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Status and upgrade plan of the pulsed spallation neutron source at MLF, J-PARC

Masahide Harada
Neutron Source Section
Materials and Life Science Division
J-PARC center, Japan Atomic Energy Agency

Contents

- Introduction
- J-PARC Neutron Source
- Operation Status, trouble, recovery, challenge
- Future plan
- Summary

Introduction

- The pulsed spallation neutron source at the Materials and Life Science Experimental Facility (MLF) of the Japan Proton Accelerator Research Complex (J-PARC) consists of a mercury target, three liquid-hydrogen moderators and a beryllium and iron reflector, providing high intense pulsed neutron beam toward to 21 instruments.

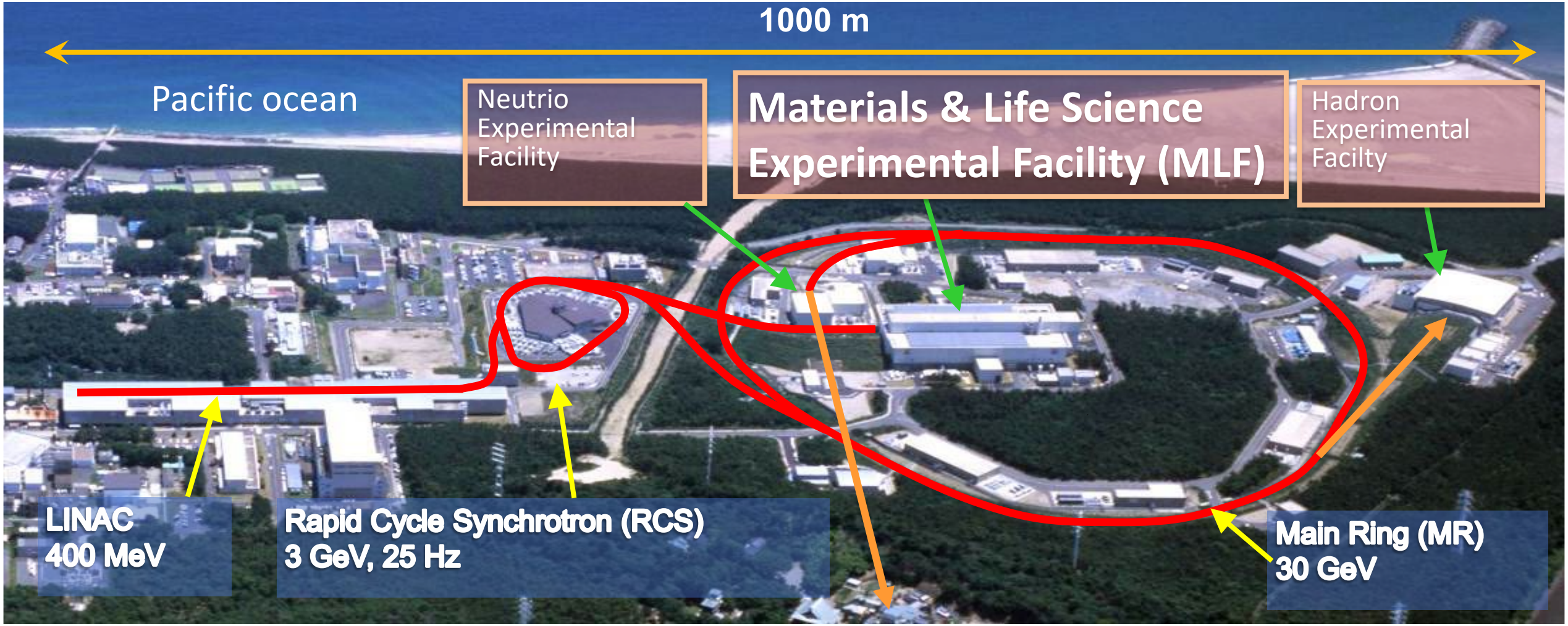
- In both 2024 and 2025, moisture in a helium vessel was detected during beam operation, leading the beam operation stop. In each case, the target vessel was replaced with a new one. The current target vessel is challenging toward a two-year operation under 800 kW equivalent proton beam.

- Ongoing efforts to improve the neutron source include the development of the mitigation technique for cavitation damage in target vessel, abnormal incident detection of target vessel, and so on.

- Report on the current status and upgrade plan of the pulsed spallation neutron source at MLF, J-PARC.

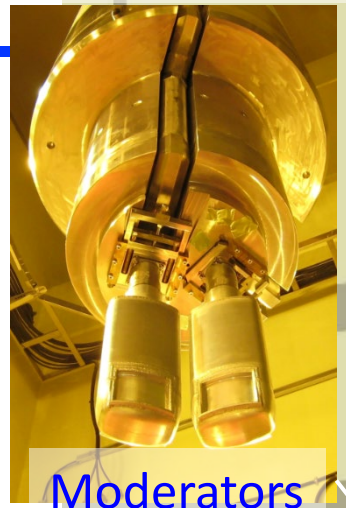
J-PARC

JAEA J-PARC MLF J-PARC MLF

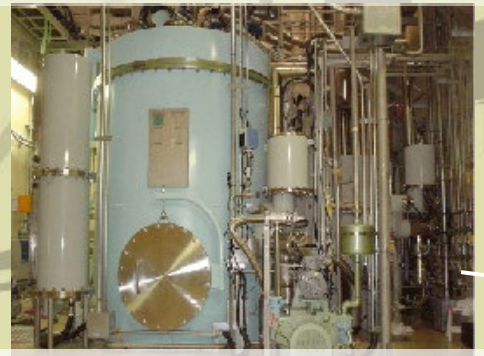


3 accelerators & 3 experimental facilities

1-MW spallation neutron source at J-PARC MLF



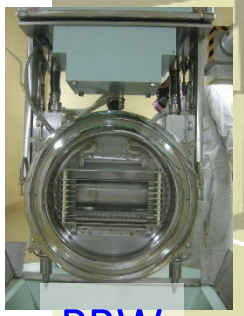
Moderators



Cryogenic hydrogen system

Maintenance area
(Hot cell)

Core vessel



PBW

Mercury target system

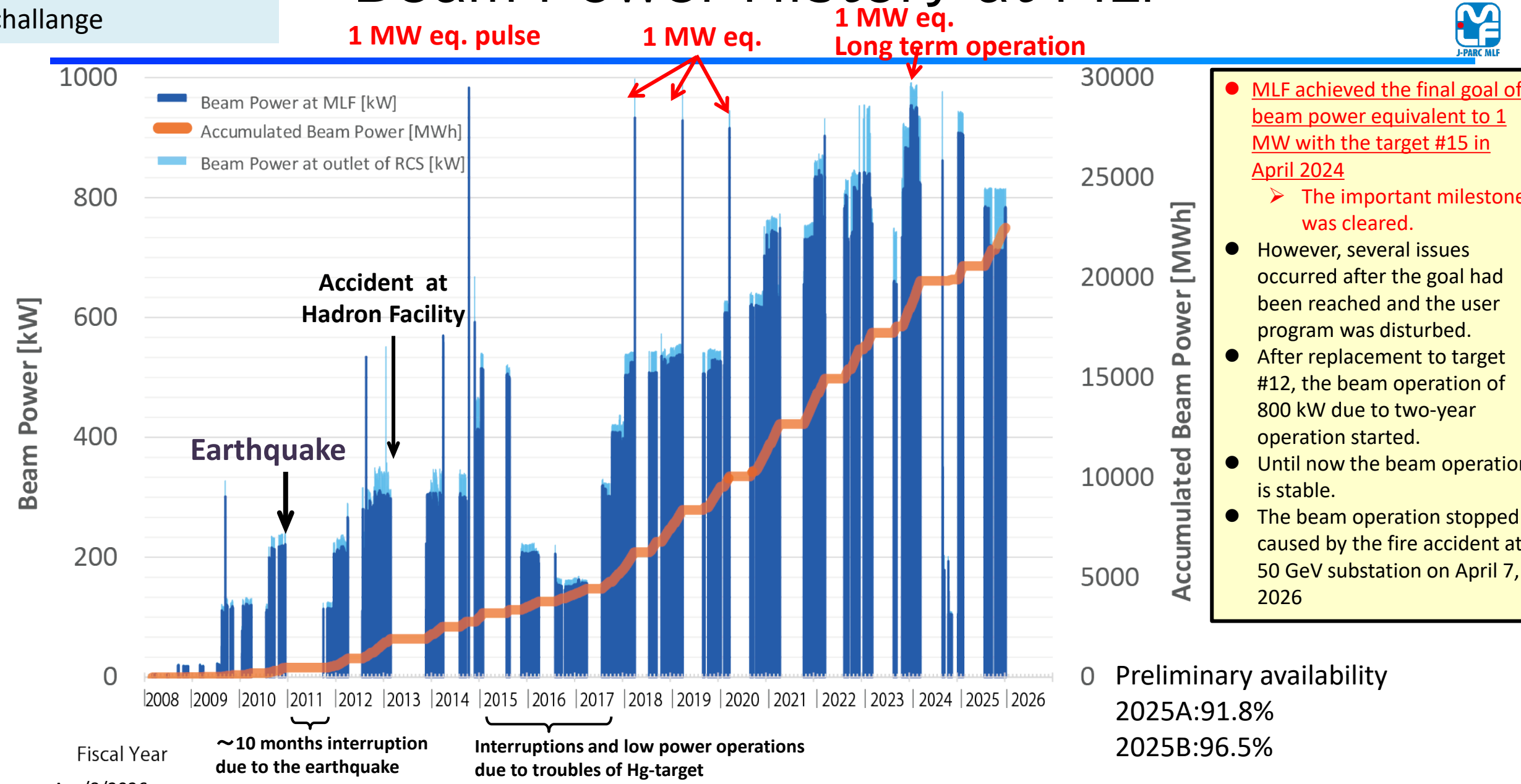
Pulsed proton beam
3 GeV, 1MW, 25 Hz
Pulse width : 1μs

5m

Neutron beam line ports (23)
21: in operation

Operation Status, trouble, recovery, challange

Beam Power History at MLF



- MLF achieved the final goal of beam power equivalent to 1 MW with the target #15 in April 2024
  - The important milestone was cleared.
- However, several issues occurred after the goal had been reached and the user program was disturbed.
- After replacement to target #12, the beam operation of 800 kW due to two-year operation started.
- Until now the beam operation is stable.
- The beam operation stopped caused by the fire accident at 50 GeV substation on April 7, 2026

Preliminary availability
2025A:91.8%
2025B:96.5%

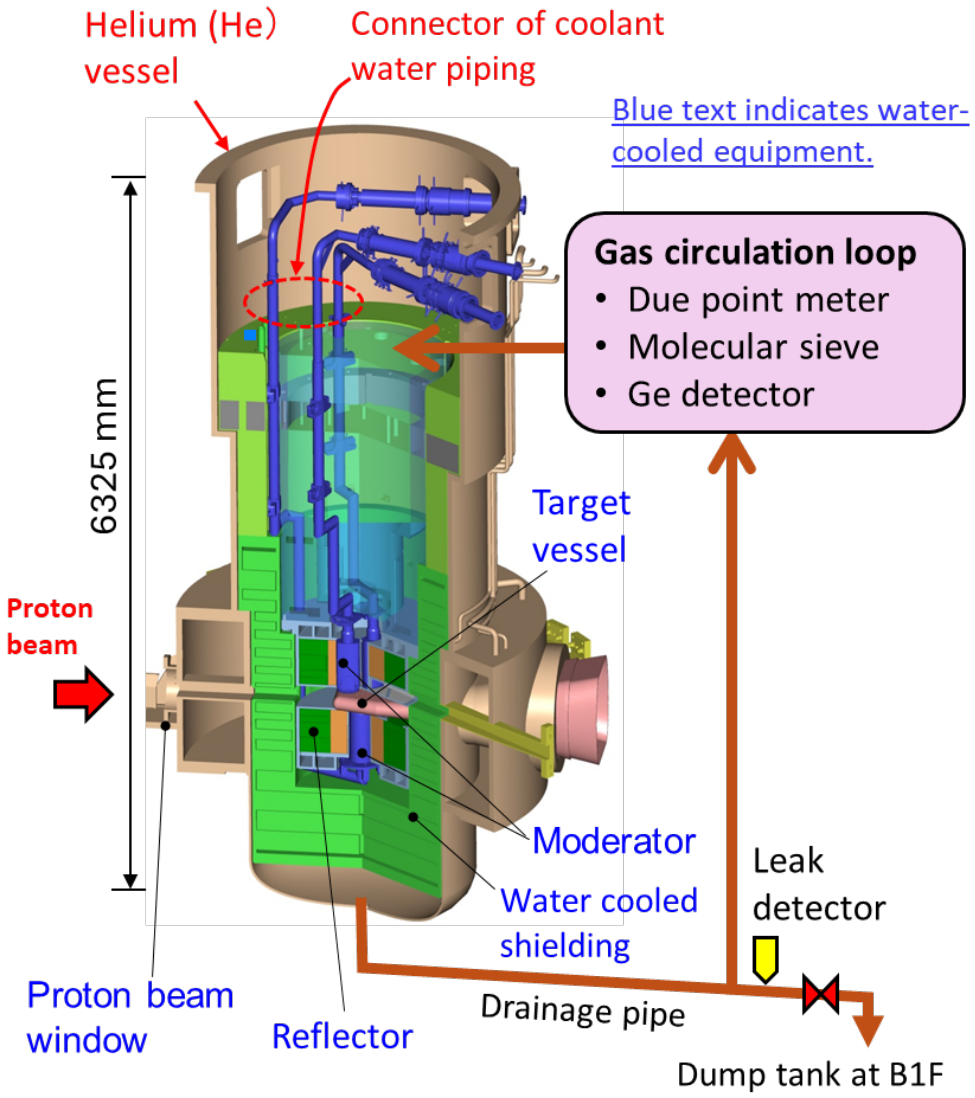
Apr/8/2026

Recent events in the neutron source

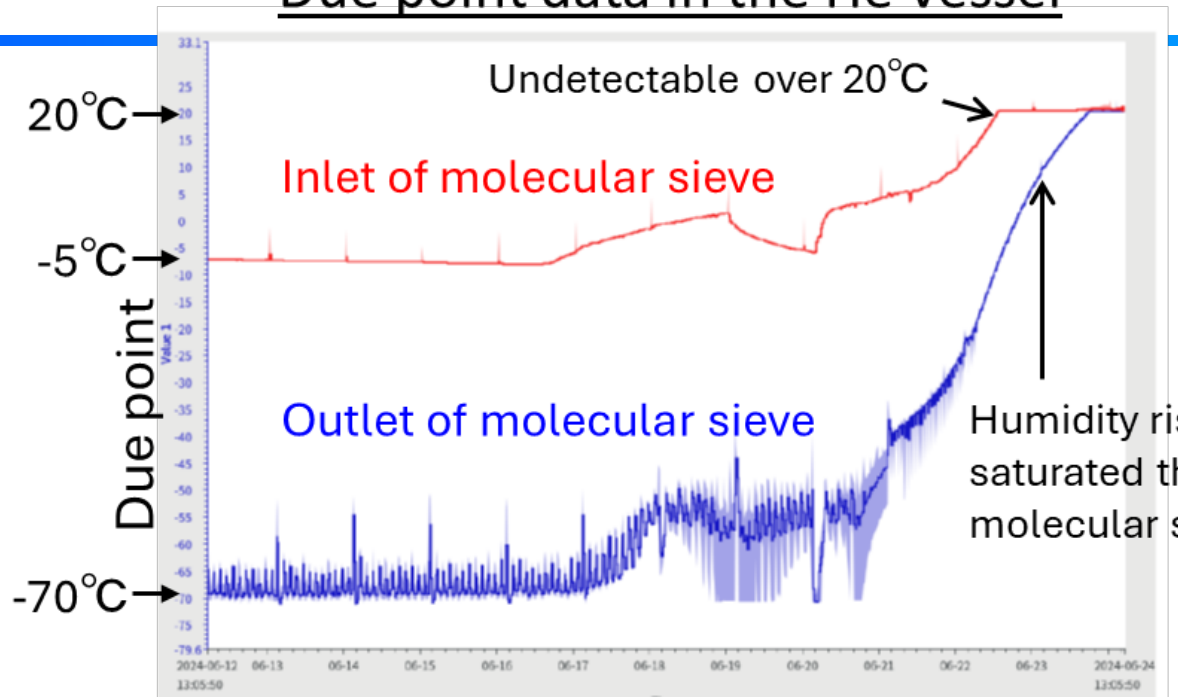
Troubles *Maintenance* *Beam operation*

- May 2024 : Achieved the stable 1MW beam operation with 50 days
- June 2024 : Water detection in the helium vessel (The beam operation stopped)
- June 2025: Transport of target vessels #9 and #11 to RAM building
- Sep. 2024 : Cutting and damage inspection of target #15
- Sep. 2024 : Failure of the power manipulator
- Oct. 2024 : Target vessel replaced to #16
- Oct. 2024 : Mercury pump replaced due to the reduction of insulation resistance
- Nov. 2024 : Elevated radioactive gas level by pump-related leakage from mercury pipe flange
- Mar. 2025 : Mercury flange metal seal replaced
- Apr. 2025 : The beam operation resumed with 1 MW proton beam power
- May 2025 : Water leak from water shroud of target #16 (The beam operation stopped)
- June 2025: Transport of target vessels #10 and #11 to RAM building
- Jul. 2025 : Target vessel replaced to #12
- Aug. 2025 : Proton Beam Window #4 cutting water channels and storage into the cask
- Sep. 2025 : Replacement of power cables for mercury pump
- Oct. 2025 : The beam operation resumed with 780 kW proton beam power for 2-year operation
- Apr. 2026 : The fire accident at the 50 GeV substation (The beam operation stopped)

Humidity Rise in the Helium Vessel Caused Early End of User Program



Due point data in the He vessel



Sequence of events

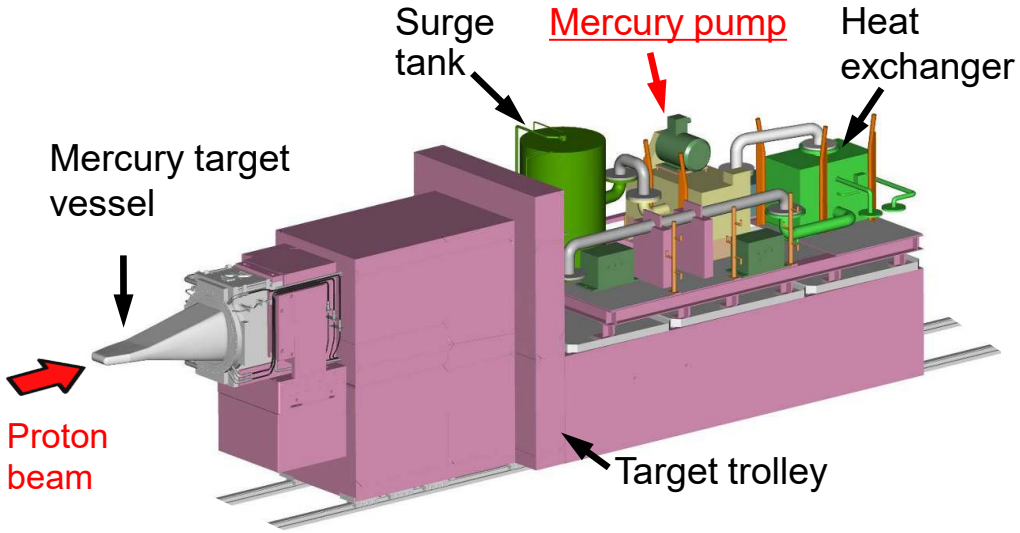
- The due point meter detected the increase of humidity that was higher than usual in the He vessel on Jun. 24, 2024.
- MLF user beam operation was stopped 7 days earlier than scheduled date .

Cause investigation

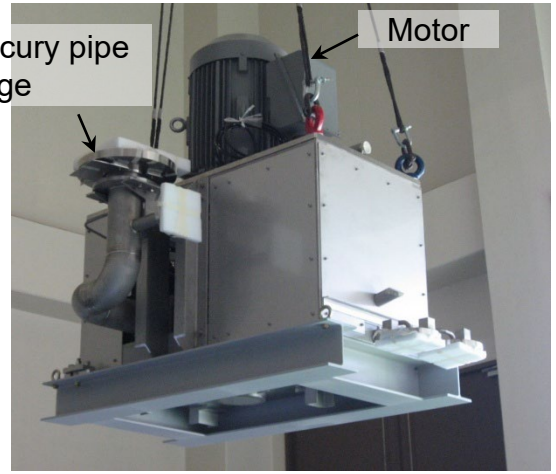
- ◆ It was found that the seal performance of the target vessel pillow seal deteriorated repeatedly during June, which might caused intrusion of humid air into the He vessel.

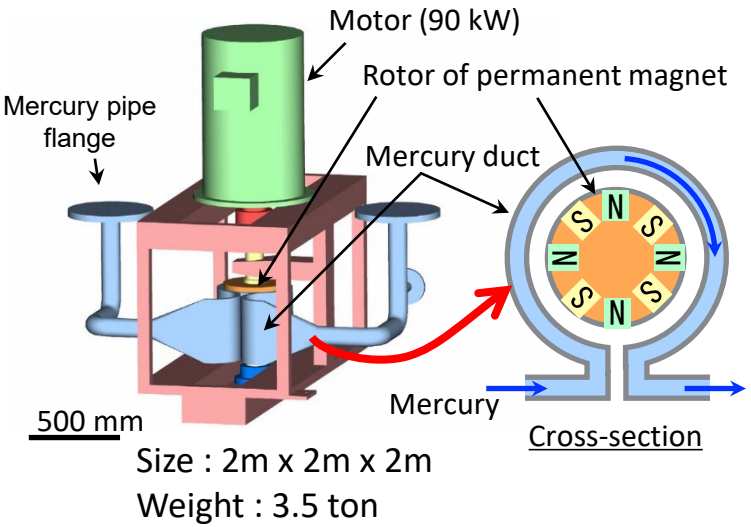
Mercury Pump was Replaced in 2024

Mercury target system

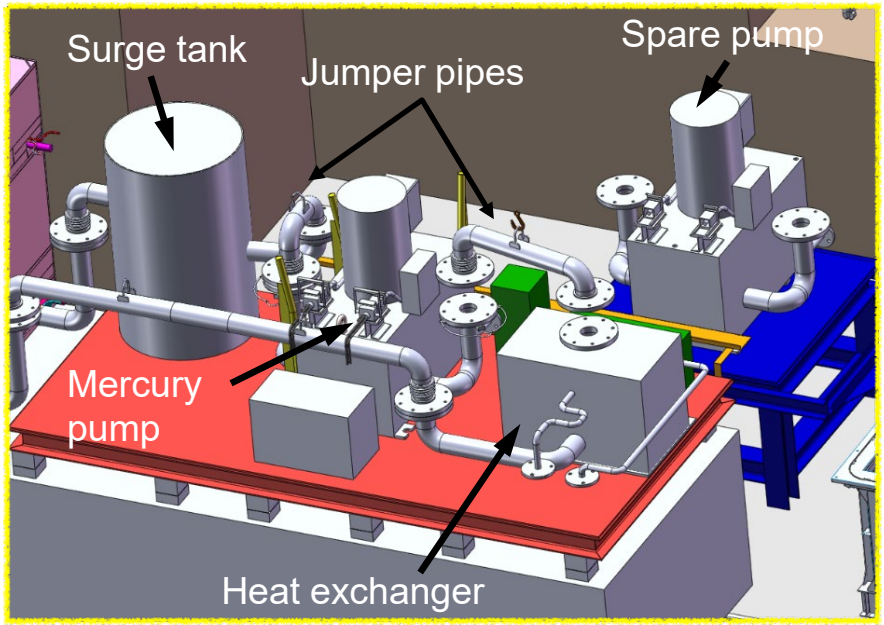


Mercury pump



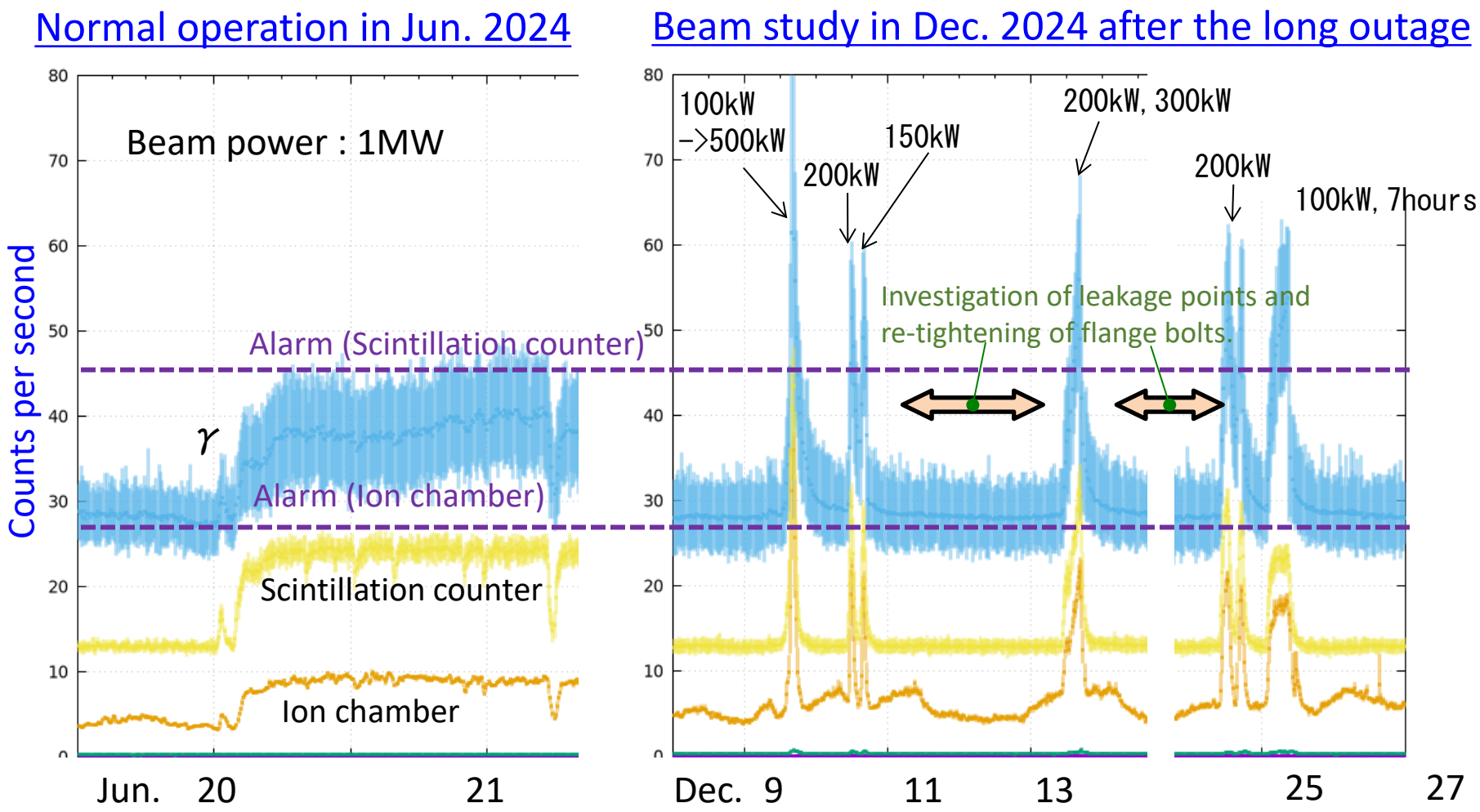


Size : 2m x 2m x 2m
Weight : 3.5 ton



- The insulation resistance of the motor declined to around 1MΩ and we decided to replace the mercury pump.
- The mercury pump is connected to the surge tank and the heat exchanger by jumper pipes with inner diameter of 143.2mm.
- The replacement work was successfully completed with the elaborate practice and dedication of the neutron source section member.

Rise of Stack Monitor Indication after Mercury Pump Replacement



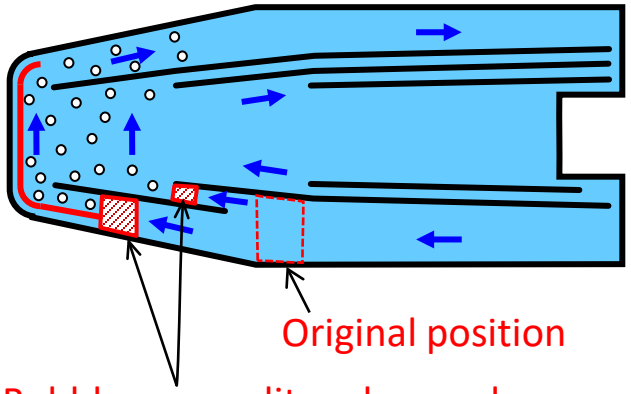
- The beam operation of MLF started on Dec. 9 in 2024, but the stack monitor indication increased sharply over the alarm level, which might be caused by insufficient seal of the mercury pipe flanges after the mercury pump replacement. →
- The 1MW beam operation resumed on April 7, 2025. However, it took 4 months.

Efficacy of Damage Mitigation Technologies

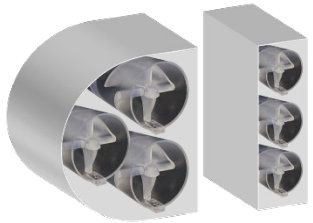
#15 target vessel

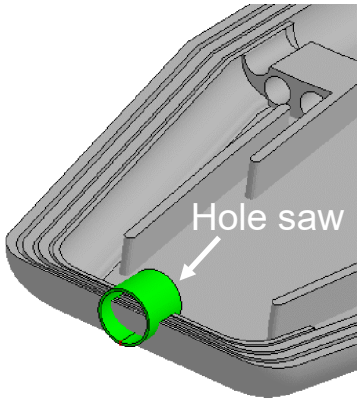
Average beam power : 912 kW
Accumulated power : 2607 MWh

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

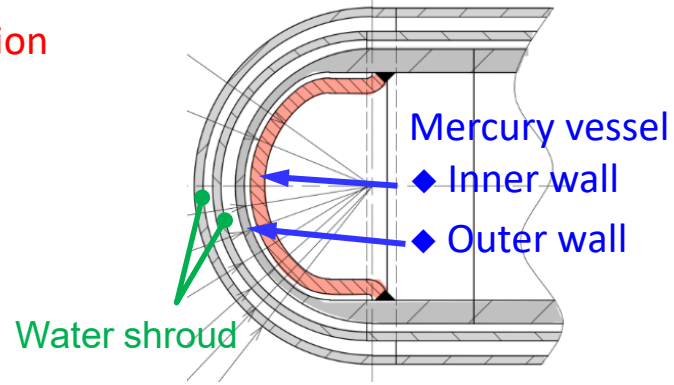


Bubbler was split and moved forward by around 200 mm.

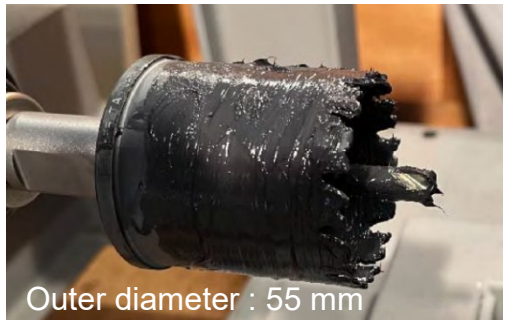


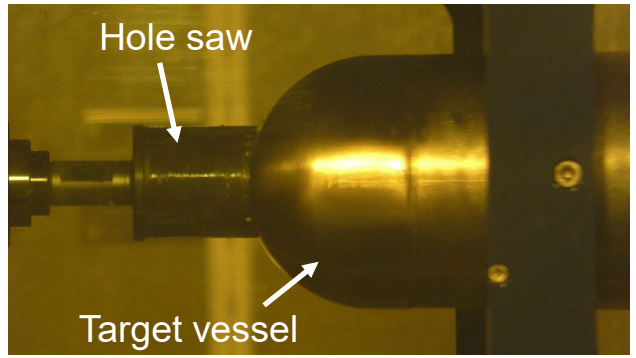


Vertical cross-section
Four walled structure



Hole saw with center-drill



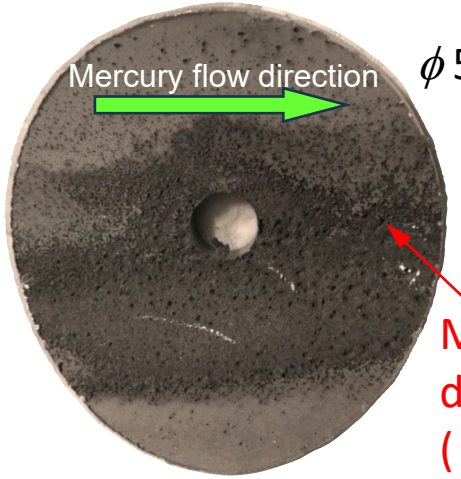


Inner wall (t 5 mm)

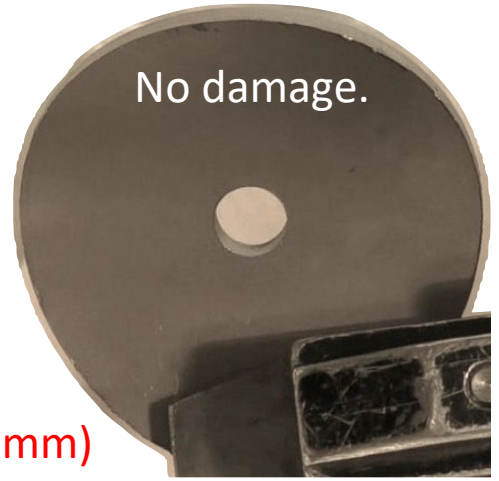
Protected by micro-bubble effect.

Outer wall (t 3 mm)

Protected by narrow channel effect.

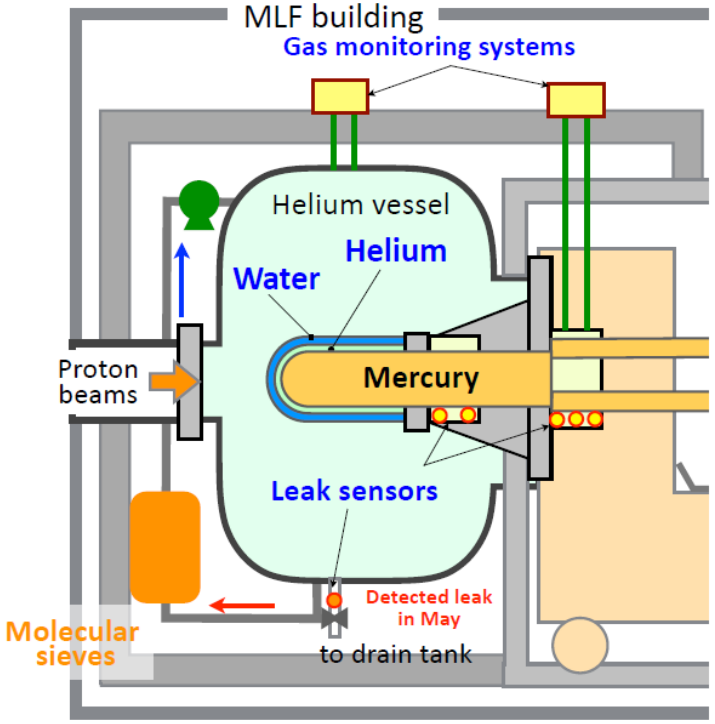


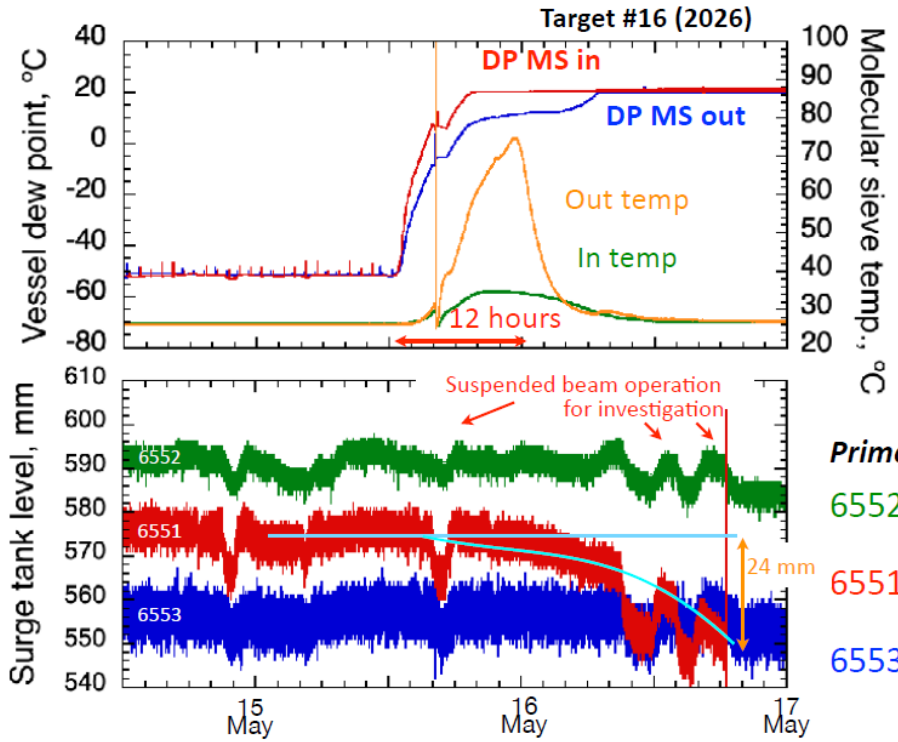
Max. damage depth : 0.76 mm
(Estimation : 1.4 mm)



- Excellence of damage mitigation effect with the new structure of #15 target vessel was confirmed with the beam power of 1 MW.
- MLF will go on to 2-year target operation with currently operating #12 target vessel.

Target #16 water leak in May 2025





Primary Water Cooling system in He vessel

6552: Moderators, Proton Beam Window

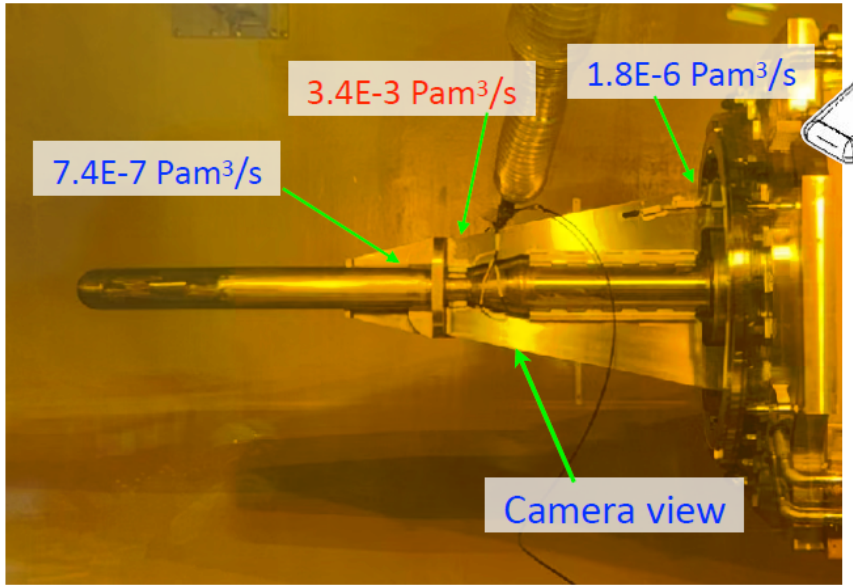
6551: Reflector, Target Water Shroud

6553: Vessel shield, Target Trolley Shield

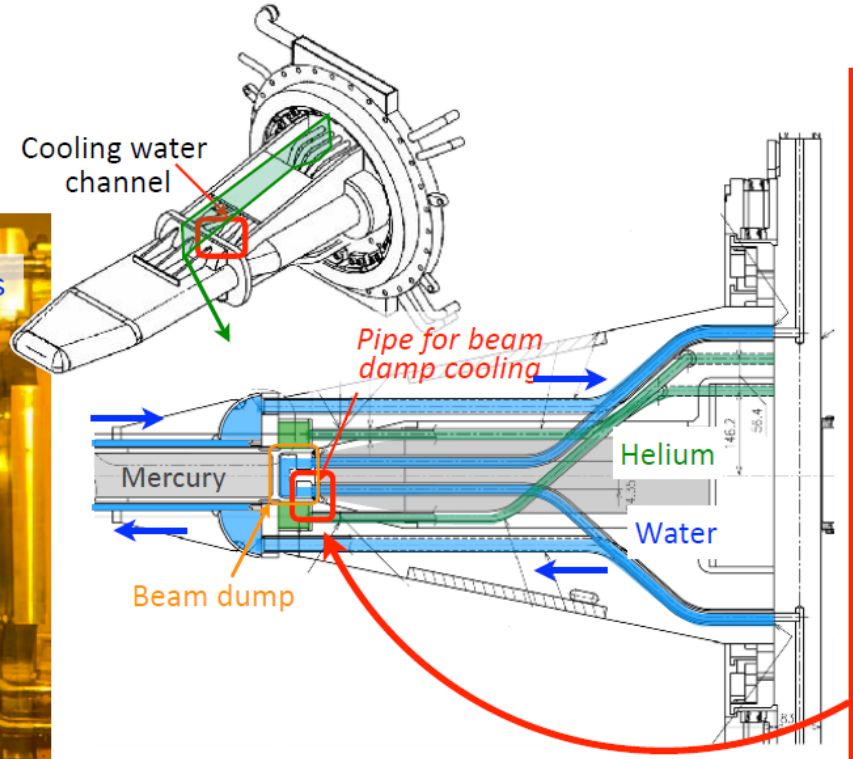
- Dew point in the helium vessel increased drastically 1 month after resuming operation
- Continued operation to clarify the reason based on experienced in 2024
- Electric sensor detected leak at drain port, and recurrence soon after draining
- Stoped beam operation at 16th May (remaining user operation 38 days) and brought forward the summer maintenance

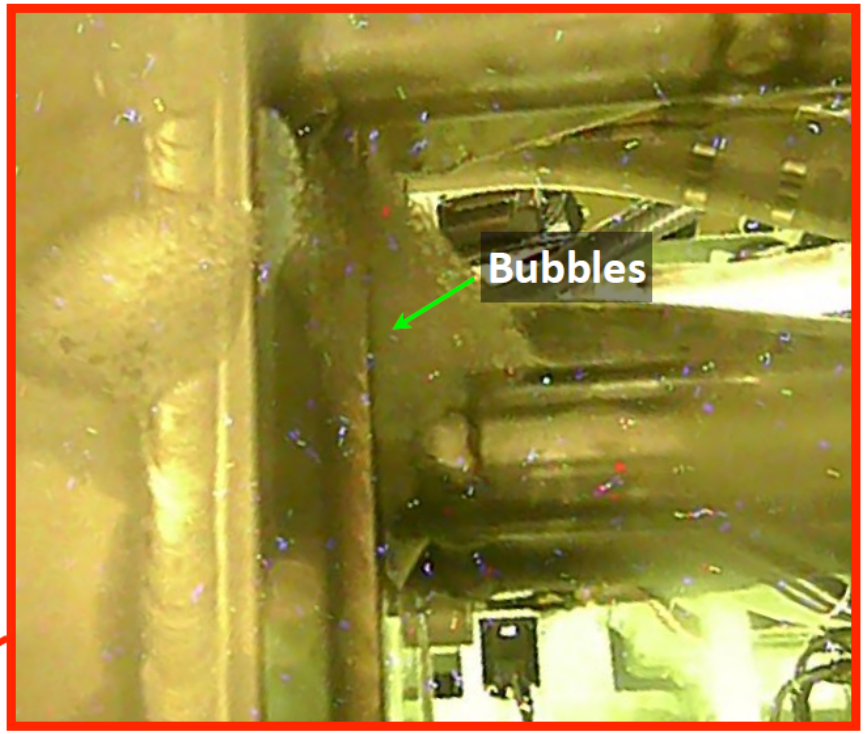
Investigation of leak location by He leak and bubble test

Target #16 Operation at 910kW
Duration: 7 Apr ~ 15 May
Beam trips: 614 times



Sniffer helium leak test using manipulator



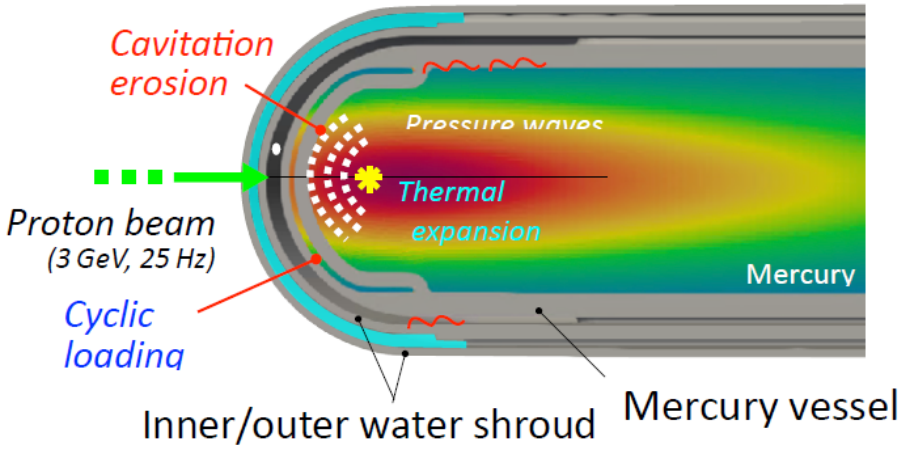


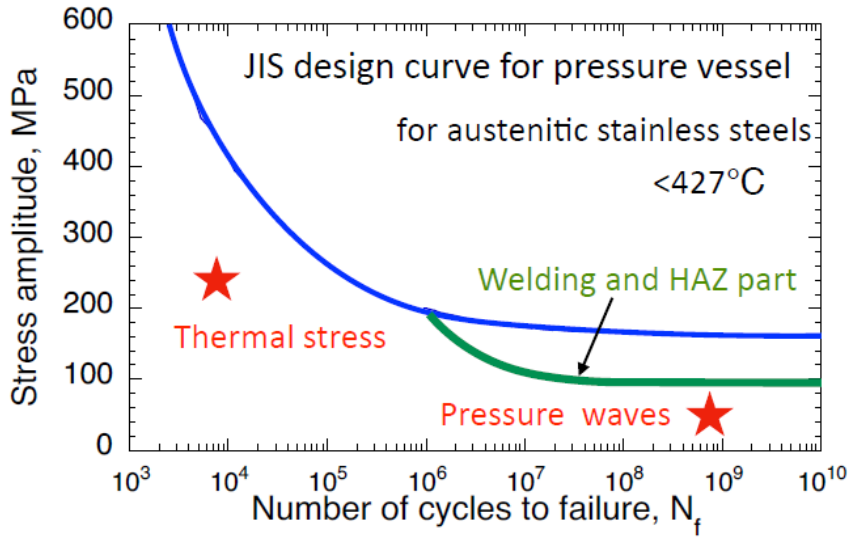
Captured image of bubble leak test

- Sniffer type helium leak test and found leak existed water cooling pipe for beam dump (3.4E-3 Pam³/s at 0.1 MPa)
- Bubble leak test suggested leak position is the neck of cooling water channel for the beam dump

Two years operation for target #12

Influencing factors for the target vessel lifetime





Irradiation damage

5.9 dpa for two years at 810 kWeq (target #12)

- Reduction in ductility
  → Referring PIE data obtained in other facilities (PSI, SNS)

Cavitation erosion

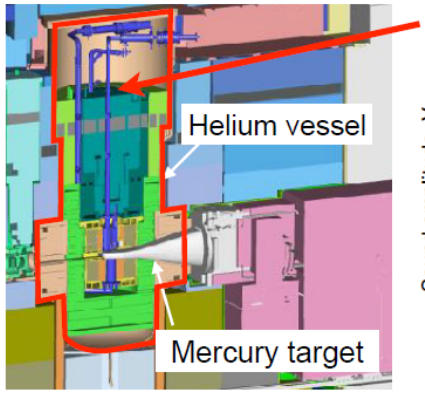
- Erosion penetrates the beam window and leads leak and fatigue failure
  → Updating damage mitigation techniques and depth prediction procedure to decide acceptable power for stable operation

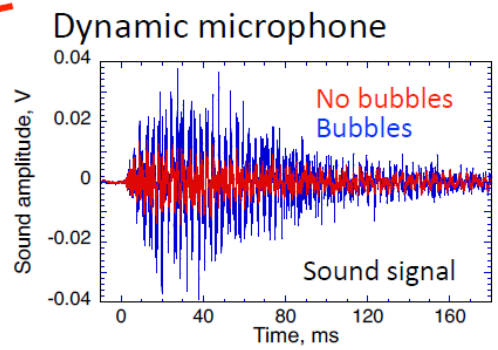
Fatigue failure by cyclic stress

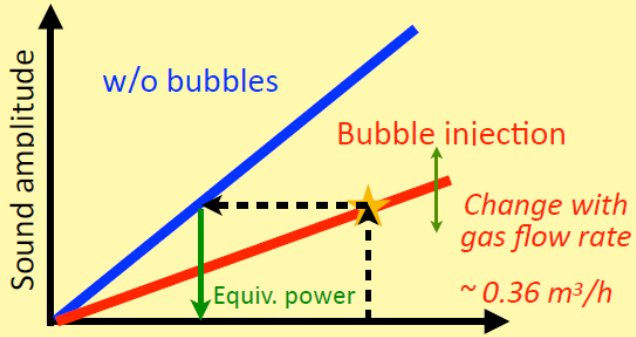
- 8000 (beam-trip 1/h), 7.2 x10^8 cycles (pressure waves) for two years
  → Fatigue strengths are much lower than that of design curve

The committee for the two-year operation will be held on March 26, 2026.
← Thanks !!

Damage depth prediction for target #12







Scale of pressure wave mitigation by bubble injection

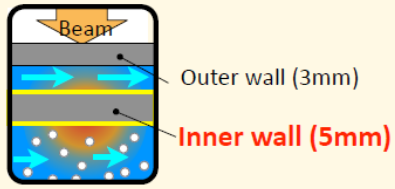
$$\text{Bubble effect } (B_e) = \frac{\text{Equivalent power under bubbling}}{\text{Operational beam power}}$$

Bubble effect =1 denotes bubble is not working
Less value means higher mitigation effect

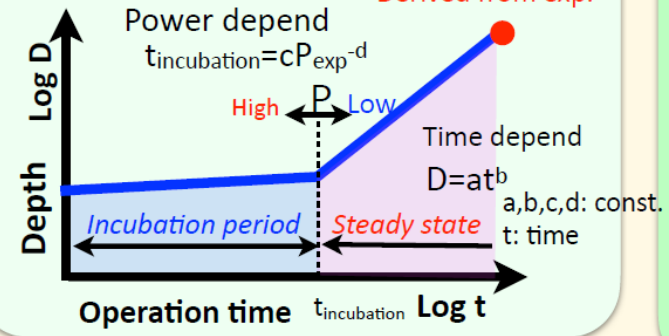
Empirical equation for damage depth prediction

Depth = f(Power, Bubble effect, Time)

$D=\alpha(PB_e)^{bd}t^b$



Damage depth growing in cavitation erosion



Decided conversion factor based on sound and actual damage measurement

Bubble effect

Convert to equivalent power from sound

$P_{equiv}=B_eP$

Convert from off-beam experimental power to proton beam power

Conversion factor

$P=\alpha P_{exp}$

Correct based on actual measurement

- Damage depth of #12 is predicted using #10 measured depth
- Lifetime is defined as the time until erosion depth on inner wall reaches 5 mm
- **For two years operation (8000 h), allowable beam power is limited less than 810 kWeq** (can keep above 700 kW regardless of MR beam-extraction mode)

Naoe-san will present in this ICANS about target in details

Management plan for operation and storage

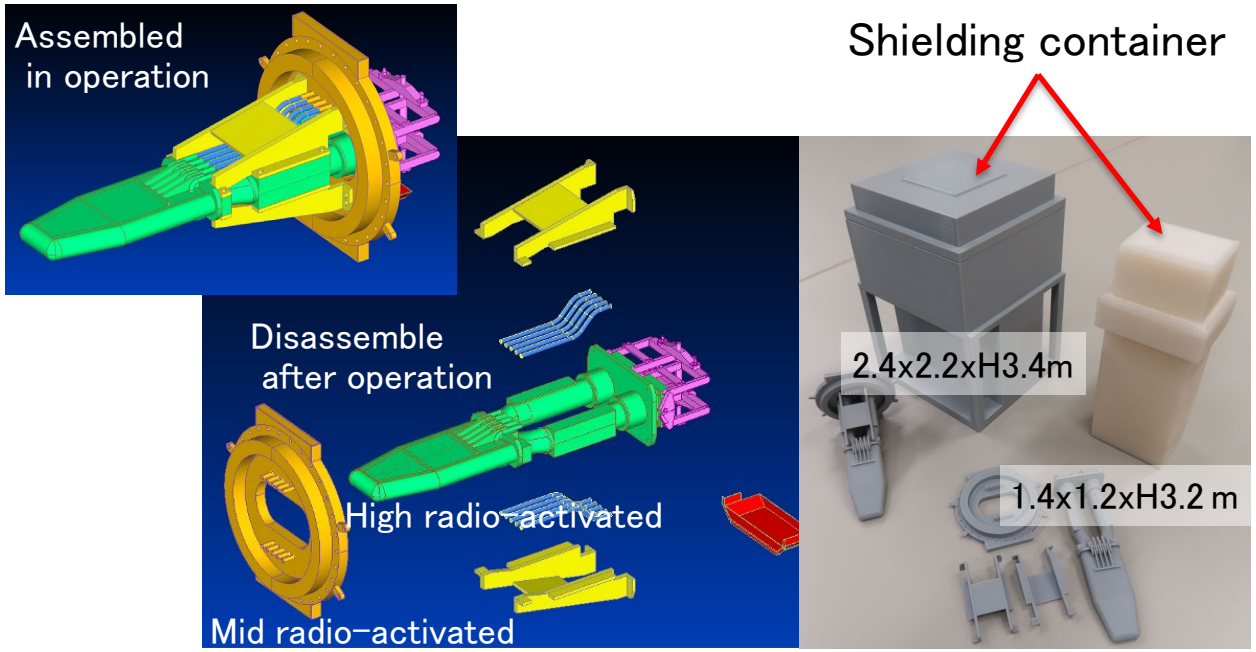
JFY		2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Beam Operation		1MW 800kW			1MW						
Target	Operation & Replacement	#16 ▼ #12		▼ #18		▼ #19		▼ #20		▼ #22	
				● #12 Cut		● #18 Cut		● #19 Cut		● #20 Cut	
	Transport	▼ #10,11	▼ #13		▼ #14		▼ #15		▼ #16		▼ #12
	Fabrication	#17			#21			#23			
		#18	#20			#22			#24		
		#19									
Proton Beam Window	Operation & Replacement		▼ #5			▼ #6			▼ #7		
			● #4 Cut		● #5 Cut						
	Tranport					▼ #1	▼ #2&#3			▼ #4&#5	
	Fabrication		#6-1	#6-2	#7			#8			
Moderator & Reflector	Operation & Replacement		▼ #2								▼ #4
							● #1 Cut?				
	Tranport									▼ #1	
	Fabrication			Pulg #3							
		CM#4			DM#4						
					PM#4						
					Ref#4						
Spare	Target	#17,#18	#17,#18	#17,#19	#17,#19,#20	#17,#20	#17,#20,#21	#17,#21,#22	#17,#21,#22	#17,#21,#23	#17,#21,#23,#24
	PBW	#5	-	#6	#6,#7	#7	#7	#7,8	#8	#8	#8
	Mod&Ref	#2,#3	#3	#3	#3	#3	#3,#4	#3,#4	#3,#4	#3,#4	#3
Storage of used components	Target (MLF)	4	3	4	3	4	3	4	3	4	3
	Target(RAM)	9	10	10	11	11	12	12	13	13	14
	PBW(MLF)	4	5	5	5	5	3	3	4	2	2
	PBW(RAM)	-	-	-	-	1	3	3	3	5	5
	MR(MLF)	-	1	1	1	1	1	1	1	1	2
	MR(RAM)	-	-	-	-	-	-	-	-	-	-

Cap. : 24?

- Target #12 will be used for 2 years → 2-year operation started.
- Moderators and reflector will be replaced in 2028.

Disassemblable target for reduction of waste volume

Conceptual design



Occupation of shielding container in storage space

	Occupation area (m^2)	Occupation volume (m^3)
Full target ($^{W}2.4 \times {}^{D}2.3 \times {}^{H}3.4$)	5.3	17.6
Disassenblable target		
Main parts ($^{W}1.4 \times {}^{D}1.2 \times {}^{H}3.0$)	1.6 (−70 %)	4.8 (−70 %)
Parts group 1 ($^{W}1.8 \times {}^{D}1.8 \times {}^{H}0.9$)	3.10	2.8
Parts group 2 ($^{W}1.5 \times {}^{D}1.3 \times {}^{H}0.8$)	1.73	1.3
Parts group 3 ($^{W}1.0 \times {}^{D}1.0 \times {}^{H}0.5$)	0.98	0.5
Total	7.5 (+40 %)	9.2 (−45 %)

Fundamental premise

Disassembling target into multiple parts

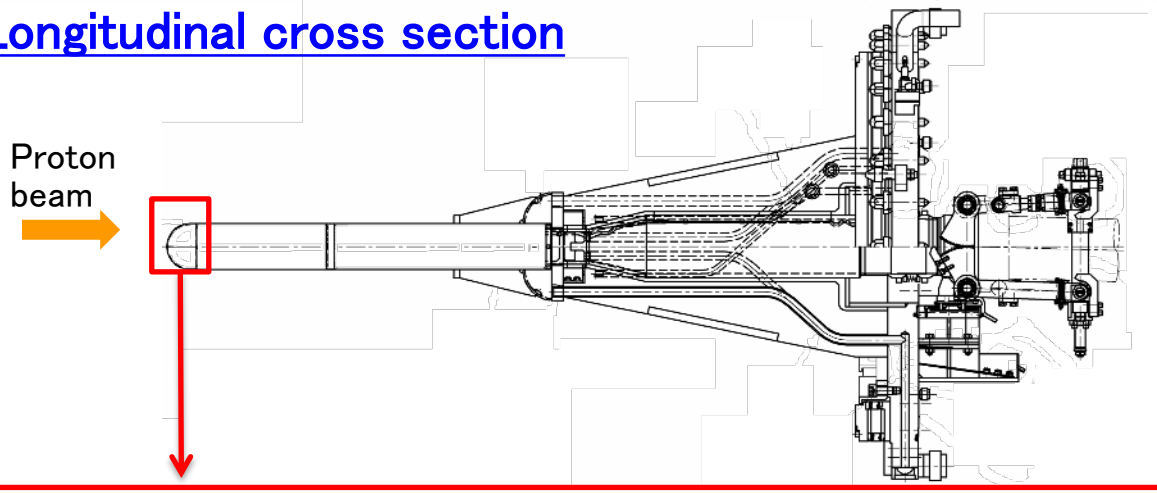
⇓

- High radio-activated parts ⇒ RAM building
  (Main parts)
- Mid radio-activated parts ⇒ Backend in JAEA site

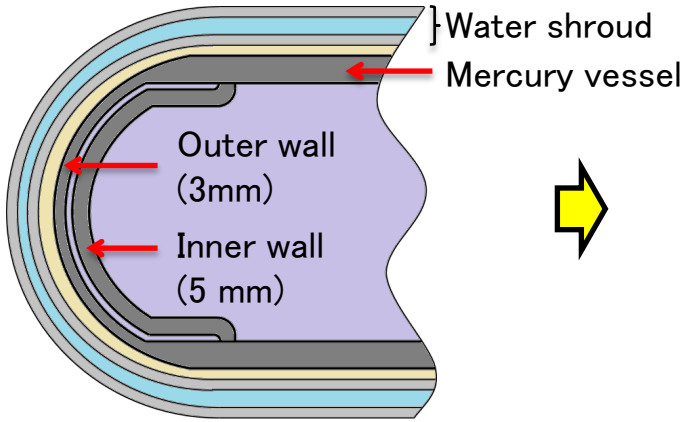
- The area required for main parts can be reduced to **30 %** of that of the full target.
- However, the total area required for all parts will increase by approximately **1.4 times**.
- **This premise is crucial**, but decision regarding the back-end takeover is still **pending**.

Cavitation countermeasures to extend lifetime of target

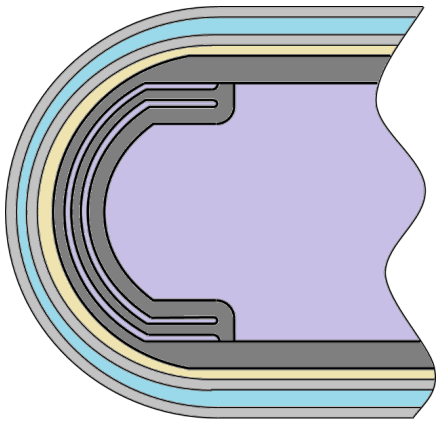
Longitudinal cross section



Double-walled structure



Tripple-walled structure

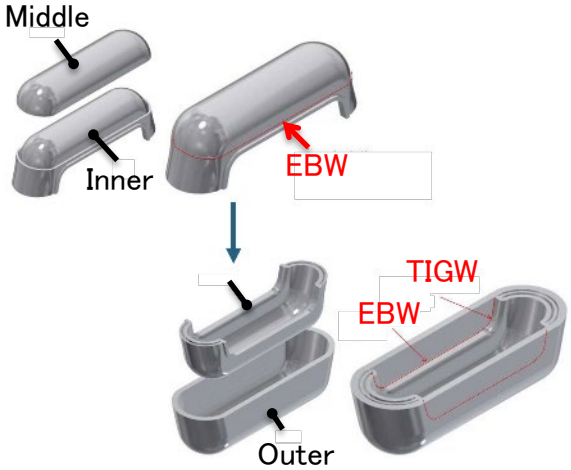


- Lifetime of target ⇐ Cavitation damage to inner wall
- Maximum wall thickness ⇐ Thermal stress

Extending lifetime ⇐ Increasing the number of walls

Issues in realizing triple-walled structure

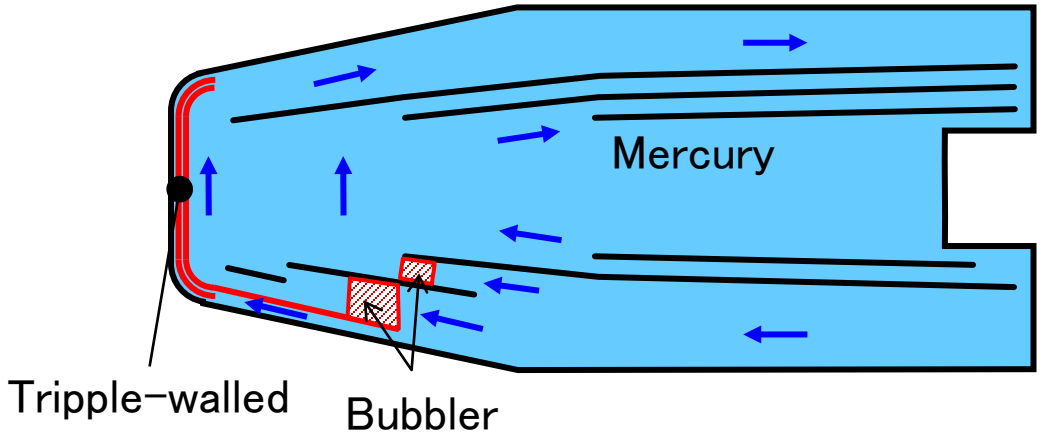
- Optimal manufacturing procedures with minimal deformation du to welding



Mockup model

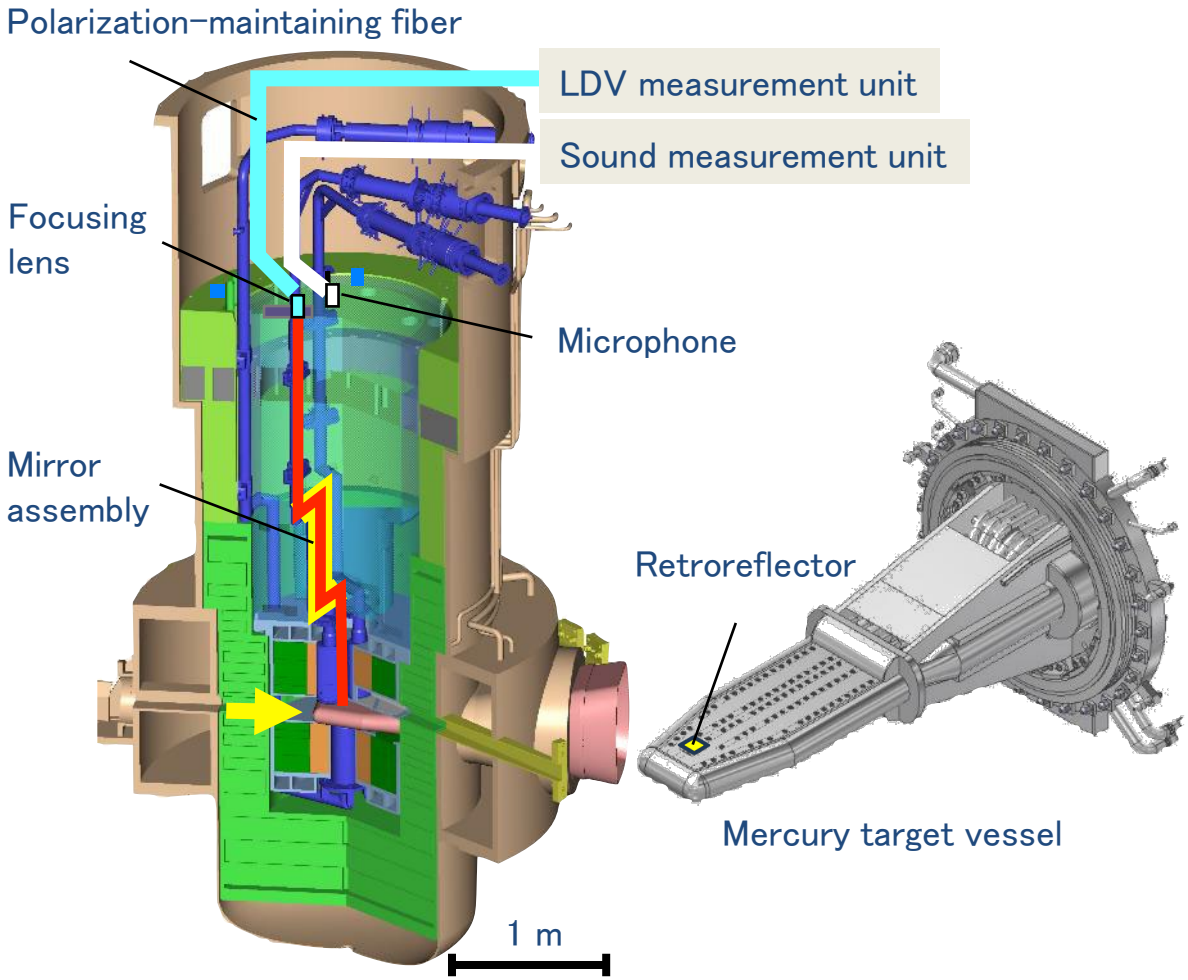
- Optimal flow structure with minimal pressure loss

Horizontal cross section



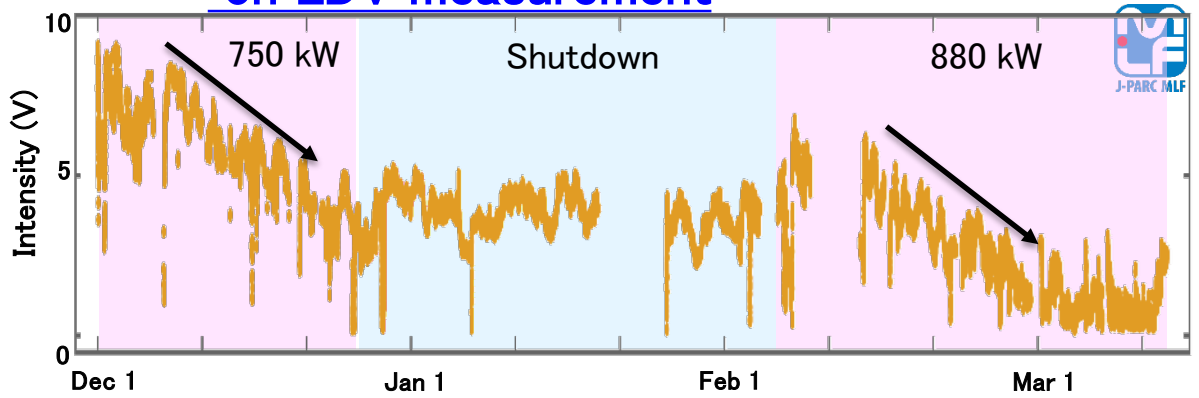
Real-time target diagnosis

Measurement system for monitoring vibration and acoustic signals of the target



AI and mechanical learning will be adopted.

Radiation damage in fiber on LDV measurement



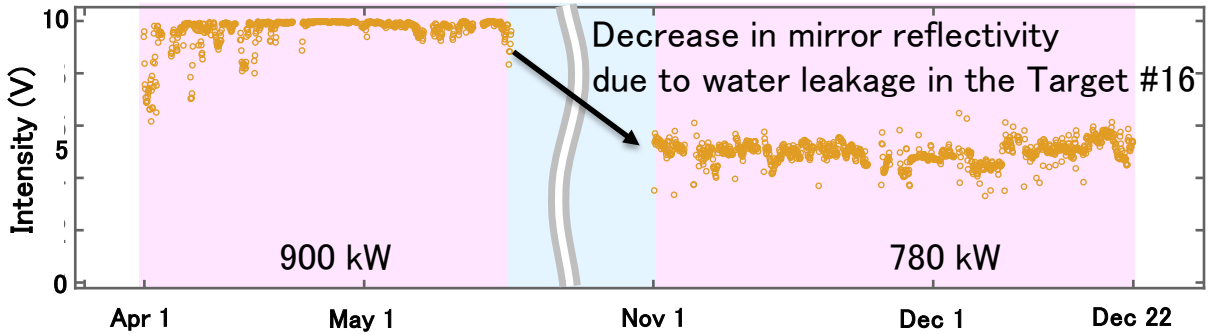
The optical intensity decreased proportionally with the operation time.

Neutron irradiation tests

× Standard Ge-doped cores

○ Pure silica cores

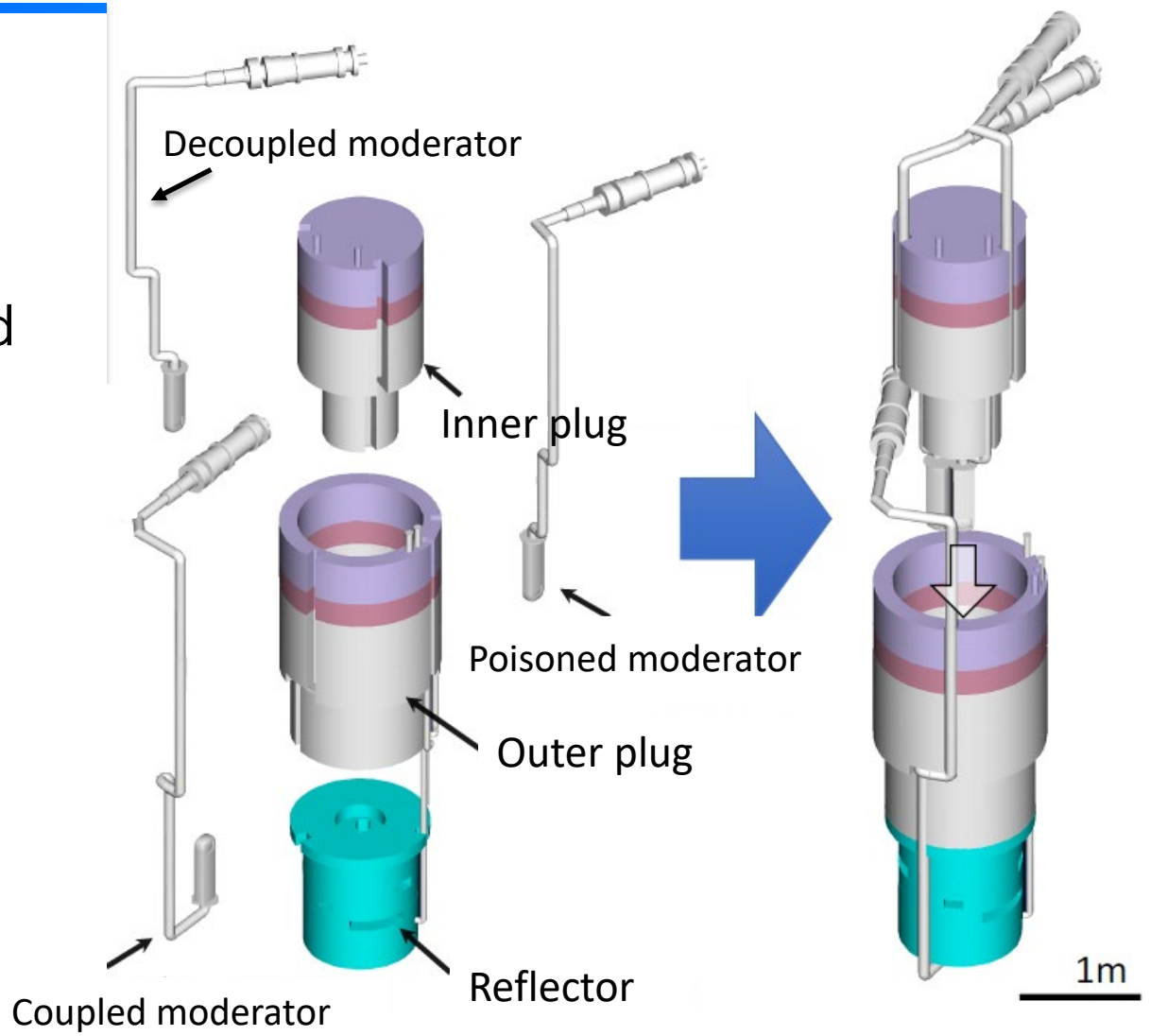
Shutdown



The optical intensity maintained and measurements continued successfully.

Moderator and reflector replacement

- TMRA consists of three moderators, one reflector, and two shielding plugs.
- Inner plug has decoupled moderator and poisoned moderator.
- Outer plug has reflector and coupled moderator.
- When replacing the moderator and reflector, replace this plug unit at once.
- In 2028, the moderators and the reflector will be replaced to new ones due to exceeding the the assumed life limit (30,000MWh).



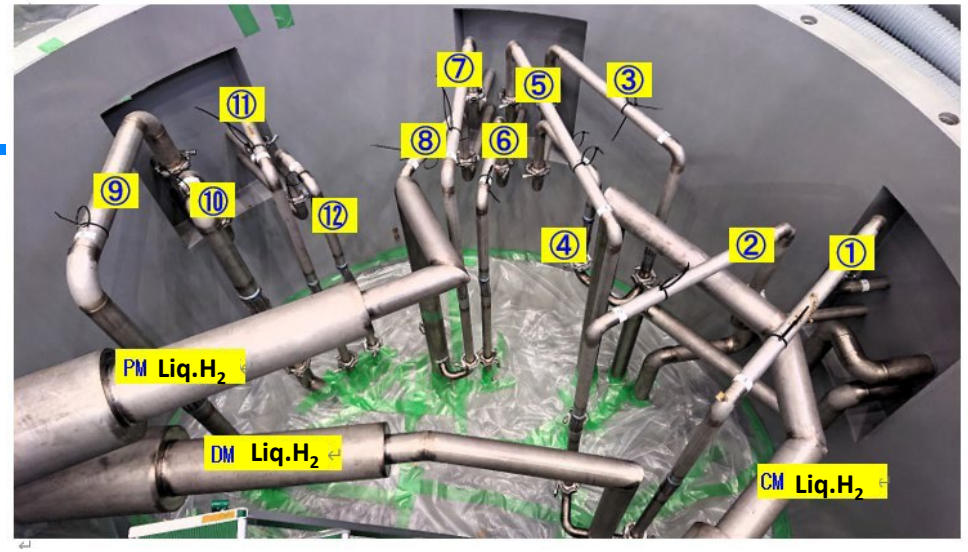
Piping mockup training for the replacement

Objectives and improvements

- Training for piping work above the vessel
  - It takes 90 minutes from the time of putting on the Airline mask to install/remove 4 pipes.
  - We need three group for all water pipe removing.

- Confirm and review work procedures
  - Changing the order of pipe installation

- Confirm the tools used in this work
  - Soft pipe need to fix it position. Use the aluminum flexible duct for local exhaust to fix the position by itself
  - Change the cramp to more easy handling



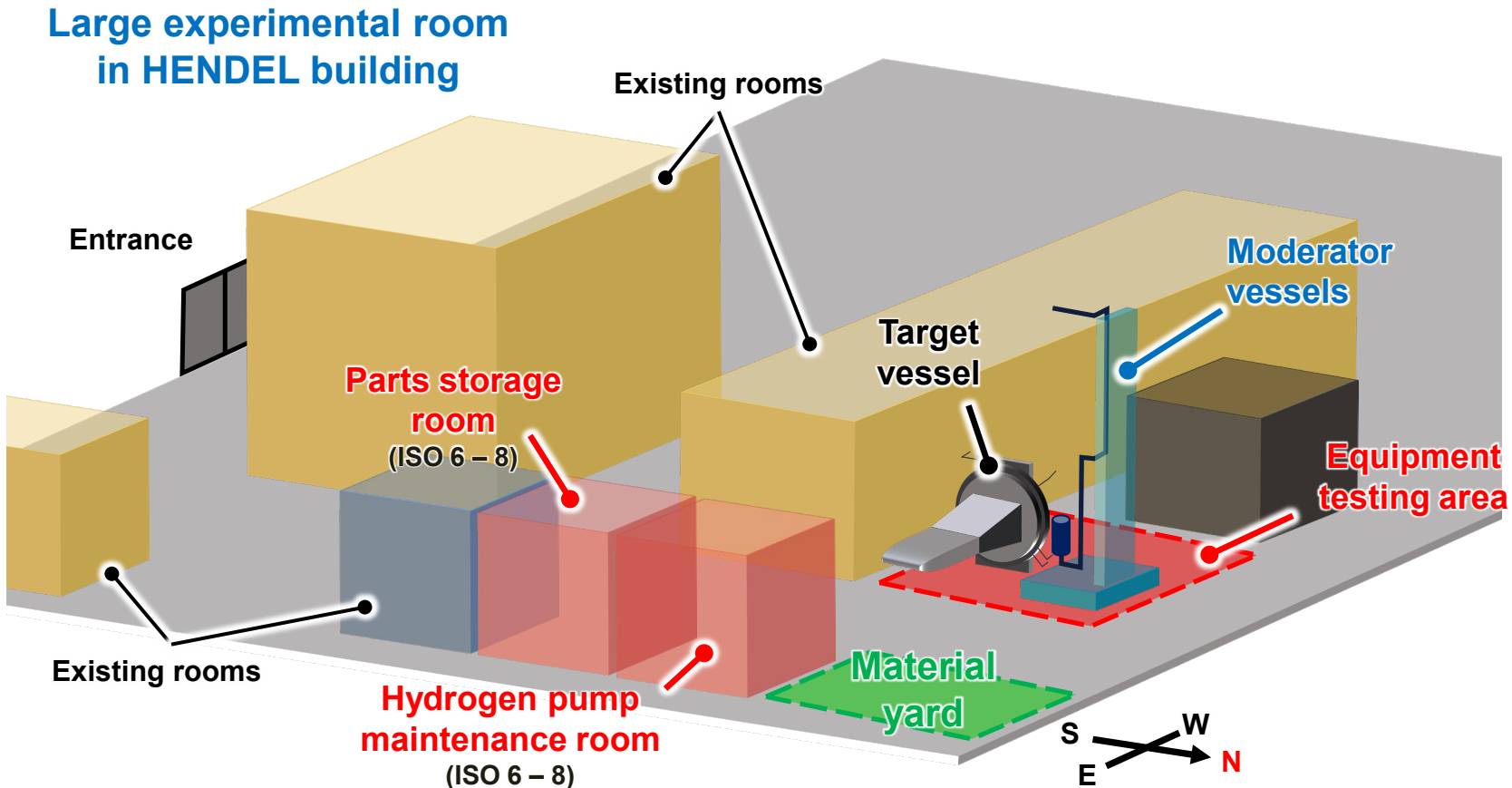
Al flexible duct

Soft pipe

Maintenance area for the hydrogen pump development, the examination of new target and moderator, reflector

- **Candidate layout at large experimental room in HENDEL building**

  To enable the pump maintenance by JAEA,
  the maintenance room and an associated parts storage room are planned to be installed in the HENDEL building, in the future.

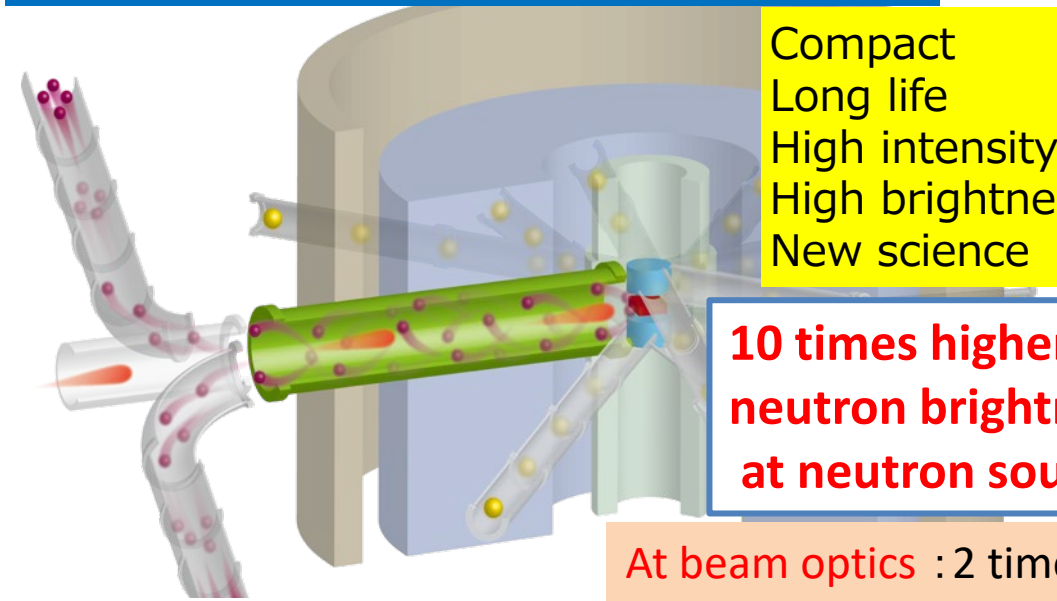


Main equipment of the room

- Surface plate (workbench)
- Electrical furnace (for pump baking)
- Water supplying system (for cooling the pump)
- He supplying system (for gas-leak tight and run tests)
- Thermostatic chamber (for storage pump and its parts)

MLF

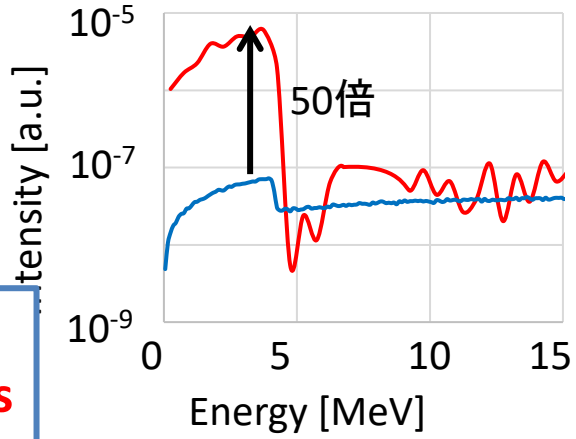
2nd target station (TS2)



Compact
Long life
High intensity
High brightness
New science

10 times higher neutron brightness at neutron source

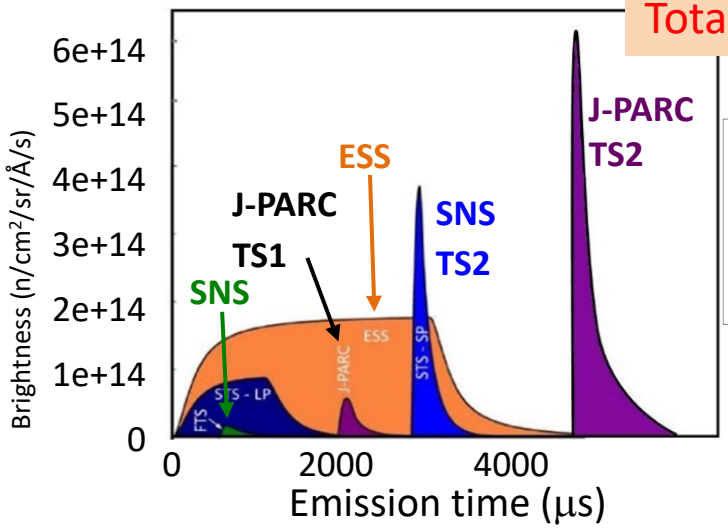
Muon intensity : 50 times higher

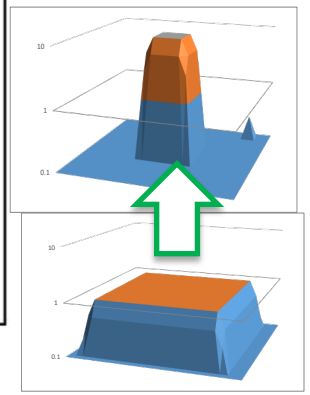


TS2 design

Concept of TMRA are under investigation

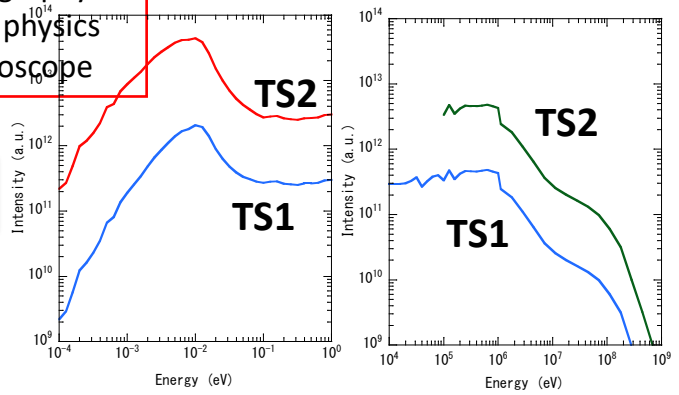
At beam optics : 2 times higher
Total neutron brightness : 20 time higher



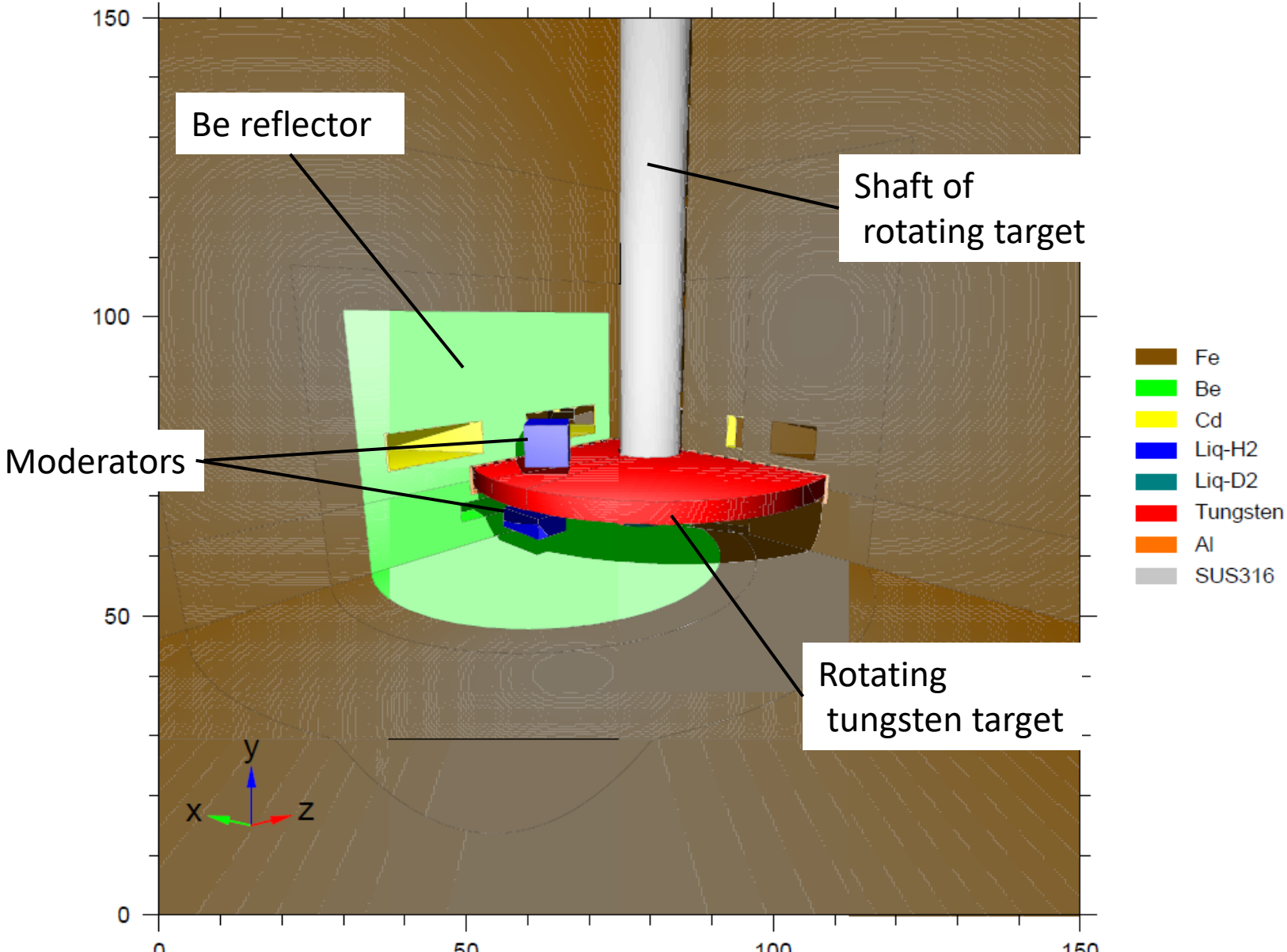


Soft error
Semiconductor irradiation
Material irradiation

Astrophysics
Protein crystallography
Neutron holography
Fundamental physics
Neutron microscope



Three-dimensional calculation of TS2

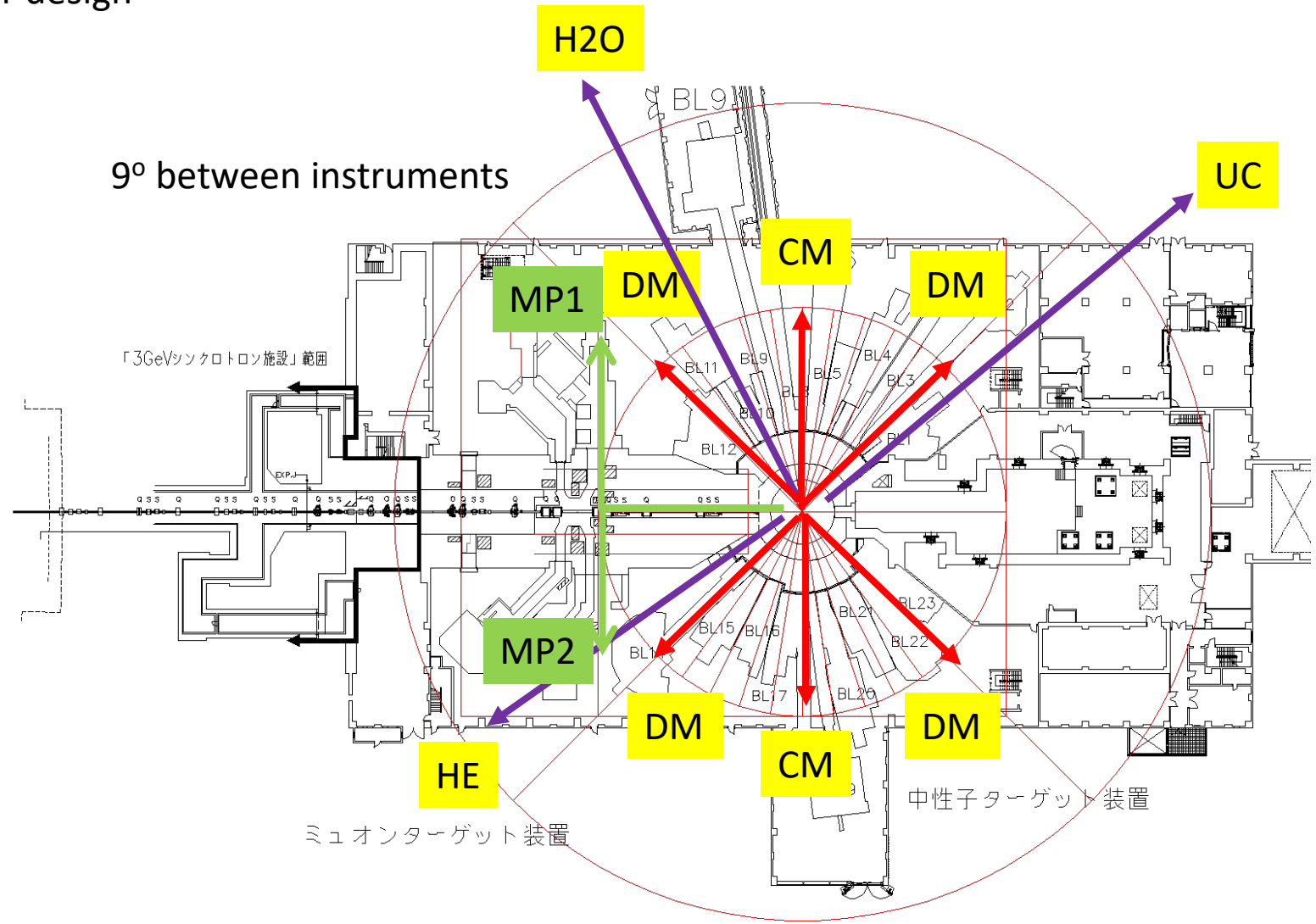


Beam power: 0.5MW or 1MW
Repitation rate: 8.3Hz or 25Hz

Combined muon source
H2 Coupled moderator : 1
H2 Decoupled moderator : 1
Ultra cold moderator :1
High energy port : 1
H2O moderator : 1

TS-2 beam line ?

For moderator design



M Port: 2

N Port
CM: 1～5 x 2
DM: 1～3 x 4
UC: 1
HE: 1
H2O: 1

Dedicated beam line ?
Non-sealed RI ?
L1?

Summary

- MLF achieved the final goal of beam power equivalent to 1 MW with the target #15 in April 2024
- Although, in both 2024 and 2025, several troubles occurred in neutron source, all of these issues have been resolved, leading to stable operation.
- The current target vessel is challenging toward a two-year operation under 800 kW equivalent proton beam.
- Efforts to improve the neutron source are ongoing.