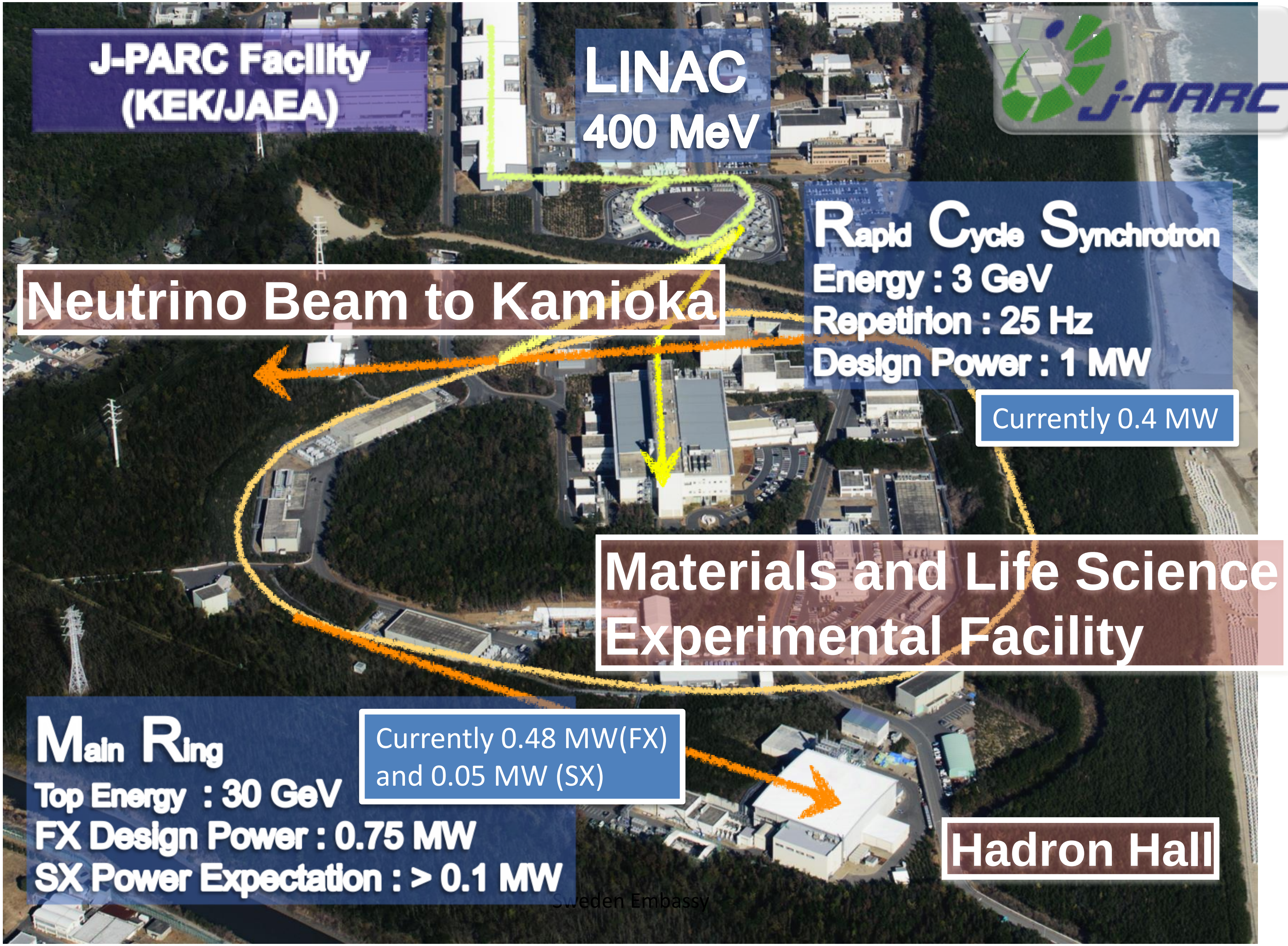
Target development activity in J-PARC and related expectation to HiRadMat irradiation facility

J-PARC center

Deputy Director

Masatoshi Futakawa


J-PARC Facility
(KEK/JAEA)
LINAC
400 MeV
J-PARC
Rapid Cycle Synchrotron
Energy : 3 GeV
Repetirion : 25 Hz
Design Power : 1 MW
Currently 0.4 MW
Neutrino Beam to Kamioka
Materials and Life Science
Experimental Facility
Main Ring
Top Energy : 30 GeV
FX Design Power : 0.75 MW
SX Power Expectation : > 0.1 MW
Currently 0.48 MW(FX)
and 0.05 MW (SX)
Hadron Hall
Sweden Embassy

J-PARC Experimental Facilities

Wide range of research fields

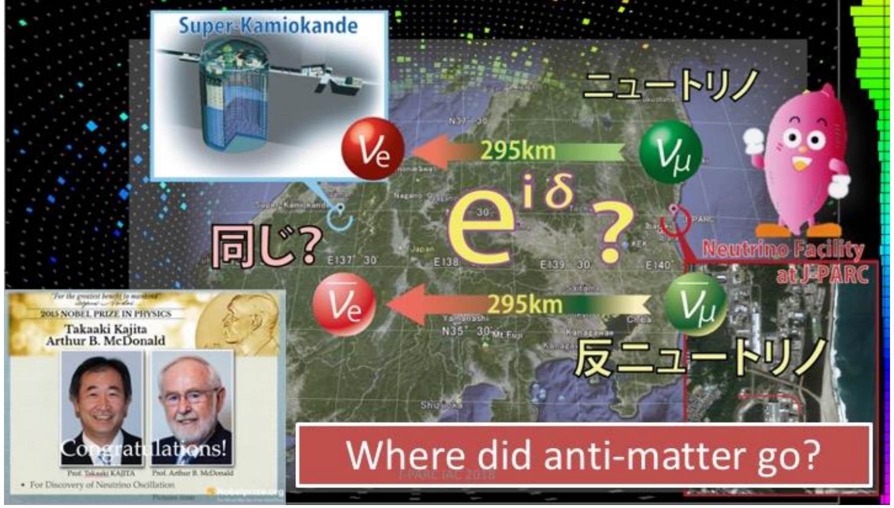
- **Materials & Life Science Experimental Facility**
  - neutron and muon beams
  - materials science, life science, industrial applications
- **Hadron Experimental Facility**
  - K mesons, π mesons, muons ····
  - nuclear physics and particle physics
- **Neutrino Experimental Facility**
  - muon neutrino beams
  - neutrino oscillation search with Super-Kamiokande
- **Transmutation Experimental Facility (Phase II)**
  - R&D for accelerator-driven nuclear transmutation with neutrons

Neutron and Muon for…

Investigation of the origins of variety of material and life！

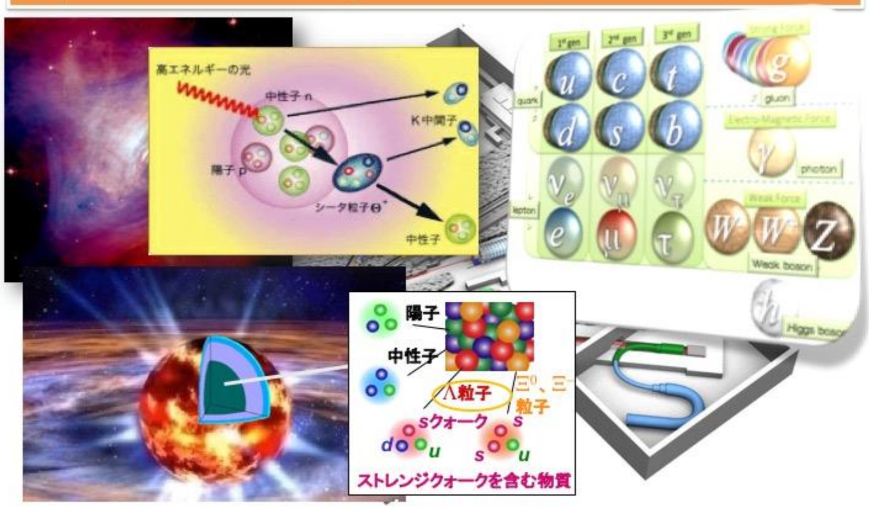
Neutrino and Anti-neutrino for…

Elucidation of the origin of universe and matter!



Hadron beams for…

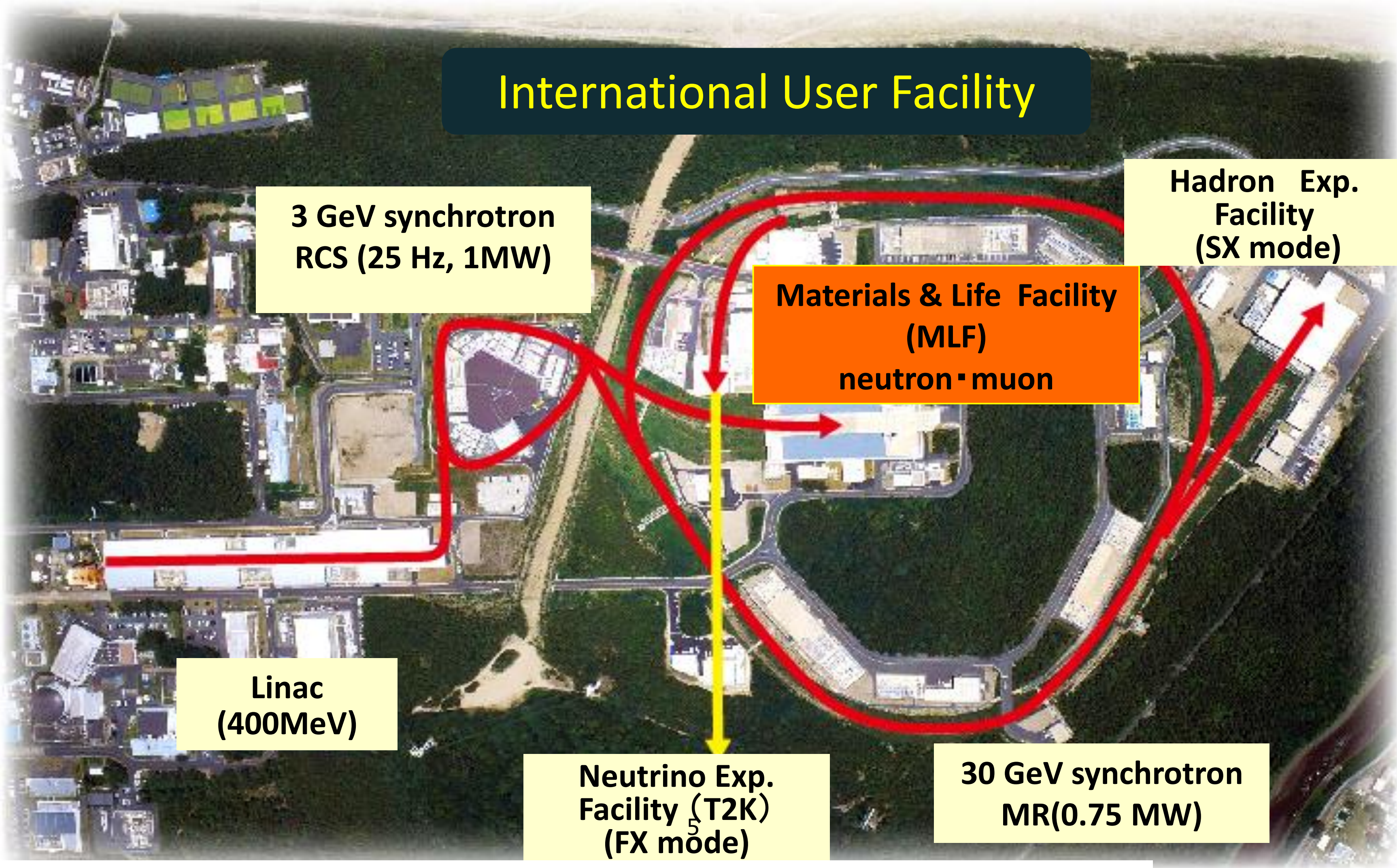
Exploration of the mysteries in formation of matter!



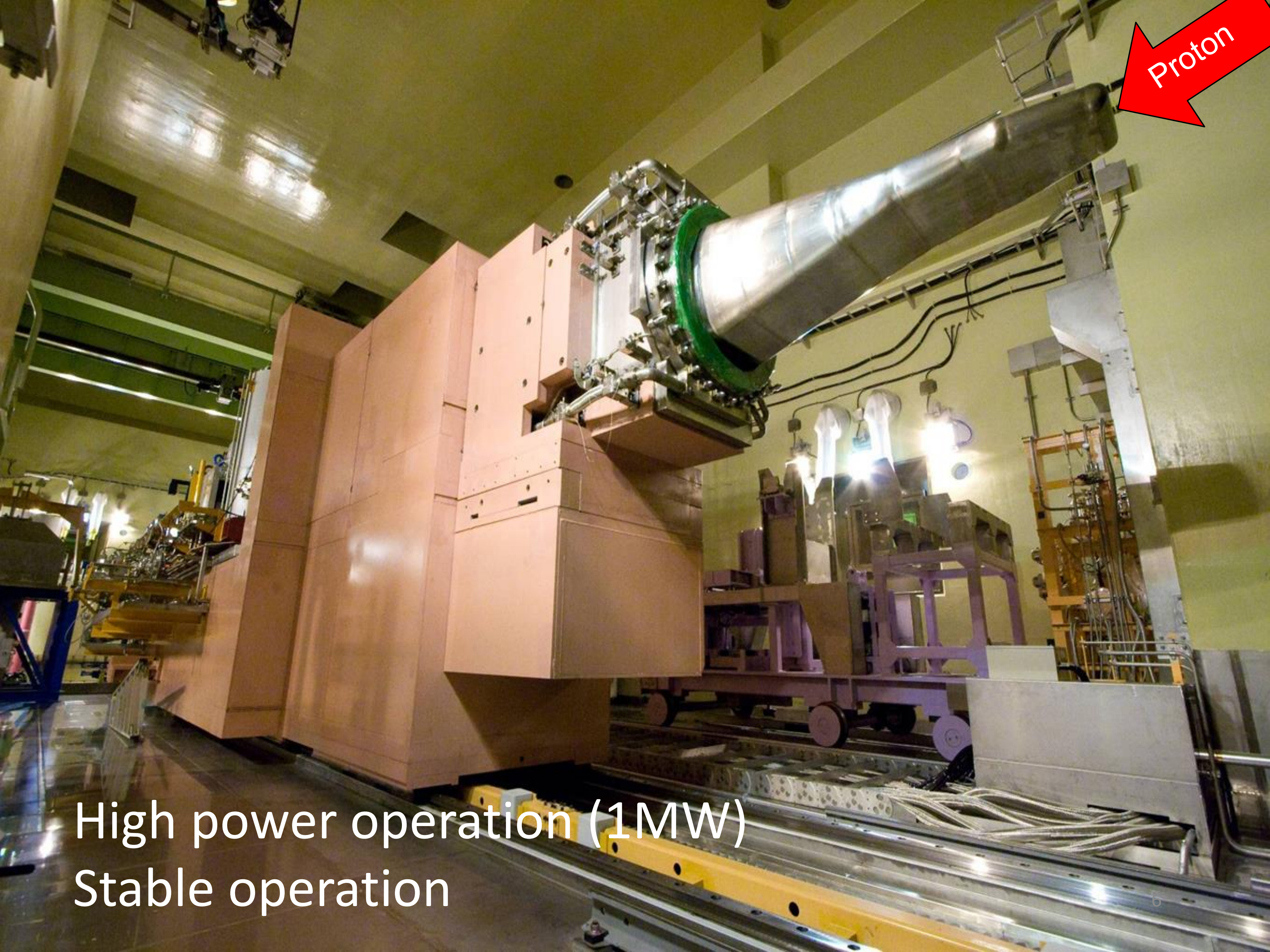
Industrial Applications for …

Acceleration of Future Technologies!

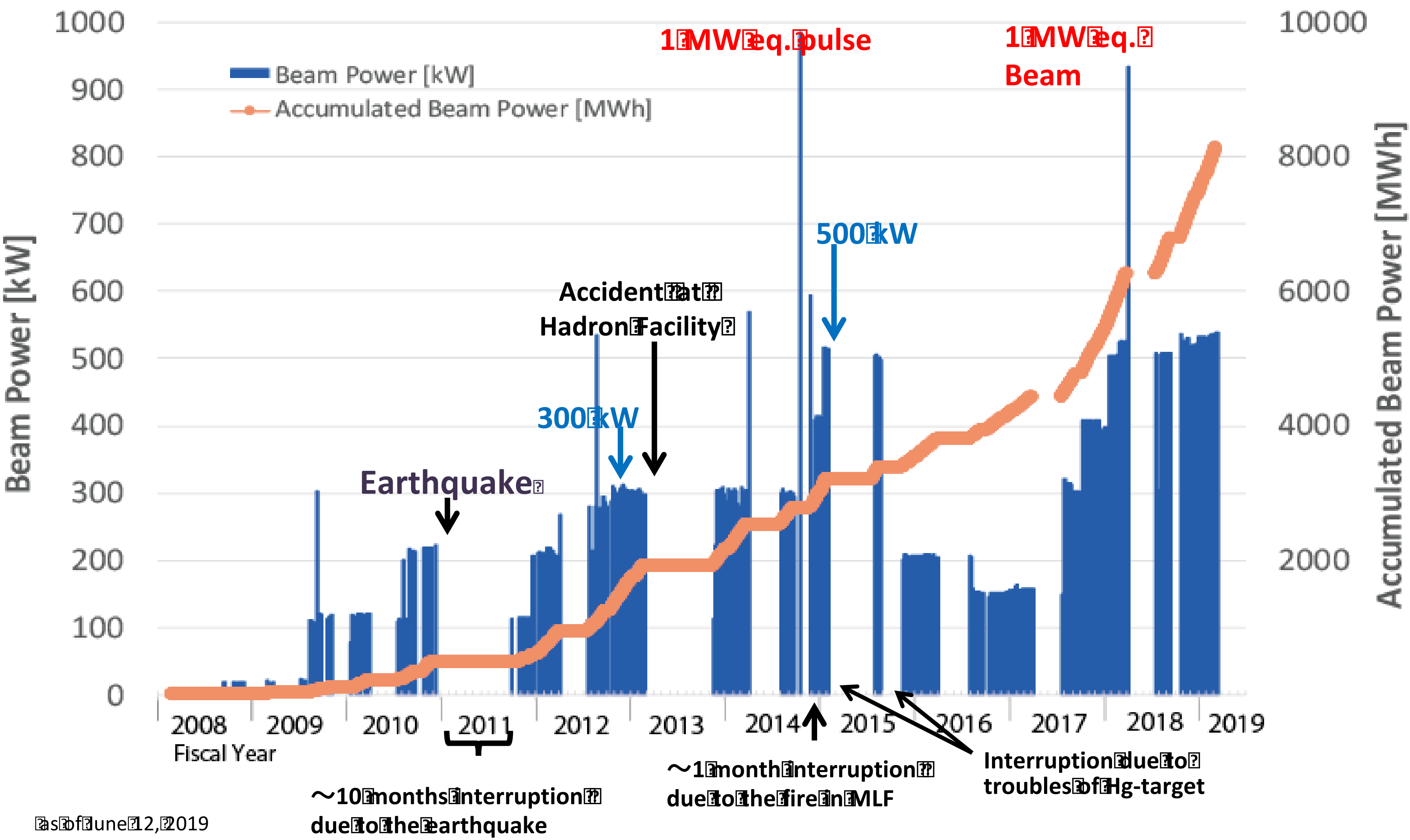
Neutron Source
at Materials & Life science experimental Facility



3 Accelerators for 3 User facilities +…

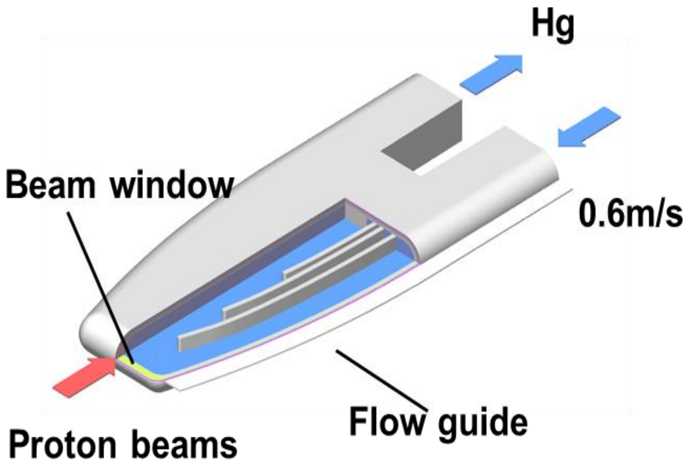

Proton
High power operation (1MW)
Stable operation

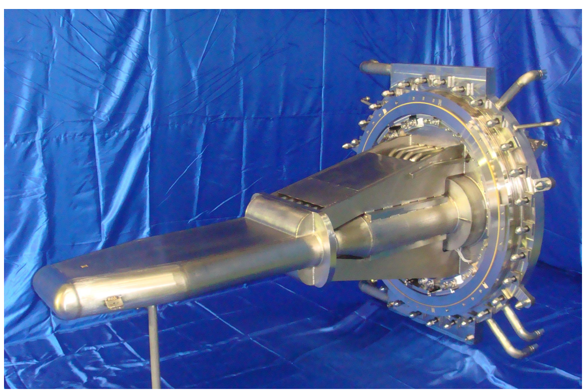
Beam Power History at MLF

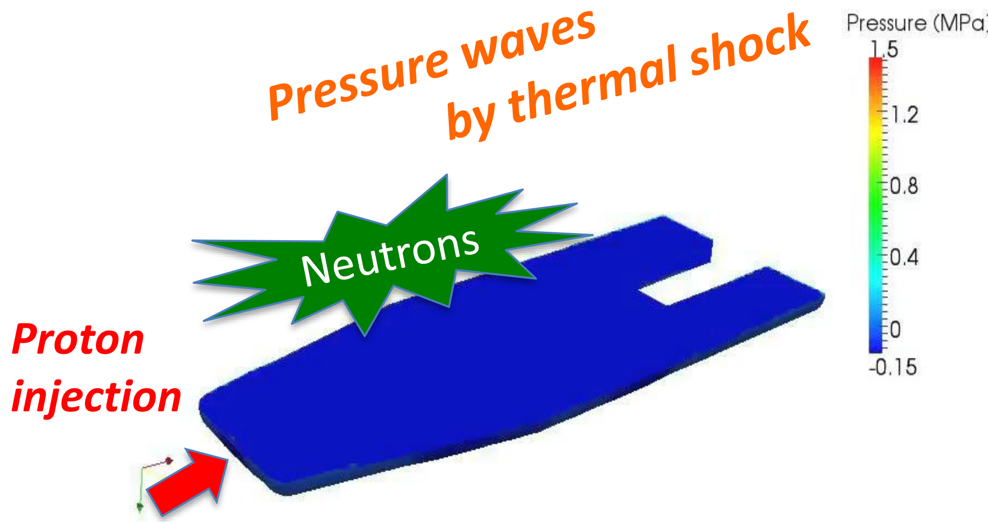


as of June 12, 2019

Background on Spallation Neutron Source





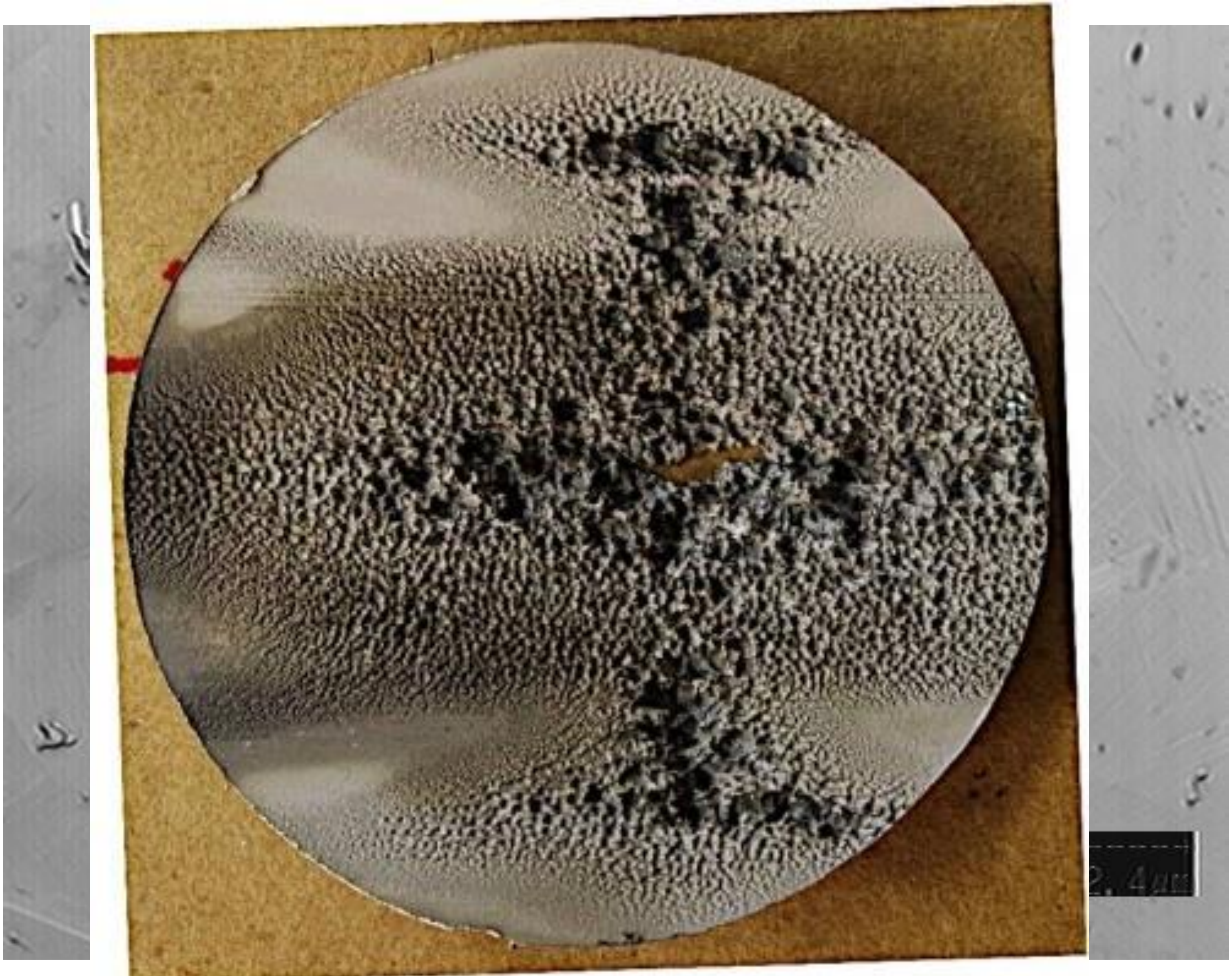


Mercury target vessel at JSNS
(Made of 316L SS)

High Intensive impulsive pressure induced by proton injection into mercury.
Repeated proton injection freq. is 25 Hz. The lifetime is estimated to be 5000 h.

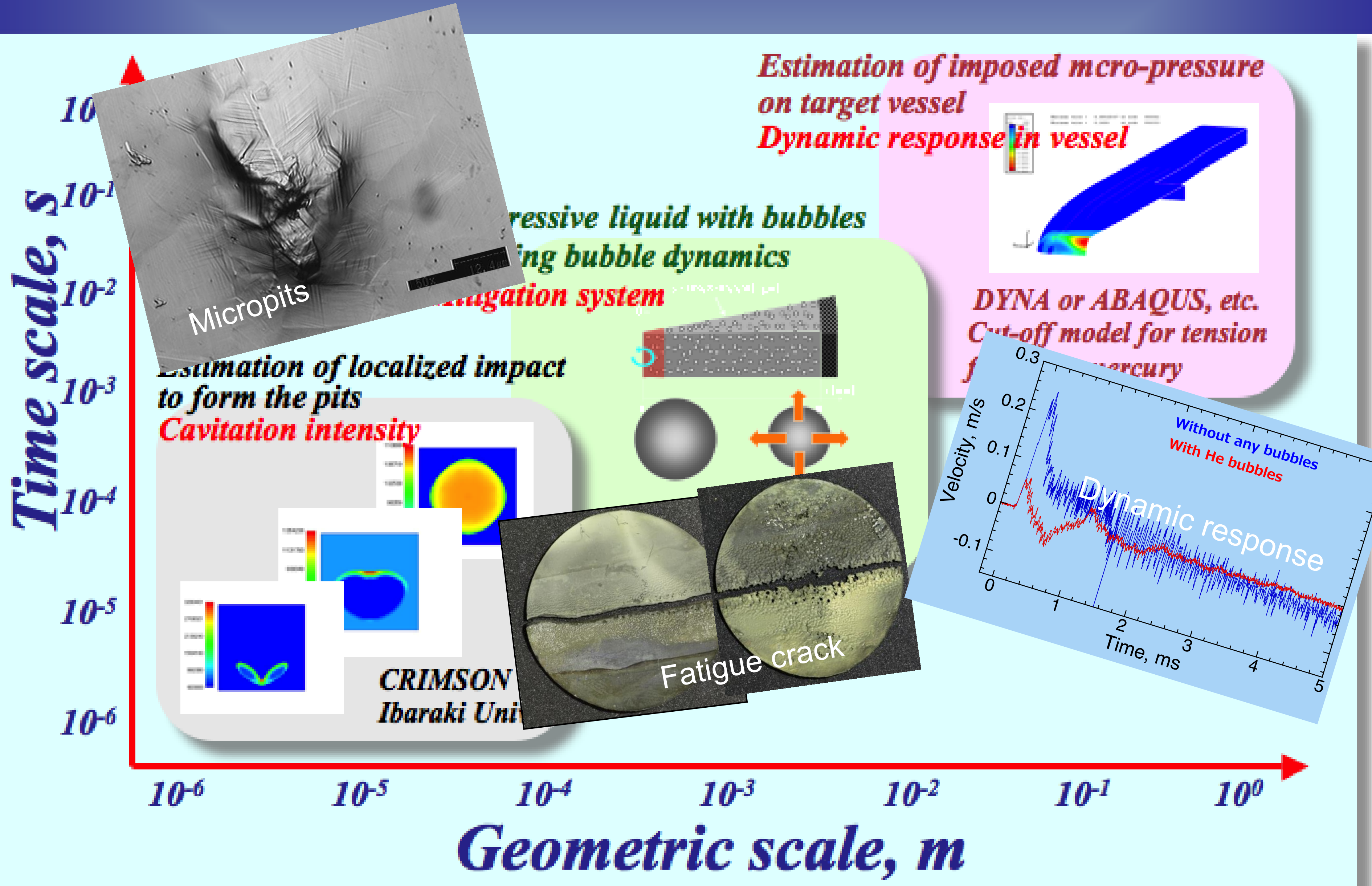
Giga-cycle fatigue (～10^9 cycles）combined with pitting damage
Irradiation by intense fluxes of neutrons; accumulated dislocations

Shock generates at bubble collapse



Micro, Mezo, Macroscopic Approaches

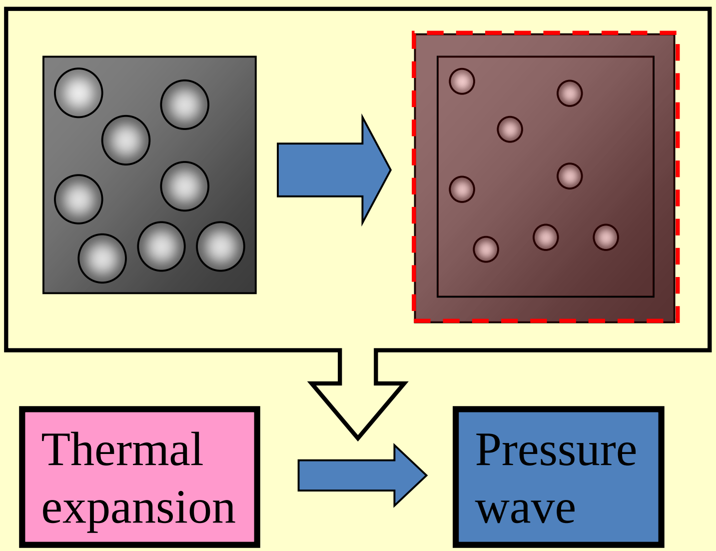
Interface damage between Liquid and Solid Metals



What is expected by introducing micro bubbles?

Decrease of pressure rise

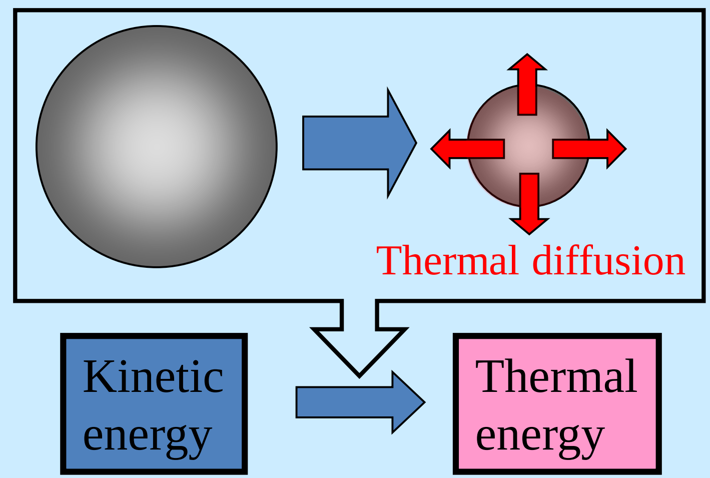
- Absorption of thermal expansion



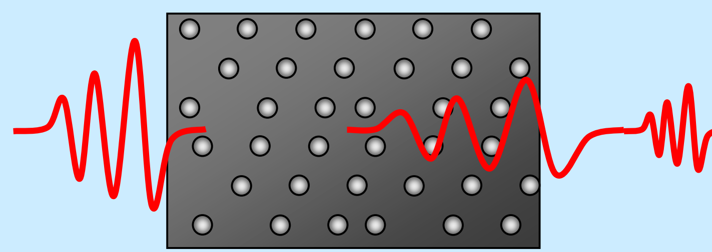
$$\frac{dp}{dt} = c_m^2 \left[\frac{\beta}{C_{pL}}\right] Q_{\mathrm{input}}$$

Attenuation of pressure waves

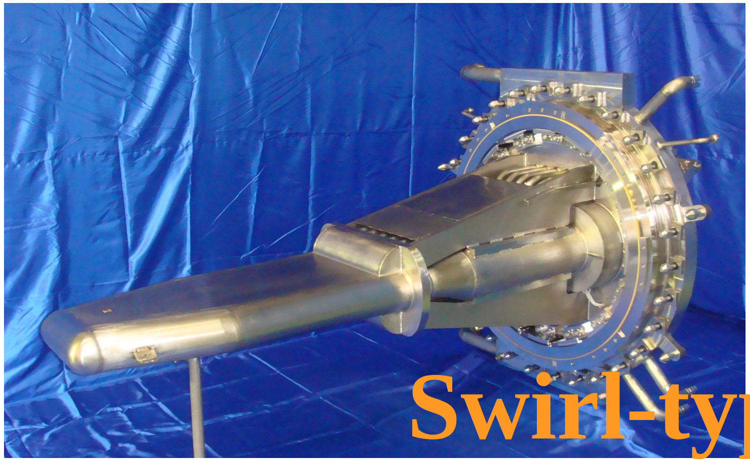
- Thermal, Viscous and Acoustic damping



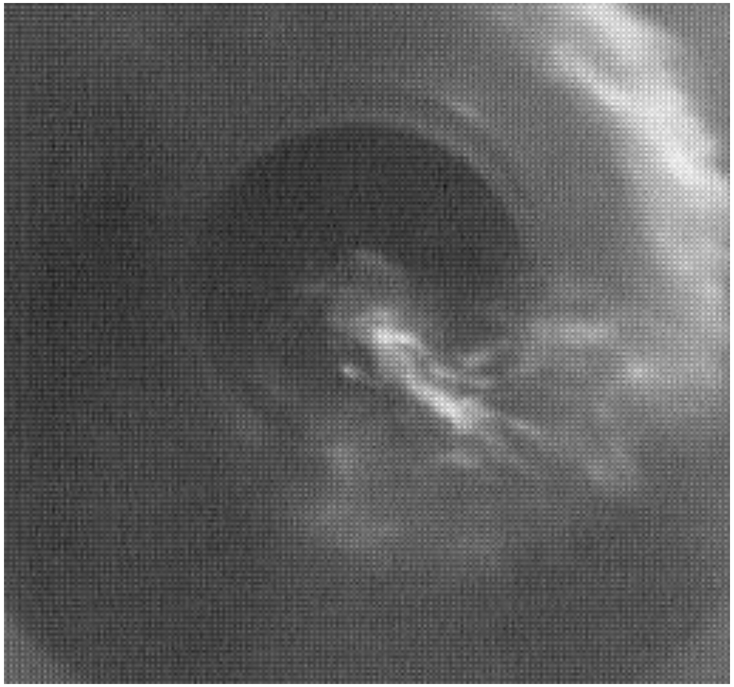
- Dispersion of pressure waves

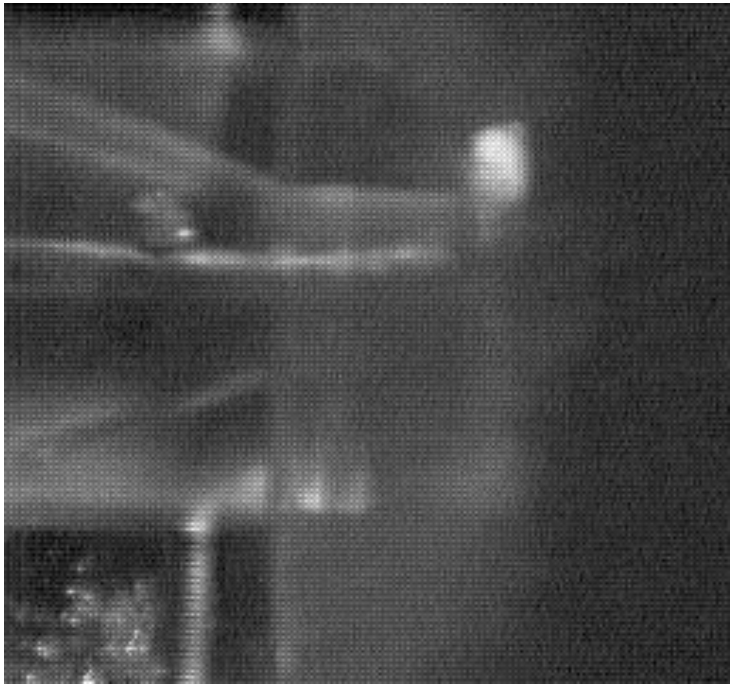


Microbubble generator for JSNS



Swirl-type bubbler

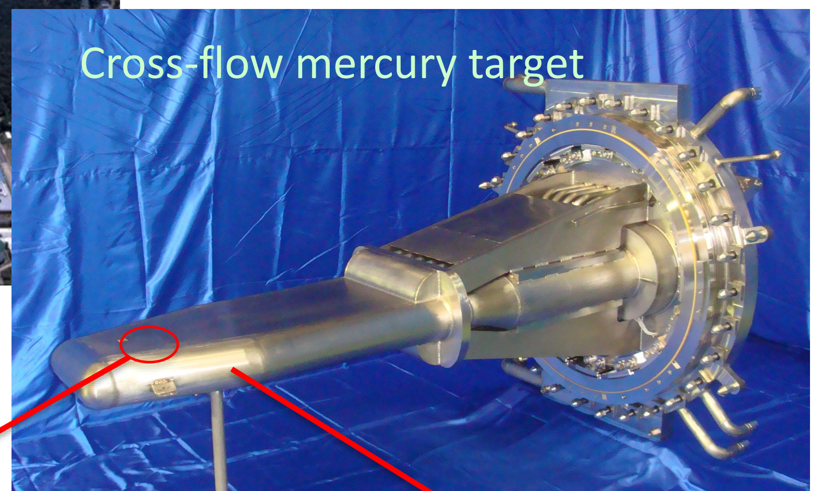


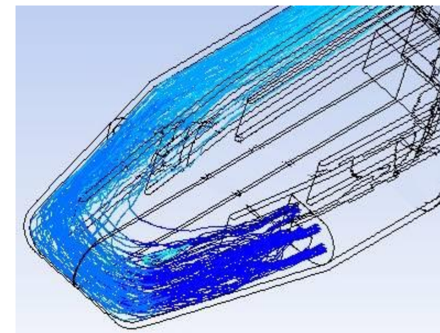


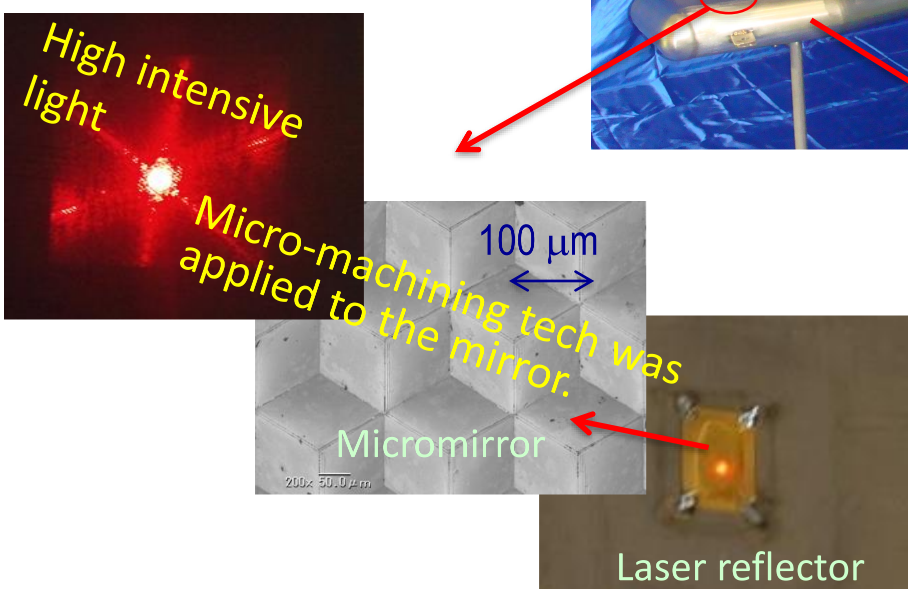
Mercury Target at MLF/J-PARC

25 Hz, short-pulse, 3 GeV H^+

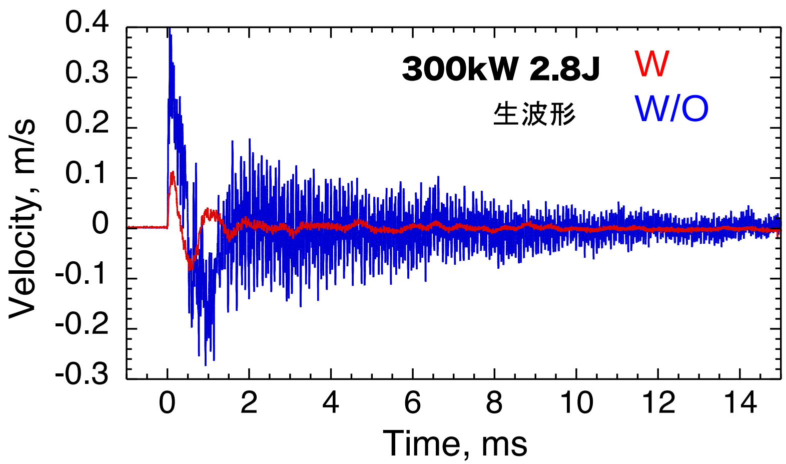
- Power in design : 1MW more
- Pressure mitigation system : Microbubbling
- Lase doppler in-situ-diagnostic system

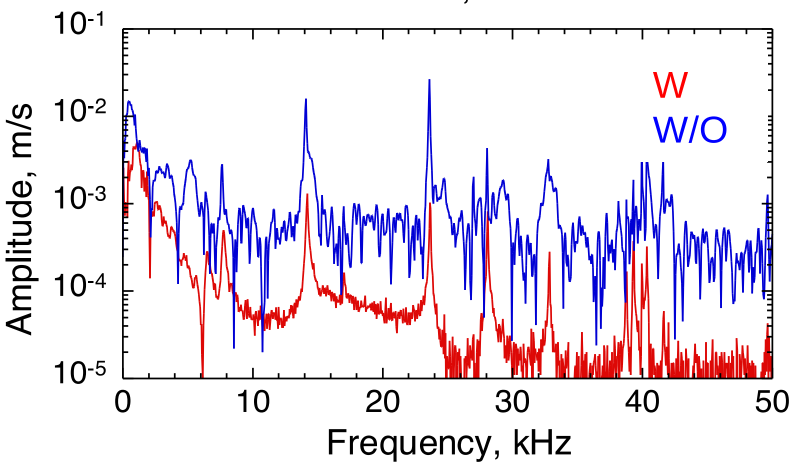




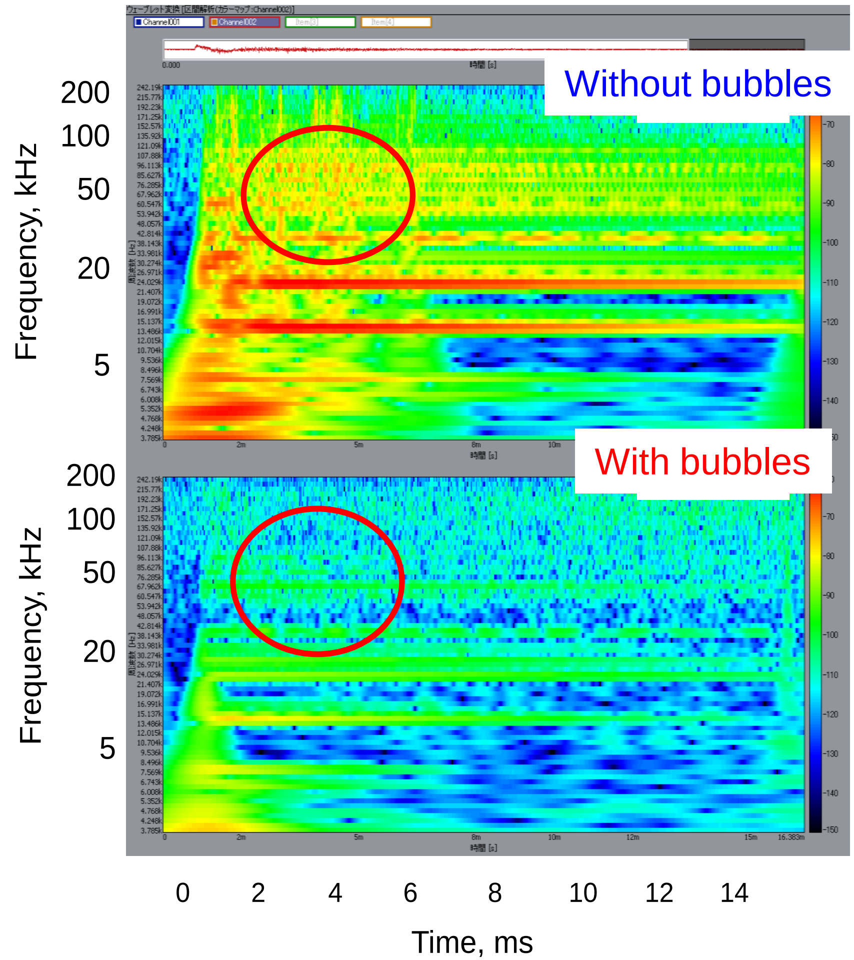


Bubbling mitigation effect on pressure wave responses



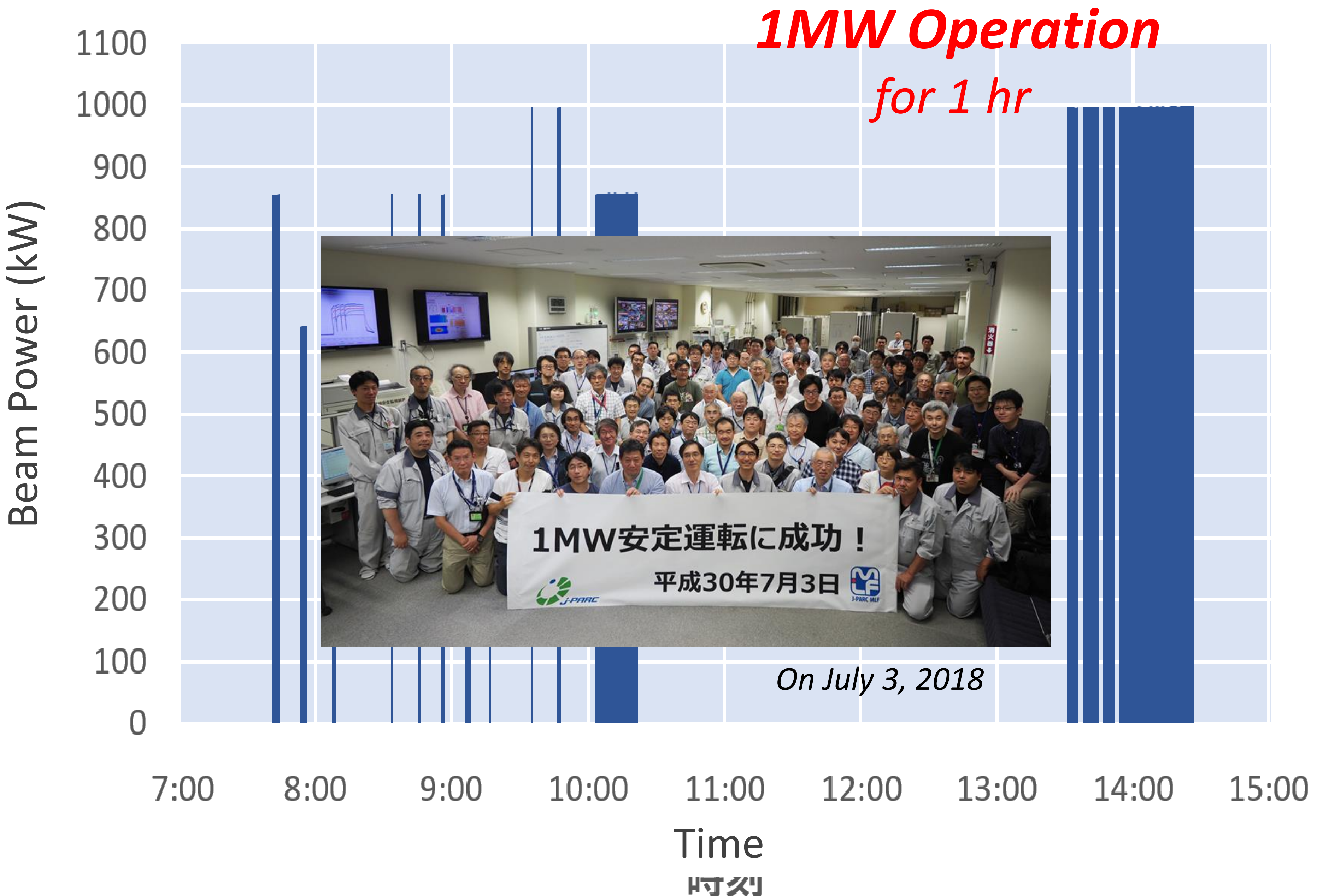


The peaks of spectrum were reduced clearly by bubbles injection regardless of frequency.



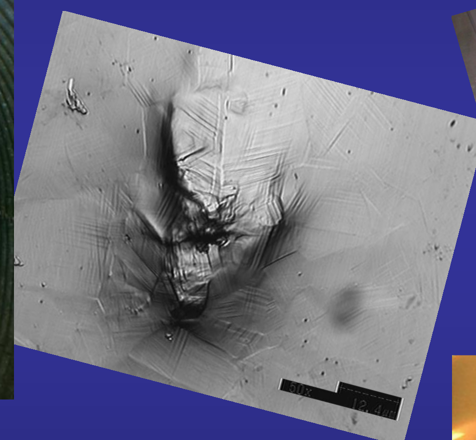
Higher freq. components, related with cavitation phenomena, were sufficiently mitigated.

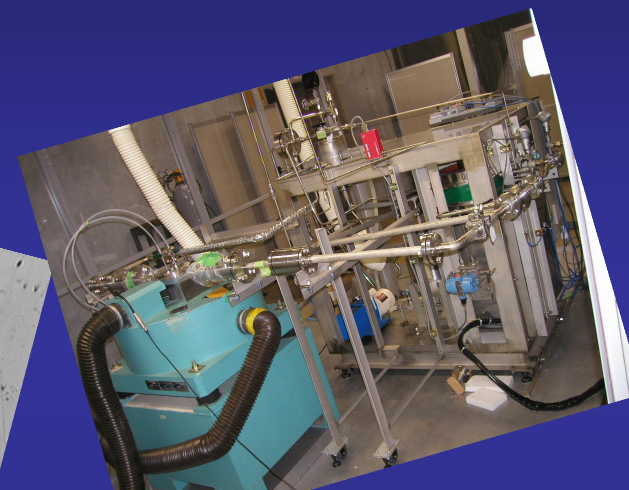
Beam Power History at MLF

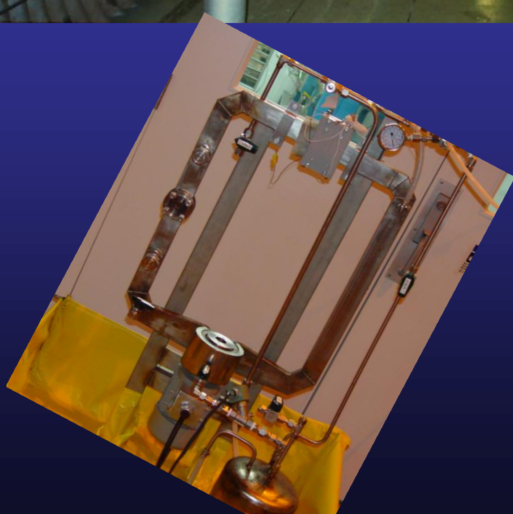


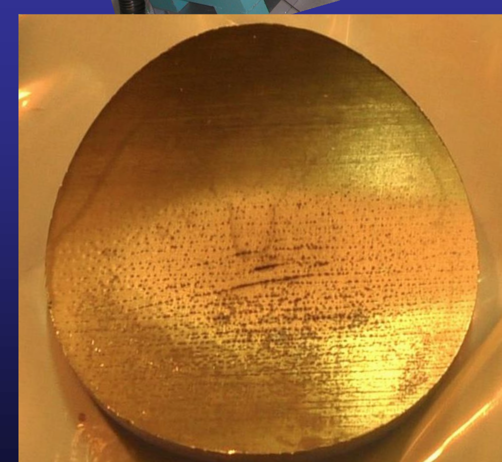
What we have done

for High Power Mercury Target Development









In-beam and Off-beam tests

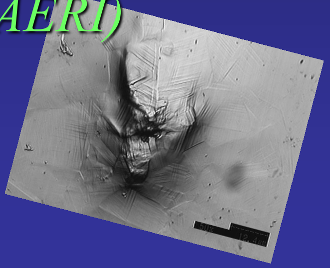
for High Power Mercury Target Development

1995 Pressure wave problem (K. Skala & G. Bauer)

1996 Prediction on cavitation due to pressure wave (J Carpenter)

1997 ASTE pressure wave measurement (JAERI, ORNL, ESS/FZJ)

2000 Pitting damage was found experimentally through SHPB tests(JAERI)



2001 Pitting damage was confirmed in-beam tests (ORNL)

Design of mercury target was suspended in SNS(ORNL)

2002 Pitting damage formation over 10 million pulses was evaluated by MIMTM (JAERI)

Design of MT was resumed in SNS (ORNL)

R&Ds on mitigation system (ORNL & FZJ)

2004 Detail analysis regarding with the bubbling effect on pressure wave mitigation (The Univ. Tokyo)

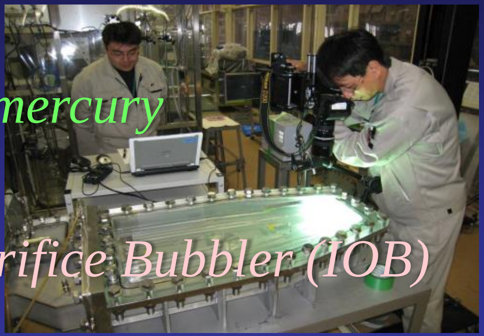
Struggle to find suitable bubbler in mercury

2005 WNR test on bubbling effect (ORNL & JAERI, ESS)

2008 Swirl bubbler to form fine bubbles in flowing mercury (Tsukuba Univ.)

2009 SNS target reached 1MW operation & PIE of real target.

In-beam and Off-beam tests
for High Power Mercury Target Development



2009 TTF experiment to measure bubble distribution in flowing mercury (J-PARC & SNS)

2011 WNR test on bubbling effect with swirl bubbler and Inlet Orifice Bubbler (IOB) (J-PARC & SNS) 1^{st} PIE of real target (J-PARC)

2012 Bubbling operation with swirl bubbler in real target (J-PARC), Confirmed bubbling pressure wave mitigation effect in target (J-PARC)

2013 Swirl bubbler was improved for bubble generation without compressor (J-PARC)

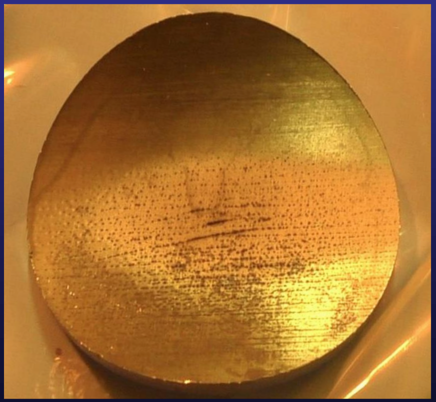
2014 Target with swirl bubbler and double flow channel (J-PARC), 2^{nd} PIE

2015 3^{rd} PIE

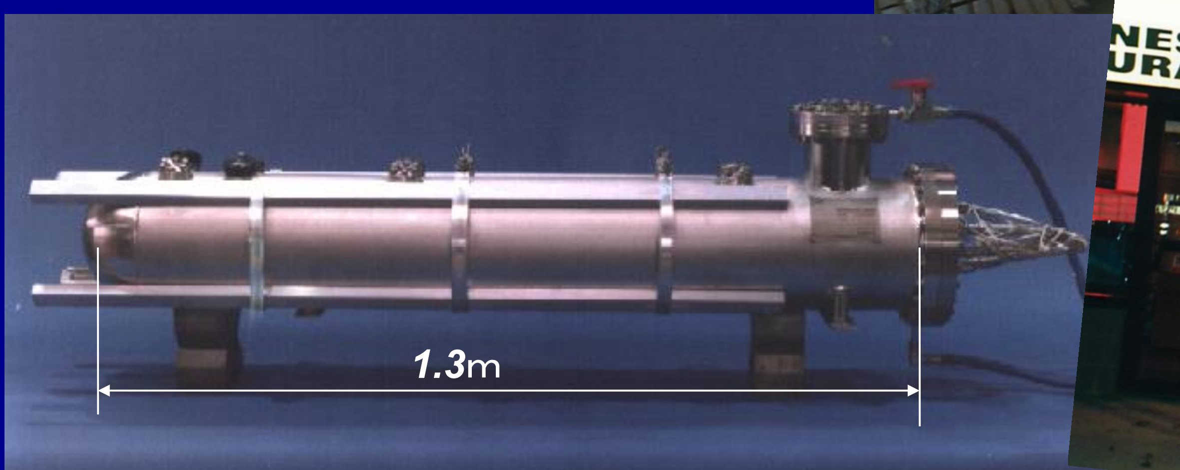
2017 Bubbling operation without compressor (J-PARC), 4^{th} PIE

2018 Bubbling operation with IOB (SNS)
1 MW - 1 hour operation was succeeded (J-PARC) , 5^{th} PIE

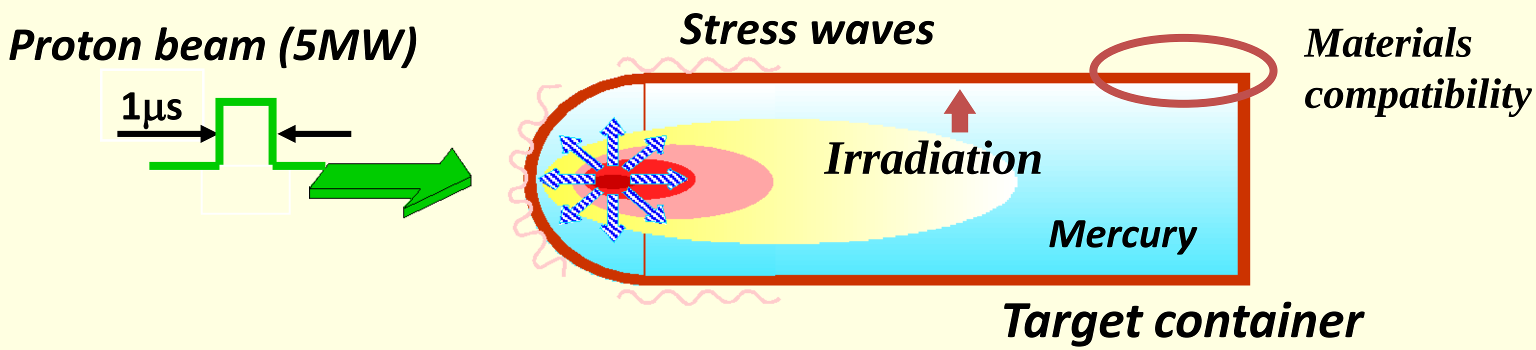
2019 1 MW - 12 hour operation will be conducted (J-PARC)



International collaboration of AGS experiment
to measure dynamic response of mercury target in 1997



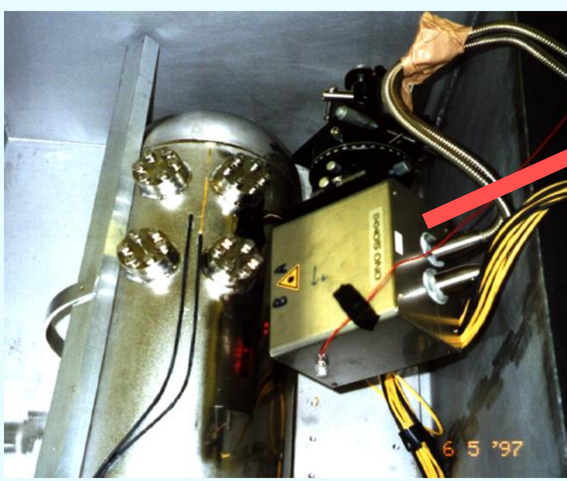
Impact problem on mercury target

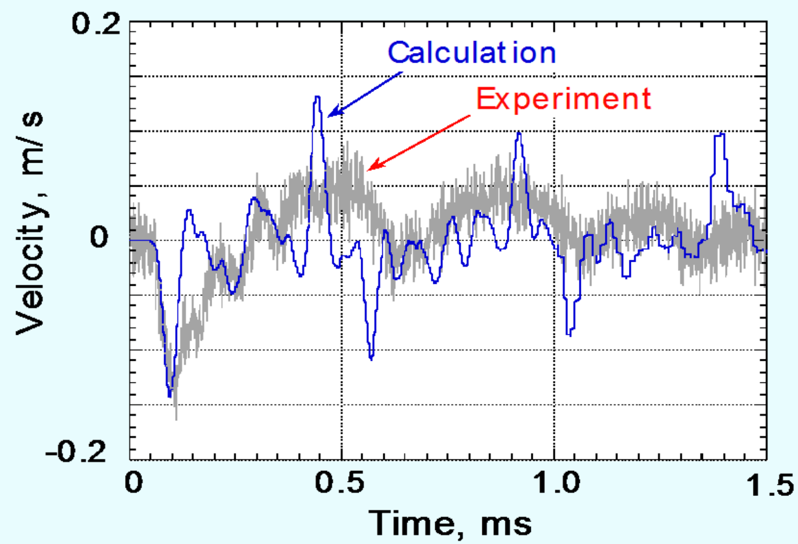


AGS experiment

Injected proton beam : 24 GeV, 10^{12} n, 40 ns

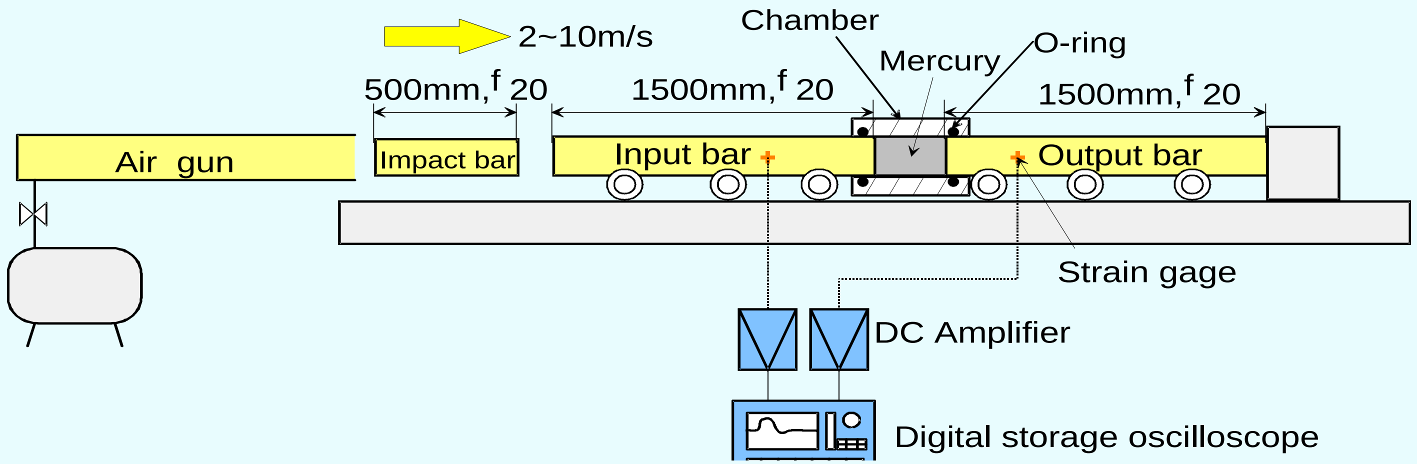
Laser Doppler technique



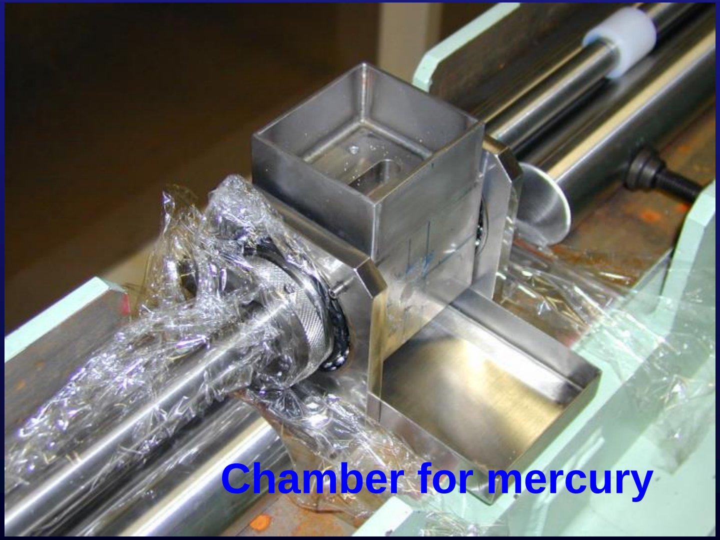


The stress propagation up to 100 ms is adequately described by the calculation. After 100 ms, in the calculation the velocity rapidly increases with superimposed high frequencies components, and in the experiment the velocity fluctuates comparatively slowly.

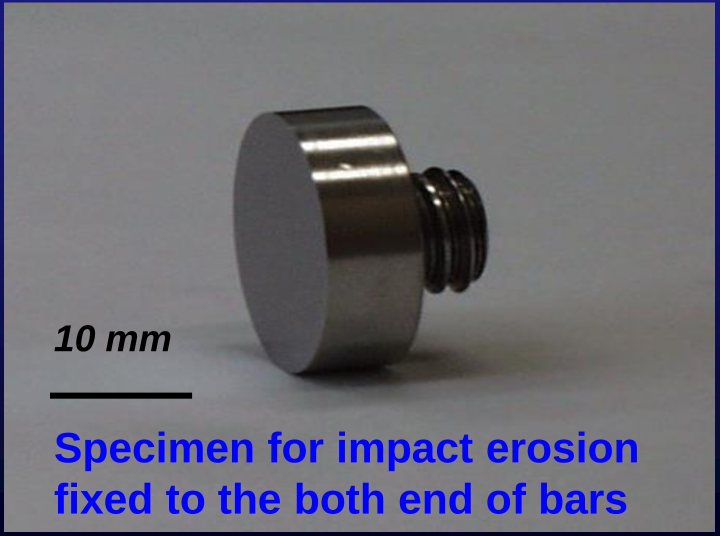
Experiment by using SHPB tech.
to evaluate dynamic behavior of mercury



Modified split Hopkinson pressure bar apparatus

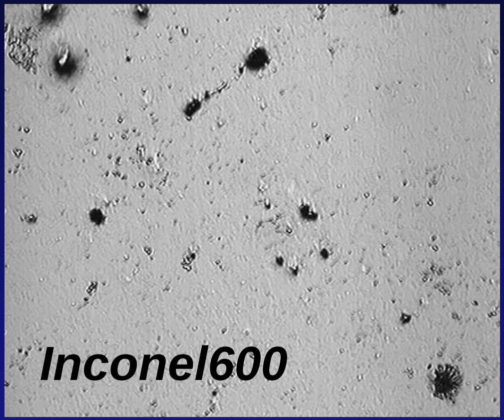


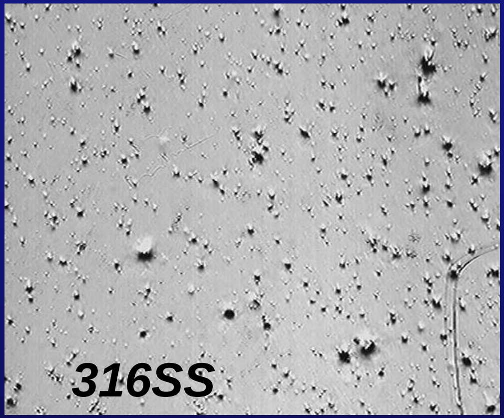
Chamber for mercury

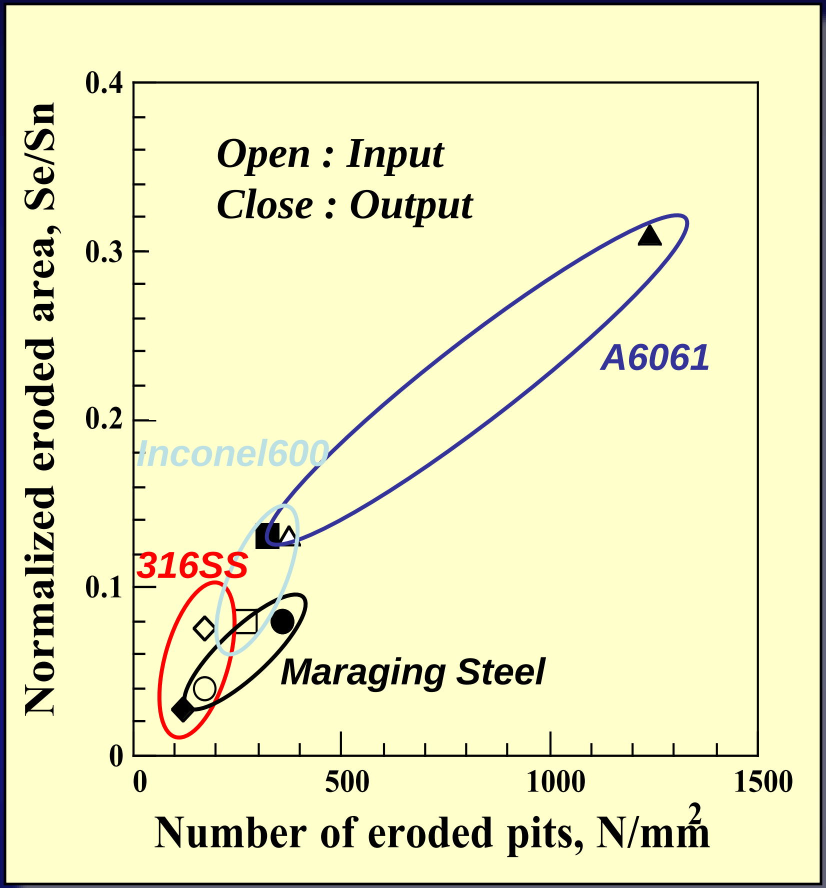


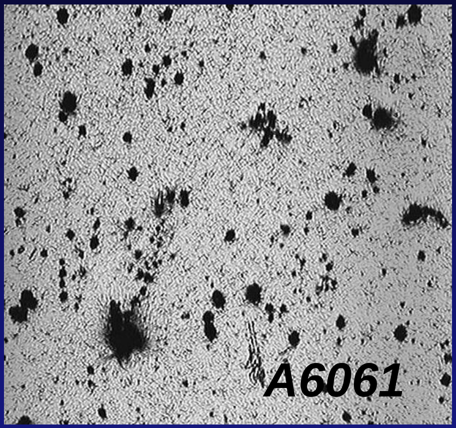
Specimen for impact erosion fixed to the both end of bars

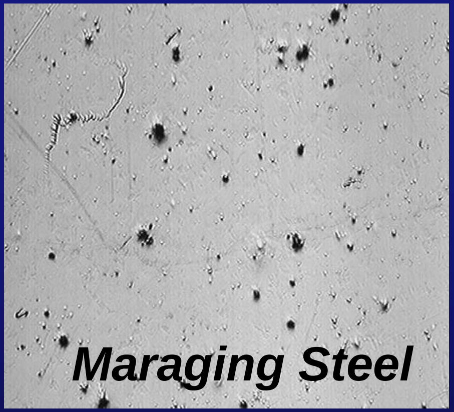
Materials dependency of impact erosion









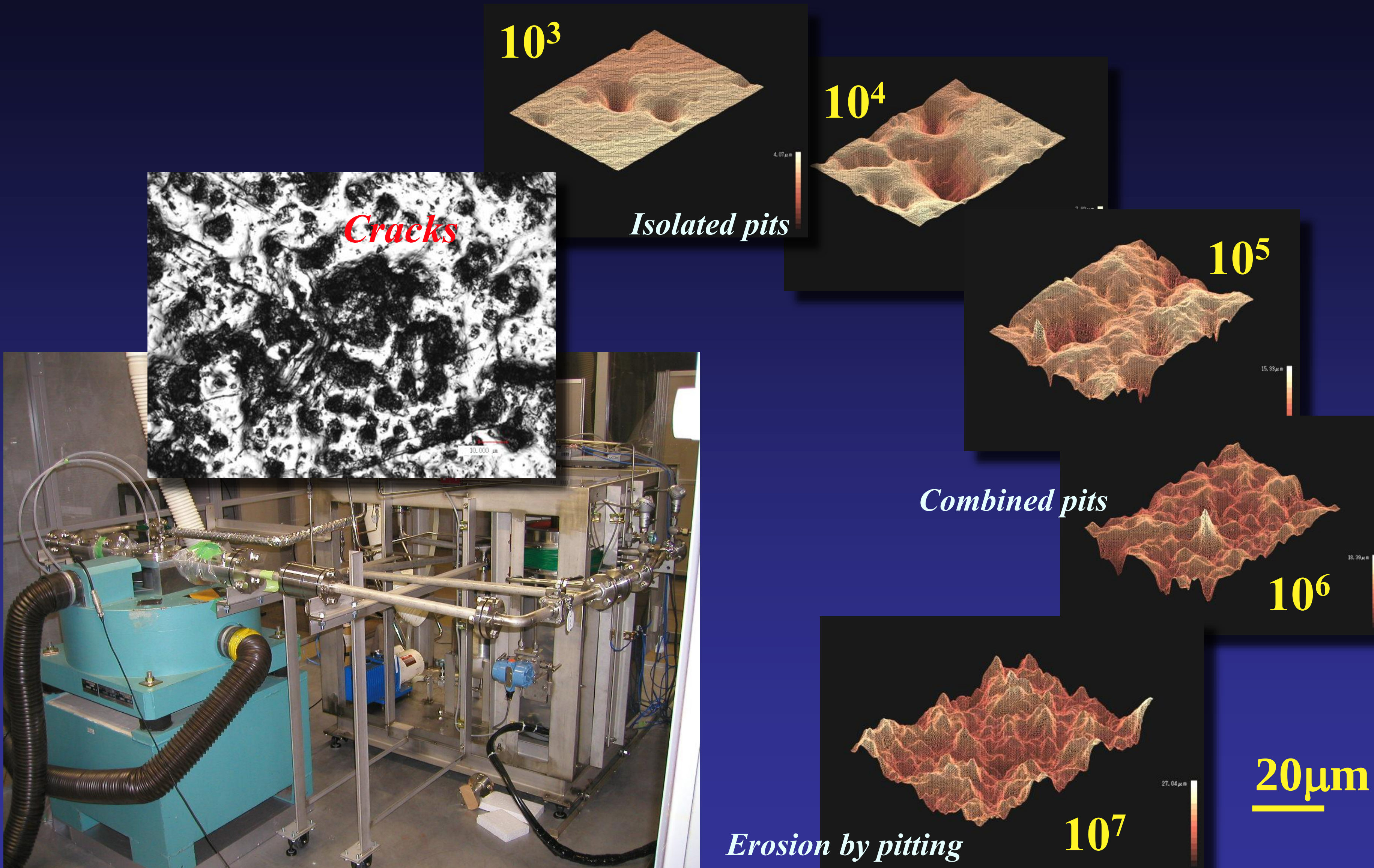


Surface degradation after 10 impacts imposed

The collapse of the cavitation bubble imposes high compressive stress on the surface microarea due to the microjet injection and the cumulative cavitation damage causes the erosion pits.

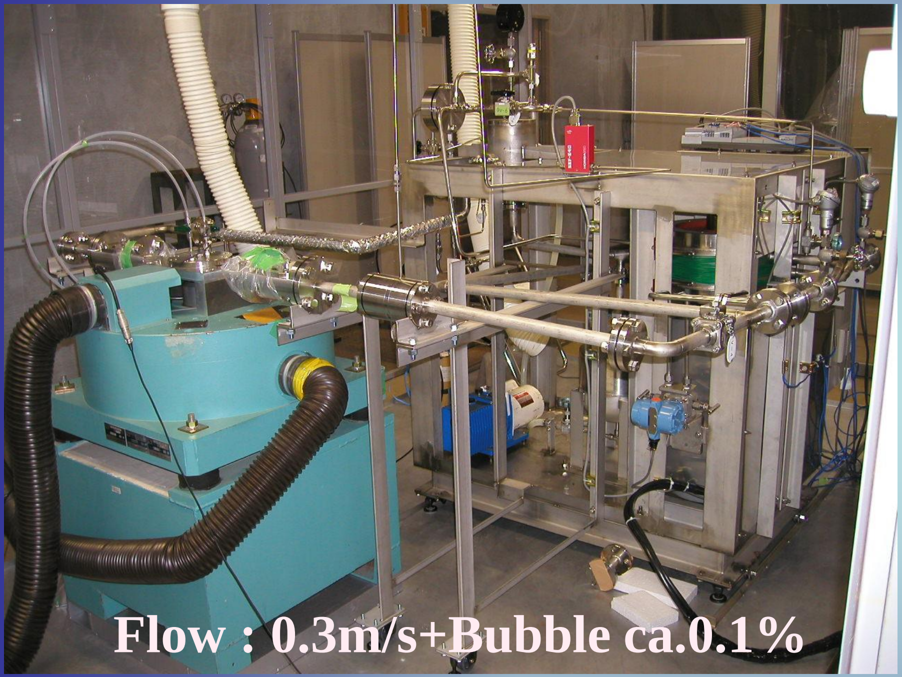
The degradation due to the impact erosion, A6061>Inconel 600>Maraging Steel>316SS.

Pitting formation by MIMTIM

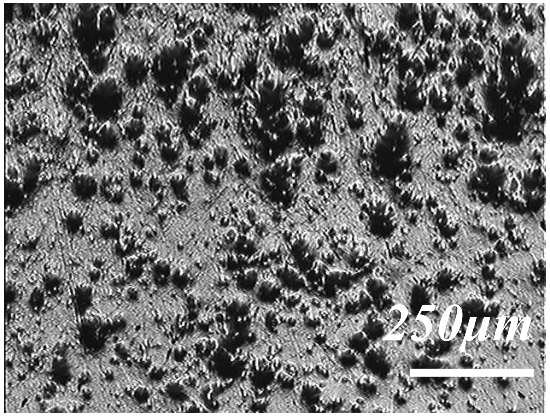


Pitting damage data are accumulated up to over 10 million

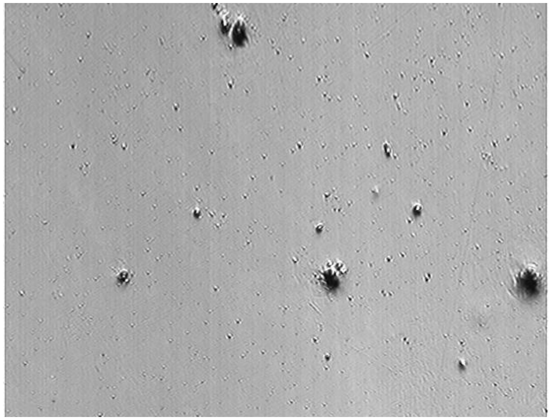
Experiment on the effect of micro-bubble on cavitation damage



Stagnant

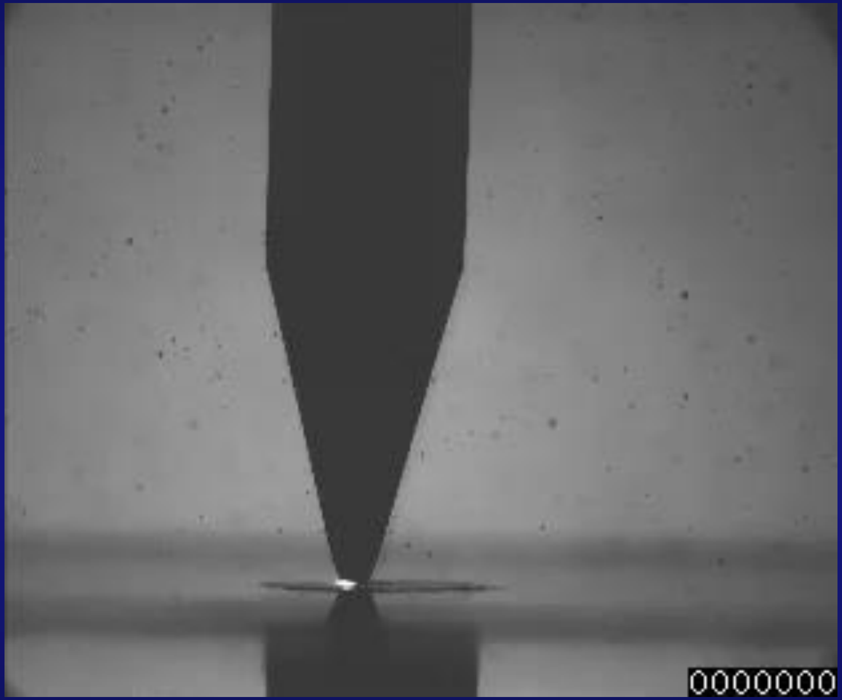


Microbubble injection under flowing

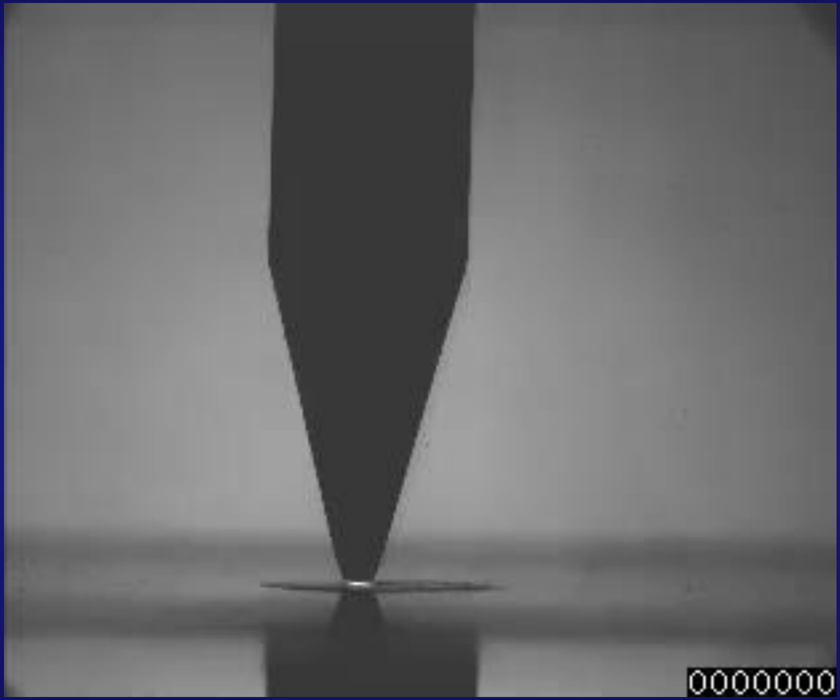


Futakawa et al; J. Nucl. Sci. Tech. 453(2008)1041-1048

Flowing effect
on bubble collapsing behavior



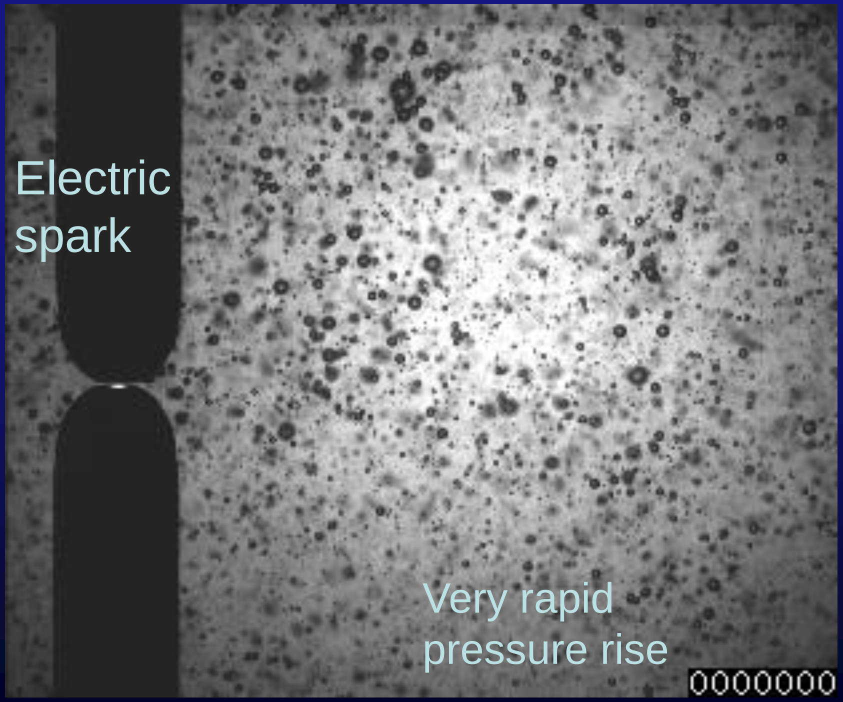
Flowing velocity (1m/s)

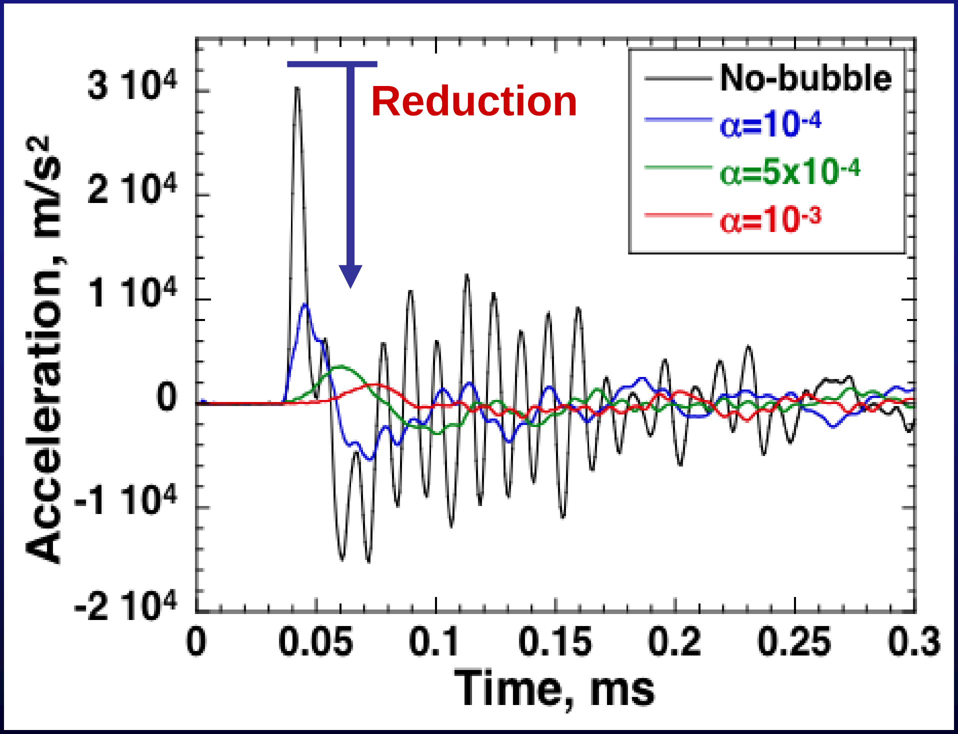


Stagnant

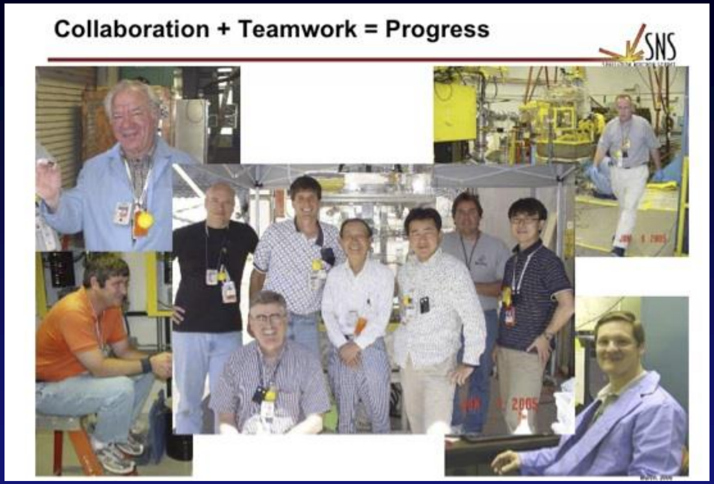
Pressure wave mitigation by bubbles

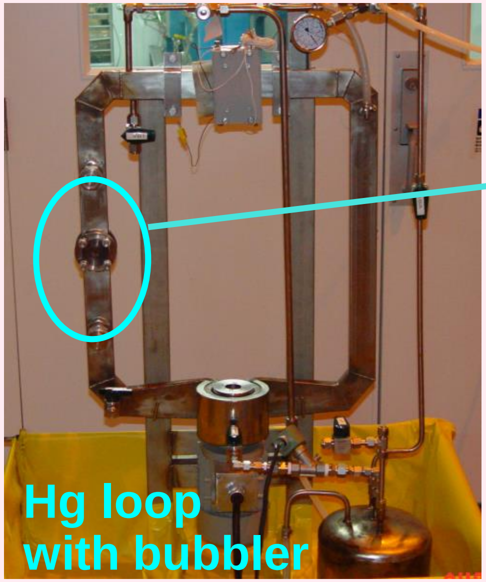
A lot of efforts have been made to realize MW-class mercury target.
Bubbling is most effective tech. to reduce pressure waves !
Prospective bubbler (simple & robust) was found finally after several years research.
Experimentally and theoretically understood mitigation phenomena more deeply.
Noticed similarity of bubble-cloud dynamics in Hg and H_2O
Effectiveness was demonstrated under water test with high pressure rising rate.

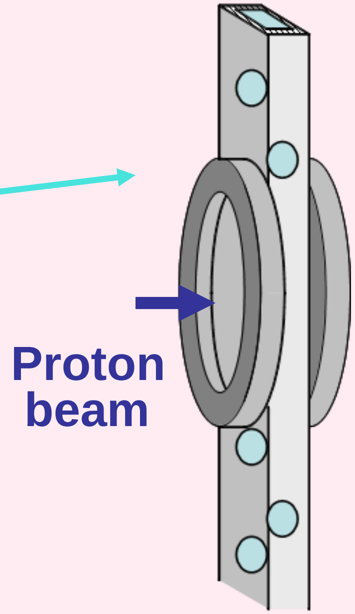


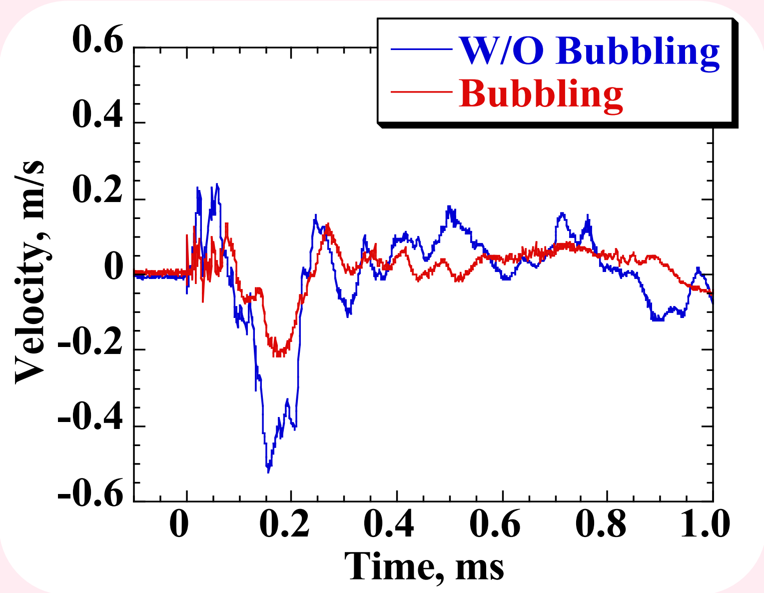


Pressure wave mitigation confirmed in–beam tests





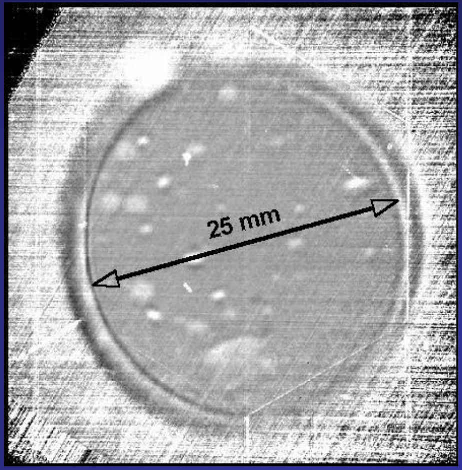


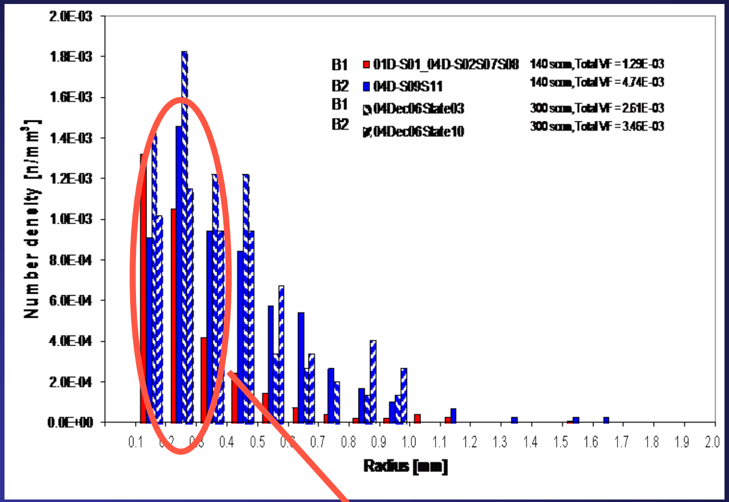


On-beam test was carried out by using WNR facility to investigate the bubbling effect on the pressure waves caused by proton beam injection. The displacement velocity measured by a Laser Doppler Vibrometer L.D.V. was reduced by bubbling.

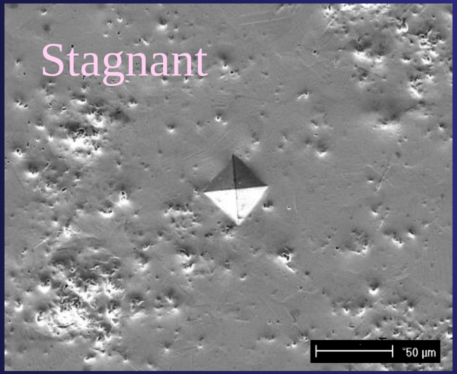
Pitting damage mitigation by bubbles

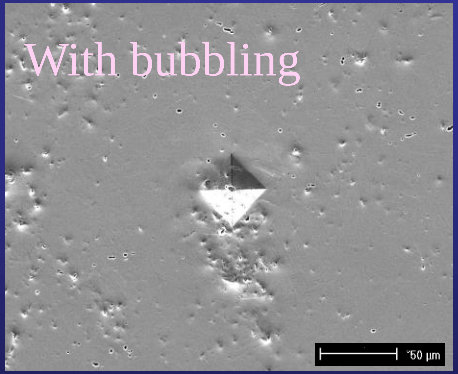
Proton radiography to observe bubbles in mercury



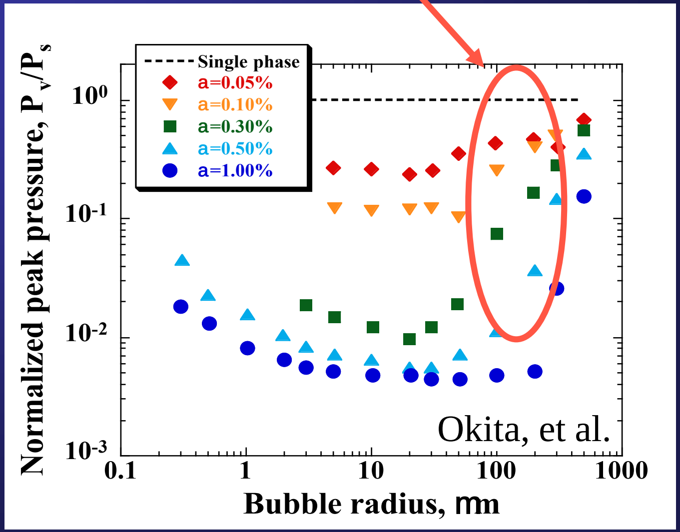


Evaluated bubble population





Damaged surfaces



Expected pressure reduction by bubbling

By ORNL

What we have learned through the high power mercury target development

In-beam tests are indispensable !

Have to learn what happens !

Sensing with visualization is Key technology to understand phenomena.

Off-beam tests and Physical modeling to explore the mechanisms are important, as well.

Future facilities at J-PARC

As usage of neutron, ADS experiment & Secondary target facilities

JAEA-Technology
2017-003
DOI:10.11484/jaea-technology-2017-003

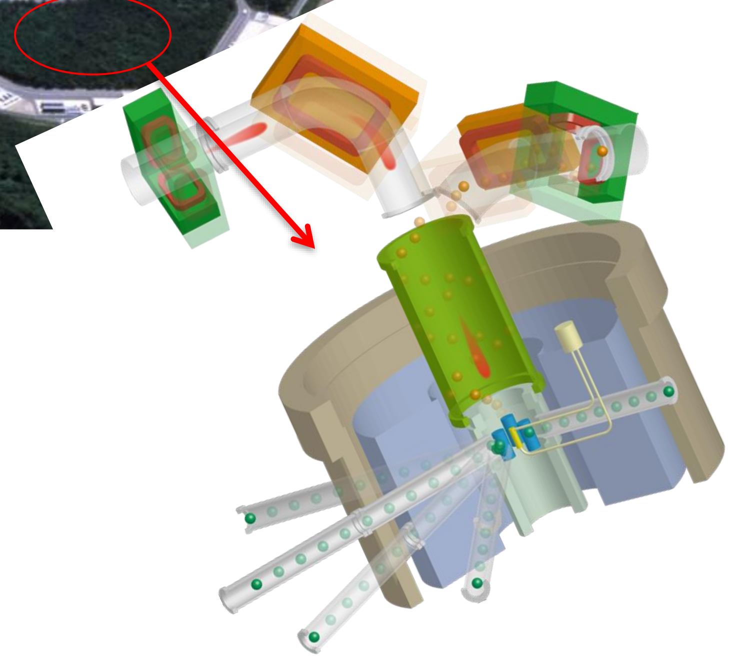
J-PARC 核変換実験施設 技術設計書
— ADS ターゲット試験施設 (TEF-T) —
Technical Design Report on J-PARC Transmutation Experimental Facility
— ADS Target Test Facility (TEF-T) —

核変換ディビジョン
Nuclear Transmutation Division

原子力科学研究部門
J-PARC センター
J-PARC Center
Sector of Nuclear Science Research

March 2017
Japan Atomic Energy Agency
日本原子力研究開発機構

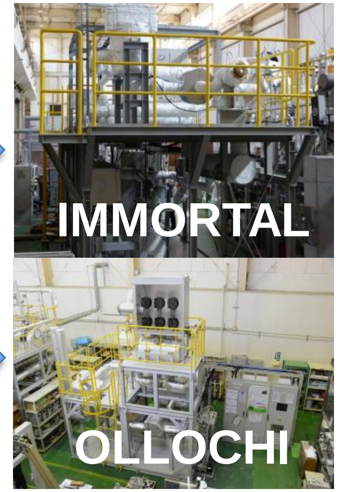
JAEA-Technology



R&D for ADS Plants (under discussion)

High-power target technology

- LBE technology
  - ✓ thermal-hydraulics
  - ✓ materials corrosion
  - ✓ Instrumentation
  - ✓ remote-handling



Experimental data for V&V

J-PARC's experimental devices

Computer simulation

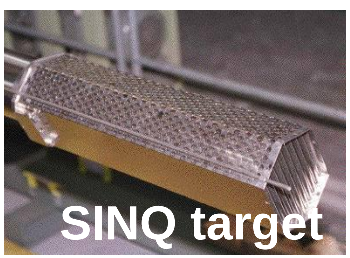
Thermal-hydraulics

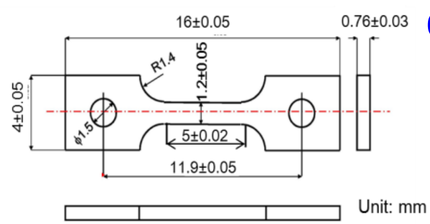
Corrosion in LBE

Simulation models

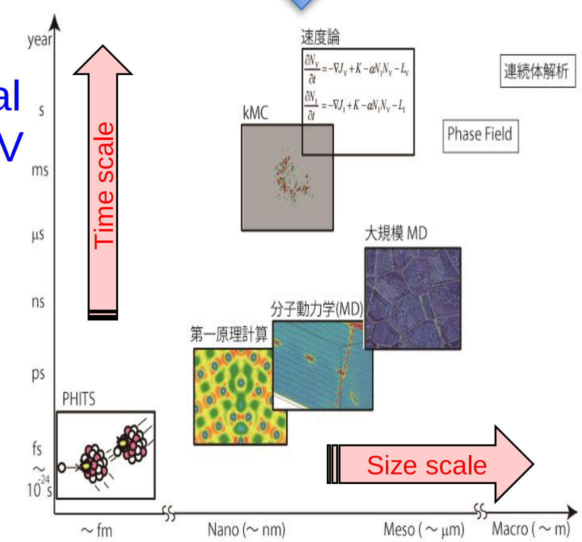
to predict stress-strain properties for irradiated materials

- Materials irradiation study with using existing facilities, such as STIP/PSI and MLF/J-PARC
  - ✓ Contracted with PSI for STIP-8



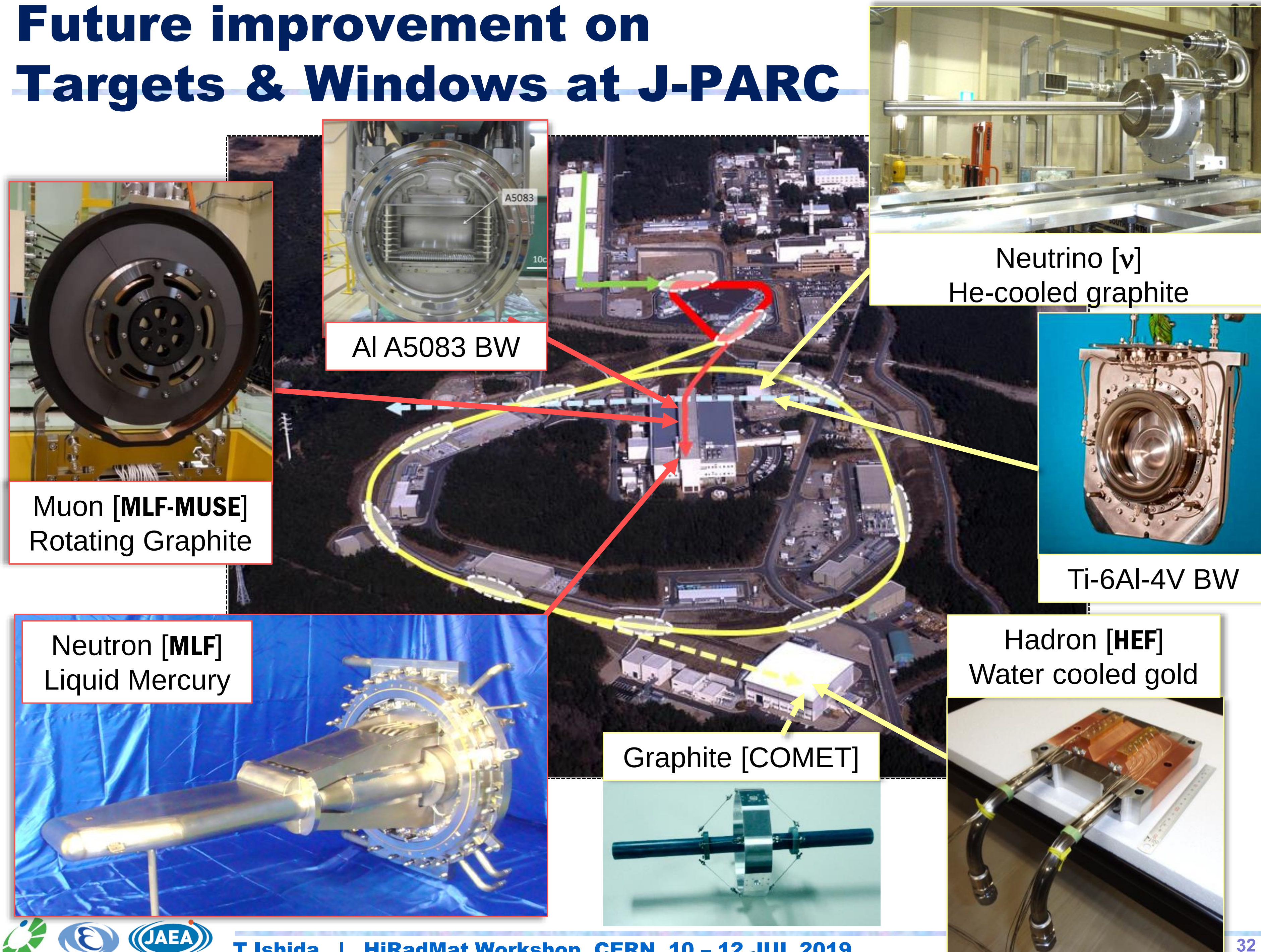


Experimental data for V&V



- Behavior of spallation products
  - ✓ Started collaborative research with Fukui Univ., "Physicochemical form of SP in LBE"
  - ✓ J-PARC's experience for MLF Hg-target

Future improvement on Targets & Windows at J-PARC



Expectation to HRM Facility

1) Developments of Advanced target/window/dump materials

2) Research on Displacement Cross-Section dependency on proton energy

3) Development of In-beam radiation-tolerant detector

……etc.

COOPERATION between CERN and J-PARC

In effect on 8 April 2011 , 5 years (8 April 2016)

In effect on 30 March 2016, + 5years (until 8 April, 2021)

To be in effect soon, + 5years (until 8 April, 2026)

Expand the co-operation to the fields of high-intensity accelerator target facilities and relevant technologies, to fully realize and accomplish the benefits of the high intensity proton accelerators

RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments

- Founded in 2012 by 5 institutions led by FNAL and STFC to bring together the HEP/BES accelerator target and nuclear fusion/fission materials communities

In 2017, 2nd MoU revision has counted J-PARC (KEK+JAEA) & CERN as official participants
Collaboration has now grown to
13(14) Institutions, 70 members

http://radiate.fnal.gov


J-PARC MoU signing & workshop in 2017

Summary

- In-beam tests are indispensable to learn what happens
- J-PARC (KEK and JAEA) express interests in the future experiments at HiRadMat facility
- Expand COOPERATION between CERN and J-PARC