7th High Power Targetry Workshop
4-8 June 2018 at MSU

# Progress of specimen cutout and damage inspection for used mercury target vessel at J-PARC

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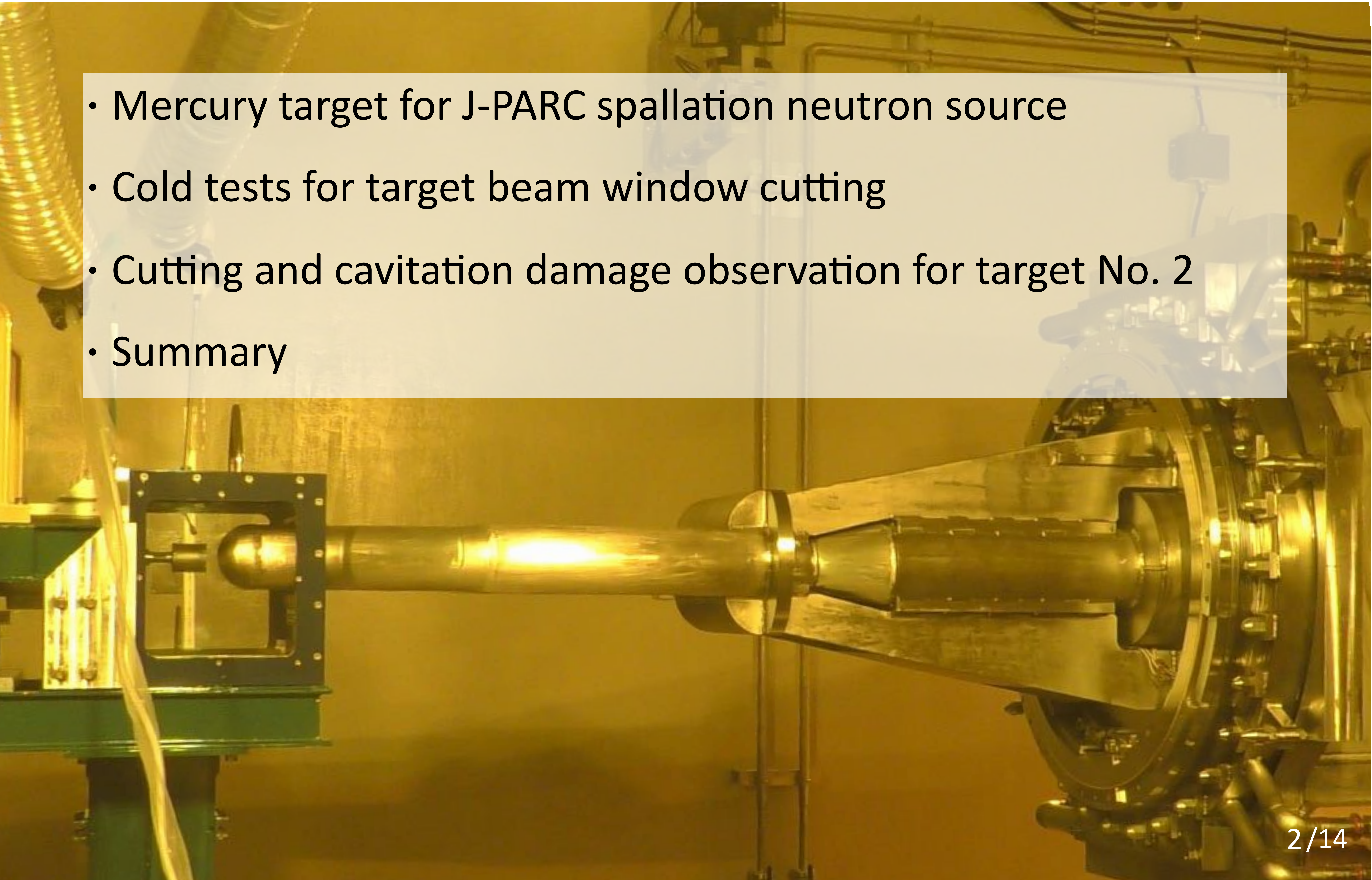
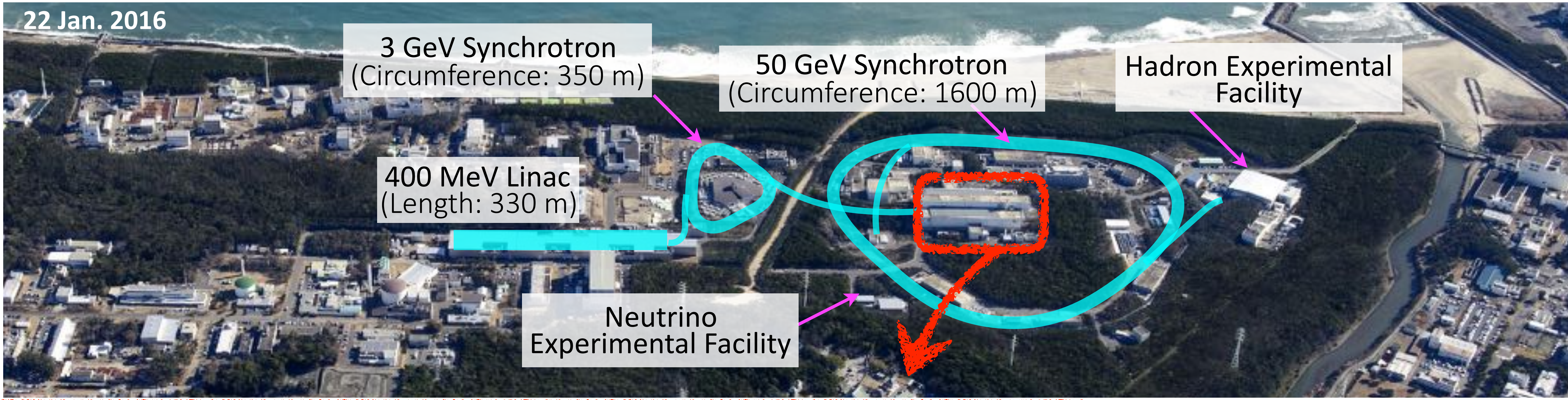
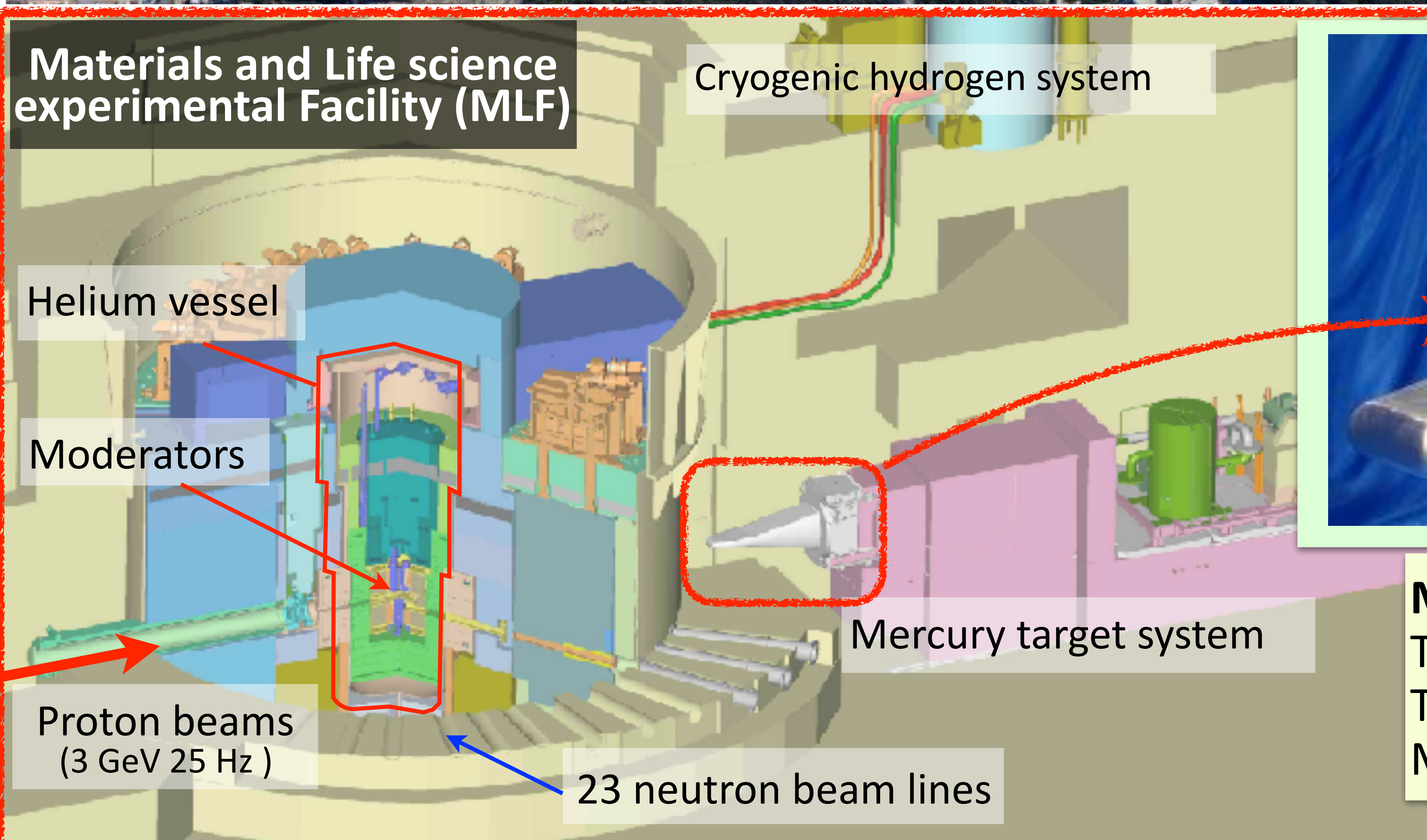


# Spallation neutron source in J-PARC

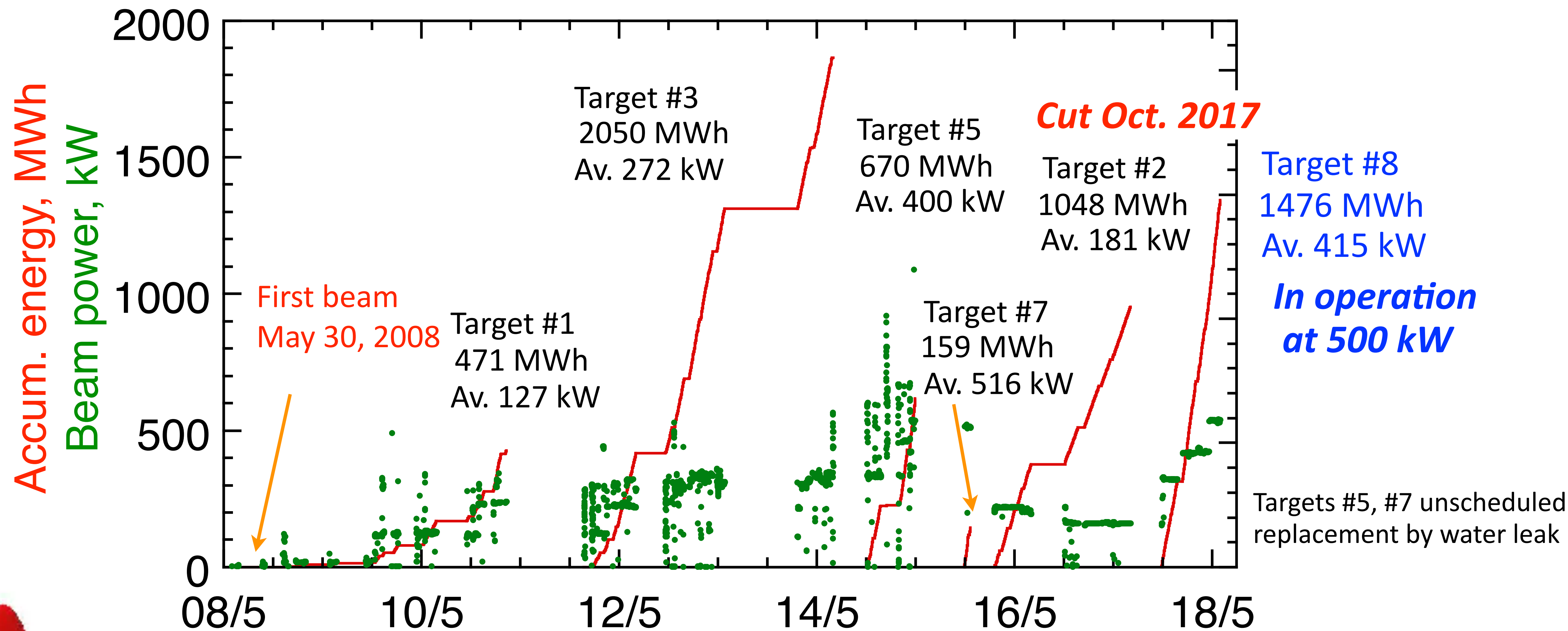
*Japan Proton Accelerator Research Complex in JAEA Tokai-site*



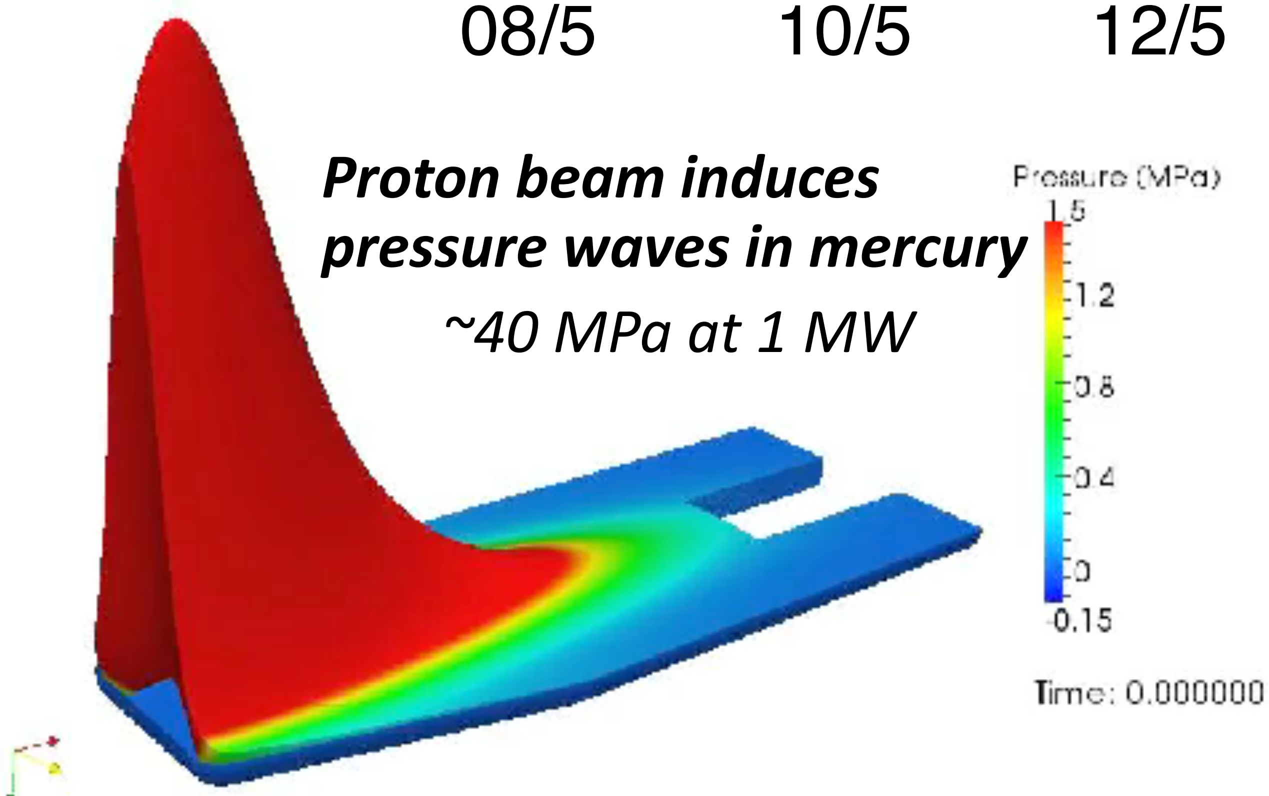

**Mercury target vessel**
Total length : 2 m
Total weight : 1.6 ton
Material : 316L SS

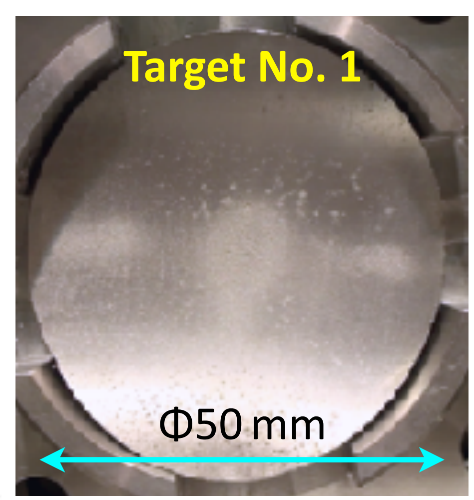
# Operation histories for J-PARC mercury target




***Proton beam induces pressure waves in mercury***

*~40 MPa at 1 MW*




- Cavitation reduces structural integrity of target vessel
- Dominant factor for target lifetime rather than radiation damage

# Cavitation damage mitigation

**Target No. 1**

## Surface hardening

Reduce cavitation damage
Nitriding & Carburizing, Kolsterising

**No. 2**

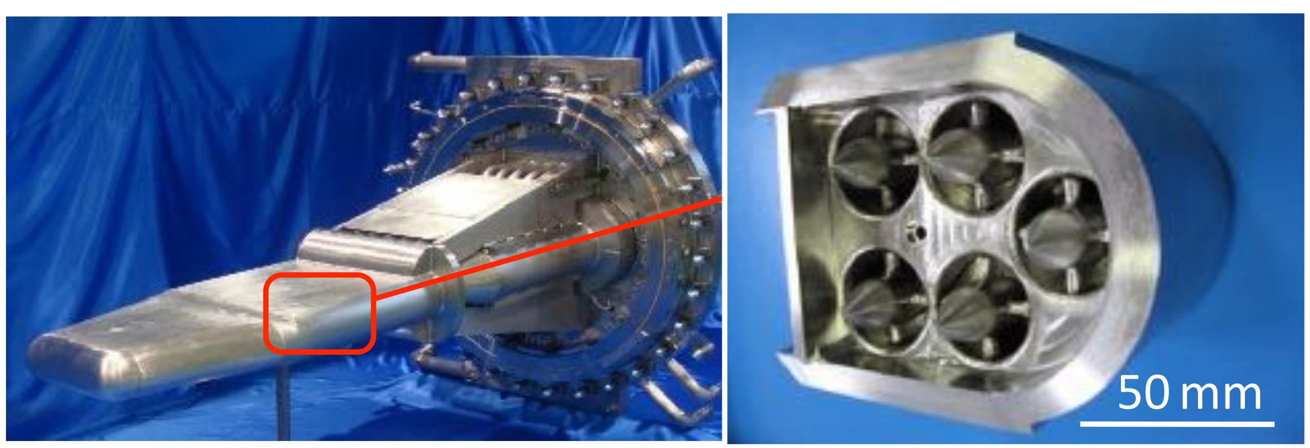
2nd target (Spare) No-bubbling techniques
to mitigate pressure waves and cavitation damage

**No. 3**

## Microbubble injection

**No. 4**

Reduce pressure wave and cavitation damage
Inject helium gas microbubbles (R<50 μm)
into flowing mercury (VF:$10^{-2}$ in flow ratio)




Target vessel No. 3 with bubble generator

**No. 5**

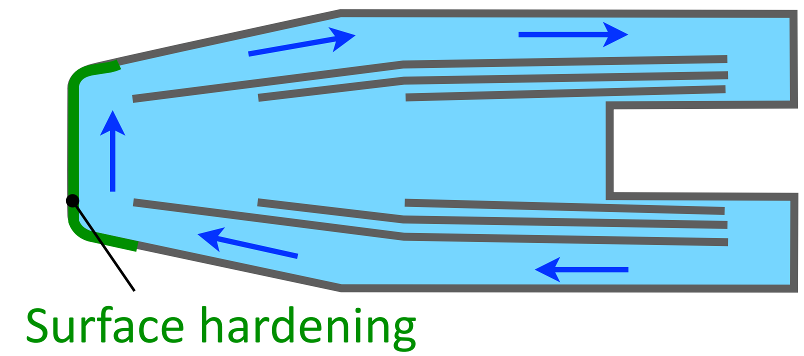
## Double-walled structure

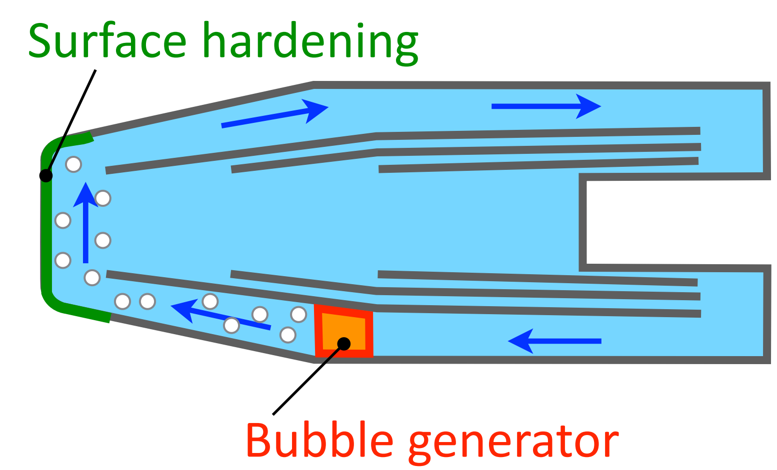
Reduce cavitation damage by high-speed
mercury flow and narrow gap

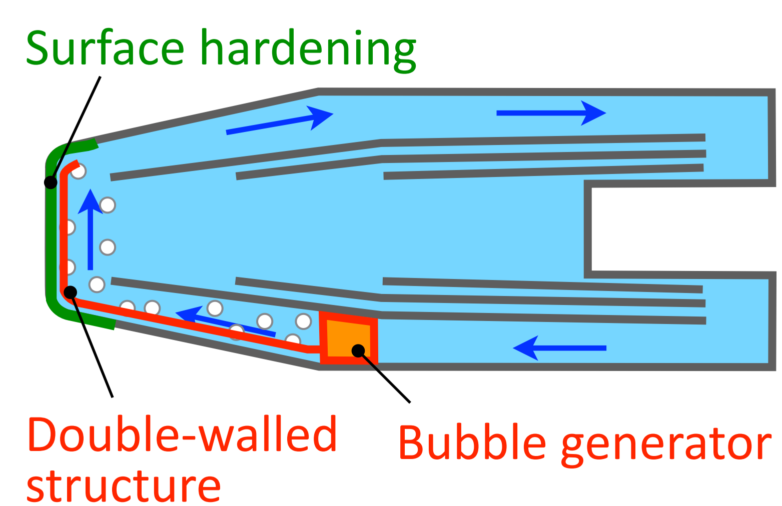
**No. 9**

*Fabrication number*

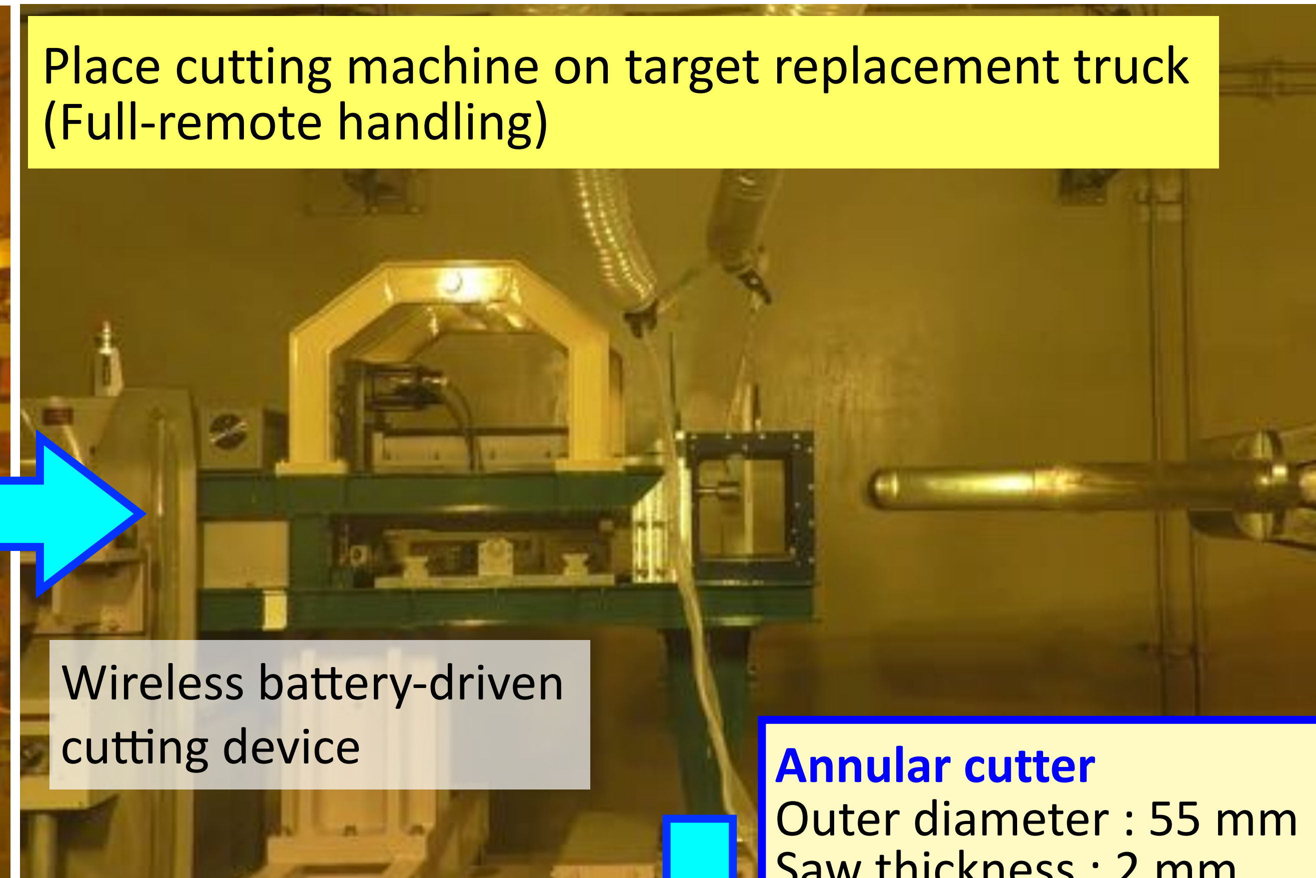
***Cut used target beam window to investigate the effect of damage mitigation technologies***

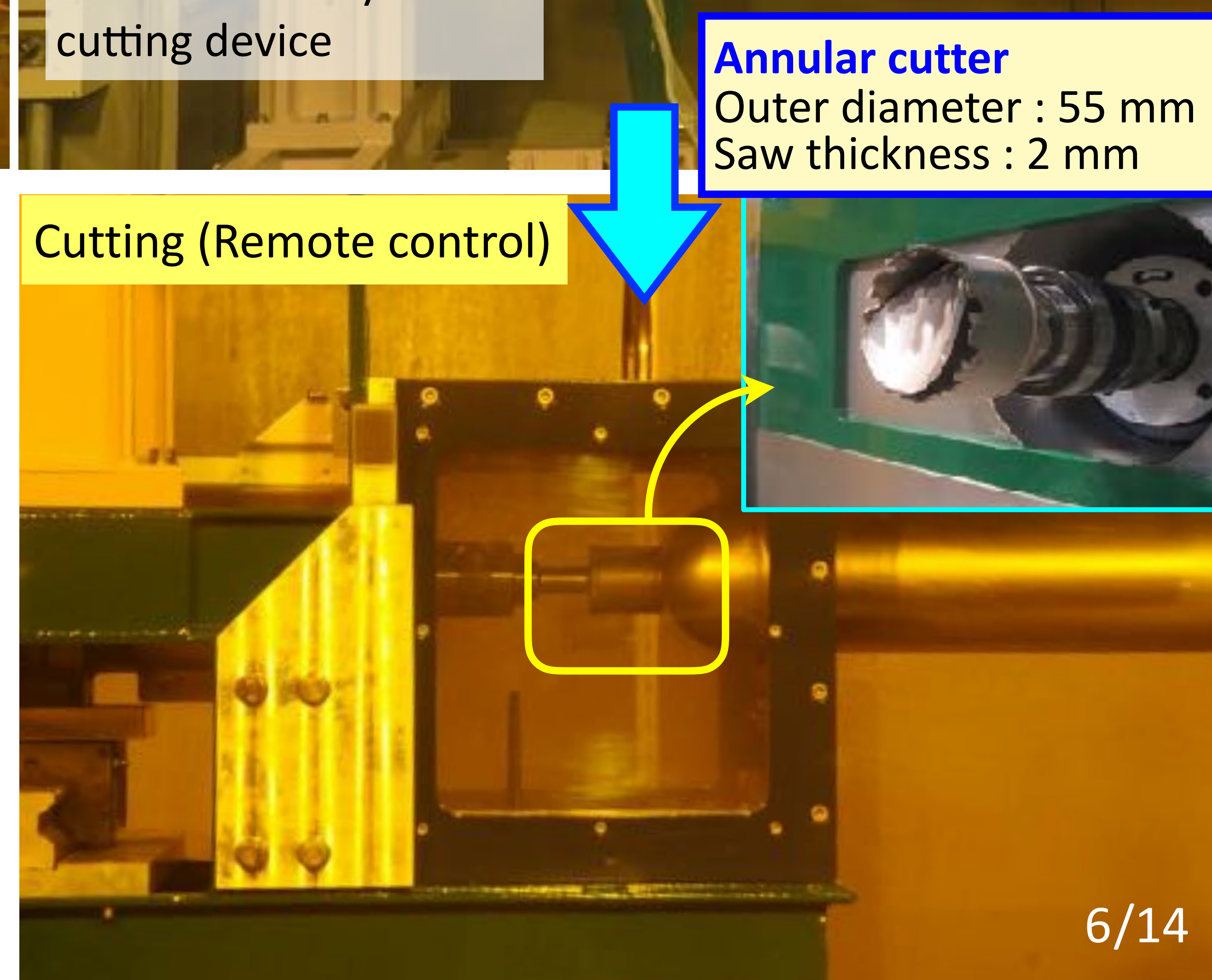


# Beam window cutting by remote handling

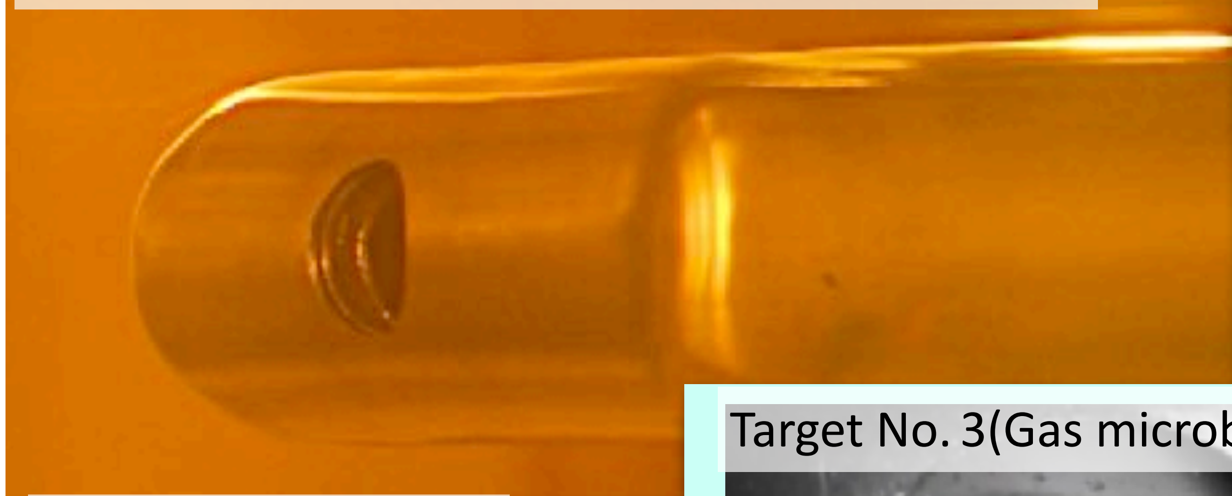

**Beam window cutting for cavitation damage inspection and future PIE**

**Dose rate of target vessel: ca. 350 Sv/h at contact**
After 77 days operation

**Cutting work by remote handling**
5 working days including decontamination

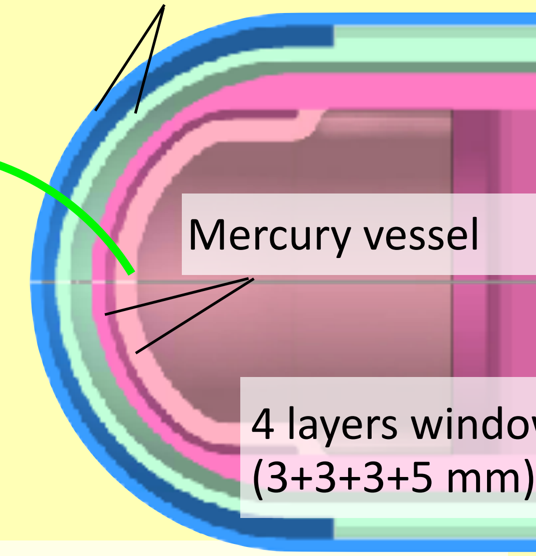
# Difficulties of cutting

**Precondition**
Liquid (water) free hot cell
→ **Dry cut**
Cut target under fixing on target trolley
→ **Horizontal cut**



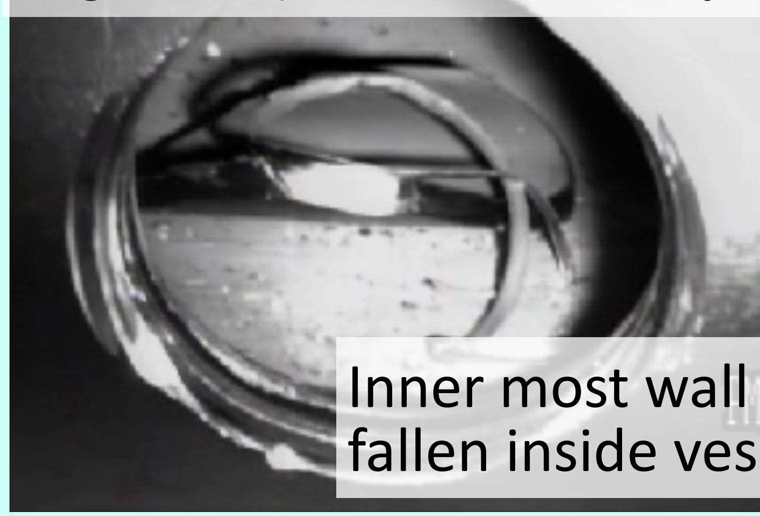
Target No. 5 (Double wall + bubble)

**Failed**




Inner most wall of 5th target remained window

Target No. 3(Gas microbubble injection)

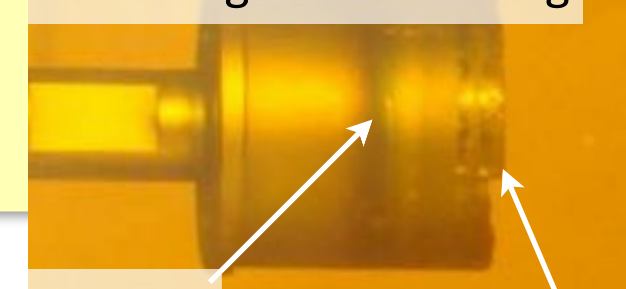


**Failed**

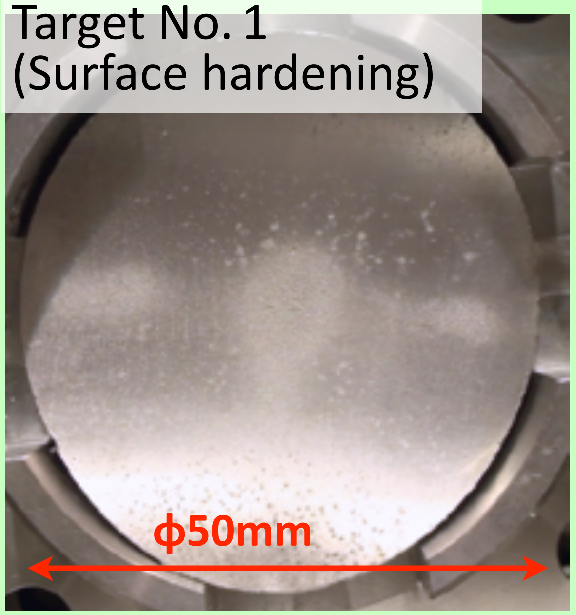
Inner most wall of target #3 fallen inside vessel

Before cutting

After Target No.5 cutting




Target No. 1
(Surface hardening)

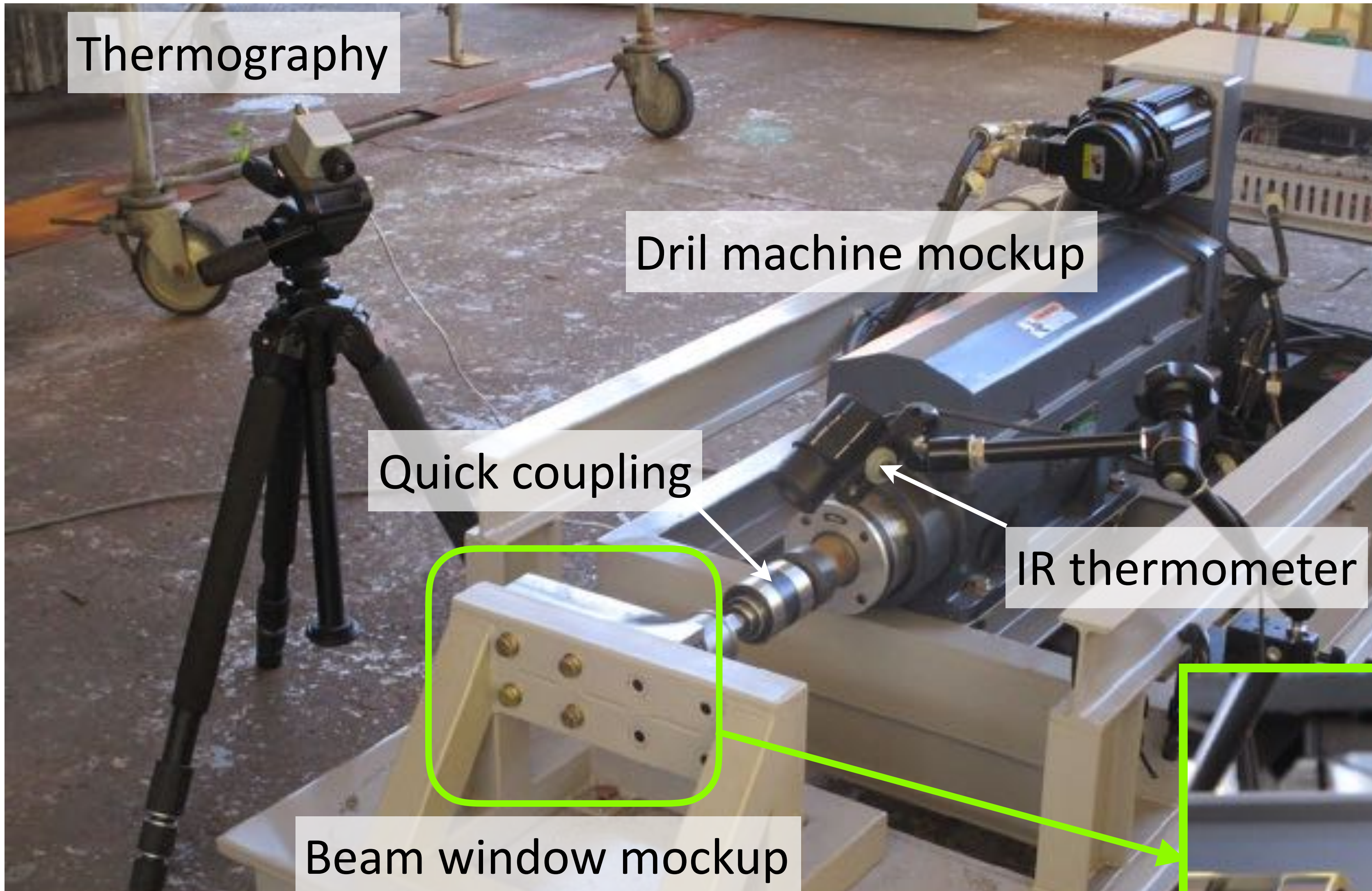


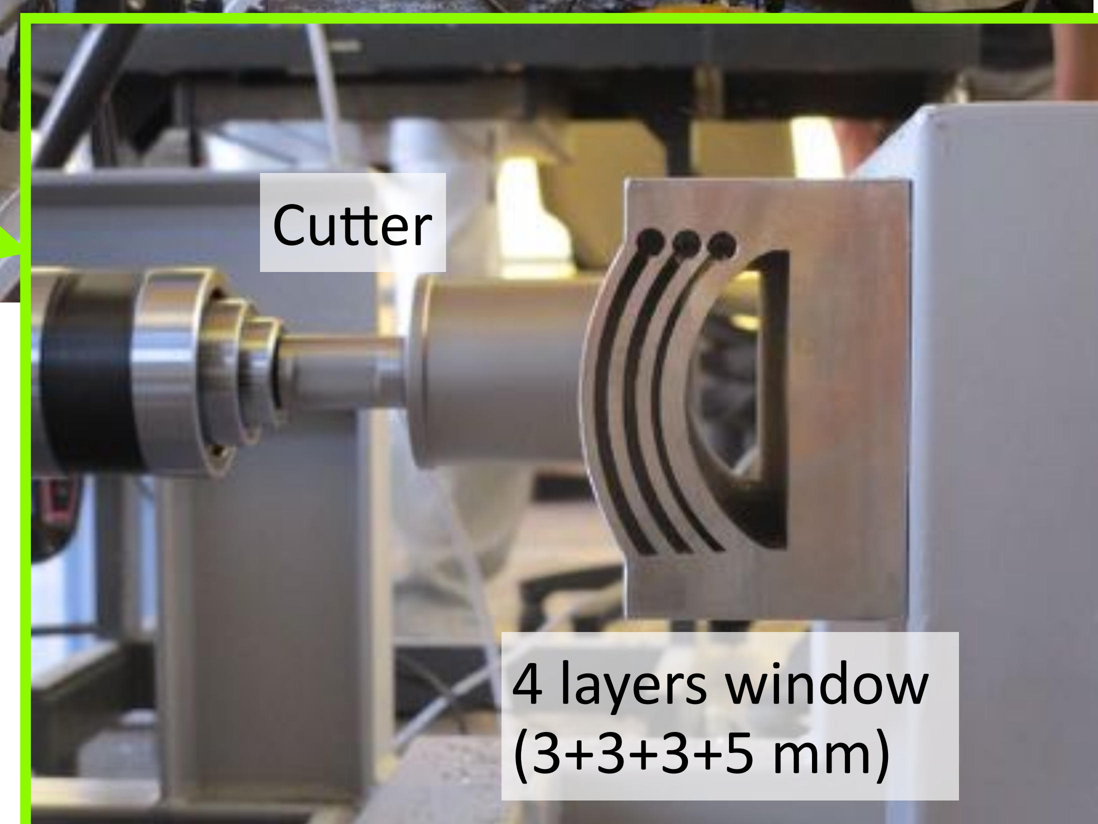

**Succeeded**
Initial cutting was successful

- Cutting performed under target fixing on trolley by full-remote handling
- Nos. 1,3,5 targets cut without any lubricant (Dry cut) →Failed #3 and #5 cutting

**Improve saws damage by dry cut, surely pick up specimen**

# Cold cutting test for optimizing cutting conditions

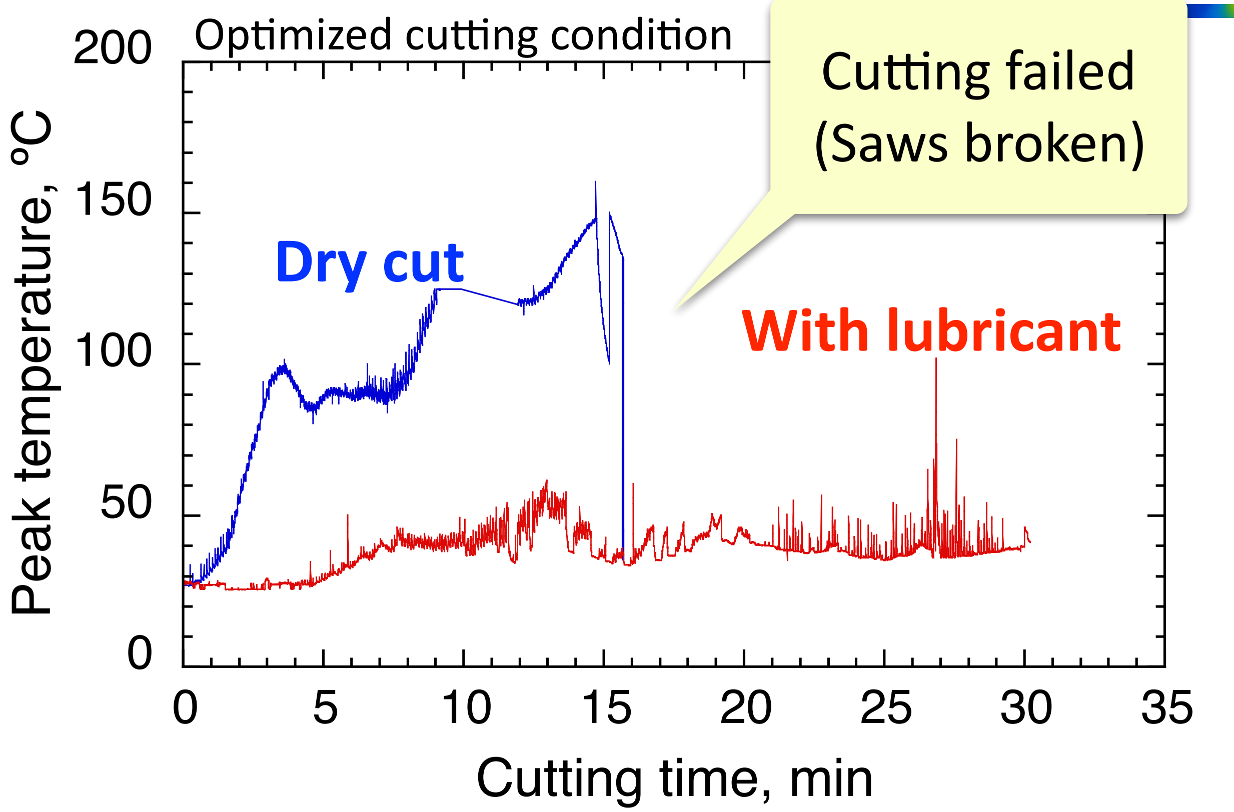


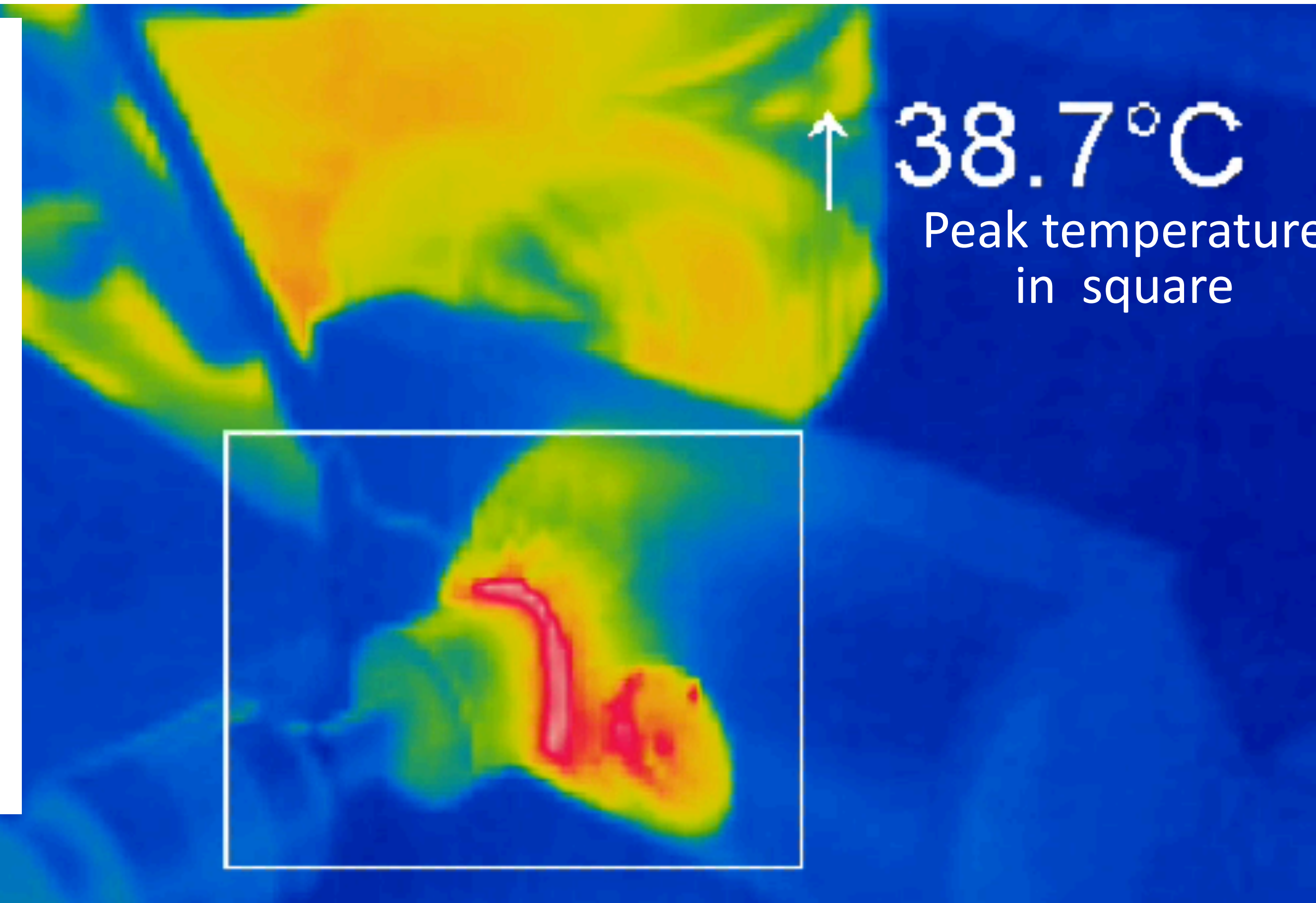




## Parameters for cold cutting test

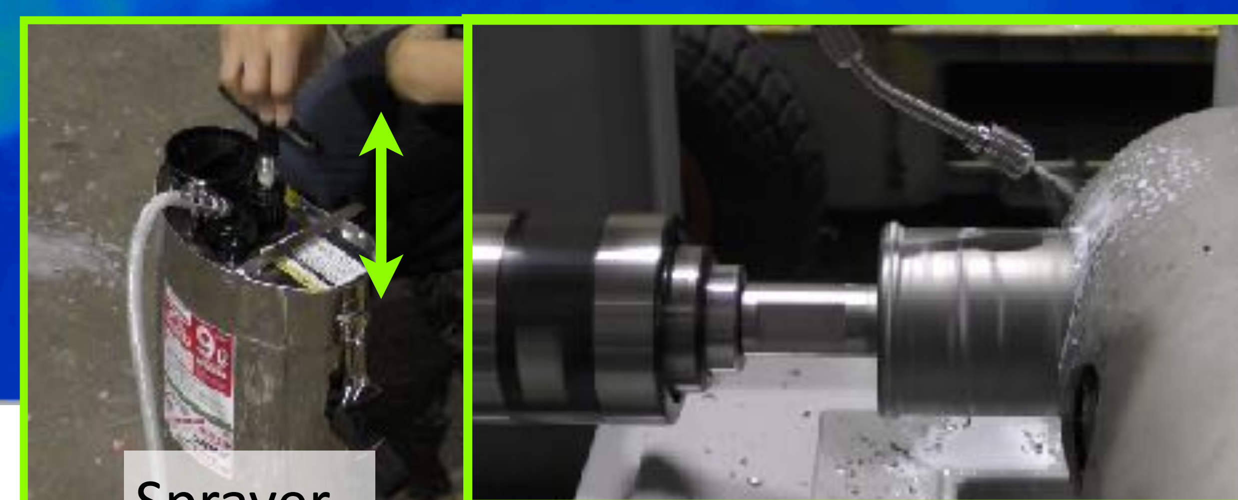
Rotation speed: **250**, 400 rpm
Feed rate : **0.017**, 0.025 mm/s
Feed frequency:
Forward 0.1 mm for 3 s + standby 3 s
**Forward 0.1 mm for 3 s + standby 3 s**
Lubricant : dry cut, oil base, emersion type
Center drill : ϕ5 dril, w/o dril

# Effect of lubricant on temperature



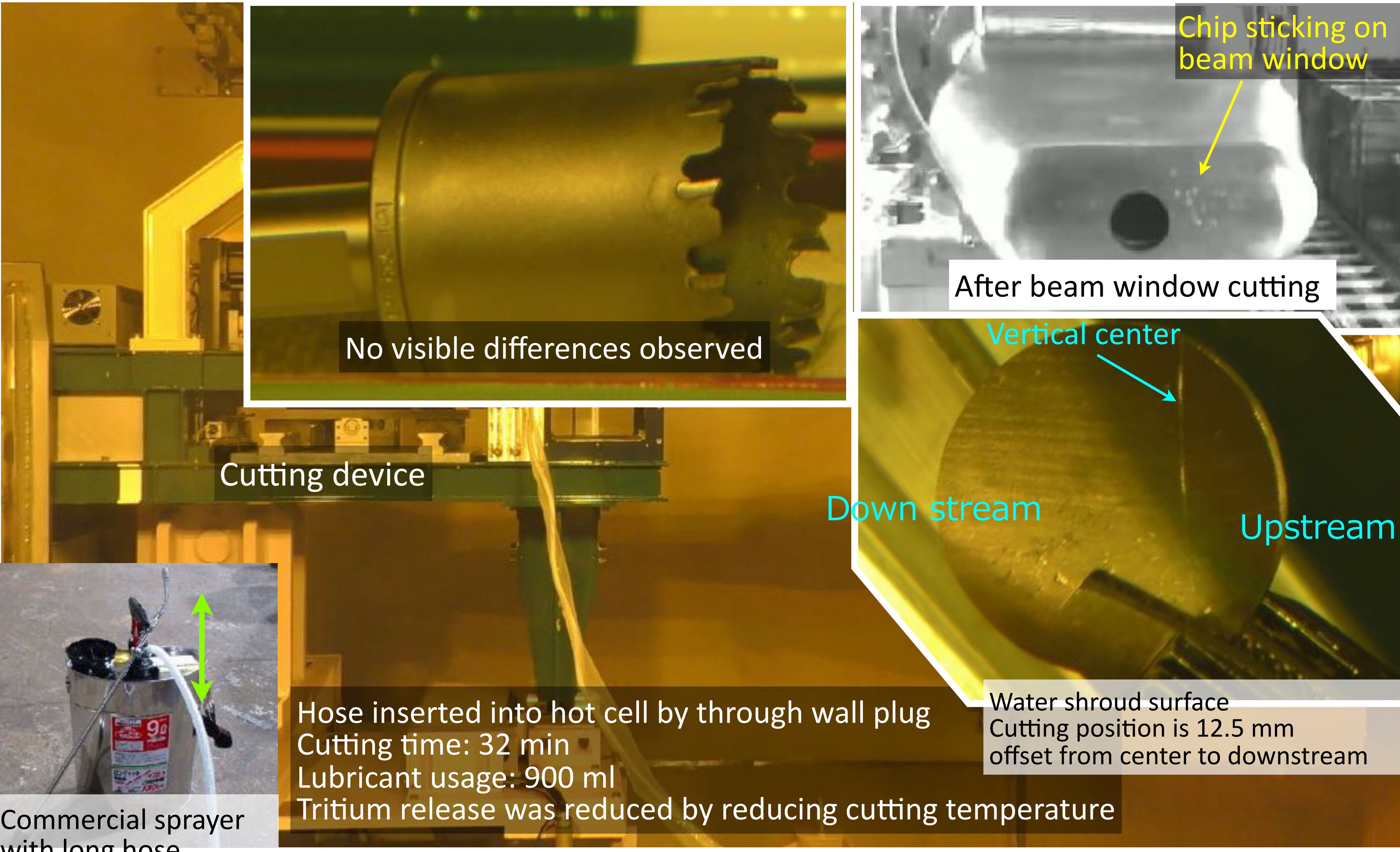



- Surface temperature of cutter and beam window were reduced by lubricant
- No visible damage on cutter after cutting with lubricant
- Lubricant is essential for surely cutting
- Center drill is difficult to adjust position for resume cutting

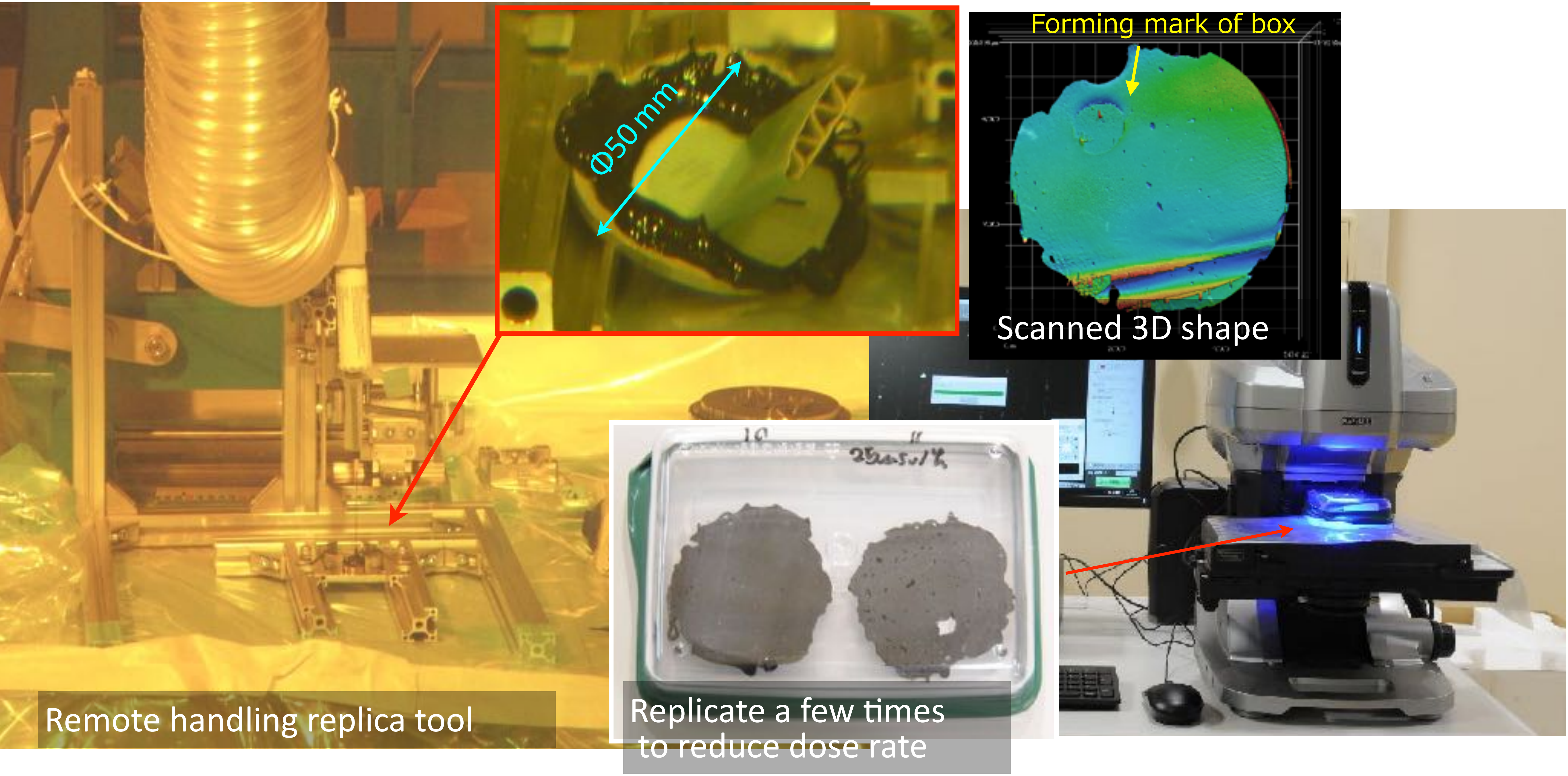
# Beam window cutting for target No.2

25, Sep. 2017



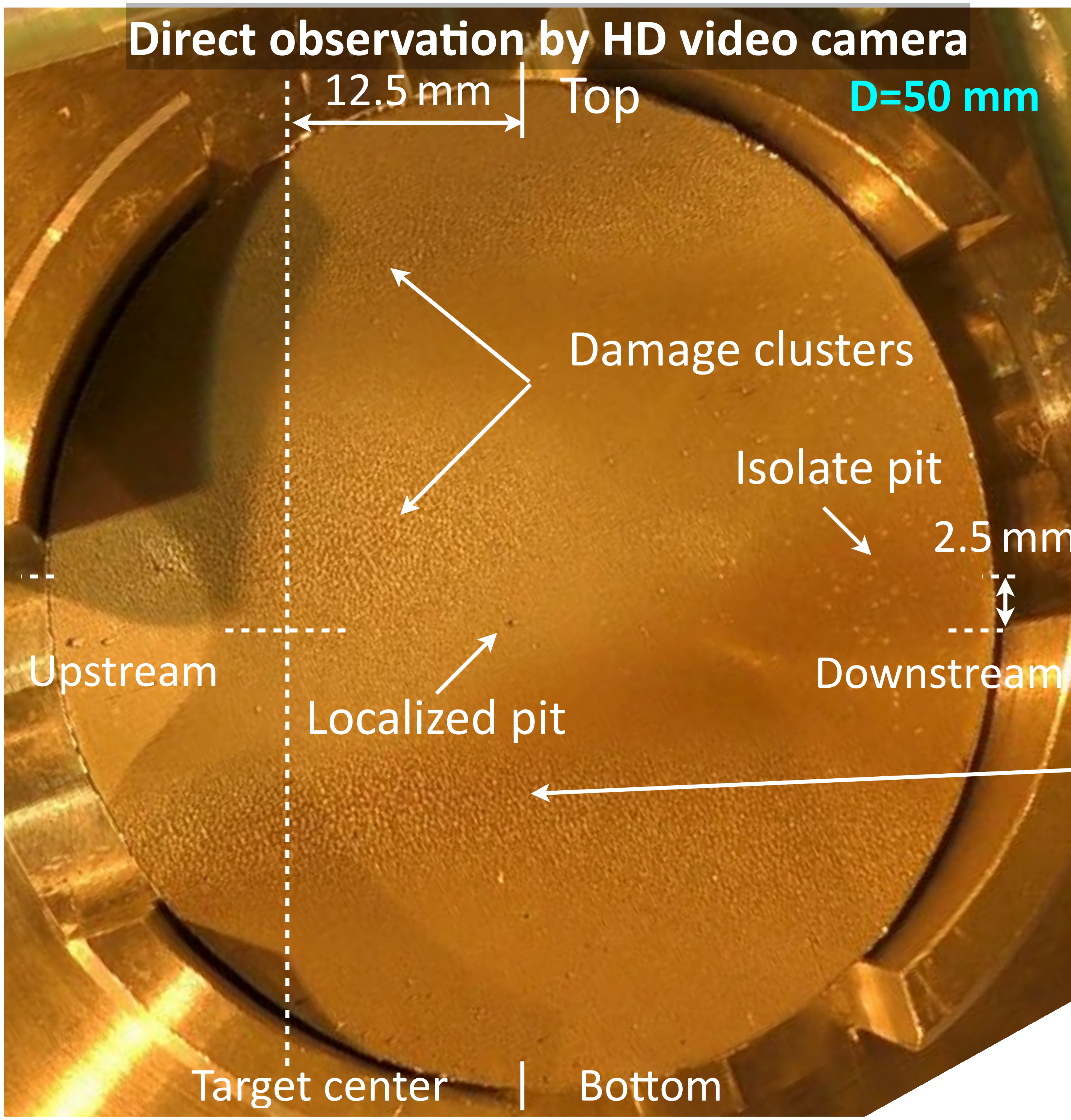

**Target No.2 cutting was successful by adopting lubricant spray**

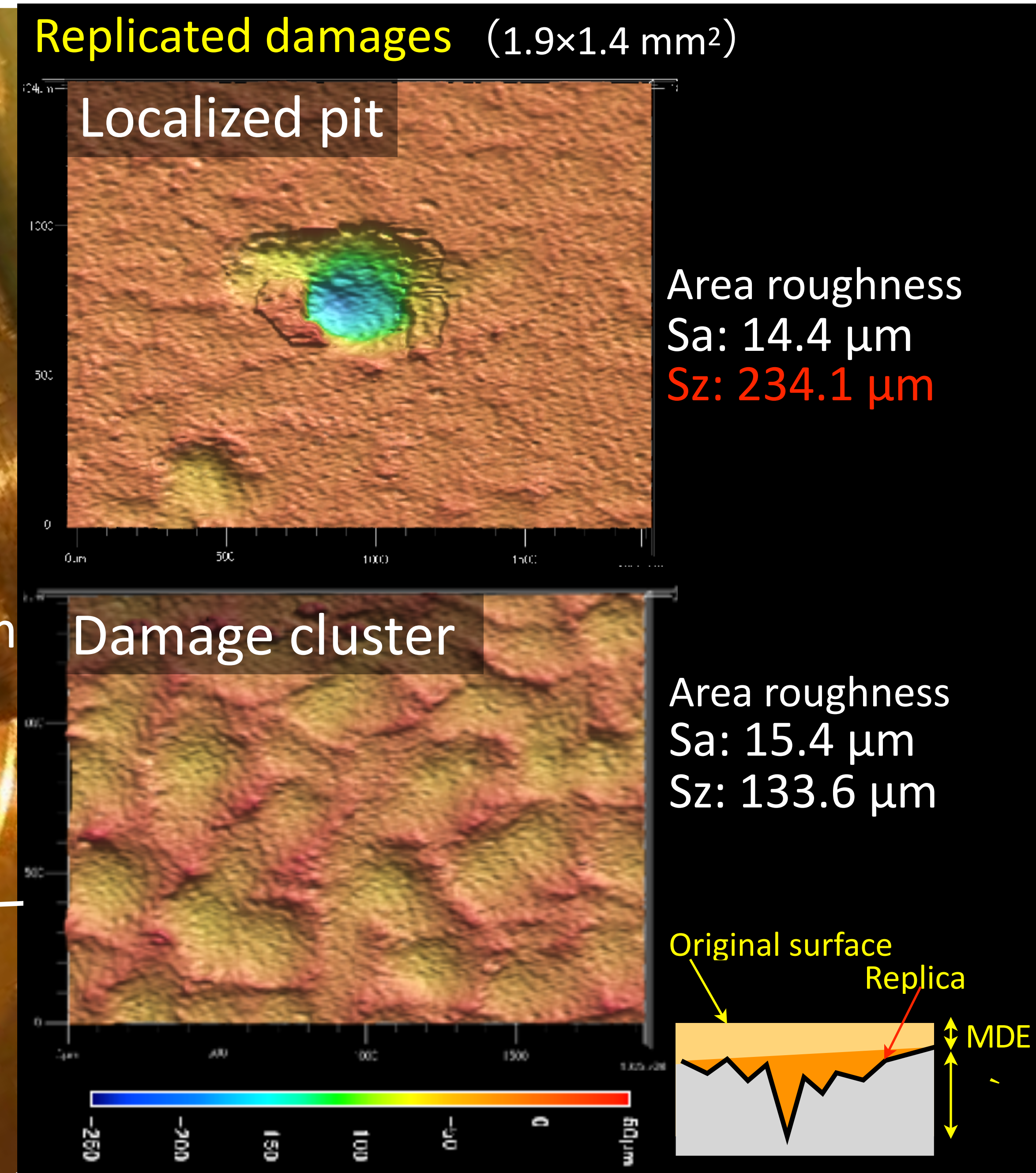
# Damage inspection by replica method




- Cut disk has high dose rate (82 Sv/h) difficult for direct observation → Replica <25 $\mu$Sv/h
- Replicated damage covered with airtight box and observed outside hot cell using 3D scanner
- Height resolution 0.1 $\mu$m for replica and 1 $\mu$m for 3D scanner

# Cavitation damage inside target vessel




Sa (Arithmetical mean height of the surface)
Sz (Maximum height of the surface) of ISO25178

- Cavitation damage distributed center and top and bottom side
- Maximum damage depth is estimated to be 268 μm

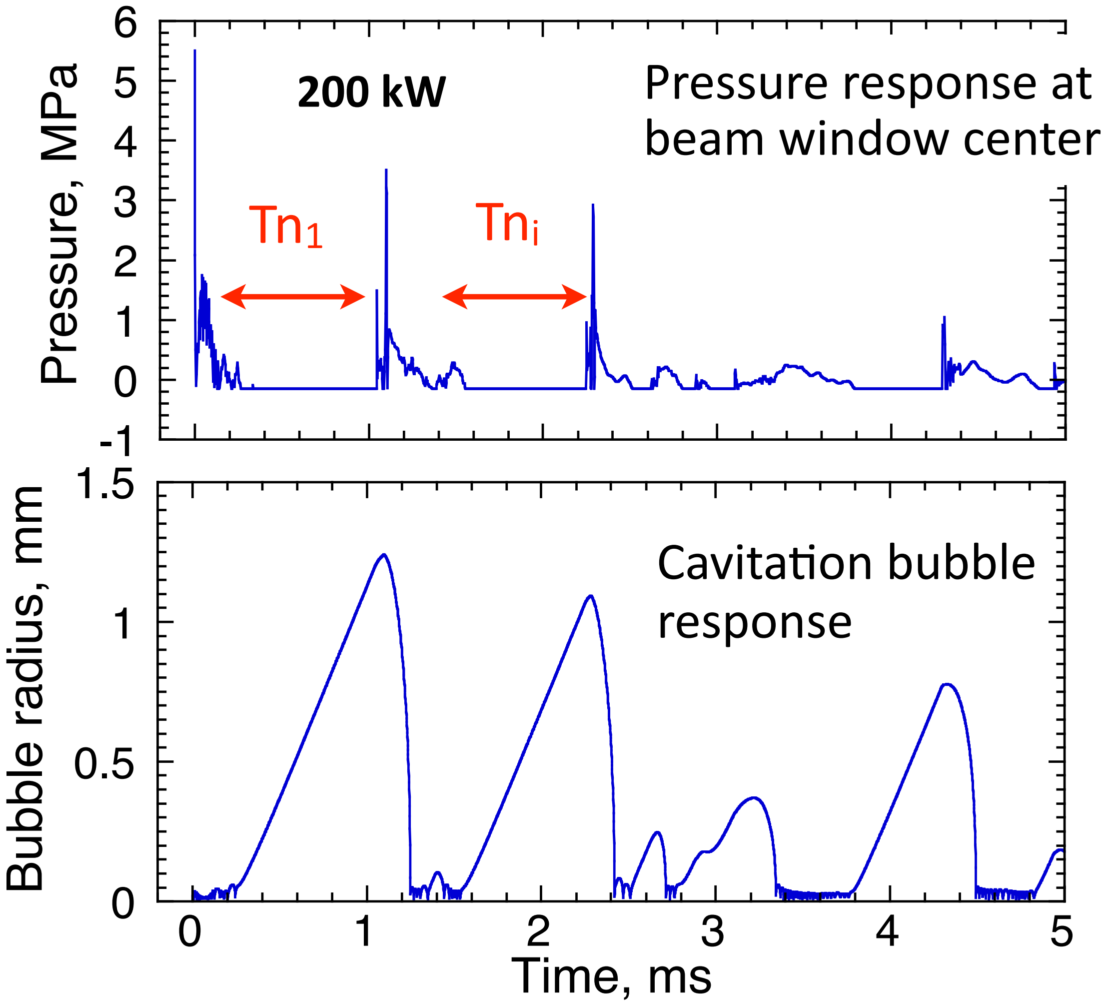
*Empirical equation*

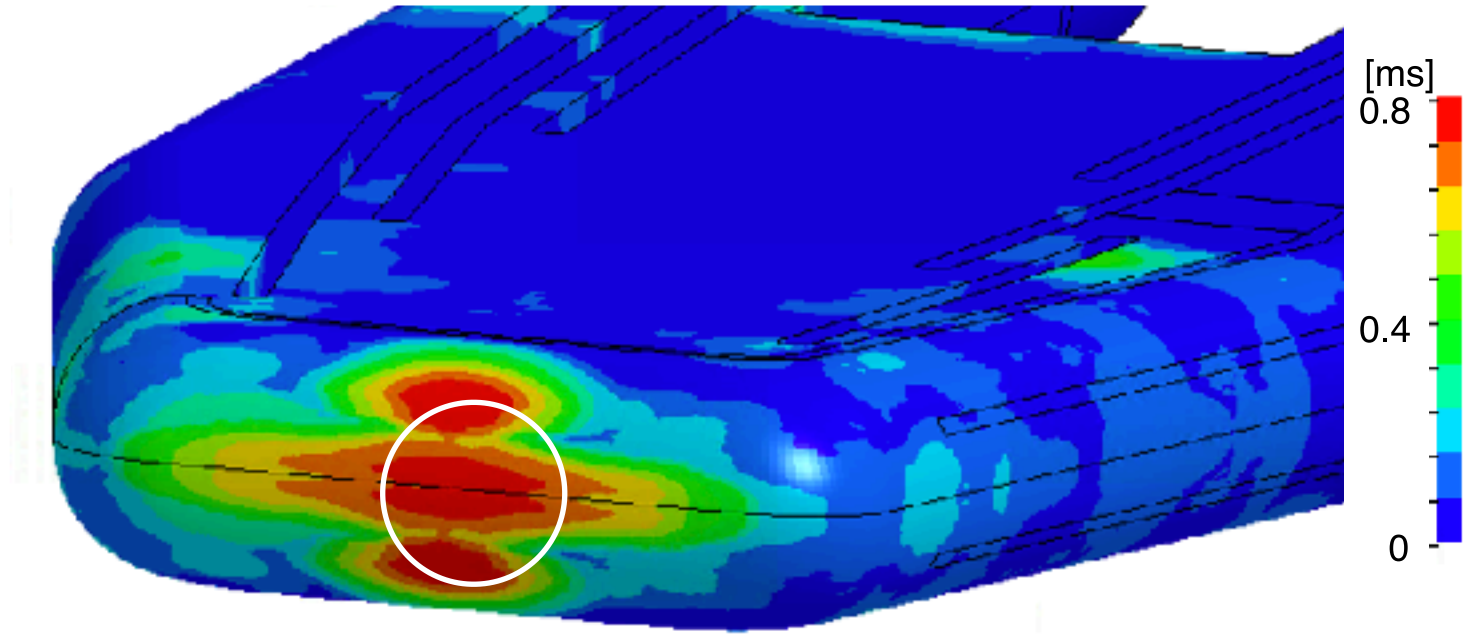
$D_{max}$=MED+Sz

$D_{max}$=8MED

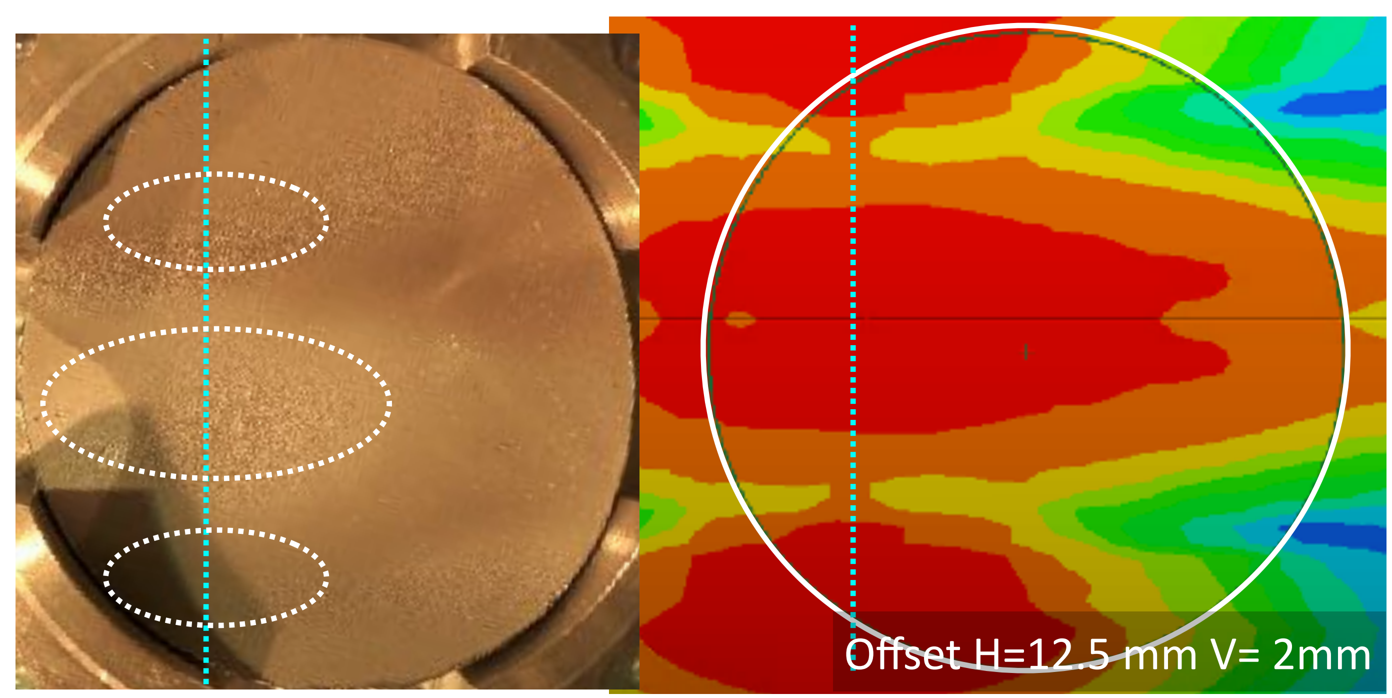
→$D_{max}$=268 μm

# Negative pressure distribution




Longest negative pressure period Max($Tn_i$)




- Cavitation bubble radius is proportional to negative pressure period Tn
- Distribution of damage cluster is correlated with the negative pressure period (Max($Tn_i$))

# Summary

- Cutting and cavitation damage inspection for J-PARC mercury target vessel No. 2 by remote handling has been successfully completed

*We would like to thank SNS target team for helpful discussion and advice*

- Lubricant is a key to reduce cut temperature and protect saws against friction heating

- Cavitation damage distribution and depth of damage without gas microbubble injection were evaluated

- Cavitation damage distribution is correlated with the distribution of negative pressure period (similar trend with the SNS target vessel)

- Cavitation damage under injecting gas microbubbles (target No. 8) will be observed in this summer shutdown period