HPTW2023, 9 Nov. 2023

Muon Production Target at J-PARC

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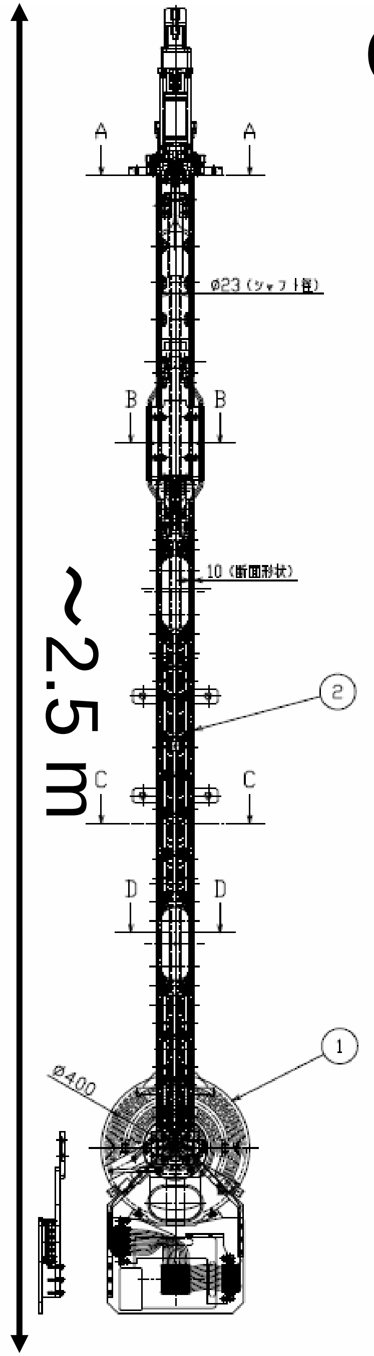
KEK J-PARC

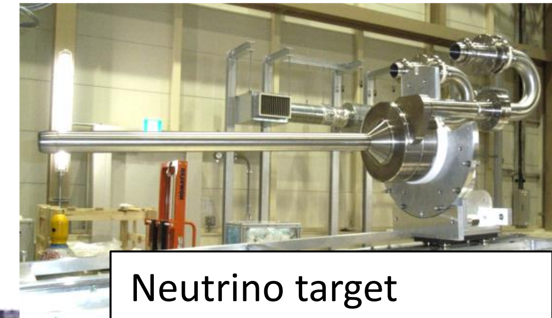


Contents

- Muon production target
- Development of monitoring systems
- Exchange of the target

Muon target
Rotating, Th. Radiation
Graphite

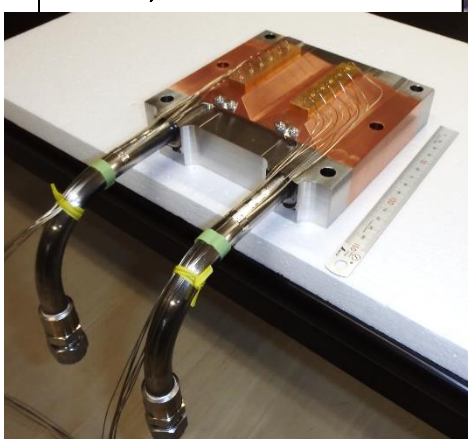
Various targets at J-PARC



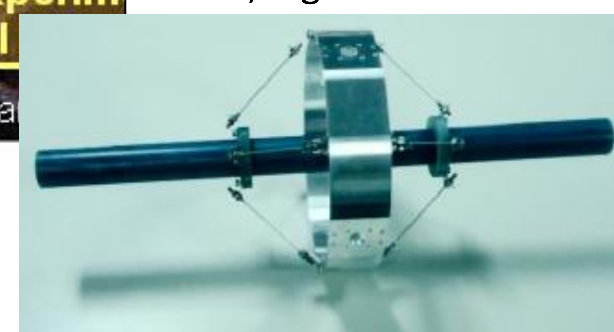
Neutrino target
He-gas-cooled, fixed,
Graphite

Neutron target
Liquid metal, Mercury

Hadron target
Indirect-water cooled,
Fixed, Gold



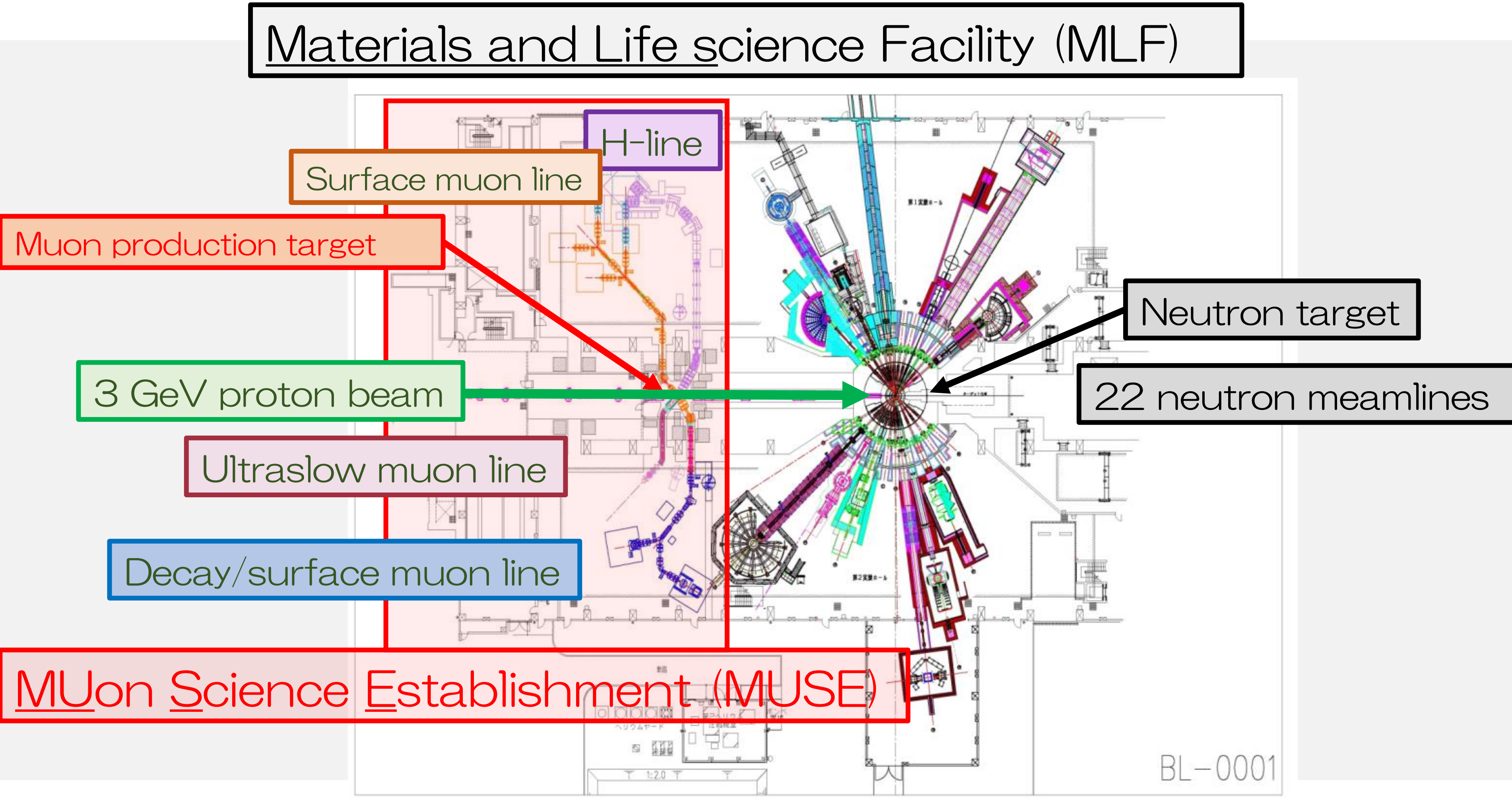
COMET target, Fixed
#1: Th. Radiation, Graphite
#2: ??, high-Z



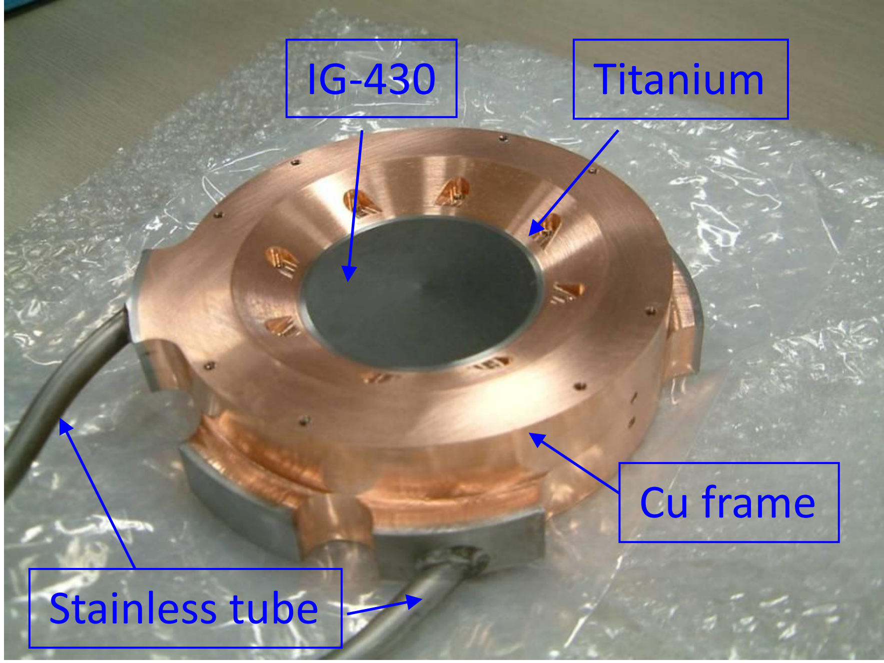
MUSE & MUON TARGET

MFL：muon and neutron production targets.

- D and S lines are opened for users.
- U and H lines are operated in beam commissioning.



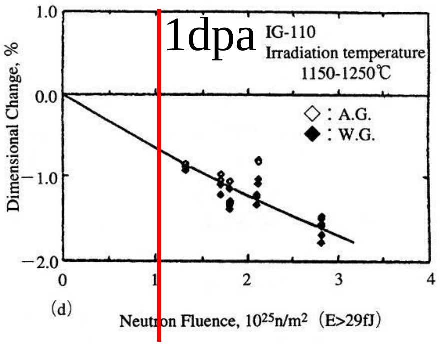
Muon Fixed Target (2008-2013)



Isotropic Graphite
(IG-430; Toyo Tanso Co., LTD.)
Thickness; 20 mm, Diameter 70 mm
4-kW heat, beam diameter 14 mm
Fixed edge-cooling method

Irradiation by proton beam to graphite,
Lifetime; 6 months (@1MW)

1 %/year shrinkage of graphite on the beam spot



H. Matsuo, graphite1991 [No.150] 290-302

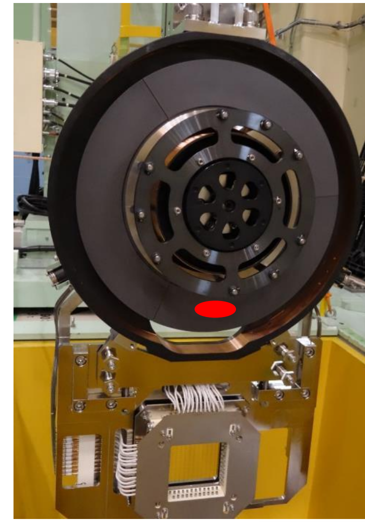
Remote controlled replacements in Hot cell

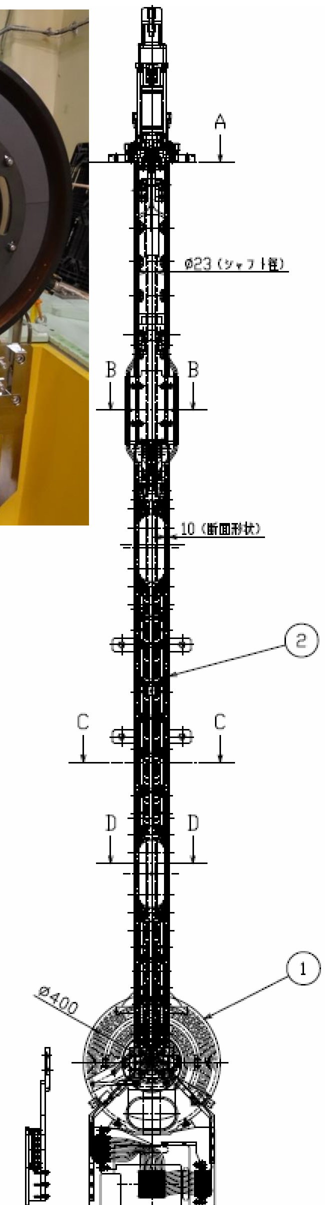
Rotating Target for muon production

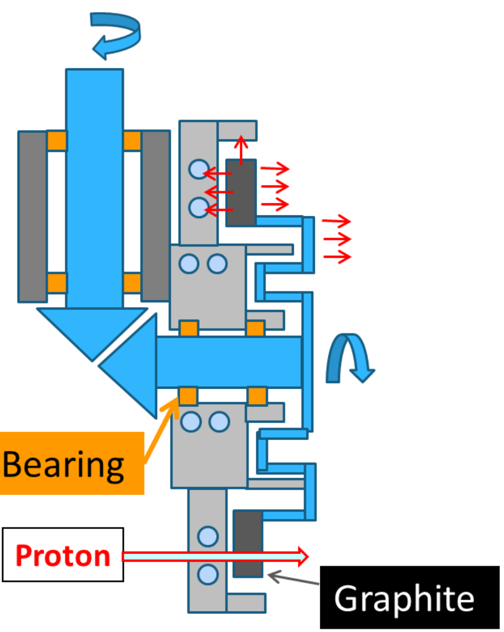
The No.1 target was installed in Sep. 2014, and was replaced with the No.2 in Sep. 2019.

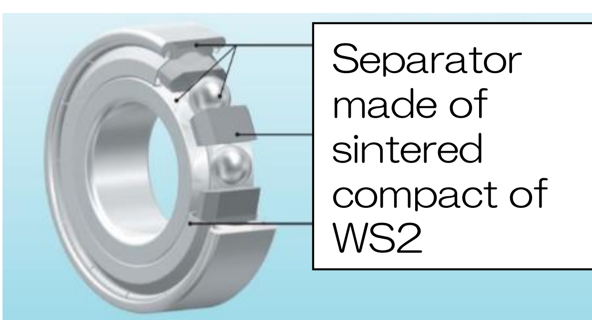
- Diameter: 33 cm, thickness : 2 cm
- 15 rpm operation
- Radiation cooling
- Lubricant of bearing: tungsten disulfide
- Life time : aiming ≧ 10 years

- Beam diameter: 14 mm (2sigma)
- 4kW heat on target at 1 MW



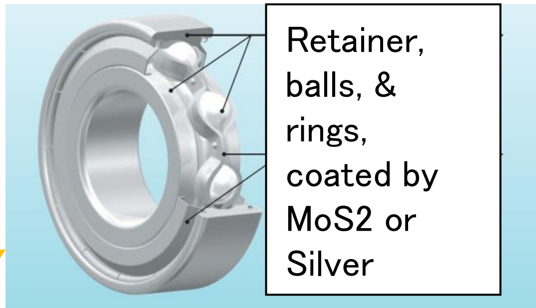






Bearings

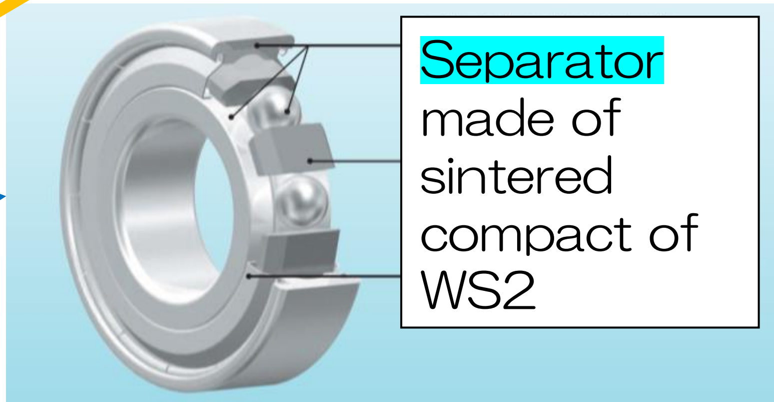
Learning from Paul Scherrer Institute,
Rotating target method to distribute the radiation damage of graphite to a wider area.



The lifetime of bearings is critical.
Solid lubricant;

- ☐ Silver coating at PSI (−2020)
- ☐ Disulfide tungsten at MUSE

Expected lifetime; 10 years



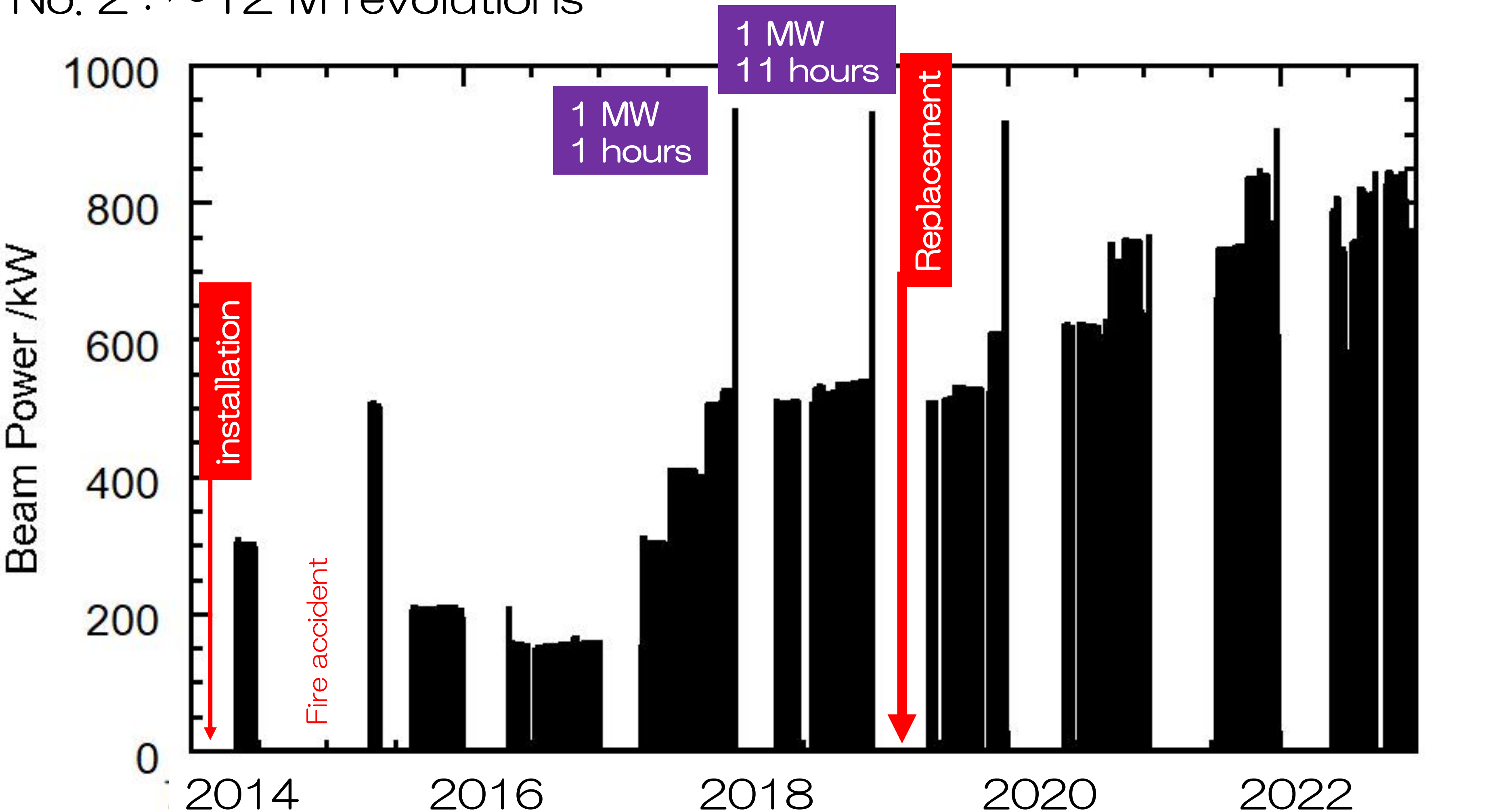
Dose ; **100MGy/year**、Vacuum ; **10^{-5}Pa**、Tmp. ; **150°C** 、Radial load ; **33N**, thrust load; 20N

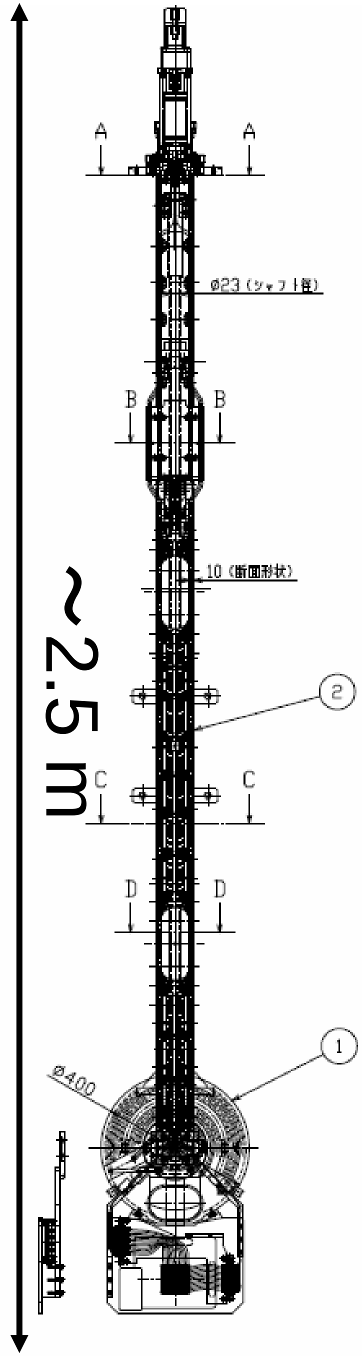
I.D. =17mm, O.D.= 40mm, w=12mm, Internal clearance C4 (ISO 5753)

	Type	Temp. (°C)	Vacuum (Pa)	radiation resistance	Inventory Storage	Life at J-PARC / h
MoS_2	Retainer	<300	10^5 to 10^{-5}	OK	Atmos.	1100
WS_2	Separator	<350	10^5 to 10^{-5}	OK (EB test)	Atmos.	110000
AIP-Ag	Retainer	<350	10^{-3} to 10^{-10}	OK	In vacuum	5800

Operation history of the rotating targets

- No.1: Operation for 5 years.
- History of beam operation (~June 2019) : ~15000 h
  Rotation : ~15 M revolutions (Service life of WS_2 bearings ~50 M)
- No. 2 : ~12 M revolutions



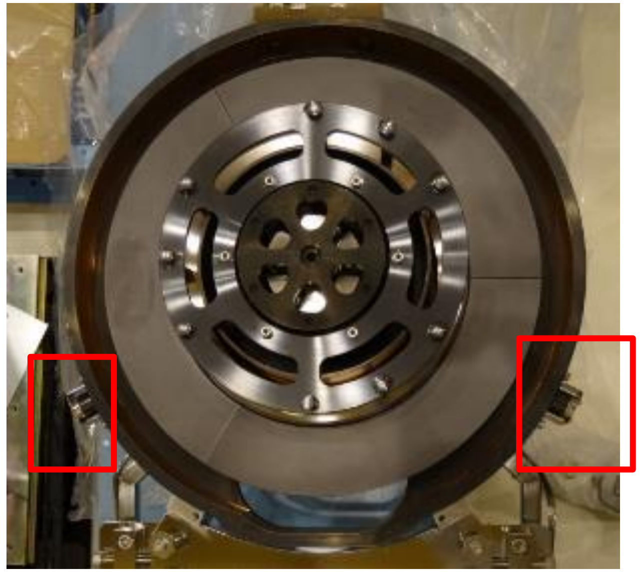


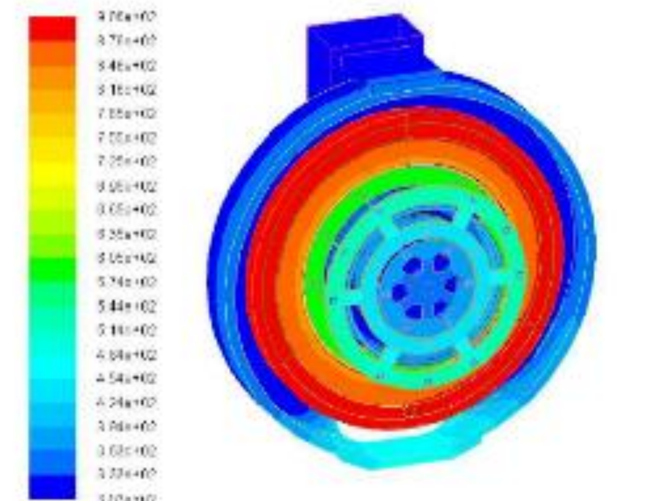
Contents

- Muon production target
- Development of monitoring systems
- Exchange of the target

Monitor with Infrared camera

■Thermocouples
- Slow response time
- Target temperature unknown





Heat conduction calc. (Static)

■Infrared camera
- Quick response
- Imaging

→Rapid beam stop when temperature abnormality increases

©Vision sensing

★ULVIPS-04171SL

Pixels：648×480
accuracy：±2 K or ±2%
focal distance：150 mm

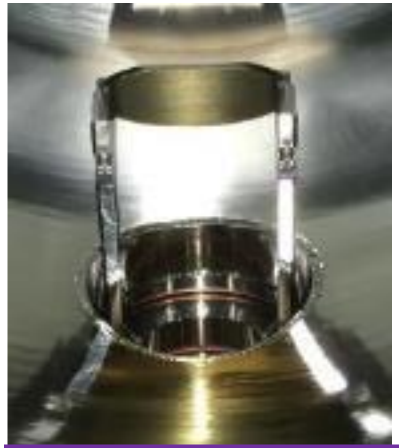
- Multiplexing and speed up for the interlock system
- Life prediction for the rotating system and target
- ABNORMALITY PORTENT

Infrared camera

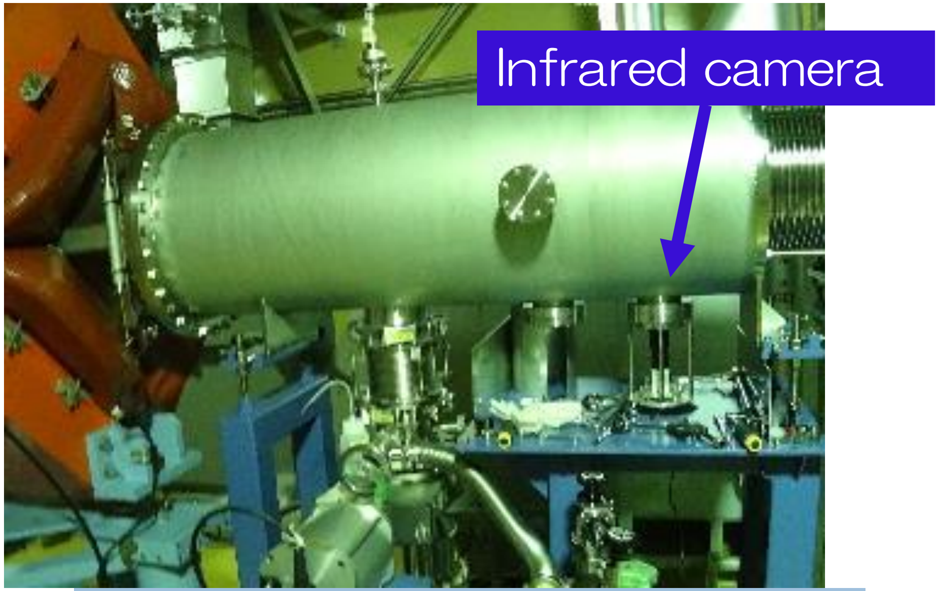
■**An infrared camera was installed to quickly detect the temperature rise due to rotation stop.**

・The infrared camera has irradiation test (QST Takasaki and NIRS).
The camera is expected to have radiation resistance of more than one year (5 Gy or more) at 1 MW operation.

・The beam duct was replaced with a duct with a camera port.
The reflected light from the mirror in the duct is measured.
We performed a trial measurement for several months.



Infrared mirror in beam duct



Beam duct with camera port

Shielding for the camera

Infrared camera

・Direct observation with the infrared camera was successful. (Figure 1, Figure 2)
・At the center, a high-temperature part, which is likely to be a beam spot with a diameter of about 1.5 cm, was observed.

Fig. 1 Infrared camera image at 1 MW

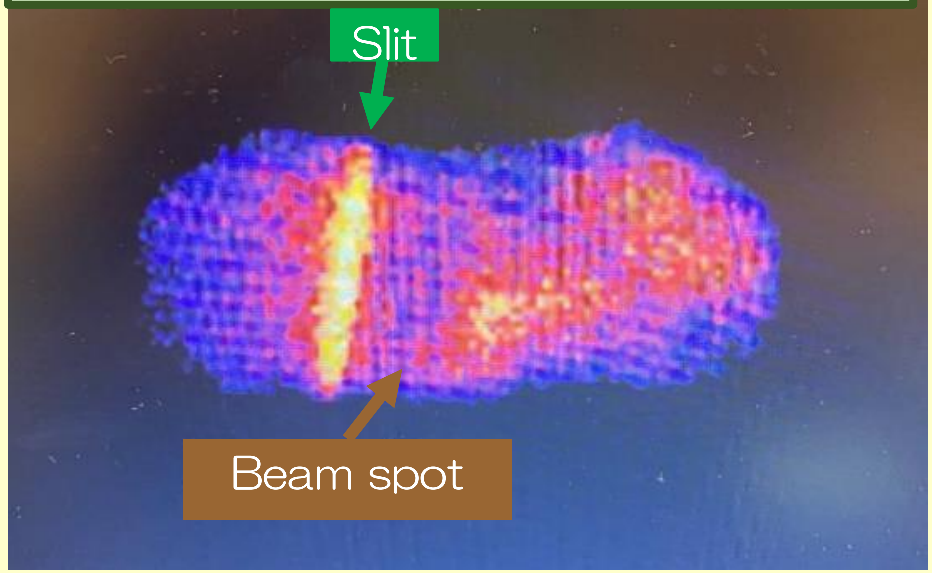


Fig. 2. Beam power dependence of muon target temperature

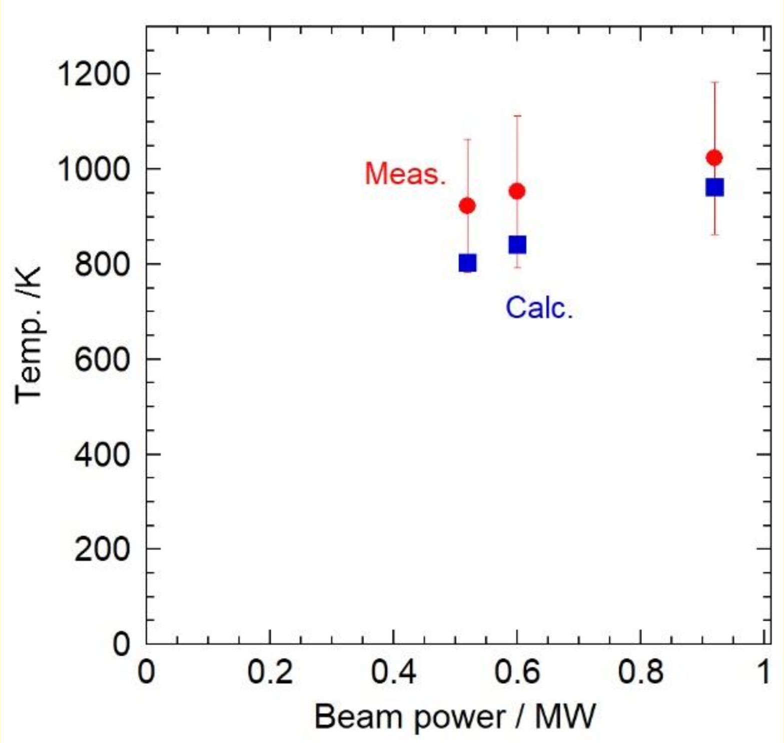


Photo of the target taken with a digital camera during the beam stop.

Infrared camera

■Interlock for beam stop

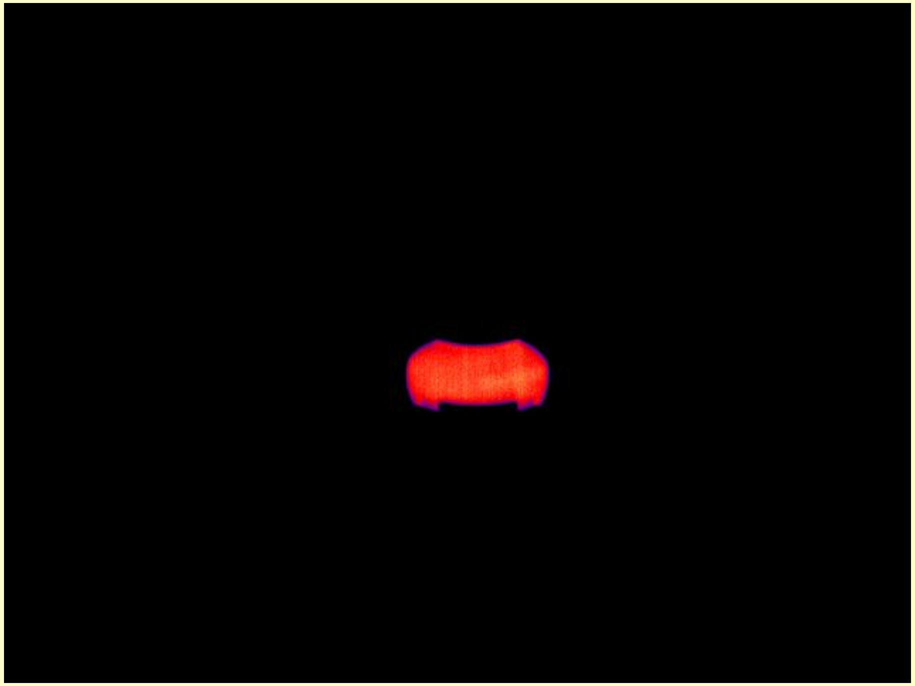
・Abnormal temperature rise

・Rotation stop by an image recognition technique

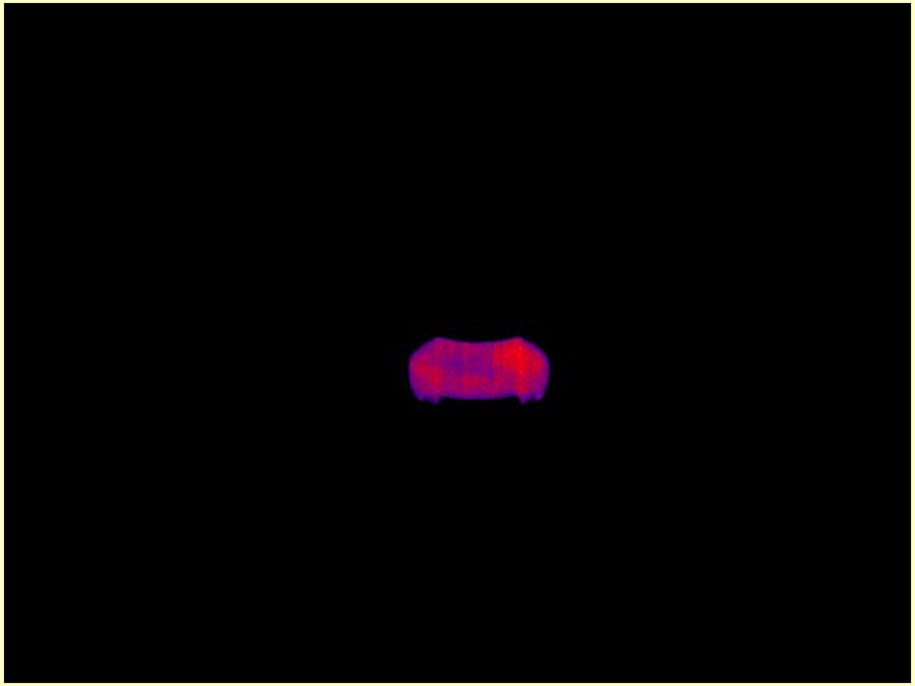
■Life prediction for the rotating system

・Evaluate damage to graphite and rotating shaft by image recognition

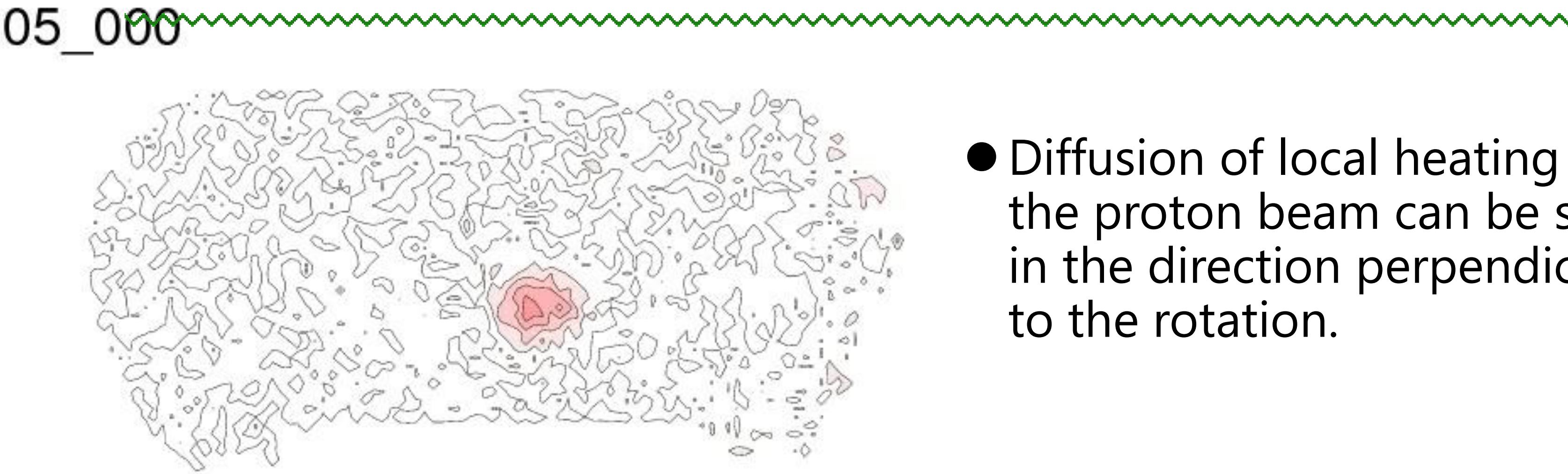
Movie. 1 Infrared camera at 1 MW



Movie. 2 at 600kW (CCW)



Analysis of images



- Diffusion of local heating by the proton beam can be seen in the direction perpendicular to the rotation.

- Fast eXtraction(FX) : Missing 4 pulses every 2480 ms at MLF
  -> Heat is more diffuse during FX.
- The infrared camera takes a picture every 99.4 milliseconds on average.
  After 25 shootings, 99.4 x 25 = 2485 ms
- **The 5 msec gap allows for stroboscopic analysis.**

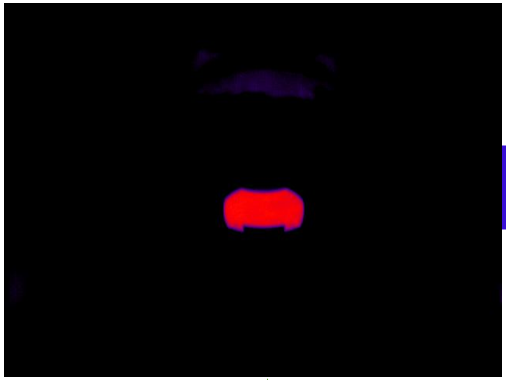
Heat conduction analysis was estimated from thermal diffusion images taken every 5 milliseconds.

Thermal conductivity $k = D \rho Cp = 144.18$ W/K/m

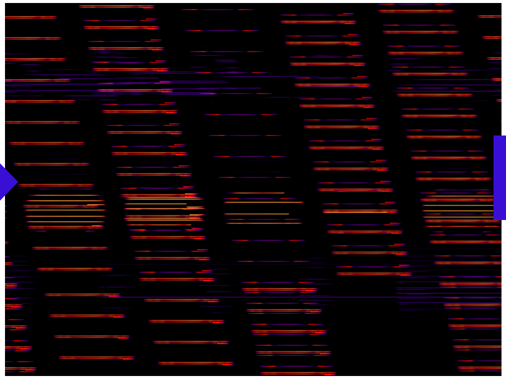
is good agreement with IG430 of the target material : k~140W/K/m

*We are currently analyzing the change in thermal conductivity due to irradiation using long-term imaging data.

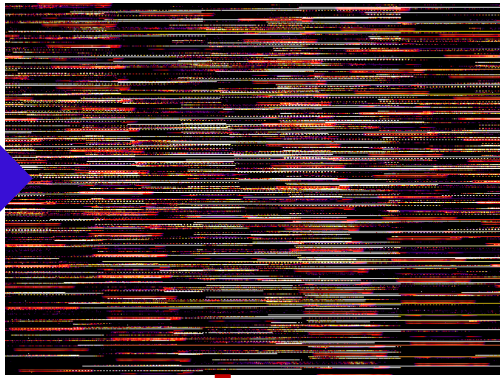
Radiation errors



1-12h



~4h



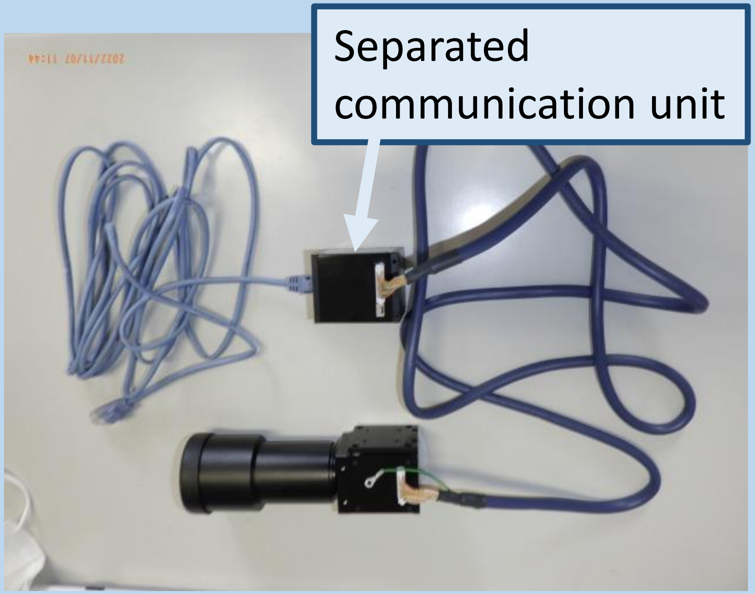
The video is distorted after
a few hours of operation.

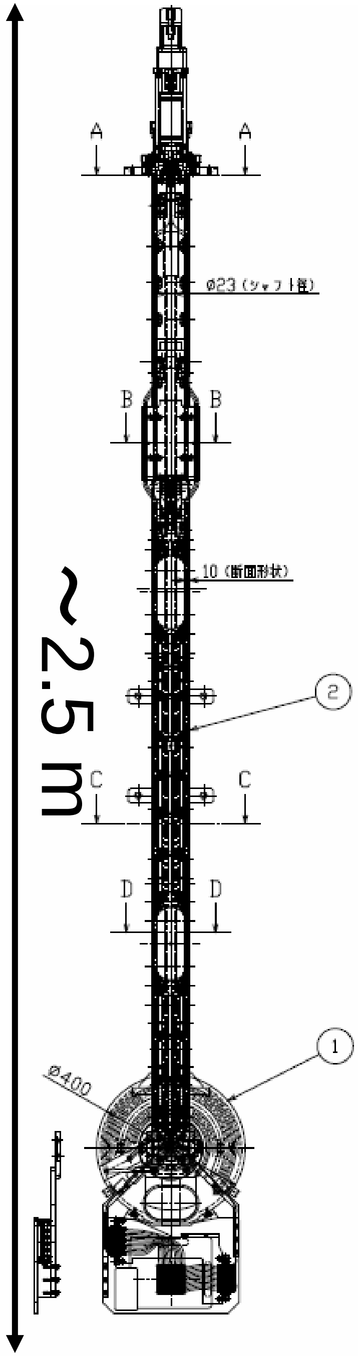
Communication disruption

Automatic recovery by “Rebooter” that pings the camera every minute.

The camera bit the dust…

A camera with a separate communication part was developed. Scheduled to be installed during the next maintenance period.





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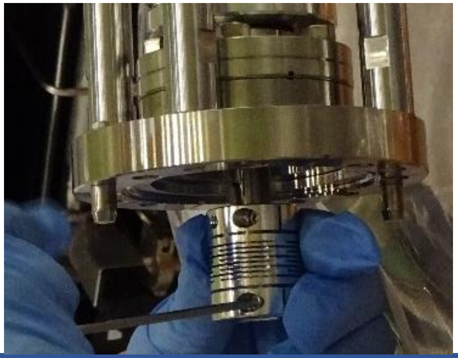
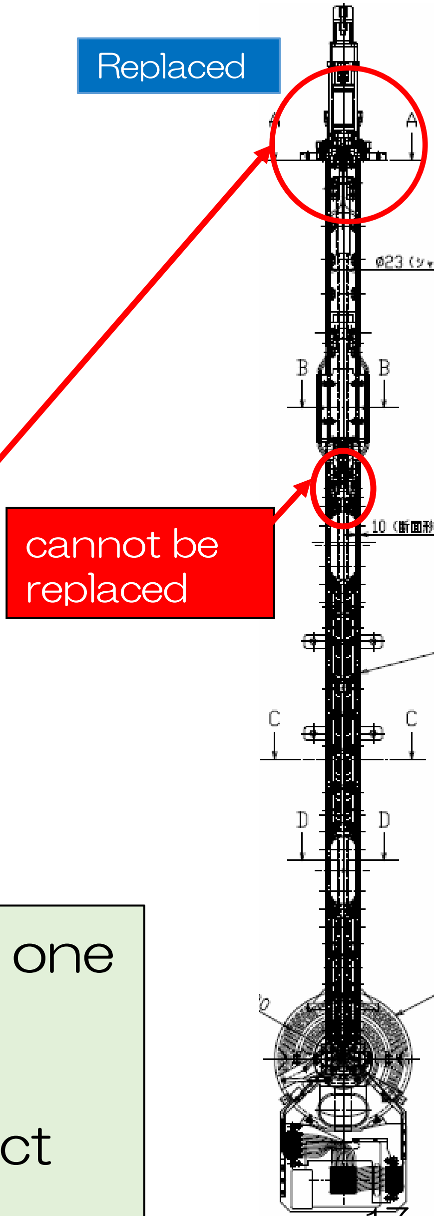
Trouble with rotating coupling (2018)

- The rotating coupling to transmit rotational motion was broken (found in Sept. 2018 during maintenance work).
- The rotating coupling has a keyway process to prevent slippage at the joint with the rotating shaft. There was a mistake in the processing of the keyway, and the strength of the coupling was reduced.

Rotating coupling



Rotational motion feedthrough

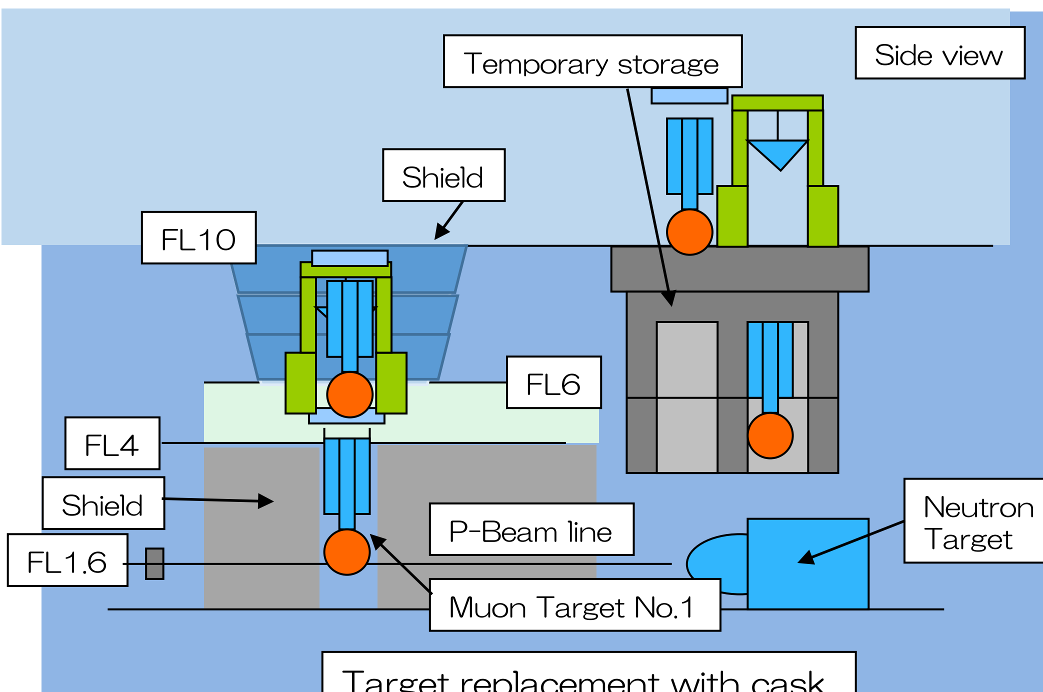


The damaged coupling was replaced with a stronger one in the summer of 2018.
Another weak coupling is used in vacuum.
Beam operation was continued until 2019 under strict monitoring.

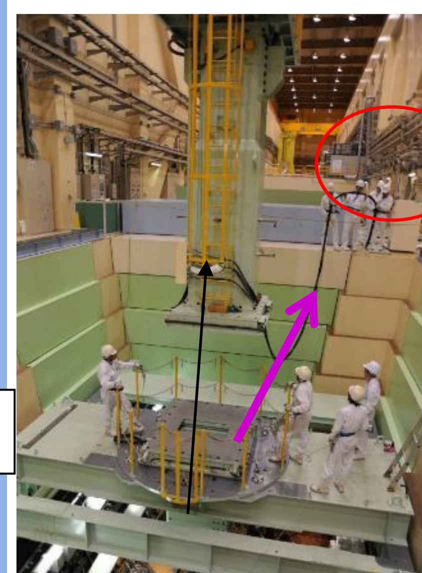
Replacement the muon production target in 2019

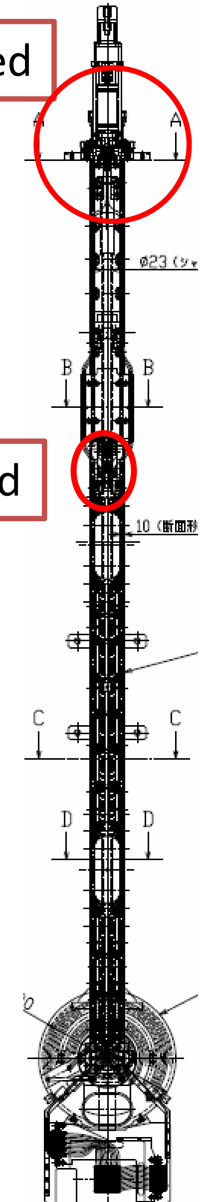
The procedure is below;

① Removal of shieldings
② Transportation of target to temporary storage with Cask
③ Replace entire target
④ Transport of No.2 target to beam line



Target replacement with cask


Cask with Shielding

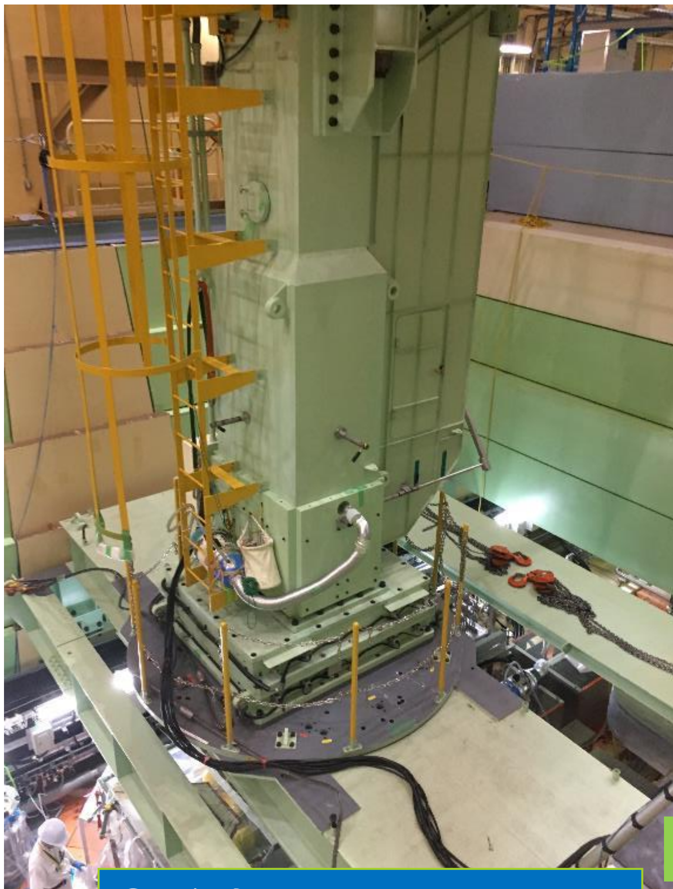


Replacement work

When water enters tritium contaminated equipment during work, tritium diffuses into the atmosphere due to isotopic exchange.

・Rotating target (No.1) was successfully pulled out from proton beamline.

Maintenance in green house with anorack suits & airline mask.

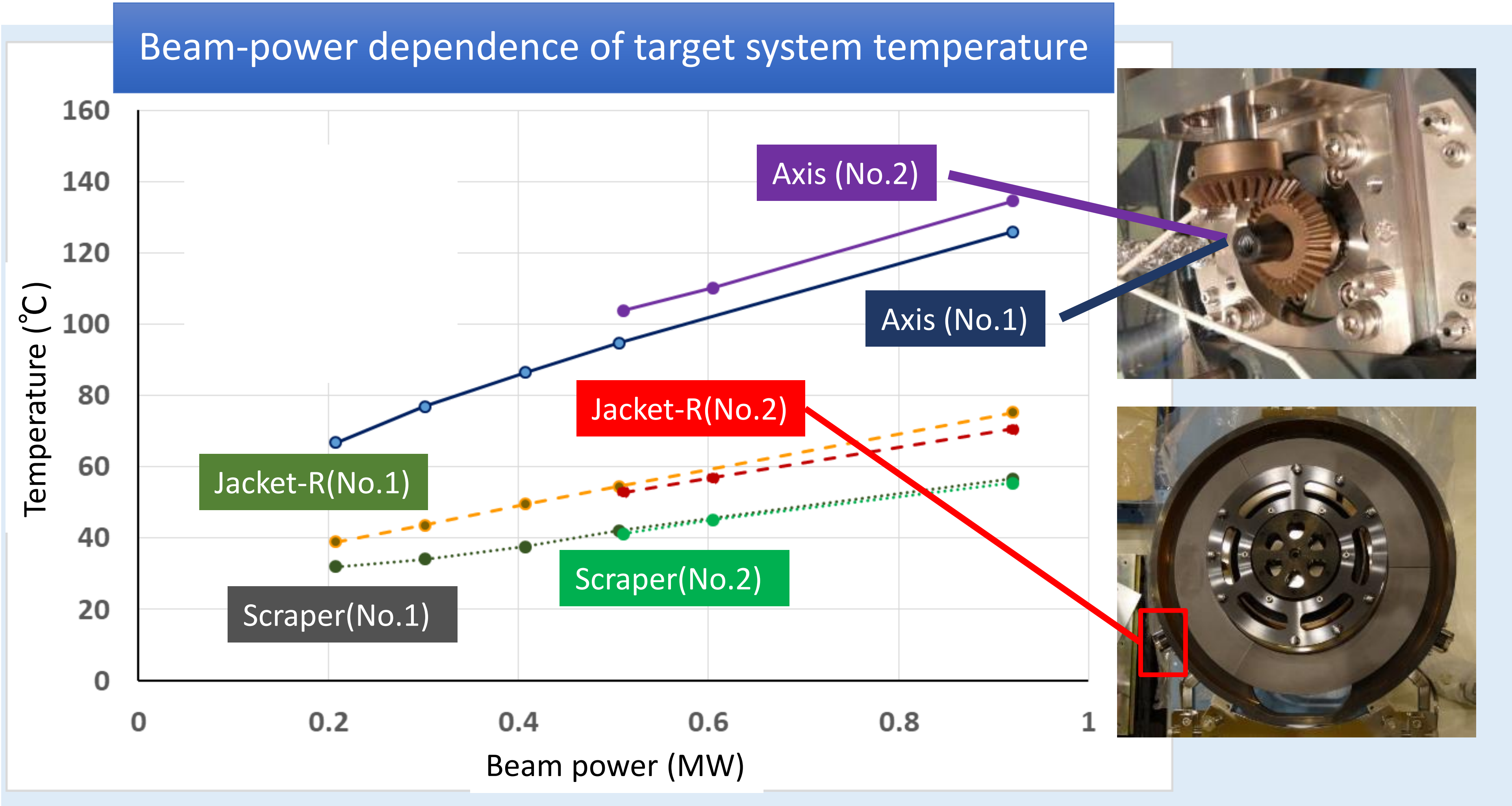


Cask for target transport

Airline respirator

1 MW operation for 32 hours (June, 2020)

- Thermal response of targets and scrapers was found to be consistent with the prediction.
  No difference was observed between the previous (No.1) and current (No.2) target systems.
- Motor torque showed no anomaly during 1 MW operation.



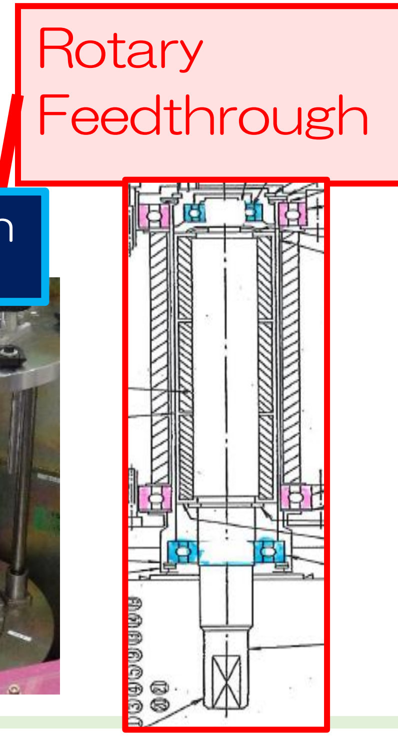
Summary

- The muon rotating target at J-PARC continues to operate stably for a long life time with WS2 bearings.
- Developing of new monitoring systems
  - Machine learning of torque. →In development (Sunagawa, POSTER 110)
  - IR Camera to measure real-time two-dimensional temperature →installed
    ※Countermeasures for radiation errors
  - Analysis of emitted gases with Q-Mass
    → Installed
- Replace of rotating target
  - Measures against tritium pollution and radiation exposure

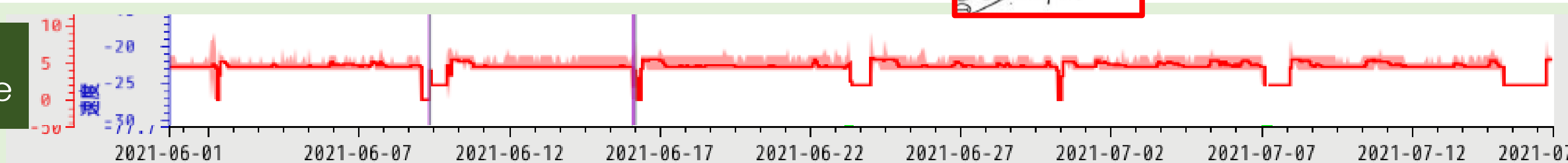
Recent trouble

■A rotary feedthrough is used to transmit rotary torque into the vacuum.
The rotation is transmitted to the shaft in vacuum by magnets inside and outside.

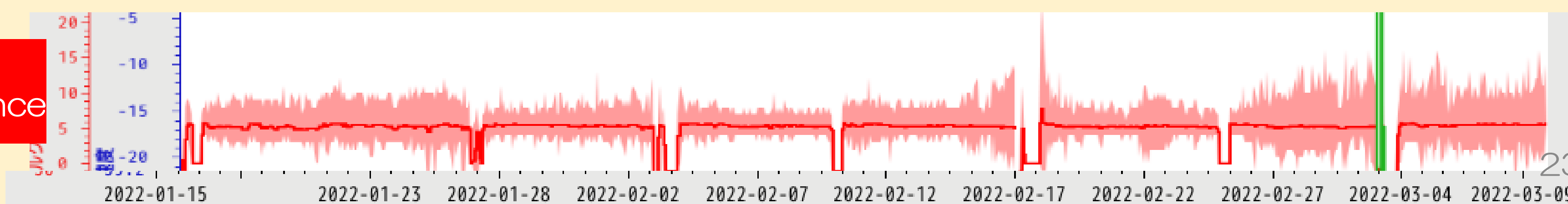
Since the summer maintenance in 2021, the motor torque has increased.



Before maintenance



After maintenance



Recent trouble

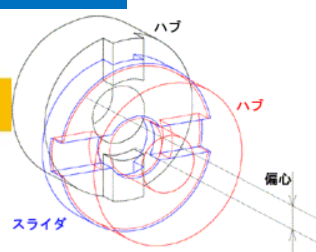
■The rotary feedthrough was examined and found to have a damaged bearing (molybdenum disulfide coating).
The cause of the bearing damage was due to misalignment of the rotating shaft.

■The misalignment was caused by the use of a vacuum sealing gasket with an inner diameter 0.1 mm smaller than standard.

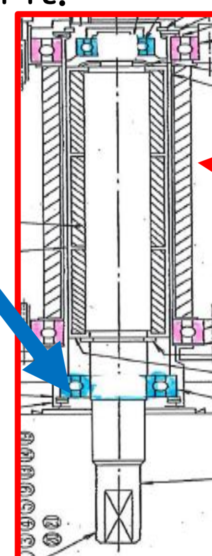
■The gasket was replaced with one of the correct specification in the 2022 maintenance.
In addition, an Oldham type coupling was installed to tolerate the misalignment.
The target itself was not replaced.

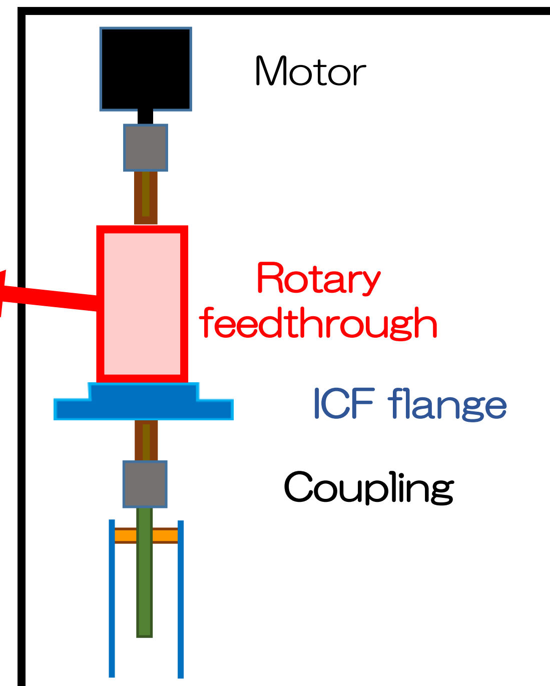
IPD(Φ48.1mm)

ICF(Φ48.2mm)



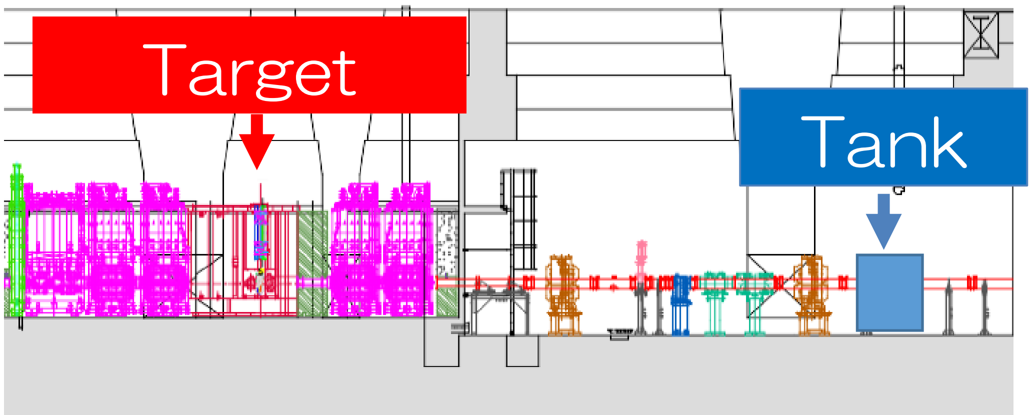
Bearing in vacuum





Buffer tank

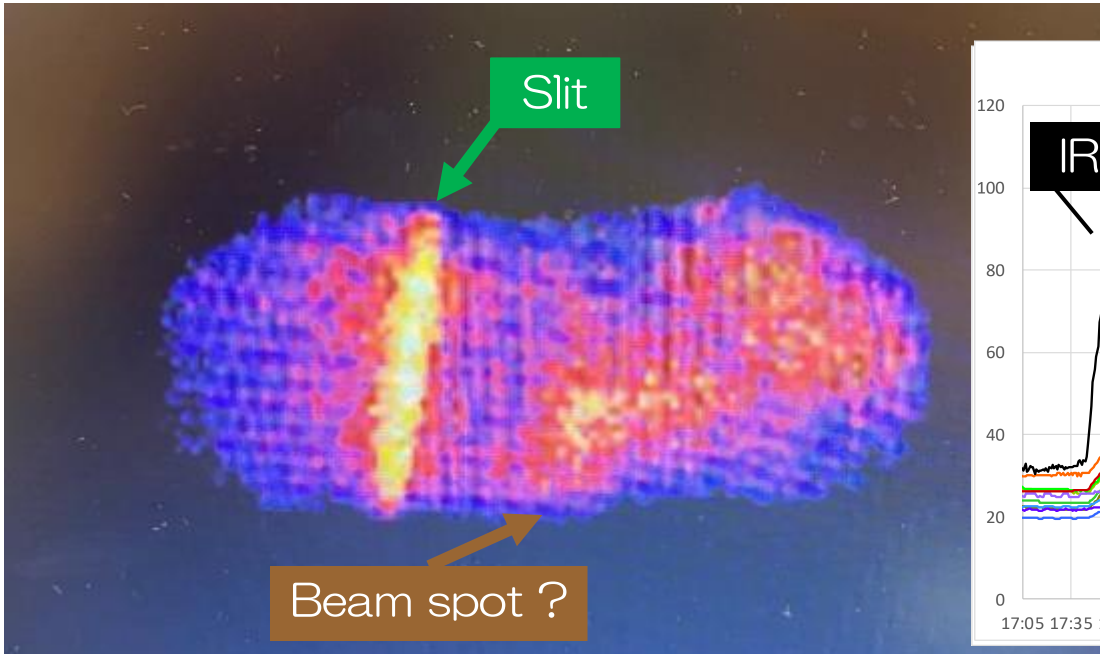
- The exhaust of vacuum pump is temporarily stored in a buffer tank and is vented after measurement of concentration of RI.
  To temporarily accumulate RI in ducts in case of trouble
  To measure the amount of RI generated

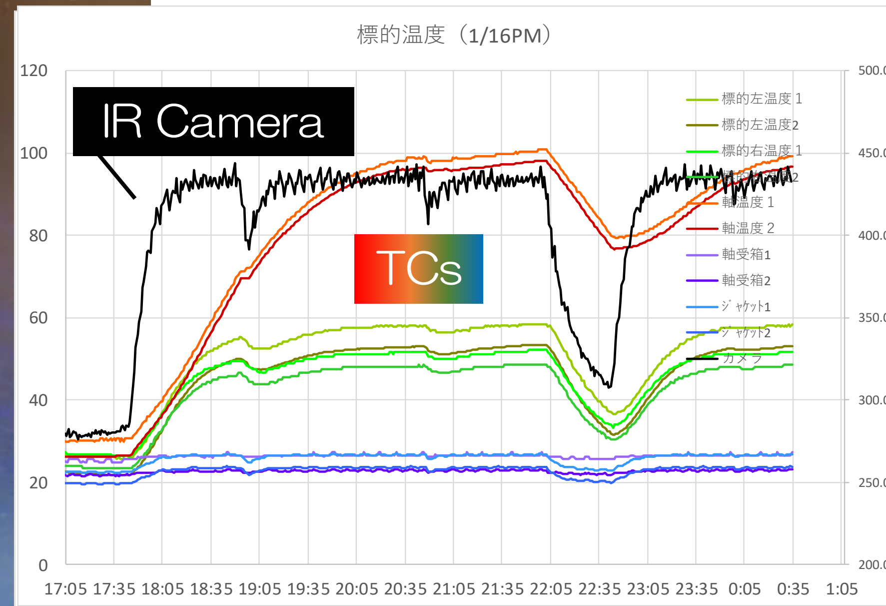


- Where is tritium?
  Tritium production at target : 500 GBq /year (at 1MW)
  Tritium (HT + HTO) measured in buffer tank : 5 GBq/year

Graphite inside?
(but the deuterium diffusion coefficient in high temperature graphite is large)
Duct walls?
We have started to measure the tritium diffusion coefficient in IG430.

Monitoring of the muon target





Temperature distribution during irradiation

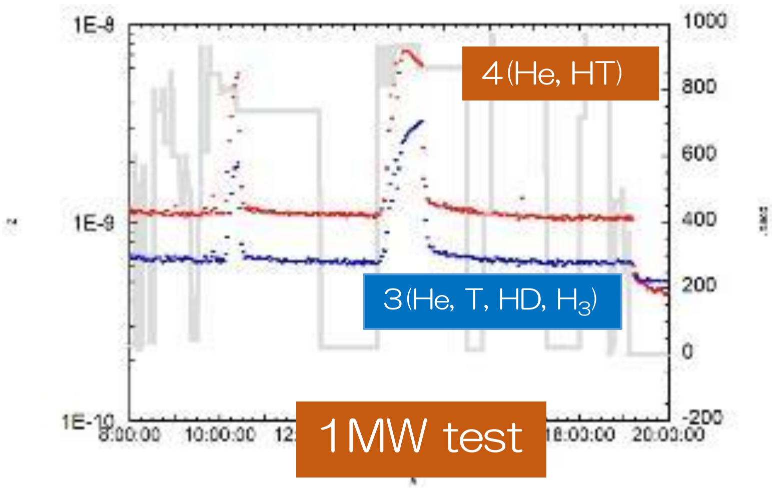
- At the center, a high-temperature part, which is likely to be a beam spot with a diameter of about 1.5 cm, was observed.
- According to a simple analysis, the temperature in the high temperature area was 650 degree C, which was different from calculated value of 510 degree C at 500 kW.

  →Detailed analysis will be performed.

Quick detection of abnormal events with Q-Mass

■Tritium produced at the target contaminates the beam duct, making maintenance difficult.

→Tritium measurement with Q-Mass

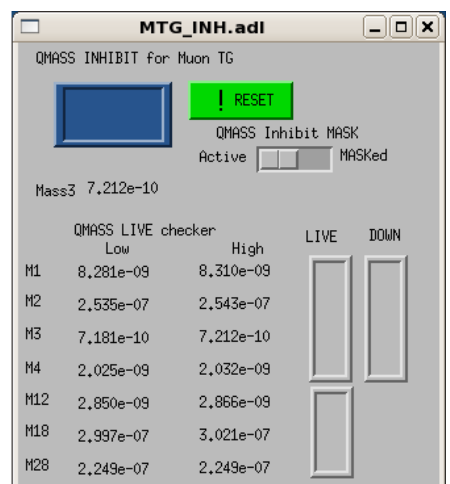


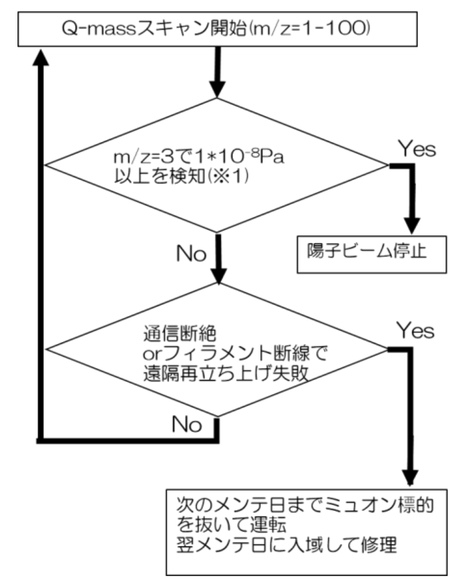
Q-Mass at the proton beam line

■Rapid detection of emitted gas by beam heating at the time of stop of target rotation

Successfully multiplexed interlock.

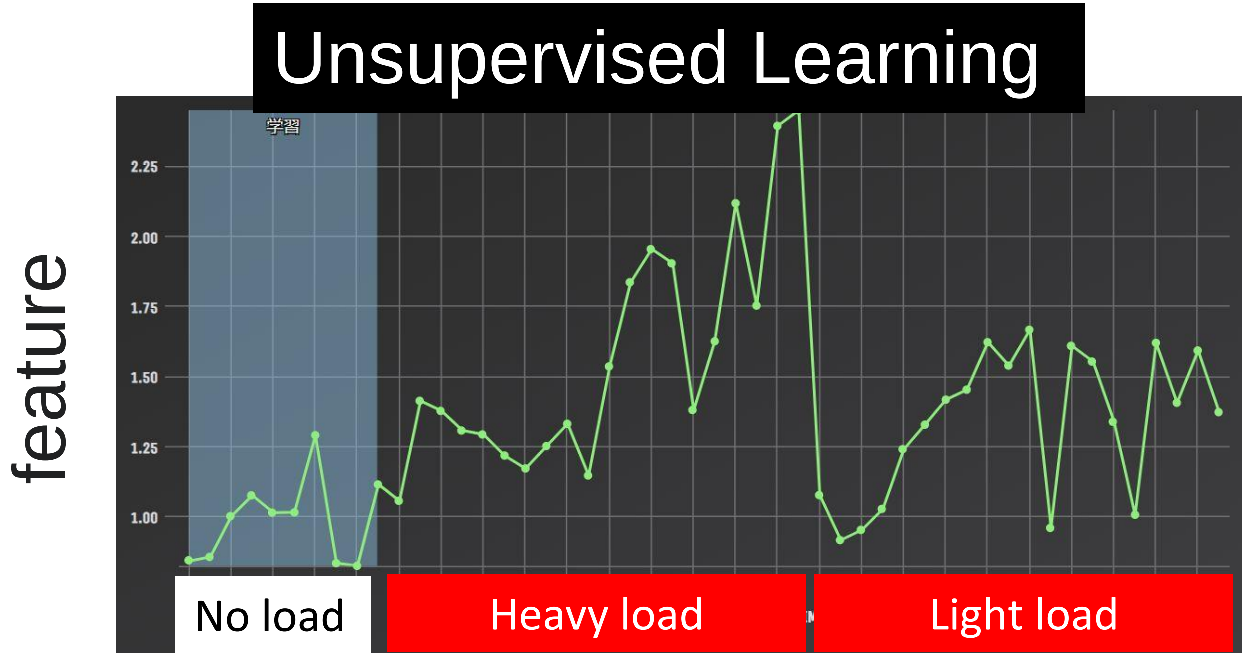
※Constructed jointly with neutron source group





Machine learning of torque and servo current

■If the rotating target stops, the target will be damaged.
By detecting abnormalities in the rotating system at an early stage, it will be possible to consider countermeasures before damage occurs.
■By sensing the "torque" and "current" of the rotating servomotor, it was verified whether the attributes at the time of abnormality could be captured.



■There is a possibility that machine learning can predict danger.
It is necessary to improve the prediction accuracy by performing supervised learning at offline site.

Target Group at MUSE

- 2014 Fabrication and installation of rotating targets


S. Makimura
(Target)


N. Kawamura
(proton beam line


Y. Kobayashi
(Controls)


Y. Miyake
(Section leader)

- 2023 Operation and development of monitoring systems


S. Matoba
(Target)

H. Sunakawa
(Monitors)


(Section leader)