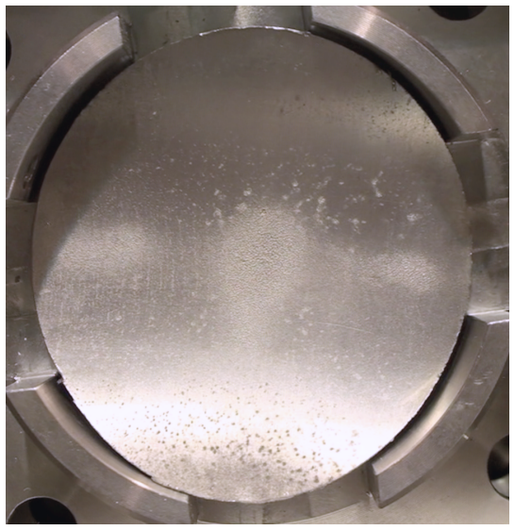
Effect of gas microbubbles on pressure wave mitigation in the JSNS mercury target

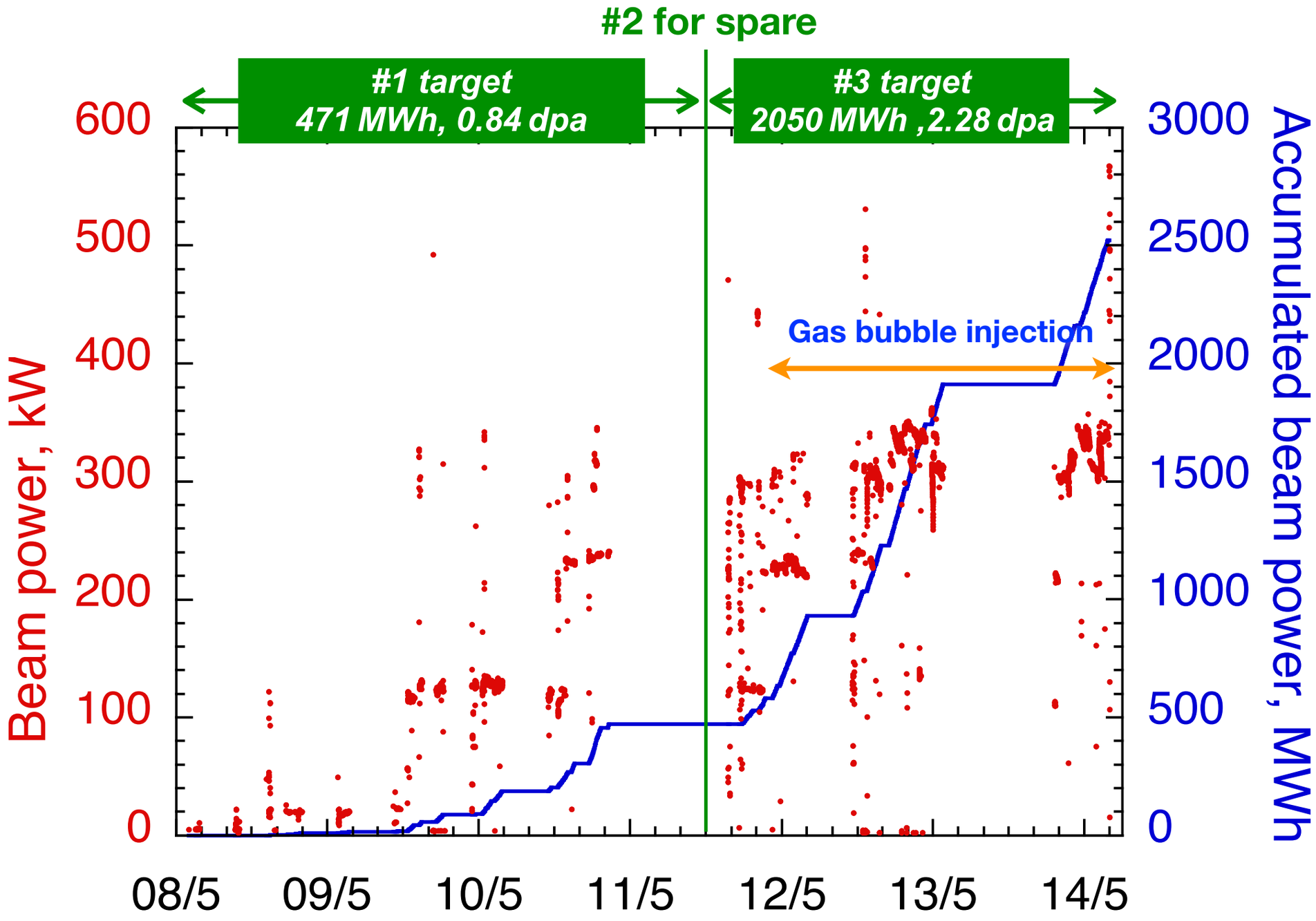
J-PARC Center, JAEA

Takashi Naoe, Hiroyuki Kogawa, Takashi Wakui,
Katsuhiro Haga, Makoto Teshigawara,
Shin-Ichiro Meigo, Hidetaka Kinoshita,
Masatoshi Futakawa, Hiroshi Takada

Operation histories of JSNS targets



#1 target
250 μm in maximum depth

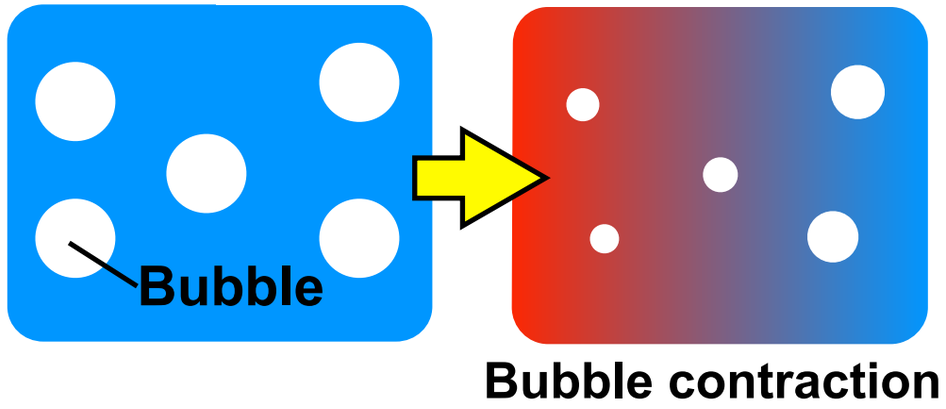


- **No-leakage detected after 2050 MWh operation at 300 kW**
- **3rd target is replacing to double flow target in 2014 maintenance period**

Suppression of pressure waves by injecting gas microbubbles

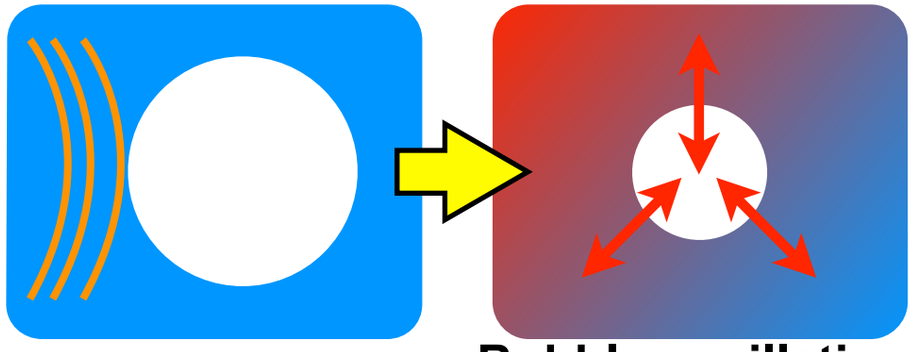
Mechanisms of pressure wave mitigation

Absorption

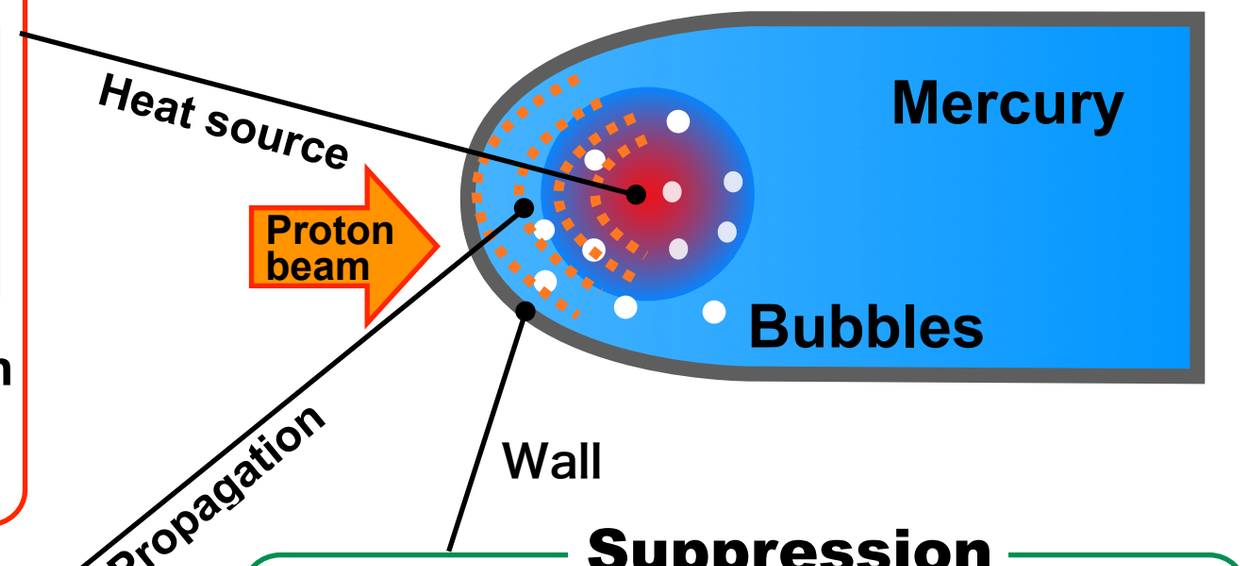


Absorb thermal expansion by contraction of microbubbles

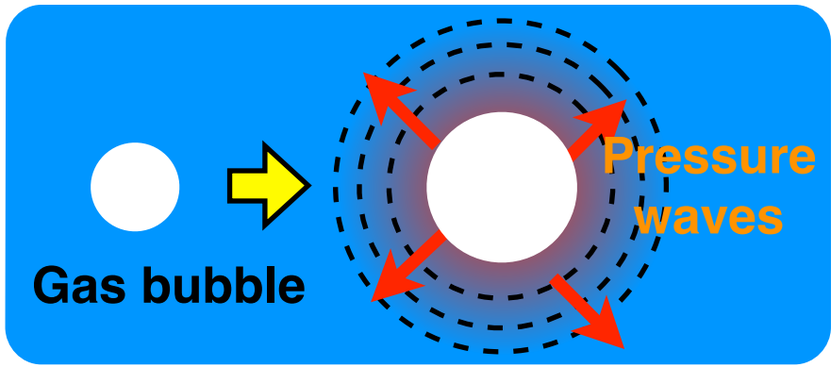
Attenuation



Attenuate by thermal dissipation of kinetic energy



Suppression

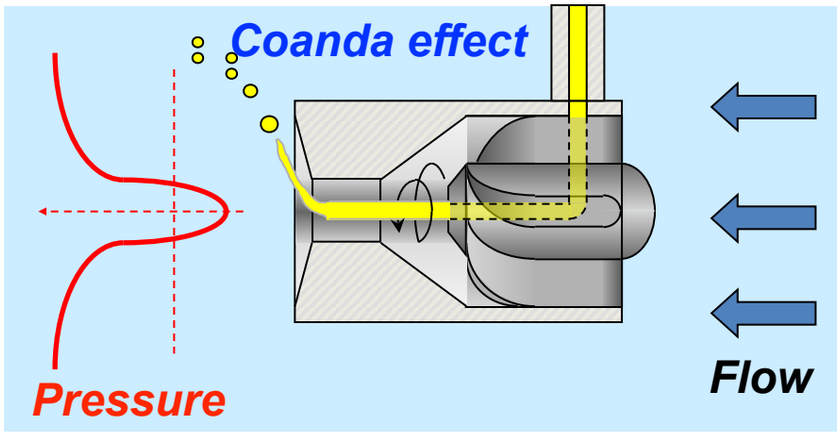


Injected bubble suppress negative pressure by its growing

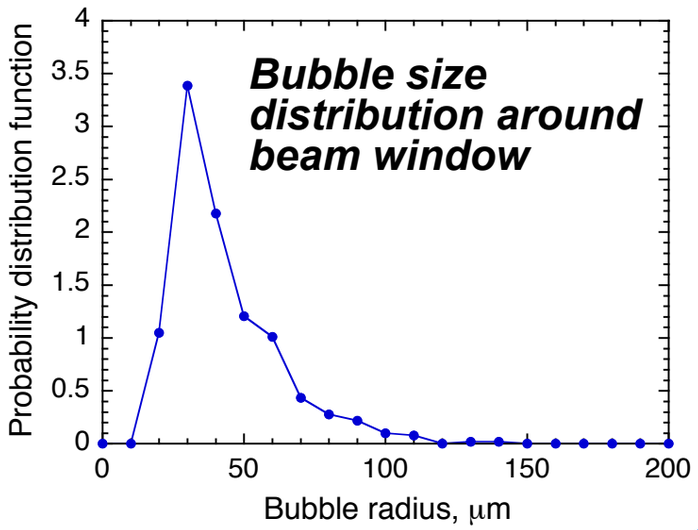
Futakawa, et al., J. Nucl. Sci. Technol., 45 (2008) 1041

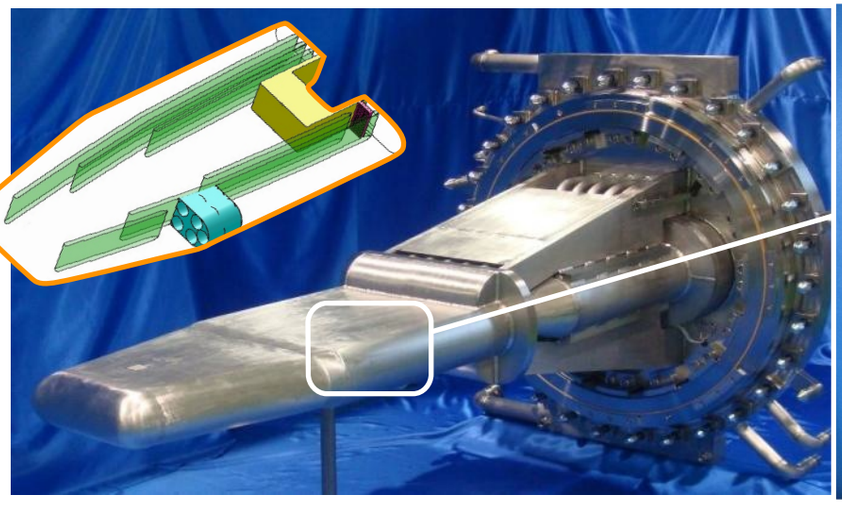
* **Requires 50 μm in radius and 10^{-4} in void fraction for mitigating pressure waves**

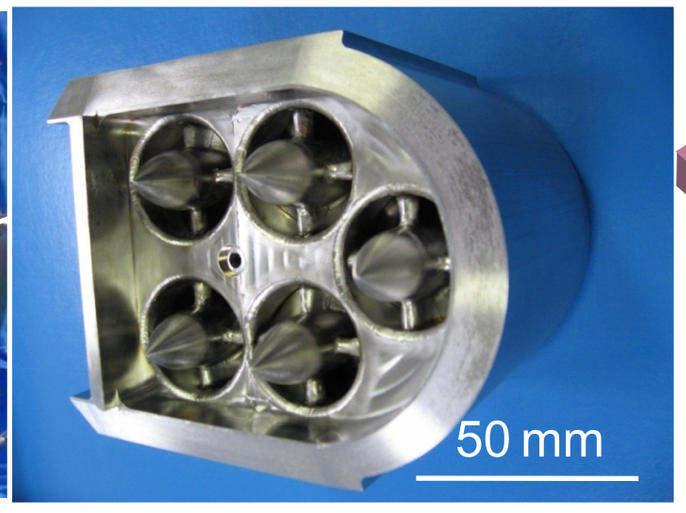
JSNS bubbling system



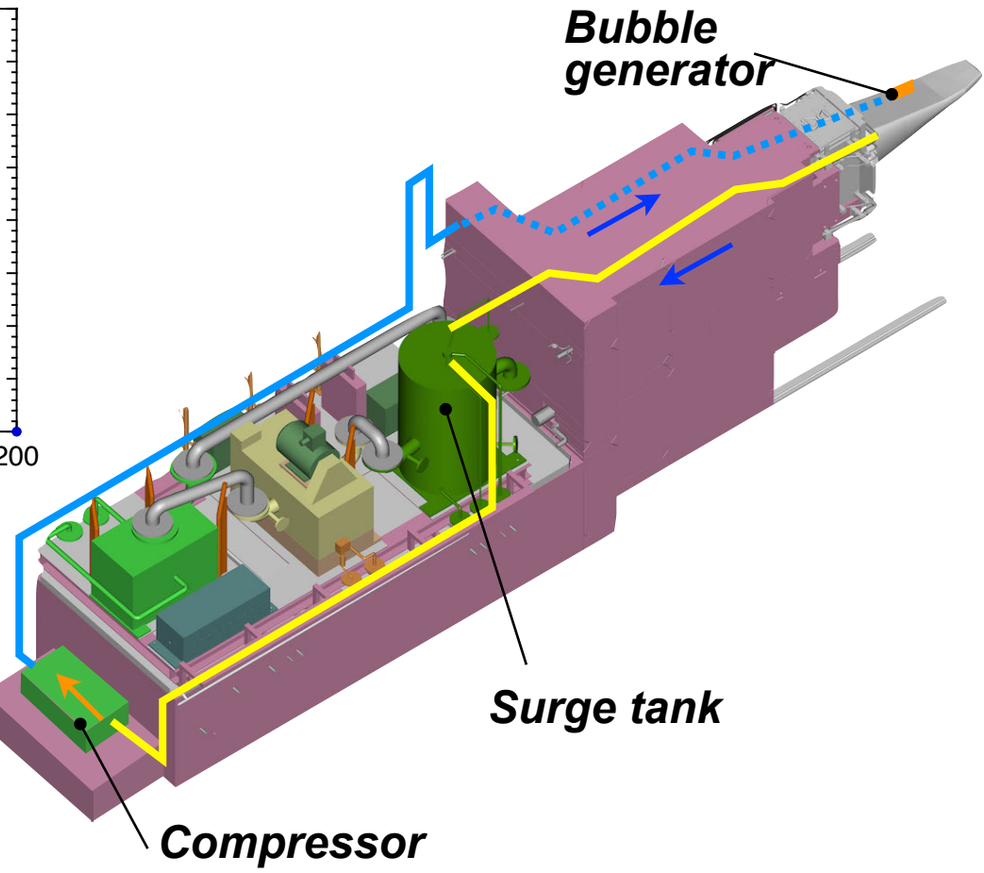
Swirl type bubble generator







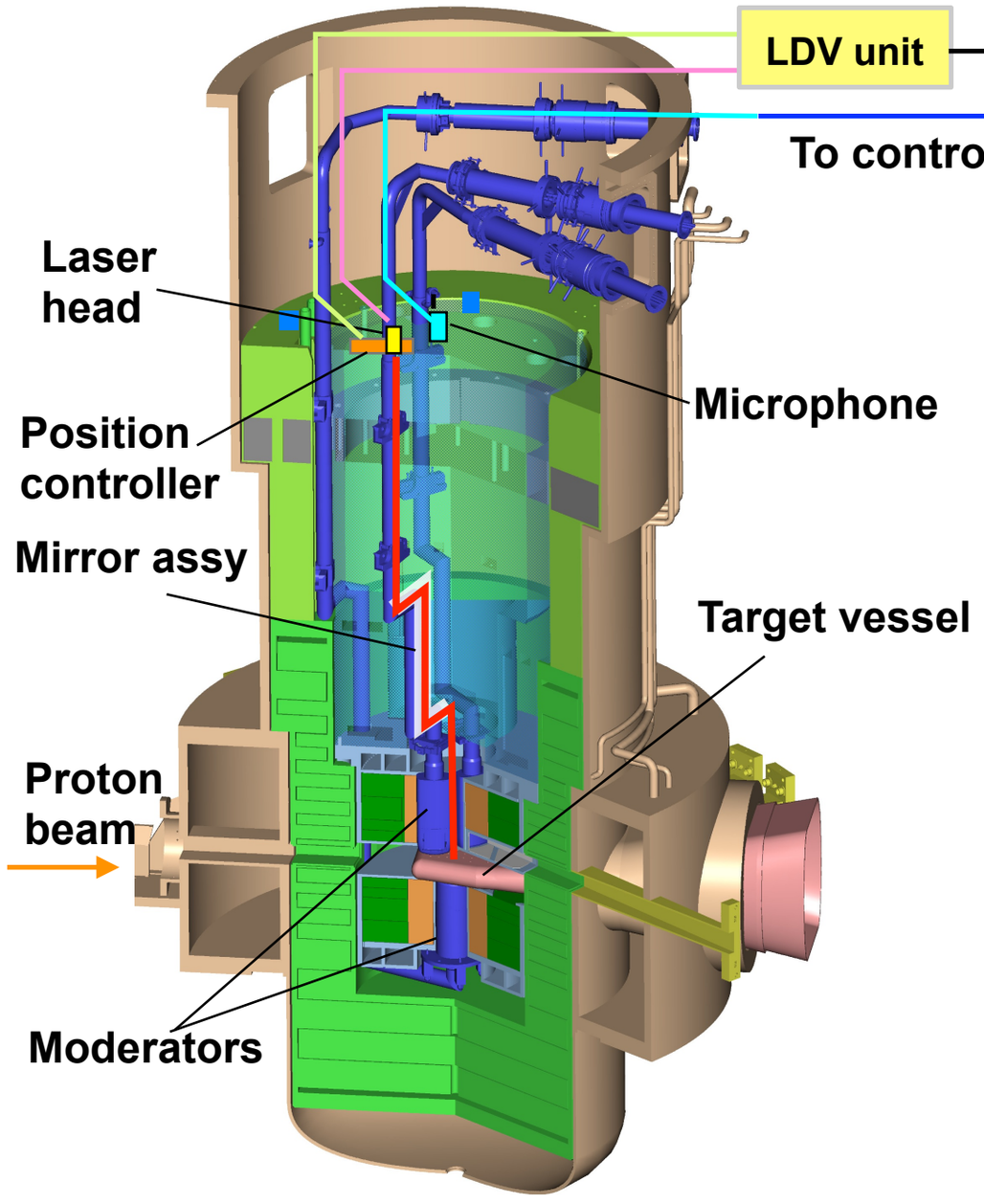
#3 target vessel with bubble generator



JSNS mercury circulation system

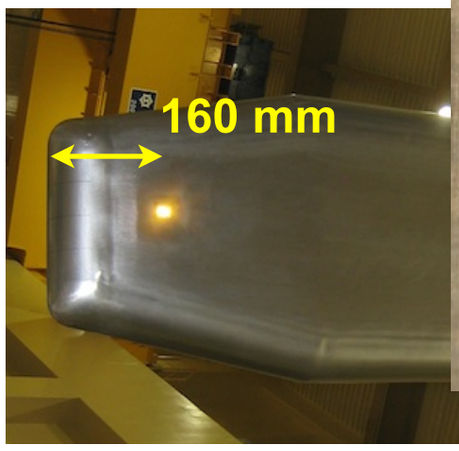
* Developed multiple swirl type microbubble generator to prevent coalescence of generated microbubbles
* Confirmed 30 μm in peak bubble radius through the mockup experiment at Target Test Facility in ORNL
* Installed bubble generator in 3rd target vessel with the helium gas circulation system (closed loop) in October 2012

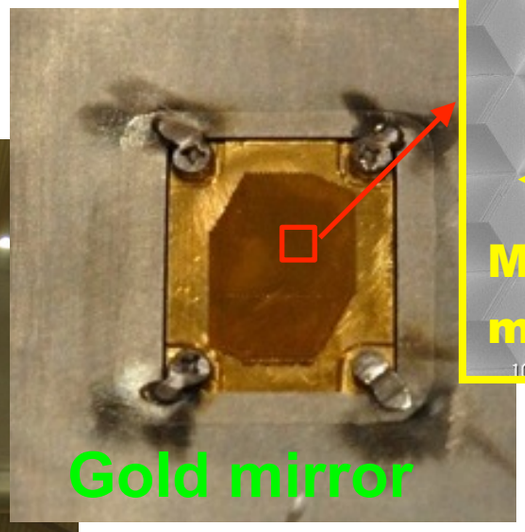
Target diagnostic system

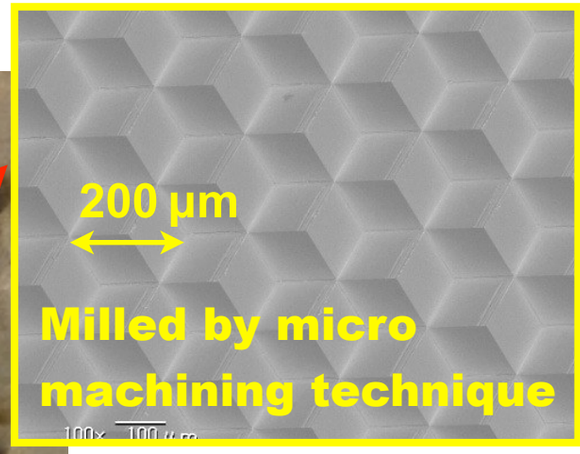


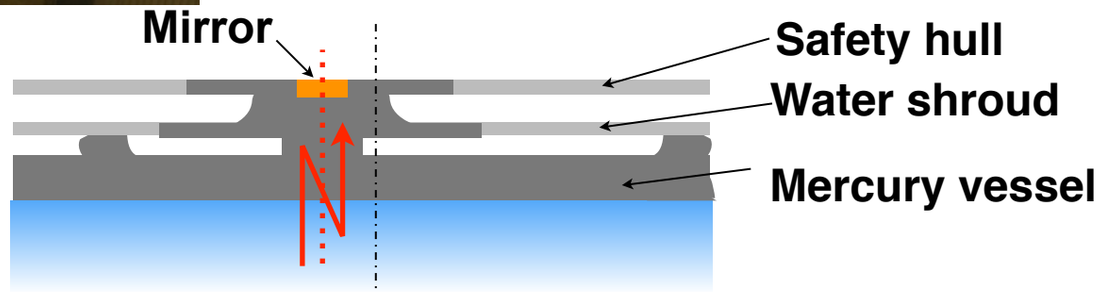
LDV system was upgraded in 2012

Velocity range: 0.01~0.5 m/s -> 0.01~ 10 m/s
Frequency range: 1 Hz ~ 300k Hz -> 0.3 Hz ~ 3M Hz
Data sampling: 1MHz





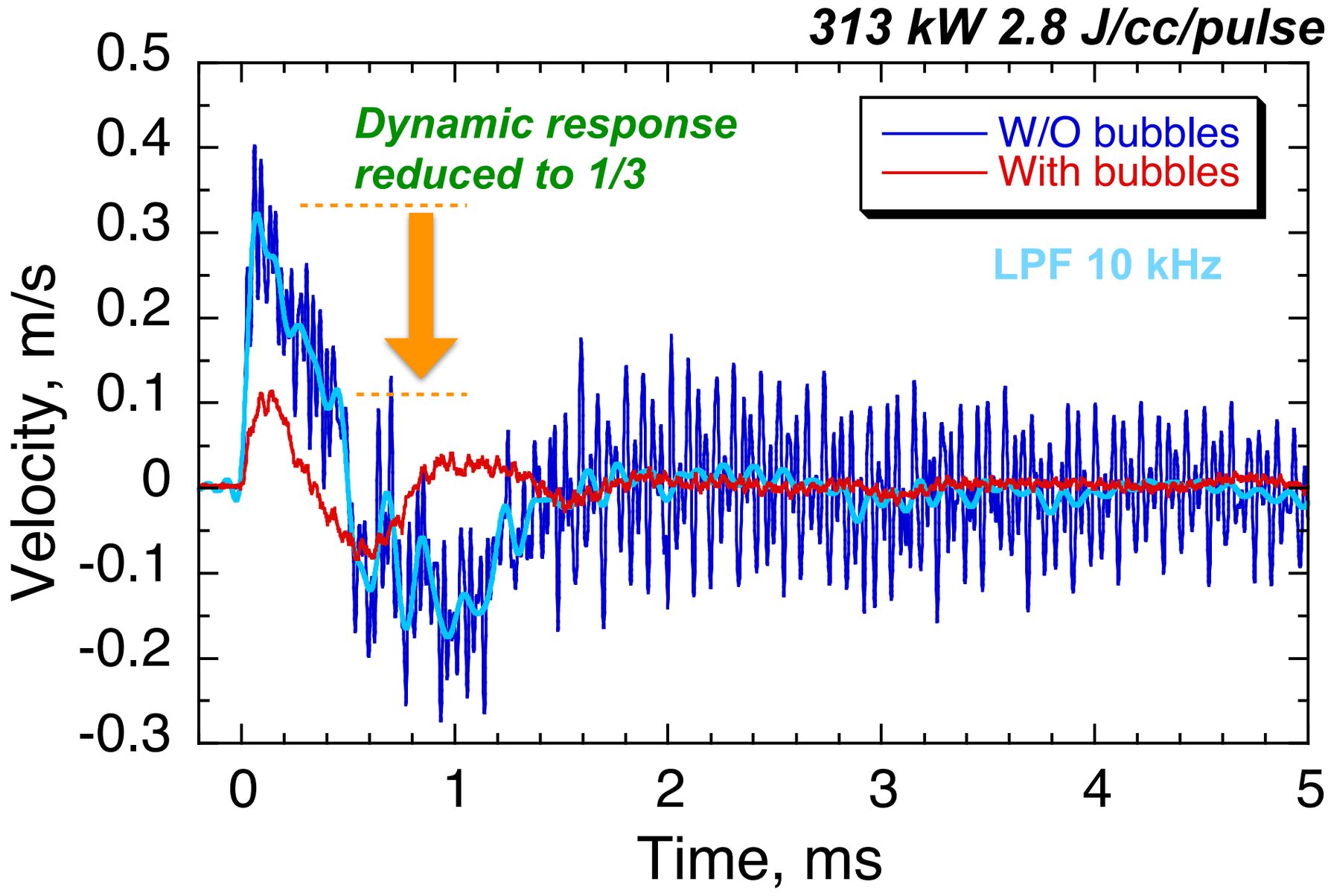




Mono-structure at mirror part

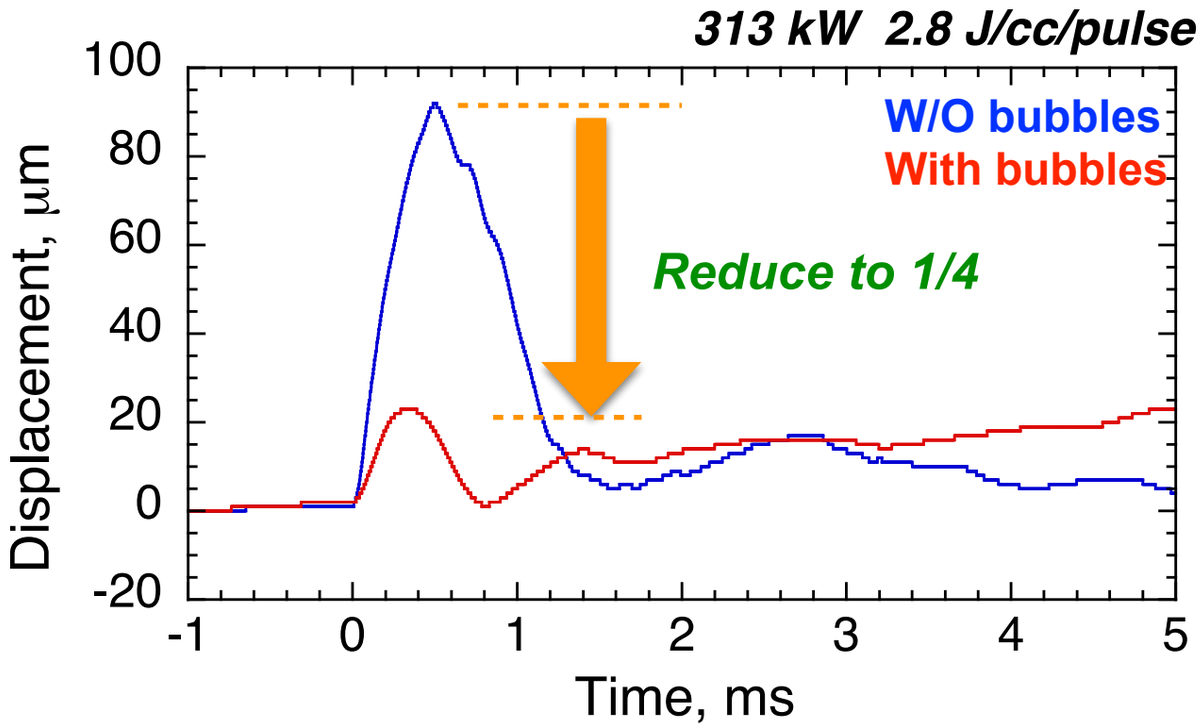
- Laser Doppler vibrometer (LDV) have been installed for monitoring the vibration of target vessel by proton beam injection
- Corner cube reflector was directly machined on pure gold plate by newly developed micro machining technique (Ni mirror of #1 target corroded)
- Mirror part is directly contacting with the mercury (mono-structure)

Effect of microbubble on vibration



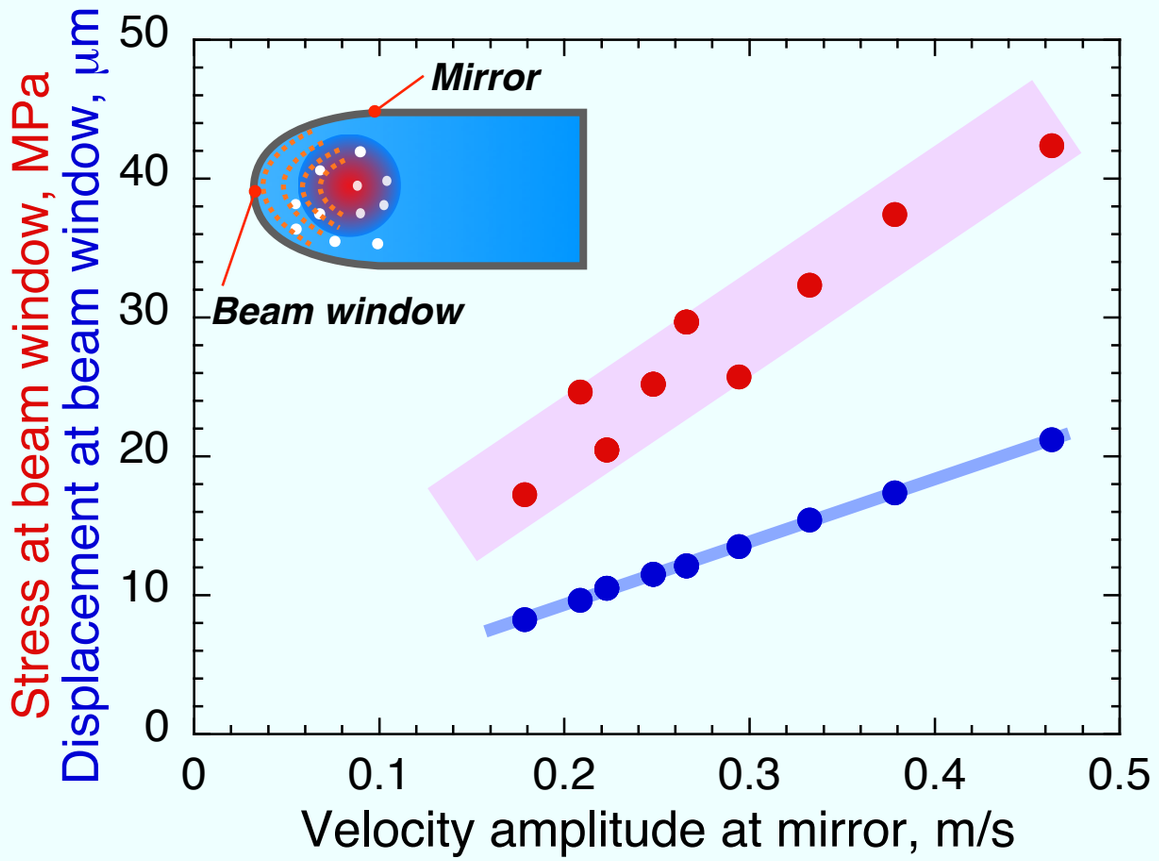
* **High-frequency components resulting from the mirror ringing is superimposed on the dynamic response of the target vessel, because the mirror was fixed on safety-hull by bolt**
* **First peak and damping of the vibration are dramatically reduced by injecting microbubbles**

Displacement and stress reduction by bubbles



Displacement change by injecting bubbles

Estimated from integral of
low pass filtered LDV responses

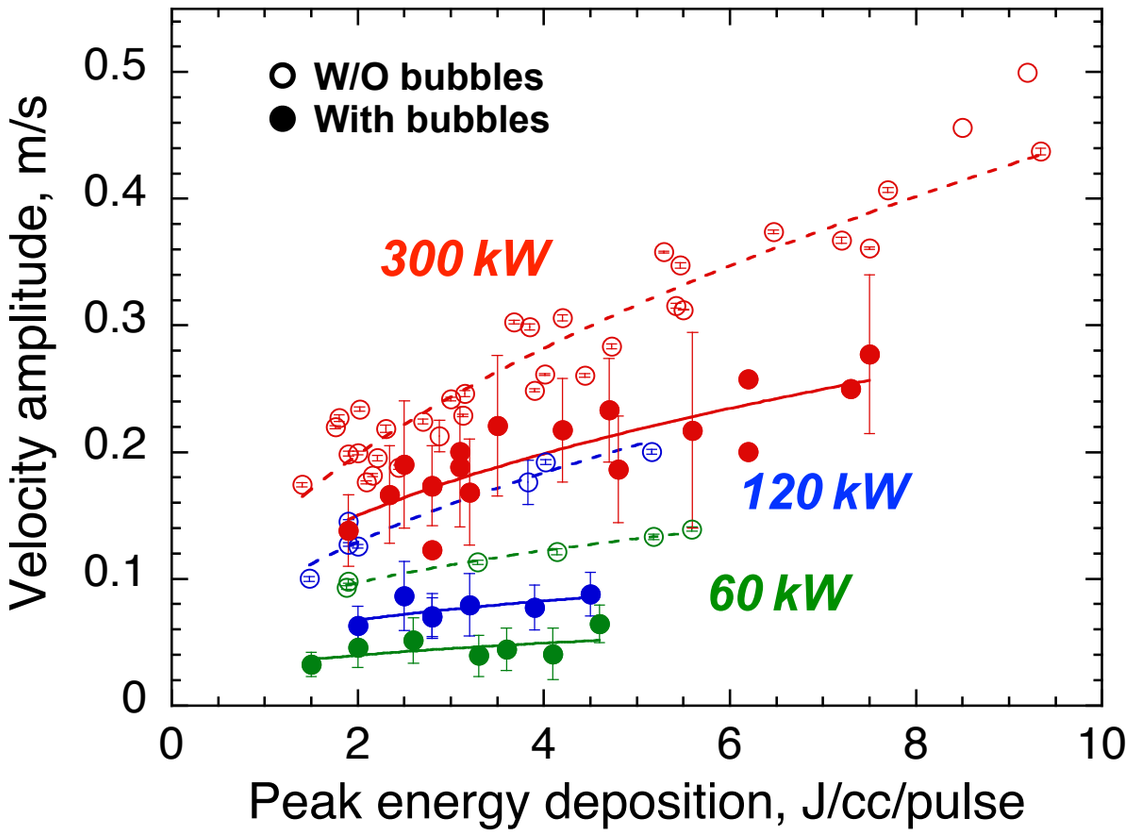


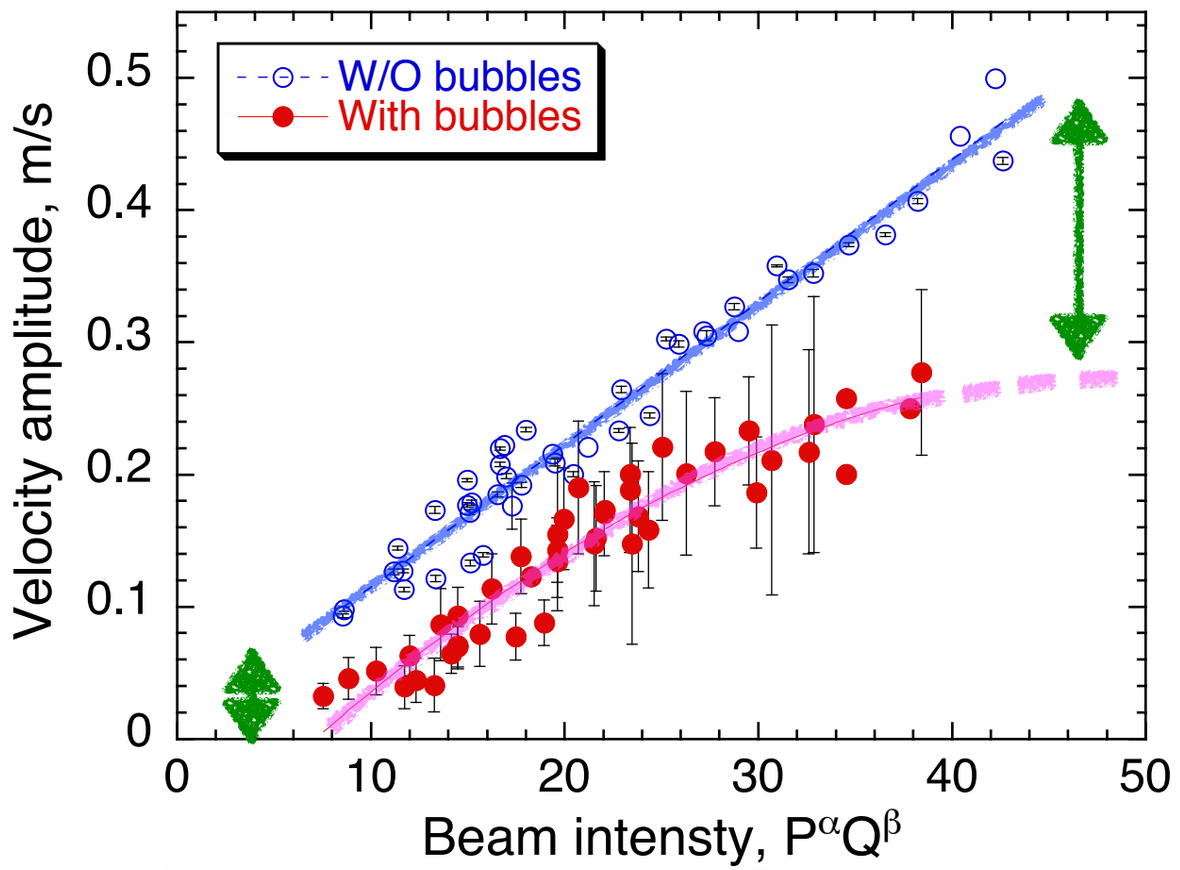
LS-DYNA simulation

Vibration at the mirror is correlated with the stress and displacement at the beam window

- **Displacement <u>at mirror</u> (top wall) is reduced to 1/4**
- **Stress at beam window may be reduced by bubbling**
  >>Prolong fatigue life
- **Negative pressure in ms-order may be dramatically reduced by bubble**
  >>Reduce cavitation damage

Effect of beam condition on vibration





$$V \propto aP^{\alpha}Q^{\beta}$$

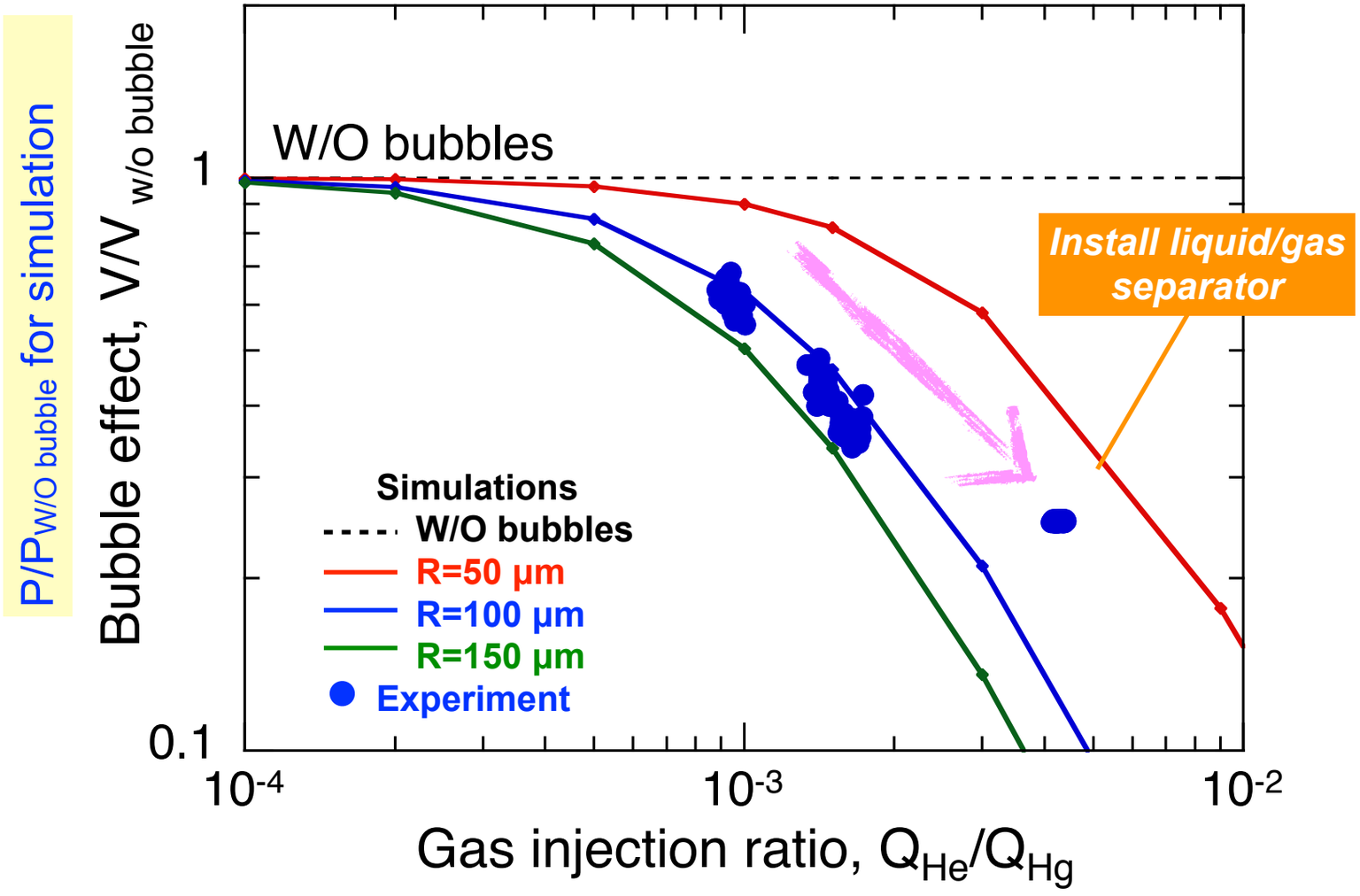
P: beam power [kW]
Q: peak energy [J/cc/pulse]
α,β: constants

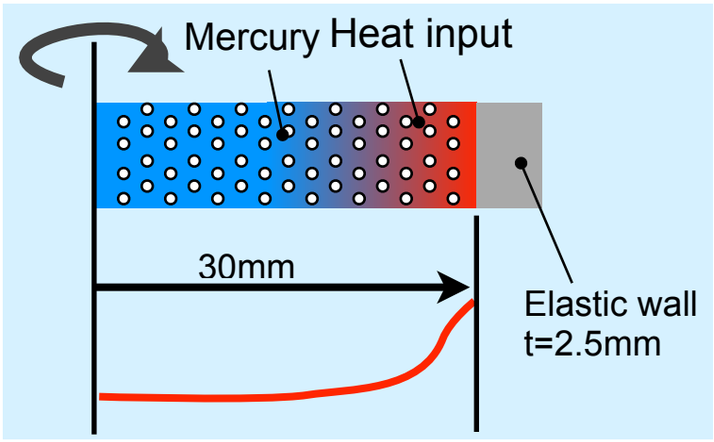
a is constant for W/O bubbles

non linear for with bubbles

- **Bubbling cases shows a large scatter, since the bubble distribution is fluctuated**
- **Velocity amplitude of the vibration is correlated with the beam conditions**
- **Effect of gas microbubbles on pressure wave mitigation will be enhanced by increasing in beam intensity**

Effect of void fraction

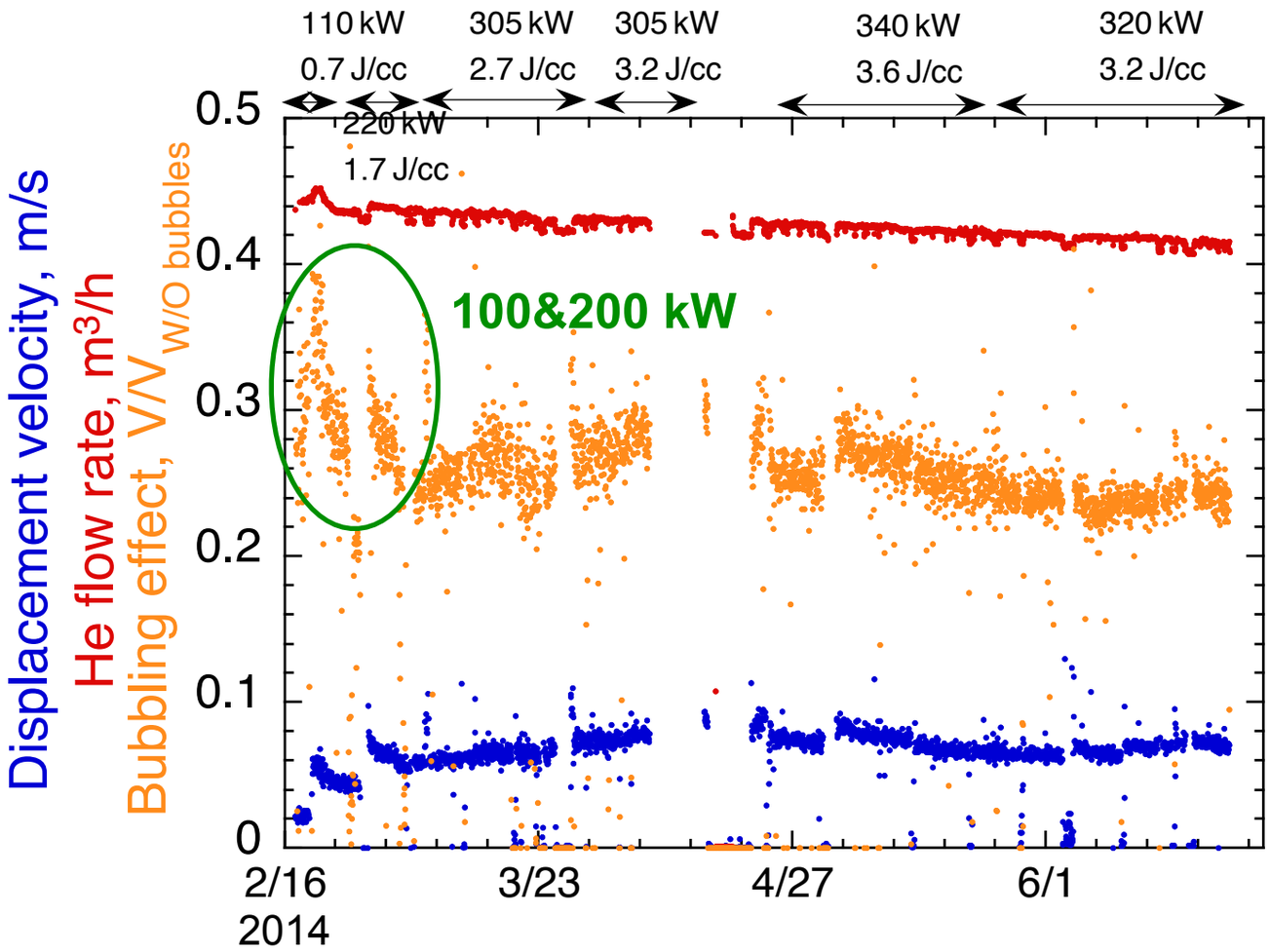


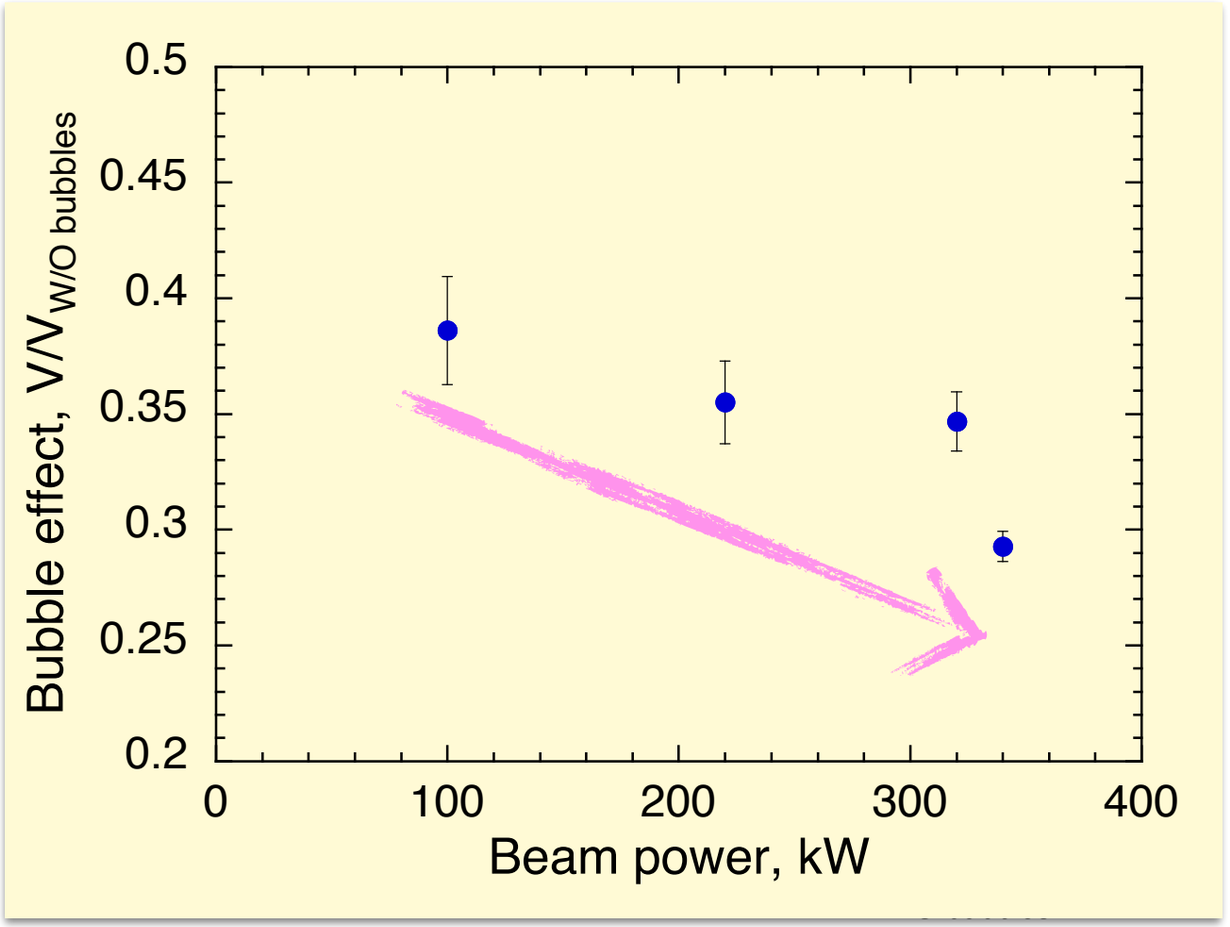


Pressure wave propagation in bubbly mercury (uniform size) obtained from simulation

- **Peak amplitude of LDV is correlated with the void fraction**
  Peak velocity was normalised at w/o bubble case predicted based on beam experiments $V \propto aP^{\alpha}Q^{\beta}$
- **LDV denotes the same tendency of the numerical simulation**
- **In December 2013, L/G separator has been installed to prevent the gas accumulation in the target vessel**

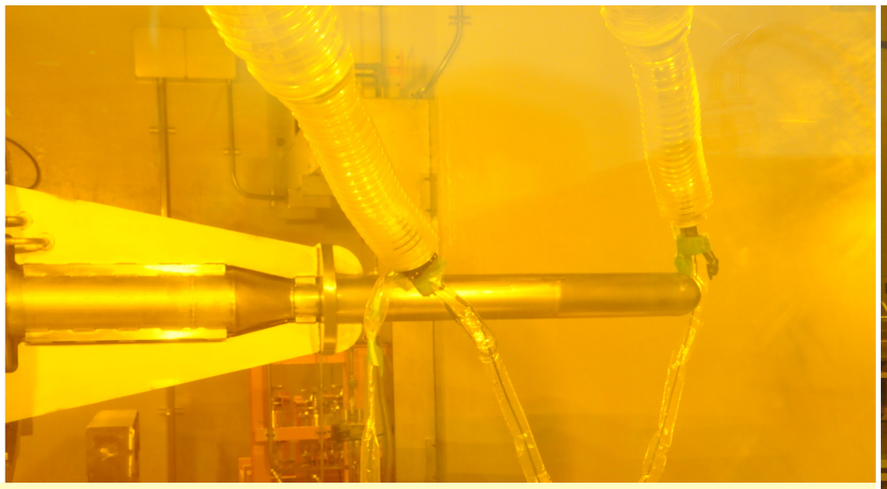
Variation of bubbling effect



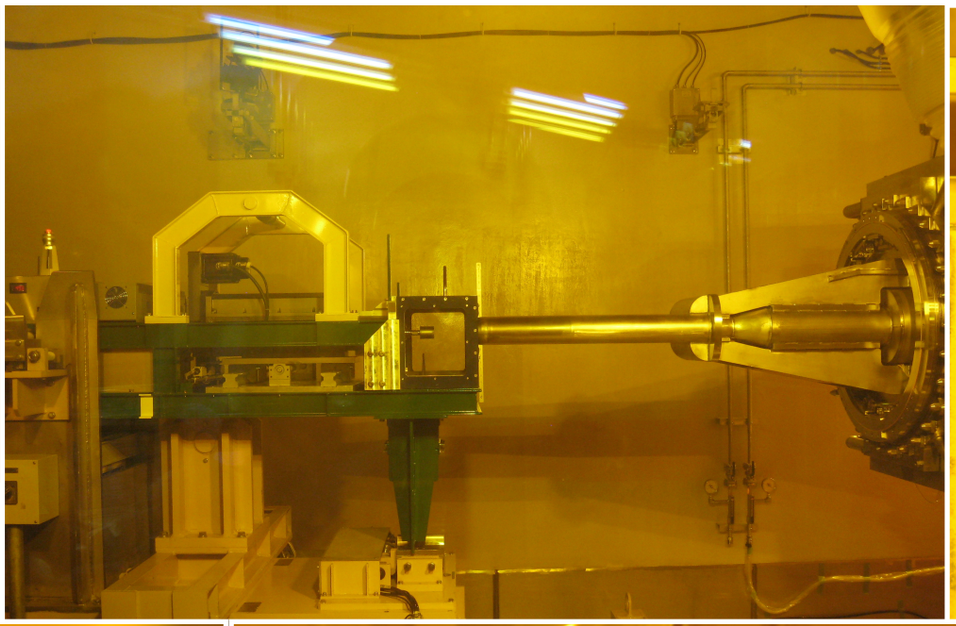


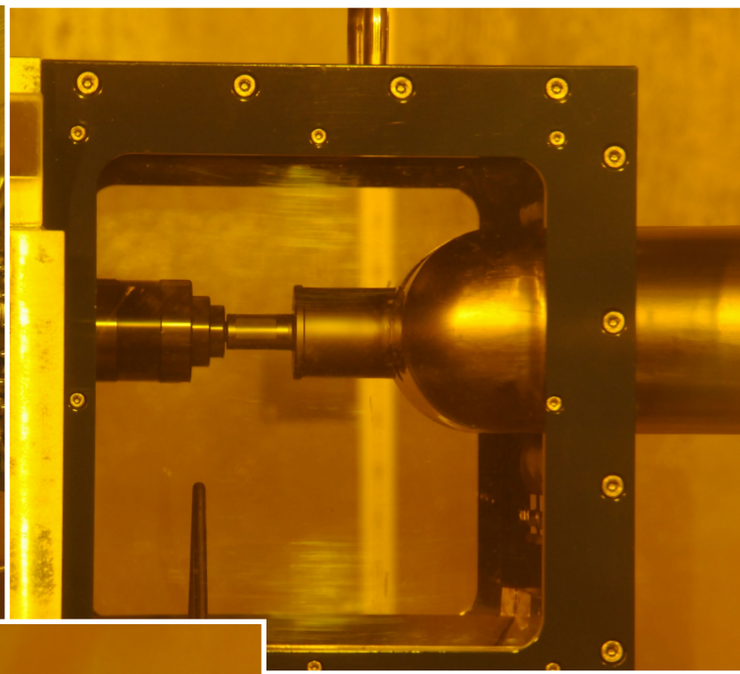
* **Small amount of gas is gradually accumulated downstream of the surge tank, however, the amount has no effect on the heat removal even at 1MW operation**
* **Bubbling effect seems to be enhanced with the increasing in beam power**

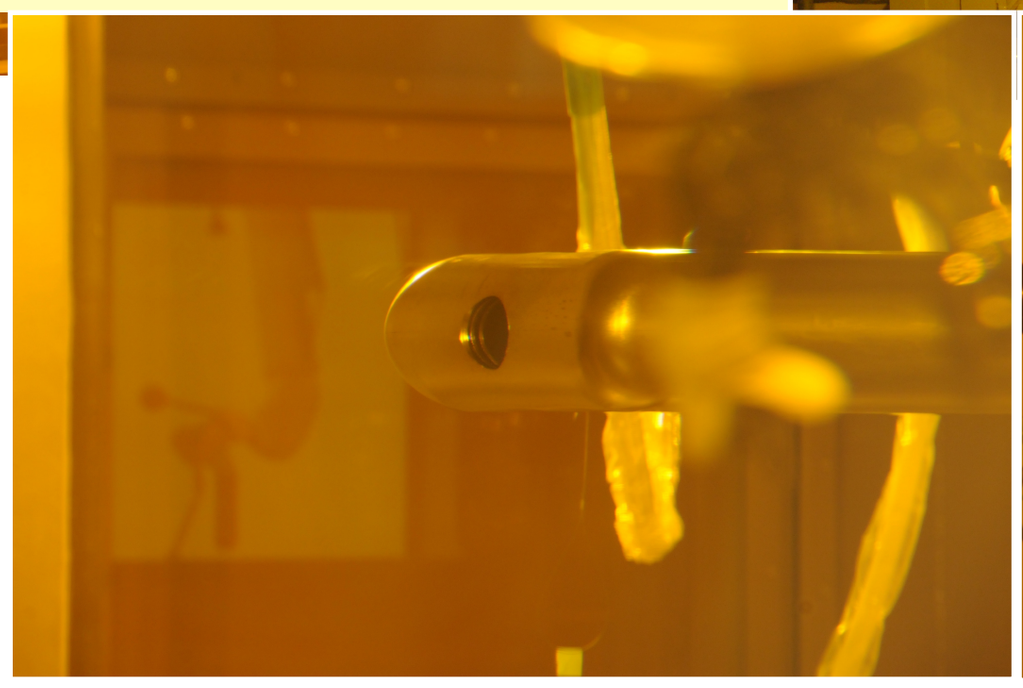
Damage inspection of the 3rd target

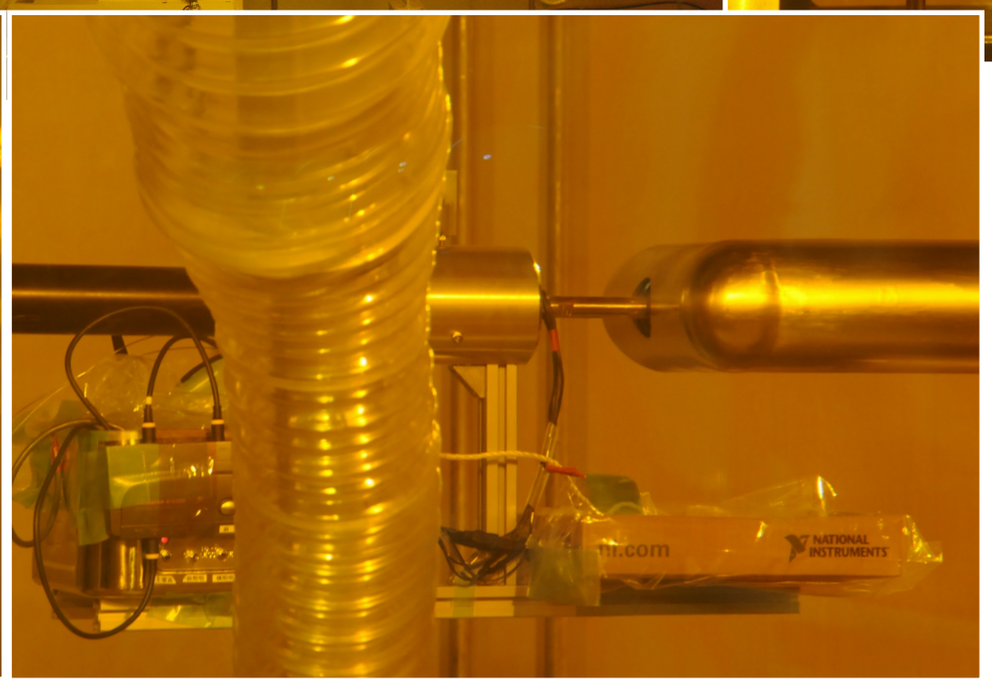


Measured dose rate at the center of beam window is 310 Sv/h



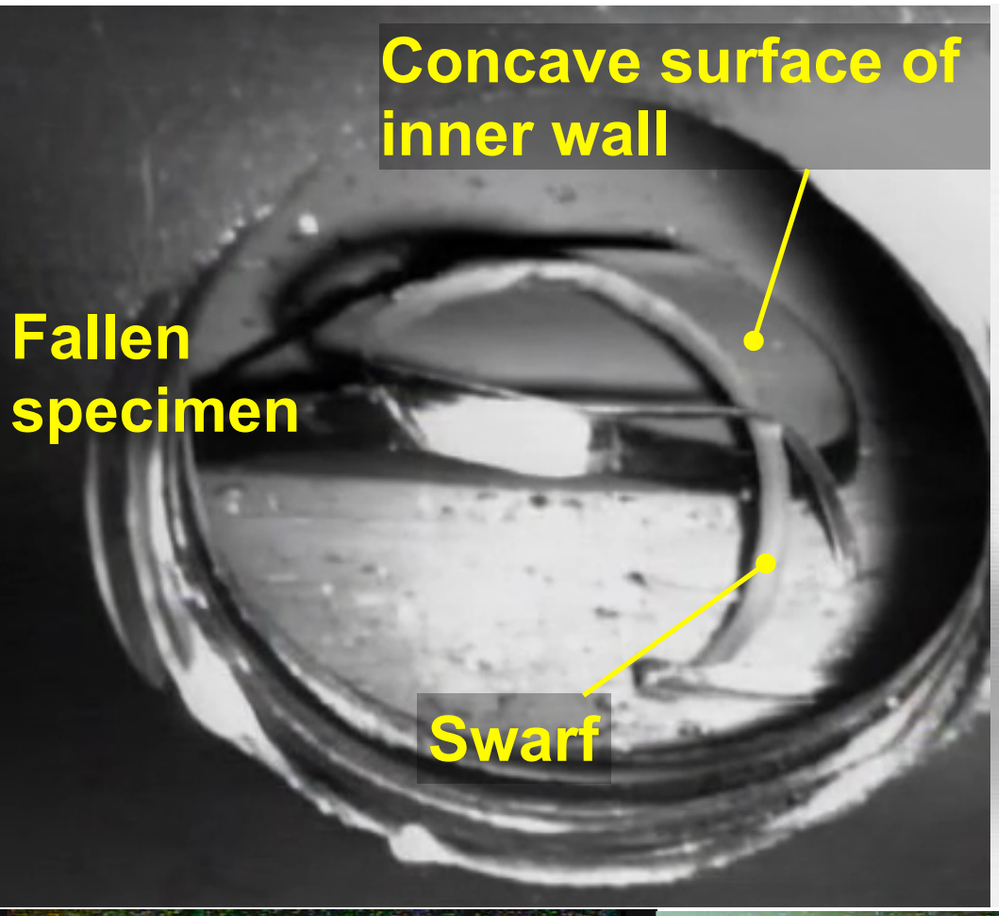


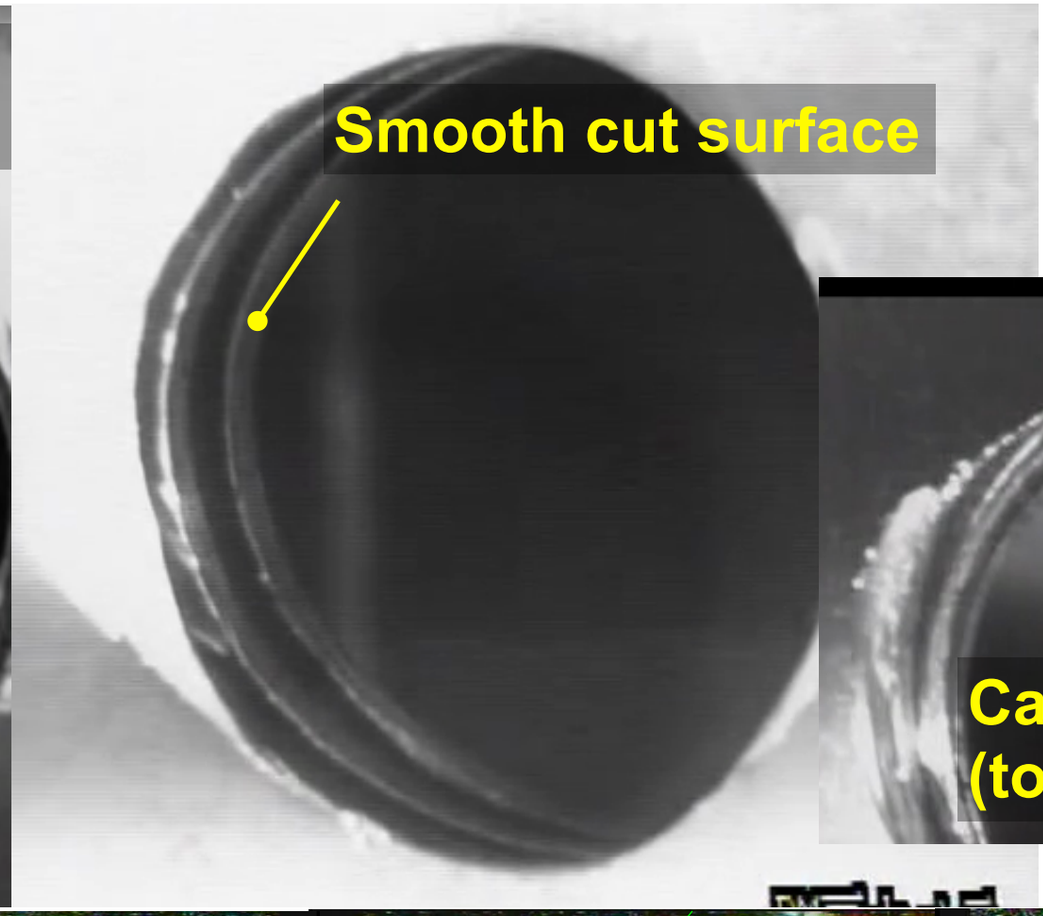


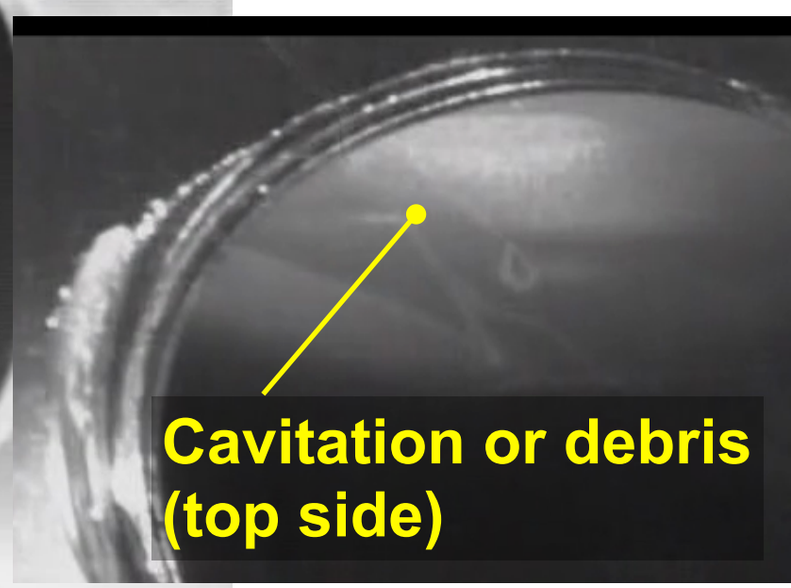


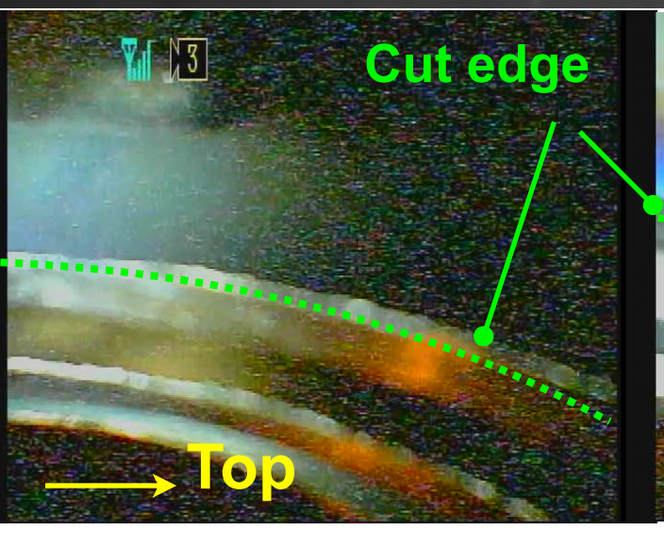
* Cavitation damage in target vessel was inspected by cutting the beam window portion
* Remote camera was broken by high-radiation environment

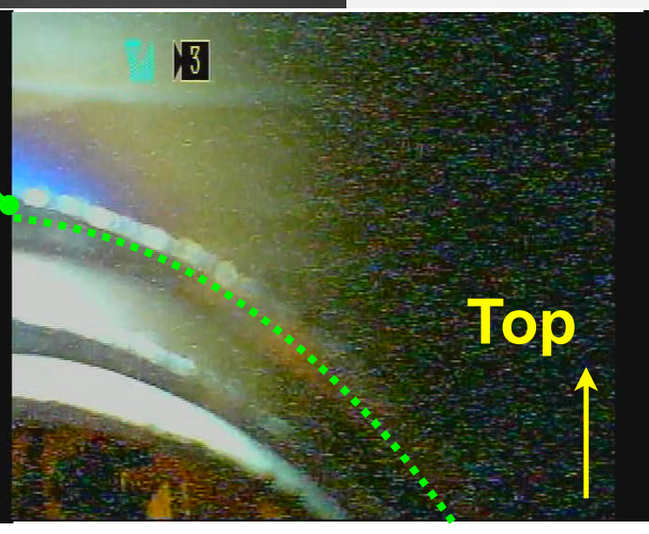
Cavitation damage inside target vessel

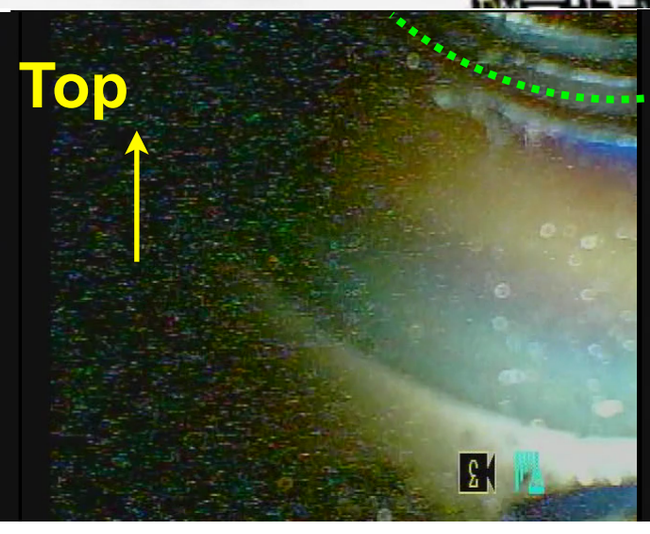


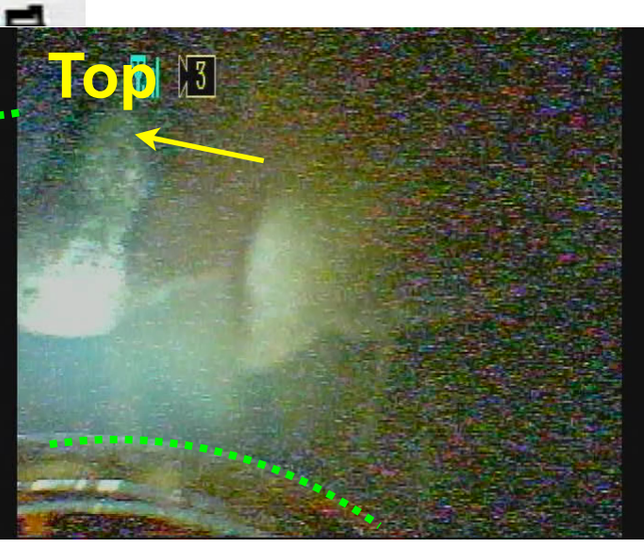






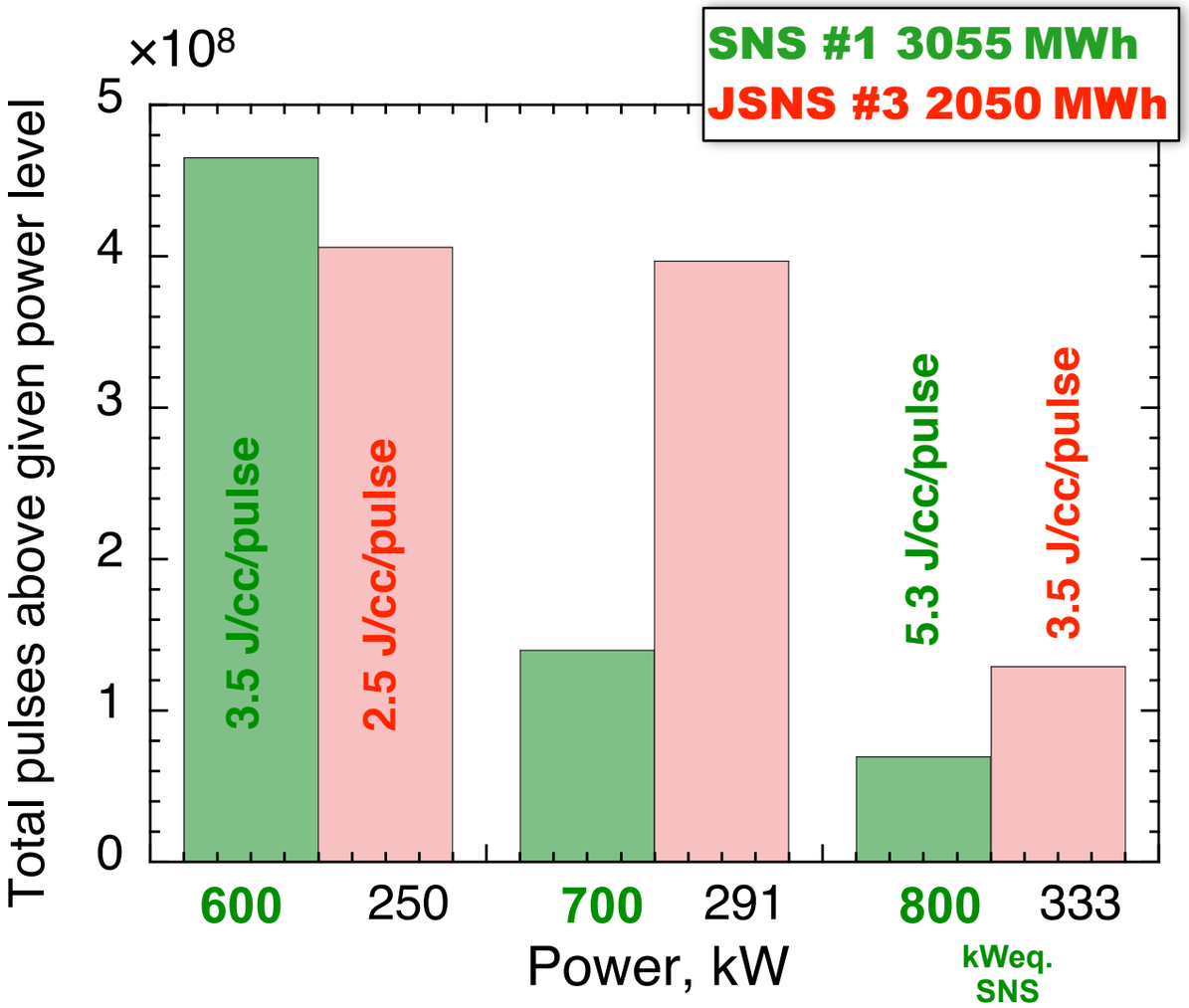


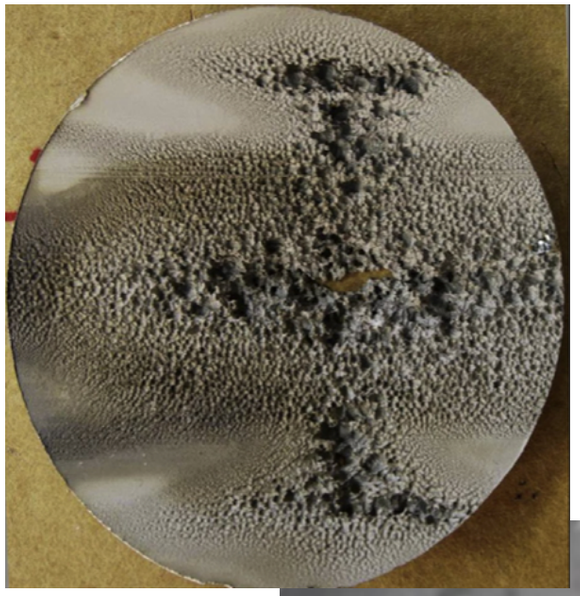




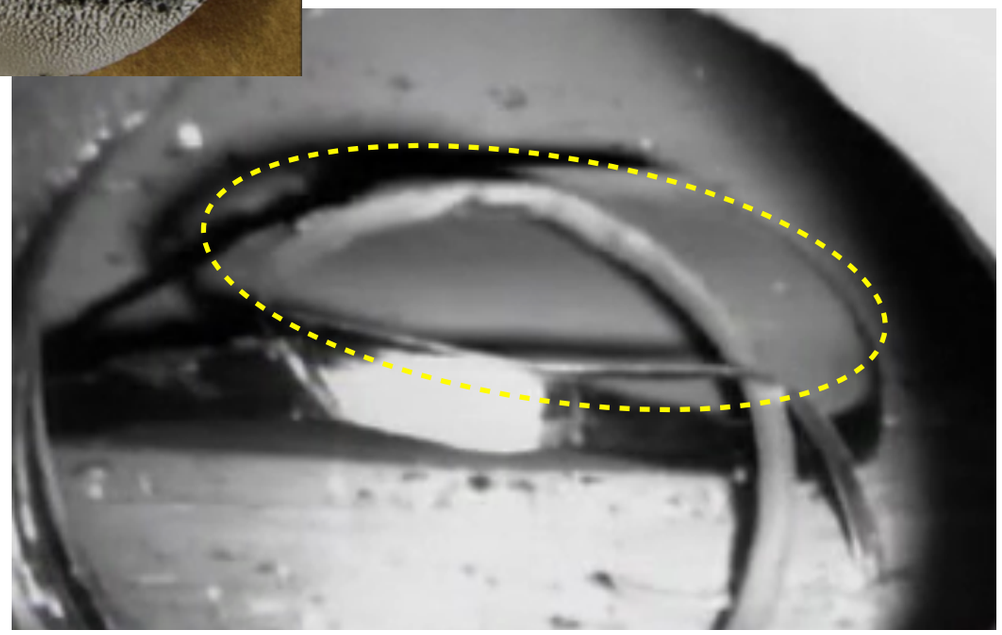
* Cut specimen of beam window fell inside vessel
* Gave up picking up fallen piece from target vessel due to radiation safety
* V-shape damage and severe cavitation damage are not recognised

Damage mitigation by bubbling





SNS #1 target
(D. McClintock, JNM 2012)



JSNS #3 target

- **Beam power and the total number of pulses (higher than 250kW) of JSNS #3 target is almost the same as SNS #1**
- **Severe cavitation was mitigated by injecting microbubbles**

Summary

- Gas microbubble injection system have been installed in the JSNS target system for mitigating the pressure waves and cavitation damage
- Vibrational velocity of the target vessel was monitored through the laser Doppler vibrometer (LDV)
- Amplitude of vibrational velocity is reduced to 1/3~1/4 of without microbubble injection
- Stress amplitude of the beam window may be reduced by injecting mirobubbles, and fatigue life of the target vessel will be prolonged
- Cavitation damage was reduced by injecting gas microbubbles