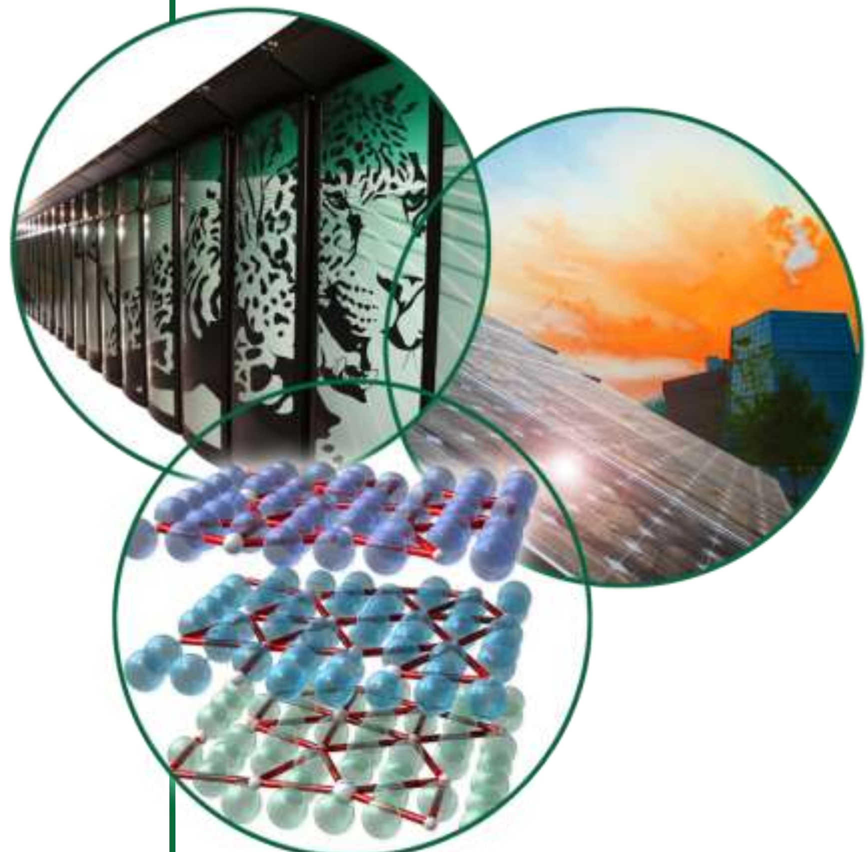
SNS Accelerator Advisory Committee
Oak Ridge, TN
February 2-4, 2010

Target Development



Bernie Riemer

Target Development Team Leader

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

General outline

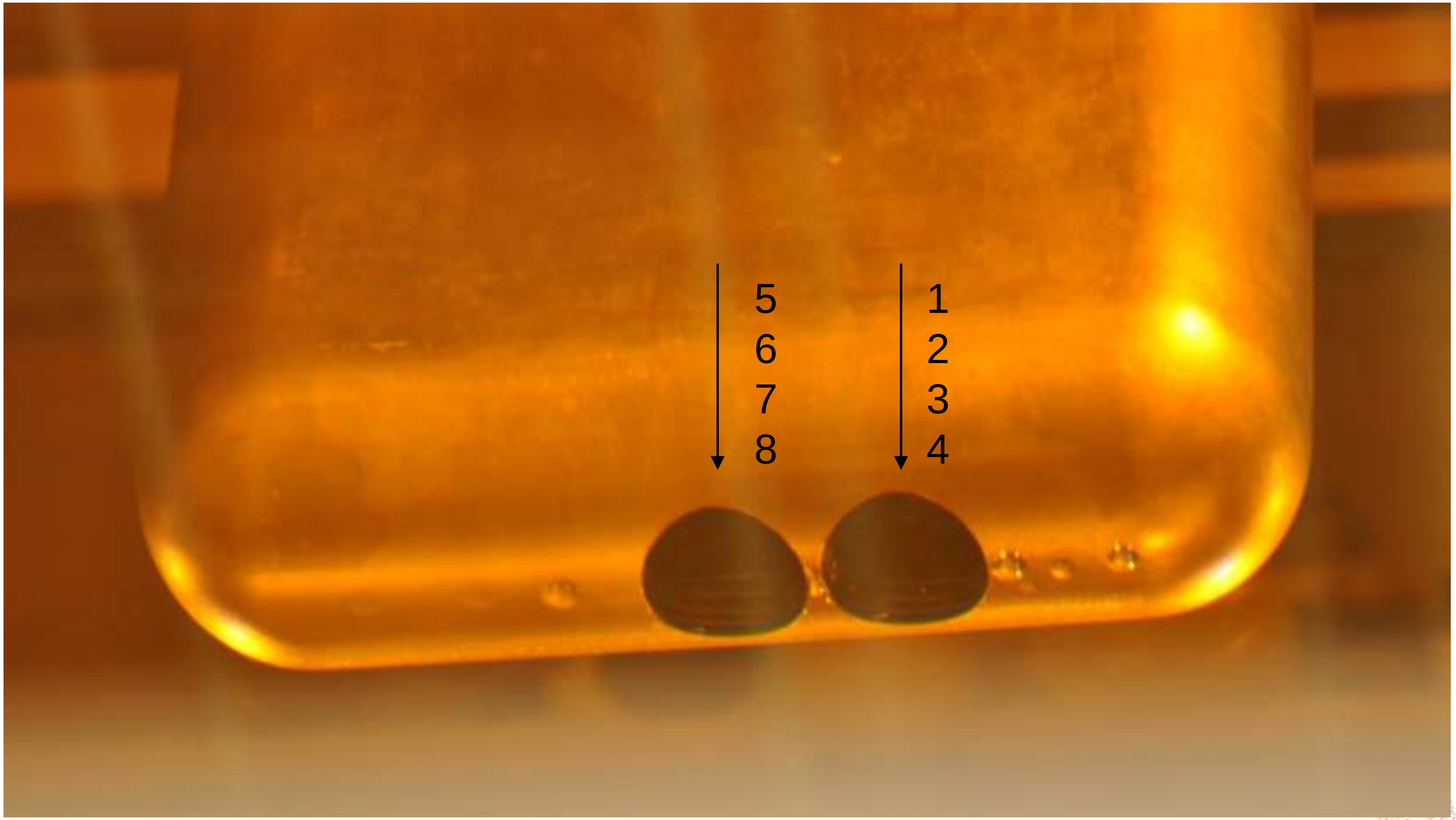
- Damage in Target #1
  - Doubts about phenomena answered
  - Influence of flow evident
- PIE plans
- Progress in R&D for damage mitigation
  - Damage analysis WNR2008 experiment
  - Gas Walls, Small Gas Bubbles, Diagnostics
  - JSNS target test on TTF
  - SGB tracking simulations
  - WNR_2010 test preparations
- Team mission is now “Target Development”

Remotely operated hole cutter was used on Target #1 in early November

- Two cuts – each through 4 layers
- Specimens would not drop out
  - Special tool was prepared to push them out
  - Examination & photography late November

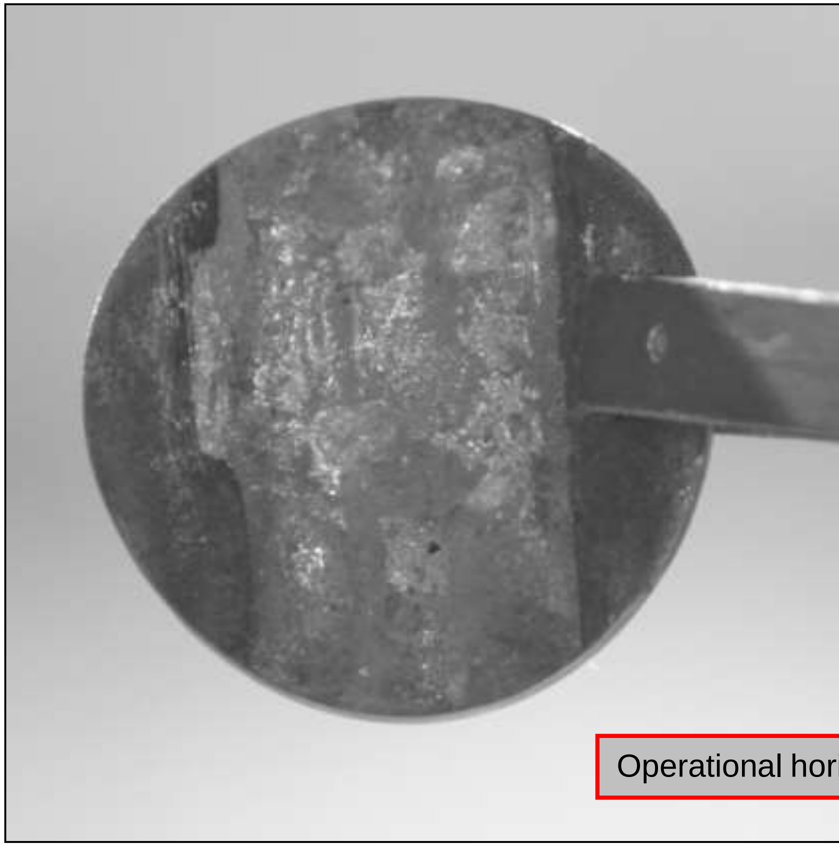
Specimen ID numbers: Center and off-center cuts

- **4 layers each location**
- **IDs from inside to outside layer**

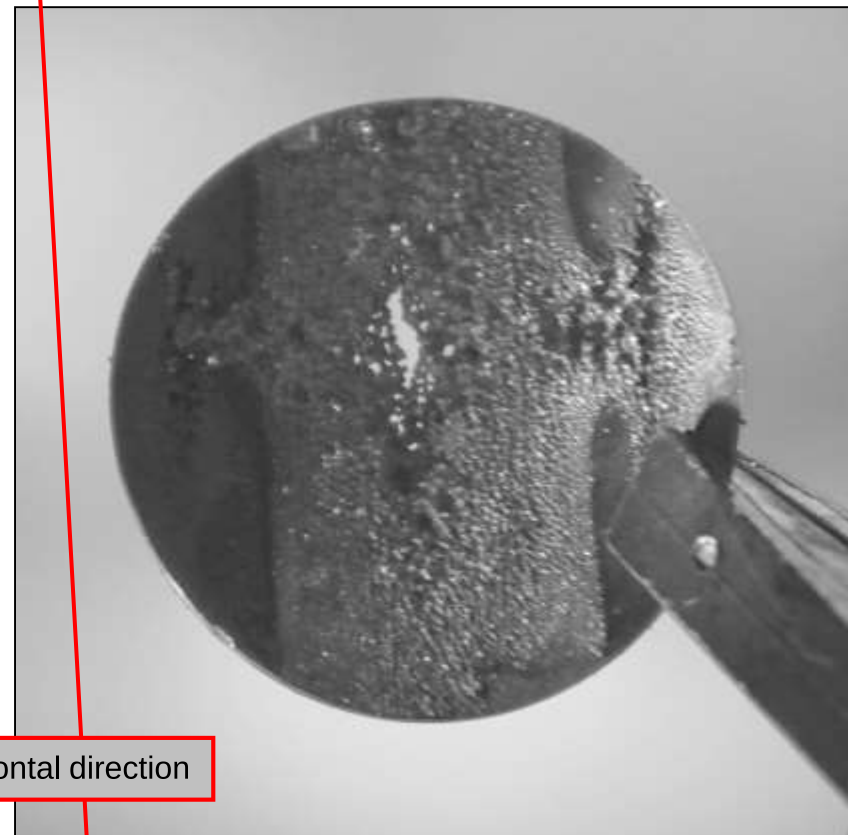


Inner mercury vessel wall
Bulk mercury surface

Specimen diameter: 60 mm
Largest hole: 9.2 x 2.1 mm ;
area ~ 11.5 mm^2



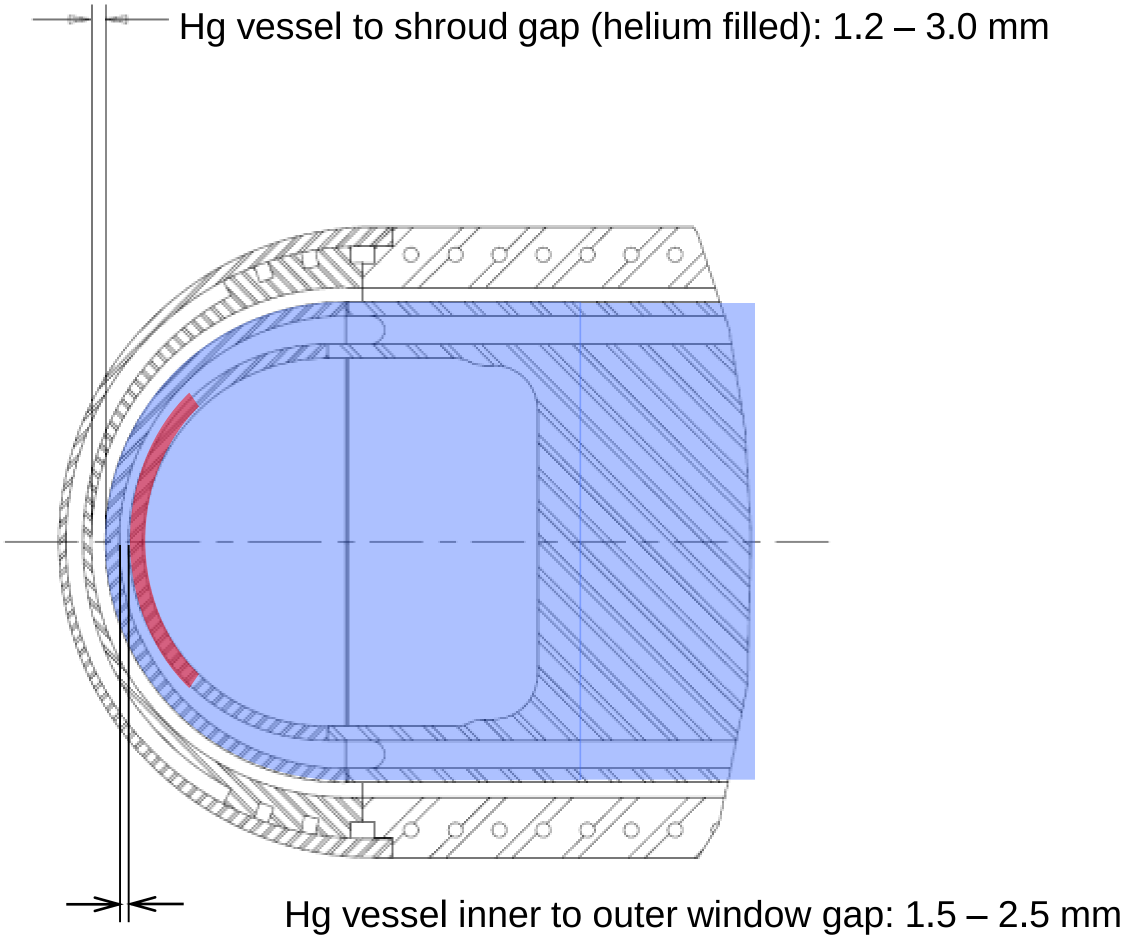
Specimen 1
Off-center



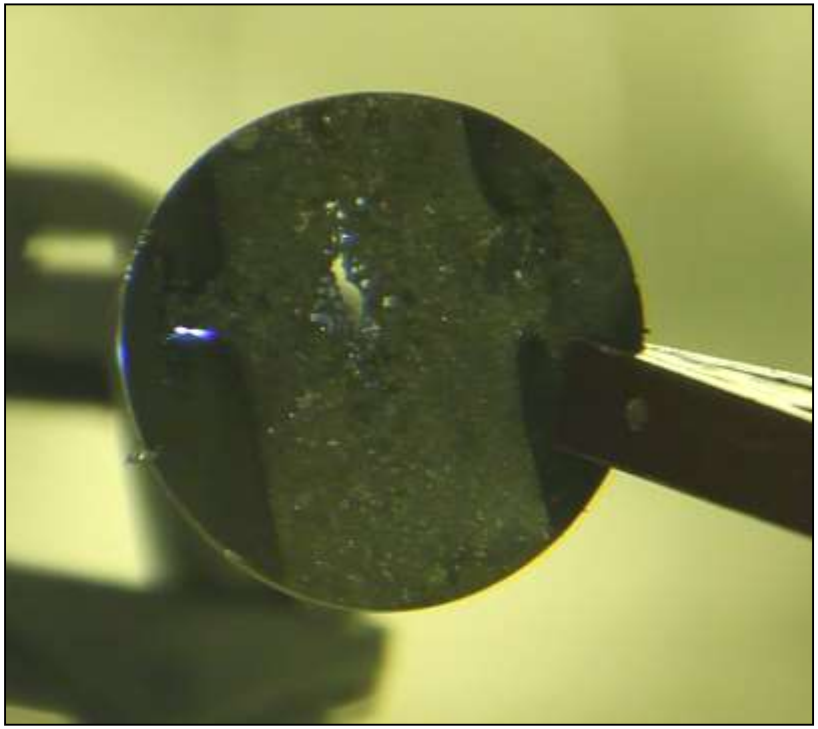
Specimen 5
Center

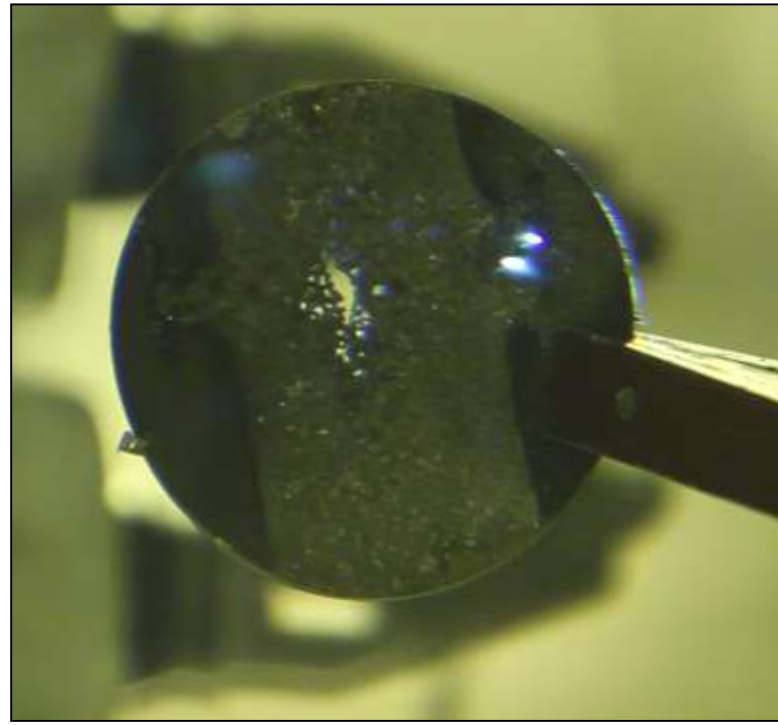
Operational horizontal direction

Worst damage is in inner mercury vessel window, center location (specimen #5)



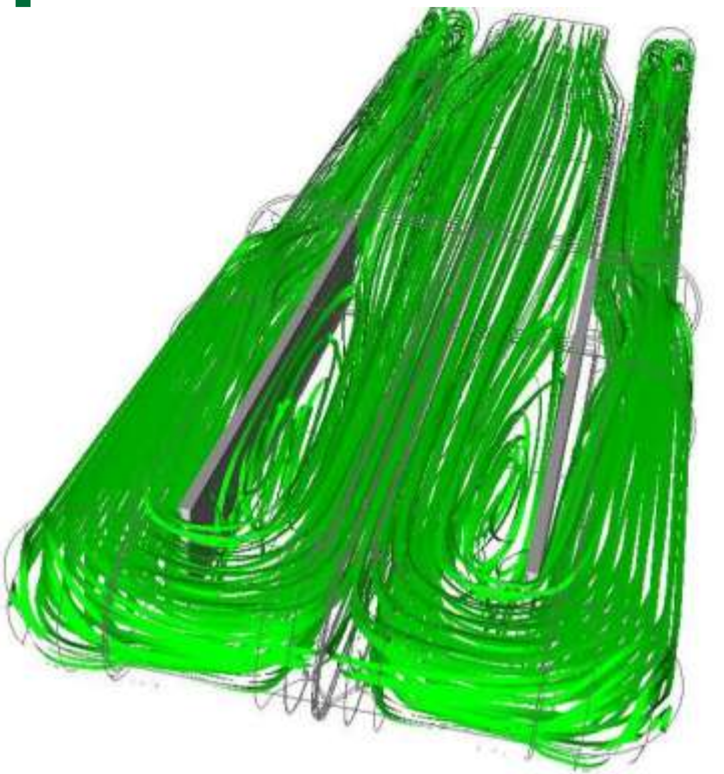
Movies with backlighting revealed multiple small holes away from center in specimen #5



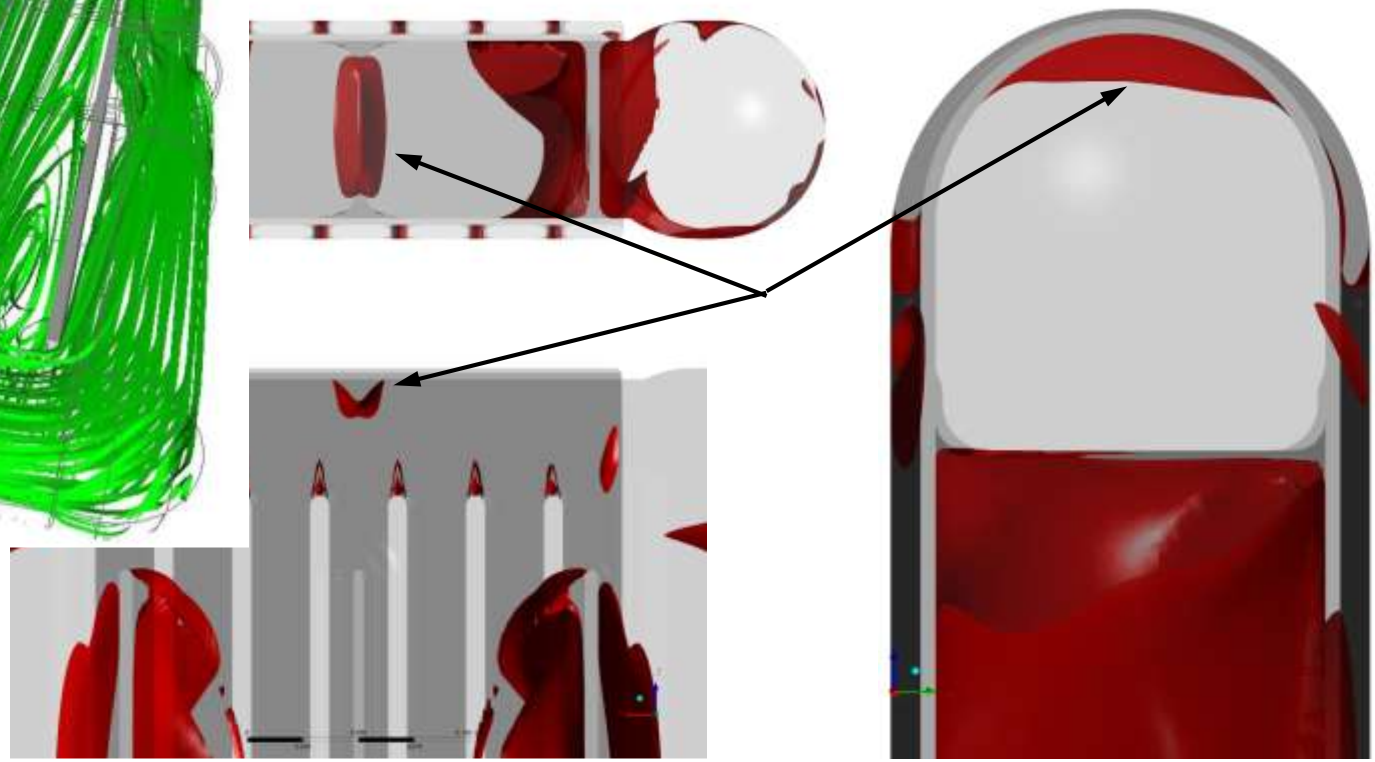


Low velocity at bulk side inner window plausibly correlates with damage pattern

streamlines



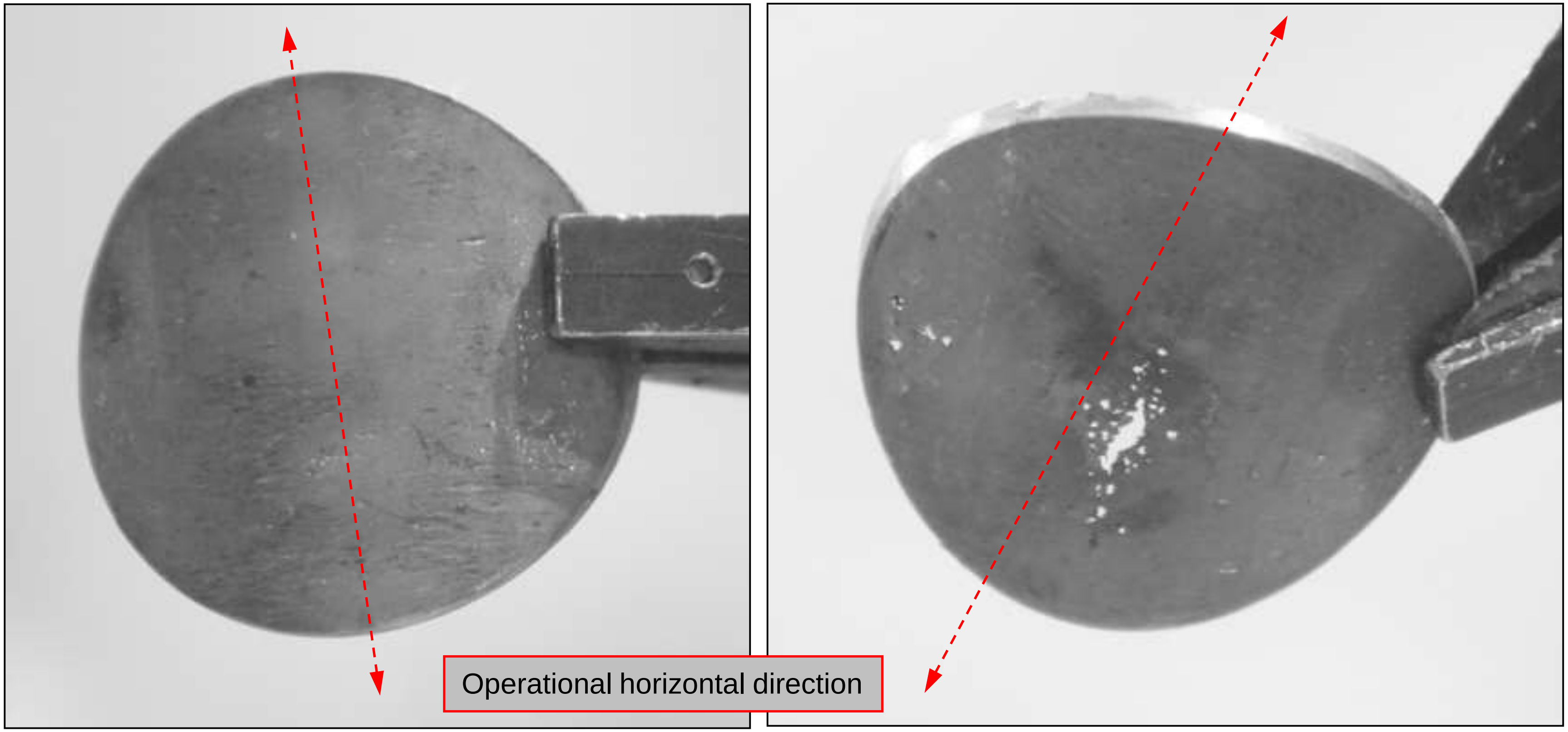
$$U = u' + U_{av} = \frac{2\sqrt{k}}{3} + U_{av}$$



0.35 m/s isosurfaces of instantaneous velocity
Mercury flow @ 270 rpm

Inner mercury vessel wall
Mercury channel surface

- **Channel side surface damage is much less than bulk side**
- **Pits are largely oriented in direction of channel flow**

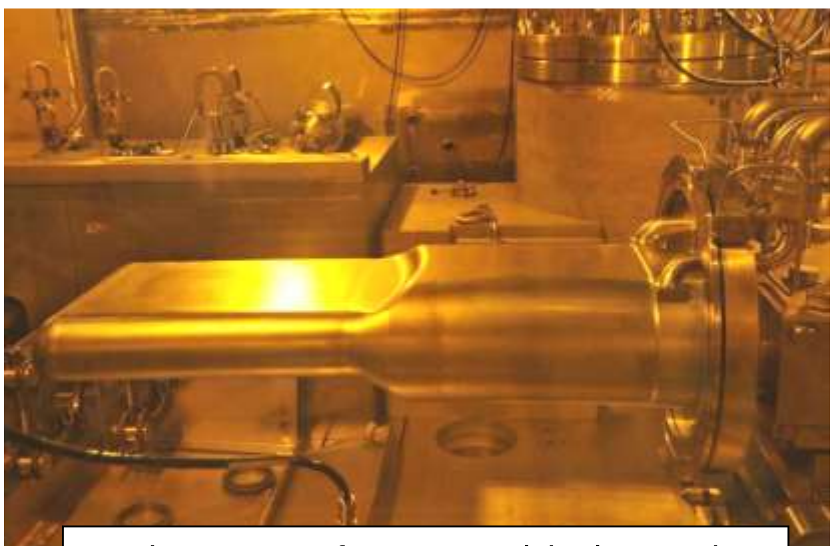


Specimen 1
Off-center

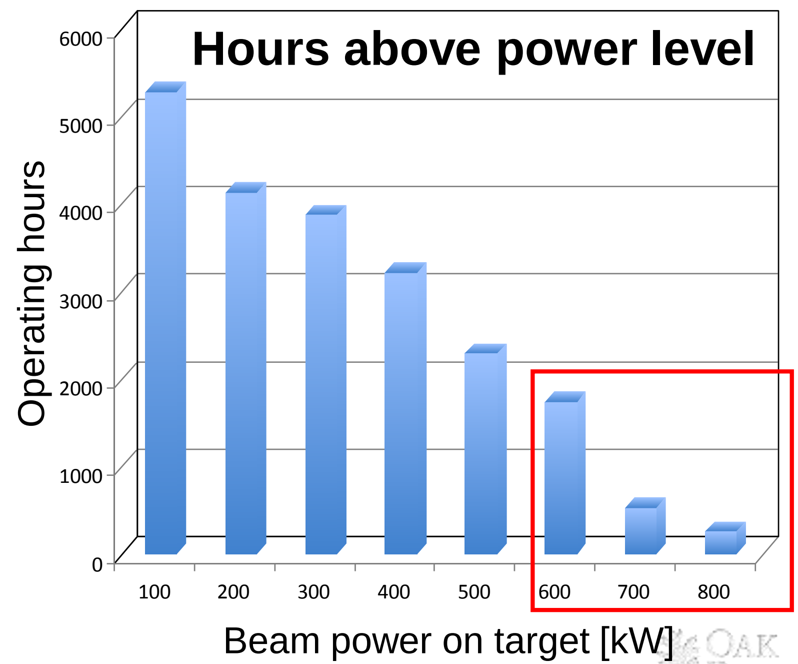
Specimen 5
Center

Target #1 operation

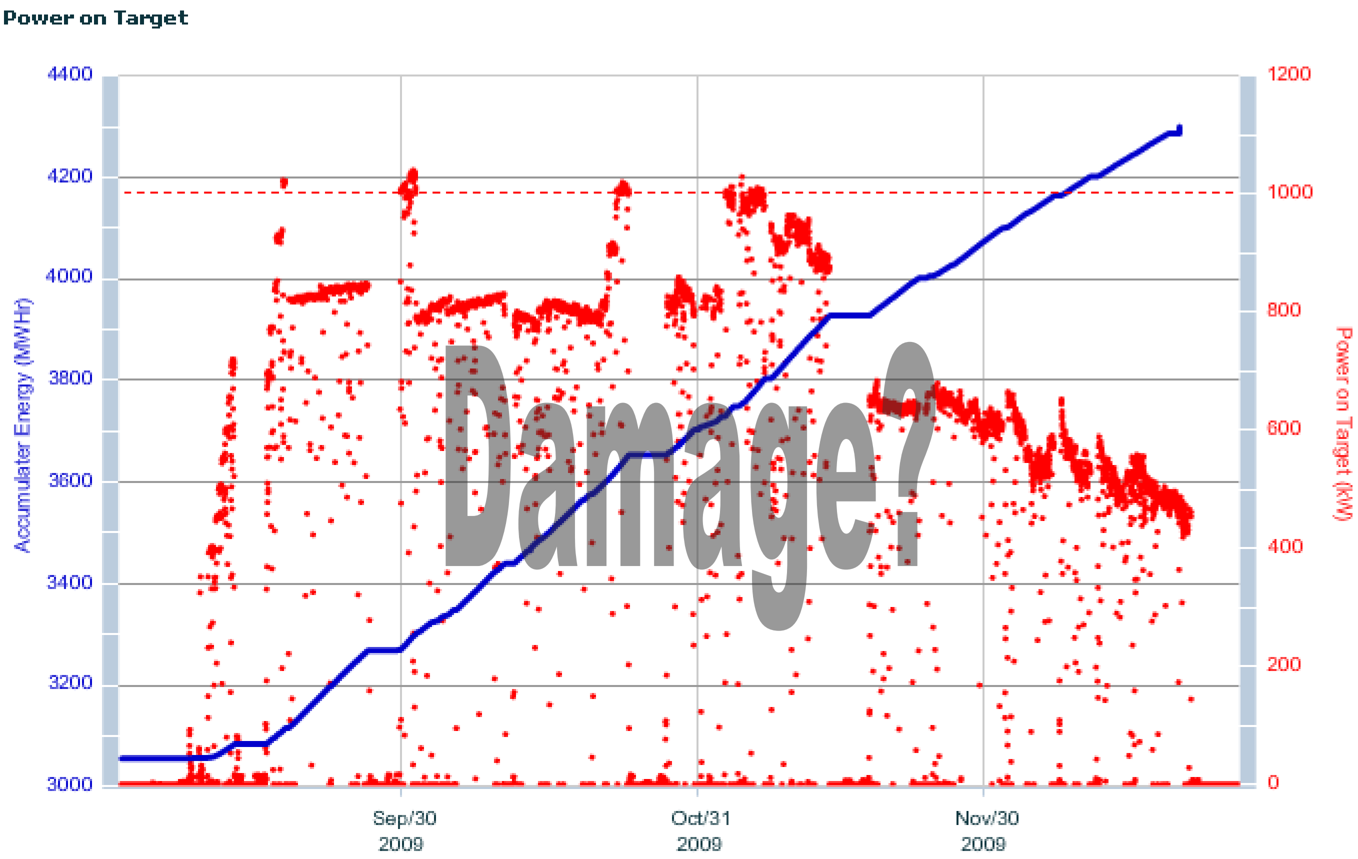
- **The first target received 3055 MW-hrs of energy**
- **It operated for >1700 hours at or above 600 kW and up to 800 kW without indication of a leak**



First target after removal (July 2009)



2nd target is now at 1244 MW-hrs



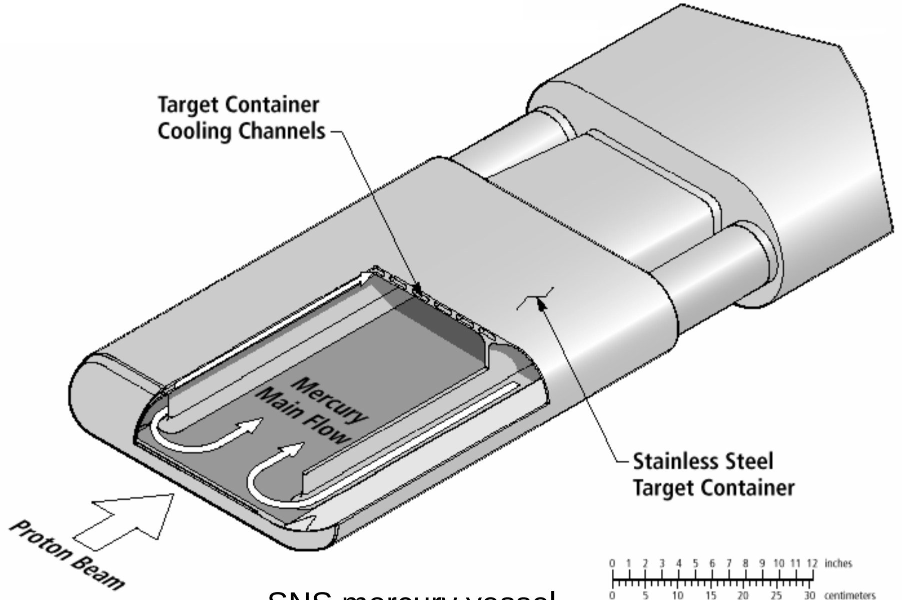
- Keep operating Target #2 until
  - Indication of a leak
  - 10 dpa is reached

Next for Target #1 PIE

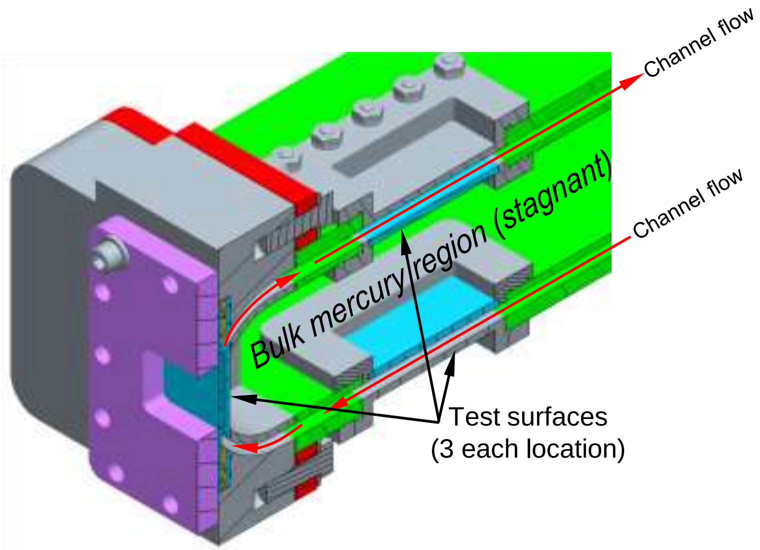
- Clean specimens, repeat photography and prepare for transport
  - Combination of Babcock & Wilcox and ORNL hot cells is likely for specimen microcopy, machining and analysis
  - Cavitation damage and irradiated mechanical properties assessment
- Cut additional holes from the target nose
  - Increase visibility to target interior
  - Additional window surfaces to examine
- Deployment of Wachs saw (full target sectioning) is deferred
- Target #1 likely to be removed from service bay in May

Window Flow Vulnerability Test Loop (WFVTL) experiments (WNR 2008)

- **In-beam experiment examined narrow mercury channel damage under conditions more prototypic to SNS**
  - **Previous in-beam test results for channel damage indicated this region is especially vulnerable**
    - **Is design change needed for SNS target?**
- **Investigated damage reduction vs. flow velocity**
  - **Previous in-beam test indicated damage *reduced by flow***

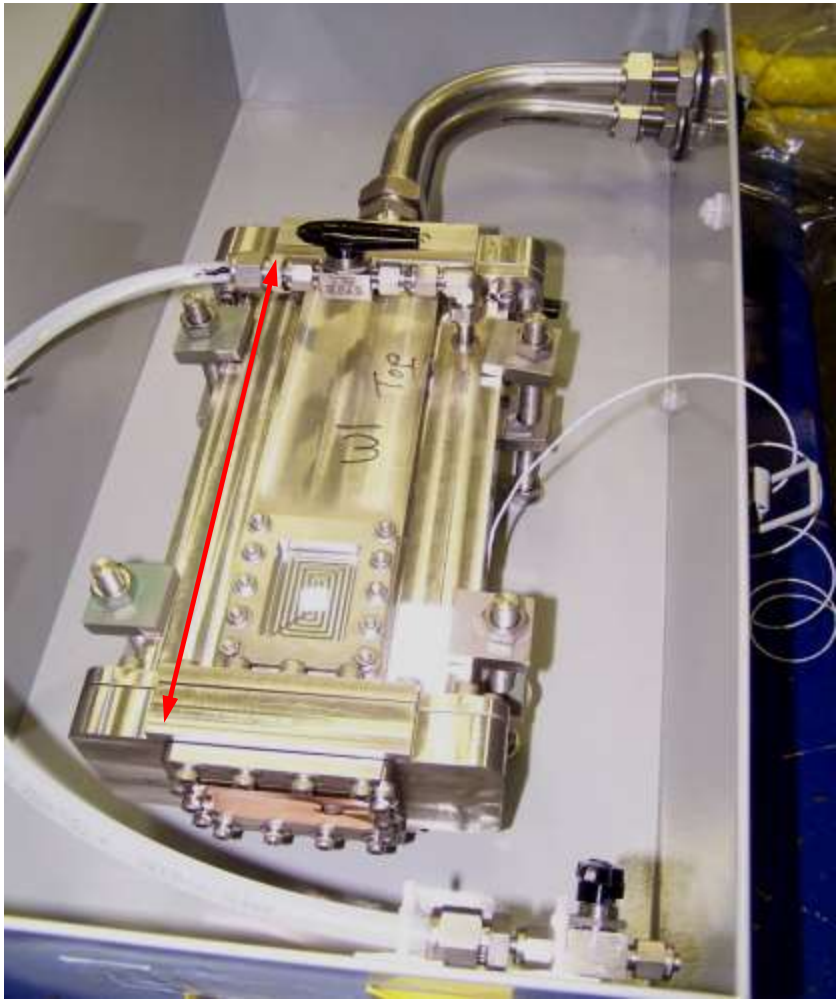


SNS mercury vessel



WFVTL module section

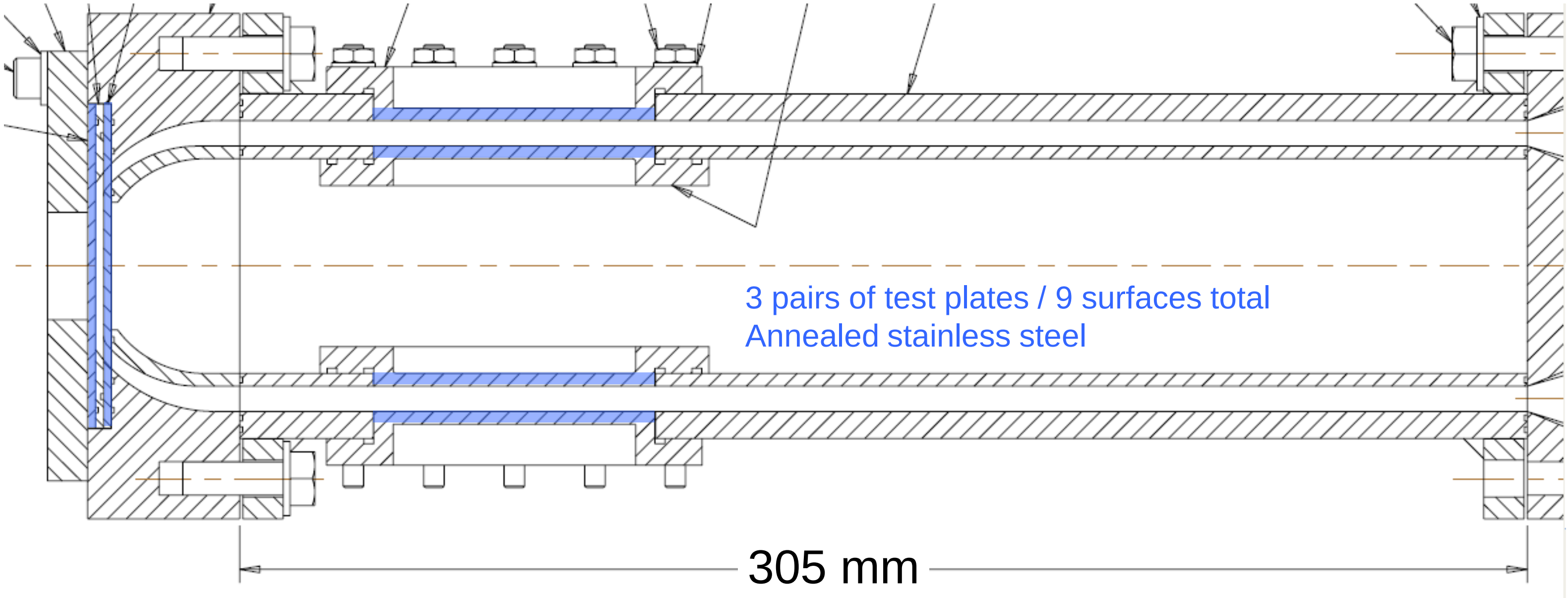
WFVTL target module and mercury loop

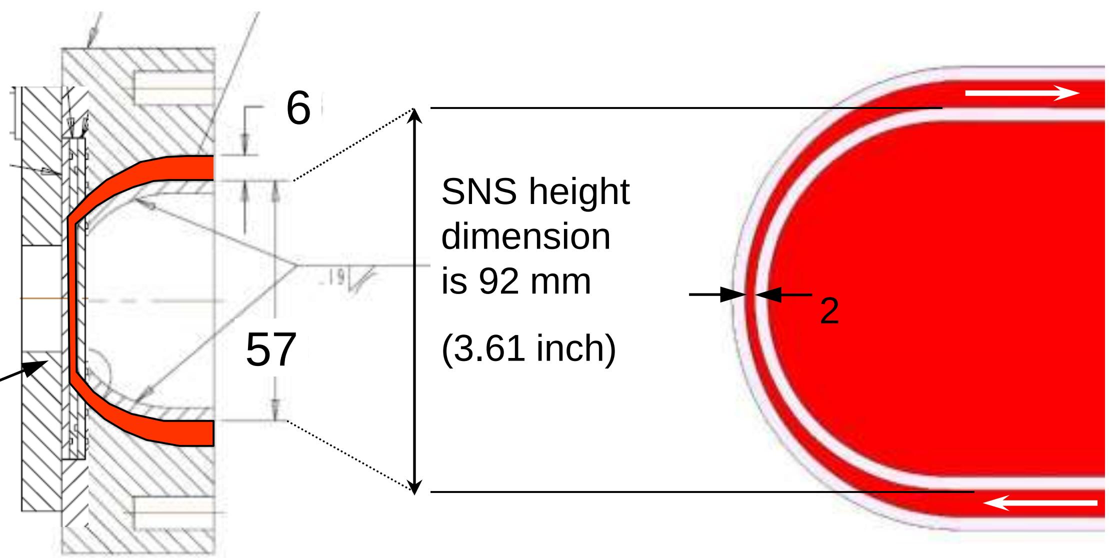


Hg length: 325 mm

- **Variable speed centrifugal pump employed for channel flow speeds for up to 7 m/s**
  - **Only ca. 4.4 m/s achieved**
- **Test targets connected to loop via flexible hoses**

WFVTL geometry vs. SNS

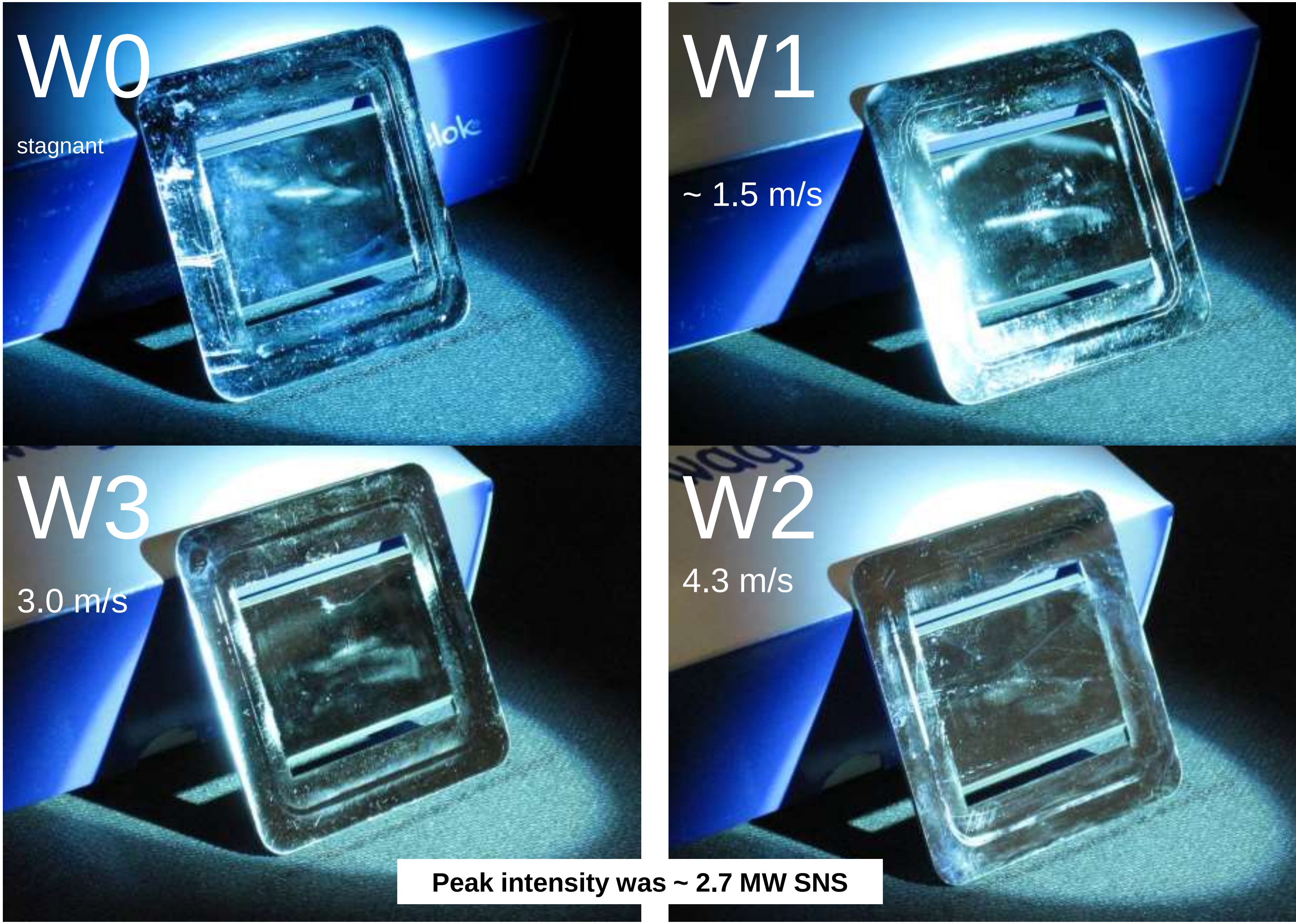




SS – Hg – SS
1.8 – 2.0 – 1.8 mm

Front inside plate – Channel side

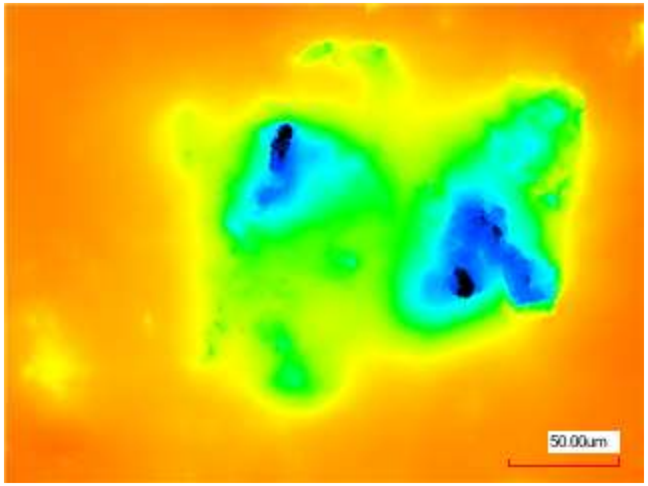
100 pulses per test condition



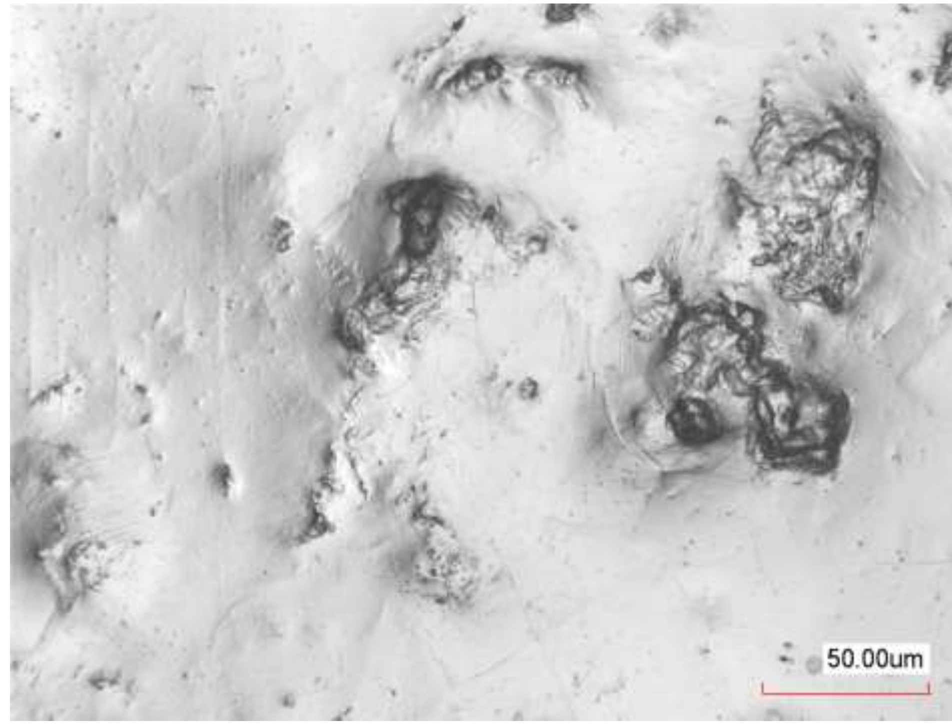
Peak intensity was ~ 2.7 MW SNS

W1 Front bulk* example image data

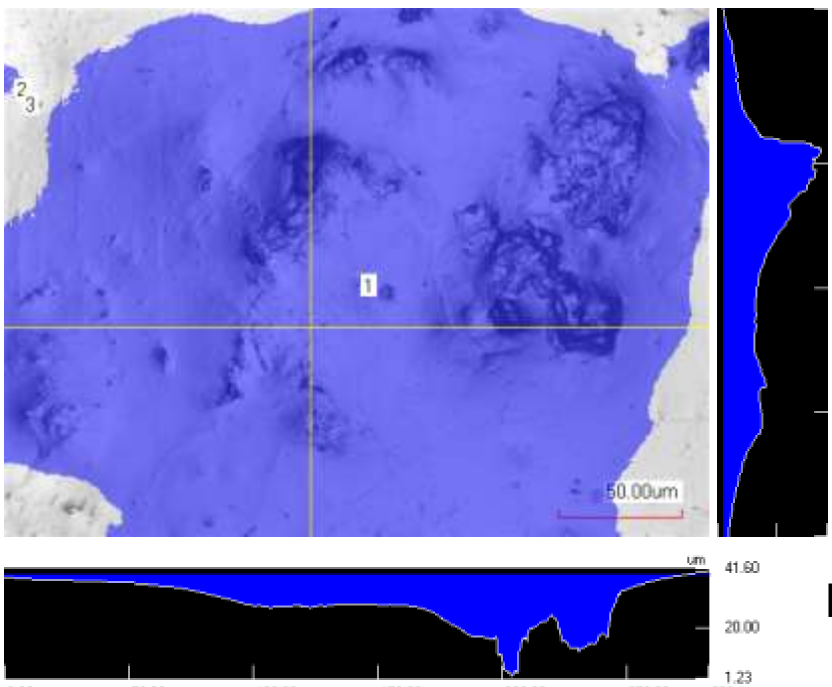
*no flow on this surface



Height profile



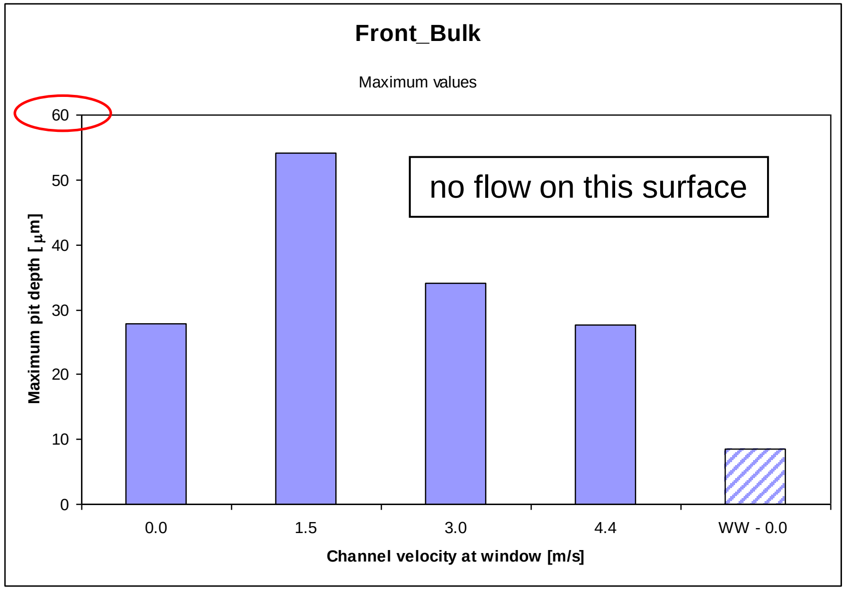
Intensity image

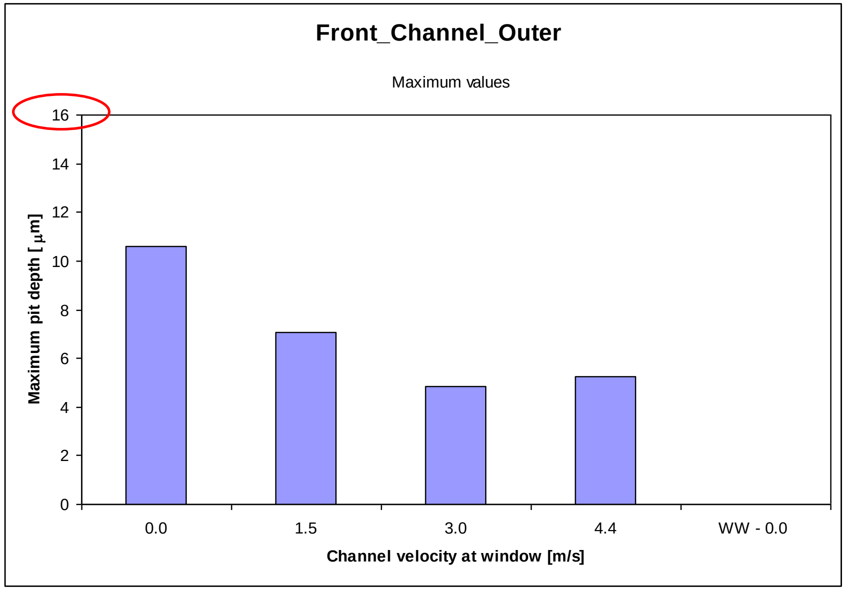


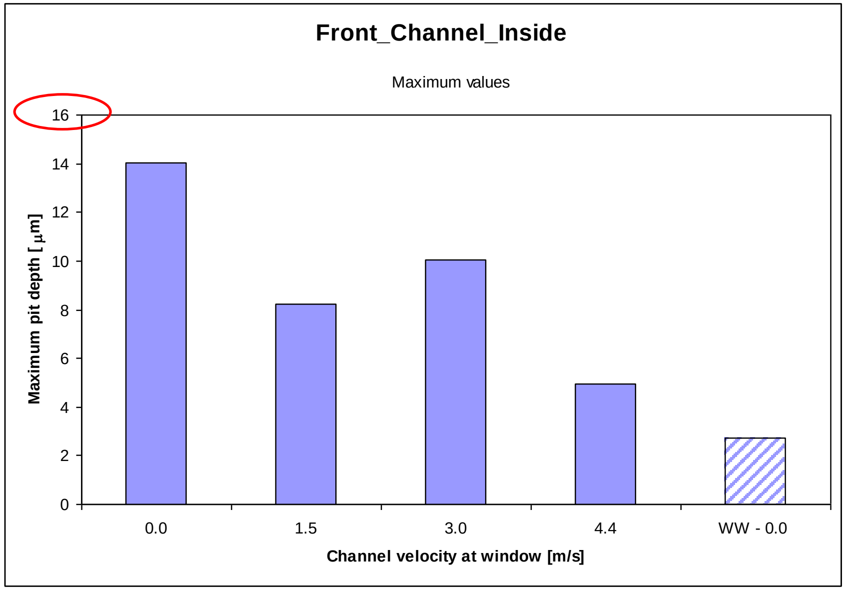
Identified damage region

WFVTL damage analysis: Design change is not warranted

- **Maximum pit depth, damage area fraction and mean depth of erosion data were compared:**
  - **Flow channel damage is <u>not</u> worse than bulk side**
  - **Flow reduced damage**





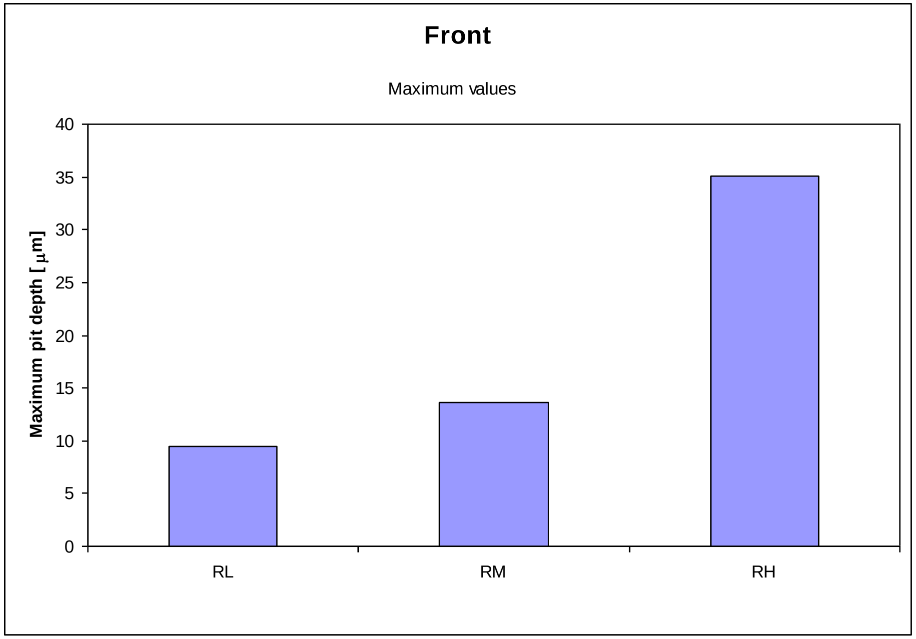


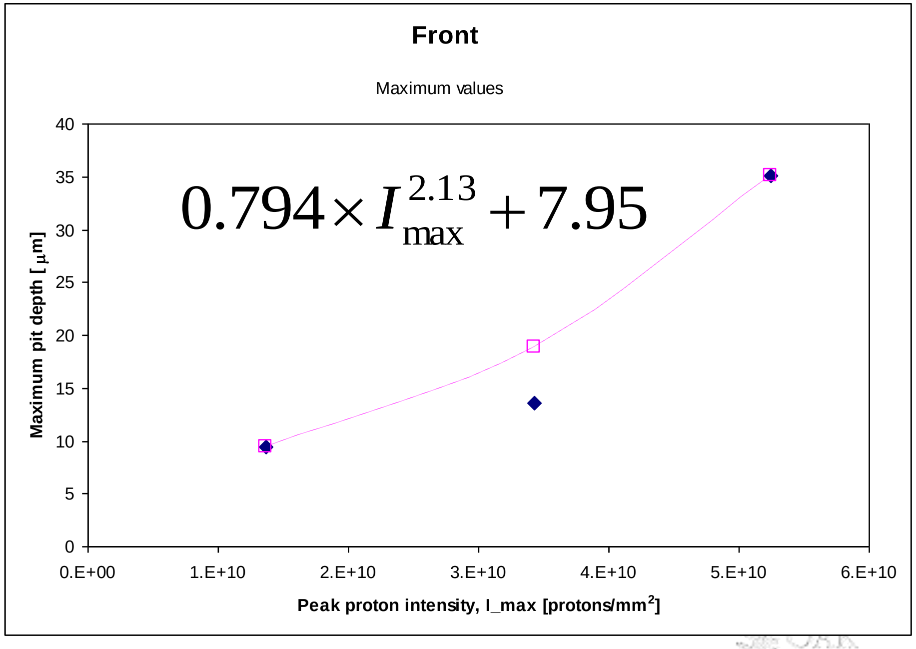
Damage dependence on beam intensity

- **Total protons per pulse held constant; beam spot size focused +/-**
- **Maximum pit depth on front surface scaling with beam intensity is closer to quadratic**

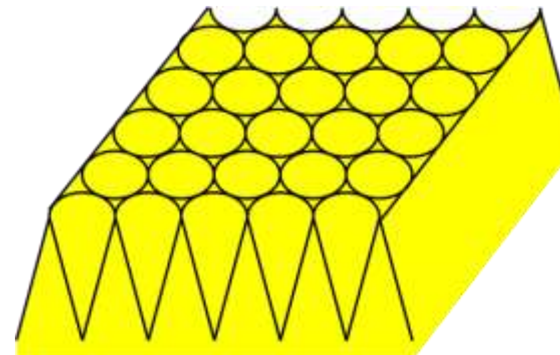
➢ **Concern on beam profile peaking somewhat relaxed**

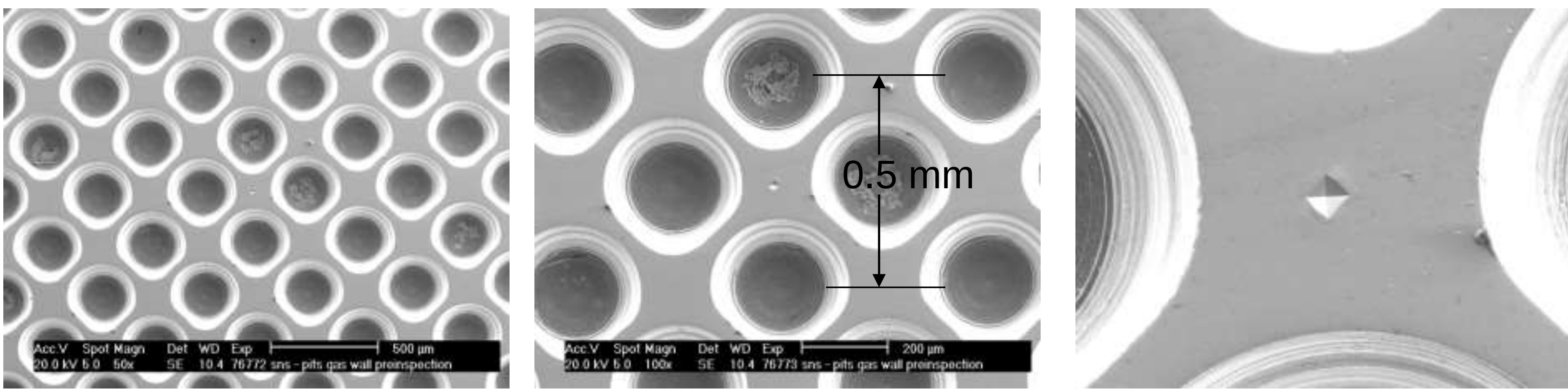
  – **Not on total power**





WNR test in 2008 with surface - textured gas wall

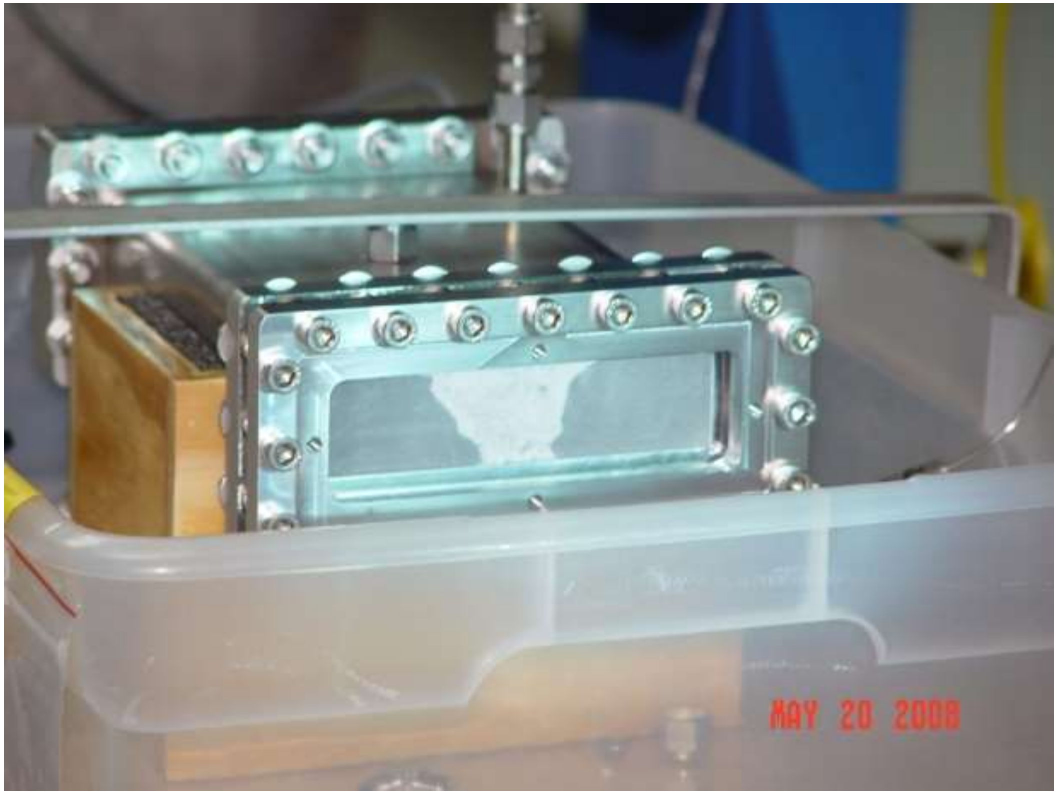




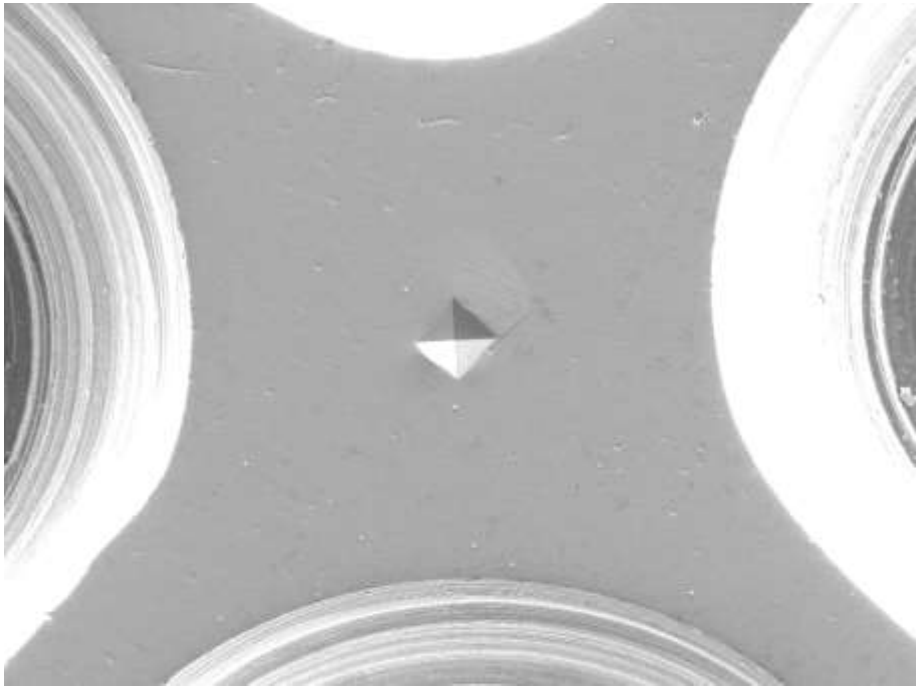
Pit texturing with top level polished smooth for inspection purposes

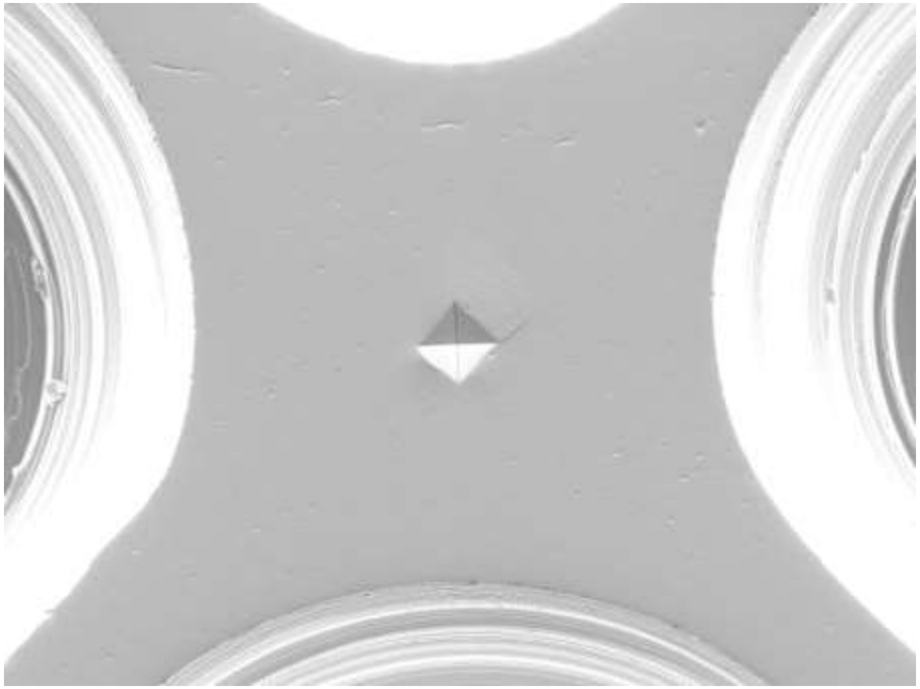
Pretests were performed with an acrylic wall

- Gas was intermittently puffed prior to beam pulses
  - Less than preferable continuous injection
  - Partial gas layer condition



No discernable damage was detected

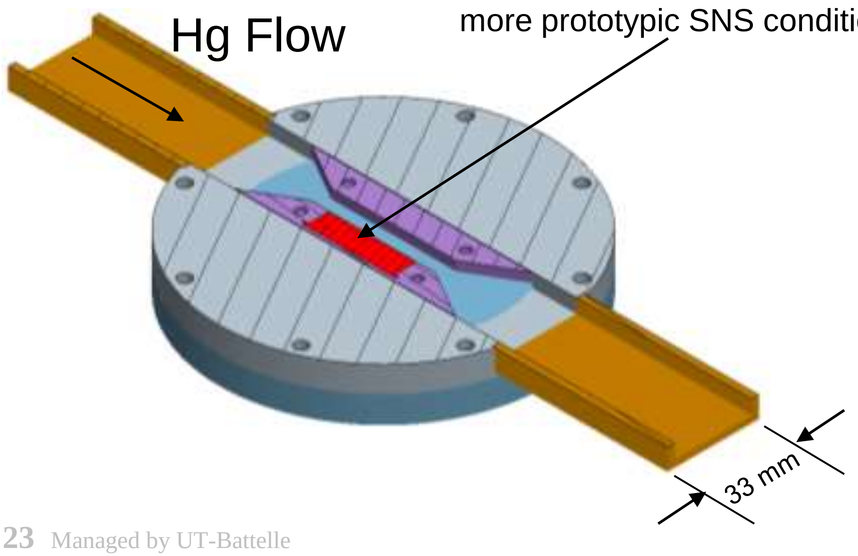




Which is before / after irradiation?

Off-line testing: SNS gas wall experiment using MIMTM at JAEA

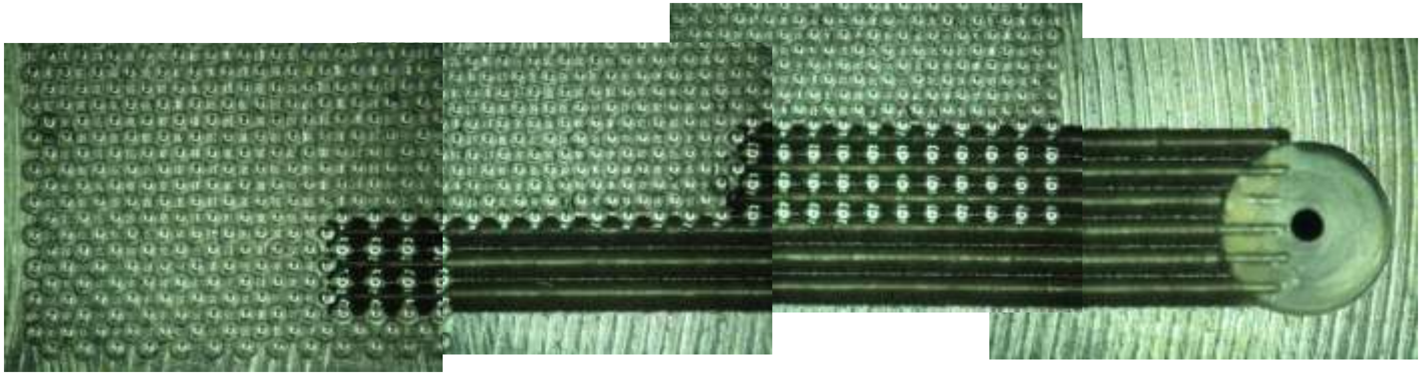
- Experiment sought to confirm damage mitigation efficacy of various gas wall configurations (texturing with grooves, pits, etc.) at high impact cycles
- One month of testing last March in Tokai covered ca. 20 test conditions, typically to 1M impacts



Thank you for generous assistance!

Gas wall experiments at MIMTM: An unfortunate outcome

- Observed damage on test and control surfaces was very low whenever gas was injected, even on surface opposite of gas injection test surface
- Measured mass loss difference was too small to be statistically meaningful
- Suspicion was that injected gas in MIMTM chamber inhibits the pressure conditions needed to create cavitation damage
  - Retest by Naoe with specially prepared control specimens confirmed this

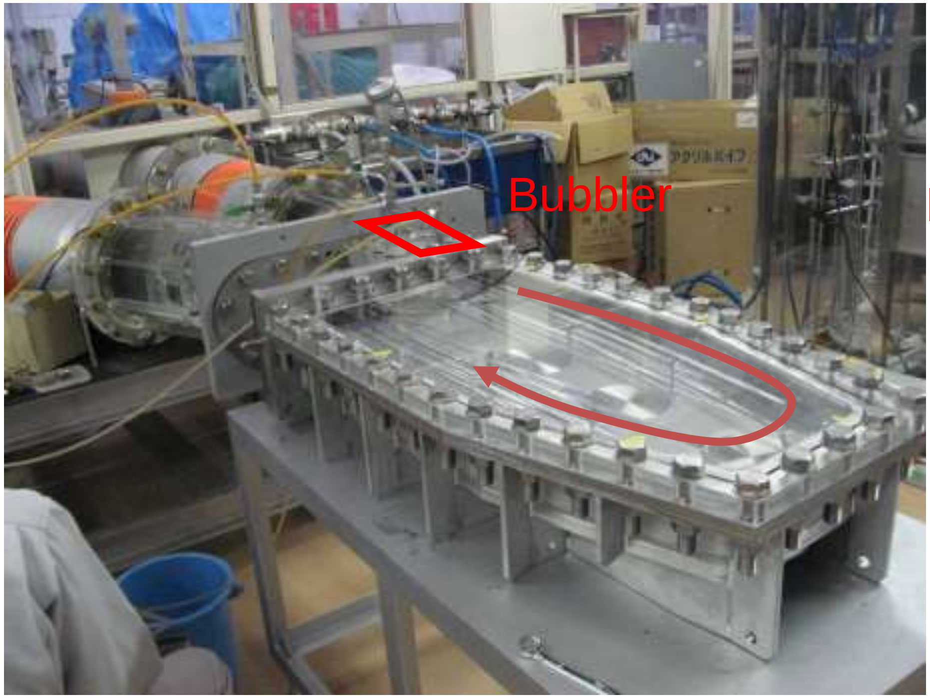


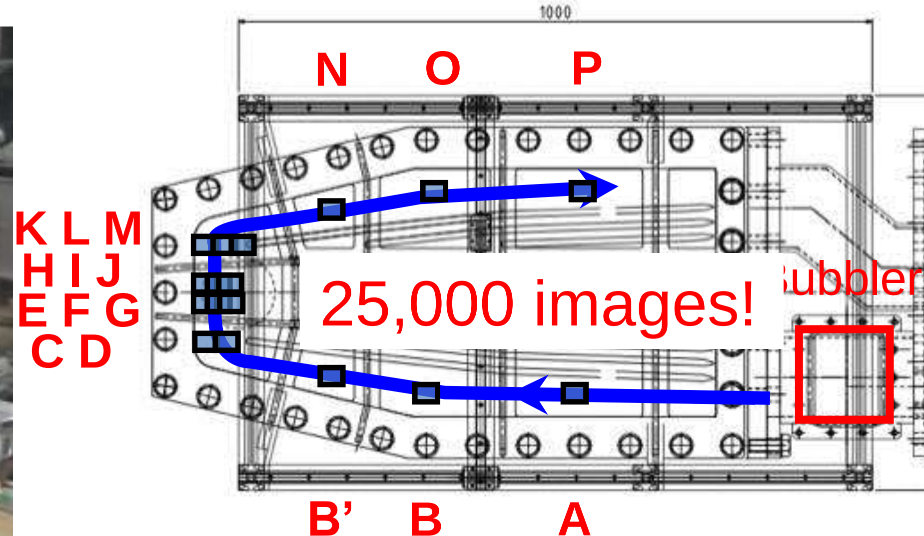
Example test surface: conical pits

JSNS target gas bubble experiment was done in TTF last summer

- Various configurations of JAEA swirl bubbler were tested
- Bubble population was assessed by photographic means
  - Transparent target lid permitted visualization at top surface
- Some 25,000 images / 90+ gb data capture
- SNS team provided installation, experiment support, gas bubble tracking / CFD simulations, work on automating image analysis

JSNS Test model in JAEA water loop
(H. Kogawa)





Images were taken at 17 points.
40 images every 0.25 sec were taken at each point.

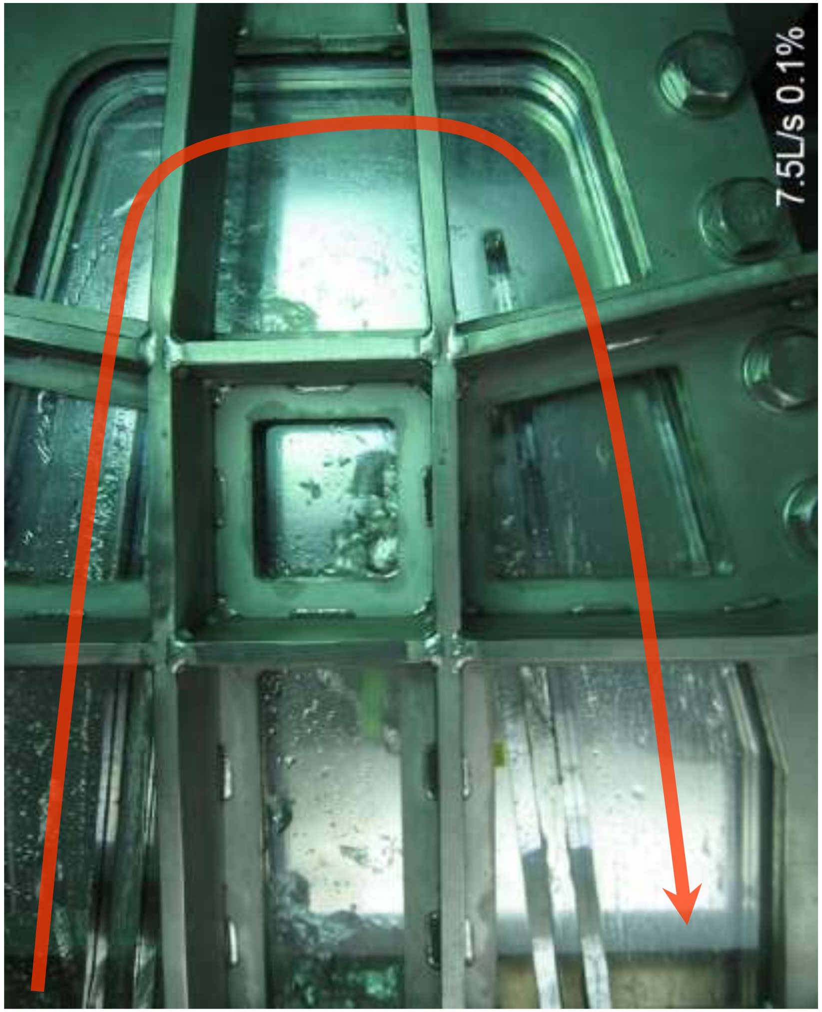
- 95 % size (horizontal) of JSNS target.
- Acrylic top to observe the bubbles in opaque mercury.

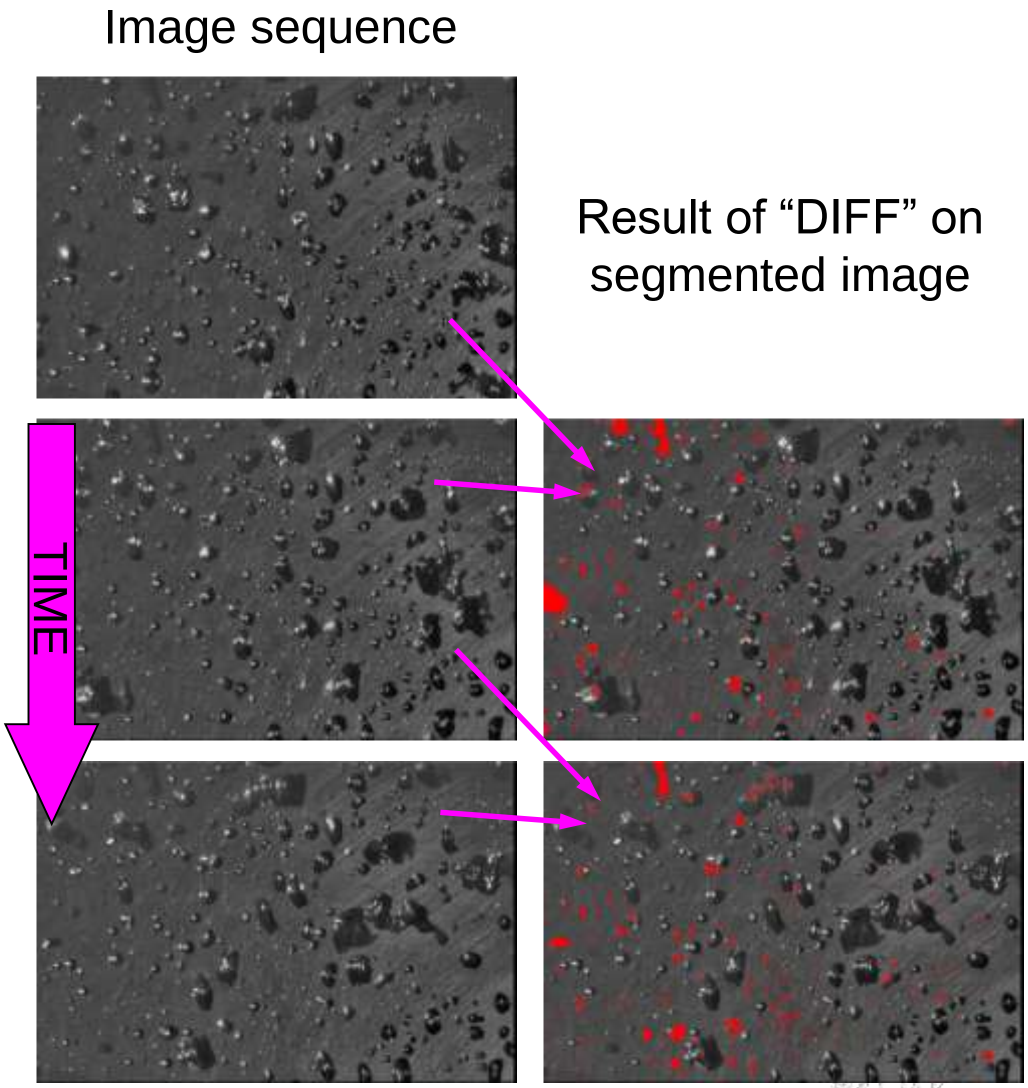
Tests were carried out under almost 40 conditions.
- Bubbler
- Flow rate of mercury
- Injected gas rate
- Bubbles injection point (Multi bubbler)

JSNS Test model installed in TTF

- Mutually beneficial collaboration

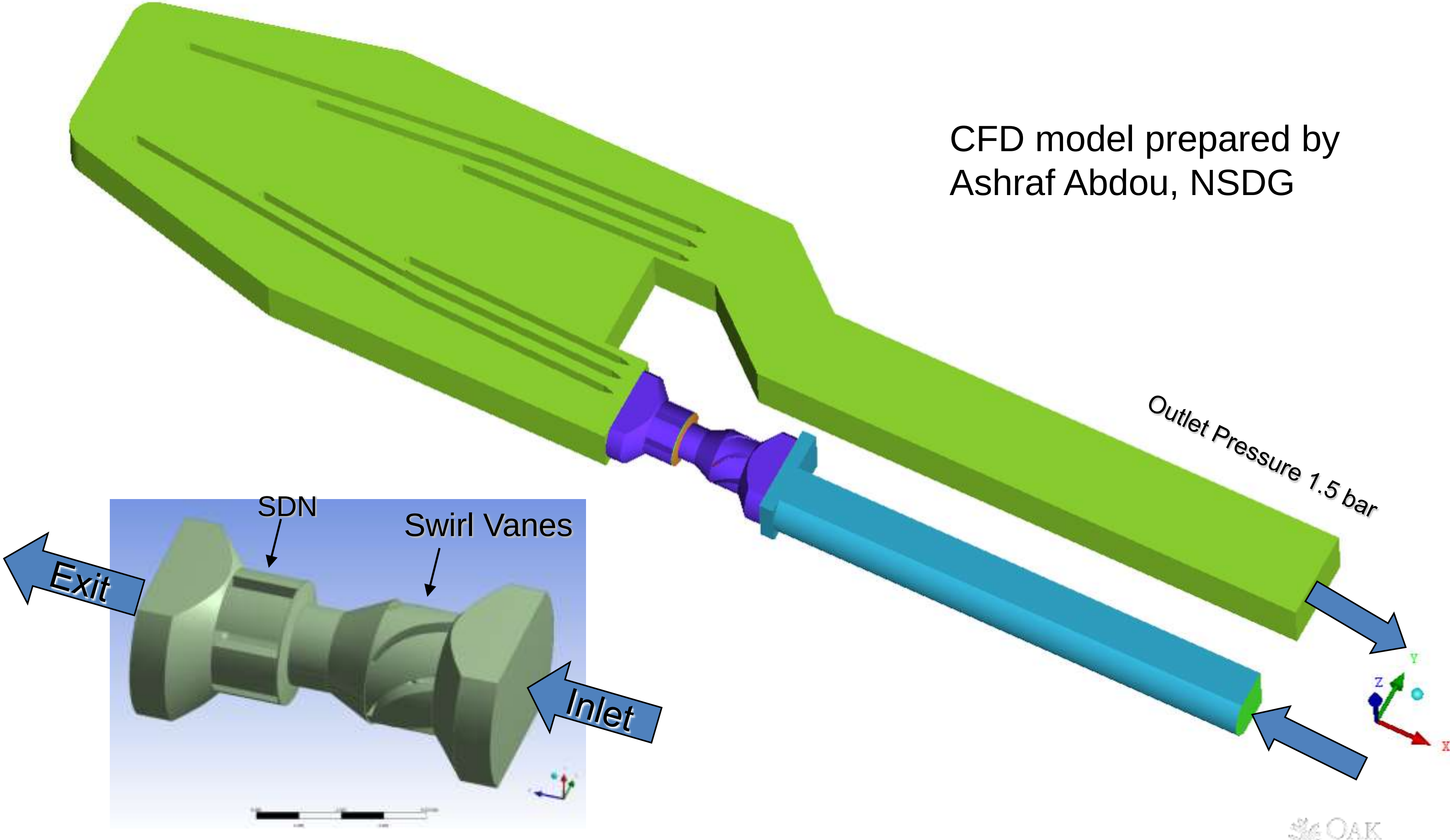
- **JSNS team is employing manual bubble identification**
- **We're trying to develop tools for automated image analysis**
  - **Improvements are still needed**



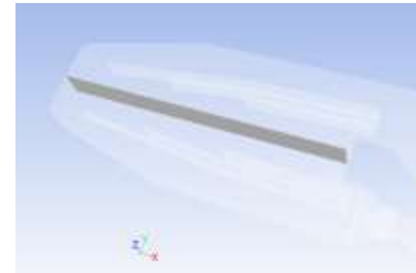


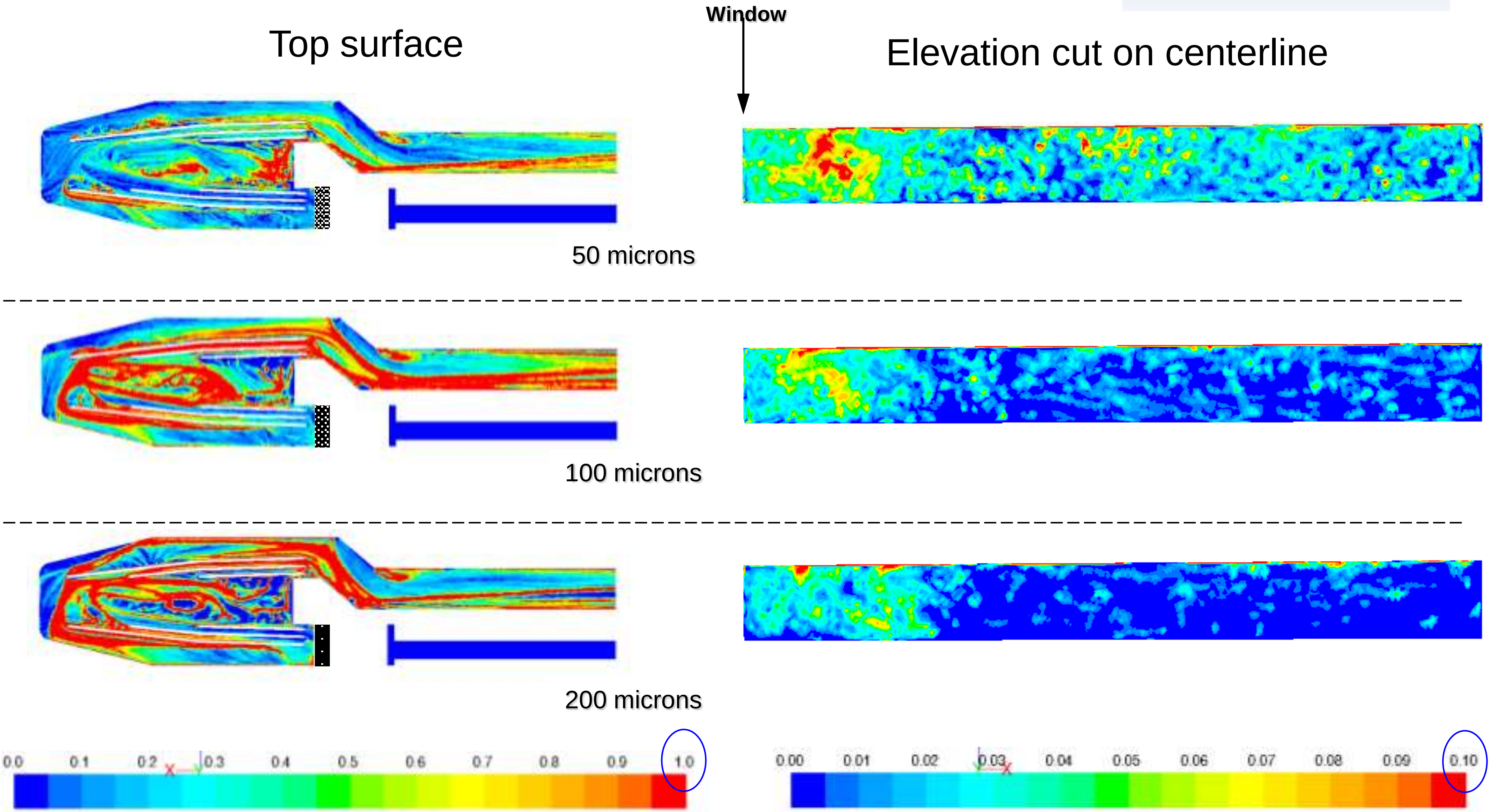
TTF JSNS blade model with single swirl bubbler

CFD model prepared by Ashraf Abdou, NSDG



Helium Volume Fraction
f(injected bubble sizes)
Mercury flow: 7.5 L/s
Injected Void Fraction : 5%

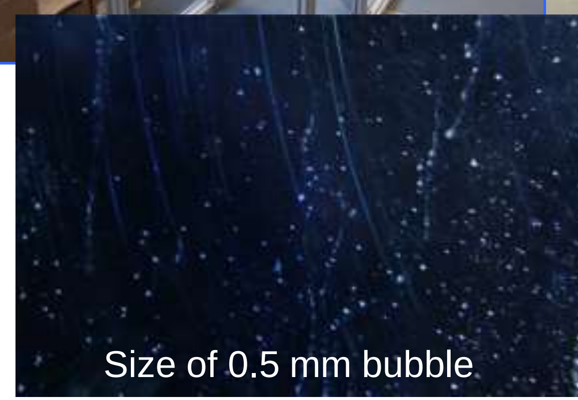




Helium volume fraction

Update: Bubble diagnostics

- Dynaflow Inc's Acoustic Bubbler Spectrometer (ABS)
- Boston University's acoustic void fraction resonator
- Prof. Timothy Leighton's acoustic diagnostic suite (Univ. of Southampton)
- Optical methods
- Proton radiography
- New: medical ultrasound



University of Tennessee NE Dept: Medical ultrasound of bubbles in mercury

- **Assistance from Boston University**

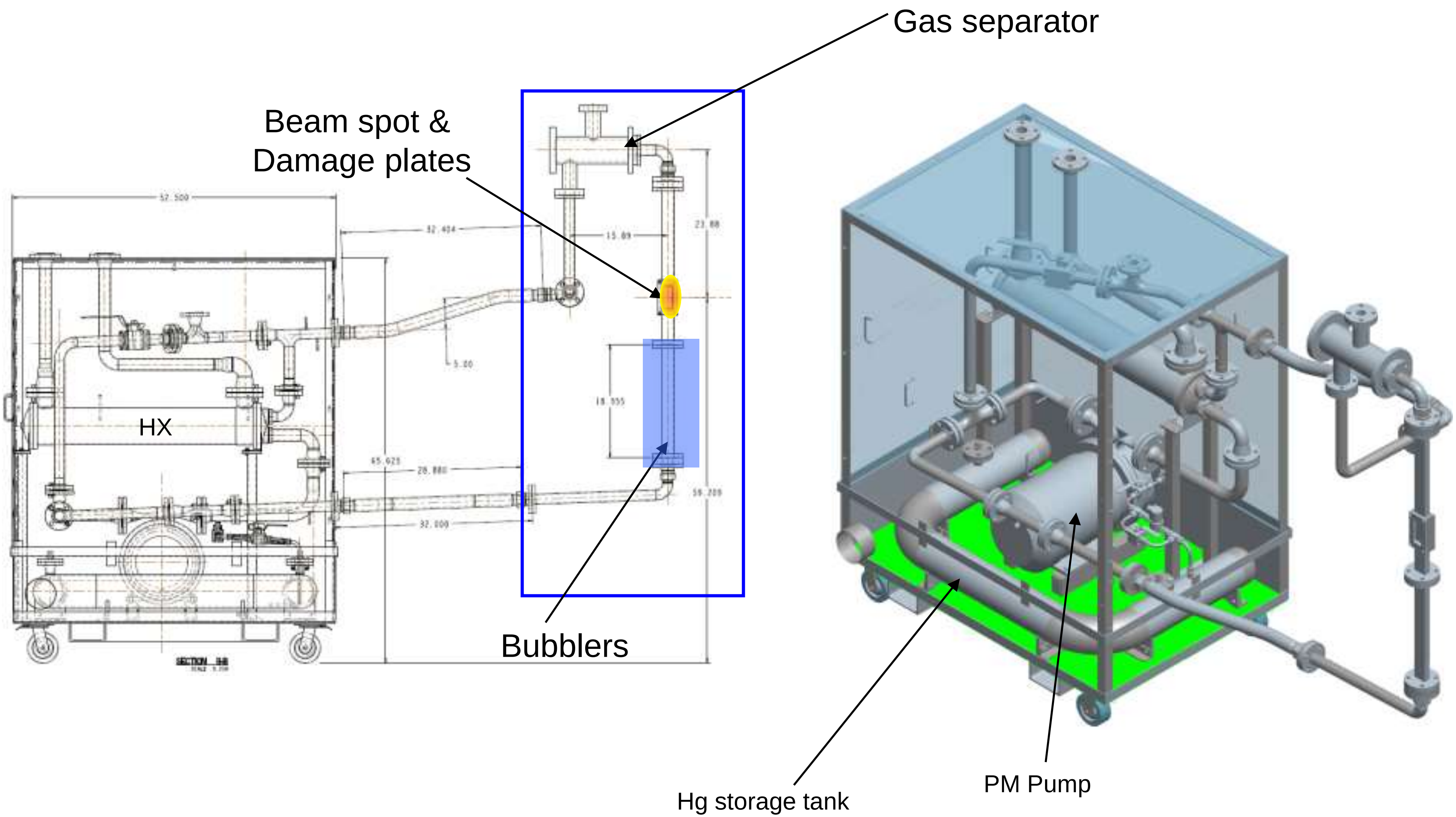
WNR 2010 experiment will focus on small gas bubble mitigation

- Prior in-beam tests showed no better than 4x reduction in damage
  - Maybe ½ of that was from associated mercury flow
  - Bubble populations were not well characterized; bubbles too large
- Tests in MIMTM have shown ca. 15x reduction, but
  - Question regarding surface imposed, 0.5 ms rise time pressure vs. beam induced < μs rise time pressure

A new test loop is nearing completion: Multi Bubbler Test Loop (MBTL)

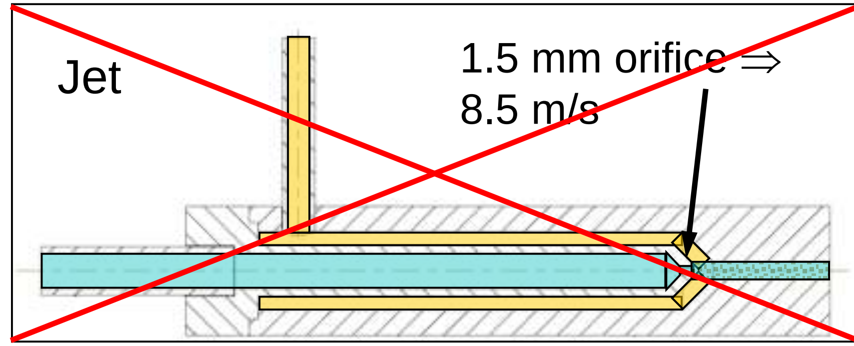
- Candidate bubblers will be evaluated for producing populations of greater mitigation efficacy
- Without reasonable confidence in creating effective populations a candidate bubbler will not be tested
- Systems testing and bubbler evaluations will be done in new mercury laboratory (8700 basement)
- Irradiation is tentatively schedule for end of CY2010
- 1000 pulses are budgeted for complete experiment
  - 24 hour, 3 or 4 day campaign likely

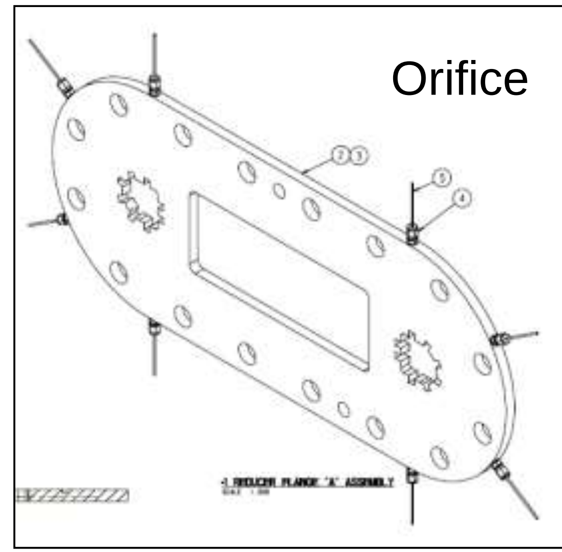
MBTL pump and test sections

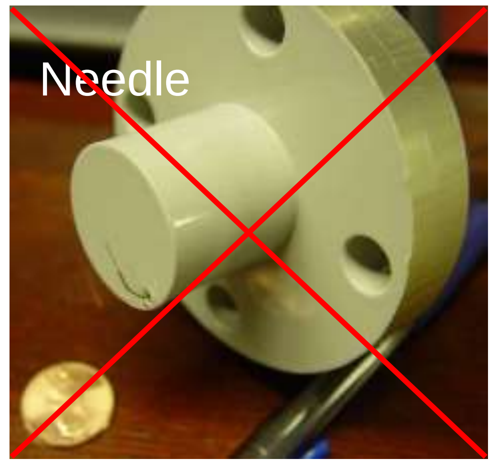


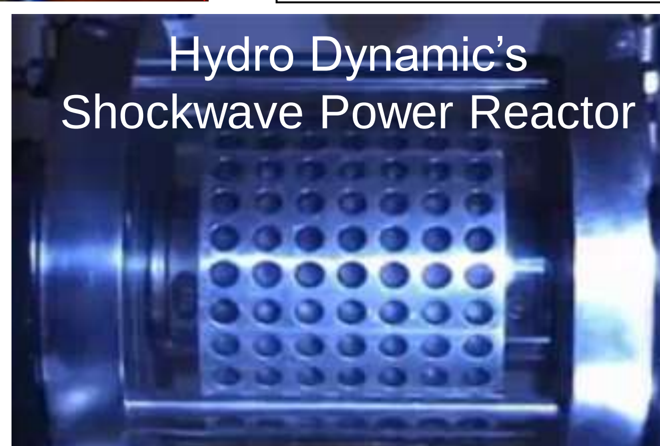
Bubble generators

- ~~"Champagne" concept~~
- **Flow channel miter bends**
- **Dynaflow bubbler(s)**
- **JSNS & UT swirl bubblers**







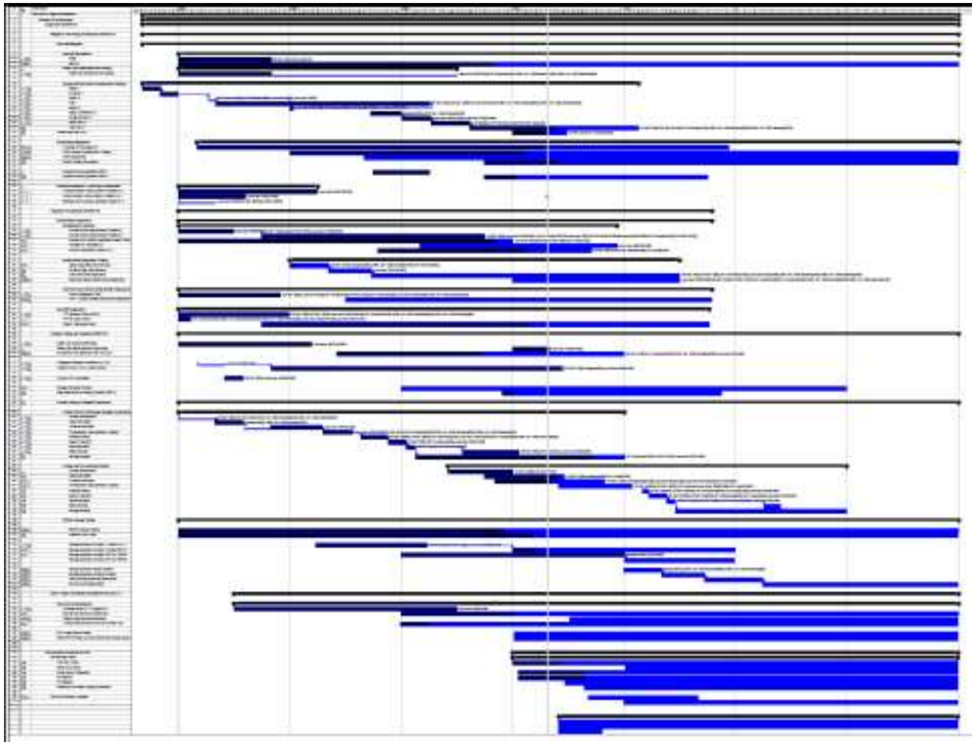


Current overall status

- Current push is on small gas bubbles
  - WNR experiment preparations underway
- Gas wall development has been taken far
  - Mitigation efficacy looks good from in-beam tests
  - Channel cooling issue GONE!
    - WNR 2008 results + Target #1 damage: channel is NOT the most susceptible location
      - Can keep mercury in the channel; switch to water unnecessary
  - Coverage at beam window with SNS flow is possible with surface texturing
    - Sweeping flow more amenable to GW
  - PIE of targets is key to knowing <u>required extent of coverage</u>

Target development plan has recently been updated

- Includes estimated resources
- Goal to deliver “Mark 3” design concept by end of FY2013 with best damage mitigation technology
- Corrective action items 2300 & 2327 resolved



Near term goals

- Small gas bubble (SGB) mitigation
  - Develop gas bubblers for mercury that produce populations that effectively reduce damage
  - Develop methods for getting those populations to essential target regions through modeling and experiments
  - In-beam test of improved SGB generators at WNR in 2010
    - Design, build and test new loop
    - Evaluate and choose bubblers for in-beam test
  - Gas separator development
  - Bubbler testing in TTF
- Damage analysis of older test plates

Mid term goals

- Install damage source device(s) in TTF and / or WNR test loop for evaluating mitigation efficacy off-line
  - Efforts at Boston University and Creare do look like deployment is some time away
- PIE assessment of SNS target damage locations is critical to path forward
  - When will we need to deploy mitigation technologies?
  - If damage is limited to beam entrance location, then protective gas walls is a viable approach
  - Irradiated material properties will set the bar for target lifetime if limited by cavitation damage

Long term goals

- Incorporate SNS target operating experience and PIE results into plans
- Complete GW testing (off-line or in-beam)
- Complete SGB testing (off-line or in-beam)
- Select best damage mitigation option and develop target design concept ("Mark 3")
  - Must consider issues
    - Installation requirements in service bay
    - Gas removal / recirculation equipment

New goals & broader mission scope for team

- Hg Target Development → Target Development
  - Activities will support both FTS and STS
    - PIE
    - Irradiated material properties
- Team will address development issues for STS for either solid rotating or mercury target options, e.g.,
  - Tantalum cladding of tungsten
  - Mercury target configuration optimization in conjunction with neutronics optimization effort
  - Flow, heat transfer R&D

Target Development Team & Resources

- Full time:
  - Ashraf Abdou
  - Dave Felde (EESD)
  - Bernie Riemer
  - Bob Sangrey
  - Mark Wendel
- Ca. 12 part time ORNL contributors
- Collaborations:
  - J-PARC target team
  - RAL
- Post-doc:
  - Dave McClintock
- R&D subcontracts
  - Univ. of Tennessee
  - Boston University
  - Univ. of Southampton
  - Penn State ARL (closed)
- SBIRs:
  - Dynaflow Inc. (2)
  - Creare Inc.
  - Ultramet

Hg Target Development Spending

- FY10 work package has $2.6M budgeted
- FY09 spending was $2.5M
- FY08 spending was $2.9M
- FY07 spending was $2.4M
- FY06 spending was $0.9M (~half year)

The next 1 – 2 years will be interesting

- Long term operation at 1+ MW is tantalizingly close
  - How much mitigation will really be needed?
- Goal for 2+ MW performance remains as stated
  - Concerns:
    - Uncertainty regarding SNS power level at which target life will be excessively shortened by cavitation damage, vs.
    - When successful mitigation concept (s) will be ready for deployment
- Now is a good time to get some advice on plans