ESS-J-PARC Workshop
ESS, January 18-19, 2018

Target status at J-PARC

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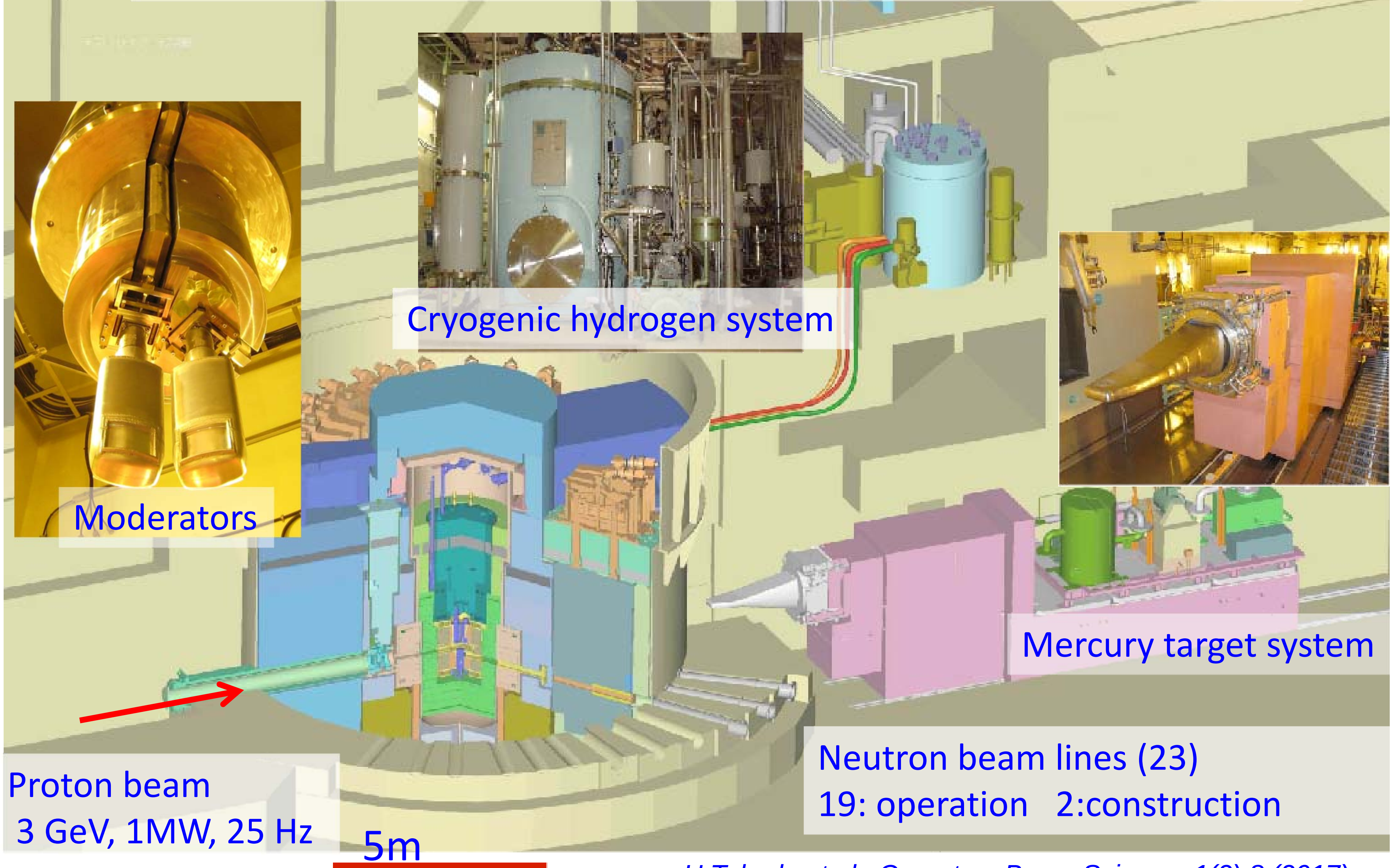
JSNS 1MW spallation neutron source



H.Takada et al., Quamtum Beam Science, 1(2),8 (2017).

History of target operation at J-PARC

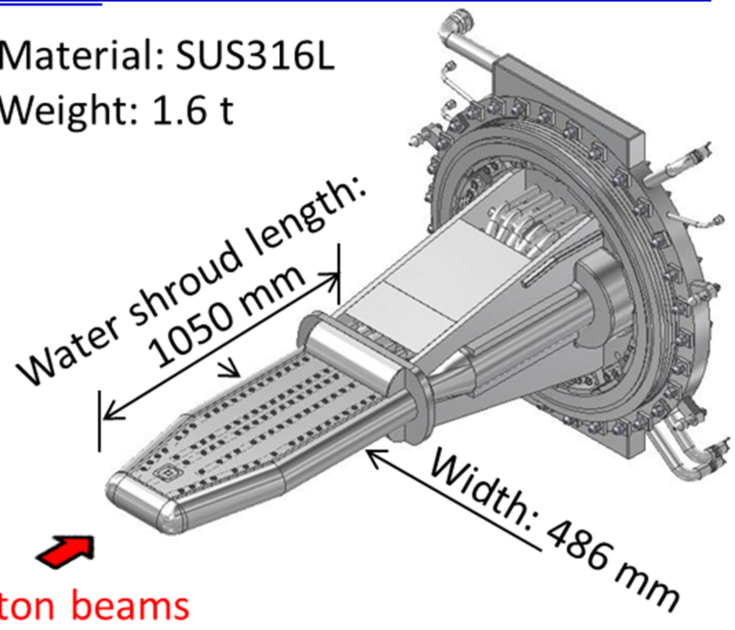
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
#1	**#1 target** **20～220 kW, 471 MWh**			**Replacement After Earthquake**						
#2								**#2 target (w/o bubbler)** **210～150kW, 1048 MWh**		
#3					**#3 target with bubbler** **120～310 kW, 2050 MWh**					
#4										
#5						**#5 target (bubbler + double-walled front)** **330～513kW, 670 MWh** **Failure on outer water shroud**				
#6										
#7							**#7 target** **Max. 505kW, 170 MWh** **Failure on inner water shroud**			
#8								**#8 target** **In use at 400 kW.**		

5 time target replacement to date

Critical issues on mercury target at J-PARC

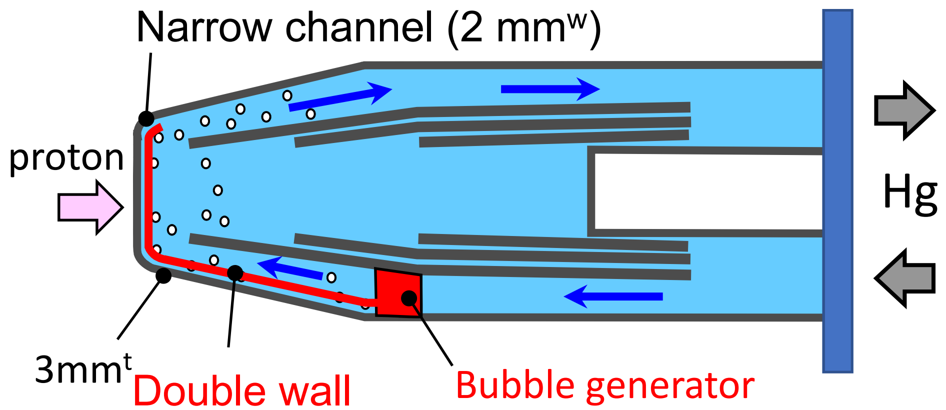
- Improvement of target vessel structure to have enough robustness for high power operation (>500 kW)
  - ✓ Failure in water shroud of the target vessels at 500 kW operations was the trigger to re-design the target vessel.

Material: SUS316L
Weight: 1.6 t



- Mitigation of pitting damage on the target front
  - ✓ Current approach: faster mercury flow in narrow channel & gas-micro bubbles injection

Note: Higher pressure wave is induced in mercury than in the SNS target due to lower repetition rate (25Hz)



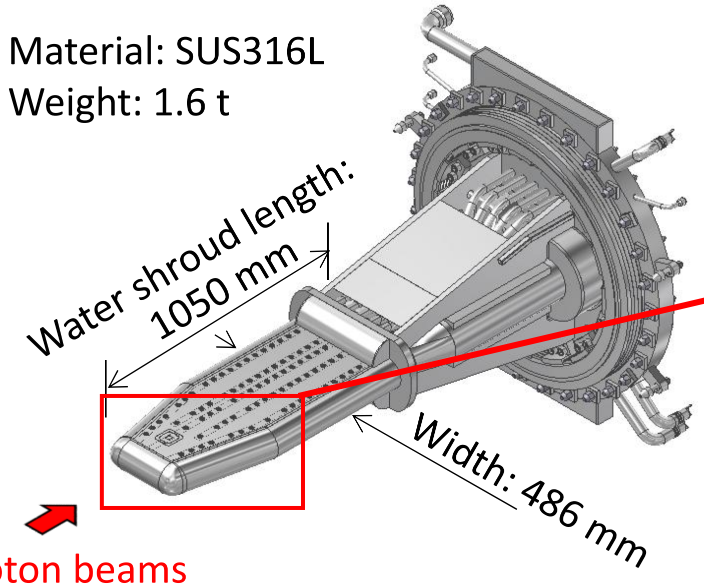
Recent experiences at neutron source operations

- Failures on water shroud at 500 kW operation in 2015
- Redesign of target vessel (#8) to have sufficient robustness and fabrication with improving welding inspection (from 2016 to 2017)
- Further target vessel design improvement with reducing thermal stress and welding. (in progress)

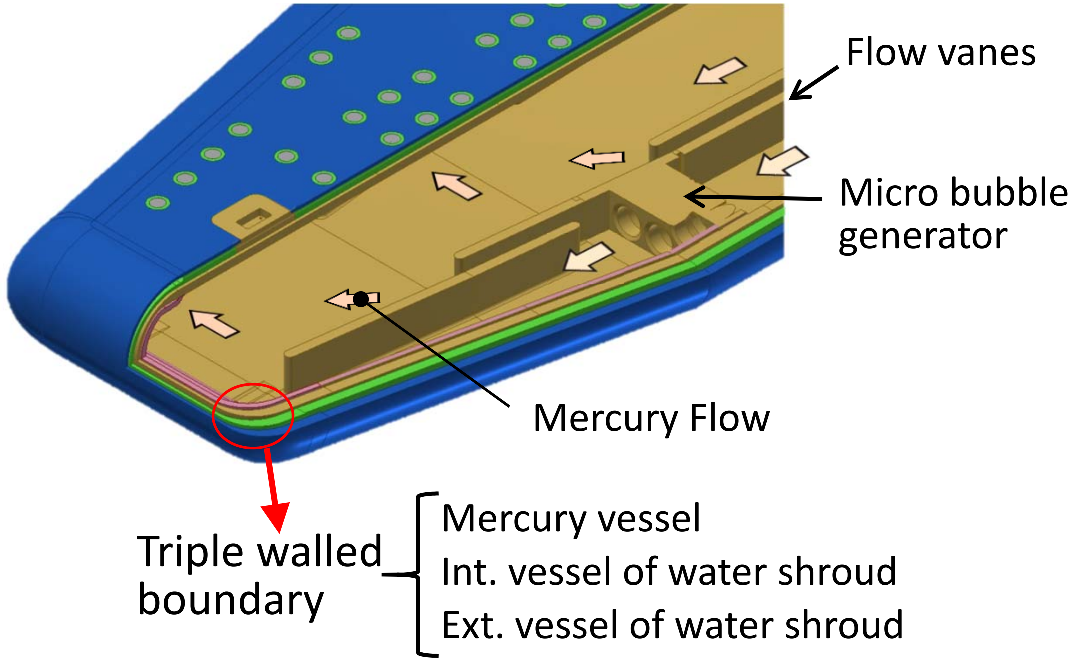
- Performance degradation of helium refrigerator of cryogenic hydrogen moderator system since 2015 and restoration in 2016
- Target vessel replacement to new one (#8) in last October
- Proton beam window replacement to 3rd one in last August.

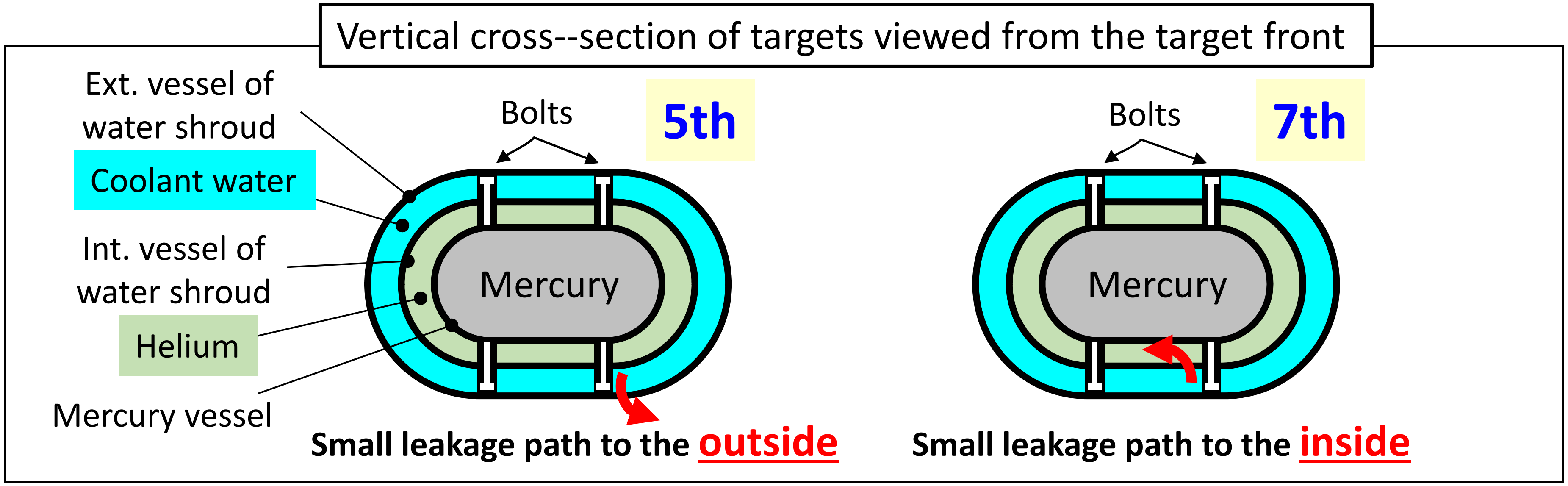
Target structure and failures occurred on water shroud in 2015

Material: SUS316L
Weight: 1.6 t



Proton beams





Failure Mechanisms in the 5th Target

Diffusion bonding of int. & ext. vessels

P lfurvfrslf#ghwdfkphqw#h{lvwhg#zklfk#zhuh#xqghwhfwdeoh#e|#xowudvrqlf#whvw

Welding of bolt heads

①DBI was detached due to welding thermal deformation.

Seal welding (Target completed)

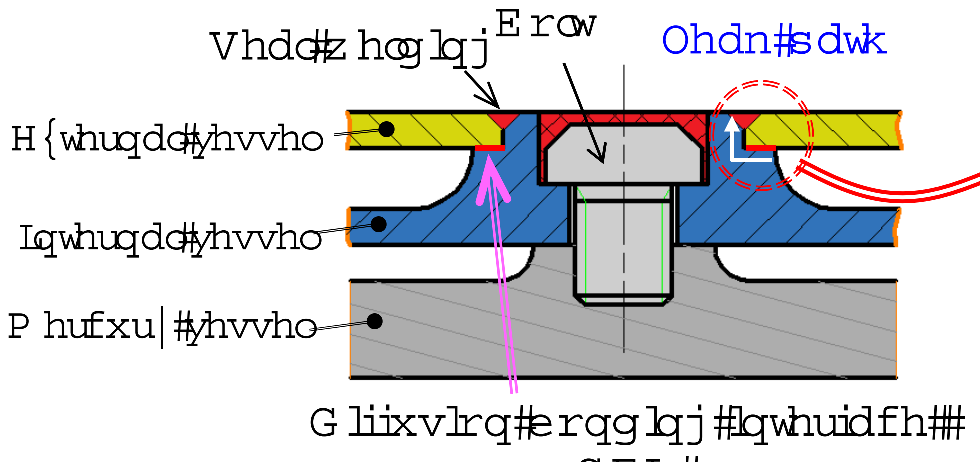
Vkdoorz#zhoglqj#ghswk

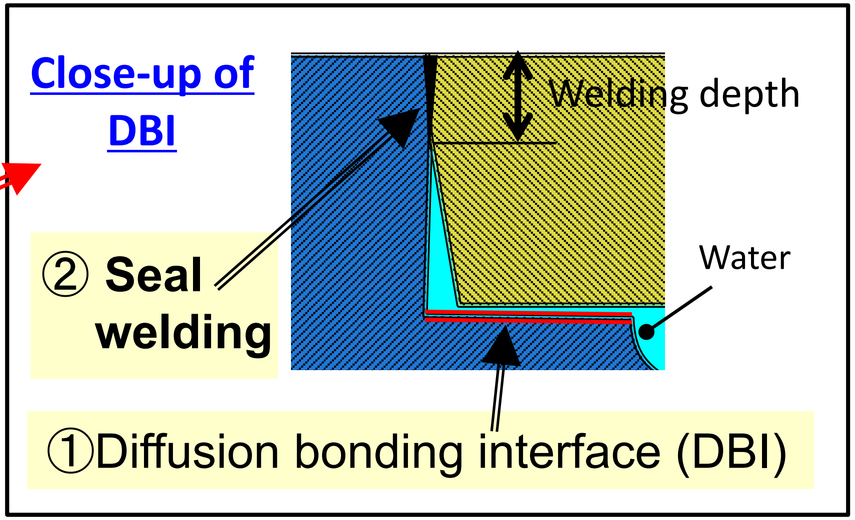
※ Suhvvxuh0surri#) #vhdd#whvw#zhuh#erwk#sdvvhg1

Beam operation

②Seal welding failed by repeated thermal stress.

Outward Leak path was generated.

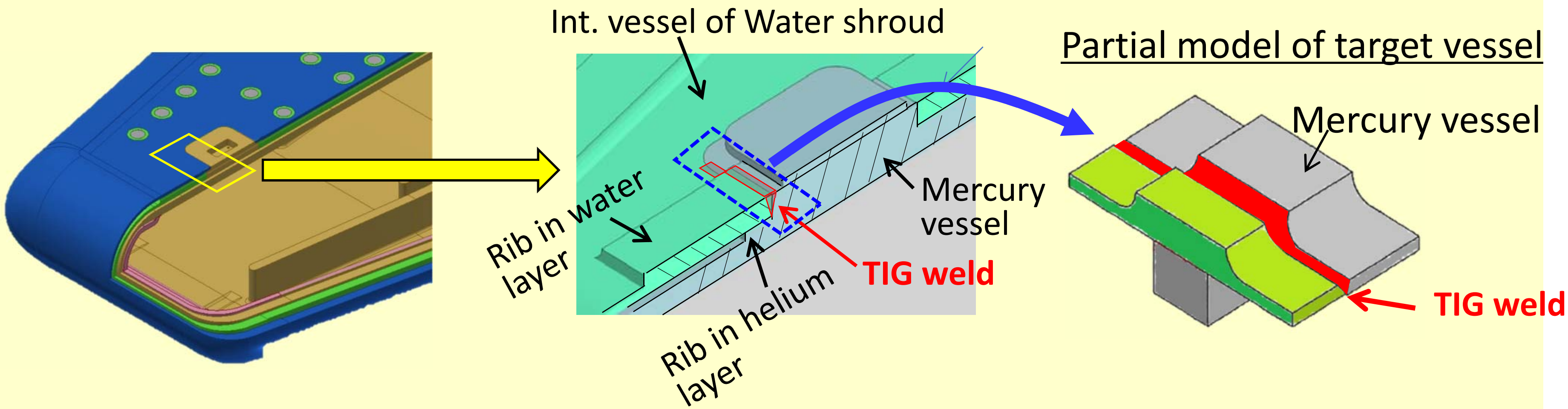


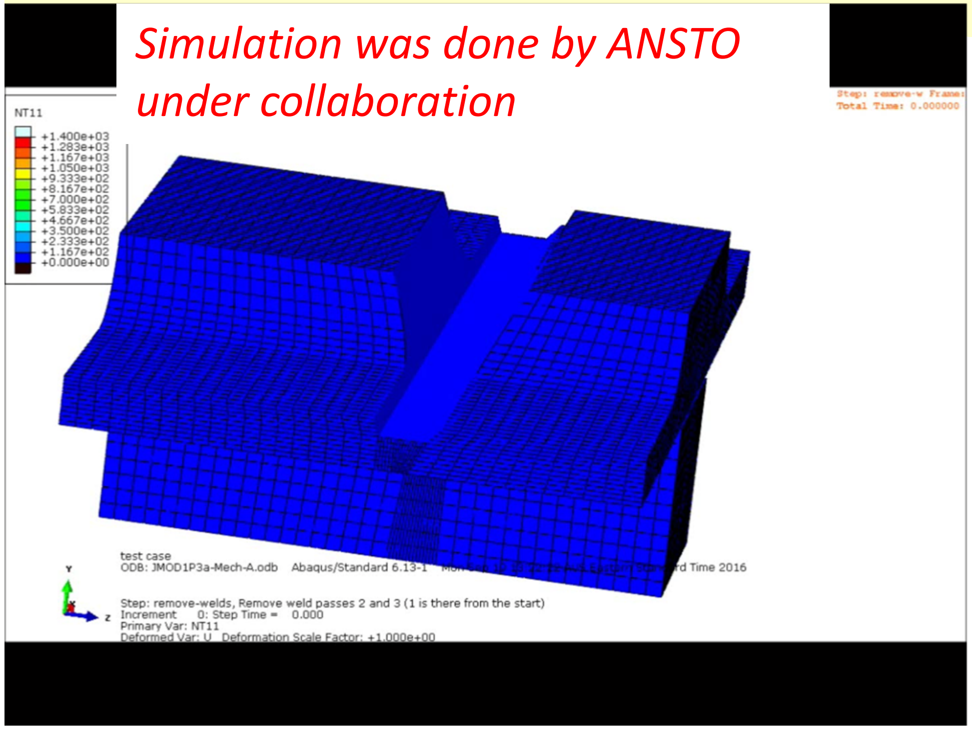


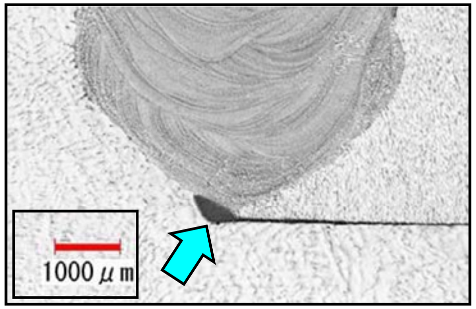
K.Haga et al., J. Nucl. Sci. technol. 55, 160 (2018).

Cause investigations of failure on target #7 -Welding -

Possibility of incomplete welding at the portion where vessel wall becomes thicker







- The area over melting point is small at the center of the rib where the vessel wall becomes thick.
- This analytical result suggests the cause of the insufficient welding.

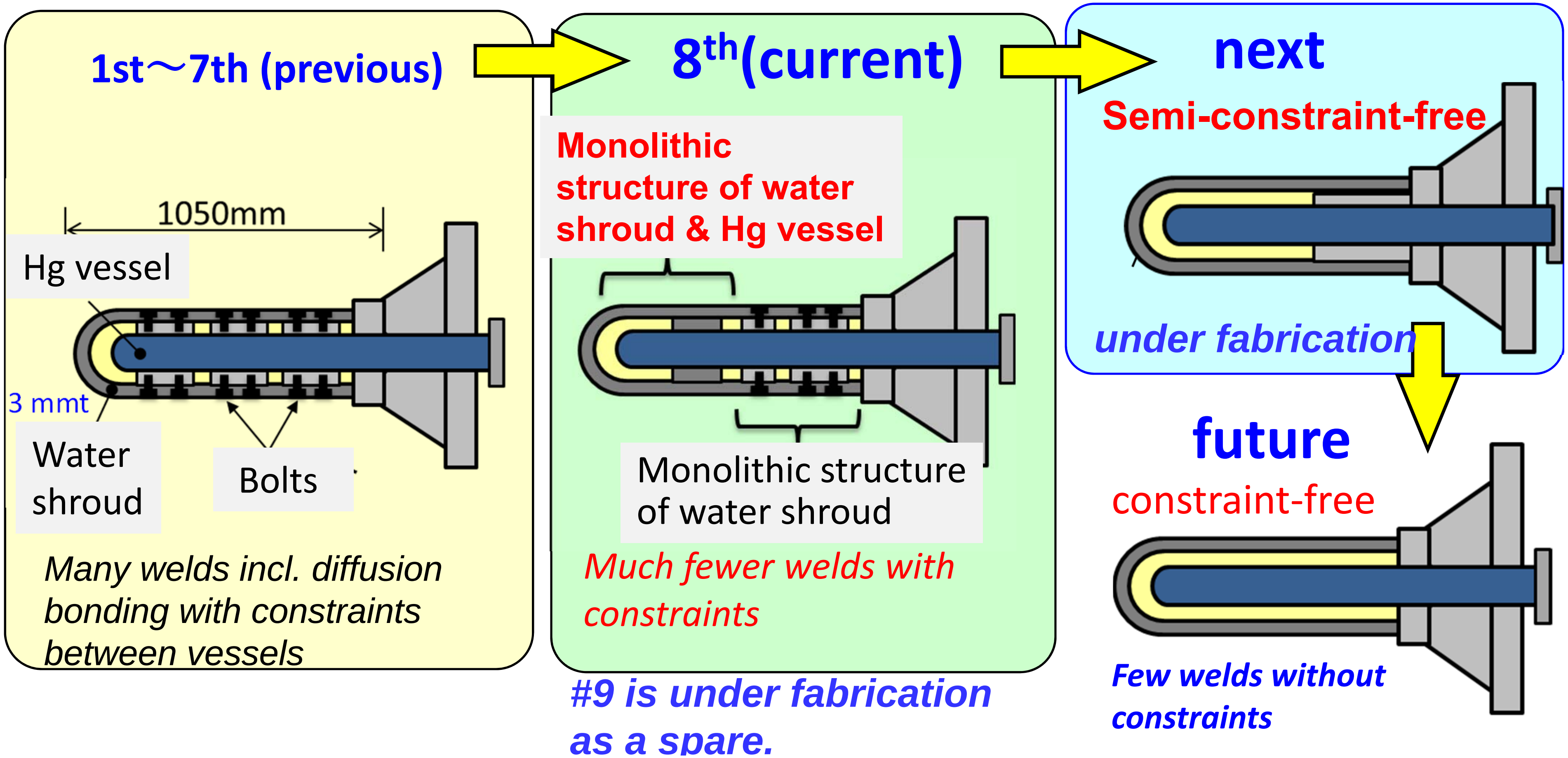
Key point in target design improvement

Target failures had been resulted from conditions difficult to examine by analytical approaches at the stage of target design, *e.g.*, those relating to the bonding/welding processes.

Designing target vessel with fewer welds and good inspection in the course of fabrication are essential to prevent the failures.

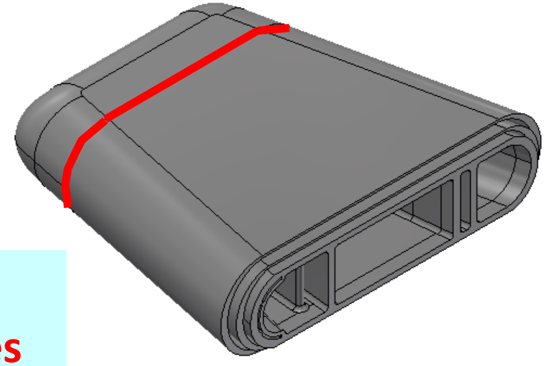
Strategy of design & fabrication improvements

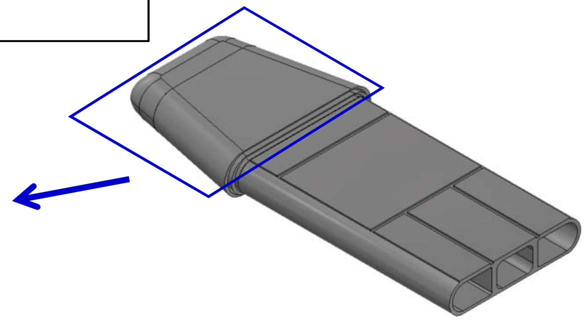
- Defect in joining and/or welding is initiation of crack propagation
- Eliminating risk to generate initial defect is important.
  - ➢ Reduction of joint lines by adopting monolithic structure
    - ◆ Further change to constrain-free between shroud and Hg vessel.
  - ➢ Improvement of inspection method by combination of RT, UT, and PT.



Modified fabrication process of target vessel #8

Welding beam window to monolithic fore part of upgraded mercury target vessel





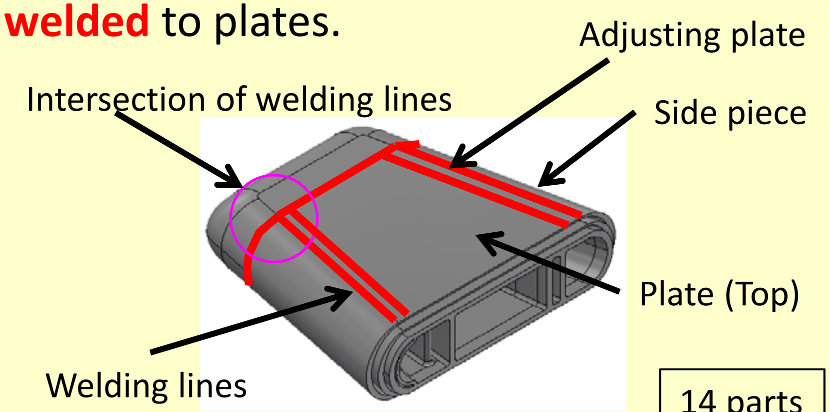
Monolithic structure

Structurally coupled mercury vessel and water shroud

Reduction of welding lines
No intersections of welding lines

Previous fabrication process

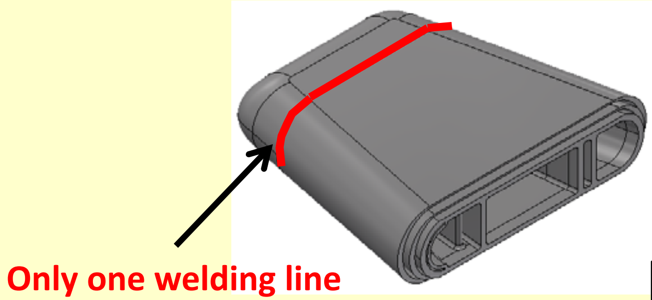
Side pieces and adjusting plates are **welded** to plates.



14 parts

Modified fabrication process

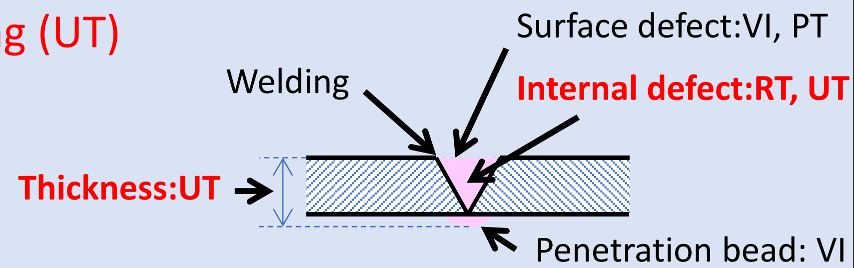
Fore part with the **monolithic structure** is machined **by the wire electric discharge machining**.



4 parts

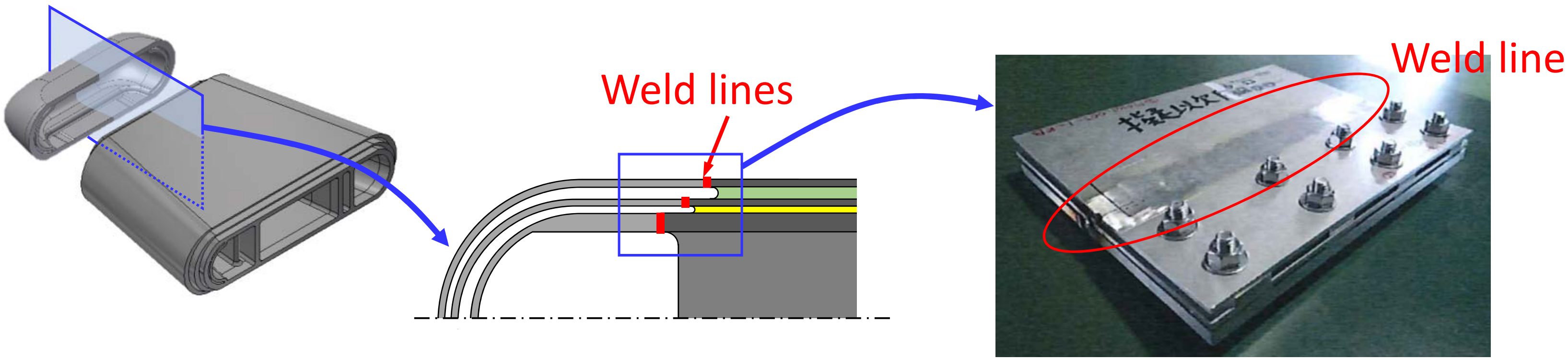
Strengthening welding inspections

Contents of welding inspection	Number of attending inspection by J-PARC Staff
Previous inspection	
◆ Visual inspection ◆ Penetrant testing ◆ Radiographic testing (Just 1 welding line in mercury vessel) ◆ Airtight test ◆ Pressure test	about 10 times.
Modified inspection done from target #8	
◆ Visual inspection (VI) ◆ Penetrant testing (PT) ◆ Radiographic testing (RT) (All welding lines in mercury vessel) ◆ Ultrasonic testing (UT) (Water shroud) ◆ Airtight test ◆ Pressure test	more than 30 times (including confirmation of welding and inspection methods.)



Radiographic Test using Multi-walled Mockup

Tests with triple-walled mockup model of the beam window in which initial defects were intentionally made in weld lines



Initial defects in weld line : φ0.5～1.5mm

- Defect detection performance for the multi-walled structure was examined .
- In the triple walled structure, radiographic picture became unclear and the detectable defect size became larger than the usual detection limit of ca.0.3 mm.

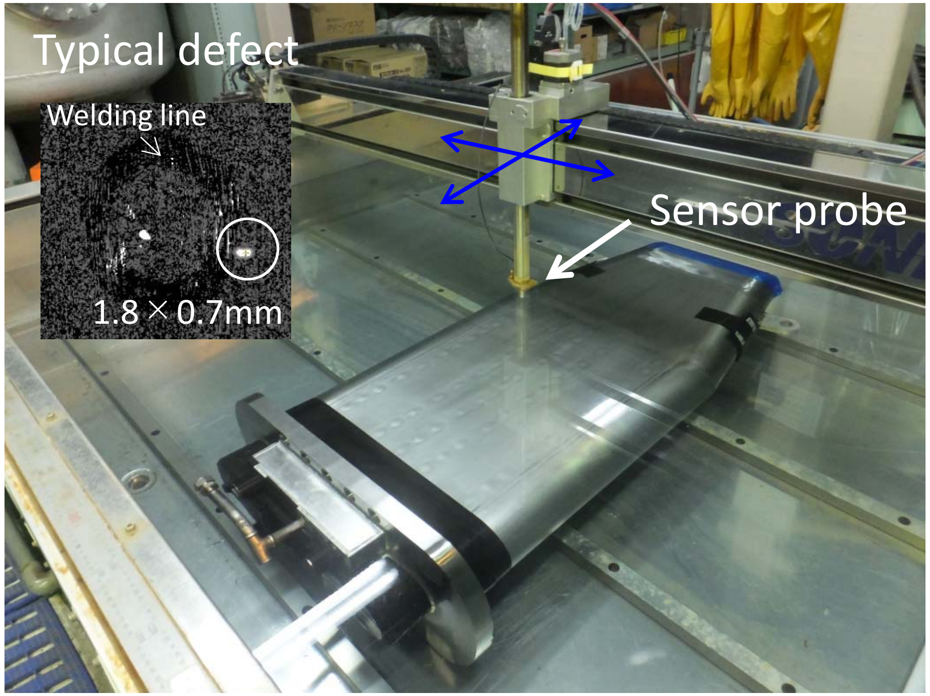
Immersion ultrasonic testing

Characteristic
(comparison with general method)

- **Thinner materials** can be inspected.
- **Small defects** can be detected using sensor probe with high frequency.
- There is **small influence of surface shape** on accuracy of inspection.
- **Wide test area** can be scanned automatically in **short time**.
- **Shape of defect** can be estimated from C-scan image obtained by scanning.

Note:
It's necessary to select frequency of sensor probe taking account of thickness of test materials, because attenuation and scatter of high frequency ultrasound in weld part is large.

Welding inspection on water shroud (3 mm^t)

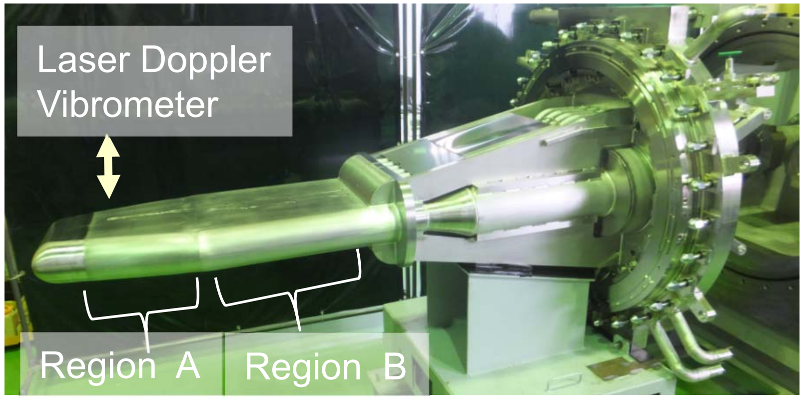


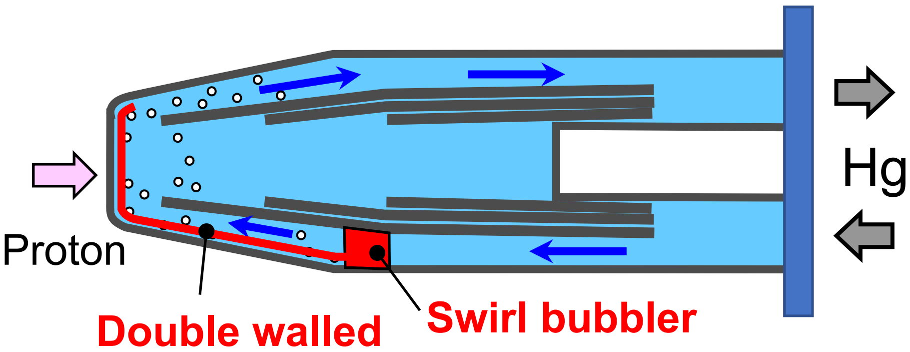
FlexScan (Insight K.K.)
Immersion ultrasonic system
Scan pitch : 0.1×0.1 mm
Sensor probe
Frequency : 50 MHz
Diameter : 6 mm
Focal length : 40 mm

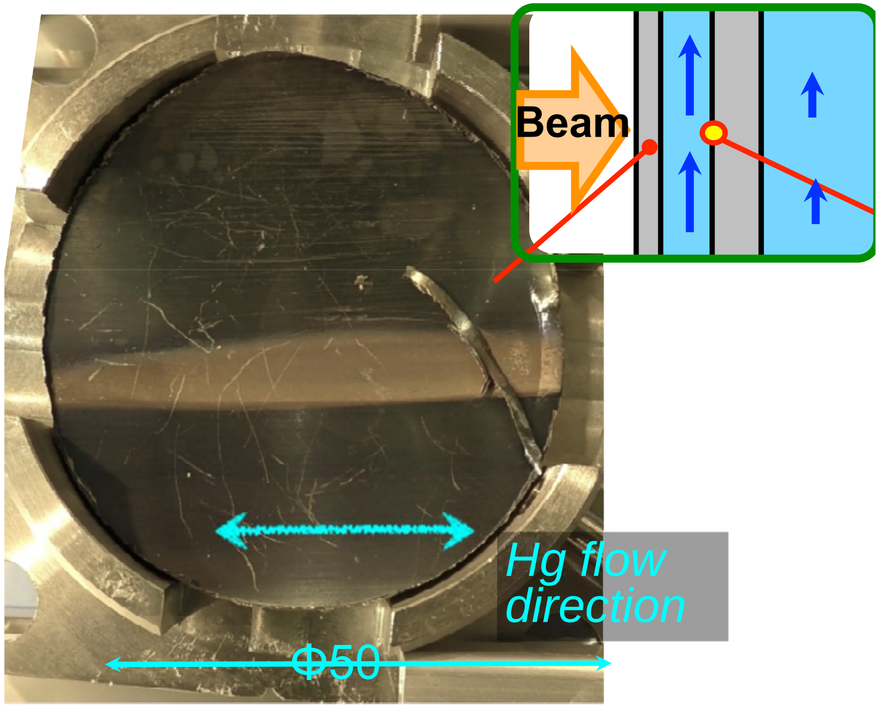
Minimum detectable size of defect: 0.2 mm

Status and aim of target #8 operation

- Operational beam power was 300 kW from Oct. 24 to Dec, ramped up to 400 kW from January to March and is planed at 500 kW from April to June.
- It was demonstrated that the velocity amplitude at the proton beam injection was reduced to ca. 1/3 with gas micro-bubbles injection.
- Investigating damage on the target front after operation at 500 kW is important to estimate lifetime because there was a pit with depth of about 25 μm on the 5-th target vessel after 670 MWh (av. 406 kW) in 2015.





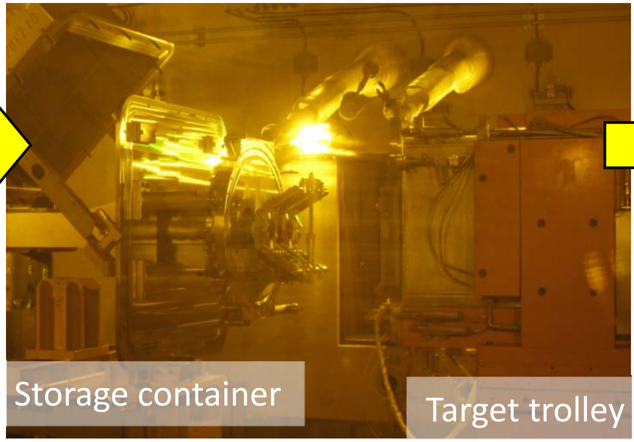


Outer mercury vessel

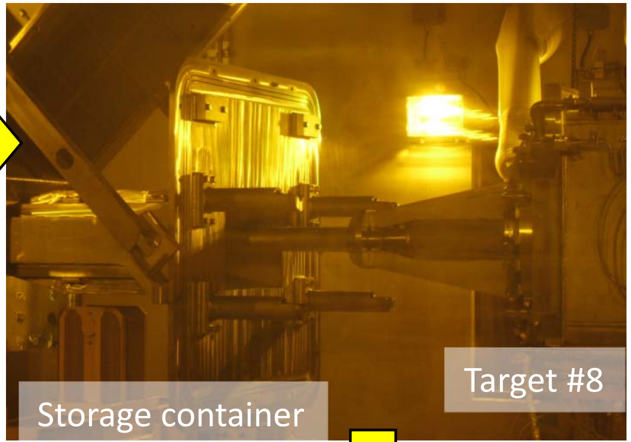
Target vessel replacement from #2 to #8

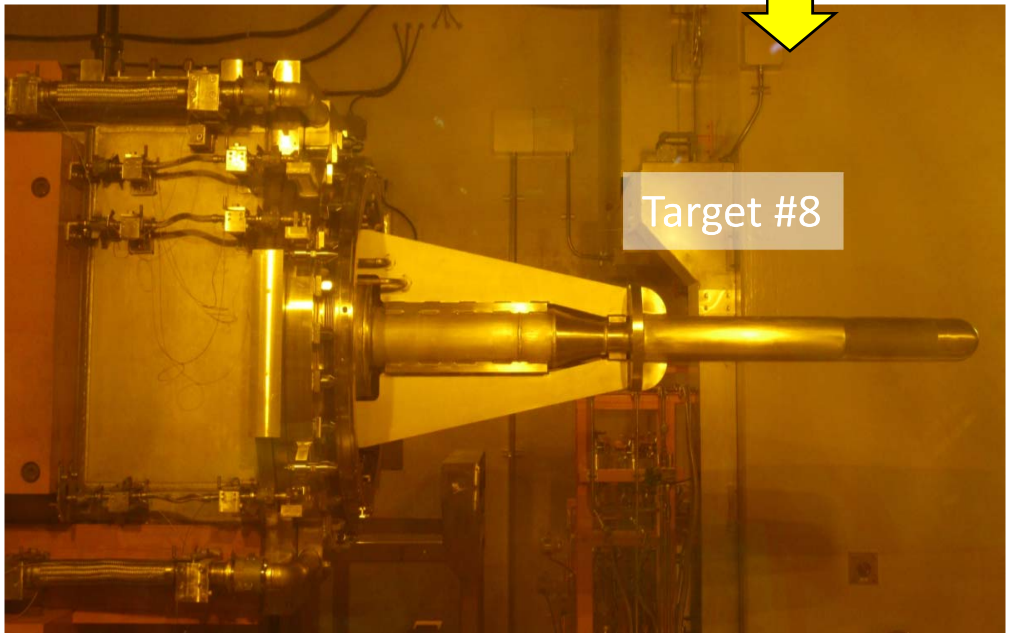
Sep. 22: Target #8 was delivered to MLF

Oct. 2: removing target #2 from target trolley and contained in a storage container.



New target #8 installation on the target trolley from a storage container.



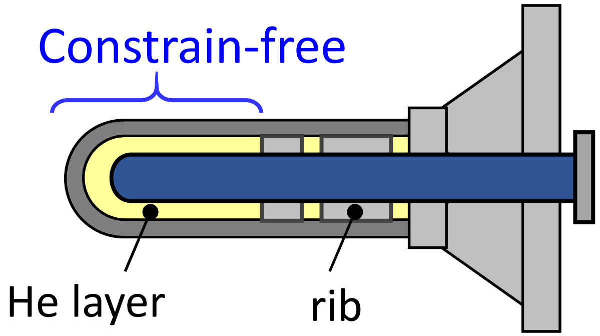


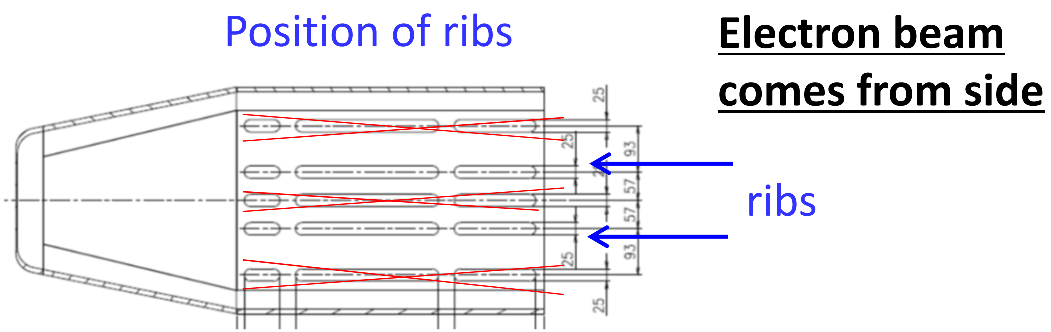
About 10 day including preparation and

Efforts to realize semi-constraint-free structure

Improvements to reduce thermal stress in target

1. **No mechanical coupling between mercury vessel and water shroud in forepart.**
2. **<u>Remove entire bolt connection</u> between mercury vessel and water shroud, but rib structure remains.**
3. **Ribs between mercury vessel and water shroud are welded with an <u>electron beam welding</u> technique, reducing thermal stress at welding**
4. **Number of ribs is reduced to two.**





<u>Plane view of target</u>

Summary

- After we experienced the failures on the water shroud of target vessel, we are making efforts to fabricate the target vessel with sufficient robustness by reducing the welding line and thermal stress and improving welding inspection by applying RT, UT and PT.
- To realize the improvement, close discussion with vendor and frequent inspection are important
- With improved target #8, the pitting damage at the target front (beam window portion) will be investigated after 500 kW operation to estimate lifetime.
  - Note that 500 kW beam injection at 25 Hz is equivalent to the power of 1200 kW at SNS/ORNL (60Hz).