HPTW2023 in RIKEN, Japan
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Updates on the operation of the MLF neutron target at J-PARC and perspectives for future operation

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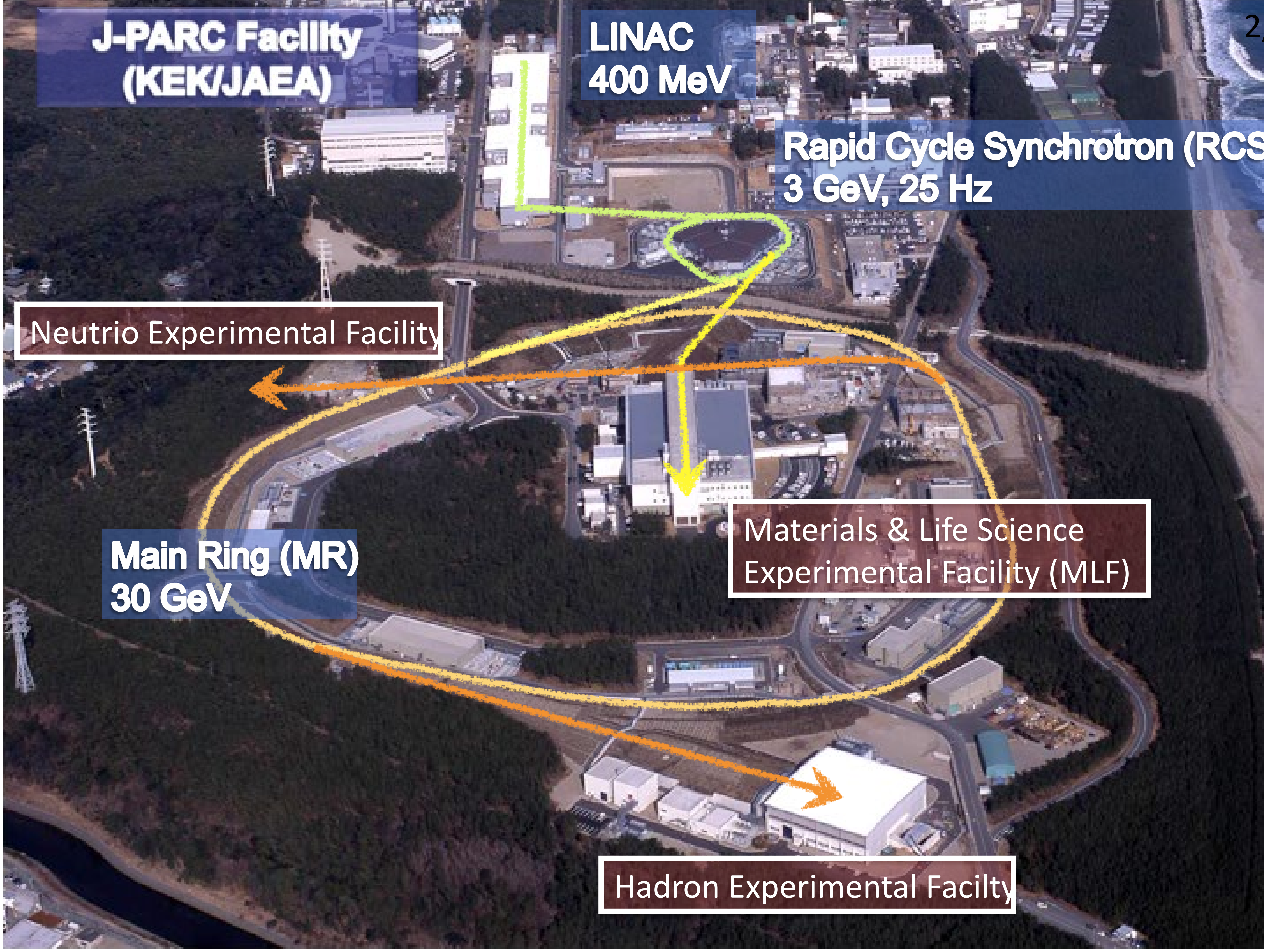
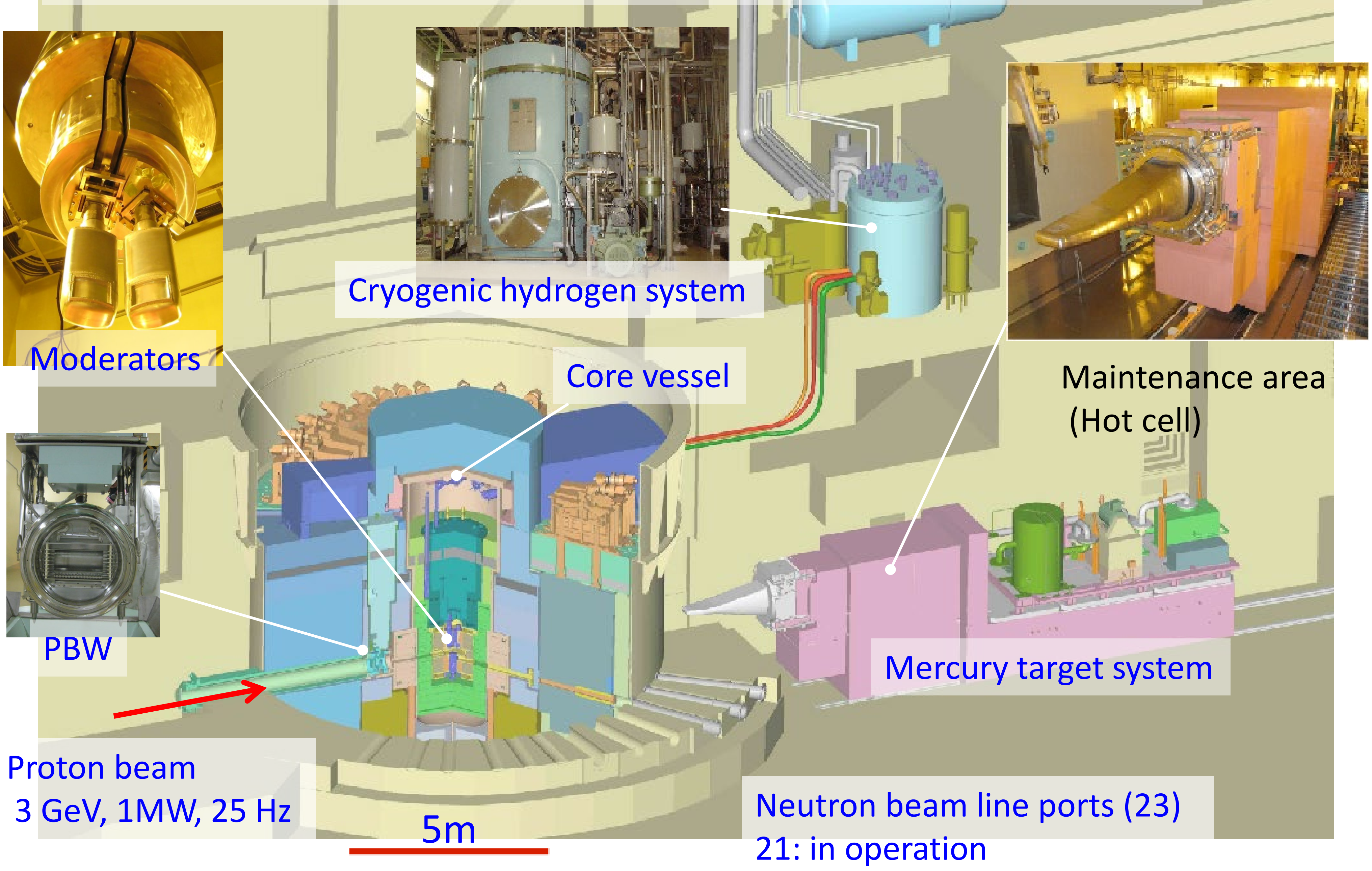
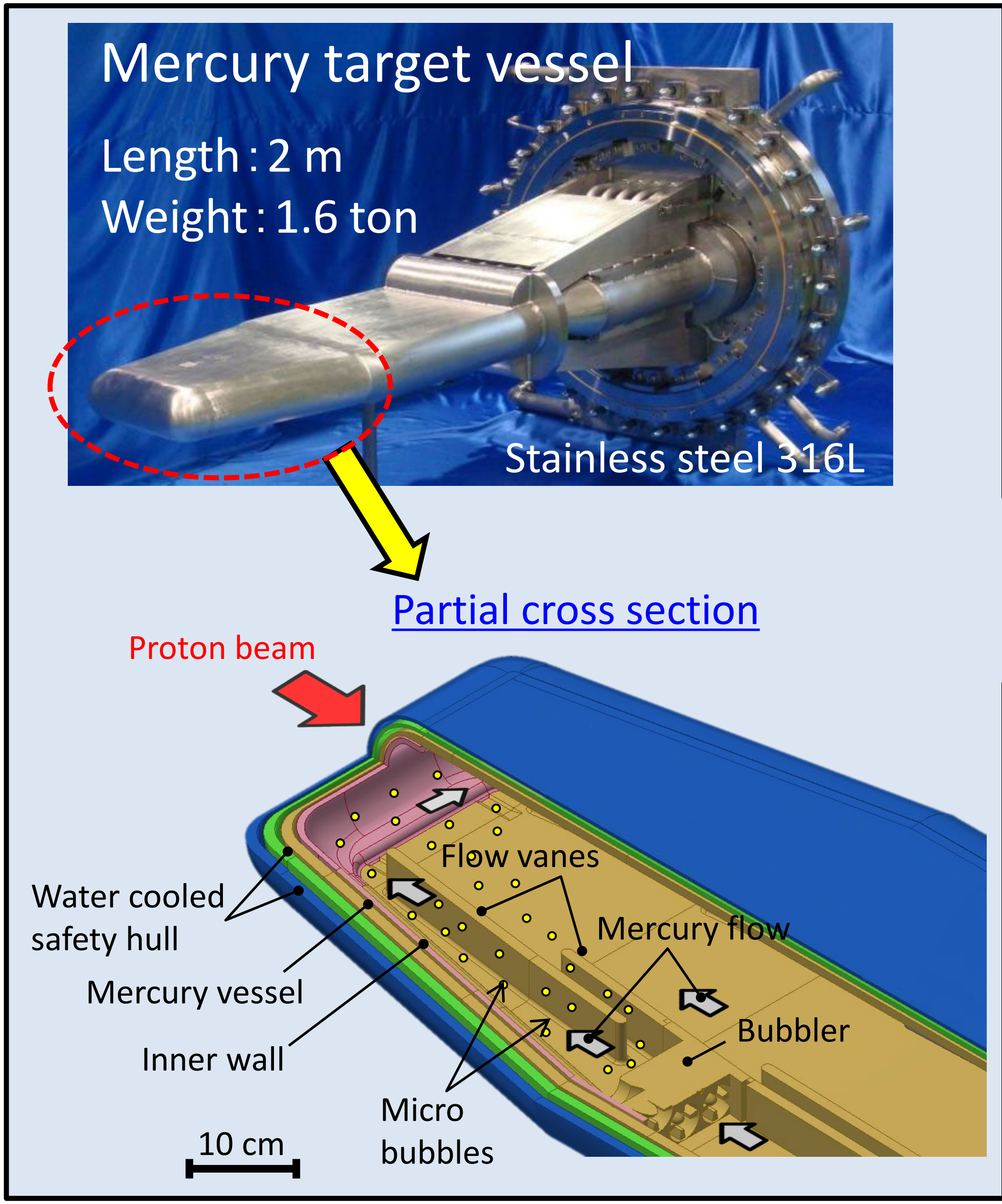
J-PARC center, Japan Atomic Energy Agency


J-PARC Facility
(KEK/JAEA)
LINAC
400 MeV
Rapid Cycle Synchrotron (RCS)
3 GeV, 25 Hz
Neutrio Experimental Facility
Main Ring (MR)
30 GeV
Materials & Life Science
Experimental Facility (MLF)
Hadron Experimental Facilty

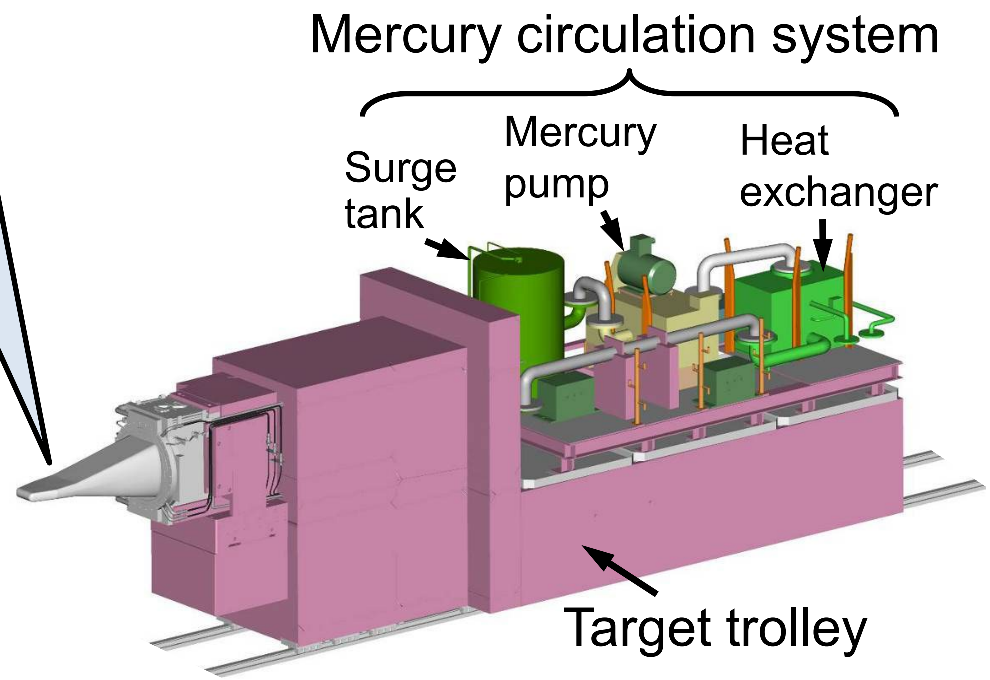
1-MW spallation neutron source at J-PARC



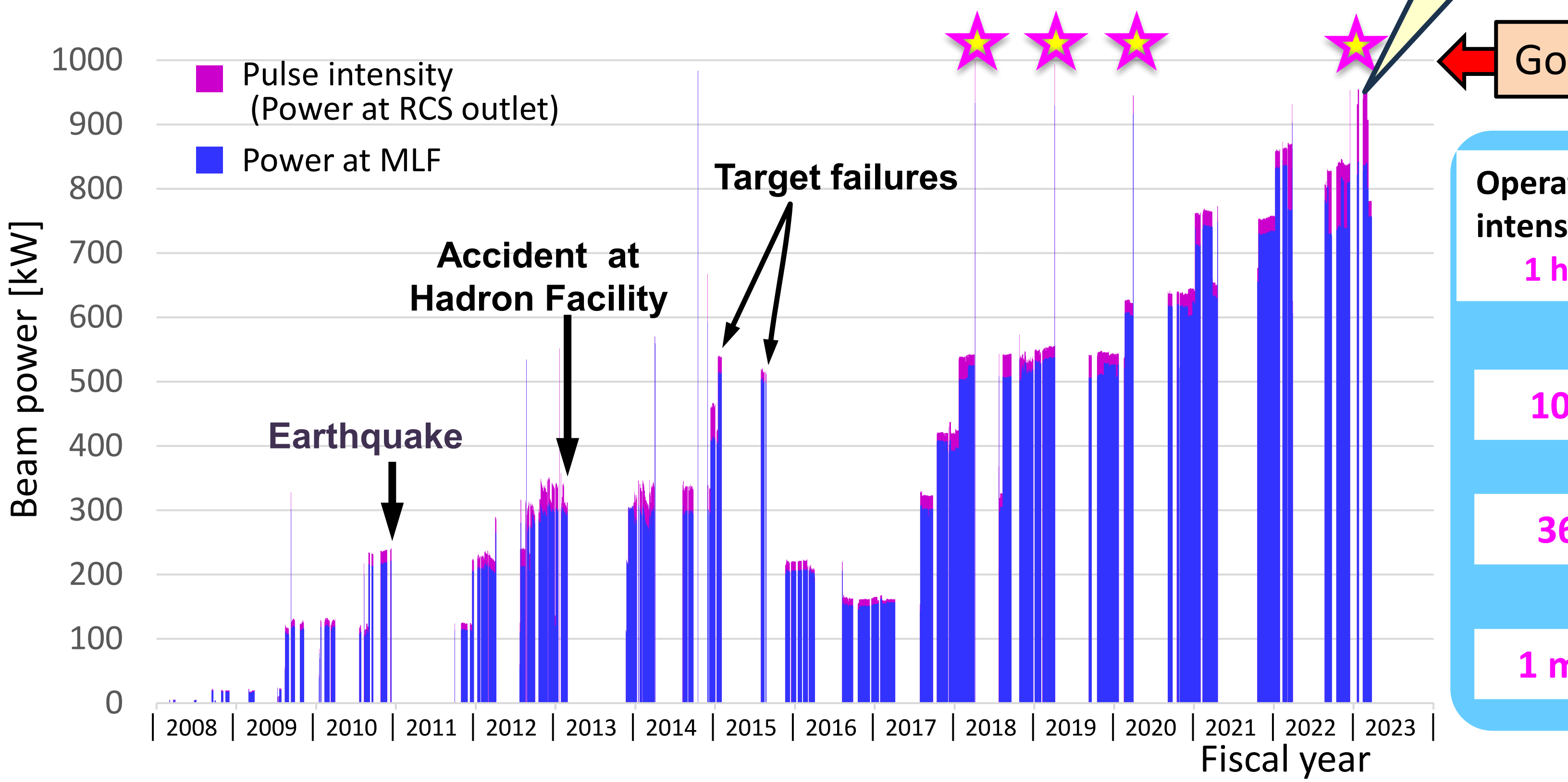
Outline of Mercury Target System



Total length	: 12 m
Total weight	: 315 ton
Mercury inventory	: 1.5 m^3
Mercury flow rate	: 41m^3/hr



Beam power history at MLF



Operation with rated pulse intensity of 1 MW

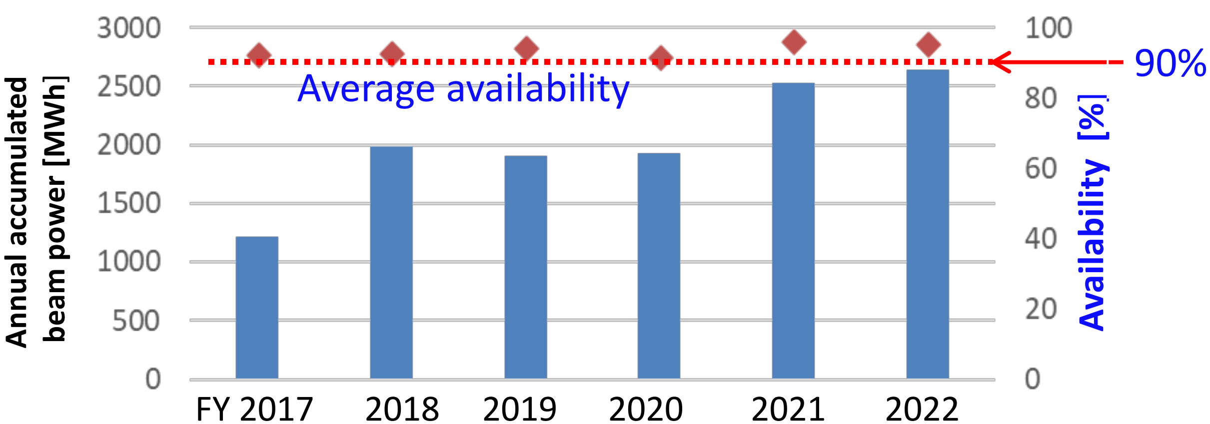
1 h in FY 2018

10.5 h in FY 2019

36.5 h in FY 2020

1 month in FY 2023

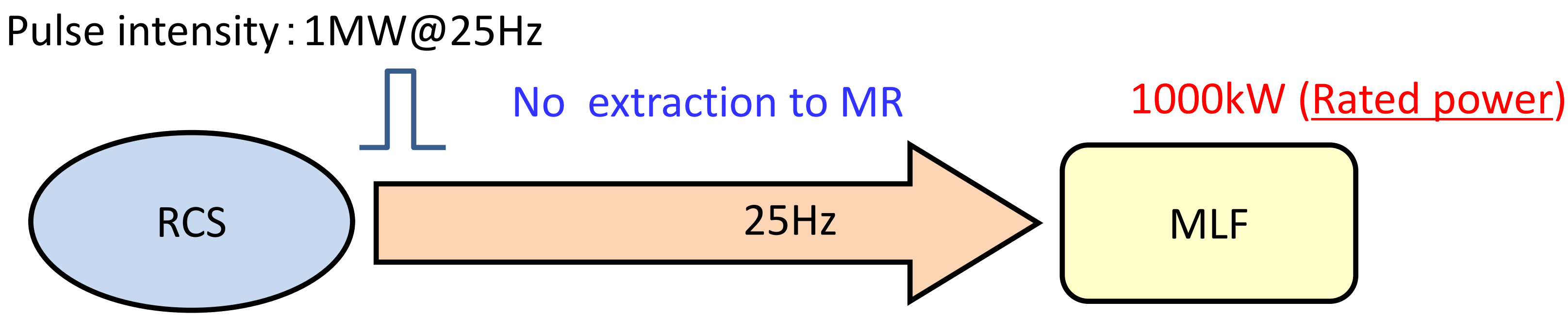
Stable operation with high availability exceeding 90% in recent 6 years

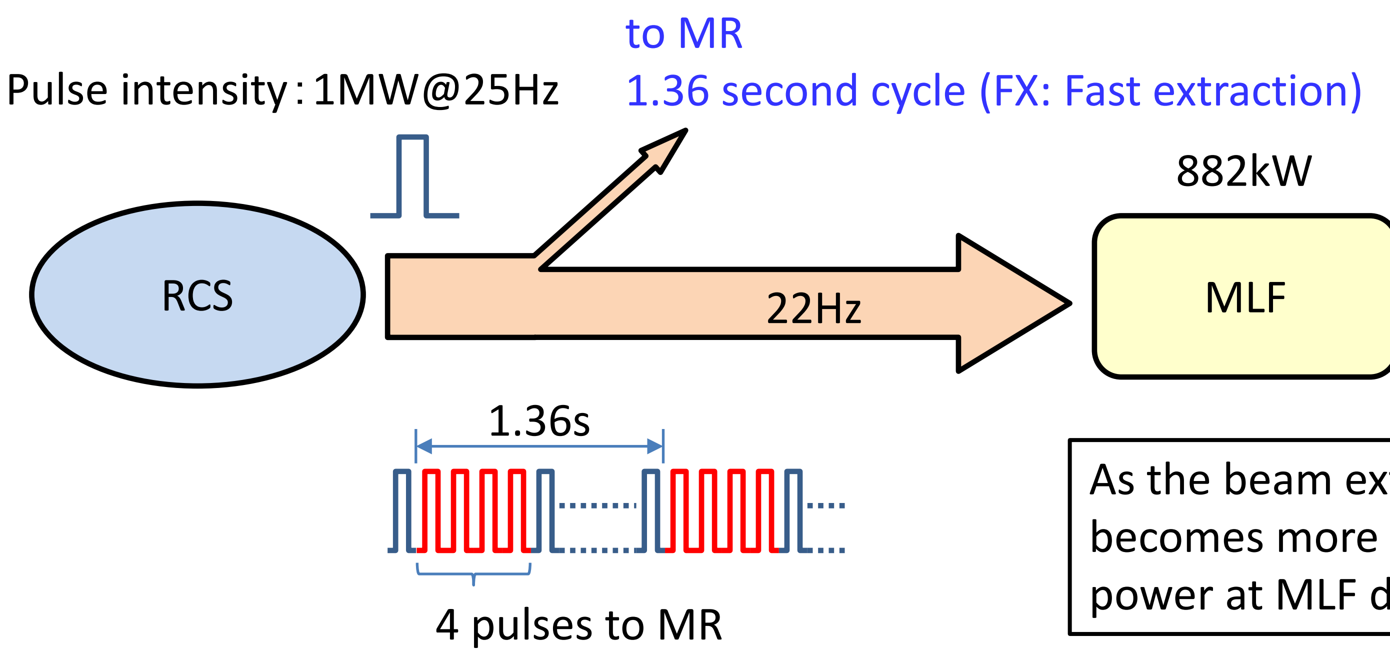


- Pulse intensity has almost reached the final goal of 1 MW!
  - The important milestone was cleared.
- Stable operation was maintained and the average availability over 90 % has been attained.

Beam Extraction to MR

Pulse intensity : Beam power at RCS outlet.

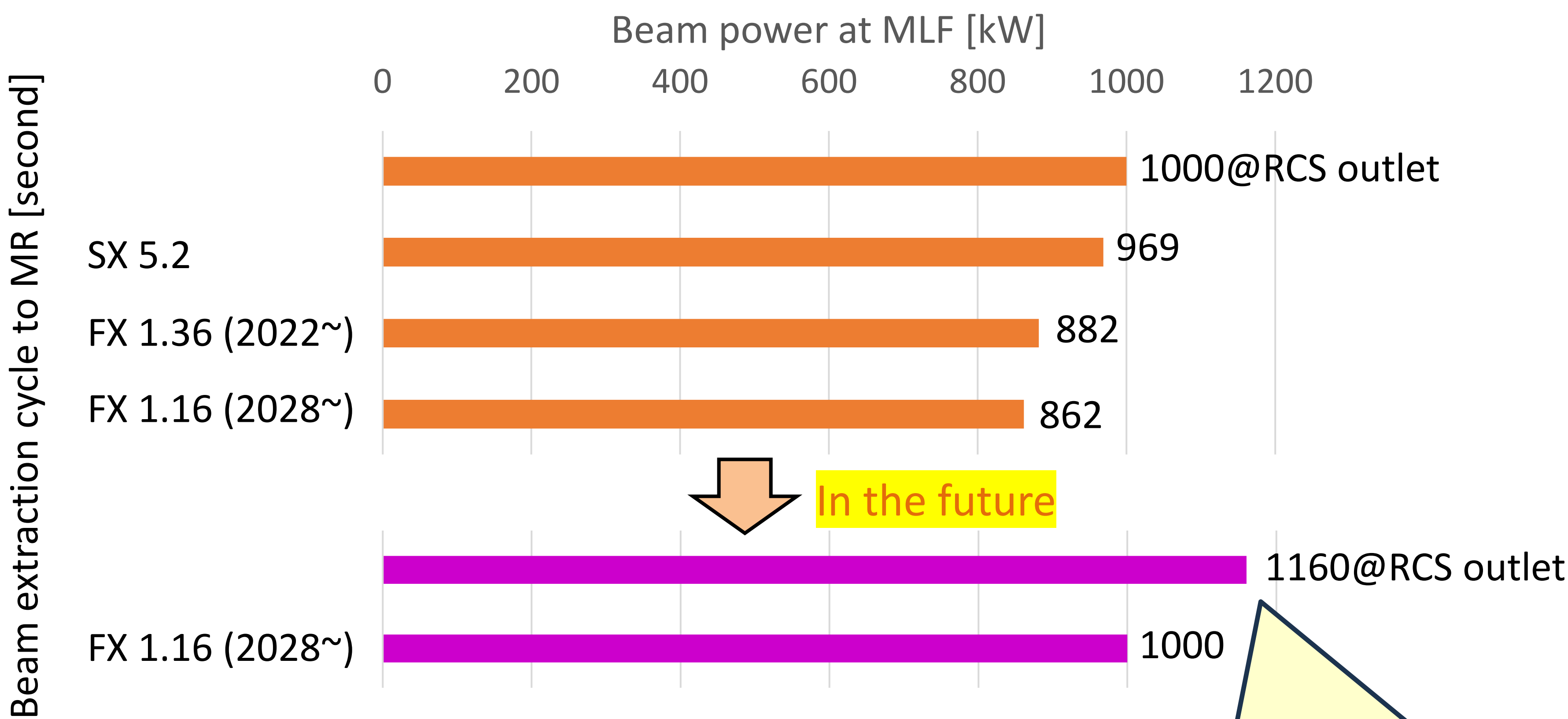




As the beam extraction to MR becomes more frequent, beam power at MLF decreases.

Influence of Beam Extraction Cycle to MR on MLF Power

SX: Slow extraction -> Operation mode for the hadron facility
FX: Fast extraction -> Operation mode for the neutrino facility



Pulse intensity should be 1.16 MW to achieve 1 MW at MLF.

Our Next Challenges for the Target

Stable operation of the neutron source is the first priority.

Essential requirement

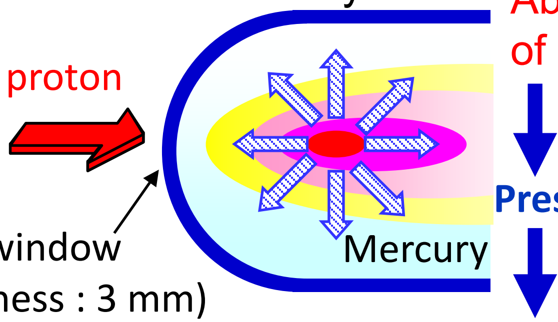
Higher power → 1 MW operation at MLF

R&D of a target vessel endurable against the pulse intensity over 1 MW.

Long operation → 2-year operation of a target vessel

Saving the storage space of the used target vessels is the serious issue.

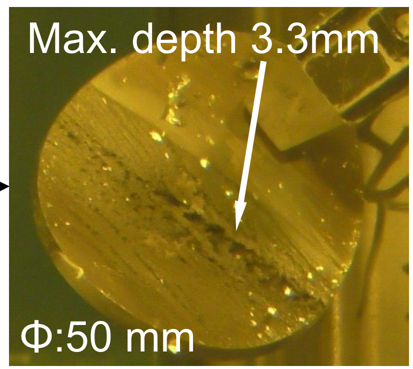
Cavitation Damage is the Major Issue



Beam window (Thickness : 3 mm)
Most vulnerable to pitting damage

Cavitation damage of the wall

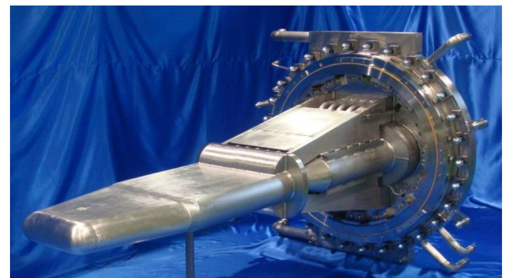
Actual cavitation damage of target #9

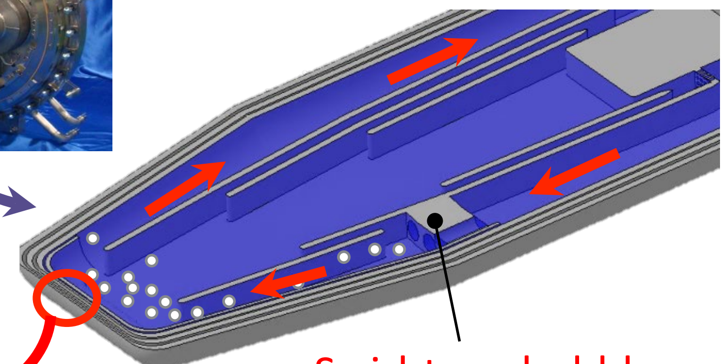


Damage depth is proportional to the 4^{th} power of pulse intensity.

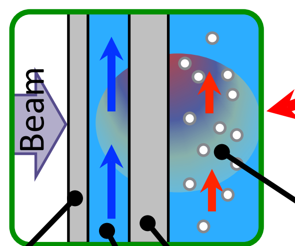
Damage mitigation technologies

- Micro-bubble injection
- Double-walled structure





Double-walled structure



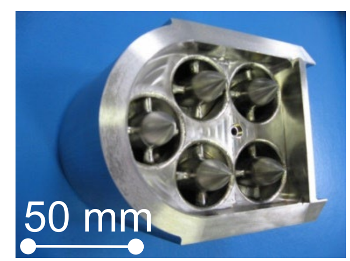
Microbubbles In bulk flow

Outer wall (t:3 mm)

Inner wall (t:5mm)

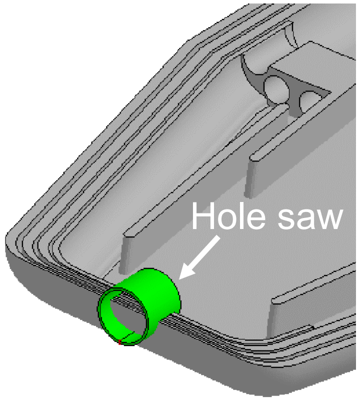
Narrow channel with 2 mm gap (High speed flow of Hg)

Swirl-type bubbler developed in J-PARC

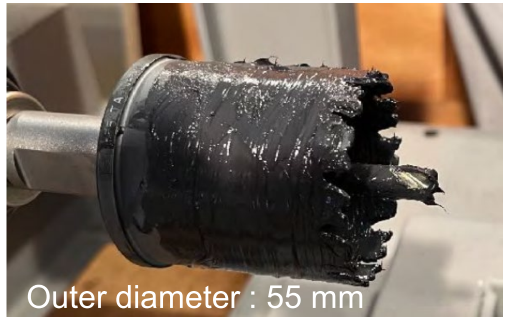


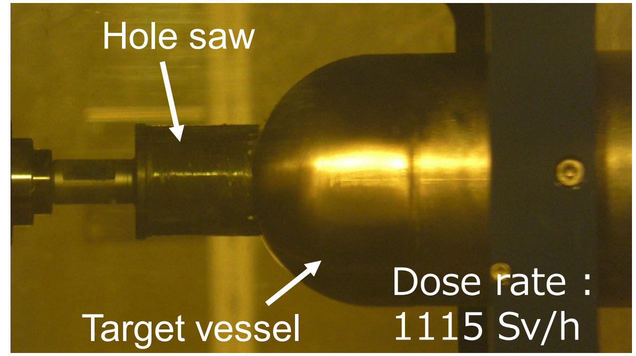
Efficacy of Damage Mitigation Technologies

Specimens were cut out of the beam window wall of the used target vessel.



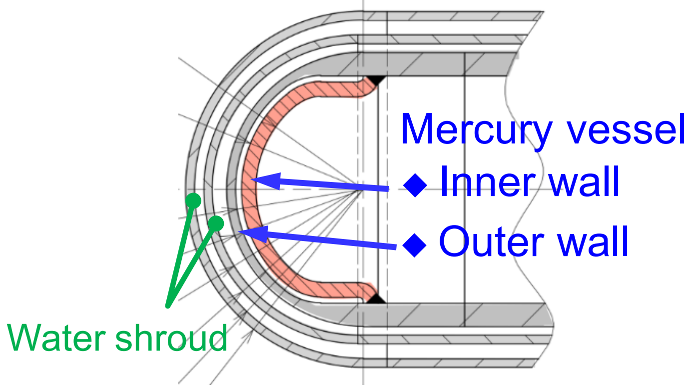
Hole saw with center-drill





Vertical cross-section

Four walled structure



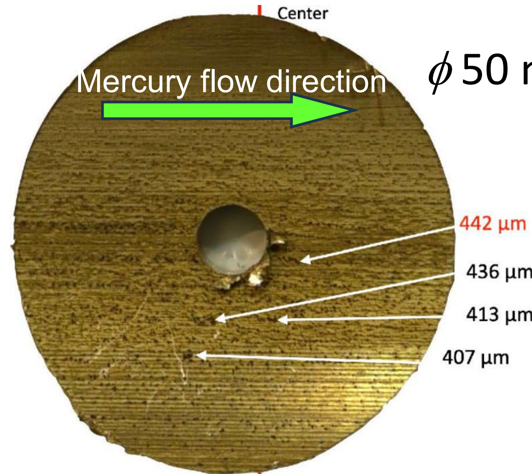
Operation time : 2922 h

Average beam power : 851 kW

Accumulated power : 2273 MWh

Inner wall (t 5 mm)

Protected by micro-bubble effect.



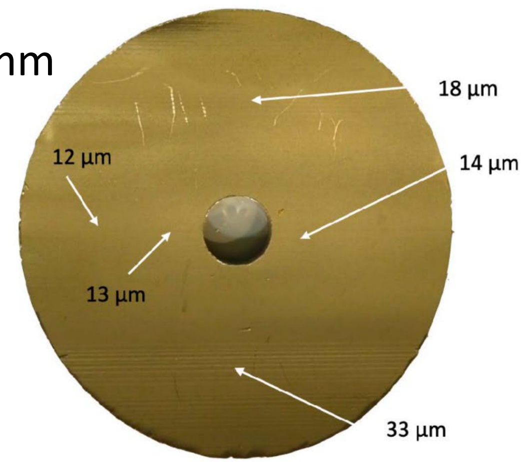
ϕ 50 mm

Max. damage depth : 0.44 mm

(Prediction : 1.2 mm)

Outer wall (t 3 mm)

Protected by narrow channel effect.



No damage.

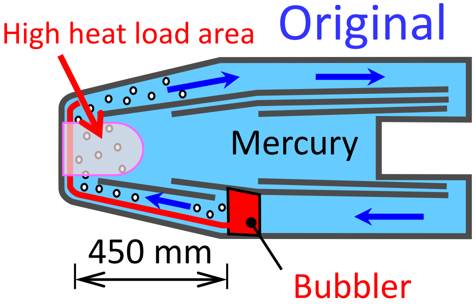
Excellence of damage mitigation technologies was confirmed.

Details will be presented by Dr. Takashi Naoe (ID33) on Friday.

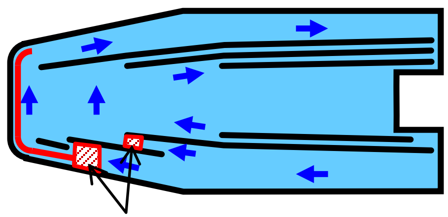
Further Improvement of Target Vessel Design

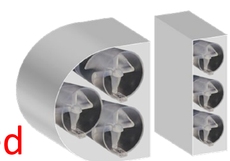
Bubbler was mounted at forward position to increase the bubble number density near the beam window by letting bubbles reach the beam window as much as possible before they rise up by buoyancy.

Original



New structure (2023~)





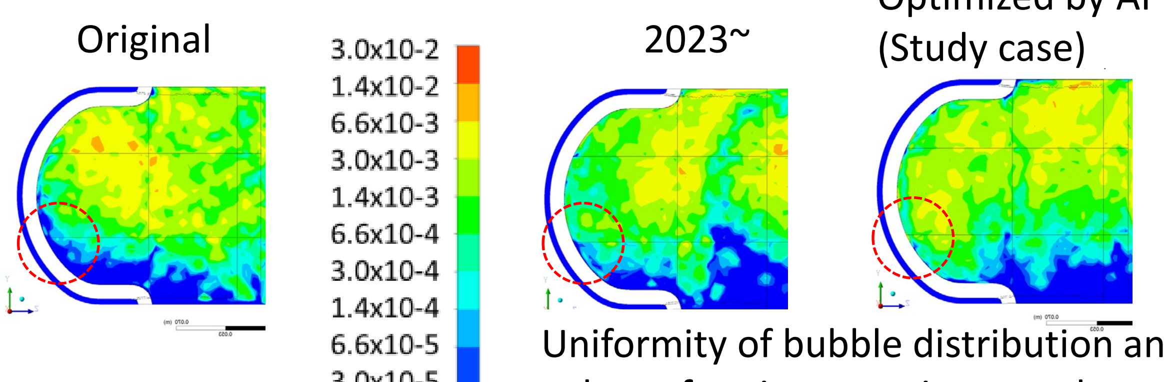
In future

Design optimization by AI
- Angle of flow vanes
- Bubbler position
- Bubbler structure

<u>Pulse intensity : >1 MW</u>
<u>Power at MLF : 1 MW</u>
<u>Lifetime : 10,000 hr (2 year)</u>

Bubble number density near the beam window is expected to be nearly 3 times larger than original one and its distribution is uniform in the vertical cross-section.

Bubble volume fraction in Vertical cross-section at the beam window (Analytical simulation)



Uniformity of bubble distribution and volume fraction were improved.

Parameter Evaluation for 2-year Operation

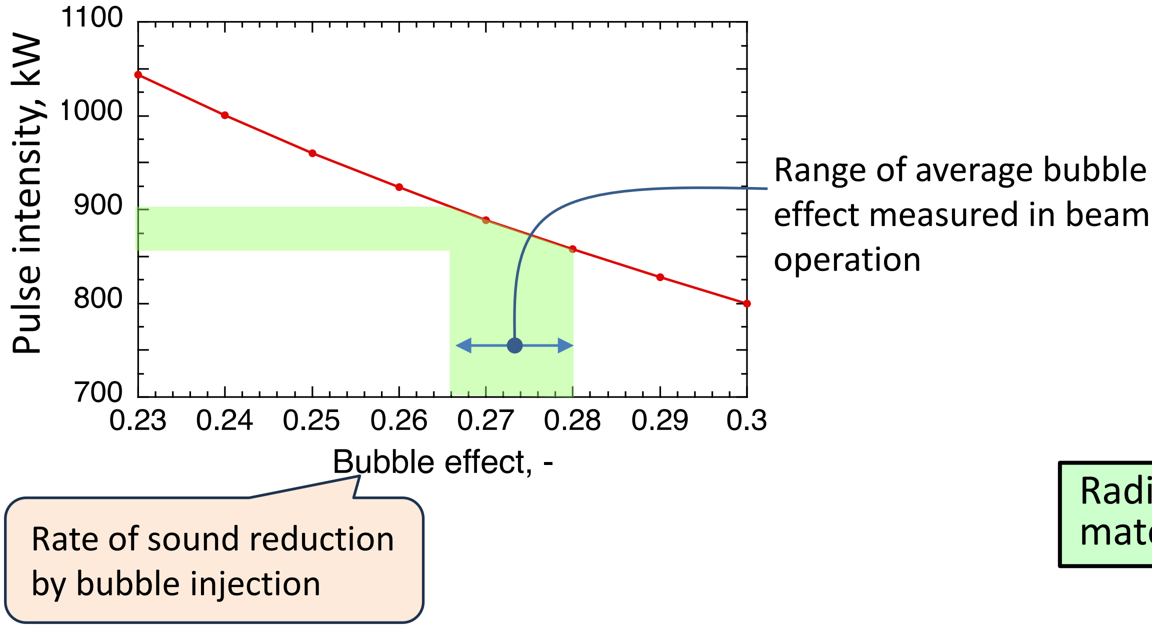
Operation time

- Total operation time for 2-year was assumed to be 7600 hr which would be approved by government budget.

Matters of concern

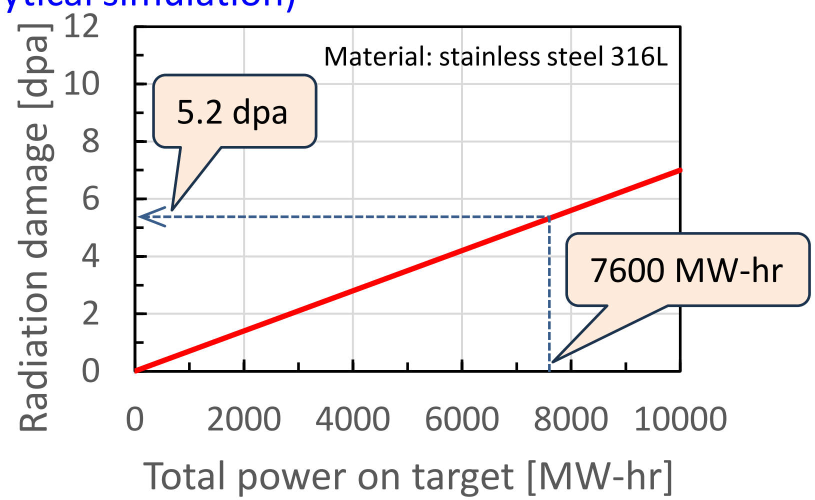
Pitting damage

Conditions at which the pitting damage penetrates the thickness of 5 mm of inner wall.
(Based on data of original-type target)



Radiation damage

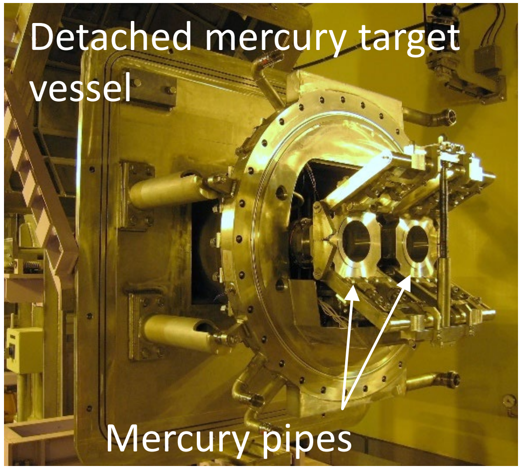
Radiation damage of the beam window of a target (Analytical simulation)



Radiation damage of 5.2 dpa is still half of the material property limit of 12 dpa suggested by SNS.

- In view of pitting damage and radiation damage of a target vessel, 2-year operation can be carried out without sacrificing the beam power and increasing the risk of target failure so much.

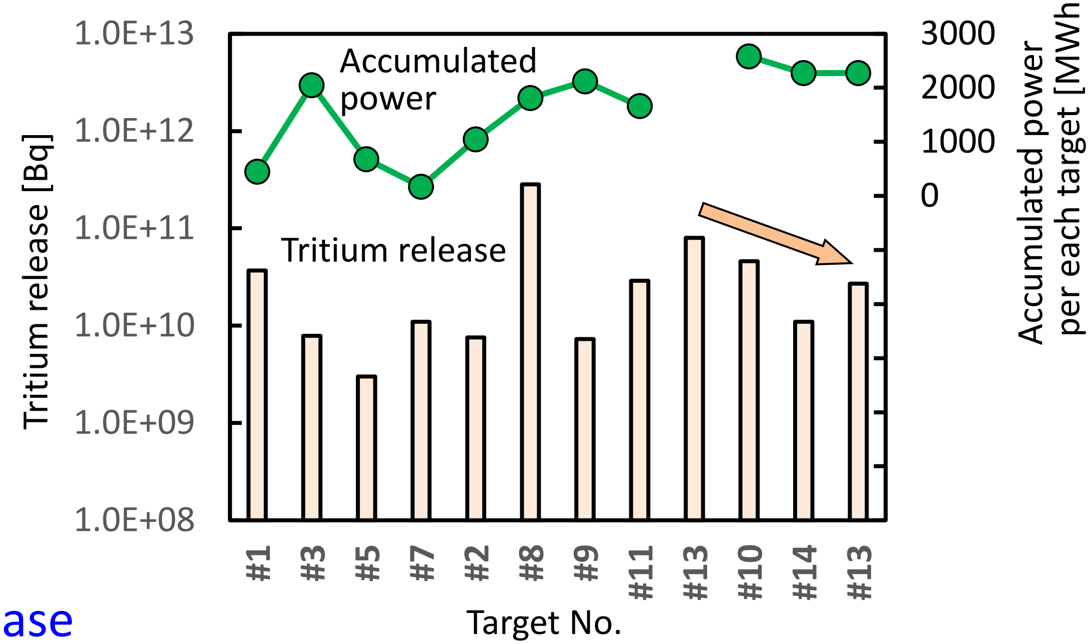
Tritium Release during Target Replacement



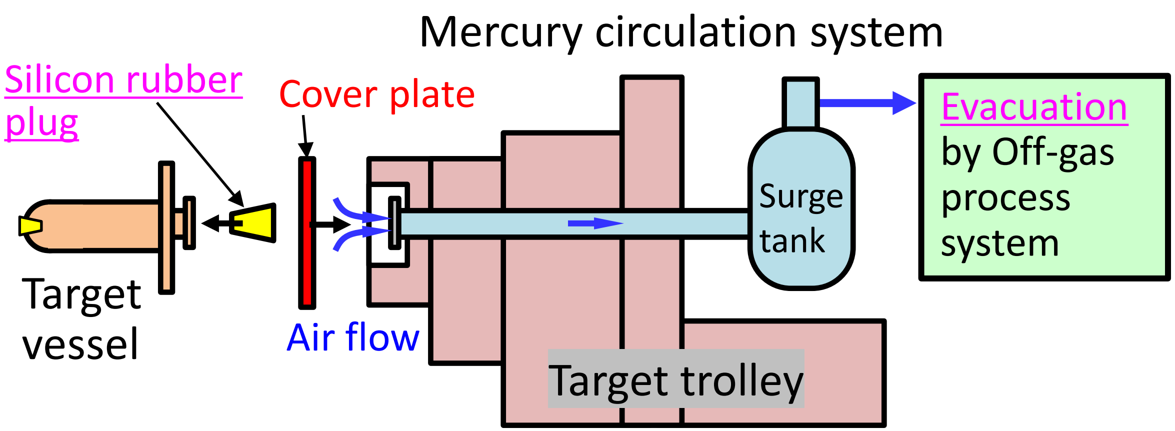
Estimated amount of tritium produced in a target by 1 year beam operation with 1MW : ～100TBq

Part of the tritium is released to atmosphere when the target vessel is detached from the target trolley.

Amount of tritium released through the stack during target vessel replacement



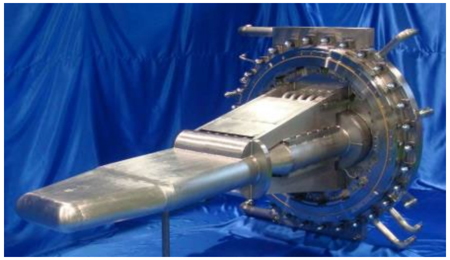
Procedure to suppress tritium release



- Released amount is less than 1/250 of upper control limit.
- Tritium release should be suppressed to the level below the minimum limit of detection at the monitoring posts in public area.

The issue remains important because the total amount of tritium in the target system will increase with higher beam power in the future.

Storage Space of Used Target Vessels is Another Serious Issue



Used mercury target vessel

Stored temporally on the basement floor of MLF for several years.

Container

Shielding container

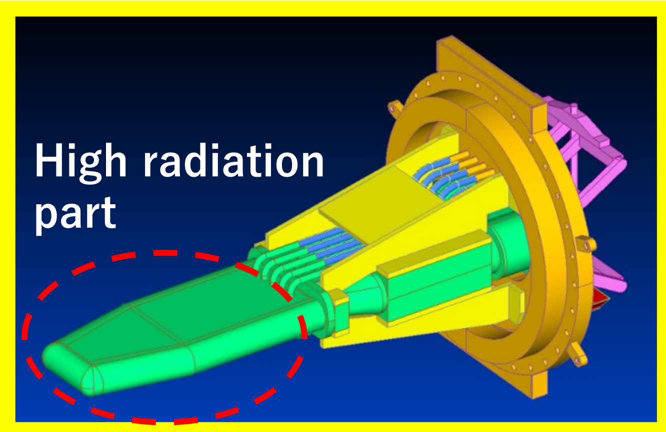
Shipping container

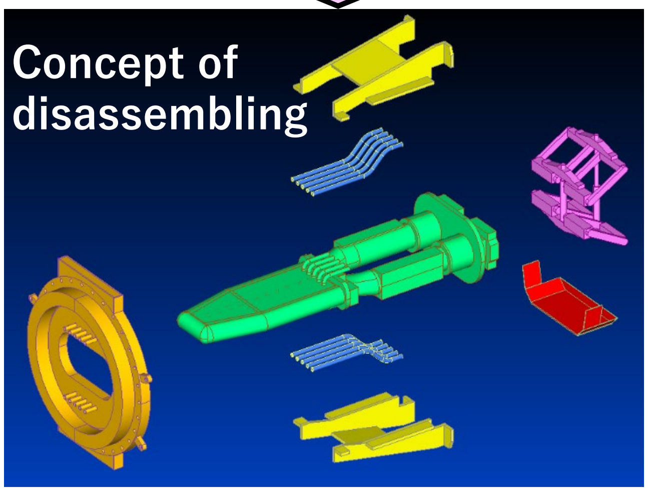
Shipping container is used repeatedly.

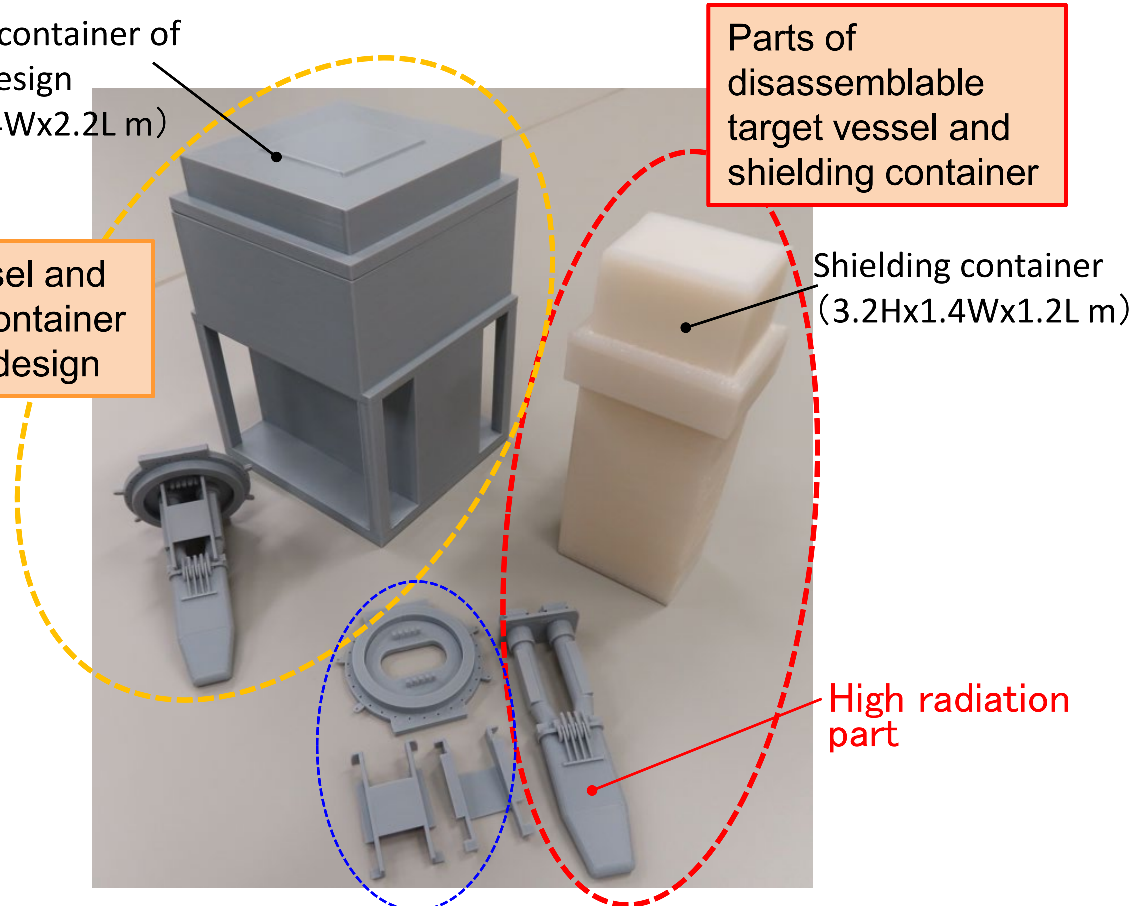
Stored in the pit of RAM building

- The highly activated target vessel need cooling time of more than 30 years.
- RAM (Radio Active Material) building will reach the limit of storage space in 2034 if no countermeasures are taken.
- Storage space should be saved by volume reduction and long operation of the target vessels.

Development of Disassemblable Target Vessel for Volume Reduction





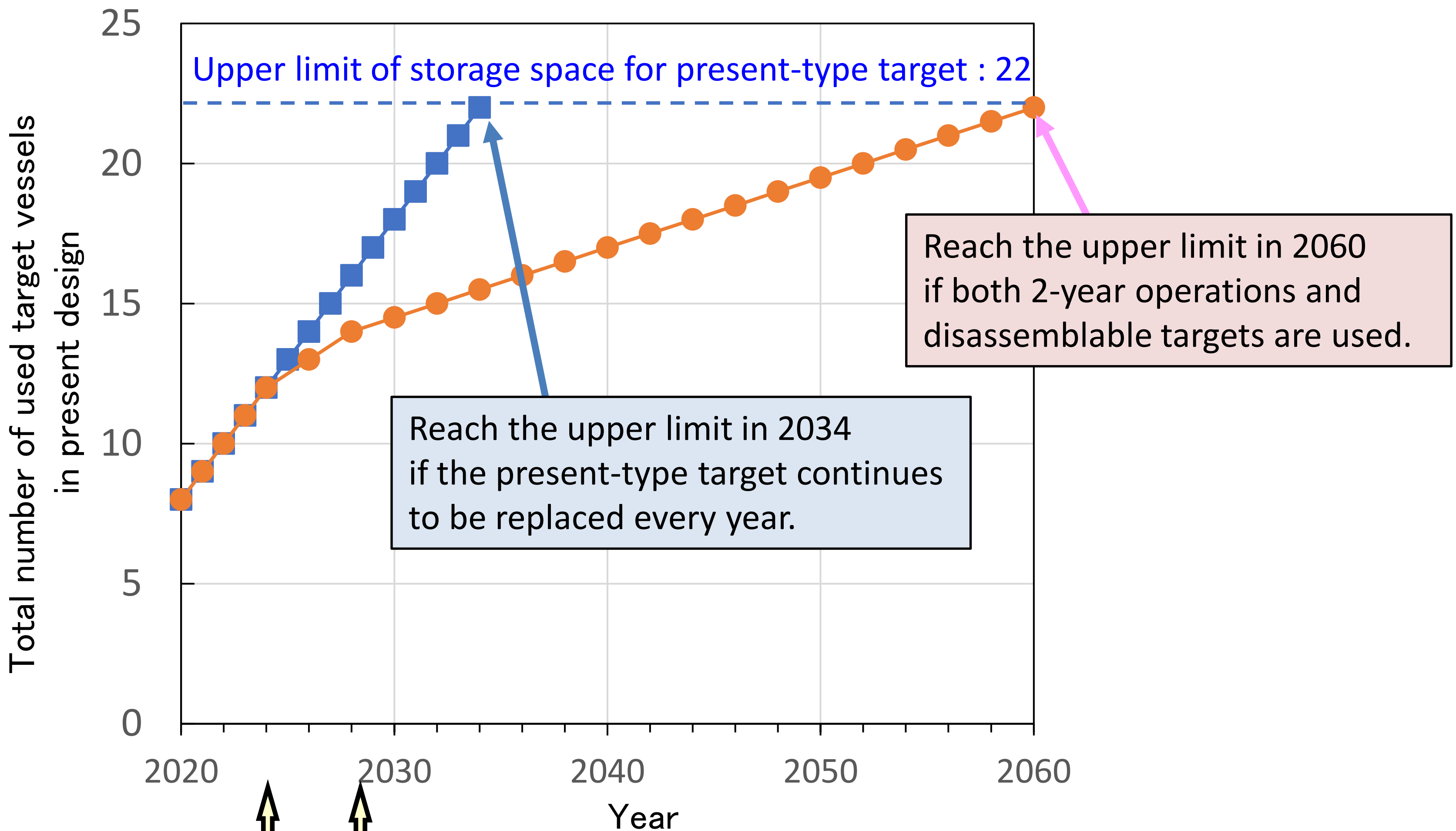


1/20 scale model

- High radiation part is separated from other low radiation parts.
- Two shielding containers of disassemblable targets can be stored in the space of one conventional shielding container, that enables more targets to be stored in RAM building.
- Low radiation parts should be handed to backend section at early stage.

Estimation of Total Number of Used Target Vessels

*Precondition : Two shielding containers of disassembled targets can be stored at the space for one shielding container of a present-type target.



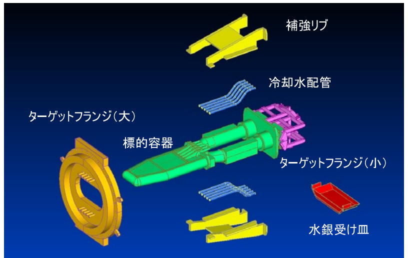
2024:
Start of 2-year operation

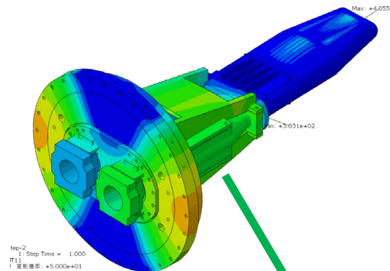
2028:
Start of disassemblable target operation

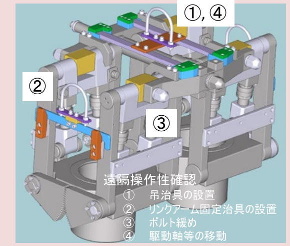
Final disposal site is expected to be decided near future.

R&D of Disassemblable Target

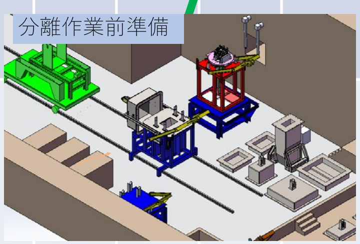
- Study of structural feasibility has been almost completed.
- R&D of remote-handling techniques are going on and the results will be reflected on the target design.
- Design of the storage/shielding container of the disassembled components are in the next step.





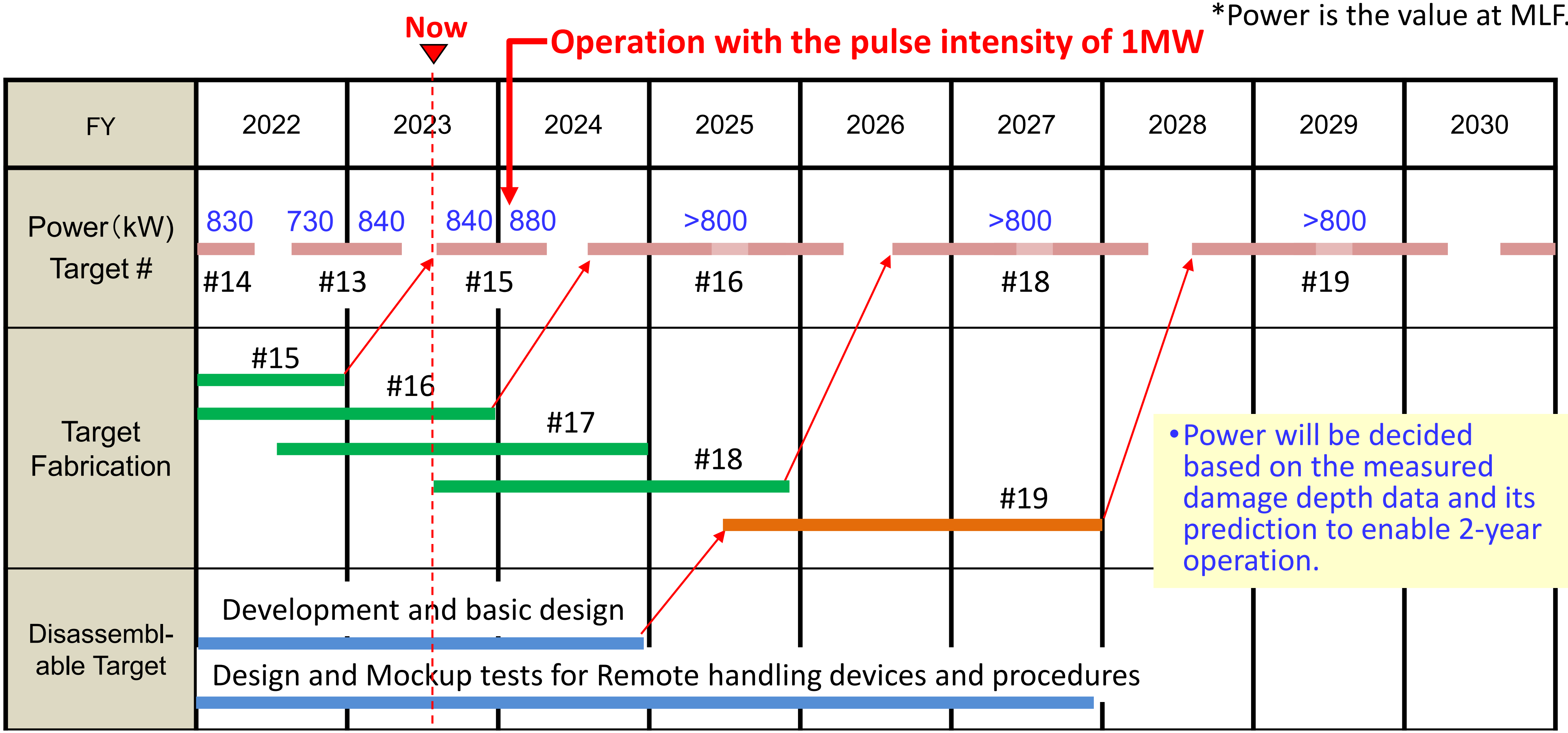


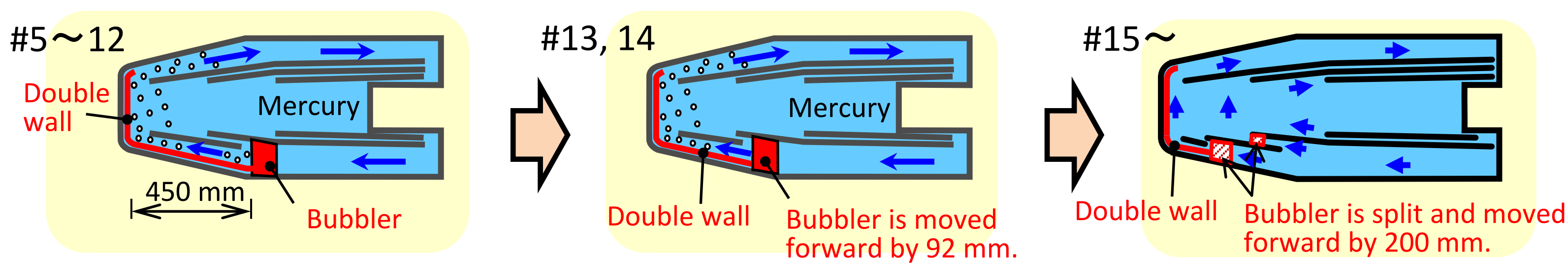
Items	FY 2020				FY 2021				FY 2022				FY 2023				FY 2024			
	4-	7-	10-	1-	4-	7-	10-	1-	4-	7-	10-	1-	4-	7-	10-	1-	4-	7-	10-	1-
Target container	・Conceptual design																			
		・Target structural design																		
					• Flange seal mock up • Detachable mercury pipe connector mechanism mock up															
Remote handling		・Remote handling concept																		
		・Mock up test for remote handling																		
																		・In-cell test		
Storage / Shielding container															・Conceptual design					
																		・Drawing		



Operation Plan of Neutron Source

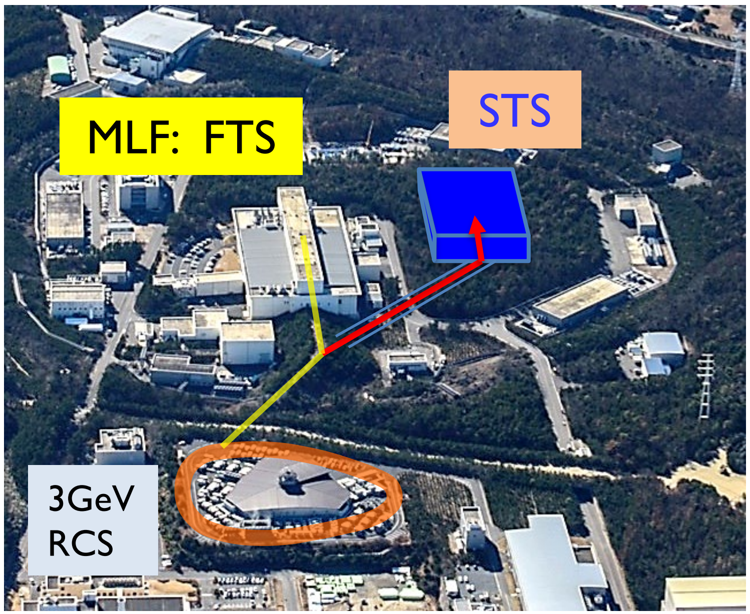
*Power is the value at MLF.





Future Plan : Pulse Intensity Rise for Second Target Station (TS2)

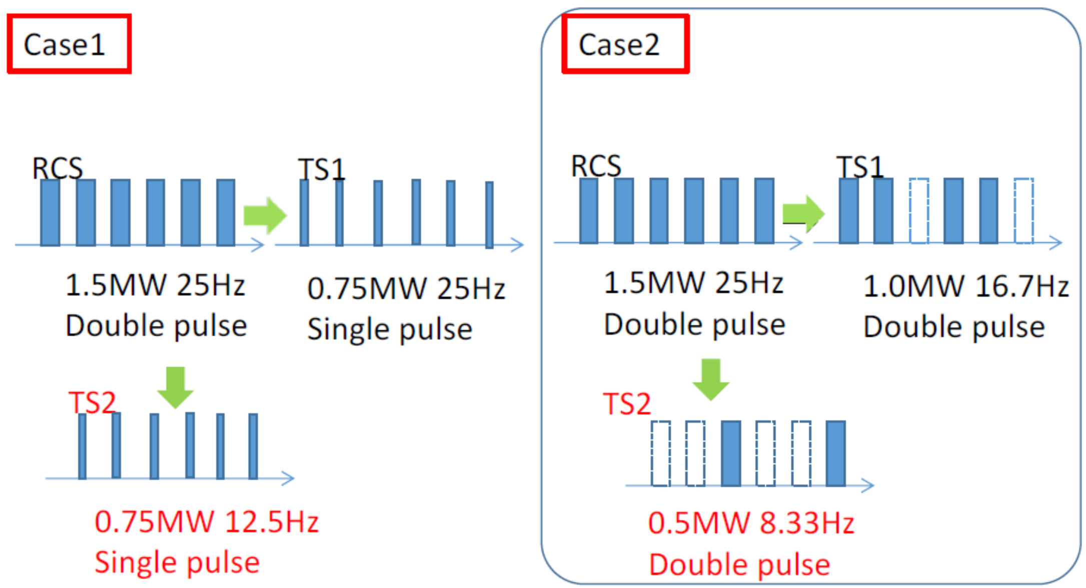
- Conceptual design report of TS2 was completed in 2020.
- As the first target station (TS1) is getting closer to the final goal of 1 MW operation, it's time to start the serious discussion on the TS2 plan.
- TS2 aims for the neutron beam of more than 20-times higher brightness than TS1.



Case study of proton beam sharing

Proton beam : 1.5 MW, 25 Hz at RCS outlet

(MR share is not considered here.)



TS1:TS2=0.75MW:0.75MW TS1:TS2=1.0MW:0.5MW

- TS1 target should endure the pulse intensity of 1.5 MW.
- TS2 target should endure the high heat density.

R&D for the high-power target will go on.

Summary

- ◆The pulse intensity has almost reached the final goal of 1 MW with high operational availability of over 90% for user program.
- ◆The higher power with the pulse intensity over 1 MW and the long operation of a target vessel are the next challenge.
- ◆The target vessel with new structure will start its operation this year and further improvement of a target vessel design by AI is going on.
- ◆Volume reduction and long operation of the target vessels are the critical requirement to save the storage space of the used target vessels.
- ◆R&D of a disassemblable target is going on aiming at the operation start from 2028.