Discoloration of RF antenna coil surface after long-term operation of J-PARC ion source

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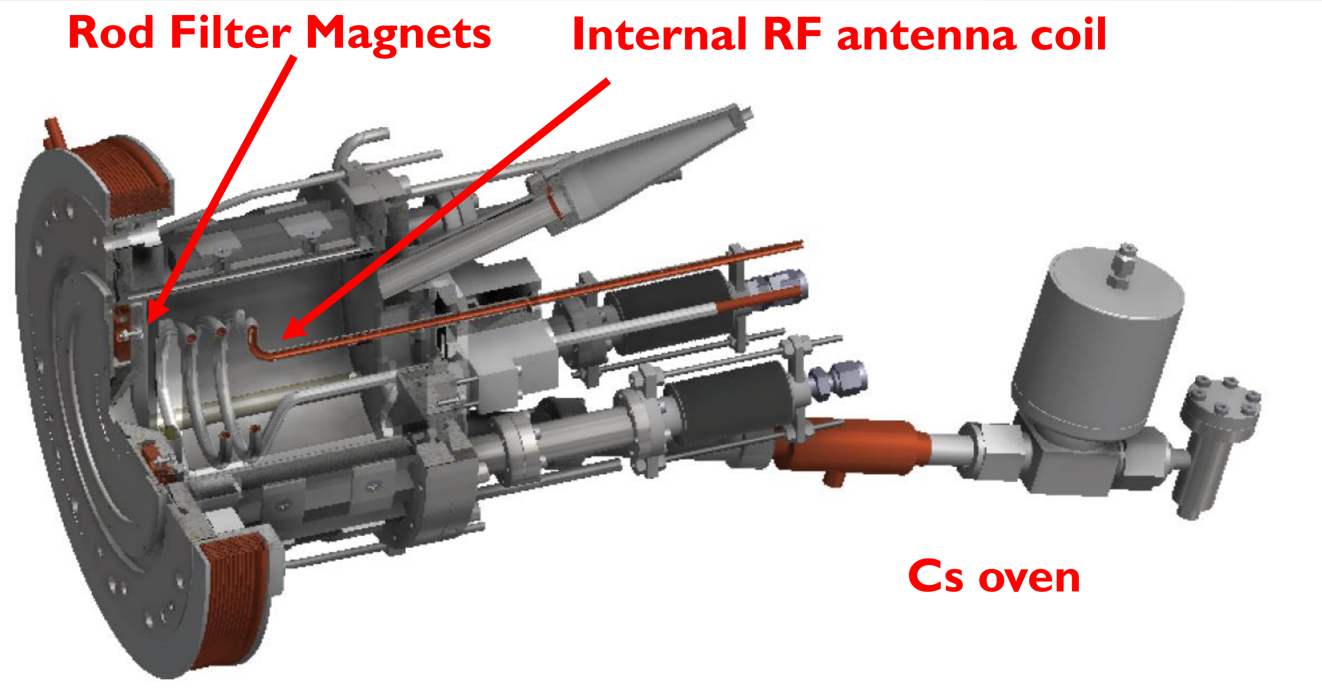
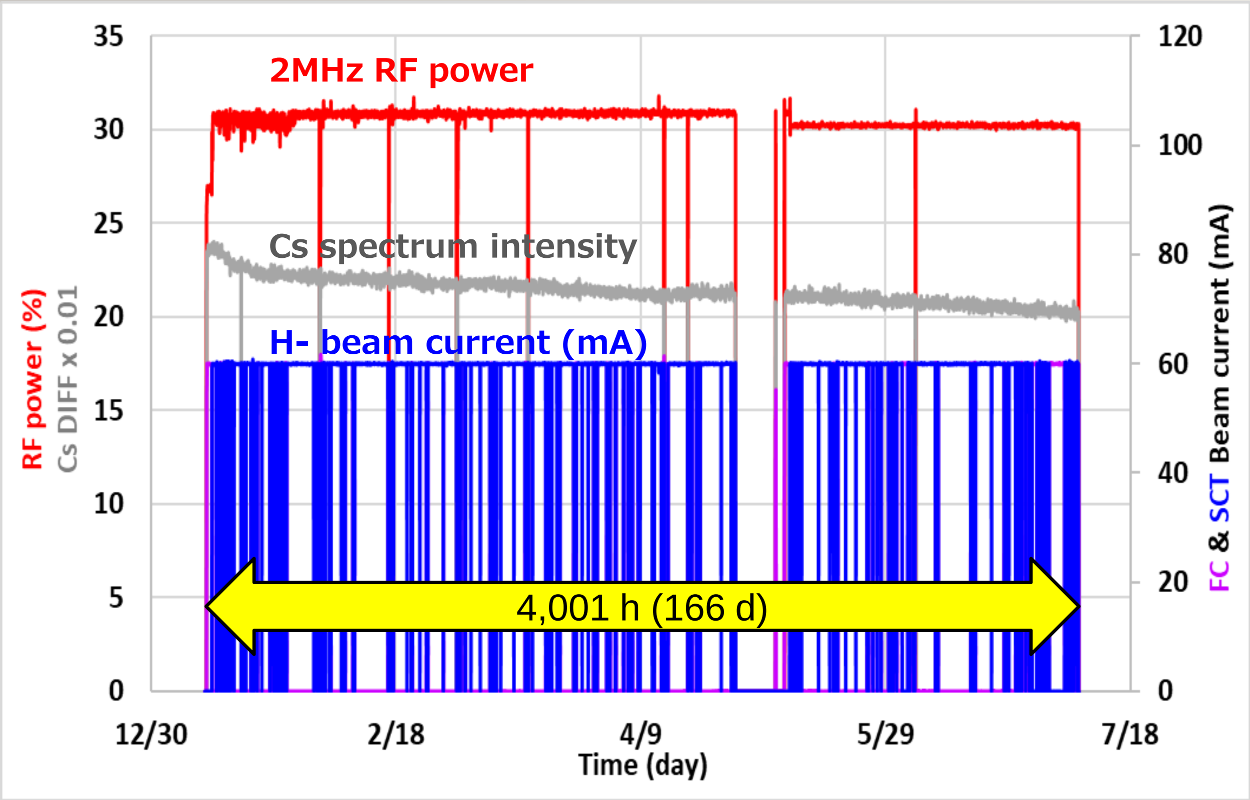
① J-PARC Radio Frequency (RF) negative hydrogen ion source



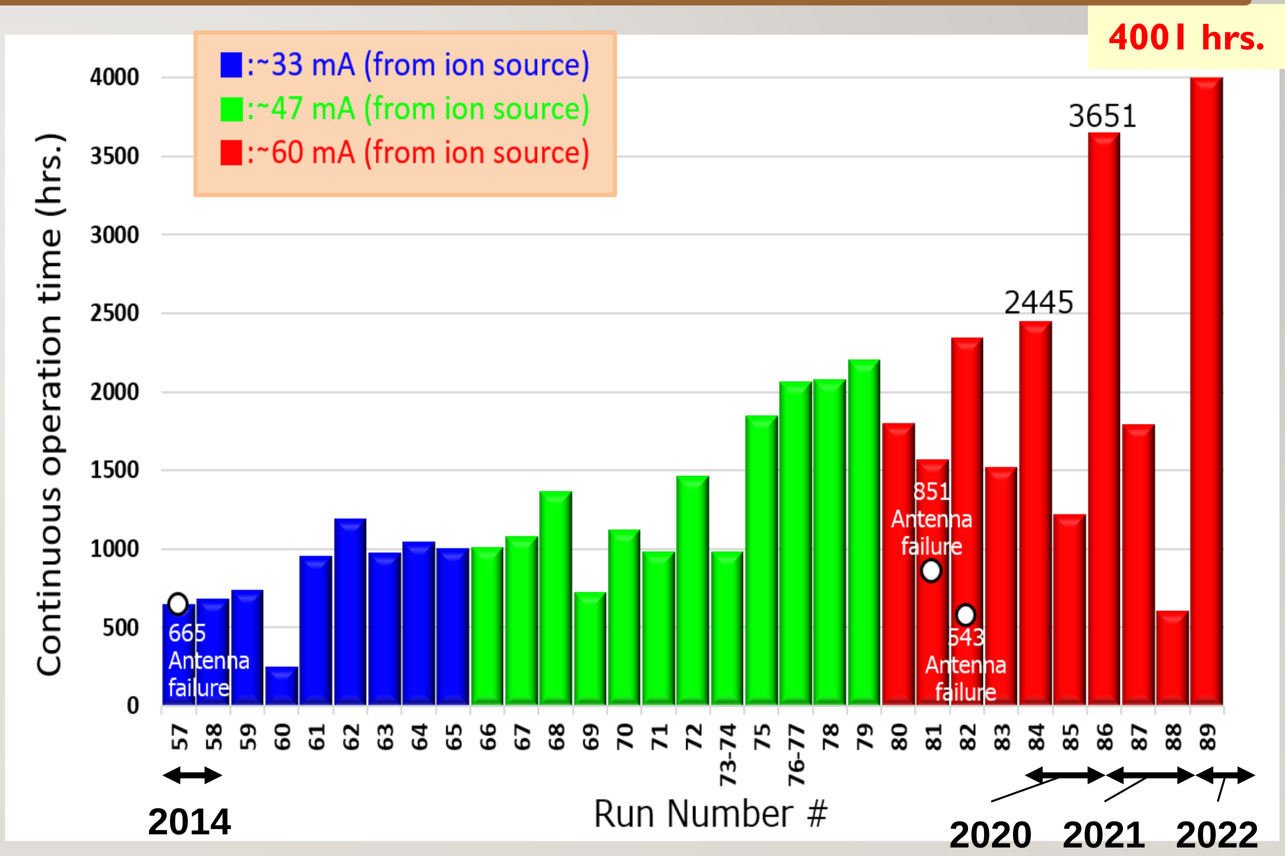
Main operation parameter of J-PARC ion source	
Typical H^- beam current	60 mA (user operation) 72 mA (accelerator study)
Beam energy	50 keV
RF frequency / power	2 MHz / 25 – 30 kW
Repetition rate / Pulse width (beam extraction)	1 – 25 Hz / 50 – 600 us
Repetition rate / Pulse width (plasma generation)	25 Hz / 800 us

②Extension of ion source continuous operation duration

- To reduce beam instability by exchanging the ion source, continuous operation duration is being prolonged.
- The immediate goal is to cover the full J-PARC user operation duration each year with a single RF ion source.



Trend of the RF ion source parameters in J-PARC user operation RUN#89 (10th Jan. 2022 – 8th Jul. 2022)

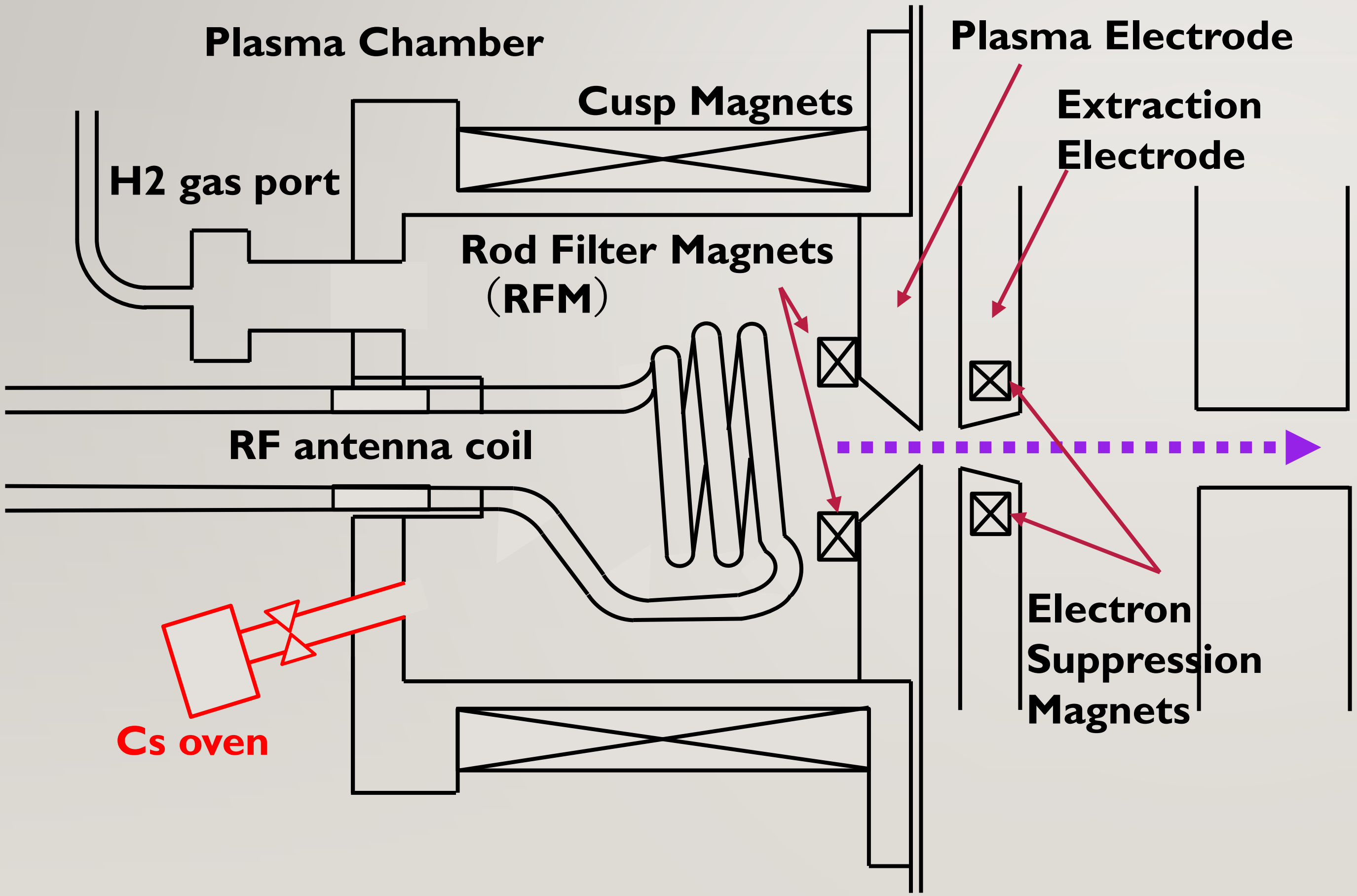


History of continuous operation duration of J-PARC RF ion source

[3] H. Oguri et al., JPS Conf. Proc. **33**, 011008 (2021).
[4] T. Shibata et al., J. Phys.: Conf. Ser. **2244**, 012041 (2022).

②Soundness evaluation of RF ion source after long-run

- Soundness evaluation is made for key components for further extension on the operation duration.
- Cs consumption in 5 month operation was estimated / visibly confirmed.



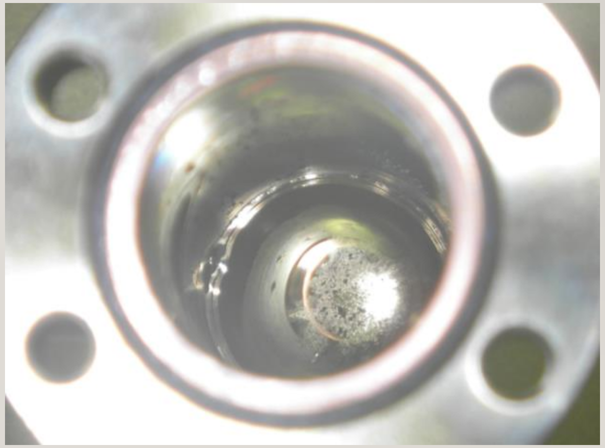
Cs consumption in 5 months

○filled Cs amount : 2.49g

○Cs remain : 2.40 g

○estimation of Cs consumption in RUN#86

- ●Cs consumption rate : 4mg/h @180℃
- ●Cs VLV open duration : 79,074 sec = 22 hrs.
- ●Total Cs consumption : 88 mg

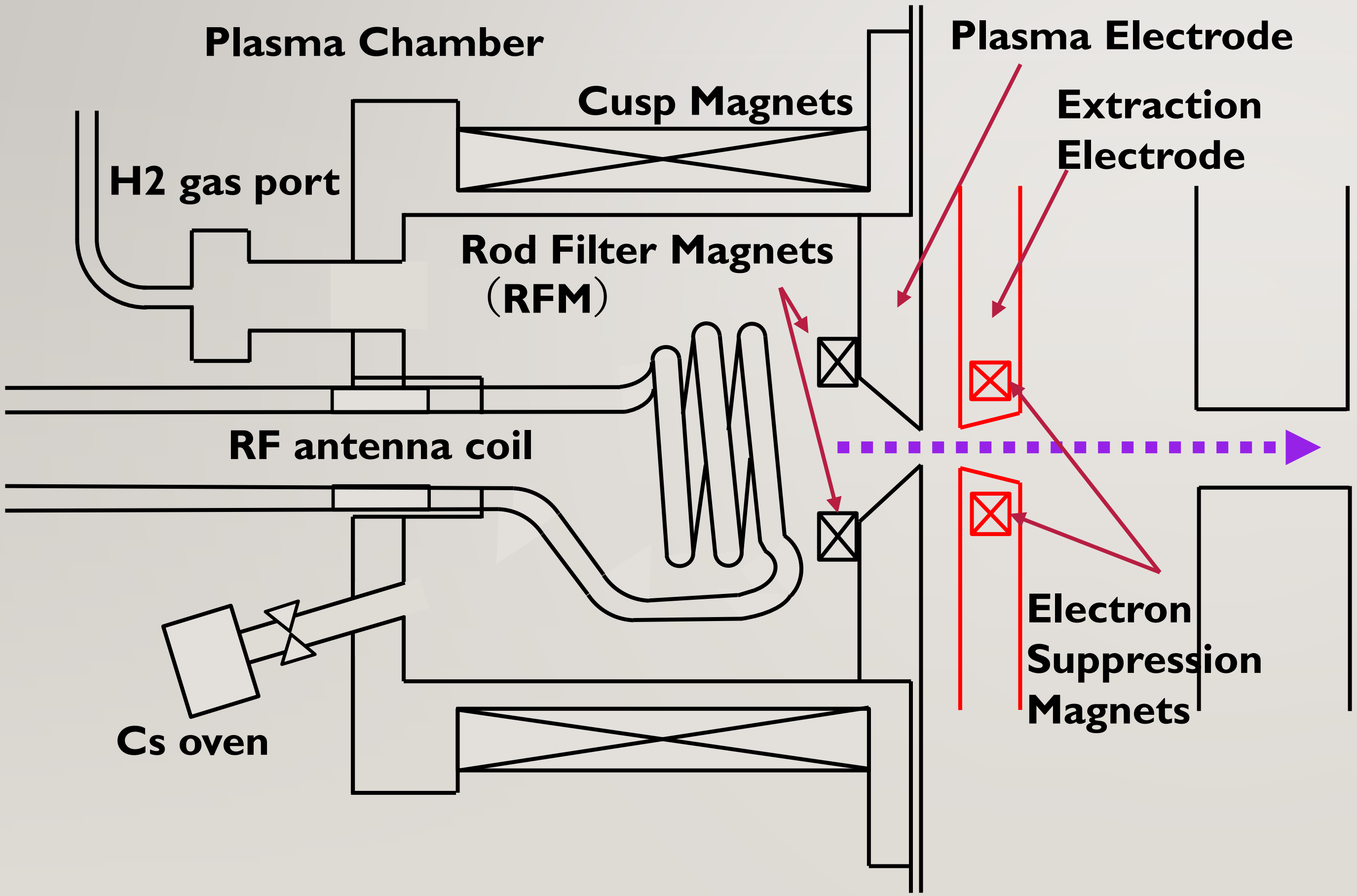


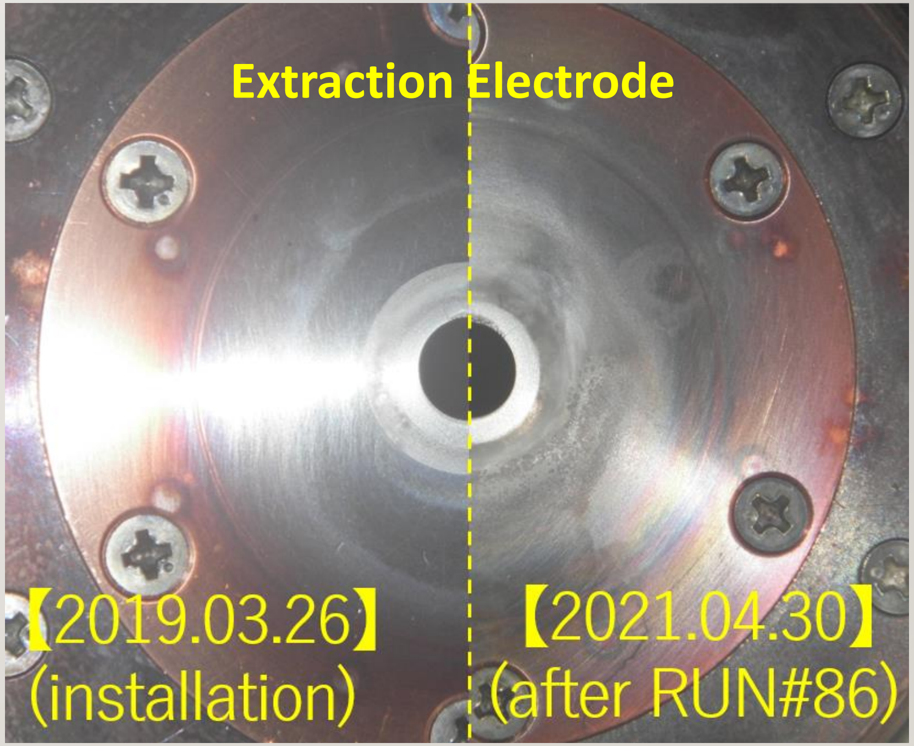
Cs oven (RUN#86)

[4] T. Shibata et al., J. Phys.: Conf. Ser. **2244**, 012041 (2022).

②Soundness evaluation of RF ion source after long-run

- Extraction Electrode used for 2 years on the beam line was confirmed.
- Although slight damage was seen in the electrode, no difference in the aperture shape was confirmed.

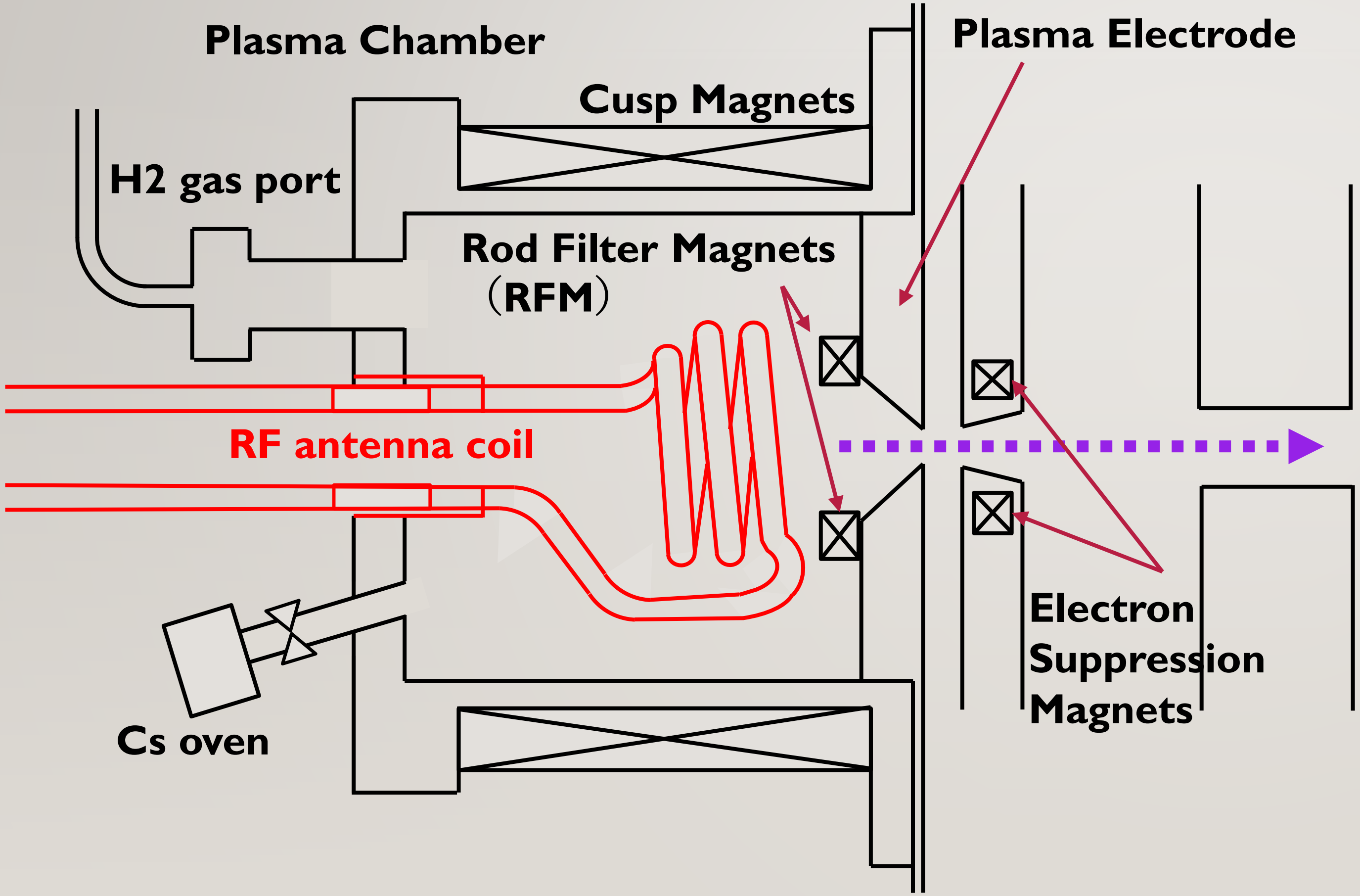


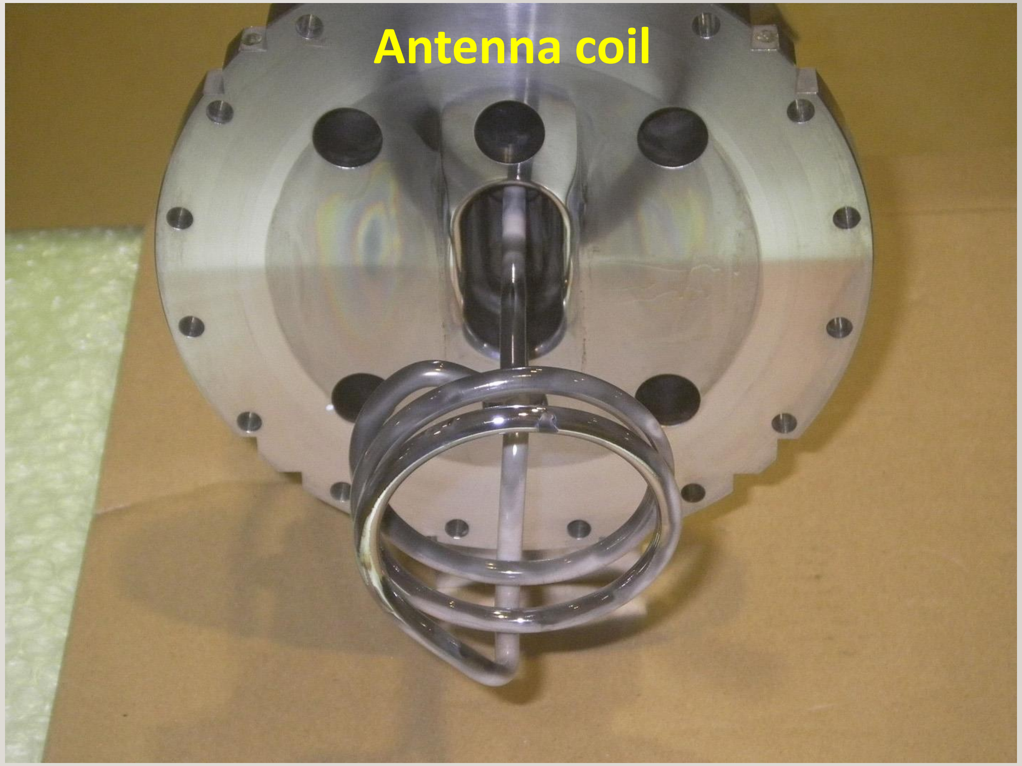


[4] T. Shibata et al., J. Phys.: Conf. Ser. **2244**, 012041 (2022).

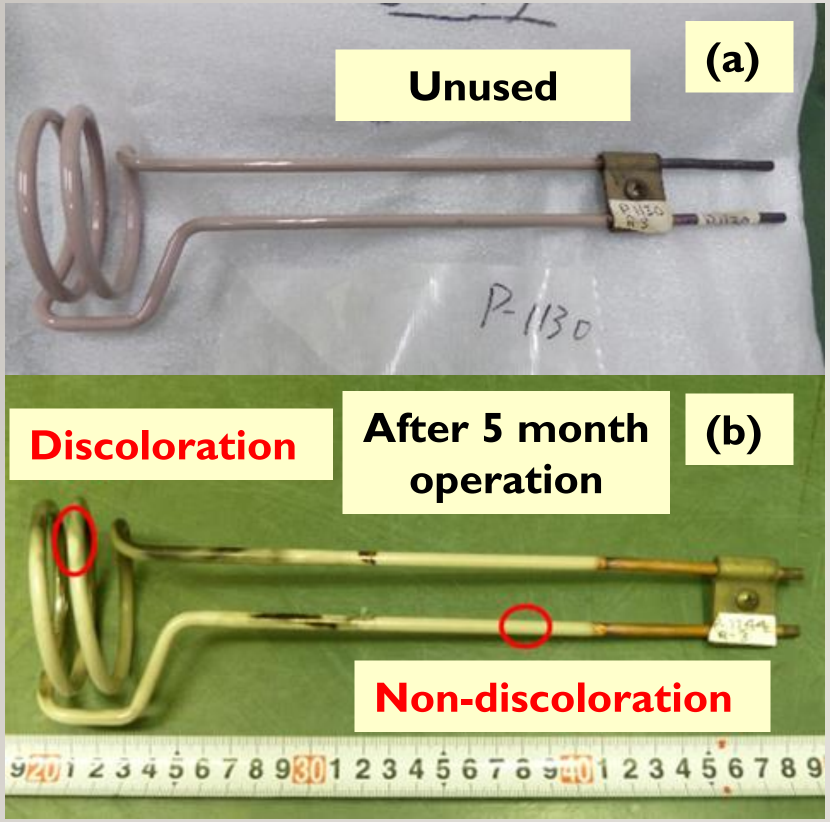
②Extension of ion source continuous operation duration

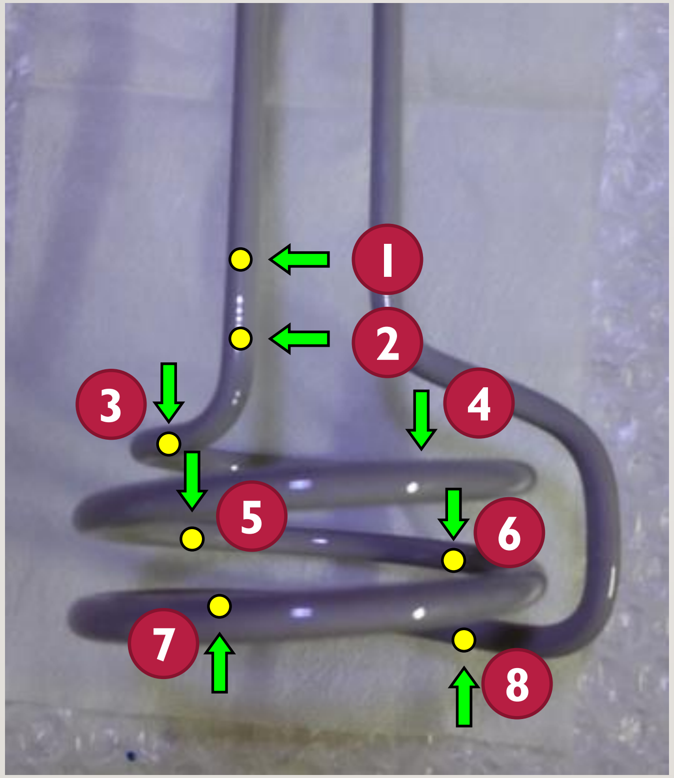
- The RF antenna coil is a copper pipe with enamel coating for insulation.
- Condition of the antenna coil surface after 5 month operation was investigated.





③RF antenna dimension measurement after 5 month operation

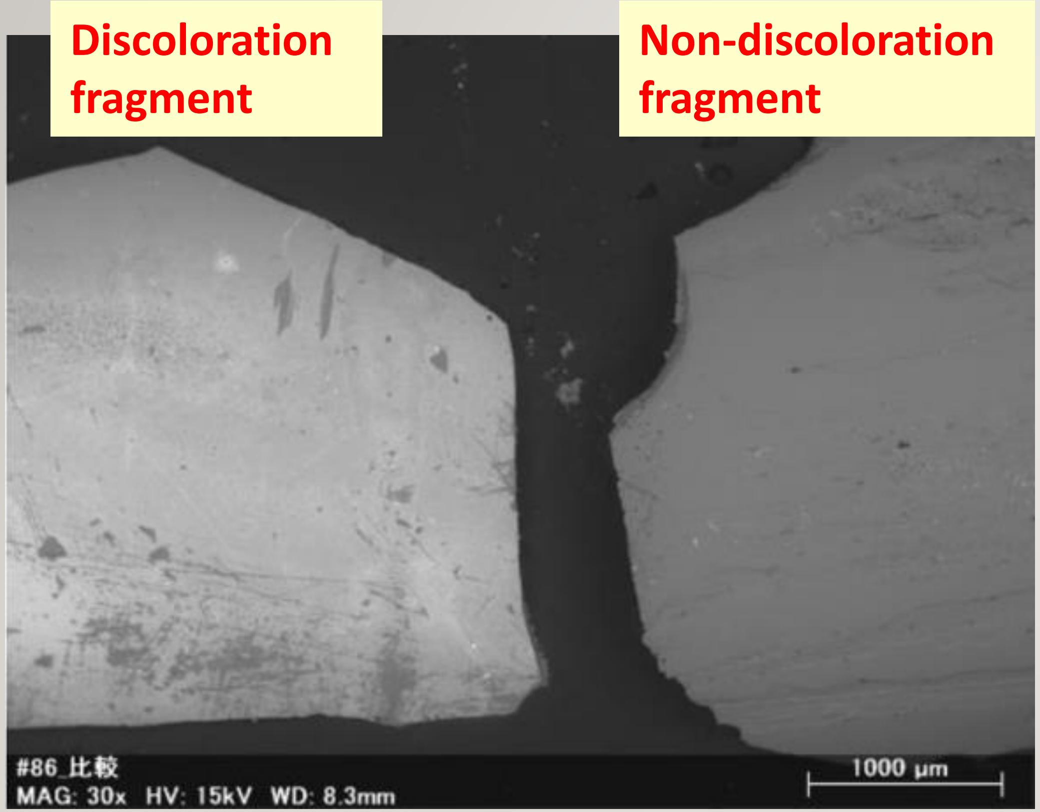




	Before Operation		After Operation	
	A	B	A	B
①	6.07	6.06	5.99	6.07
②	6.09	6.00	6.15	6.03
③	5.93	6.04	6.23	6.12
④	5.92	5.93	5.98	5.94
⑤	5.88	5.93	5.89	5.94
⑥	-	5.87	-	5.92
⑦	5.78	6.04	5.86	6.03
⑧	5.76	5.96	5.80	6.01
W/O ②③	5.88	5.97	5.90	5.99
W/O ②③ (A+B)/2	**5.92**		**5.94**	

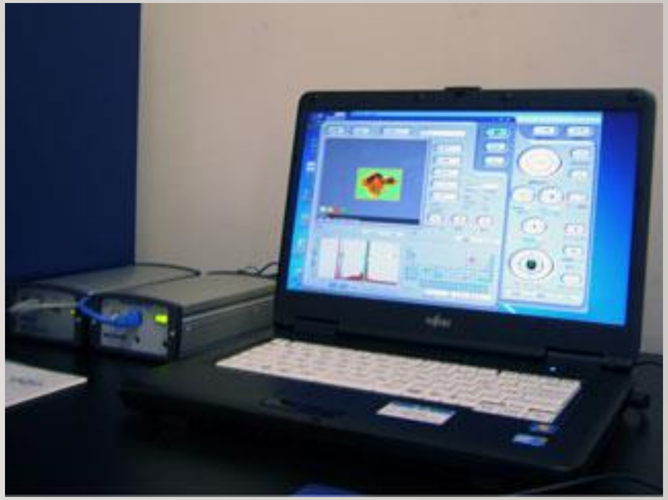
- From the visible confirmation, discoloration areas were seen on the antenna surface after 5 month operation.
- From the dimension measurement, no decrease in the antenna coil diameter was confirmed.
- Fortunately, no crack or pinhole was confirmed on the antenna surface.

④SEM/EDS measurements for discoloration fragment of RF antenna



SEM photograph of discoloration fragment (left) and non-discoloration fragment (right)

Tabletop Microscope TM3000 (Hitachi)



EDS System
Quantax70 (Bruker)

TM3000

- **Accelerating Voltage : 15 kV**

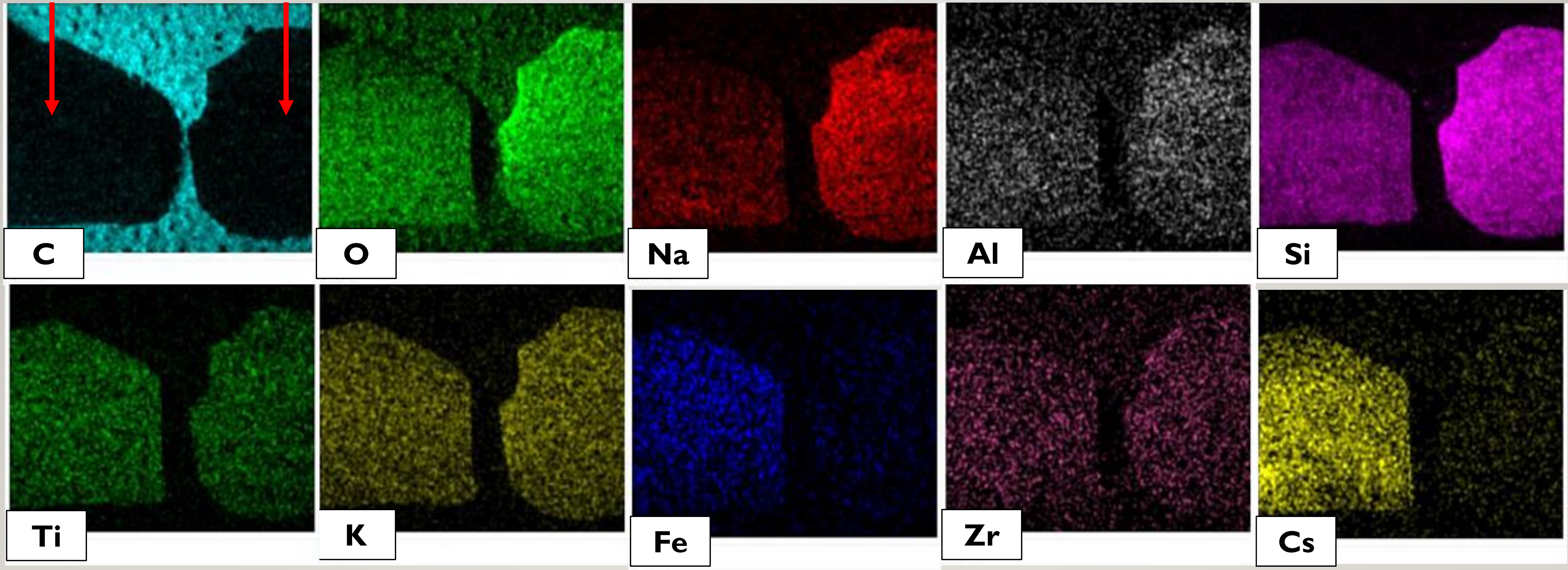
Quantax70

- **Accumulation time :**
  100 s (for non-discoloration fragment)
  200 s (for discoloration fragment)

④SEM/EDS measurements for discoloration fragment of RF antenna

Discoloration Non-discoloration

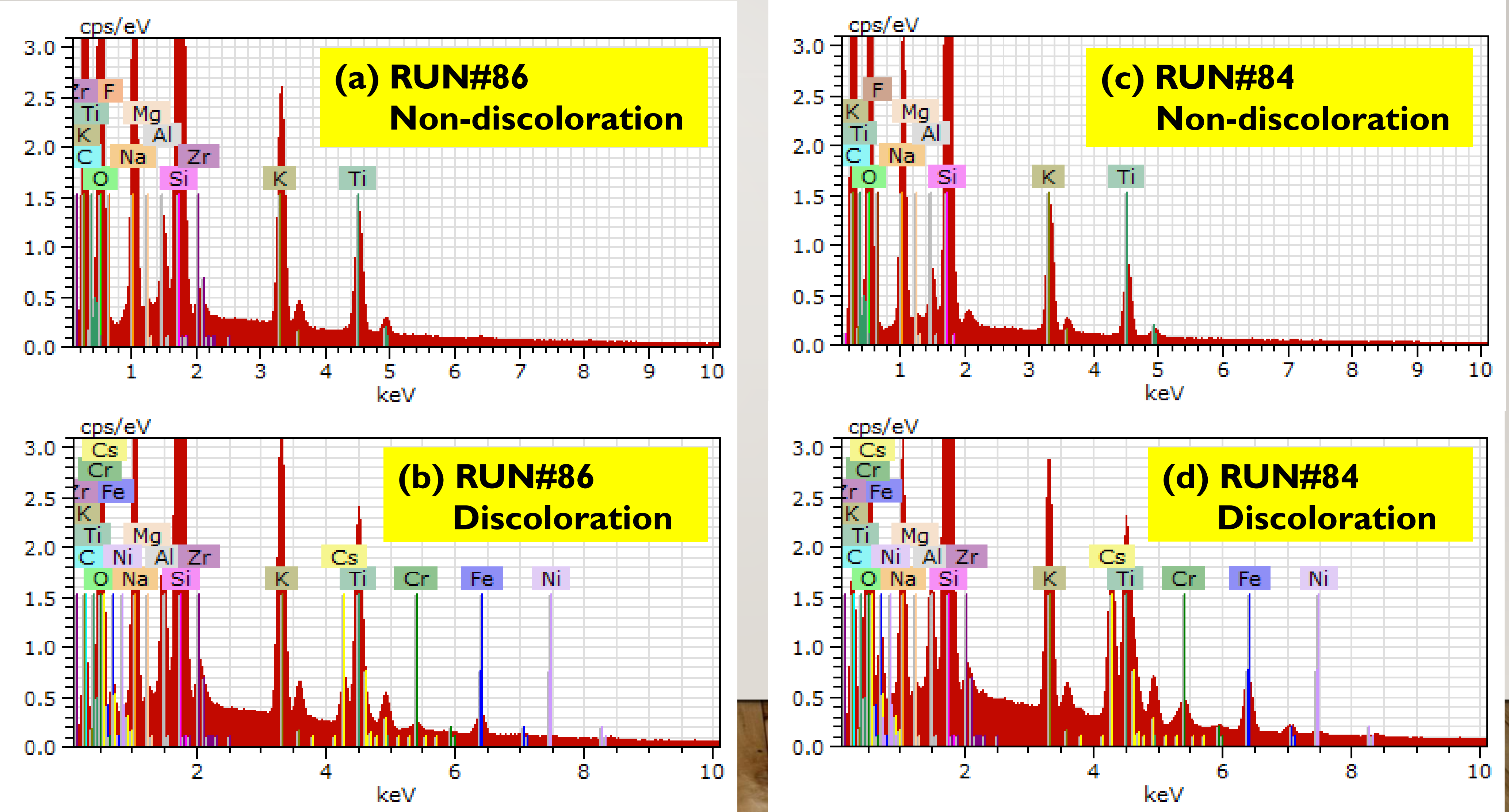
<u>Material mapping of discoloration and non-discoloration fragments</u>



- The main material observed from the non-discoloration fragment was O, Na, Al, Si, K, Ti, Zr, which are composition of enamel foundation.
- From the discoloration fragment, Fe and Cs are observed in addition to the enamel foundation.
  → Cause of the discoloration on the antenna is external deposition.

⑤Characteristic X-ray spectrum and semi-quantitative analyses

- **Characteristic X-ray spectrums** are obtained from the EDS measurements for the RF antenna coils used in 5 month (RUN#86) and 3.5 month (RUN#84) operations.
- Line spectrums of **Cs, Fe, Cr and Ni** are detected only on **the discoloration fragments.**



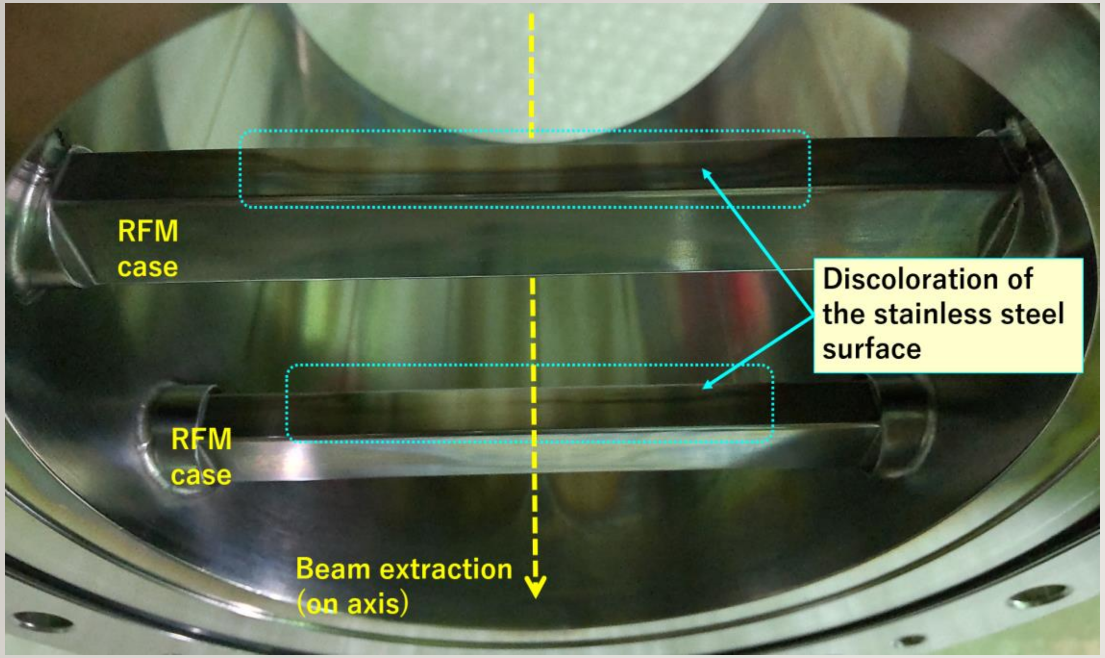
⑤Characteristic X-ray spectrum and semi-quantitative analyses

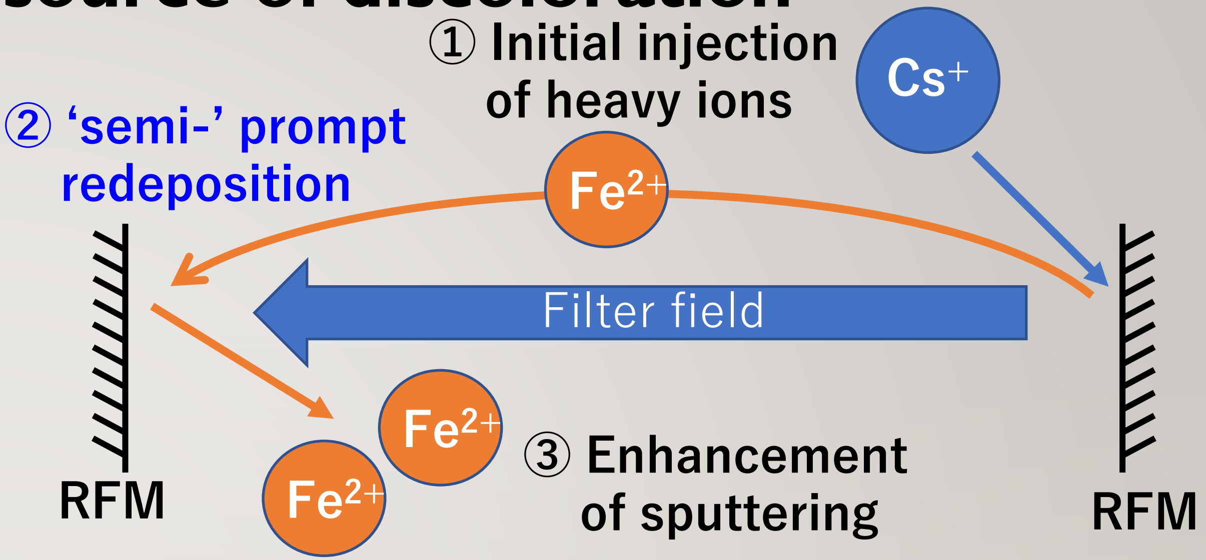
Semi-quantitative amounts of materials on the discoloration fragments from RUN#86 and RUN#84

	RUN#86 [norm. wt.%]	RUN#84 [norm. wt.%]
Oxygen	40.65	41.36
Silicon	20.10	14.99
Carbon	9.82	11.94
Titanium	7.65	5.64
Sodium	6.38	4.59
Potassium	5.76	4.06
Cesium	3.56	9.63
Aluminum	1.88	1.31
Iron	**1.78**	**3.82**
Zirconium	1.48	0.92
Chromium	**0.38**	**1.11**
Nickel	**0.34**	**0.47**
Magnesium	0.22	0.17
ALL	100.00	100.00

- Focusing on Fe, Ni and Cr (depositions except Cs) on the discoloration fragments, mass ratio of these 3 materials was Fe: 71%、Cr: 12 – 16 %、Ni: 10 – 16%.
- This ratio matches well with that of stainless metal composition which is used as the ion source chamber components.
- Difference of few months in the continuous operation duration does not lead to significant difference of the antenna surface condition.

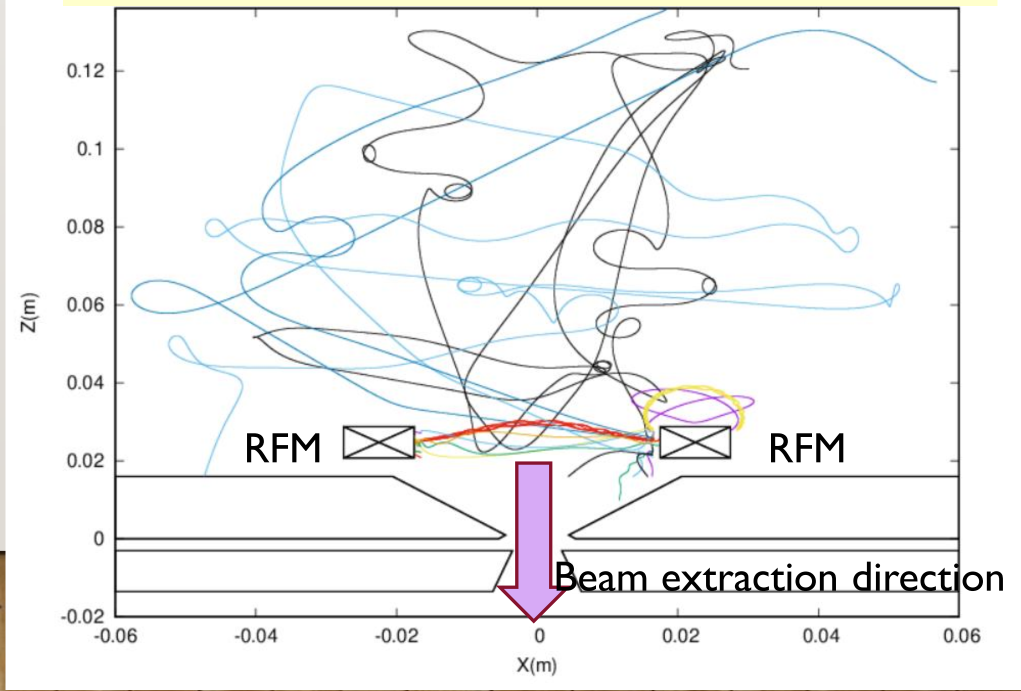
⑥ Discussion : possible source of discoloration





- **Excessive coverage of the antenna by stainless steel may cause extra heat load.**
- **Discoloration of the RFM cases was observed.**
  → Main source of the deposition?
- **Injection of heavy ions such as Cs+ leads to 'semi-' prompt redepositions of the stainless materials and to the RFM sputtering.**

Fe^{2+} orbits in the magnetic field configuration



Summary

- Continuous operation duration of 4,001 hours (5.5 months) was achieved by J-PARC RF ion source in the user operation 10th Jan. – 8th Jul. 2022.
- For further extension of the operation time, soundness evaluation of the RF antenna coil after the long-run was performed.
- Discoloration areas were confirmed on the enamel coating after the long-run. From the SEM/EDS measurements, it has been shown that the discoloration of the antenna is due to depositions of (1) injected cesium and (2) sputtered stainless steel from the ion source components.
- The results show the enamel coating was not deteriorated by the 5 month continuous operation.
- It is also noticeable that the surface condition does not change largely by difference of operation duration for few months.
- However, the excessive deposition may result in extra heat load via eddy current on the antenna surface. Measures to the plasma sputtering of the RFM cases (for example, coating of RFM cases with plasma sputtering resistant materials) can be one of the method to extend the ion source lifetime.

Thank you for your attention! *Grazie per l'attenzione!*