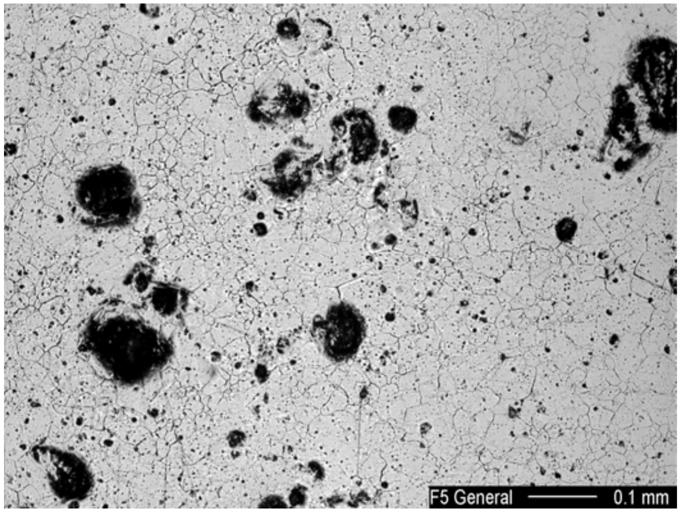
Cavitation Damage Erosion in Short Pulse Liquid Metal Spallation Targets

- At November 2000 Target Workshop in Japan, JSNS researchers investigating wave speed in mercury using a Split Hopkinson Pressure Bar presented pitting damage inside test sections exposed to compression levels comparable to mercury targets.

- The first in-beam confirmatory tests were conducted at the WNR in July 2001 using two "Large Effects" type test targets.

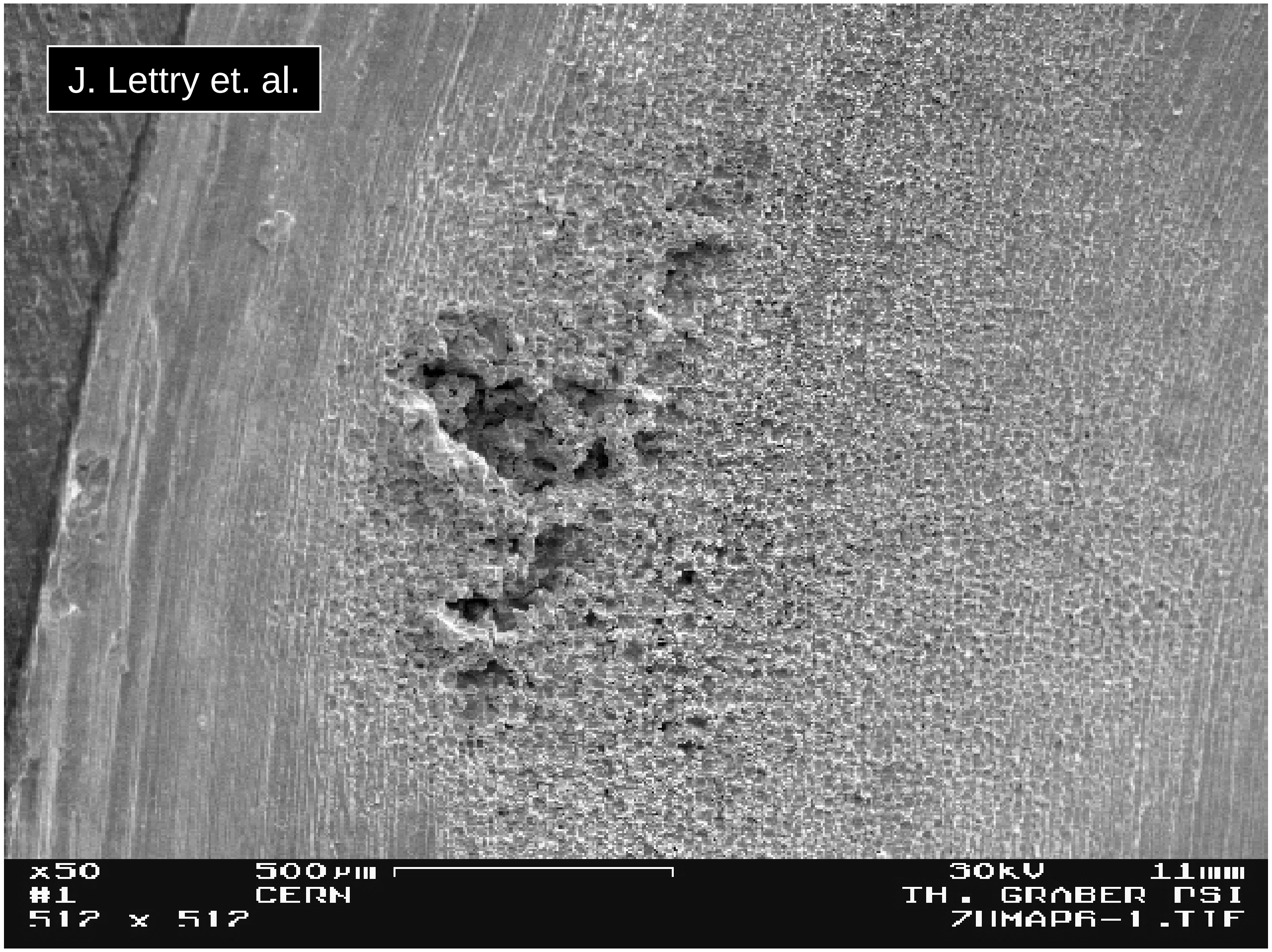
N=100, Vi=5.7m/s





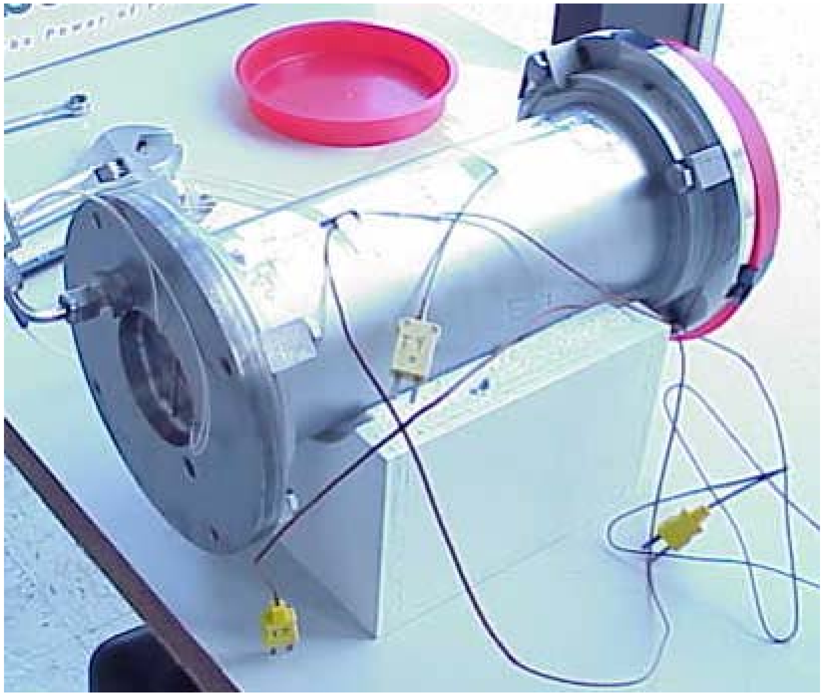
200 WNR Pulses

Mid 1990's - ISOLDE Molten Lead – Tantalum Vessel Target



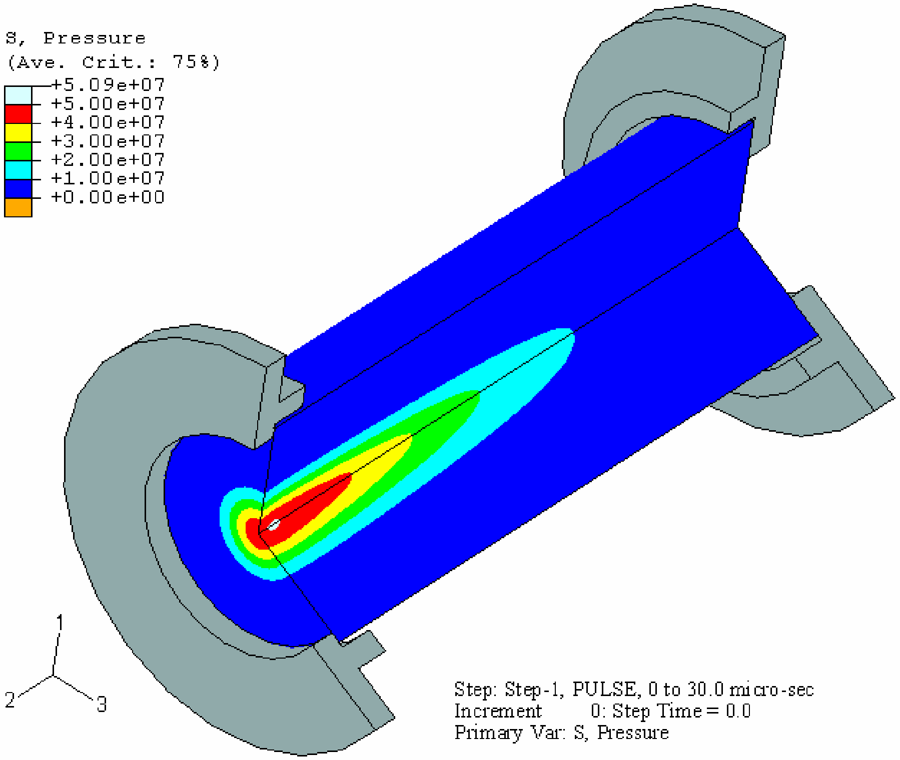
Mechanism for cavitation originates with abrupt pressure rise from deposited beam energy

Mercury filled test target being prepared for in-beam test



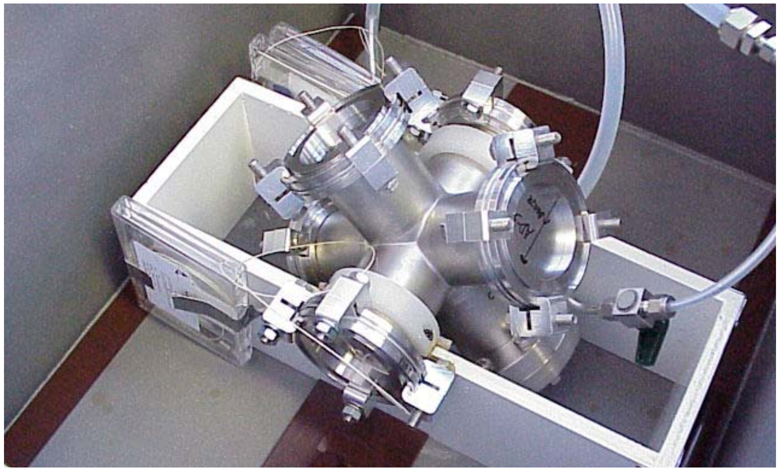
Simulation of test target response to beam show mercury pressure evolution

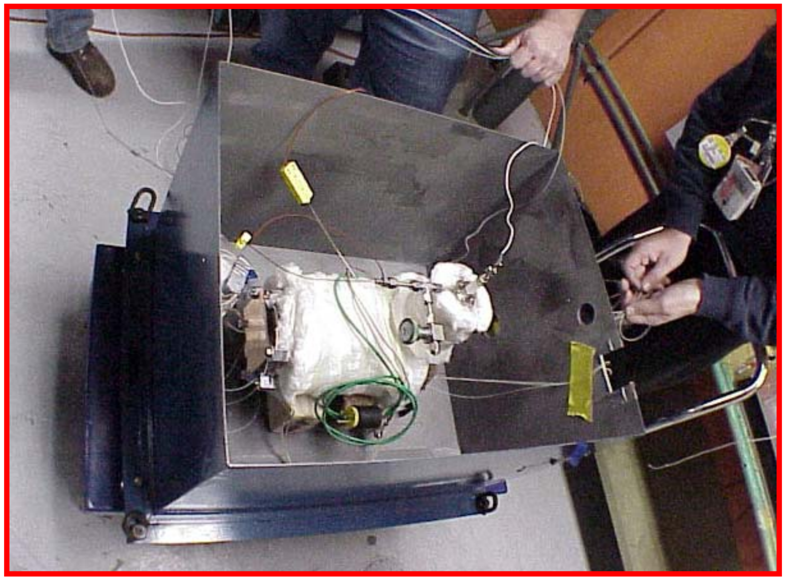
[Pa]



Mercury in state of cavitation

December 2001:
Alternate target materials, shapes, PbBi, etc.



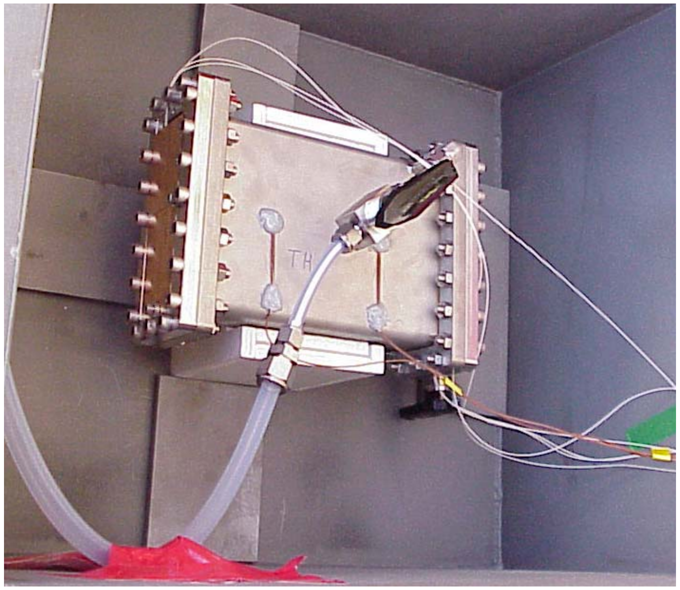


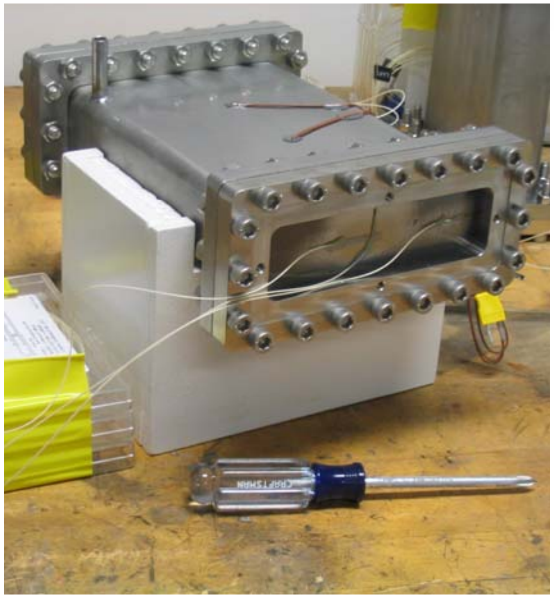
June-July 2002 at the WNR Facility
21 Targets / 19 Tests / 12 days beam time / 2800 pulses

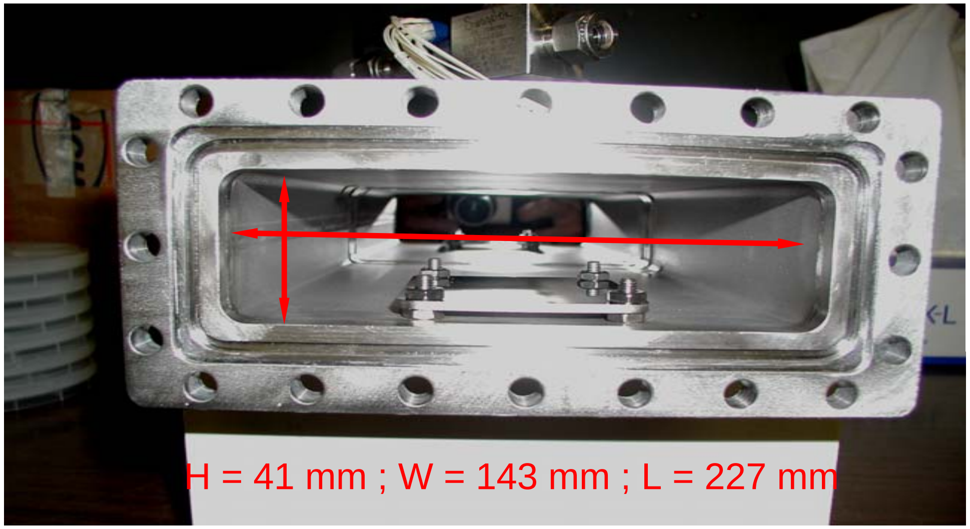
- Most targets have rectangular cross-section
- Many have plates at top or bottom to simulate slot in duplex structure
- Base case uses CW 316SS test surfaces and 100 pulses

- Power dependence
  - High-Power (Base Case)
  - Medium Power
  - Low Power
- Bubble/gas layer tests
  - Three thin targets in series (study effect of length and bubbles)
  - Protective gas layer flowing along the beam window
  - Small, stagnant gas layer at top of target
- Geometry effects
  - Double-wall: “Water-Cooled” Container
  - Double wall: “Hg Cooled” Container
  - Curved nose effect
  - “L” shape with 45° reflection on rear and free surface on top to simulate long target
- Material variations
  - Kolsterized, CW 316SS test surfaces
  - Electro-polished surface
  - Nitronic-60 instead of 316SS
- Bubble diagnostic target
- 1,000 pulses instead of 100
- Three Cylindrical targets fabricated by FzJ (material/coating variations)
  - Martensitic steel from ESS
  - CrN coating from JAERI
  - Annealed 316LN
- PbBi filled cylindrical target
  - Repeat of previous test, but with target completely filled

Rectangular Test Target



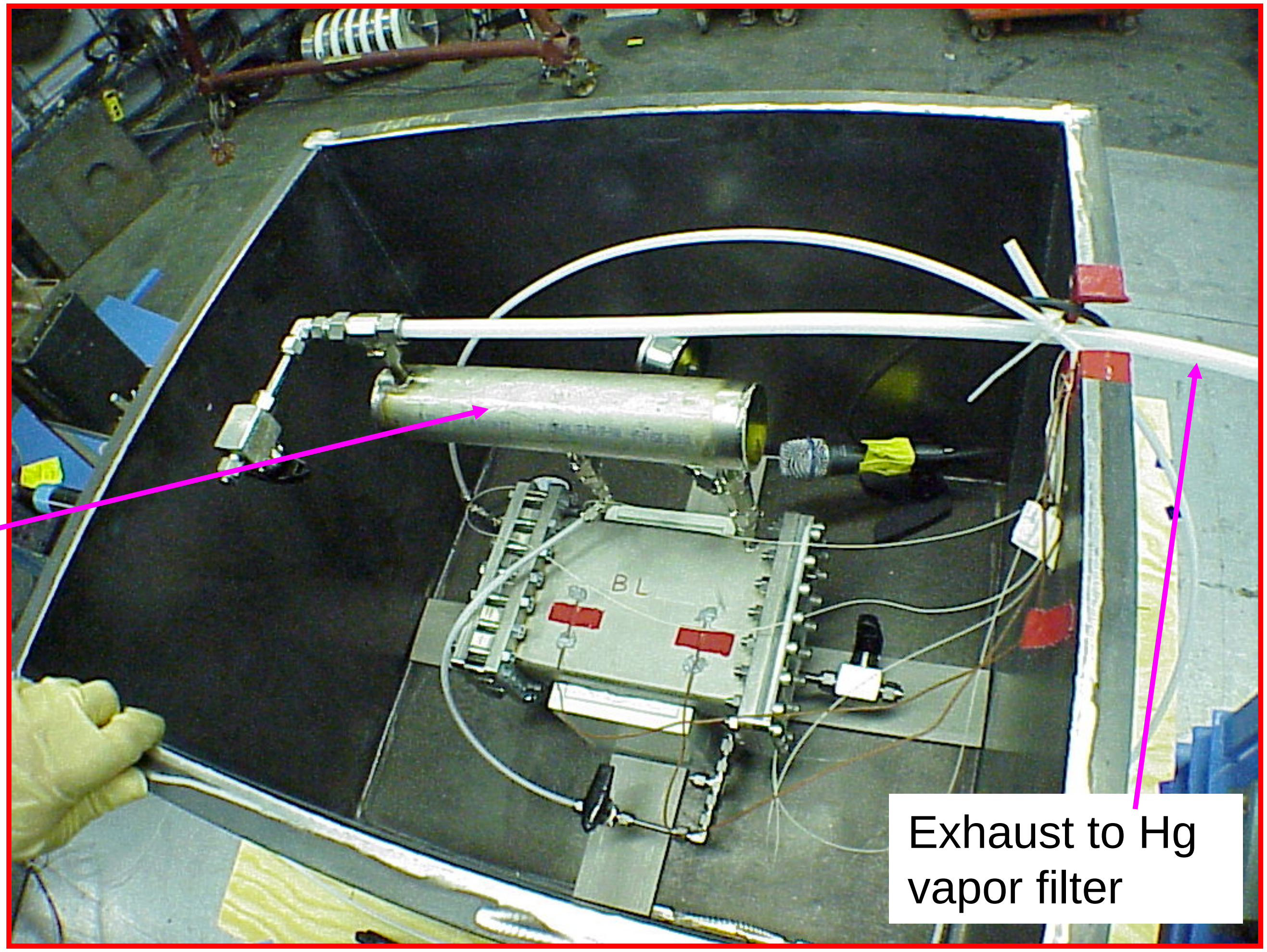




October 10-14, 2005

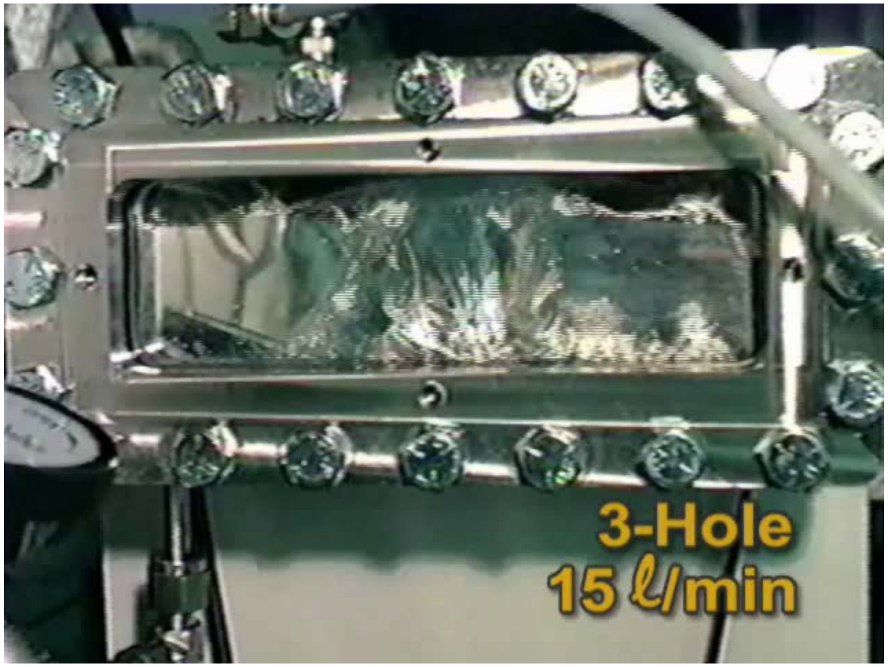
Bubble Layer Target

- "Wall" of bubbles attempts to isolate beam window from mercury.



Gas wall / impedance barrier

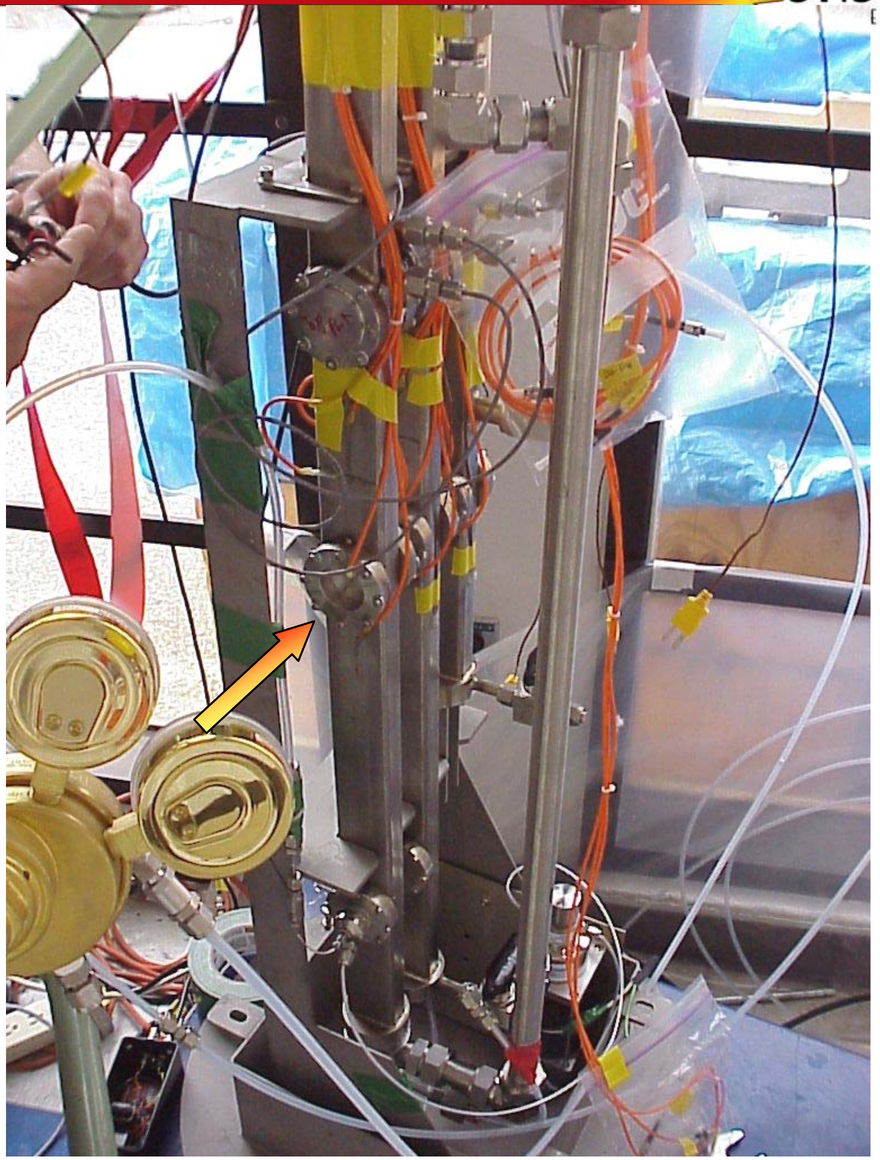
- Demonstration conducted as part of the WNR tests in June 2002. Damage reduction to 6% of baseline was measured.
- Conditions did not include mercury flow.



- This approach will require a greater design change to the SNS target and process loop. It will be necessary to water cool the beam window.

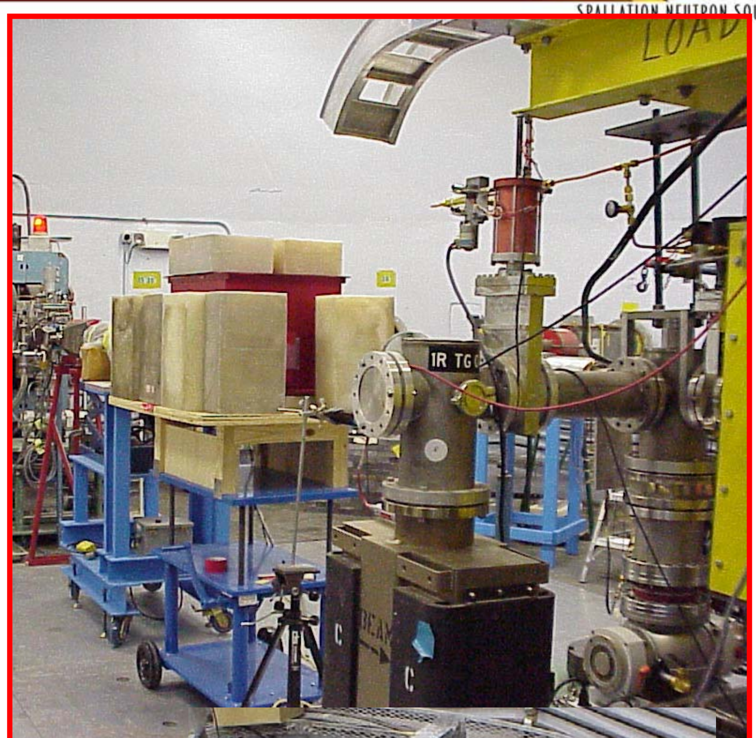
Bubble target

- Effort led by Helmut Soltner (FzJ) under a difficult schedule.
- 2 types of bubble generators.
- Bubbles moved by buoyancy.
- Achieved bubble population was unknown.



"KILO" Target tested with 1000 pulses

- Standard geometry with CW SS316 windows.
- Intensity equivalent to 3 MW SNS.
- Two pulses per minute.
- Maximum temperature reached: 96°C
- Borated poly blocks used to minimize room activation during test.
- Lead cave constructed for lengthy cool down period.



Highlights of 2002 WNR Pitting Tests

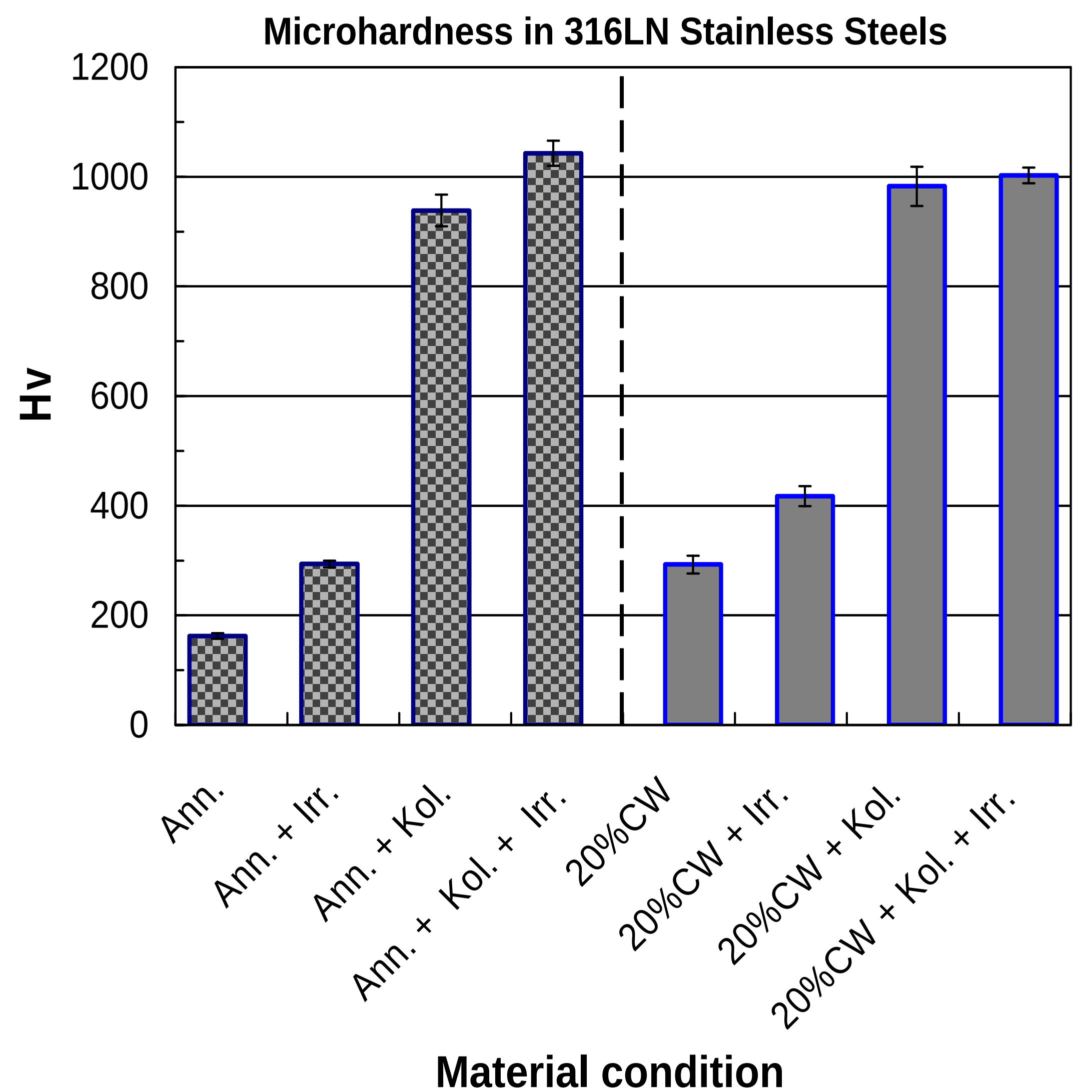
- Several test cases showed significantly reduced erosion on the front wall specimen
  –

Feature	Normalized Erosion*
Bubble Layer	0.06
Kolsterized surface	0.0008
1/2 Reference Power	0.09
* Erosion relative to reference (2.5 MW) case	

- Several other features had a negligible effect on erosion
  - Gas void, L-shaped target, Nitronic-60 instead of 316SS, curved nose
- Bubble injection reduced the erosion by a factor of 2 compared to a similar target without bubble injection; by a factor of 4 if proton intensity is accounted for.

Kolsterised 316LN maintains hardness after irradiation

- Irradiated in HFIR to about 1 dpa at 60 - 100°C.



T.S. Byun and K. Farrell; IWSMT-7, June 2005

In-beam testing for Cavitation Damage Erosion

- LANSCE – WNR
  - July 2001 (2 targets, 200 pulses each)
  - December 2001 (7 targets, up to 200 pulses)
  - July 2002 (19 targets, up to 1000 pulses)
  - June 2005 (8 target tests, up to 100 pulses)

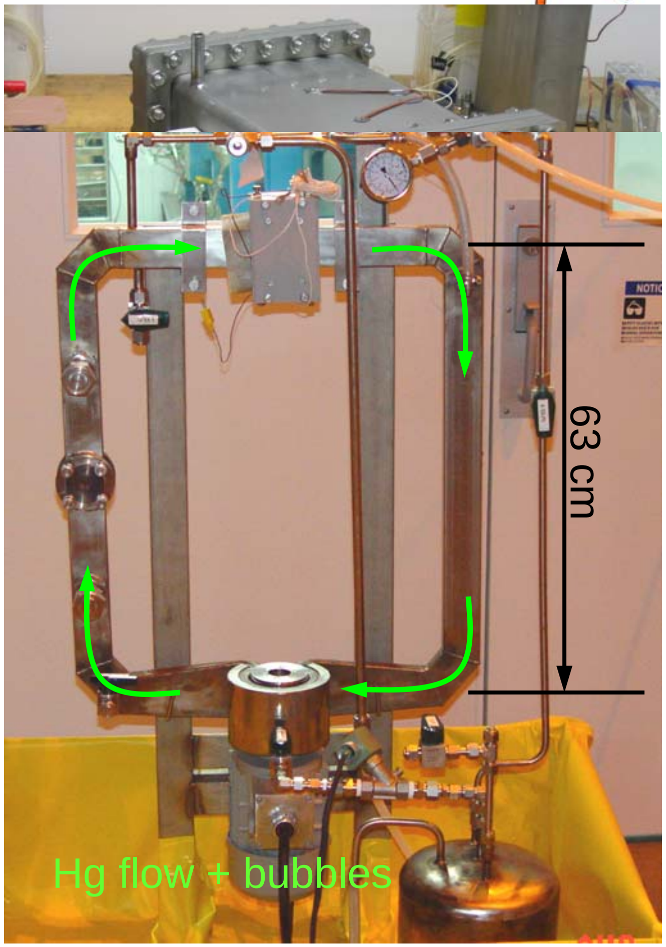
\+ Modest activation levels allow “hands on” access.

\- Pulse numbers are limited vs. real target. Only early incubation stage damage can be generated.

\- Pulse rate is not representative.

\- Slow & difficult analysis of damage.

\- Radioactive and mercury waste.

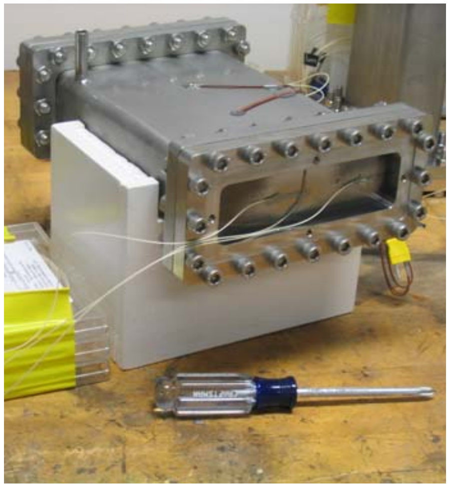


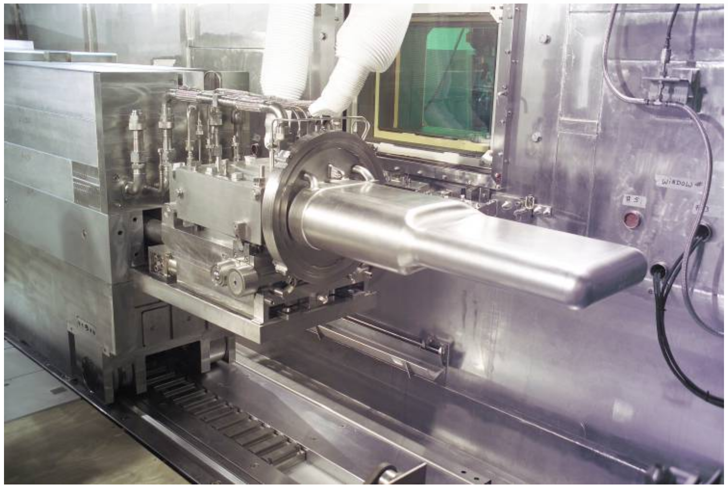
In-Beam Bubble Test Loop

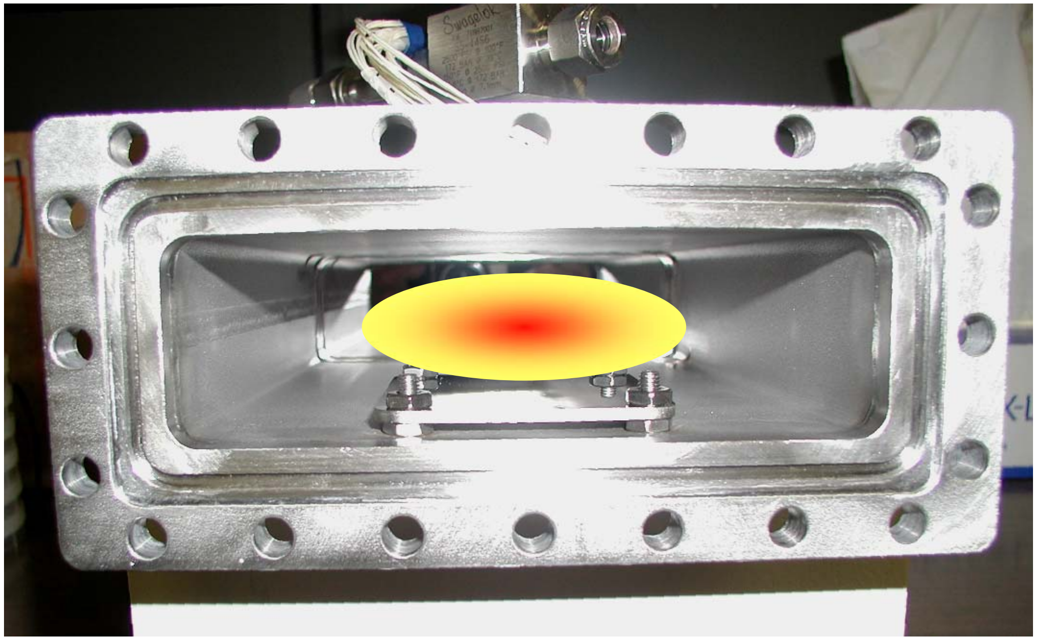
WNR vs. SNS & JSNS

	SNS	JSNS	WNR
Operating Power [MW]	1.4	1.0	n/a
Proton Energy [GeV]	1	3	0.8
Protons per pulse	1.5×10^{14}	8.3×10^{13}	2.8×10^{13}
Pulse frequency [Hz]	60	25	Single pulses only
Beam shape & size [mm]	Elliptic, ~ 200x70	Rect., ~ 170x80	Circular, σ ~ 10
Energy deposited in mercury [kJ]	12	15	2.1
Max. energy deposition density [MJ/m^3]	9.2	17	19
Peak initial pressure [MPa]	25	44	50
Target pulses	$> 10^8$	$> 10^8$	<= 1000

Beam characteristics drive damage, but so does target geometry. Flow effects are tbd.



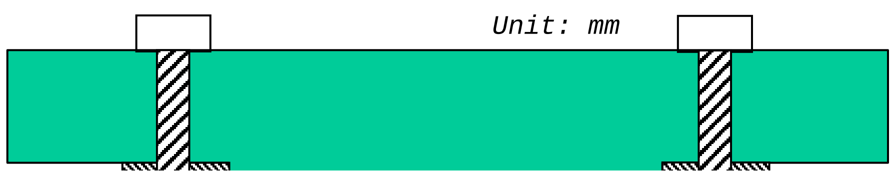




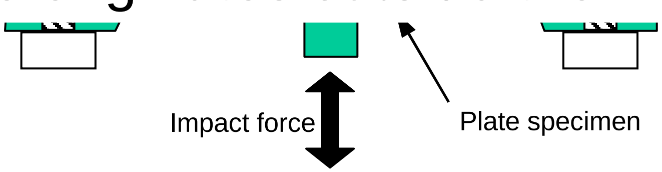
Off-line testing for Cavitation Damage Erosion with mercury

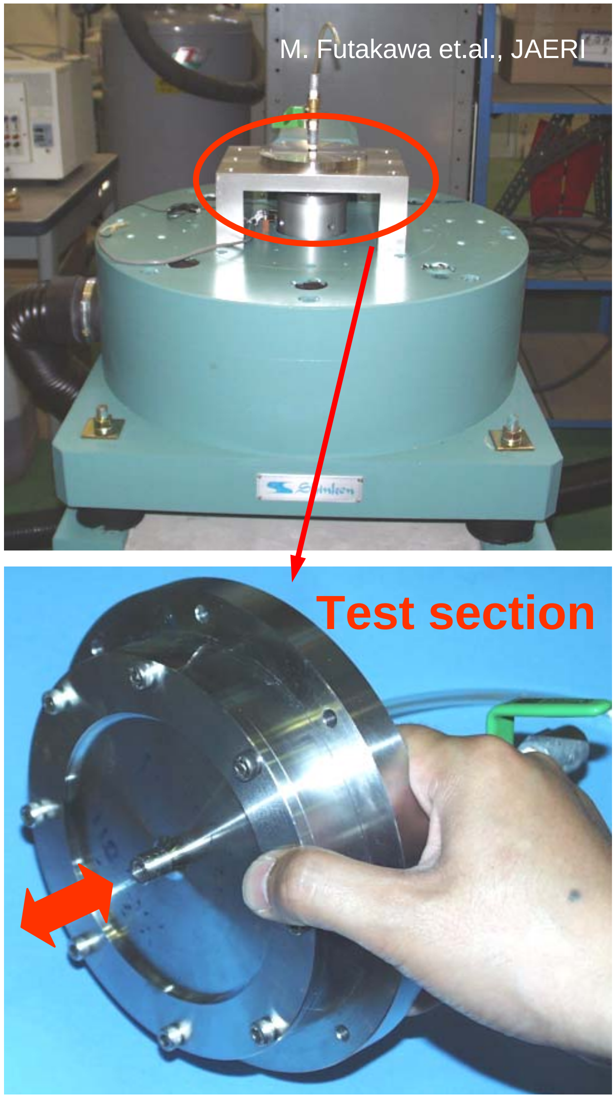
- **S**plit **H**opkinson **P**ressure **B**ar
  - single pulse; 100 cycles
- Automated SHPH - 1 Hz; 10^6 cycles
- Ultrasonic horn - 25 kHz; 10^8 cycles
- Lithotripter - 1 Hz; 10^4 cycles

- **M**agnetic **IM**pact **T**esting **M**achine
  - Up to 100 Hz; 10^8 cycles



Common characteristic is that pressure wave originates *outside* the mercury.





Current knowledge and strategy

- CDE *rate* is strongly sensitive to beam power; *perhaps* $\propto P^4$.
- Pulse frequency effect on CDE has been demonstrated in MIMTM but remains unknown for in-beam conditions.
- Alternate materials and surface hardening treatments can provide only modest potential for extending target life.

- Required improvements in target life and power capacity must come by mitigation of the damage mechanism, either by:
  – Reducing pressure wave magnitude at generation, e.g. through gas bubble injection.
    ▪ Long lived bubbles.
    ▪ Short lived bubbles.
  – Isolating the vessel wall from damaging bubble collapse by creating a layer of gas between it and the mercury.

- New bubble generation and gas wall technologies will need:
  – Off-line R&D for fundamental development, including bubble *diagnostics*.
  – Testing under more prototypic flow, beam and target geometry conditions than currently is possible.

Power Upgrade Project – HPTD ~ 3 year plan includes

- *Analysis* of in-beam tests at the WNR for damage mitigation.
- Development of technologies for gas bubble generation in mercury.
- Development of practical, laboratory bubble diagnostic techniques.
- Experimental validation of damage mitigation, both off-line and in beam testing.
- Experimental validation of desired bubble population under full scale flow conditions. Install and test on the TTF.
- Improvements to our infrastructure to measure damage accurately.
- Development of simulation methods to improve understanding of damage, bubble behavior, as well as how to implement gas walls.
- Assistance from university & research institute experts on bubbles, diagnostics and cavitation damage.

Collaboration with J-Parc (JSNS) is an integral part of the SNS HPTD plan.

- JSNS is completing construction of a test loop for development and testing of bubble generation and diagnostics. It will also demonstrate (off-line) damage mitigation.
- JSNS has elicited expertise from universities and industry to assist with generation and diagnostic technologies.
- At the Target Workshop held last March, it was agreed that SNS would increase its effort on the short-lived bubble and gas wall approaches to mitigation. SNS will not build a test loop like that of JSNS.
- Both parties will work on bubble generation and diagnostics; SNS testing can be on the JSNS test loop.
- In-beam testing will continue to be lead by SNS and will include JSNS developed technologies.

A few more points …

- Demand for brighter neutron intensity means target power handling capacity & lifetime will have to improve. Cavitation damage erosion must be controlled.
- Three years will not be the end of HPTD for the SNS. The aggressive goals of the 3-yr may not be met.
- There is no facility for testing targets with fully prototypic conditions. The only opportunities to study targets under all relevant conditions will be when SNS and JSNS operate at significant power levels. Post Irradiation Examination will be vital to understanding failure mechanisms and improving future performance.

What facility features are desired for HPTD testing?

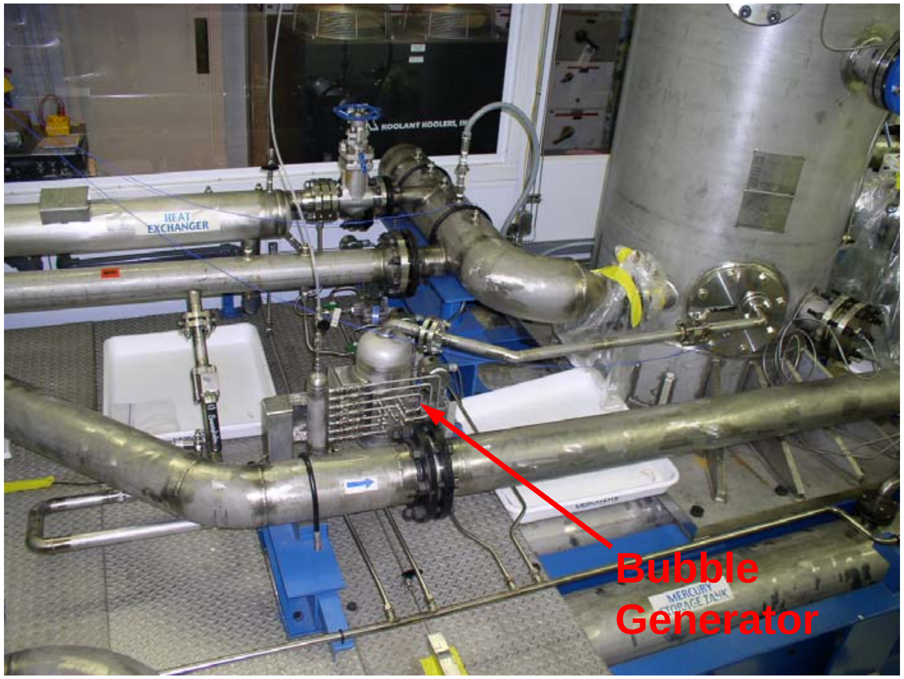
- Accommodations for mercury.
- Two classes of test station:
  - Hands on access with shielding for moderate radiation;
  - Access by remotely handling equipment and shielded for high radiation.
- Sufficient space for up to prototypic size targets, mercury process and support equipment.
- Test station utilities including cooling water, hot off gas, vacuum, electric power & instrumentation.
- Post irradiation examination facility on site or nearby equipped with tools for dissection and analysis of target components.
- Hot storage area.
- Infrastructure for dealing with radioactive and mixed waste.

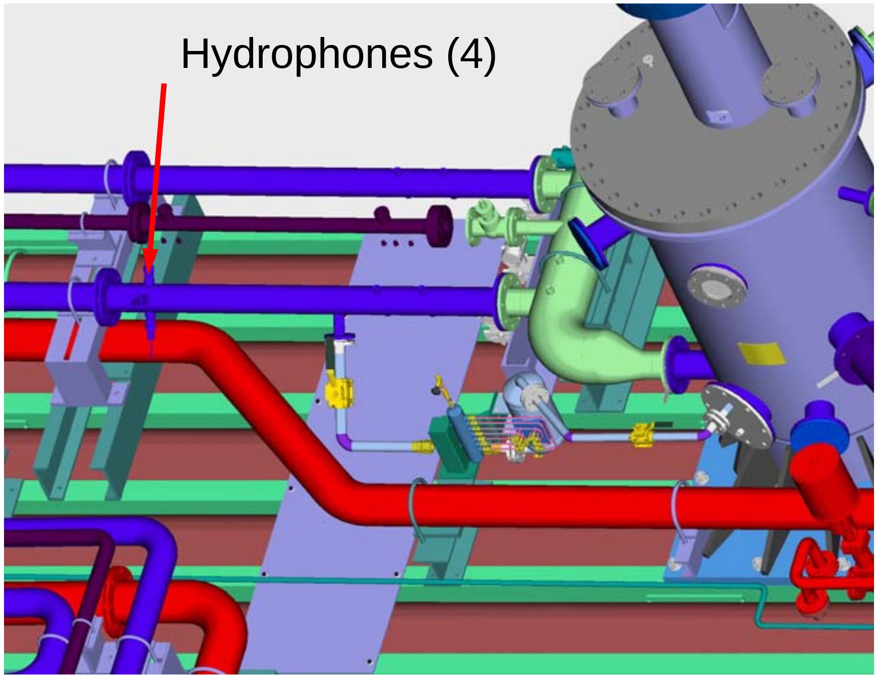
Desired Proton Beam Parameters		
	From	**To**
Proton energy [GeV]	0.8	3.0
Pulse length [µs]	≤ 1	Continuous
Intensity [protons/m^2/pulse]	10^{16}	10^{18}
Allowed number of pulses on target	1	10^8
Pulse repetition frequency	Single pulse	100 Hz

[redacted]

Bubble Injection in the TTF

- The TTF bubble generator used seven jet-nozzles in parallel.
- Hg flow rate: 100 to 573 gpm; helium: 0.05 to 4.8 liter/min.
- Acoustic diagnostic technique used. Instruments included the **A**coustic **B**ubble **S**pectrometer.





+ Attenuations of 1000x measured.
- ABS readings of void fraction were not credible.