High power operation of J-PARC 3 GeV Rapid Cycling Synchrotron under high temperature and humidity

ARW2022
18 Oct., 2022

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on behalf of J-PARC Center
Accelerator Division

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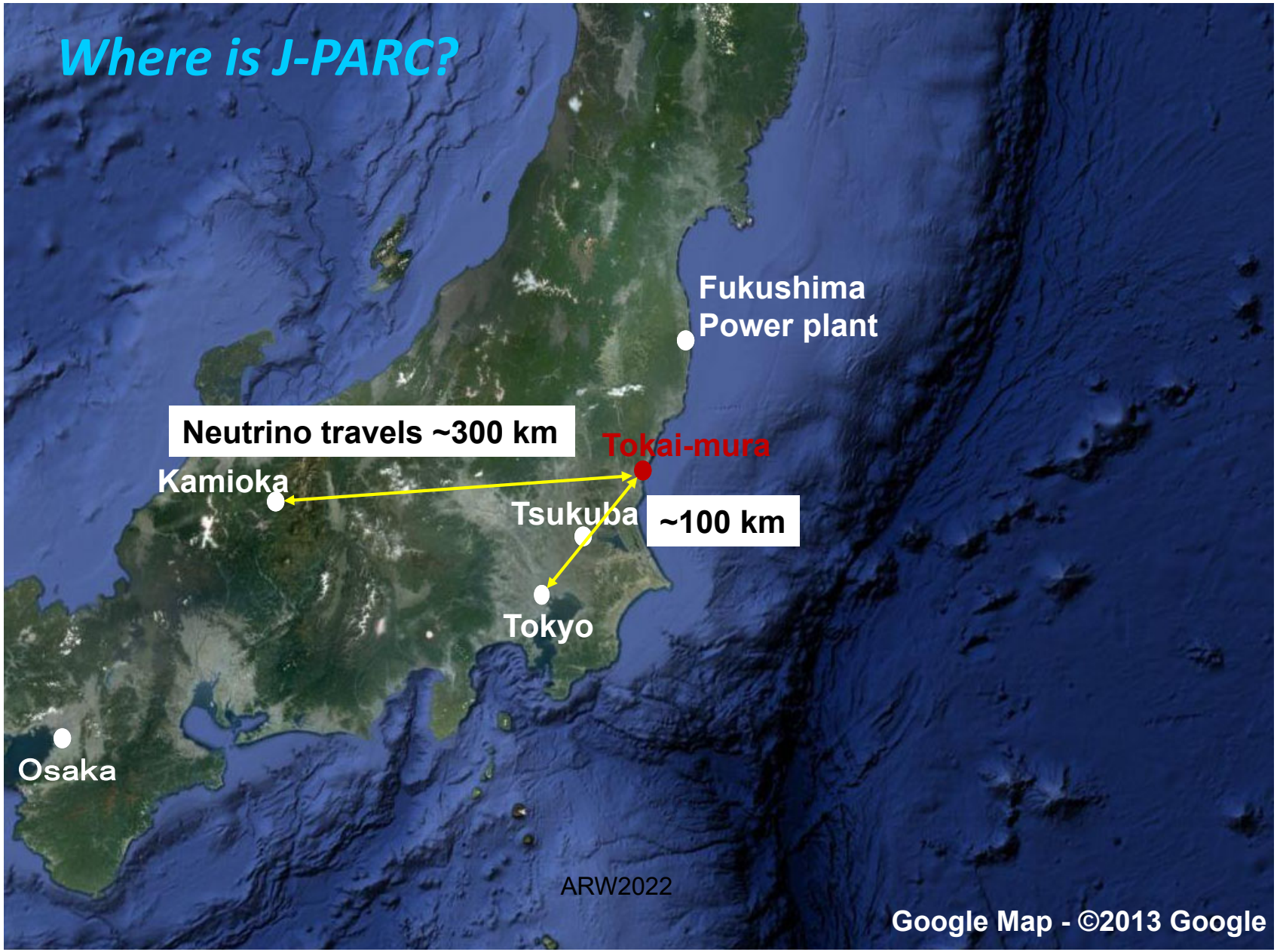
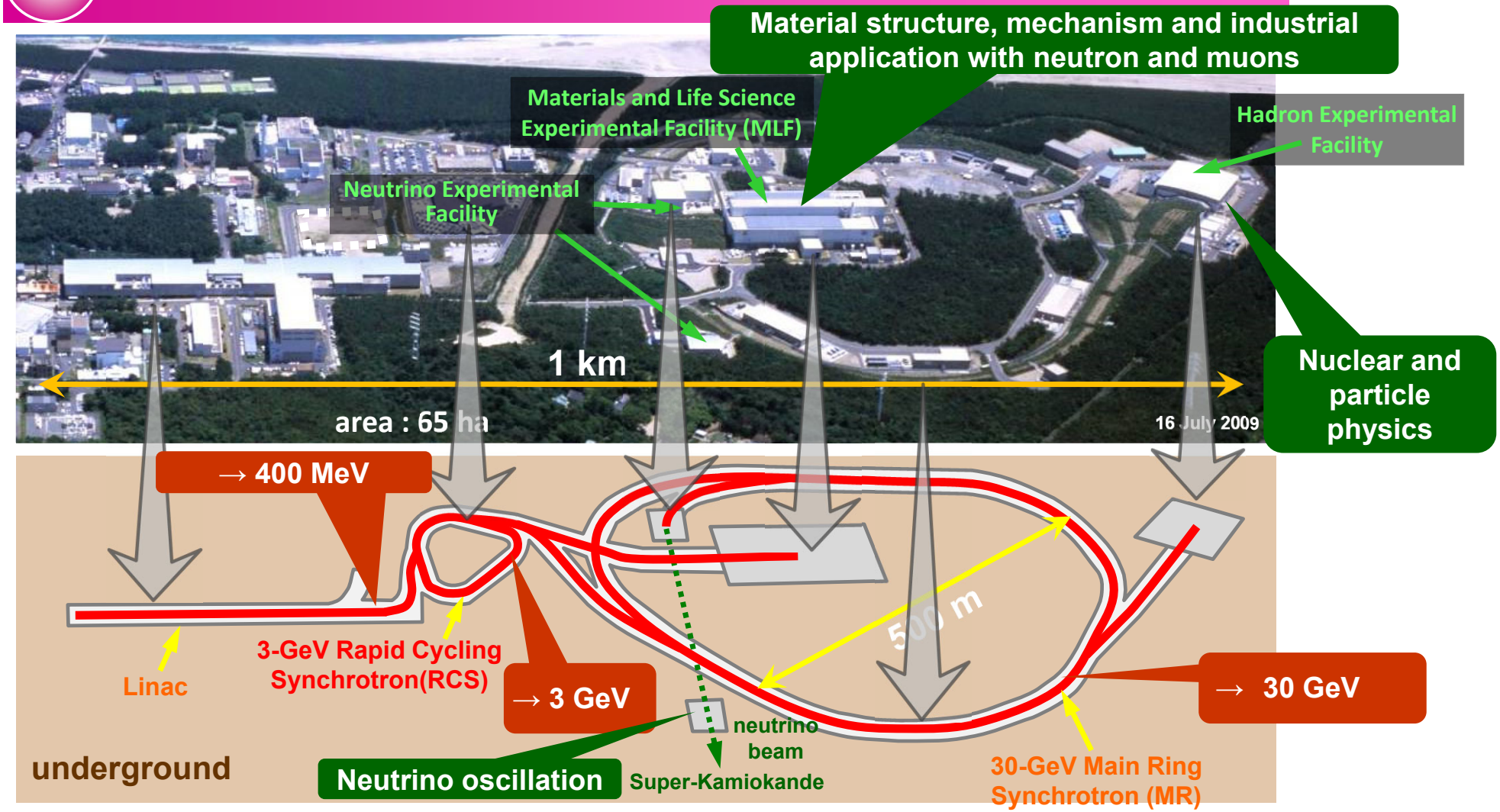

Where is J-PARC?
Fukushima
Power plant
Neutrino travels ~300 km
Tokai-mura
Kamioka
Tsukuba
~100 km
Tokyo
Osaka
Google Map - ©2013 Google

Japan Proton Accelerator Research Complex

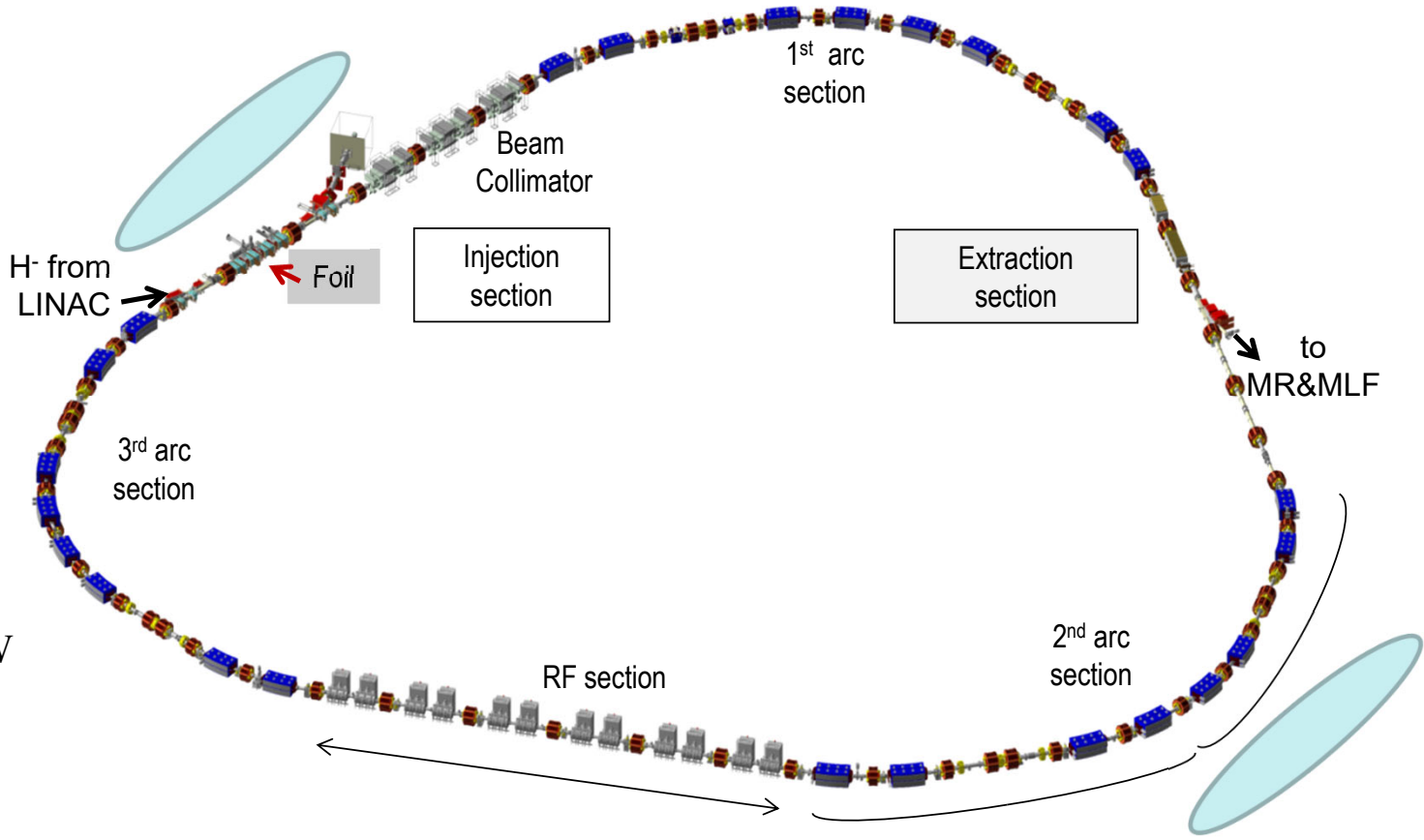


3 proton accelerators and 3 experimental facilities

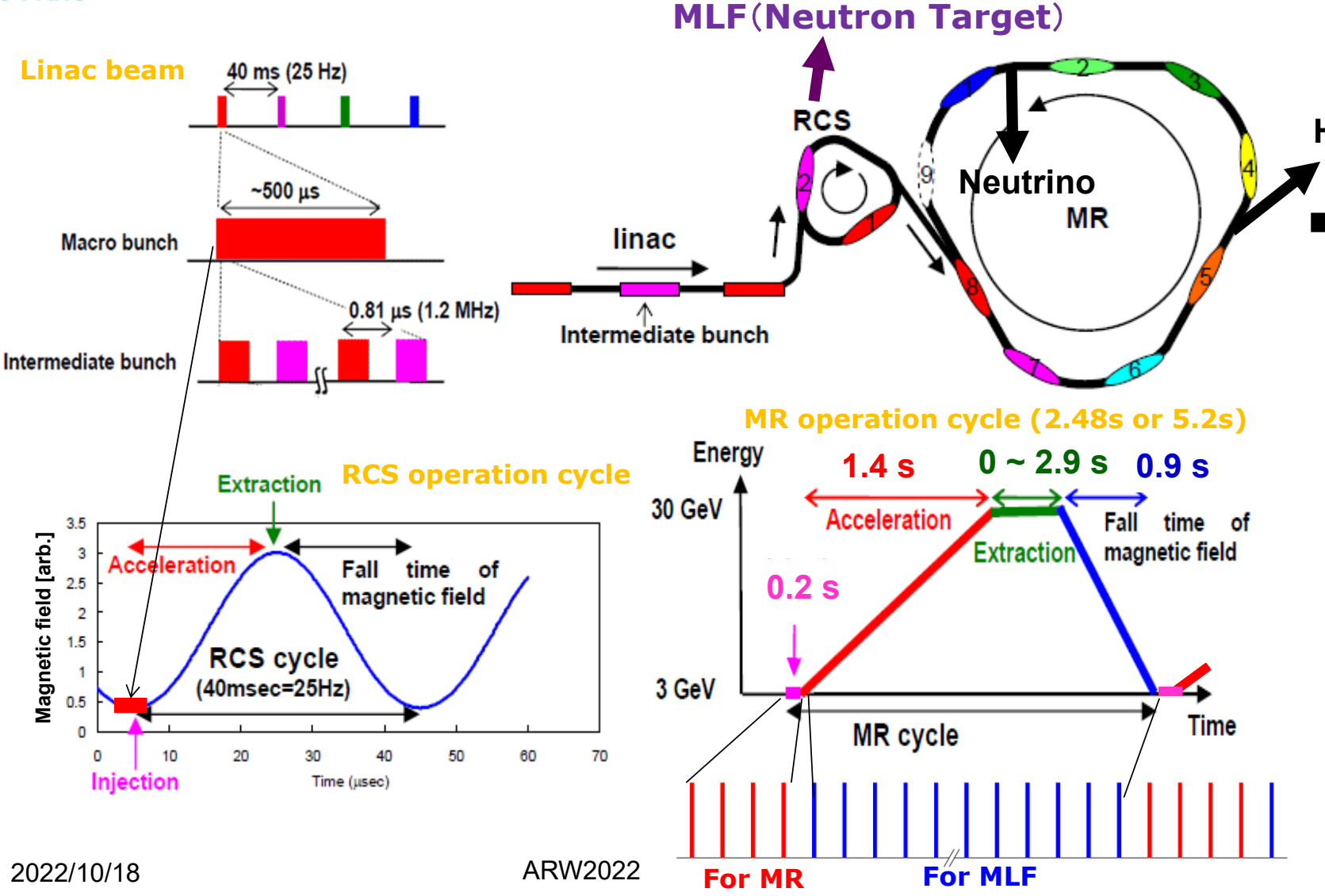
3GeV-RCS in J-PARC

Parameters

Circumference	348.333 m
Superperiodicity	3
Harmonic number	2
F_{rev}	0.61-0.84 MHz
F_{rf}	1.23-1.67 MHz
Injection energy	400 MeV
Extraction energy	3 GeV
Repetition rate	25 Hz
Particles per pulse	8.3e13 with 1 MW
Output beam power	0.8 MW (1 MW)

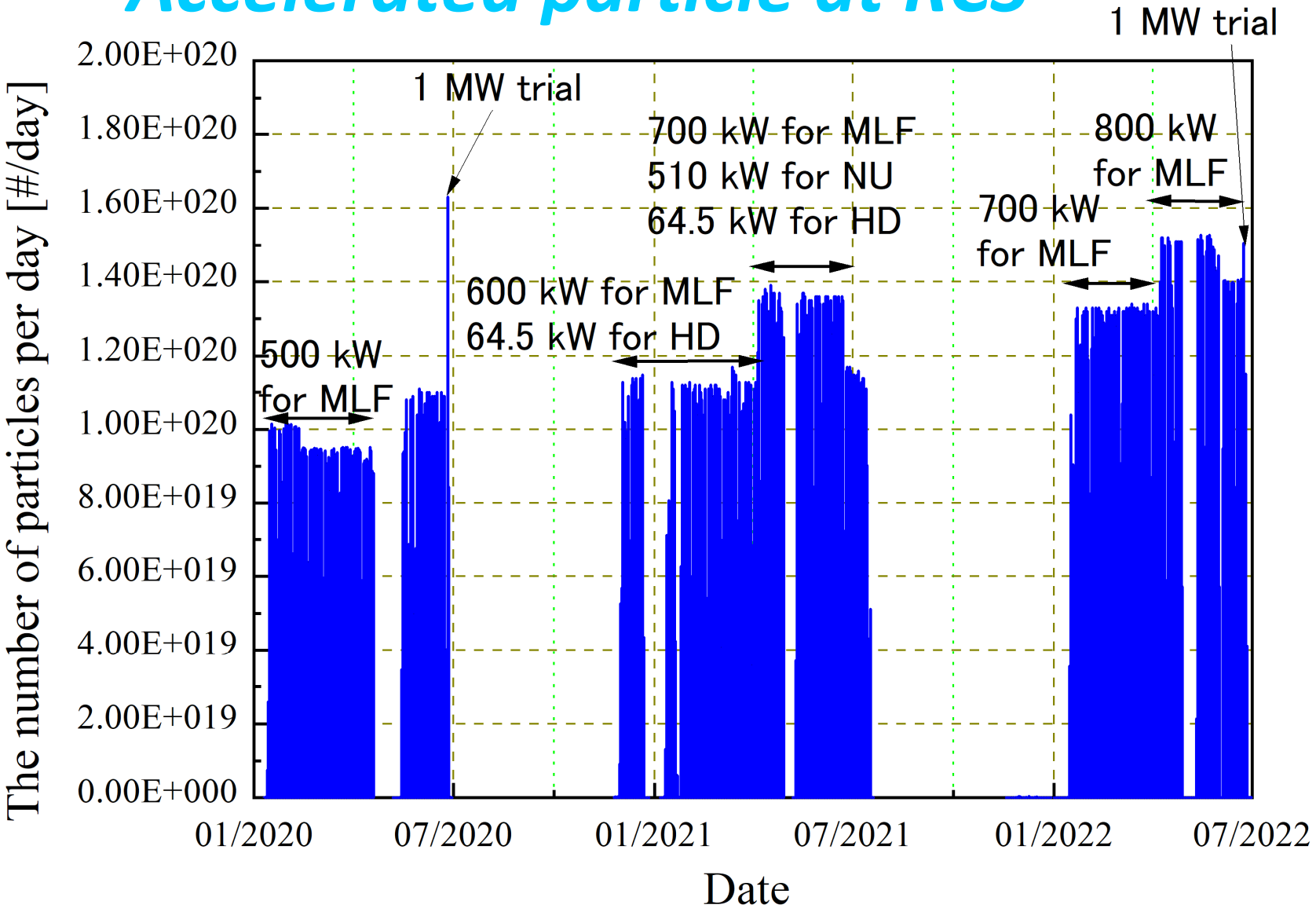


Time structure of accelerator operation

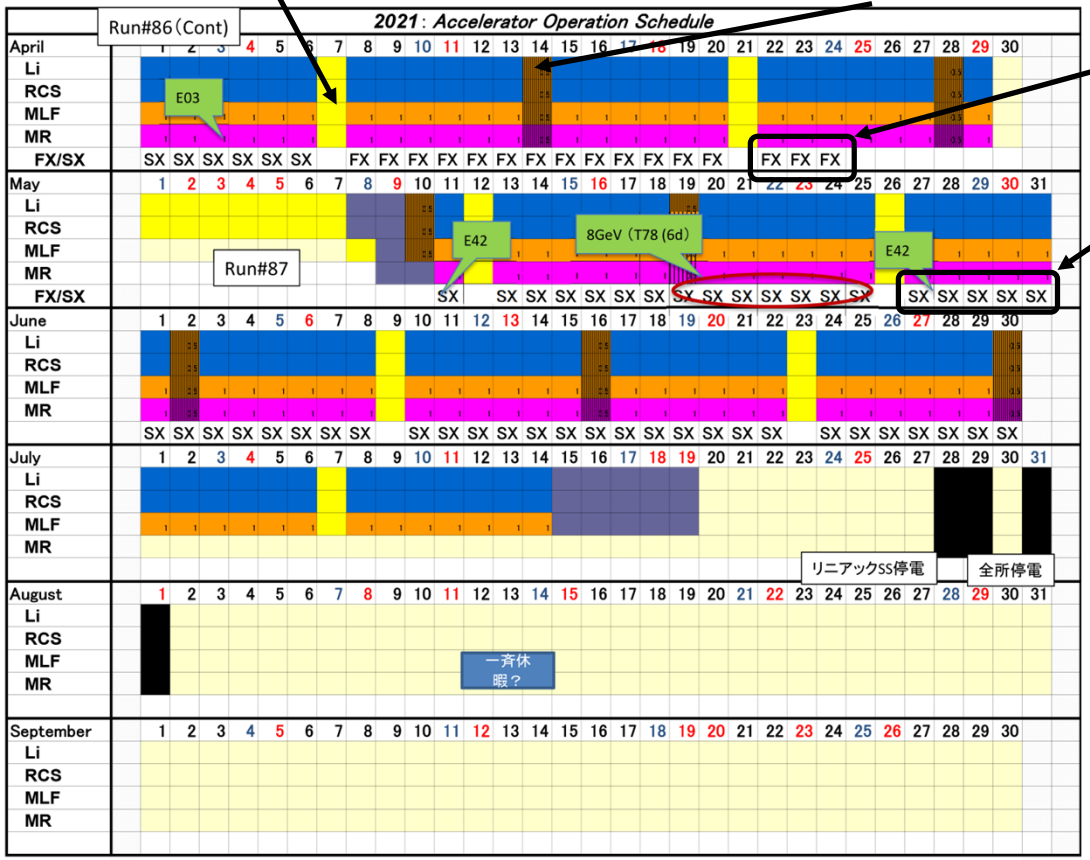


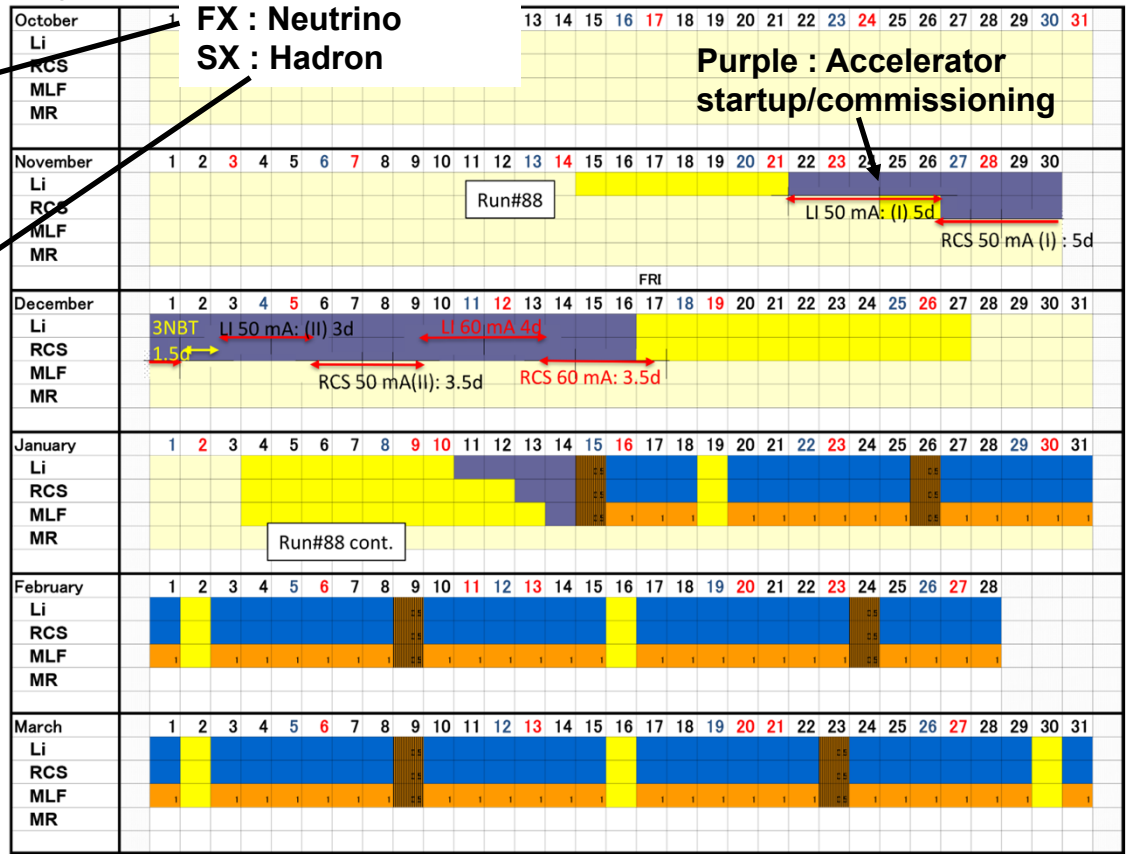
- MLF and MR can be simultaneously operated.
  Therefore, all pulses are NOT delivered to MLF!
  (Actual beam power is < 1 MW for MLF)
- However, Hadron Facility and Neutrino Facility cannot be simultaneously operated.
- MR has to select the operation mode (FX for Neutrino, or SX for Hadron)

Accelerated particle at RCS



Operation schedule and statistics of JFY2021



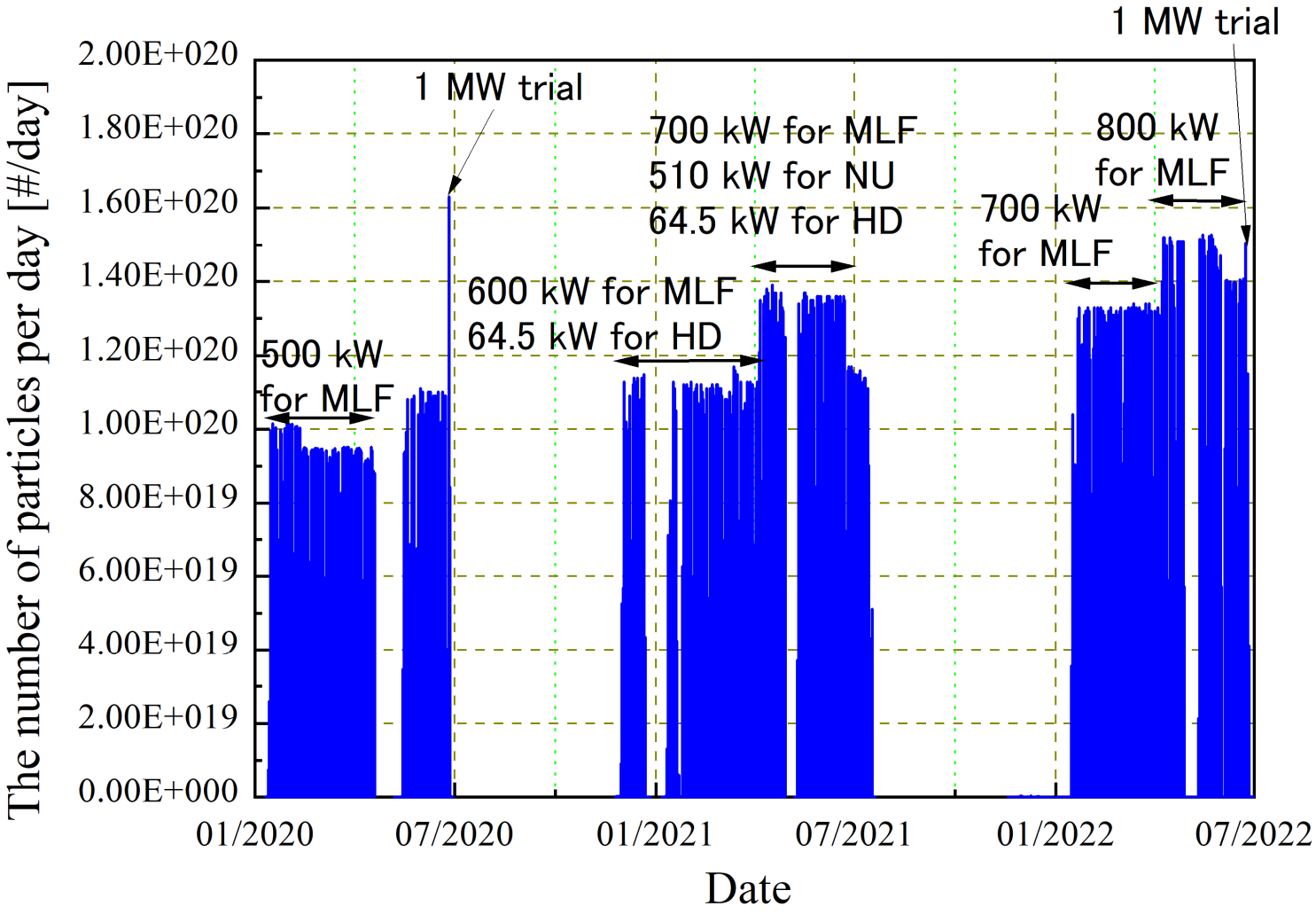


	Scheduled time [h]	Net operation time [h]	Availability [%]
MLF (Neutron)	3608	3480	96.5
Neutrino	371	347	93.5
Hadron	1016	952	93.7

2022/10/18

1 MW operation condition and issue under high temperature and humidity

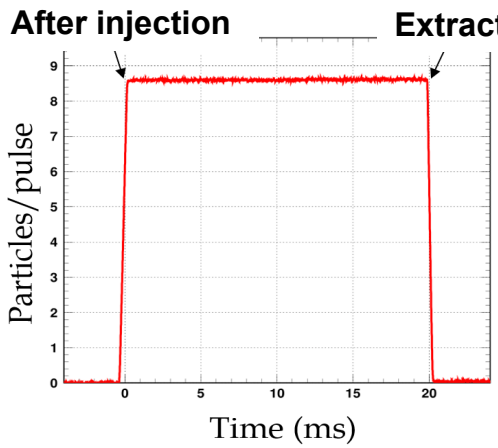
1 MW trial



We tired 1-MW continuous operation on June 2020 and 2022.

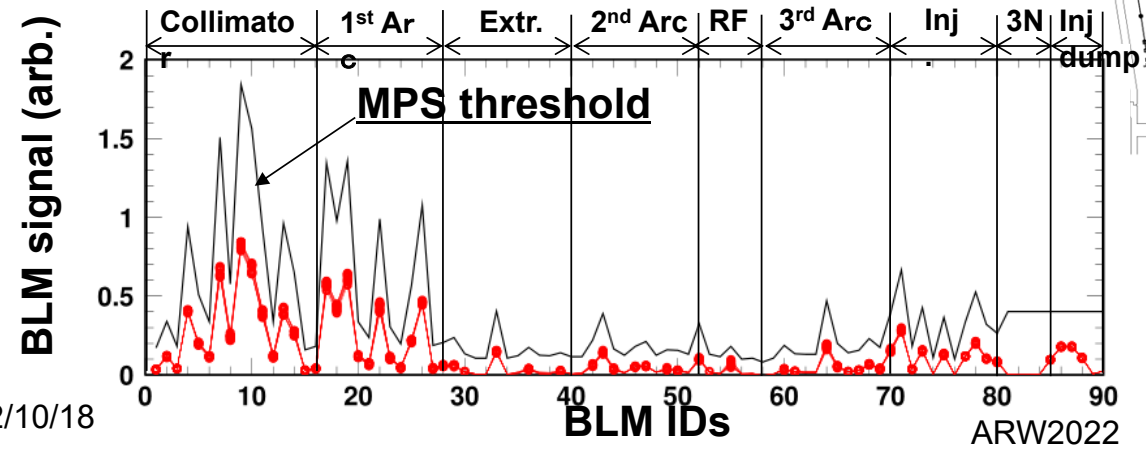
Beam loss@1MW

Beam current@1 MW

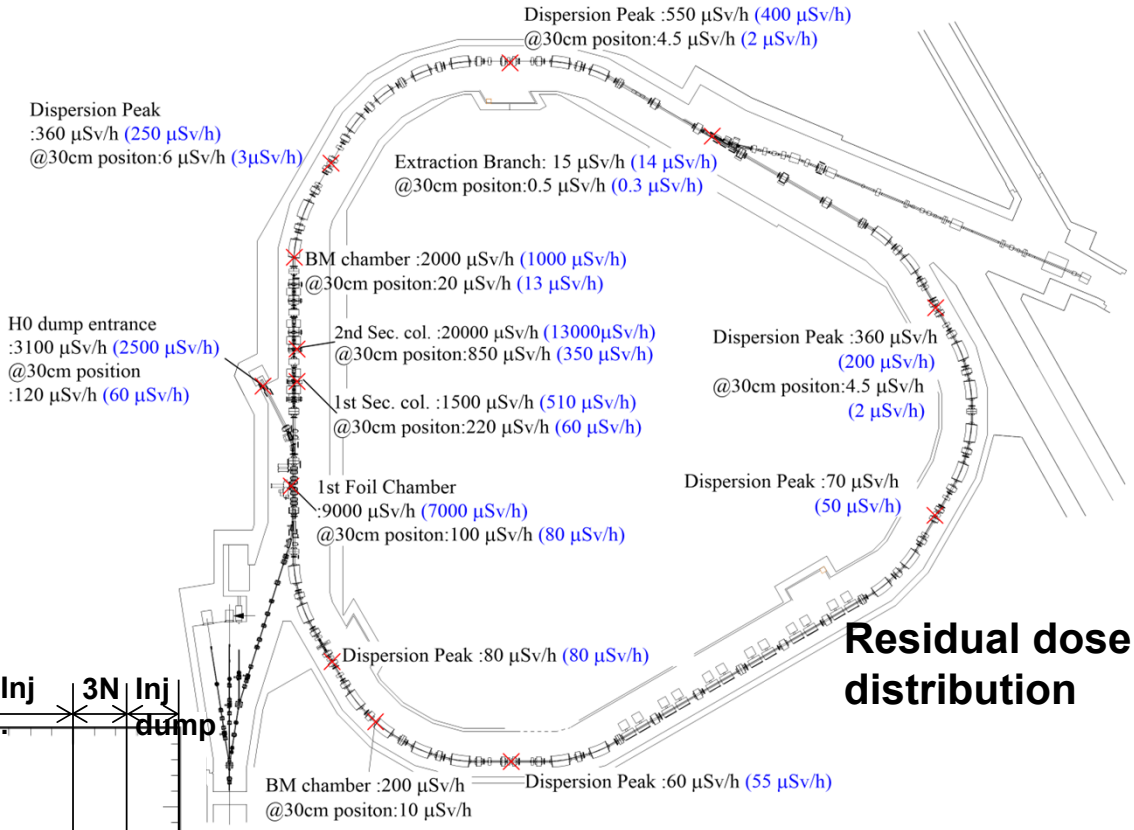


There is no significant loss in the current monitor signal.

Beam loss monitor signals



After 1 MW, 40 hr trial for MLF (27th Jun. 2020), Measurement after 5 hours from beam stop
600 kW user operation (24th Jun. 2020) , Measurement after 4 hours from beam stop

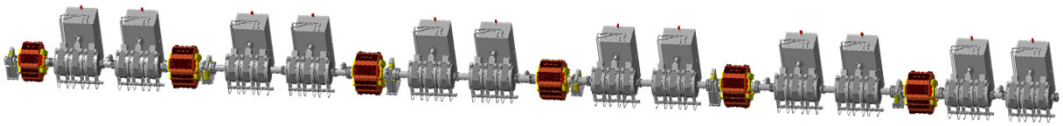


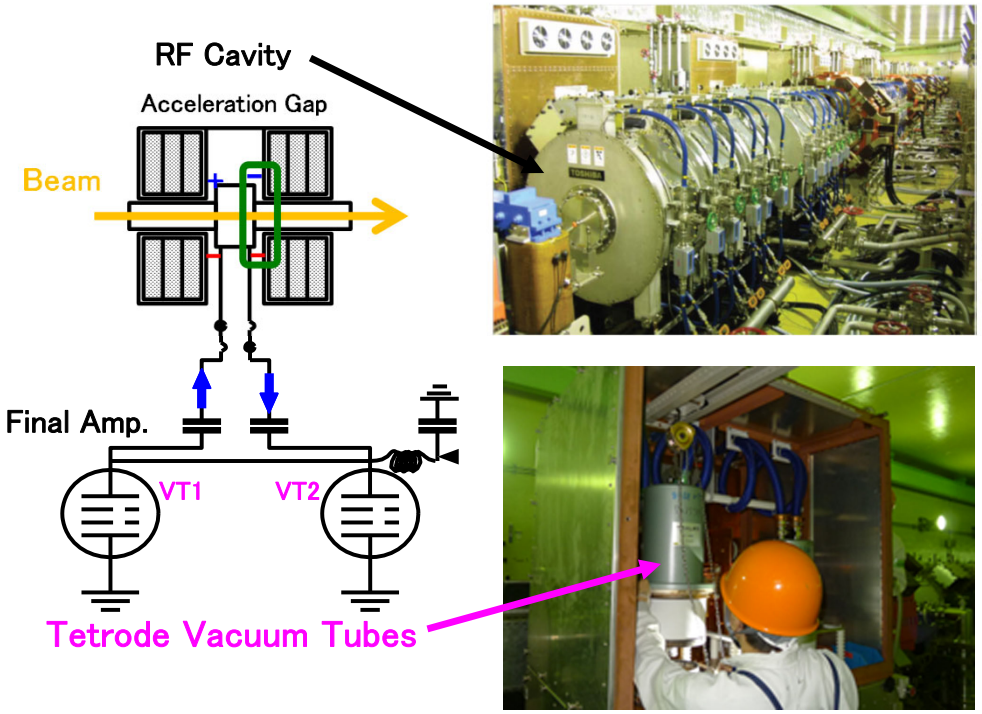
Residual dose distribution

Black : after 1 MW continuous trial
Blue : after 600 kW user operation

✓ **Enough small, acceptable beam loss**

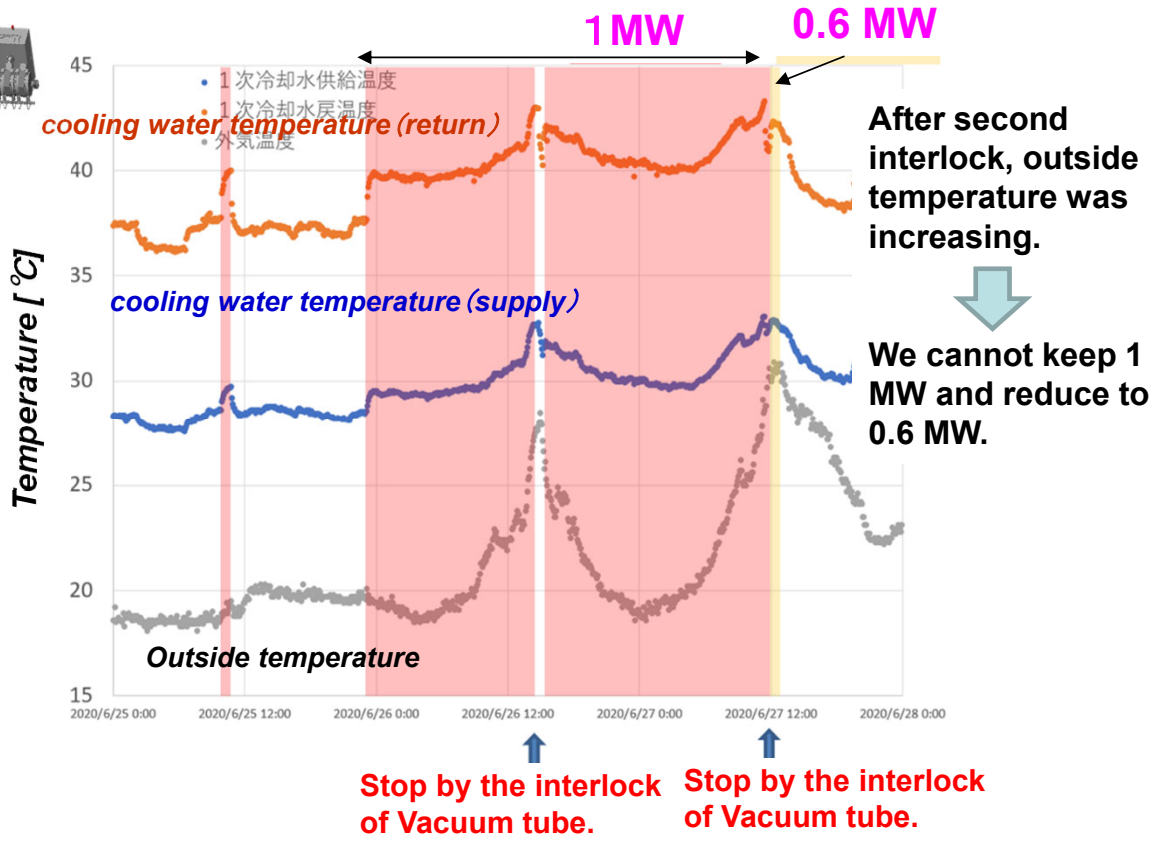
Cooling water issue (2020)





RCS RF system.

Trend of cooling water temperature in 1 MW trial 2020.

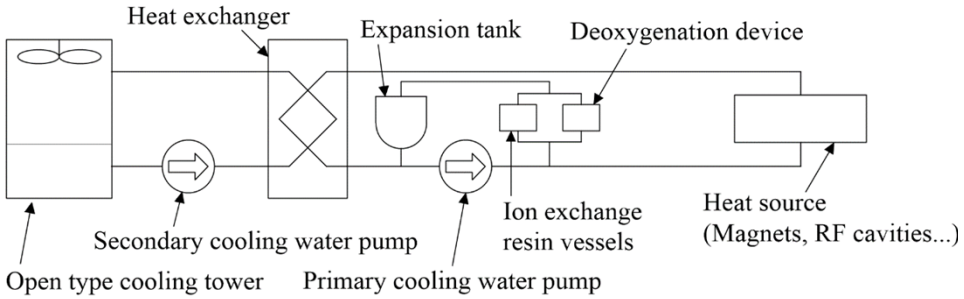


After second interlock, outside temperature was increasing.

We cannot keep 1 MW and reduce to 0.6 MW.

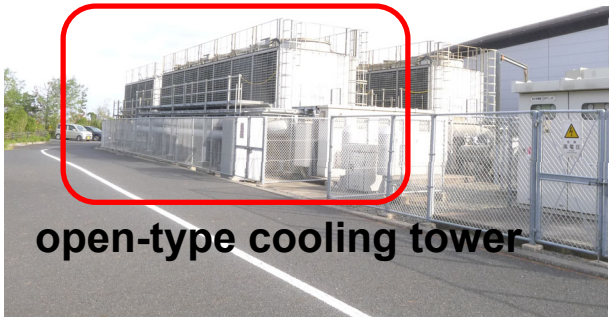
To protect the vacuum tube, beam operation was stopped by the interlock when the cooling water temperature exceeds 47 degrees.

Cooling water issue (2020)

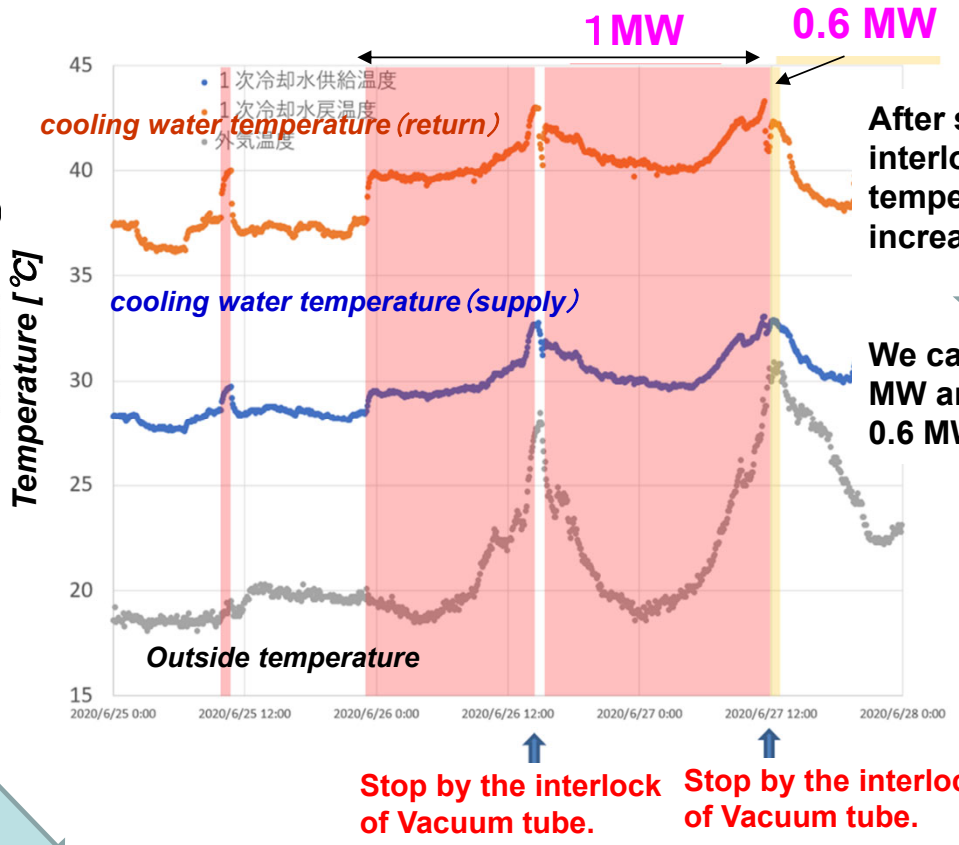


Schematic view of the RCS cooling water system.

- **The primary cooling water is separated from the secondary cooling water by a heat exchanger.**
- **The secondary cooling water is cooled by an open-type cooling tower installed outdoors.**
- **Since the heat is removed by the vaporization of the secondary cooling water itself, the performance of the cooling water system deteriorates with rise in the outside air temperature and humidity.**



Trend of cooling water temperature in 1 MW trial 2020.



After second interlock, outside temperature was increasing.

We cannot keep 1 MW and reduce to 0.6 MW.

We could not continue the operation of the 1 MW beam when the outside temperature was high

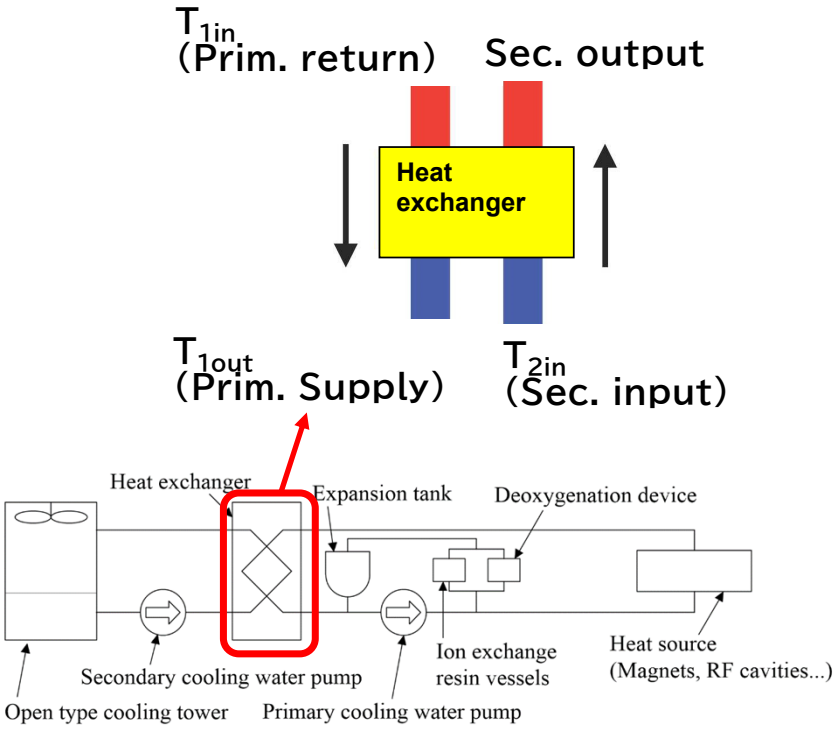
Investigation of the cooling water system performance

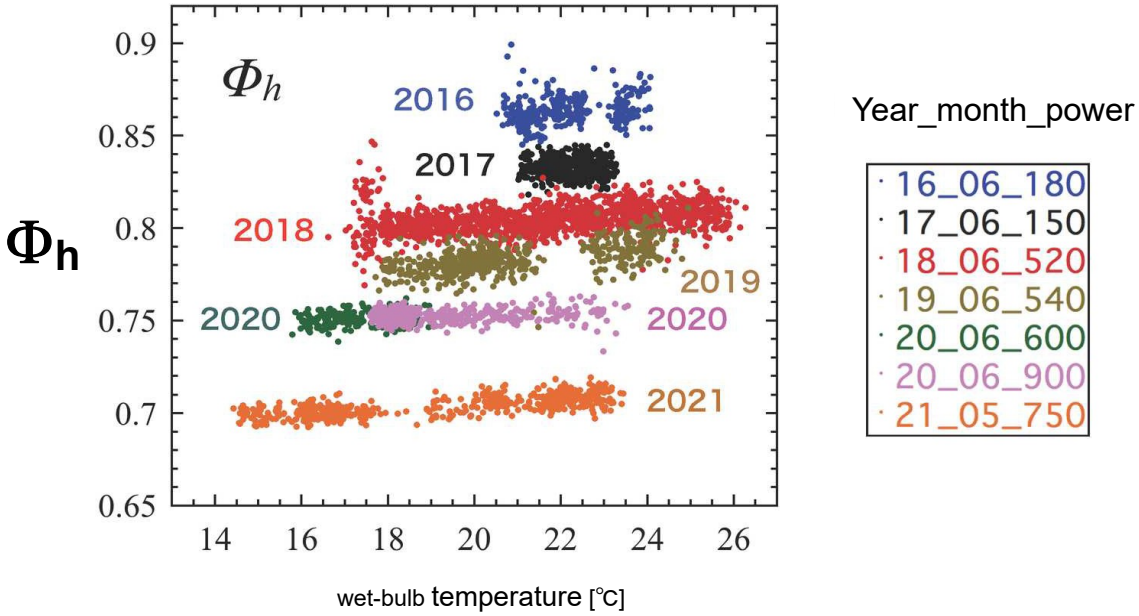
We analyzed the performance of the cooling water system by thermal exchange efficiency Φ_h

Thermal exchange efficiency

$$\Phi_h = \frac{T_{1in} - T_{1out}}{T_{1in} - T_{2in}}$$

Differential between the return and supply temp. of primary water was normalized by the differential between the return temp. of primary water and input temp. of secondary water





Degraded each year!

Recovery work of the cooling water system performance 2021

Heat exchanger
Plates are layered

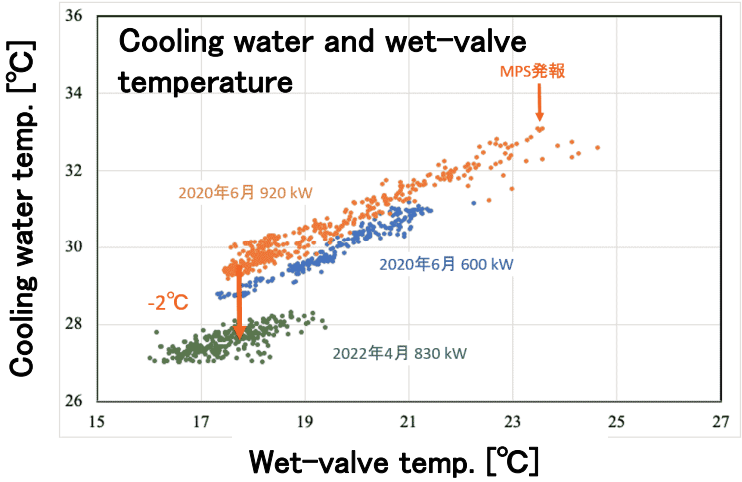
Primary and secondary water flows alternately between the layered plates.

Plates are disassembled.

Plate of the heat exchanger

We disassembled and washed the heat exchange unit in the summer shutdown period 2021.

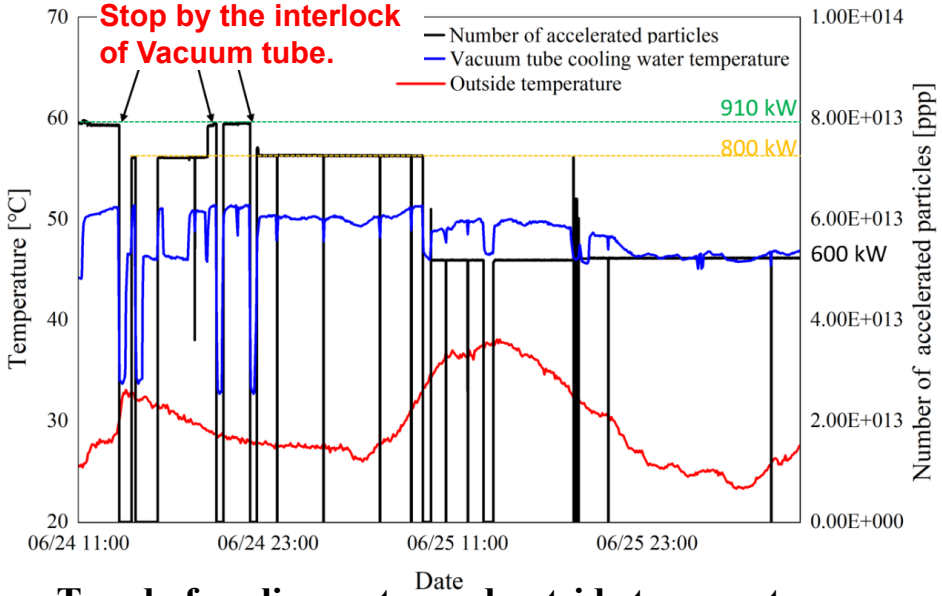
Secondary loop was contaminated with sludge ! Removed it by the chemical cleaning



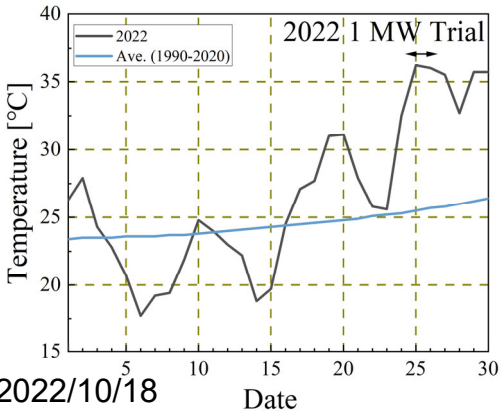
After cleaning, the cooling water temperature had decreased by about 2° C even though the power had increased!

Results of 1 MW trial on June 2022

Finally, we tried 1 MW continuous operation June 24-26 2022.



Trend of cooling water and outside temperatures.

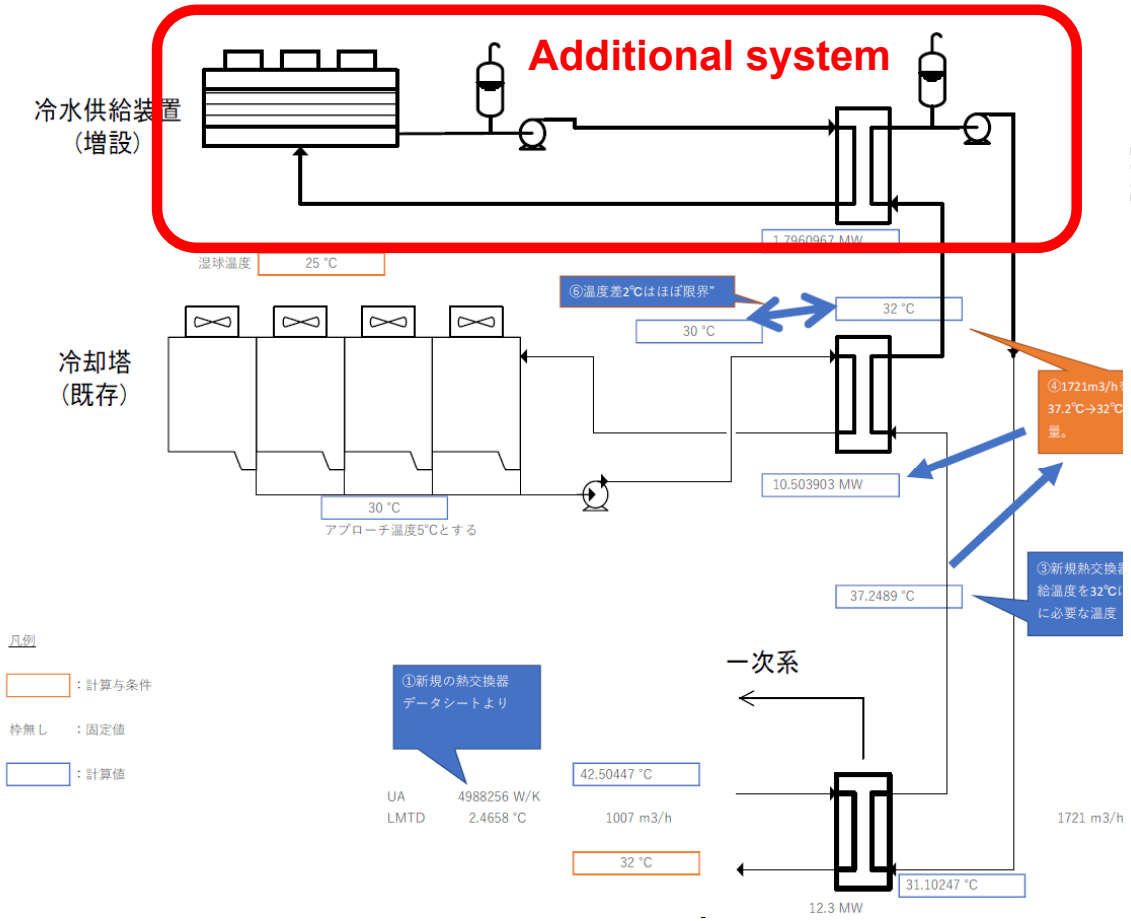


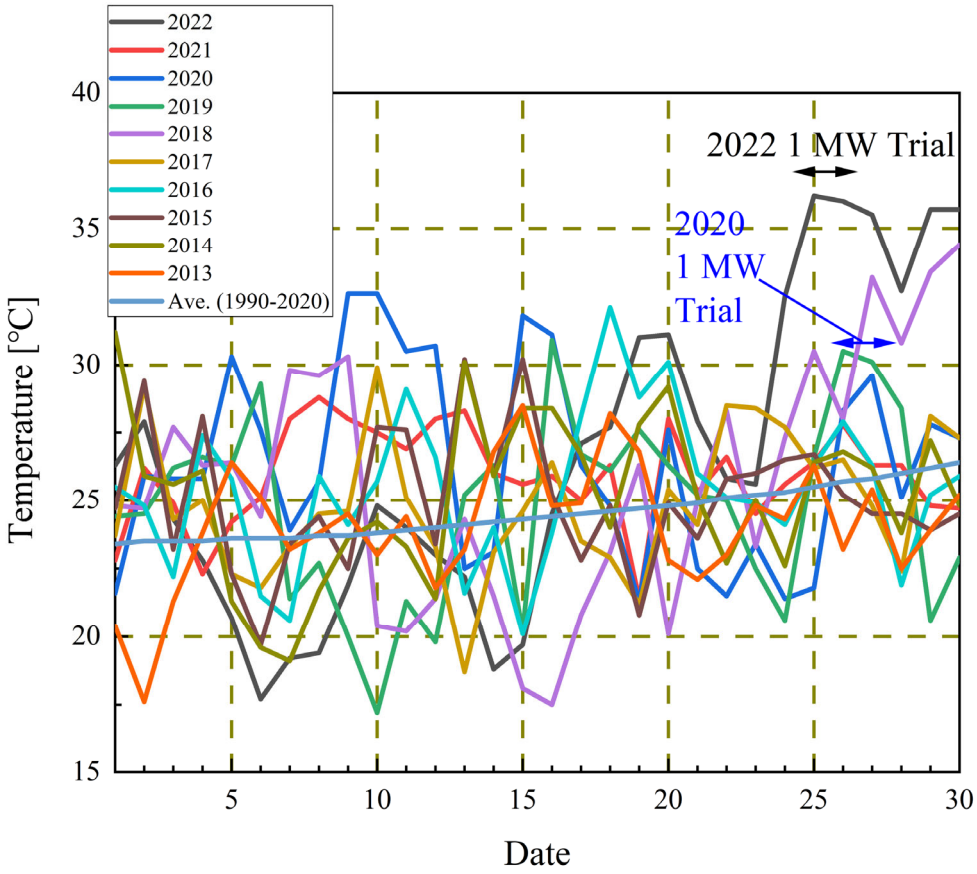
Temperature trend of Mito city (~10 km from Tokai-mura)

Temperature of 25th was more than 35 ℃! This value is just mid-summer!

- **Operation started at 11:14 June 24, but stopped at 13:33 due to interlock of vacuum tube temperature.**
- **We reduced the beam power to 800 kW and restarted at 14:21, but the temperature of the vacuum tube frequently rose to near the threshold. Therefore, we had to stopped each time and wait cooling down.**
- **However, the outside temperature was kept around 30℃ and the cooling water temperature did not down enough. We gave up 1 MW and ran at 800 kW until morning.**
- **8:30 in the morning of June 25, the temperature of the vacuum tube rose to just before the threshold. We Reduced 600 kW.**
- **12:38, an failure occurred at RF #10. We could not recover it immediately.**
- **We tried to 800 kW in the evening(18:00), but at 800 kW and 700 kW, there were frequently an additional loss during acceleration and the beam was stopped.**
- **Finally we continued to operate at 600 kW until the next morning.**

How to improve?





Temperature trend of Mito city during 10 years

We considered reinforcement of the cooling water system
cost : ~several Oku-¥ (M$)

Temperature of this year is extraordinary!
We need this new cooling system only a few days because we stop the operation at the end of June.
Not cost effective.

Summary

- As a result of the 1 MW trial at J-PARC RCS, it was found that the performance of the cooling water system deteriorated due to high outside temperature and humidity.
- An analysis of the thermal exchange efficiency revealed that it had been deteriorating year by year.
- We cleaned the thermal exchanger unit during the 2021 summer maintenance period. We confirmed the effect of the cleaning.
- Unfortunately, it turned out that the capacity of the cooling water system itself was insufficient in the extremely hot and humid environment of Japan's summer.
- The enhancement of the cooling water system seemed not cost-effective, thus it is necessary to consider an operation plan with systematically reducing the power in June.