

Magnet

MR and BT/DR

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On behalf of the Magnet Group

- MR magnets
 - Cooling system
 - Magnet Activation
- Power converters
 - Maintenance
 - Failure response
- BT/DR
 - Failure response
 - Others

MR magnets: cooling system maintenance

If the MR magnet system (including power converter issues) shuts down, it may be necessary to re-initialize all magnets before resuming operations; this has a significant impact on beam operation and tuning.

The following procedures are carried out annually during the summer shutdown for the cooling water system of the MR magnets. As a result, there have been no issues originating from the magnets during operations **since October 2019**.

- Cleaned the strainers and checked the flow rates of all water-cooled magnets.
- Cleaned the hoses of magnets showing a significant decrease in flow rate compared with last year.



Strainer maintenance



Hose cleaning



Flow-rate measurement

MR magnets: activation and affected locations

Following beam operation, residual radioactivity tends to be higher near the injection points of both rings and downstream of the collimators just after the injection point. It is estimated that, between the 2025c and 2026b runs, some magnets accumulated radiation doses exceeding 10% of their design-specified radiation tolerance.

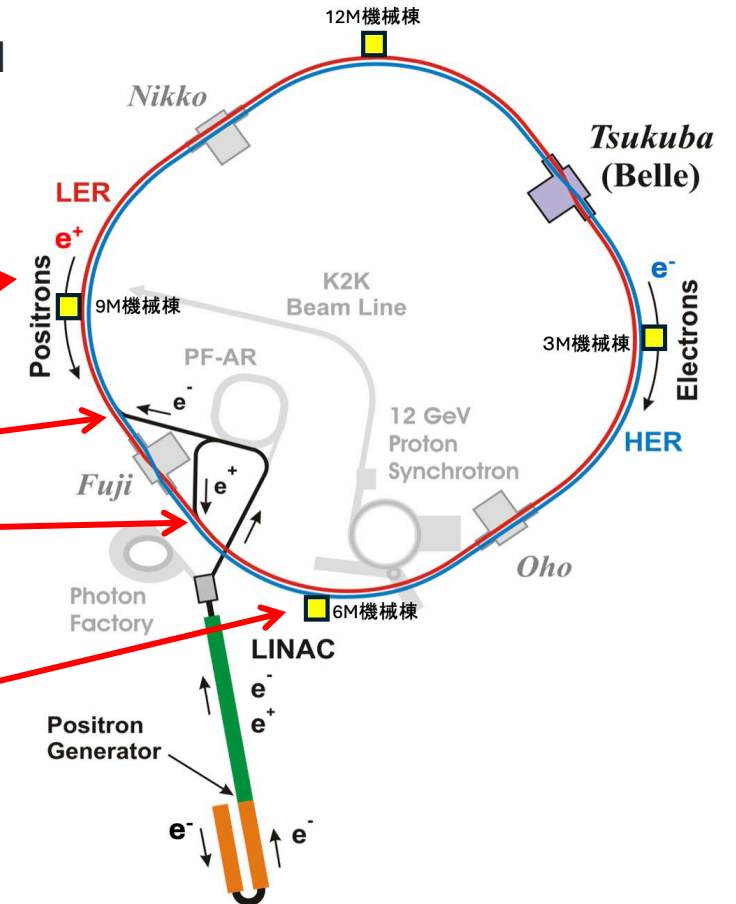
HER, west tunnel

D09V1 collimator area: B2E.51 and QD5E.22

Injection regions of both rings

LER, south tunnel

D06V1 collimator area: **QT4FOP.1**



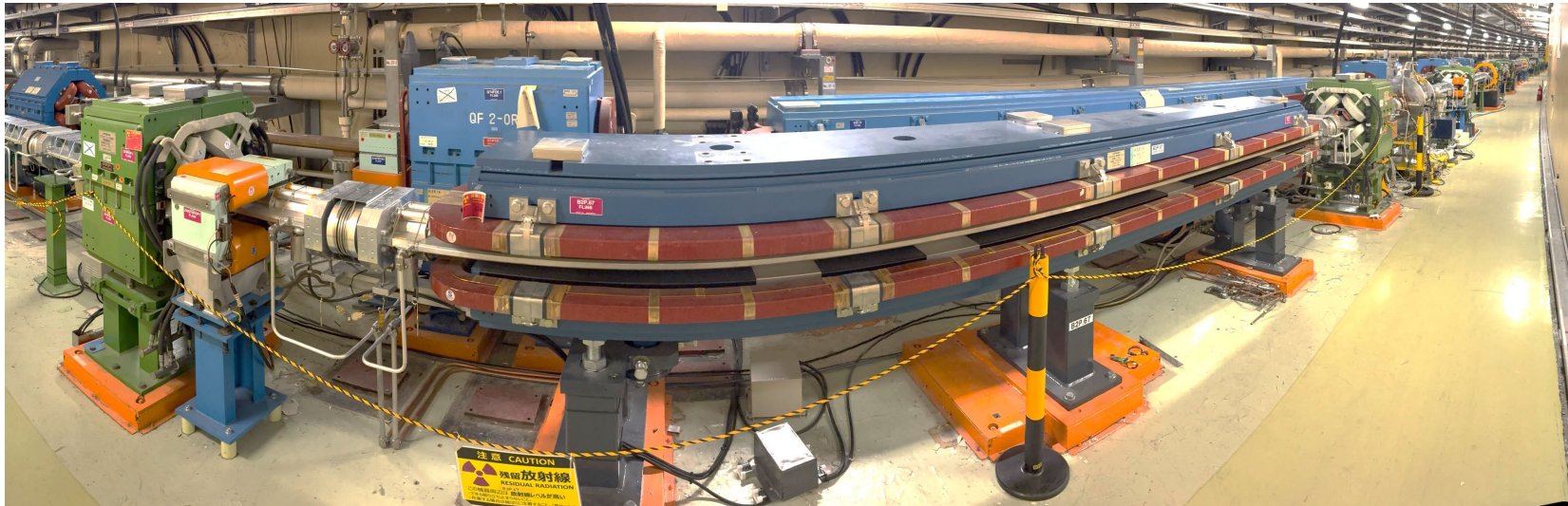
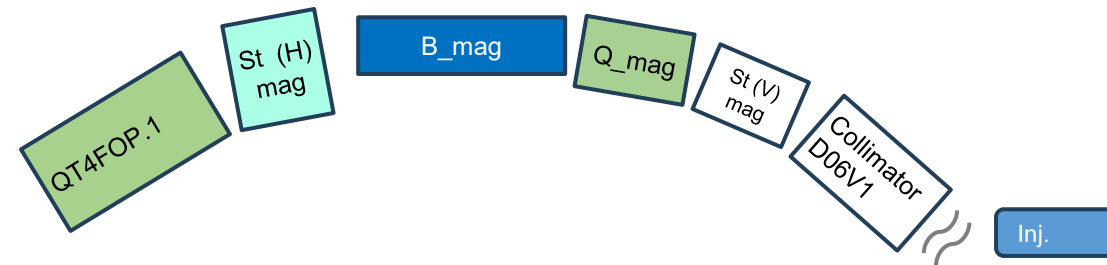
QT4FOP.1: exposure monitoring and design limits

On 8 October 2025, we installed RADCOLOR film and replaced hardened, cracked cable protection with new EPDM rubber.

Design radiation tolerance

Quadrupoles: 5×10^8 rad

Steering magnets: about 10^8 rad



QT4FOP.1: observed radiation effects

The radiation group measured 1,200 $\mu\text{Sv/h}$ on 30 June 2026.

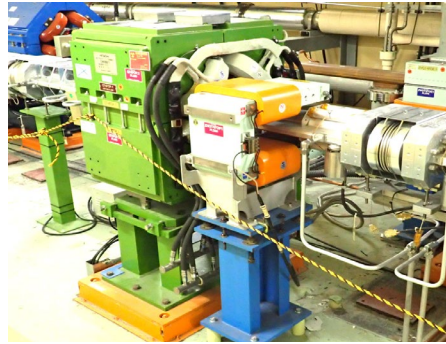
RADCOLOR film turned dark red, indicating at least 10^7 rad over about one year.

New EPDM hardened.
Hardening alone cannot quantify the dose.

Flow-switch resin parts broke.

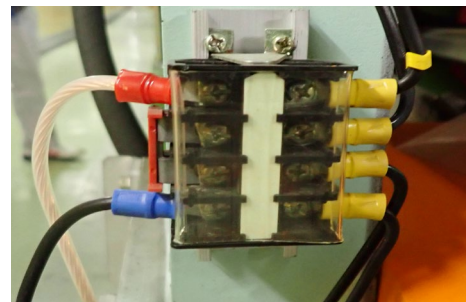
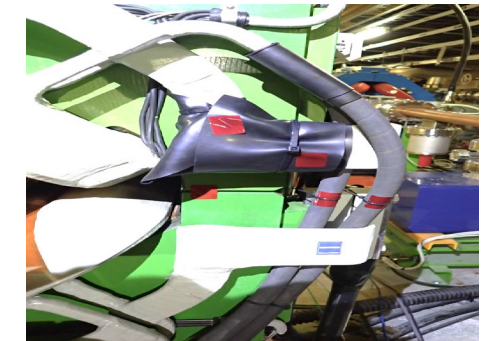
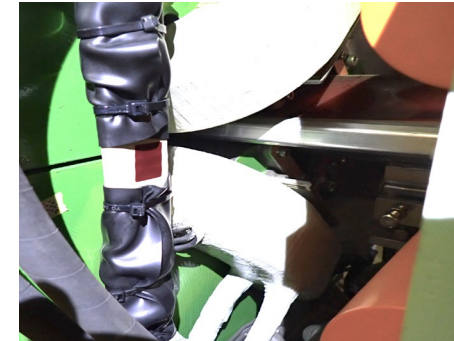
At the upstream magnet ZHQT4FOP.1, the connector showed discoloration and the cable sheath had cracked.

The main concern is loss of dielectric strength, leading to shorts between coils or ground faults.

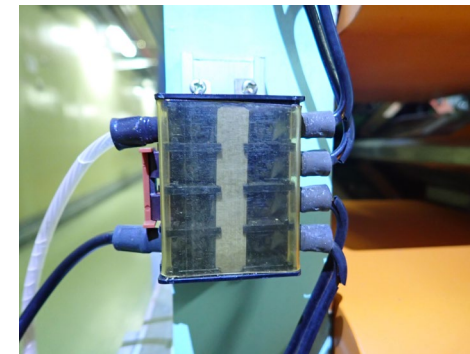


Magnet and surrounding equipment

RADCOLOR film
Dark red: 10^7 rad = 10^5 Gy
Dark blue-green: Unused



Original
St connectors and wiring



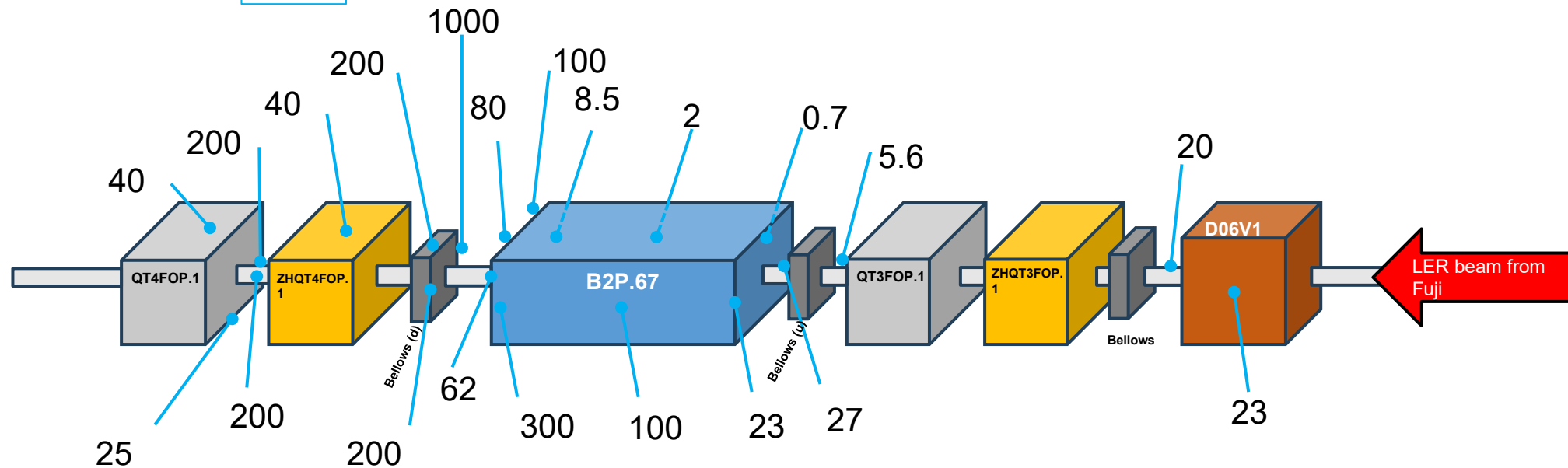
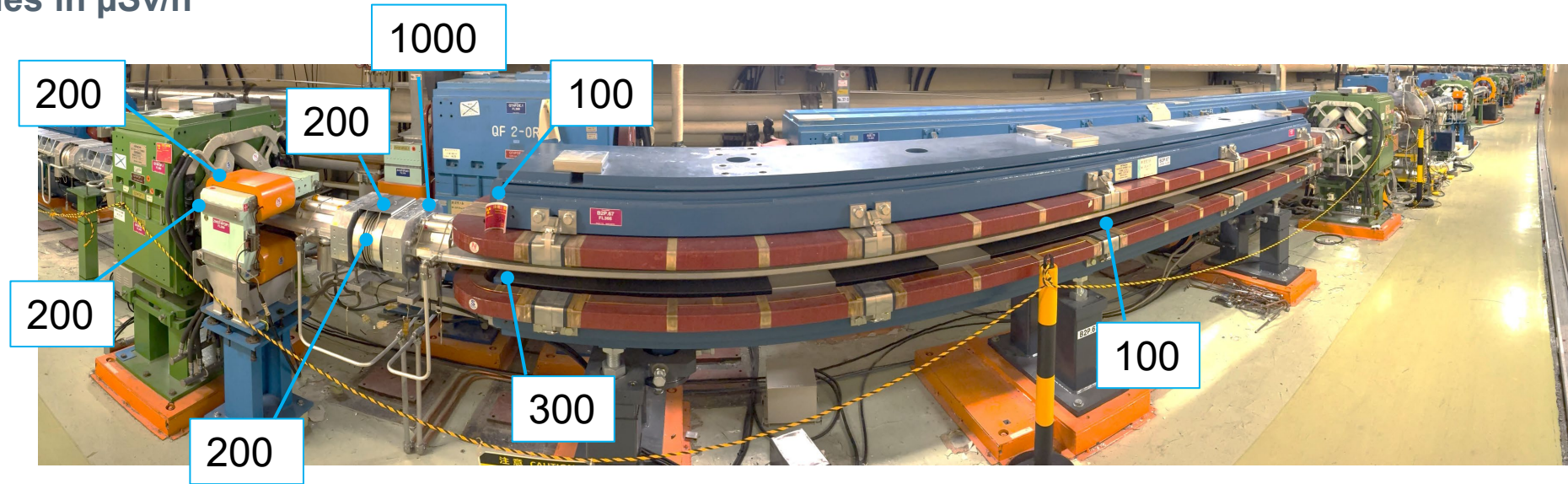
Discoloration
St connectors and wiring



Damaged flow-switch part (POM)

QT4FOP.1 area: residual dose-rate survey (Oct. 2026)

Point values in $\mu\text{Sv/h}$

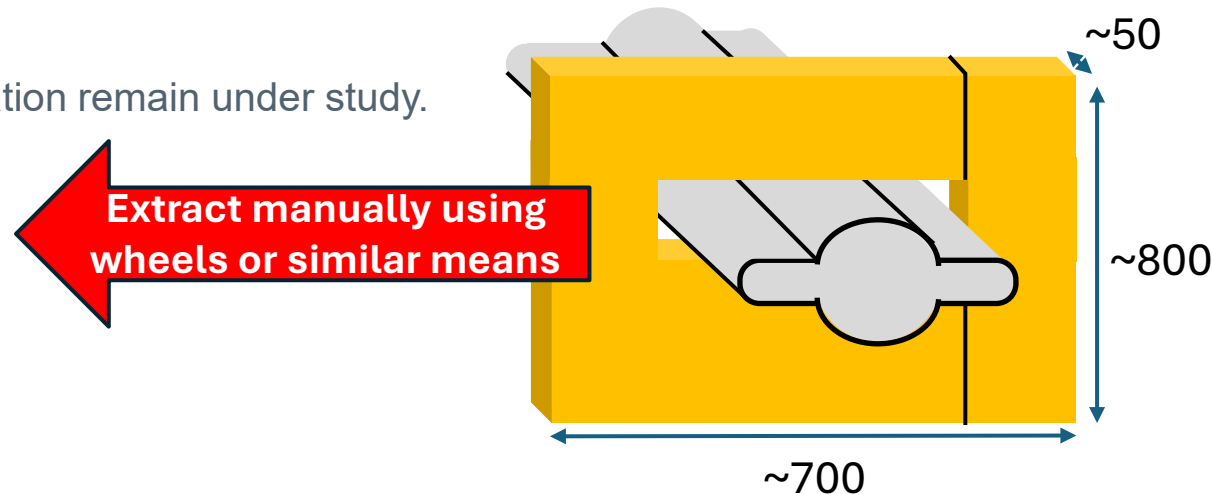


QT4FOP.1 area: preliminary lead-shield concept

We are considering a detailed radiation survey and lead shielding at one affected location. In the future, it may be necessary to install localized shielding at approximately four additional locations.



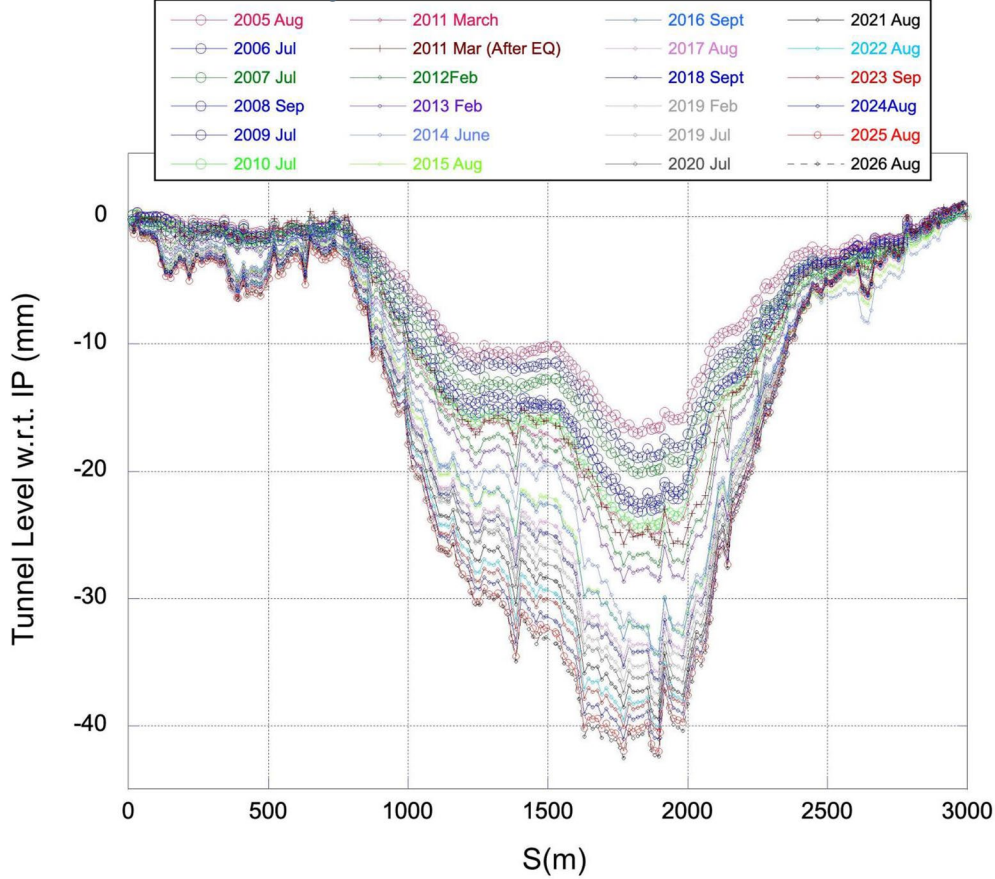
Preliminary concept.
Shield geometry and installation remain under study.



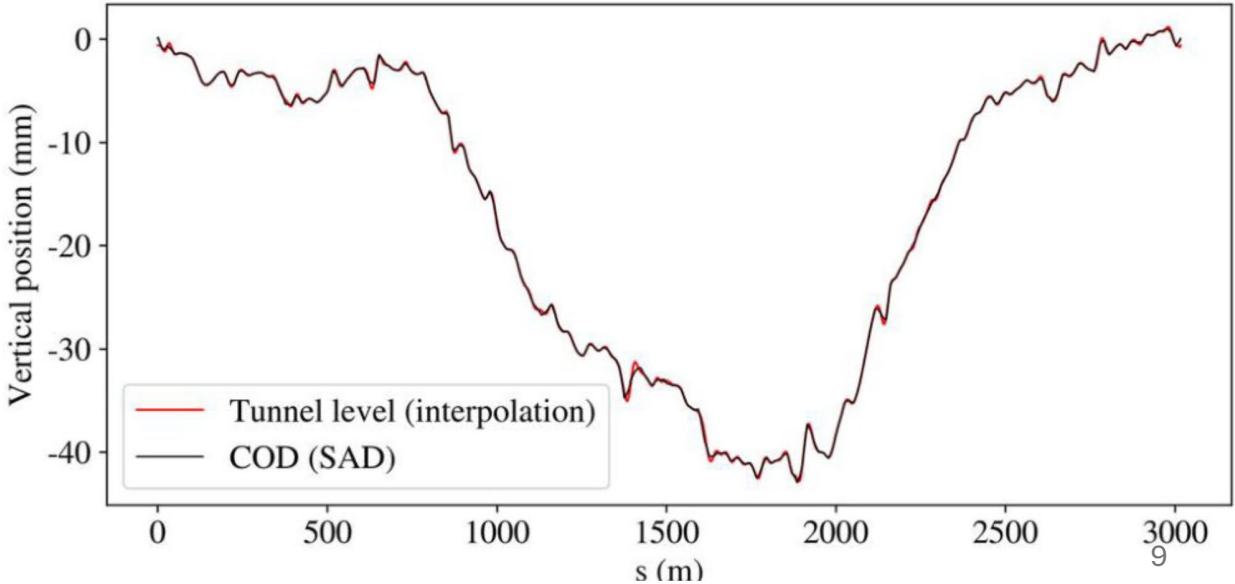
MR survey: tunnel level

Preliminary tunnel-level data are available.
Constrained SAD simulations show no indication of emittance growth under the some assumptions.
Need to conduct various assessments to consider more realistic situations.

Tunnel-level history, 2005–2026



Interpolation compared with SAD COD



MR power converters: maintenance

- Magnet Power Converters

- High-power quadrupole magnet power converters (manufactured in 1997, with no backup units):
 - ✓ Annual maintenance inspections.
 - ✓ A replacement plan has been developed, but the necessary budget has not yet been secured.
- Middle-power converters (with spare parts and alternative units available):
 - ✓ Approximately 450 power converters (about 500 units including series/parallel configurations).
 - ✓ All units inspected over a three-year cycle (Approximately 150 units inspected annually).

- 6.6 kV Receiving Switchgear

- Completed routine inspection.

- Interlock PLCs

- Verified correct output of the 24DCV operation-permit signal.

- Optical Fiber Communication

- Measured optical loss in fibers connecting interlock PLCs between power-supply buildings.
- Attenuator tests confirmed approximately 15dB of communication margin.

MR power converters: fault response

QFRNE: A type of high-power converter

A failed synchronization transformer limited maximum current during 2025c and 2026ab. Replacement is scheduled for the November maintenance period.

BLY5RP_2: A type of middle-power converter

Output-current offset and fluctuations appeared during 2026a. We operated with a spare converter while investigating the fault.

ARCNET control network

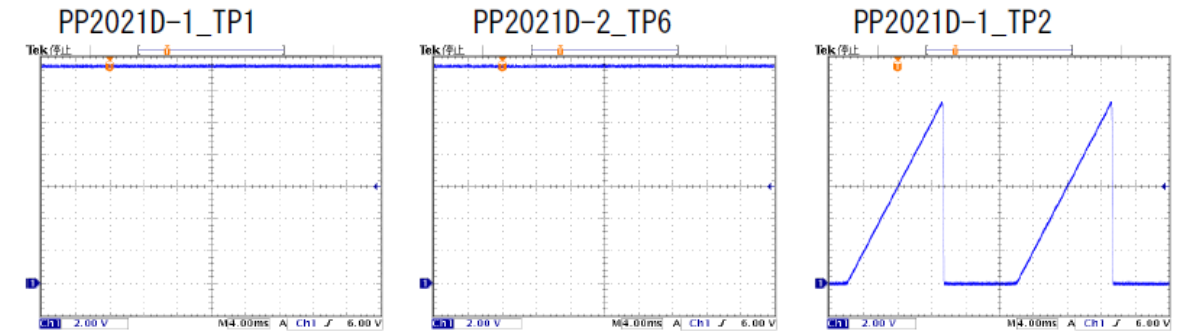
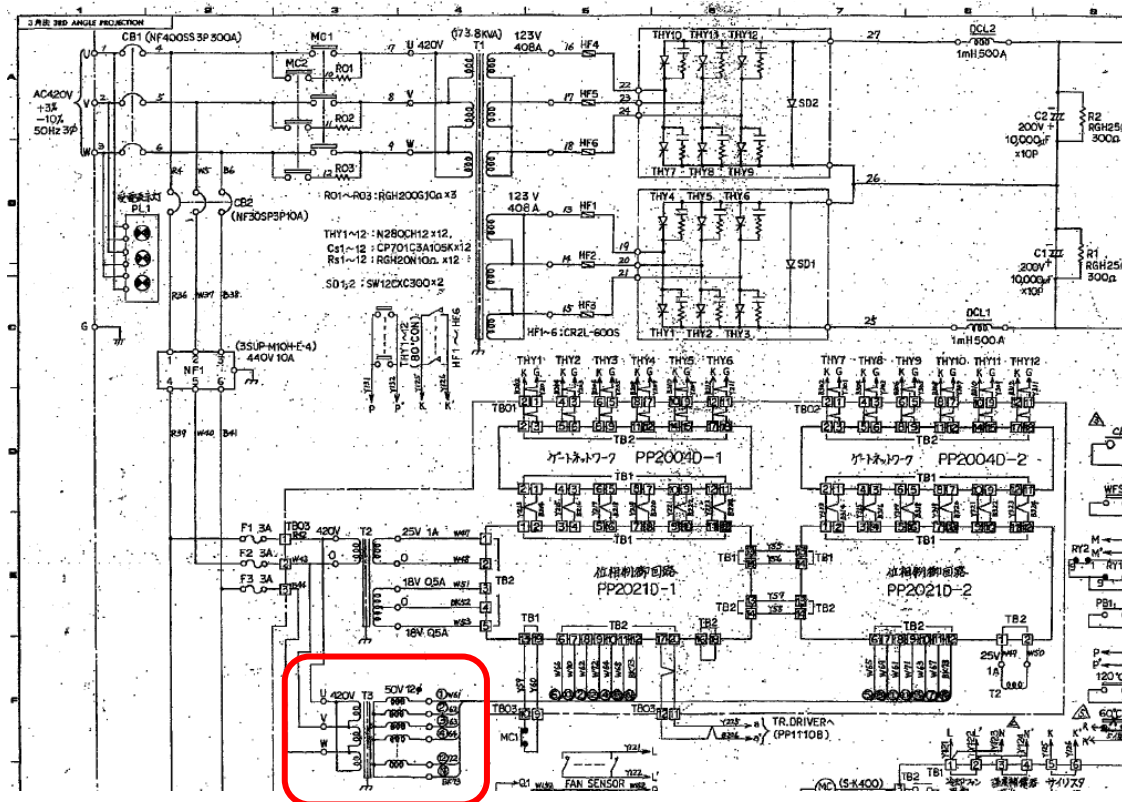
We checked signal levels throughout the network to address intermittent communication failures at downstream converters.

QFRNE: current limit and planned repair

Since 2025c, the maximum current has been limited. Magnet initialization had therefore used a current below the rated value.

Two failed phases of the transformer used to synchronize thyristor gate pulses with the AC supply caused the fault.

Abnormal signals (left and center), normal reference (right)



2 V/div, 4 ms/div

The replacement transformer has arrived. We will replace it on November maintenance period.

We will also replace the control power supply, as the converter is approaching 30 years of service.

BLY5RP_2: output-current offset and fluctuations

An offset and fluctuations appeared in the output current during 2026a.

- Output Current Issue during 2026a

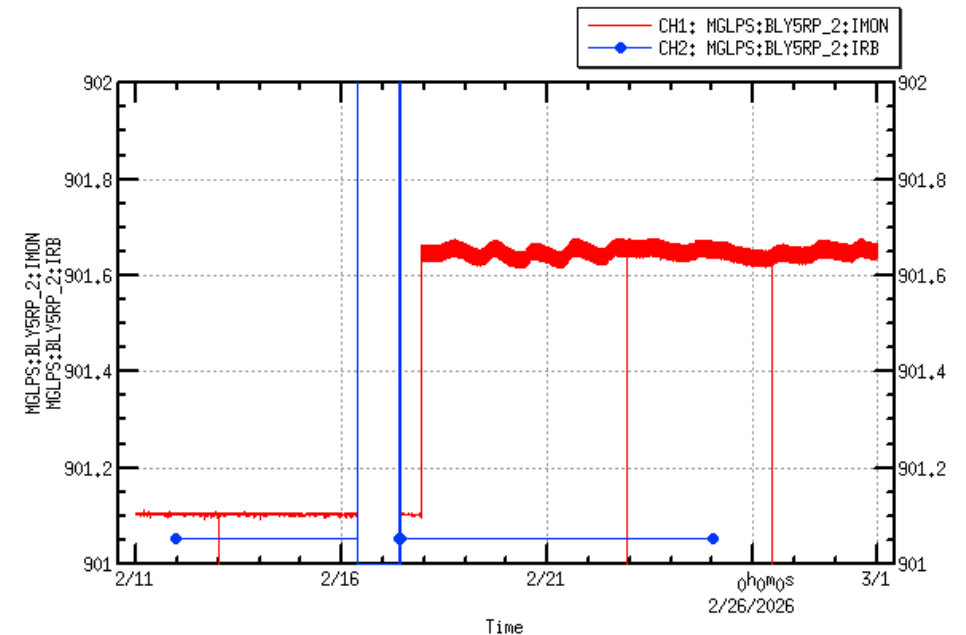
- An offset and fluctuations appeared in the output current.
- Switched to a spare power converter during operation.

- Investigation during Maintenance

- Currently investigating the cause of the issue.
- The suspected faulty converter operated normally when connected to a load and powered on.
- The condition may have changed during inspection of connection points, such as connectors.

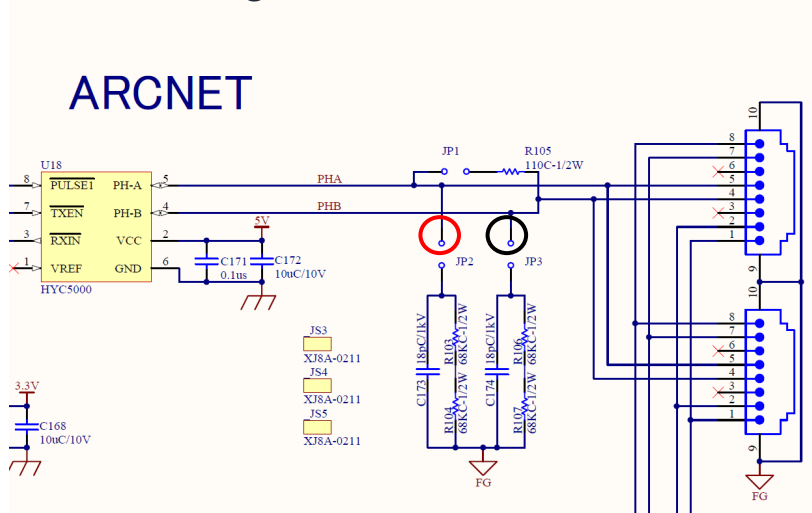
- Next Steps

- Continue investigating the cause.
- If the issue does not recur, return the unit to operation with a backup unit ready for immediate deployment.

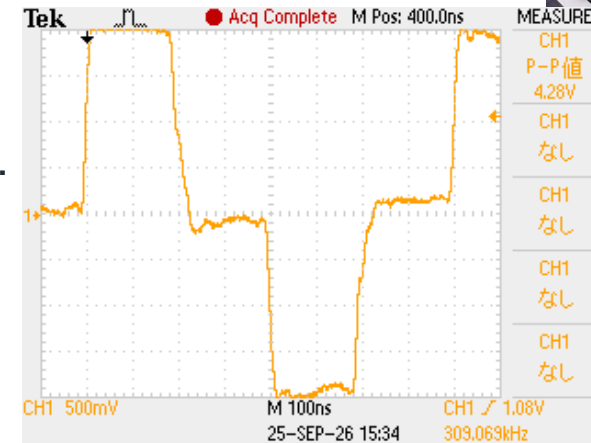


ARCNET: communication checks and corrective work

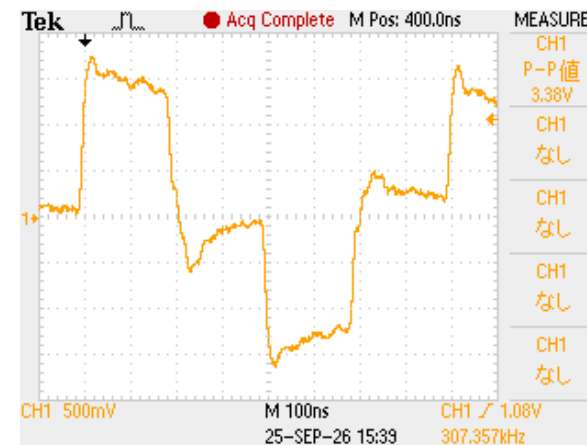
- **ARCNET Communication**
 - Power converters use ARCNET for remote control.
 - Intermittent communication failures can prevent proper orbit or tune corrections.
- **Signal-Level Inspection**
 - Check communication signal levels for all power converters.
- **Address significantly attenuated links through:**
 - PSICM-board replacement.
 - Cable replacement.
 - Reconfiguration of network branches.



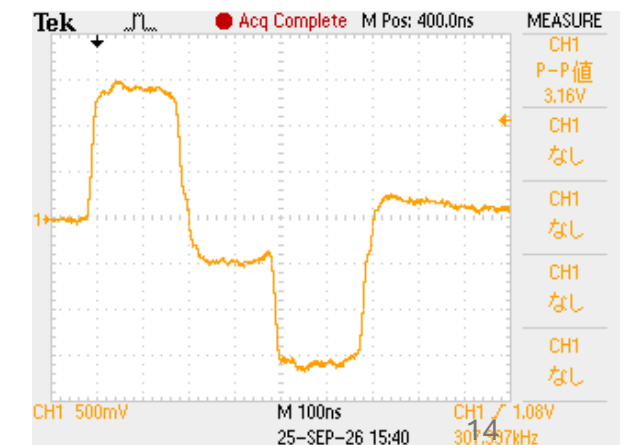
1 board



24 boards



24 boards: intermittent trace



BT/DR: 2026ab trouble records

Category	Records
Magnet cooling water	12
DC power converters	7
LER K1-3 thyatron self-firing	12
Septum	4
Other kicker faults	3
BPM oscilloscopes	2
Other	2
Total	42

- ❑ LER K1-3 self-firing
- ❑ Magnet cooling water
- ❑ others

LER K1-3: 2026ab event log and countermeasure

Twelve unintended self-firing events. Three triggered QCS quenches.

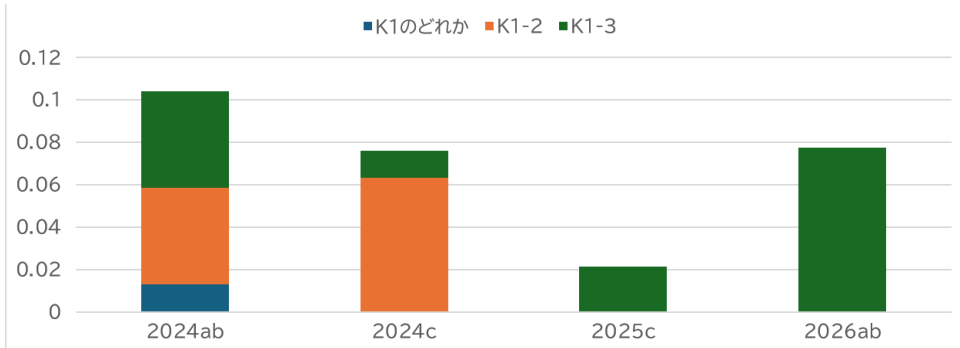
Furthermore, these events have impacted stable operation, including by causing damage to collimators.

Date	Time	Kicker No.	Thyratron No.	QCS Quench	LER Current [A]	Bunch No.	K1-3 voltage [kV]	Quench Coil
2026/3/29	9:06	K1-3	#4314	Yes	1595	2346	15.0	QC1RP
	11:02	K1-3	#4314	No	499	2346	15.0	
	15:20	K1-3	#4314	No	337	2346	15.0	
2026/5/15	0:41	K1-3	#1984	Yes	1596	2151	14.3	QC1LP, QC1RP
	2:33	K1-3	#1984	No	27	2151	14.3	
	3:38	K1-3	#1984	No	1209	2151	14.3	
	19:26	K1-3	#1984	No	407	2151	14.3	
2026/6/6	18:14	K1-3	#1984	No	1606	2053	14.3	
2026/6/12	0:25	K1-3	#1984	No	498	2021	14.6	
	3:03	K1-3	#1984	No	998	2021	14.6	
2026/6/24	3:10	K1-3	#1984	No	1516	2031	14.9	
2026/6/27	13:46	K1-3	#1984	Yes	1390	1990	14.8	QC1RP

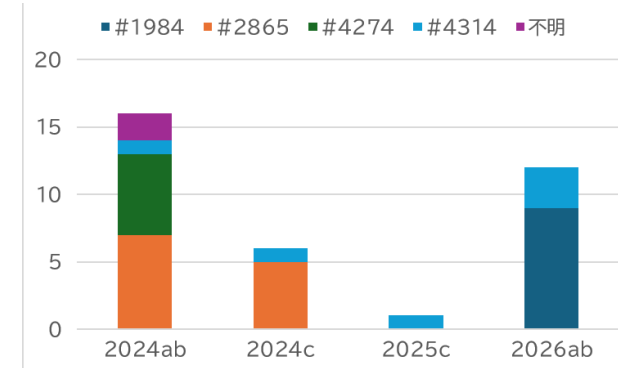
Despite reducing the reserve heater voltage as a countermeasure, self-firing could not be prevented.

LER kicker: self-firing history

The daily rate decreased after 2024ab, then increased again in 2026ab.



Events per day by kicker
Blue: any K1(not identified)
Orange: K1-2
Green: K1-3



Events by tube S/N
Dark blue: #1984
Orange: #2865
Green: #4274
Light blue: #4314
Purple: no record

Historical observations

K1-2 self-firing stopped after a thyatron replacement.
(#2865 → other)

K1-3 events continued after some replacements.
(#4274 → #4314 → #1984)

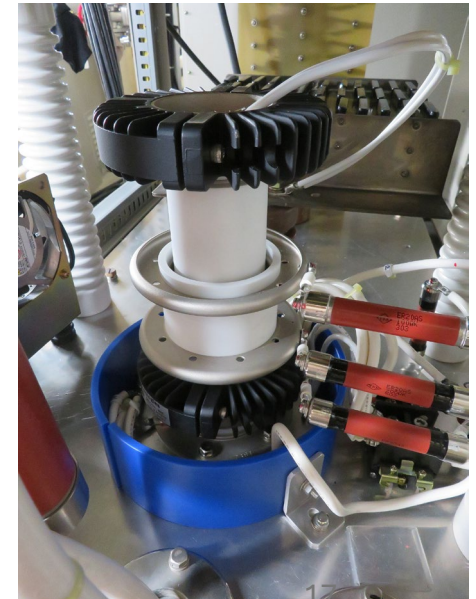
We decided to replace the thyatron in the LER kicker power supply K1-3, CX1174, with the type used in the HER kicker power supply, CX1826A.

The possibility of the cause lying elsewhere-outside of the thyatron-is considered low, given that measures such as duplicating the trigger have been implemented.

CX1174



CX1826A



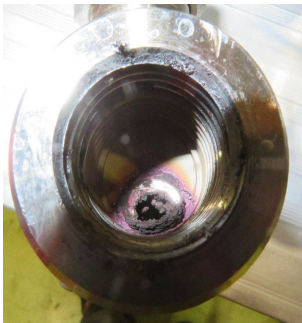
BT magnets: cooling-water faults and maintenance

Water-interlock event log

Interlock date	Magnet
2026/02/14	BH1P.7
2026/02/16	BH1P.7
2026/02/17	BH1E.13
2026/02/17	BH2P.2
2026/03/11	B3P.1
2026/03/25	BH1E.15
2026/04/10	BH1E.13
2026/04/10	BH1P.14
2026/04/15	BH1E.14
2026/4/26	BH3E.10
2026/4/26	BH3P.11
2026/04/30	B3P.3
2026/05/07	Resin replaced



Demineralizer resin samples, 2026. (Left) Used resin, (Right) New resin.



(Left) Needle valve, (Right) Strainer clogged with copper oxide.



Strainer undergoing maintenance. It is clogged with copper oxide.

Cooling Water Interlock Events

- Increased from 1 event (2021-2024) to 2 (2025c) and 12 (2026ab).
- No events since demineralizer resin replacement on May 7.

Impact on Beam Operation

- Recovery takes several hours, preventing beam injection and reducing integrated luminosity.

Maintenance and Corrective Actions

- Flushed cooling water circuits, removed needle valves, and cleaned strainers.
- Observed copper oxide deposits in strainers.
- Cleaning BT cooling tower strainers is expected to reduce deposits.

Additional Flow Monitoring

- Installed temperature sensors on several magnet coils to detect decreasing coolant flow.

BT/DR: Power converter and magnet survey

Power Converters

- Aging converters require maintenance and inspections within available resources.
- Occasional failures have begun to occur, even in converters installed during the SuperKEKB upgrade.
- Inspected and implemented corrective measures for issues identified during the 2026ab run.

BT Magnet Survey

- Conducting magnet surveys section by section as time permits.
- Survey time is limited by radiation access restrictions during PF-AR operation.

Summary

MR Magnets

- Annual cooling-water maintenance: no magnet-originated operational issues since October 2019.
- Radiation-related damage near injection points and collimators; surveys and shielding are under study.

MR Power Converters

- Aging converters require inspections; funding for replacement of 1997 high-power units remains unsecured.
- Fault investigations and ARCNET checks continue; QFRNE transformer replacement is planned for November.

BT/DR

- LER K1-3: 12 self-firing events in 2026ab, including 3 QCS quenches; HER-type thyratron installed.
- Cooling-water interlocks: 12 in 2026ab; none since demineralizer resin replacement on May 7.
- Cooling-system maintenance, power-converter inspections, and BT magnet surveys continue within available resources and access periods.

Appendix

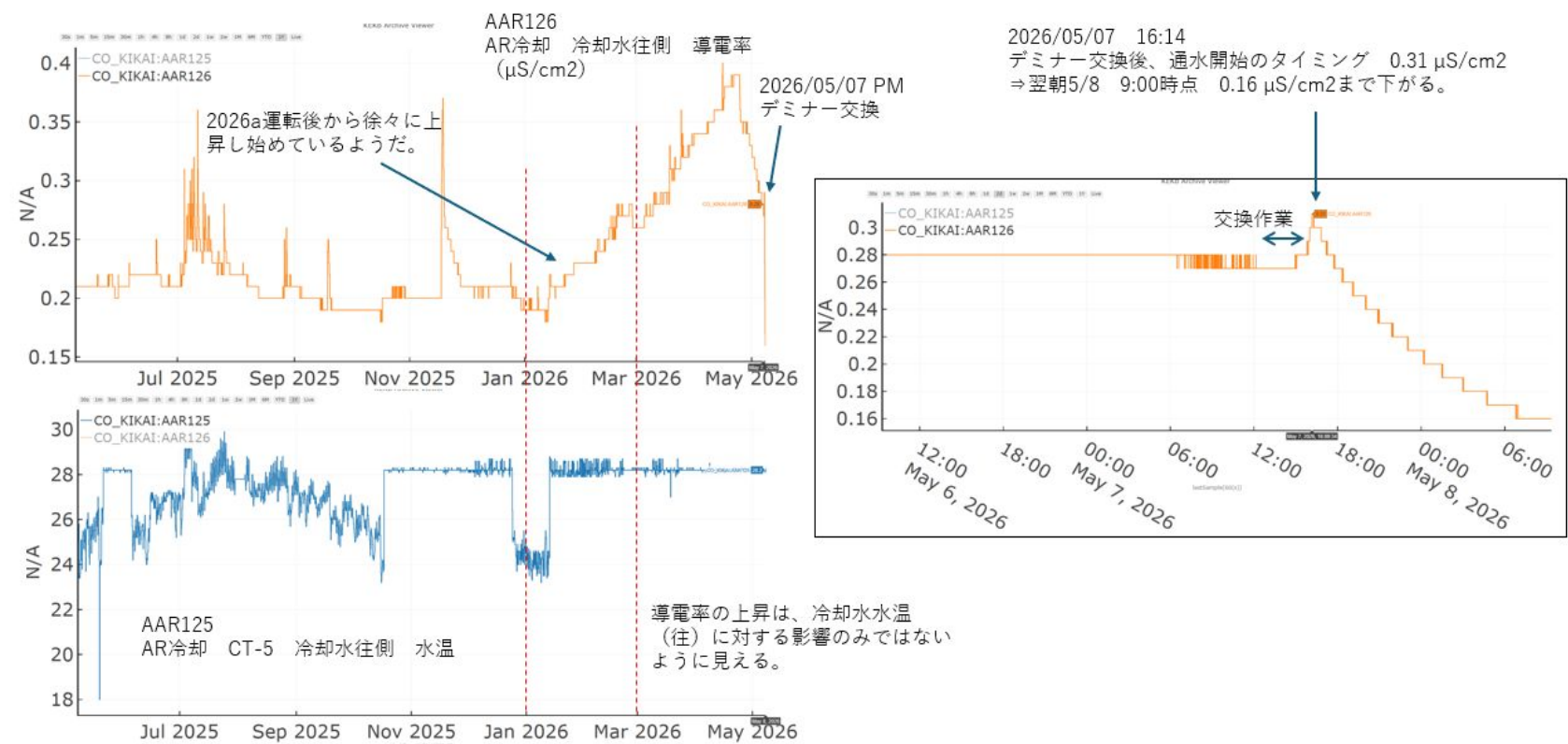
2024年からのLER Inj. Kicker自爆リスト

Date	Time	Kicker No.	Thyratron No. (すべてCX1174)	QCS Quench	LER Current [A]	Bunch No.	自爆Kicker設定電圧 [kV]	Quench Coil	Pressure Burst
2024/2/25	13:57	K1のどれか		なし	447	1565	15.3(K1-2), 15.1(K1-3)		
	14:30	K1のどれか		なし	448	1565	15.3(K1-2), 15.1(K1-3)		
2024/3/10	4:01	K1-2	#2865	なし	398	1565	16.5		
2024/3/13	1:05	K1-3	#4274	なし	398	1565	14.4		
	2:55	K1-3	#4274	なし	397	1565	14.4		
	4:58	K1-3	#4274	なし	398	1565	14.4		
2024/3/19	14:00	K1-3	#4274	なし	596	2346	16.5		
	14:15	K1-3	#4274	なし	9.9	2346	16.5		
	15:31	K1-3	#4274	なし	198	2346	16.5		
2024/4/24	2:16	K1-3	#4314	なし	623	2346	16.5		
2024/4/27	12:28	K1-2	#2865	なし	1146	2346	16.3		
2024/4/28	18:56	K1-2	#2865	なし	1147	2346	16.3		
2024/5/4	0:15	K1-2	#2865	なし	28	2346	16.2		
	14:27	K1-2	#2865	なし	996	2346	16.2		
2024/5/6	16:52	K1-2	#2865	なし	996	2346	16.2		
2024/5/22	19:34	K1-2	#2865	なし	1298	2346	15.9		
2024/11/6	4:58	K1-2	#2865	なし	998	2346	16.4		
2024/11/10	0:16	K1-3	#4314	✓	1296	2346	16.0	QC1RP	D06_L03 D06H3collimator
2024/12/3	6:11	K1-2	#2865	なし	1200	2346	14.8		D06_L03 D06H3collimator
2024/12/12	13:44	K1-2	#2865	なし	604	2346	14.0		
	15:32	K1-2	#2865	なし	46	2346	14.0		
2024/12/21	9:44	K1-2	#2865	✓	1347	2346	14.6	QC1RP	D06_L03 D06H3collimator
2025/12/18	21:41	K1-3	#4314	✓	1236	2346	14.0	QC1RP	D02_L12 D02H1collimator
2026/3/29	9:06	K1-3	#4314	✓	1595	2346	15.0	QC1RP	D02_L12,D02H1collimator, D06_L03,D06H3collimator
	11:02	K1-3	#4314	なし	499	2346	15.0		
	15:20	K1-3	#4314	なし	337	2346	15.0		
2026/5/15	0:41	K1-3	#1984	✓	1596	2151	14.3	QC1LP, QC1RP	D02_L12,D02H1collimator, D06_L03,D06H3collimator
	2:33	K1-3	#1984	なし	27	2151	14.3		
	3:38	K1-3	#1984	なし	1209	2151	14.3		
	19:26	K1-3	#1984	なし	407	2151	14.3		
2026/6/6	18:14	K1-3	#1984	なし	1606	2053	14.3		D02_L12,D02H1collimator, D06_L03,D06H3collimator
2026/6/12	0:25	K1-3	#1984	なし	498	2021	14.6		
	3:03	K1-3	#1984	なし	998	2021	14.6		
2026/6/24	3:10	K1-3	#1984	なし	1516	2031	14.9		D02_L12,D02H1collimator, D06_L03,D06H3collimator
2026/6/27	13:46	K1-3	#1984	✓	1390	1990	14.8	QC1RP	D02_L12,D02H1collimator

BT cooling water: conductivity after resin replacement

No water-interlock events occurred in the reported period after replacement, but several countermeasures were introduced together.

BT magnet cooling-water measurements, 8 May 2026



Conductivity trend

AAR126: conductivity
AAR125: water temperature

Resin replacement: 7 May 2026

Conductivity fell from 0.31 after replacement to 0.16 by the next morning (source units).

The earlier rise does not appear to follow temperature alone.

Conductivity-unit label requires confirmation. All plotted data are unchanged.

2026ab DR/BT Trouble List (1)

No.	Date	Equipment	Failure	Action
1	2026.01.09	QMD5P	ARCnet failure	ARCnet card was replaced
2	2026.01.19	QAF3E	Fan failure	Fan was replaced
3	2026.02.03	QMD8E,QMD10E	Incorrect wiring	Corrected wiring
4	2026.02.09	BPM OSC (RTL0)	Network failure	Replaced with a spare unit
5	2026.02.14	BH1P.7	Water stop	Adjusted the flow rate
6	2026.02.16	BH1P.7	Water stop	Reset
7	2026.02.17	BH1E.13	Water stop	Performed cleaning
8	2026.02.23	HER kicker K2	Control failure: 3 times	Disable the sensor and replaced the relay
9	2026.03.04	BV1P.1-2	NFB trip due to a water leak	Fixed the water leak
10	2026.03.06	BPM OSC (CBT1)	Screen failure	Replaced with a spare unit
11	2026.03.11	B3P.1	Water stop	Performed cleaning
12	2026.03.22	HER septum 1	Voltage fluctuation	Replaced the voltage divider

2026 Feb DD/RT Trouble List (2)

No.	Date	Equipment	Failure	Action
13	2026.03.25	BH1E.15	Water stop	Performed cleaning
14	2026.03.29	DR ext. kicker	Ext. ILK failure	Disabled ILK, A noise filter will be added to prevent malfunctions.
15	2026.03.29	LER k1-3 kicker	Self-firing:3, Quench	Installed a new thyatron
16	2026.04.10	BH1P.14, BH1E.13	Water stop	BH1P.14:Perfomed cleaning、BH1E.13:Reset
17	2026.04.15	BH1P.14, BH1E.14	Water stop	Adjusted the water flow rate
18	2026.04.19	DR ext. septum	Charger failure	Unable to operation at 19Hz only. Further investigation is planned
19	2026.04.24	BH3E.10	Water stop	Removed the flow control valve
20	2026.04.30	B3P.3	Water stop	Removed the flow control valve
21	2026.05.15	LER k1-3 k1-3	Self-firing:4, Quench	30-min conditioning run at 22kV and 25Hz
22	2026.05.17	QMF4S	Output current suddenly dropped to 0A	Tunned the NFB off and on. A ferrite core was added to the AC input line.
23	2026.06.03	HER ceramic duct	Water stop	Restarted the water pump
24	2026.06.05-	BH1E.11-15	ARCnet failure	Push the connector in

2026ab DR/BT Trouble List (3)

No.	Date	Equipment	Failure	Action
25	2026.06.06	LER k1-3 kicker	Self-firing:1	Continued operation without corrective action
26	2026.06.08	HER septum 4	Sudden output change, Water stop	Further investigation is planned. The water filter was replaced.
27	2026.06.12	LER k1-3 kicker	Self-firing:2	Continued operation without corrective action
28	2026.06.13	BV2E.4	Stability failure	Further investigation is planned
29	2026.06.17	BV1E.1-4	Sudden output change	Could not be reproduced
30	2026.06.19	-	Momentary power outage	
31	2026.06.19	HER septum magnet water	Water flow rate control	Further investigation is planned.
32	2026.06.24	LER k1-3 kicker	Self-firing:1	Continued operation without corrective action
33	2026.06.27	LER k1-3 kicker	Self-firing:1, Quench	Continued operation without corrective action