Status of N-infusion R&D at KEK furnace

2019/12/2

IHEP-KEK meeting@KEK

Kensei Umemori on behalf of KEK-SCRF group

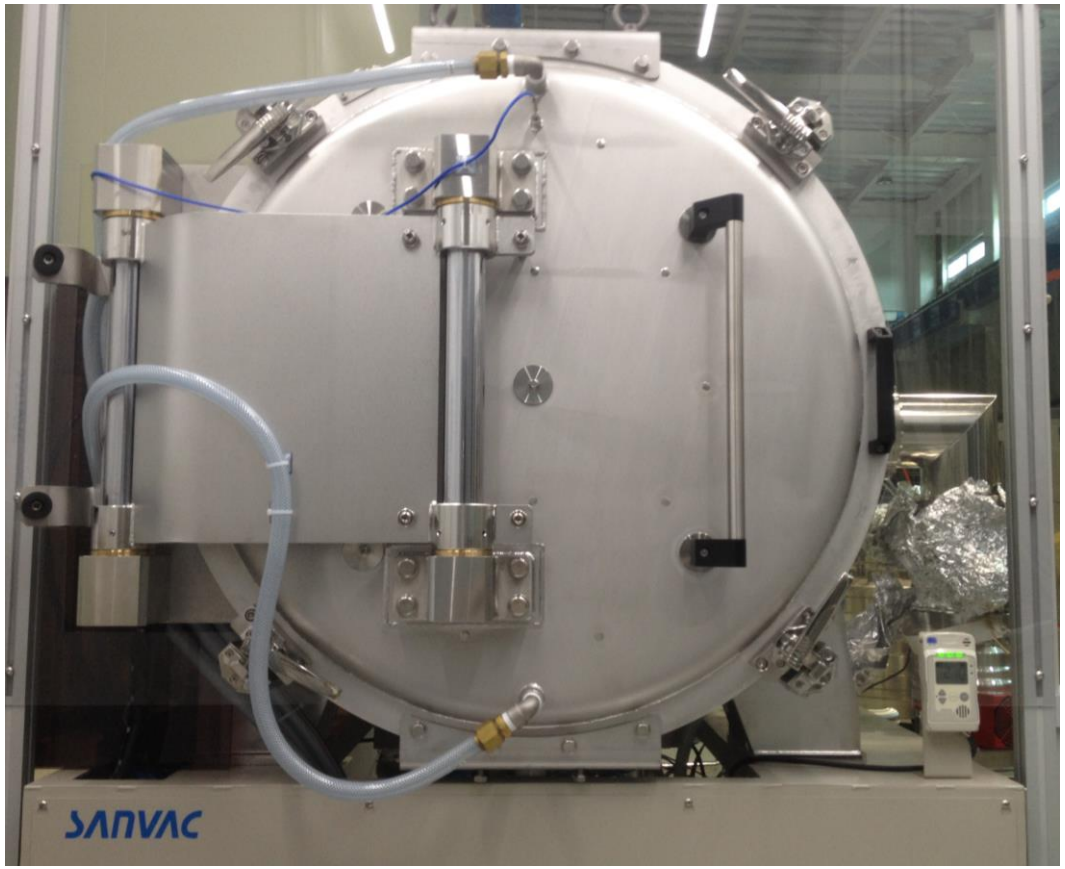
Outline

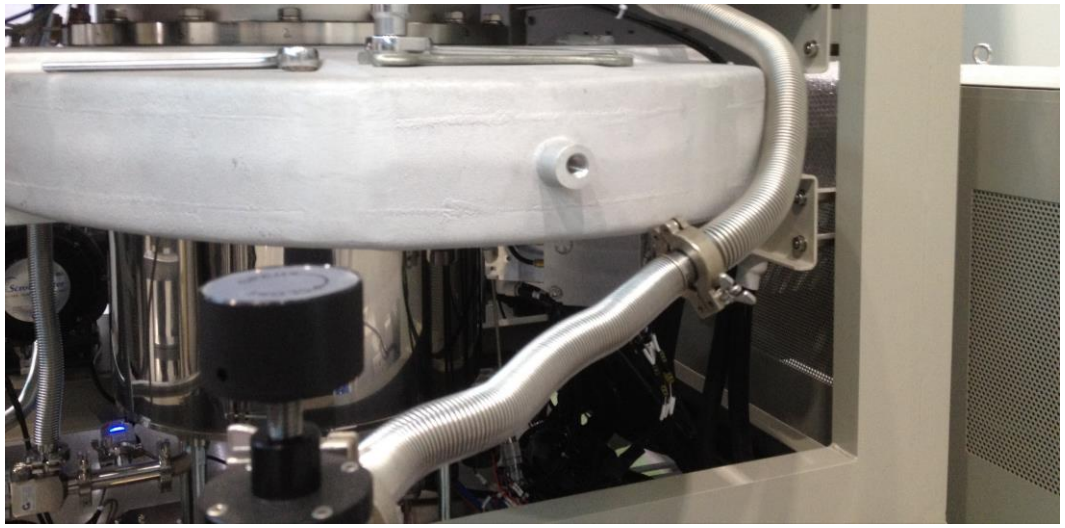
- KEK furnace
- N-infusion summary table, carried out at KEK
- Some results of N-infusion.
- N-infusion procedure (800C + 800C + 120C)
- N-infusion results for a 9-cell cavity
- Sensitivity for N-infusion cavity
- Summary

Motivation of N-infusion R&D

- N-infusion technique was proposed by FNAL, to realize high-Q/high-G performance of SRF cavities.
- For the ILC, high-Q and high-Gradient performance of SRF cavities are beneficial for cost reduction.
  - ➢High-Gradient → smaller number of cavities and cryomodules
  - ➢High-Q → less cryogenic loss
- KEK has tried to obtain N-infusion technique for three years.

KEK furnace(located at COI)

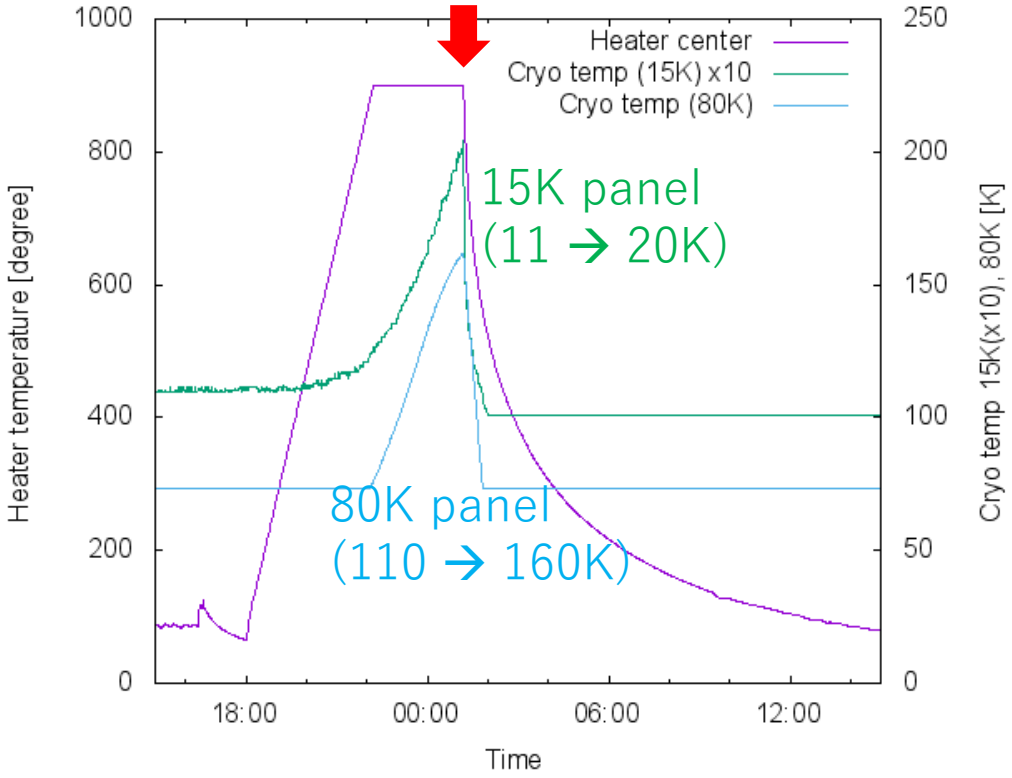




- Completed at the end of FY2017
- Cryopump for main pump, oil-free pumping system.
- Molybdenum is used for heater, reflector, table etc.
- TMP is used during N-injection, can reach ~2e-5Pa.
- Clean-booth surround entrance door.

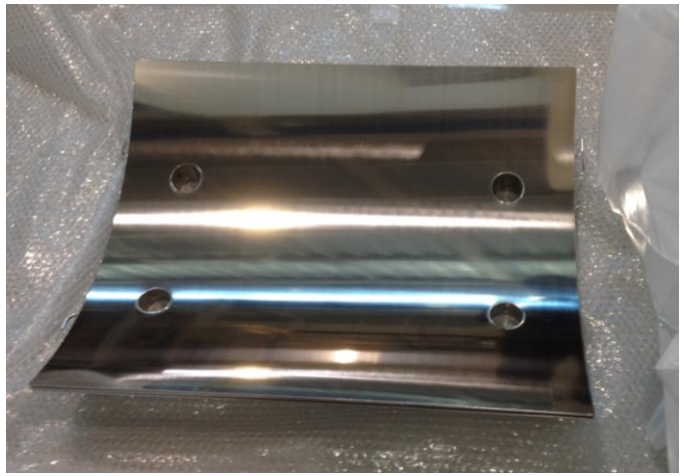
Problem of temperature rise on cryo-pump

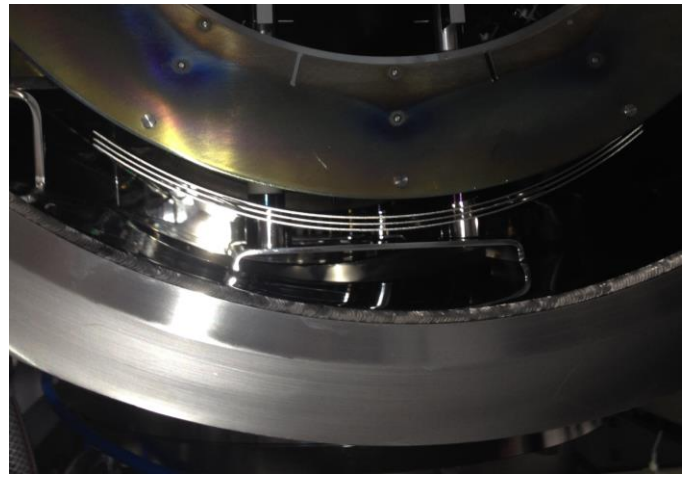
Cryo-pump down after 900C, 3h operation



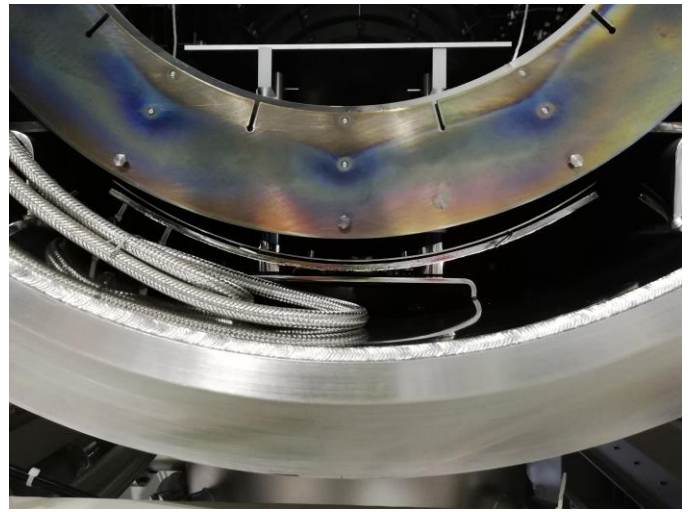
- Temperature rise was observed for 15K/80K panel of the cryo-pump.
- High temperature operation was difficult.

1st trial; install multi-layer shield





2nd trial; install water-cooled shield



Not perfect, but became much better

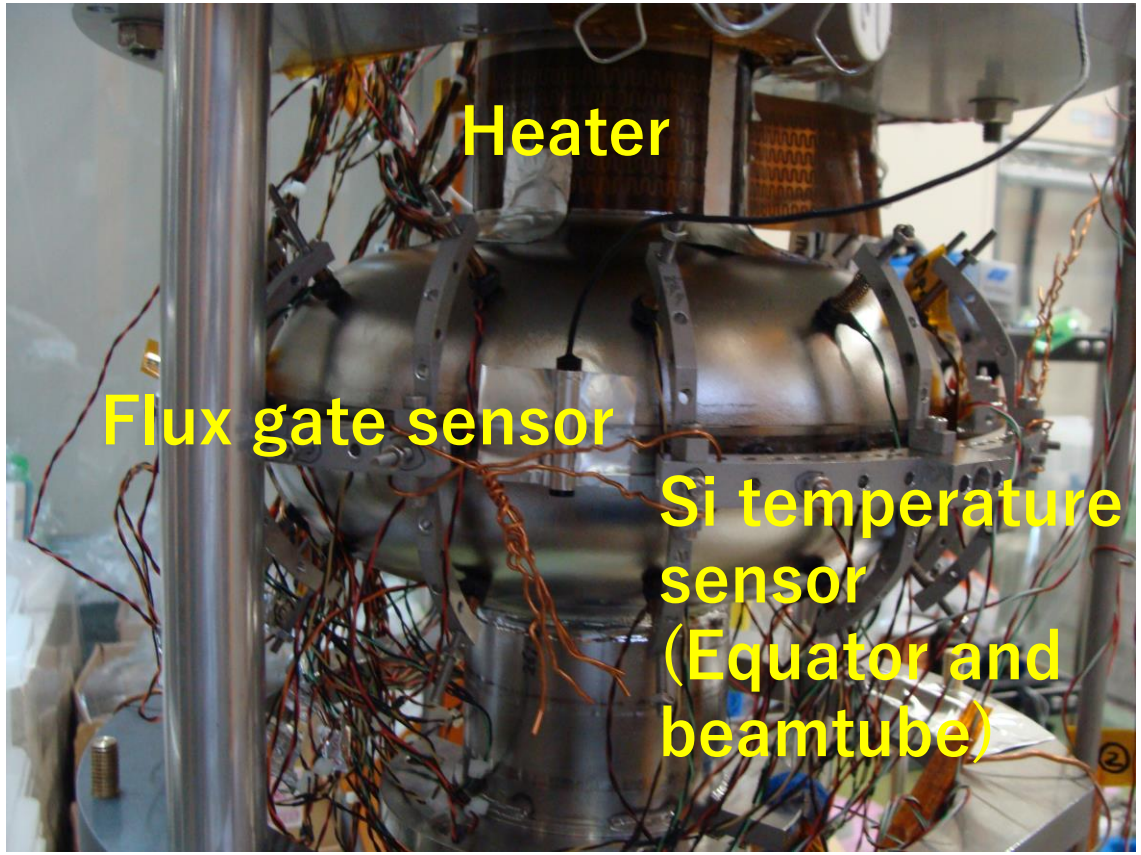
#	Day (N-inf / VT)	Cavity name	# of cell	Nb	Treatment	Results	Eacc (MV/m)	Comment
1	2018/Jun	R-6	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	35	
2	2018/Jun, Jul	R-9b	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	26	Defect limited
3	2018/Jun, Jul	R-10	3	LG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	27	F.E. limited
Summer shutdown								
4	2018/Sep, Oct	R-2	1	FG	800C, 3h + 160C, 48h, 3.3Pa N2	Q-degradation	19	No defects found
5	2018/Oct	R-6	1	FG	800C, 3h + 120C, 48h (without N2)	Q-degradation	32	
Apply dedicated burning run after this period								
6	2018/Nov, Dec	R-8	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	36	
Improve cooling of cryo-pump by adding cooling-water type shielding plate								
7	2018/Dec 2019/Jan	R-9b	1	FG	800C, 3h + 800C, 2h + 160C, 48h, 3.3Pa N2	Q-degradation	24	Defect limited
8	2019/Jan, Feb	AES18	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	No Q-degradation	38	
Modify N2 injection line								
9	2019/Apr	R-4	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	39	
10	2019/May	AES18	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	31	
Remove cooling-water type shielding plate due to water leak trouble								
11	2019/Jun, Jul	MHI31	9	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	37	
12	2019/Sep	R-4	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Q-degradation	36	

No dedicated burning run

#	Day (N-inf / VT)	Cavity name	# of cell	Nb	Treatment	Results	Eacc (MV/m)	Comment
1	2018/Jun	R-6	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	35	
2	2018/Jun, Jul	R-9b	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	26	Defect limited
3	2018/Jun, Jul	R-10	3	LG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	27	F.E. limited
Summer shutdown								
4	2018/Sep, Oct	R-2	1	FG	800C, 3h + 160C, 48h, 3.3Pa N2	Q-degradation	19	No defects found
5	2018/Oct	R-6	1	FG	800C, 3h + 120C, 48h (without N2)	Q-degradation	32	
Apply dedicated burning run after this period								
6	2018/Nov, Dec	R-8	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	36	
Improve cooling of cryo-pump by adding cooling-water type shielding plate								
7	2018/Dec 2019/Jan	R-9b	1	FG	800C, 3h + 800C, 2h + 160C, 48h, 3.3Pa N2	Q-degradation	24	Defect limited
8	2019/Jan, Feb	AES18	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	No Q-degradation	38	
Modify N2 injection line								
9	2019/Apr	R-4	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	39	
10	2019/May	AES18	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	31	
Remove cooling-water type shielding plate due to water leak trouble								
11	2019/Jun, Jul	MHI31	9	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	37	
12	2019/Sep	R-4	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Q-degradation	36	

Typical vertical test setup

※ Pictures are for different measurement.
※ But setup of sensors and coil are same.



Flux gate sensor, Si temperature sensor, heater and solenoid coil were used.

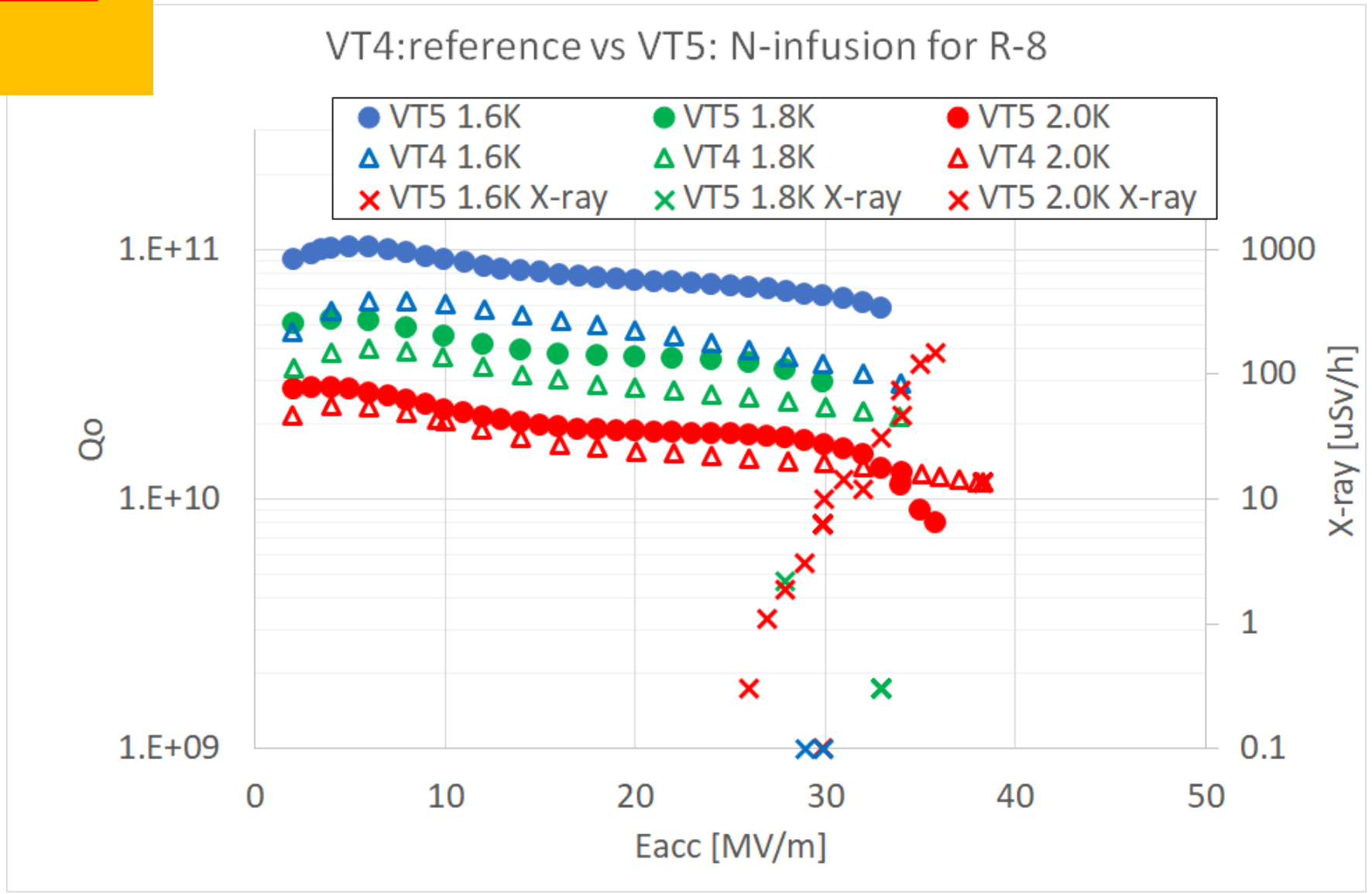
Typical good results ⑥ R-8 cavity

- 0mG cancelled by the coil.

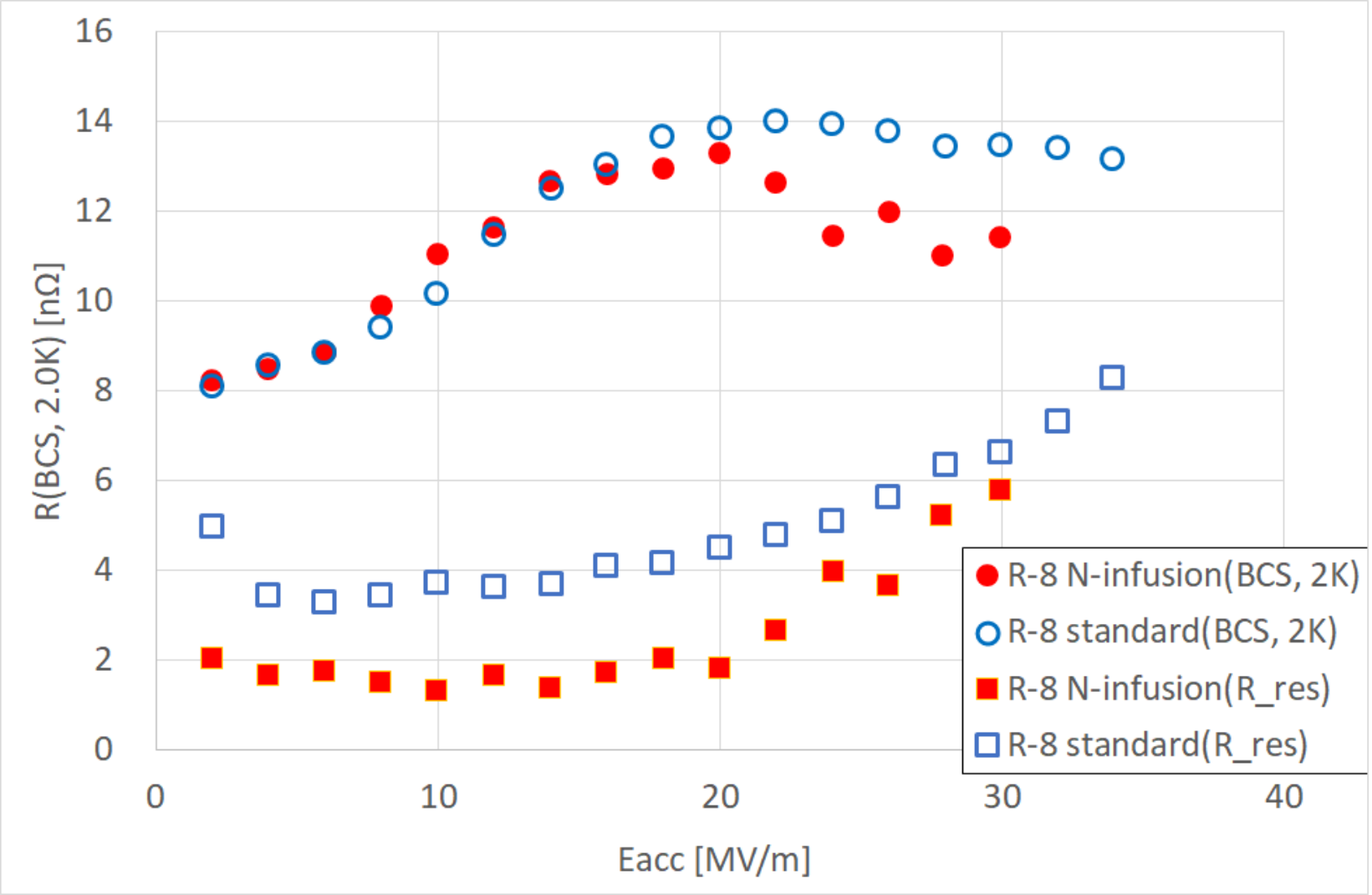
- Very high-Q was achieved.
- Good Q for medium to high field too.

⇒Feature of N-infusion

- Eacc degraded from 39 to 35 MV/m.
- F.E. started from 25 MV/m.



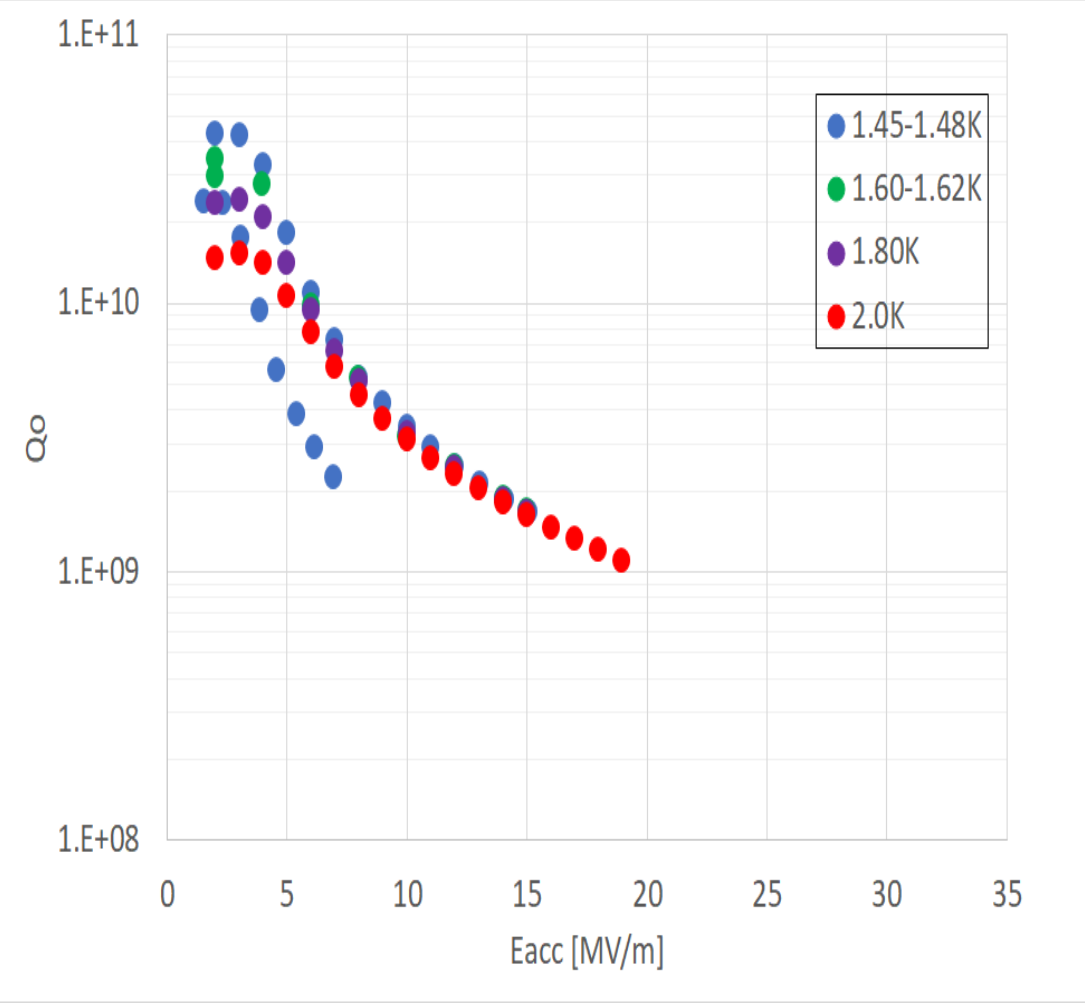
R_BCS(2K) & R_res for N-infusion cavity(R-8)



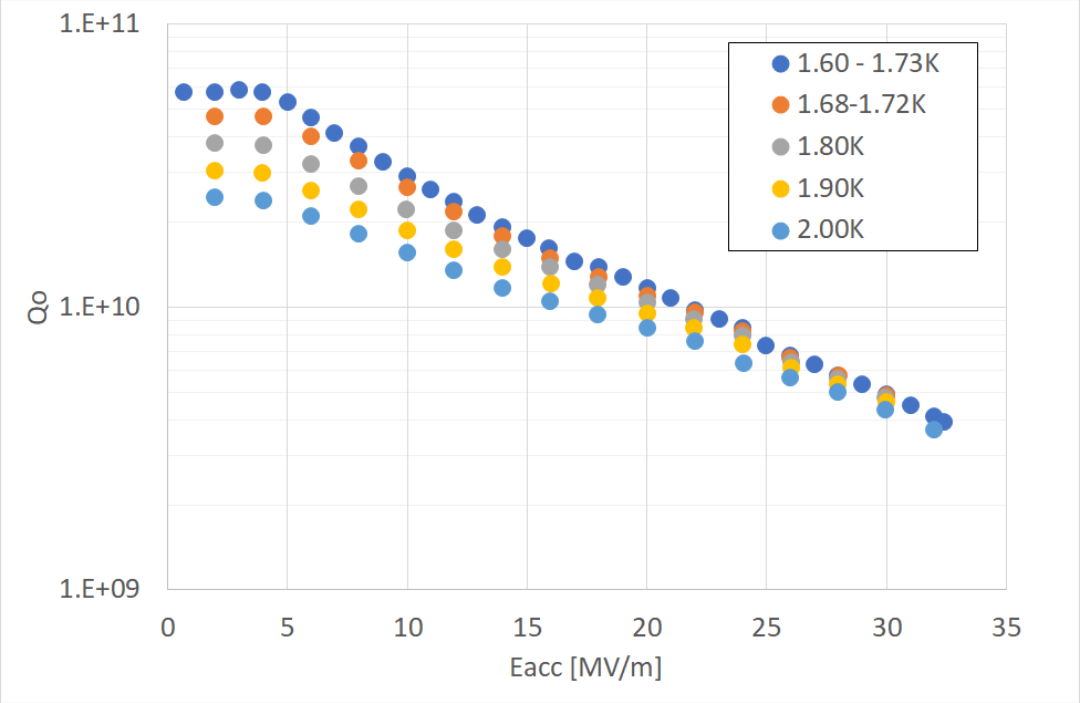
- BCS resistance does not change much.
- R_res tend to be smaller for N-infusion cavity.
- F.E. above 25 MV/m

Bad results of N-infusion

④ Results for 4th N-infusion (160C) at COI, R-2 cavity



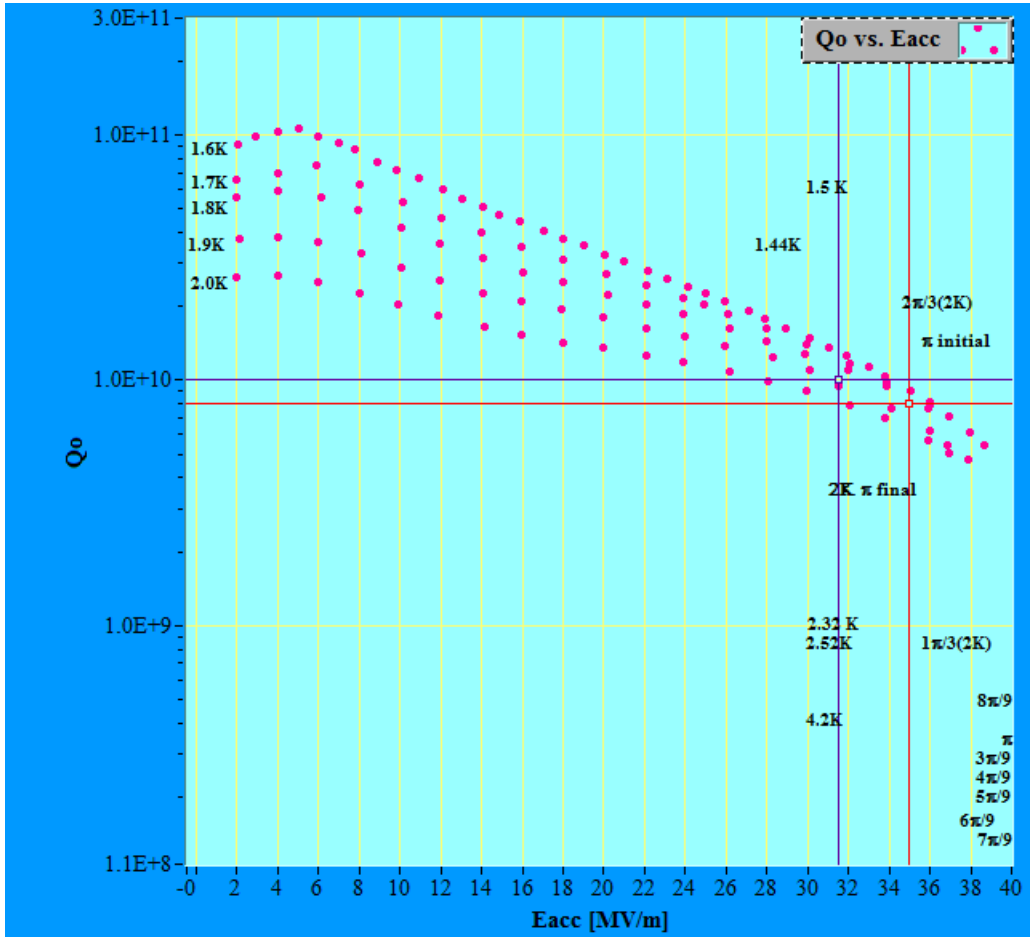
⑤ Results for 5th N-infusion(120C, w/o N2) at COI, R-6 cavity



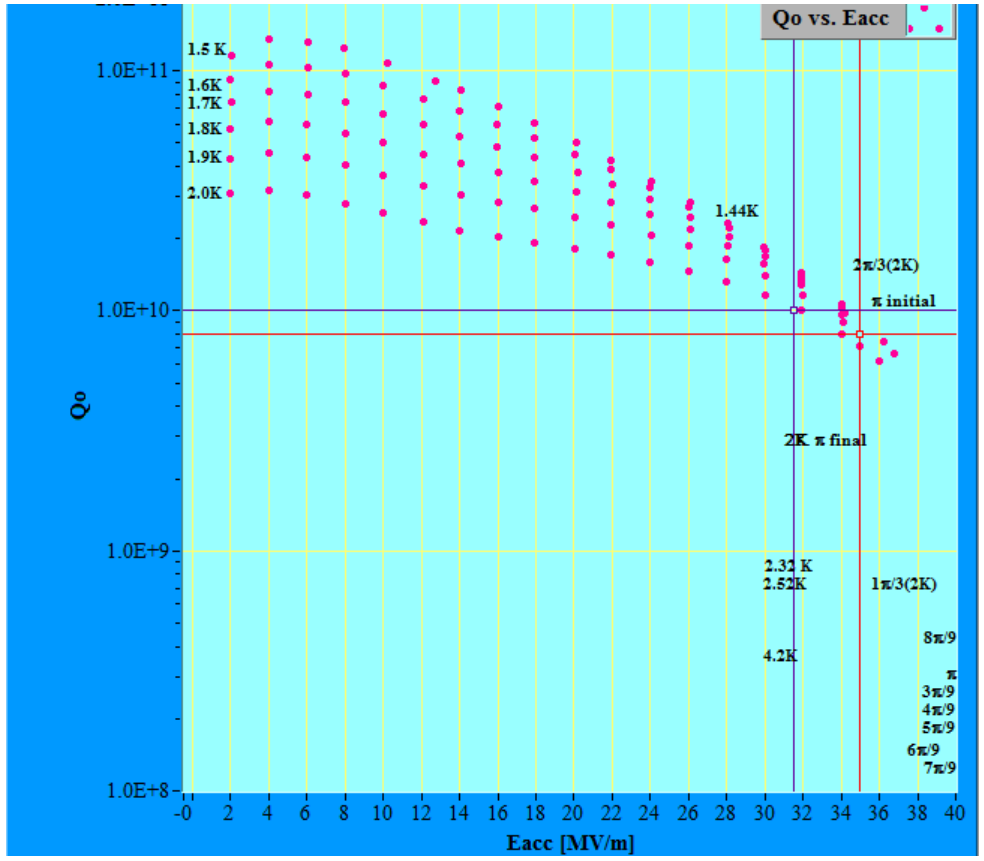
- Q-degradation occurred even at KEK New furnace.
- What's reason of degradation??
- Lack of burning run after summer?

Mild Q-degradation

⑨ Results for 9th N-infusion (120C) at COI, R-4 cavity



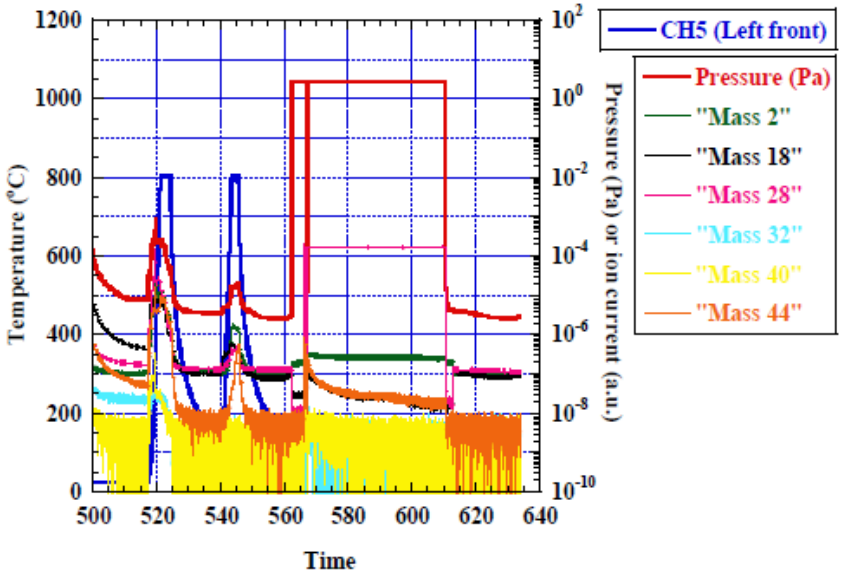
⑫ Results for 12th N-infusion (120C) at COI, R-4 cavity

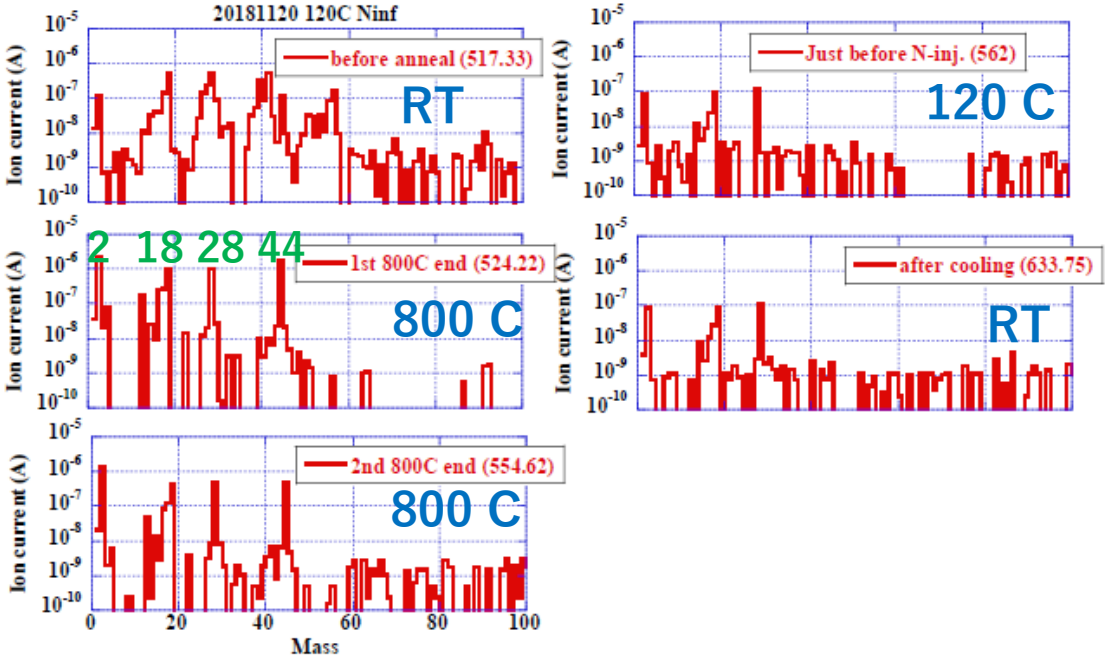


Typical RGA spectrum

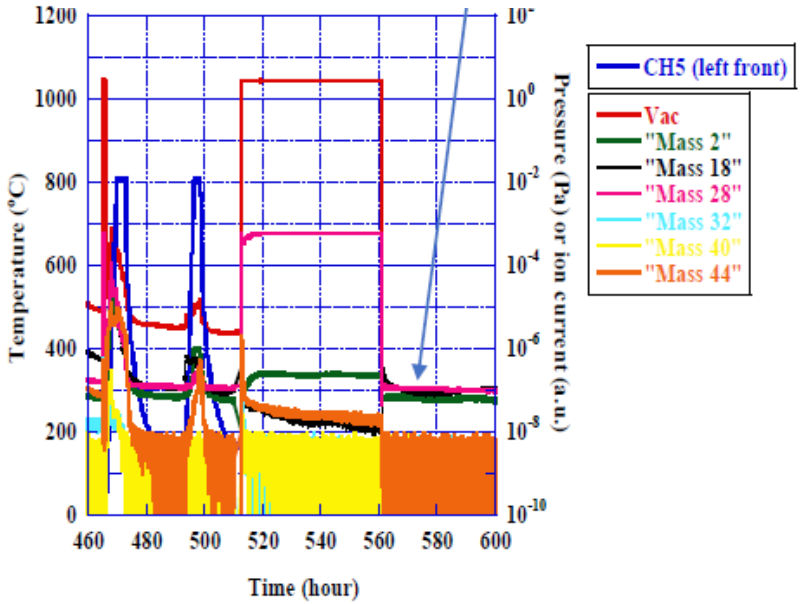
RGA does not show difference between good and bad examples.

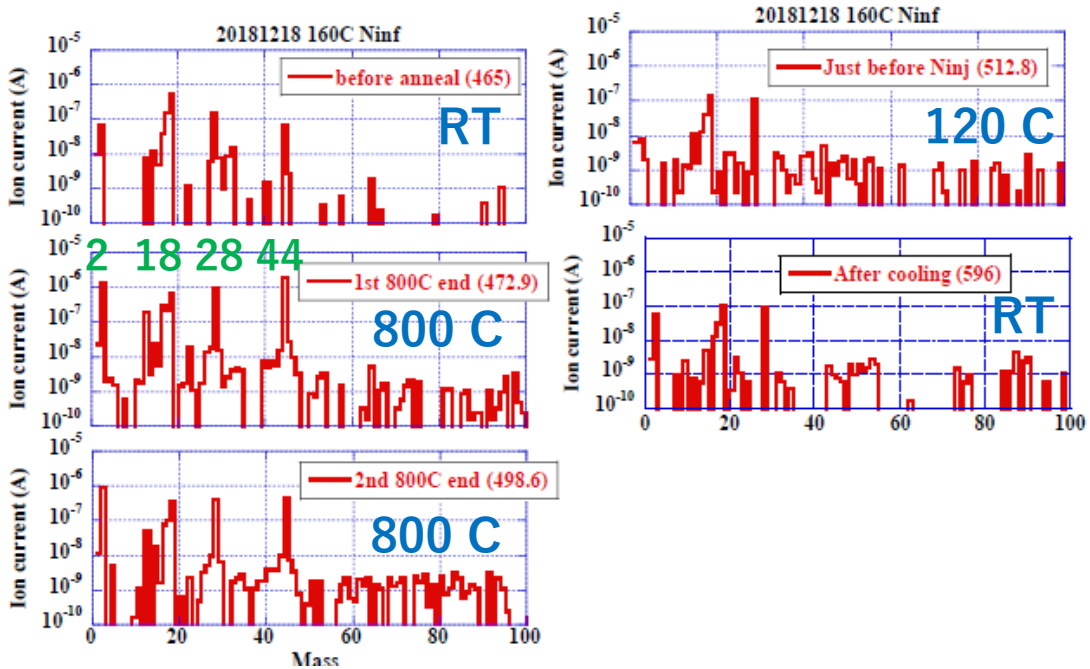
Good ⑥120C N-infusion



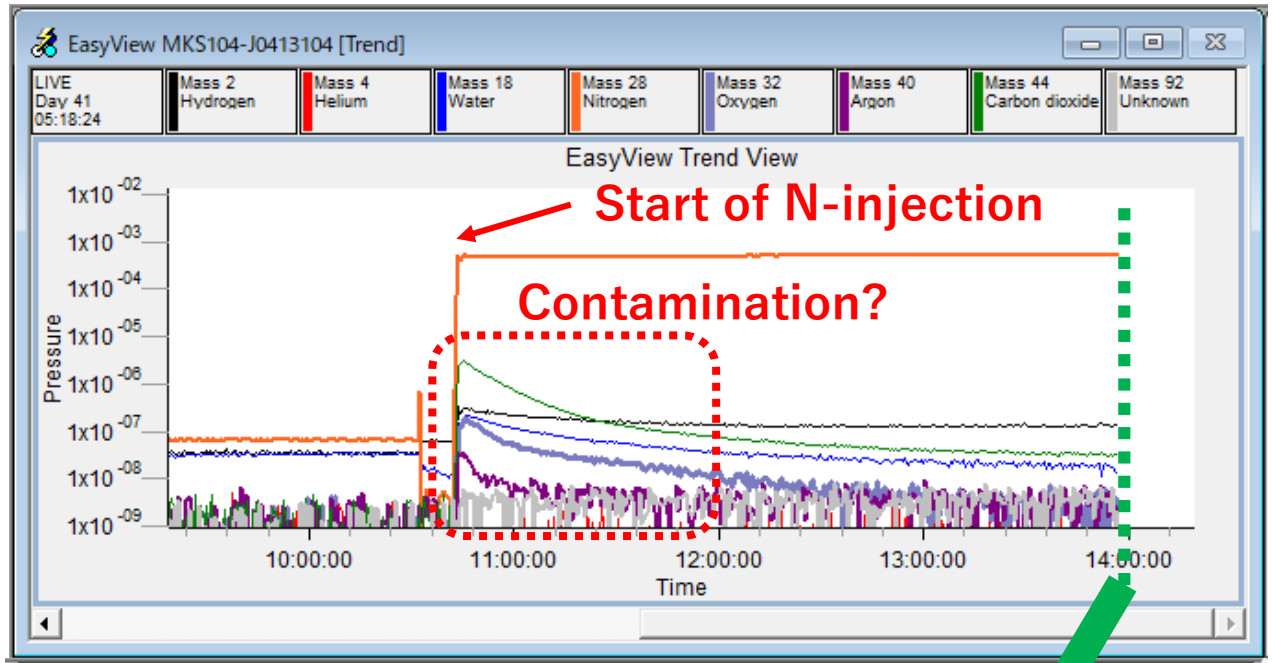


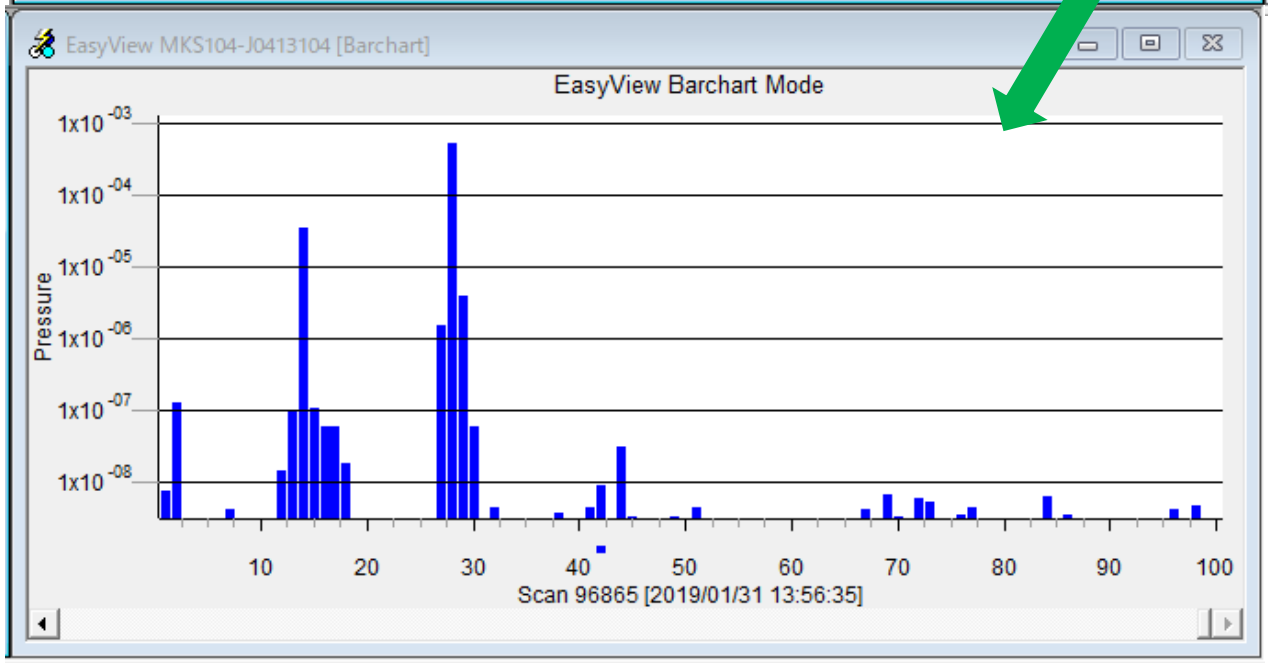
Bad ⑦160C N-infusion (Gauge not fired)

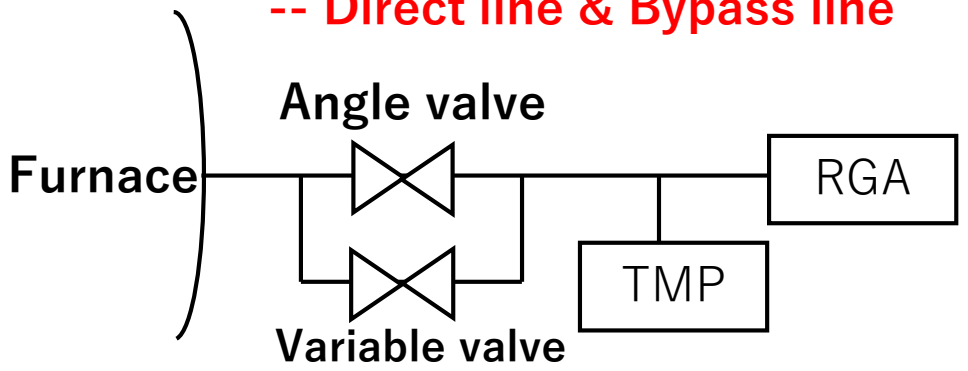




RGA spectrum during N-injection







Bypass line wad developed to monitor purity of N2.

Some gas(44, 32) components are observed and show higher value at beginning.
→ Source of bad results?

First N-injection line was suspected.
→ Add gas purifier → No change on results

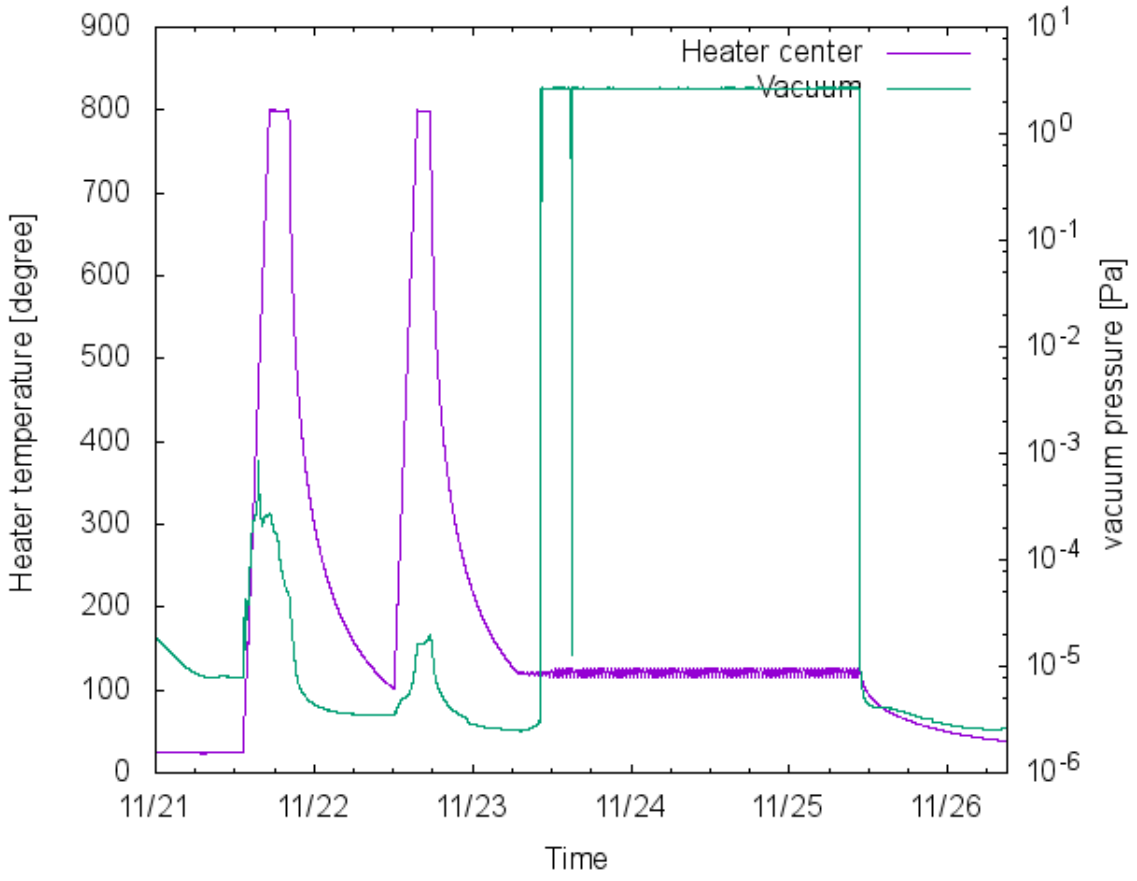
Later it was found that contamination come from combination of “Open to air + heating furnace + flushing by N-injection”. Difficult to remove

#	Day (N-inf / VT)	Cavity name	# of cell	Nb	Treatment	Results	Eacc (MV/m)	Comment
1	2018/Jun	R-6	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	35	
2	2018/Jun, Jul	R-9b	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	26	Defect limited
3	2018/Jun, Jul	R-10	3	LG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	27	F.E. limited
Summer shutdown								
4	2018/Sep, Oct	R-2	1	FG	800C, 3h + 160C, 48h, 3.3Pa N2	Q-degradation	19	No defects found
5	2018/Oct	R-6	1	FG	800C, 3h + 120C, 48h (without N2)	Q-degradation	32	
Apply dedicated burning run after this period								
6	2018/Nov, Dec	R-8	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	36	
Improve cooling of cryo-pump by adding cooling-water type shielding plate								
7	2018/Dec 2019/Jan	R-9b	1	FG	800C, 3h + 800C, 2h + 160C, 48h, 3.3Pa N2	Q-degradation	24	Defect limited
8	2019/Jan, Feb	AES18	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	No Q-degradation	38	
Modify N2 injection line								
9	2019/Apr	R-4	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	39	
10	2019/May	AES18	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	31	
Remove cooling-water type shielding plate due to water leak trouble								
11	2019/Jun, Jul	MHI31	9	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	37	
12	2019/Sep	R-4	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Q-degradation	36	

#	Day (N-inf / VT)	Cavity name	# of cell	Nb	Treatment	Results	Eacc (MV/m)	Comment
1	2018/Jun	R-6	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-degradation	35	
2	2018/Jun, Jul	R-9b	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	No Q-d		
3	2018/Jun, Jul	R-10	3	LG	800C, 3h + 120C		27	F.E. limited
4					+ 160C, 48h, 3.3Pa N2	Q-degradation	19	No defects found
5		R-6	1	FG	800C, 3h + 120C, 48h (without N2)	Q-degradation	32	
Apply dedicated burning run after this period								
6	2018/Nov, Dec	R-8	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	36	
Improve cooling of cryo-pump by adding cooling-water type shielding plate								
7	2018/Dec 2019/Jan	R-9b	1	FG	800C, 3h + 800C, 2h + 160C, 48h, 3.3Pa N2	Q-degradation	24	Defect limited
8	2019/Jan, Feb	AES18	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	No Q-degradation	38	
Modify N2 injection line								
9	2019/Apr	R-4	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	39	
10	2019/May	AES18	1	FG	800C, 3h + 120C, 48h, 3.3Pa N2	Q-degradation	31	
Remove cooling-water type shielding plate due to water leak trouble								
11	2019/Jun, Jul	MHI31	9	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Better Q than reference	37	
12	2019/Sep	R-4	1	FG	800C, 3h + 800C, 2h + 120C, 48h, 3.3Pa N2	Q-degradation	36	

「800C, 3h + 800C, 2h + 120C, 48h with N2」seems to be better?

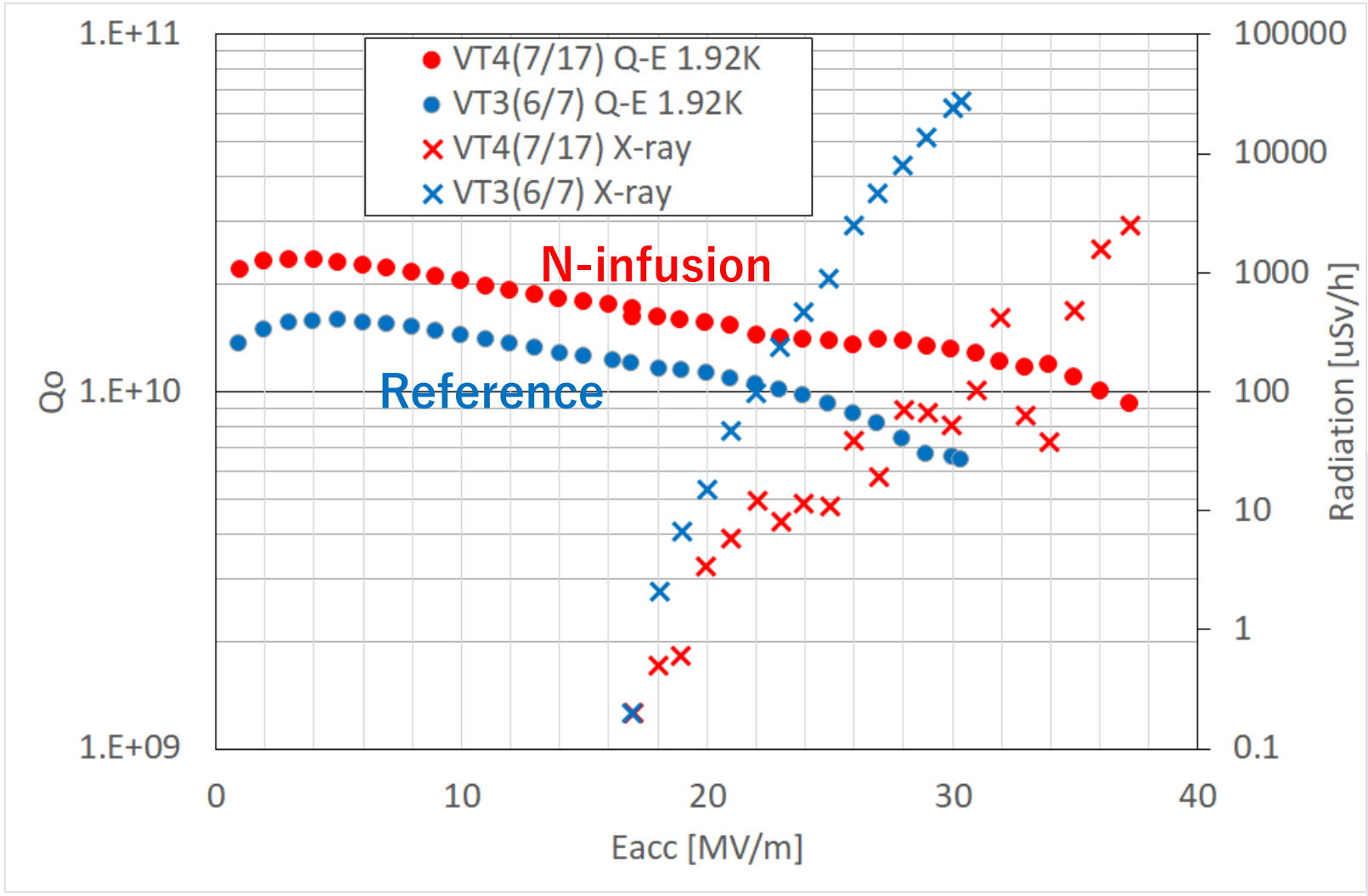
Process, “800C, 3h + 800C, 2h + 120C, 48h, N2”



- **“Better vacuum” or “less hydrogen” might be necessary condition for N-infusion.**
- **Is Hydrogen key components?**

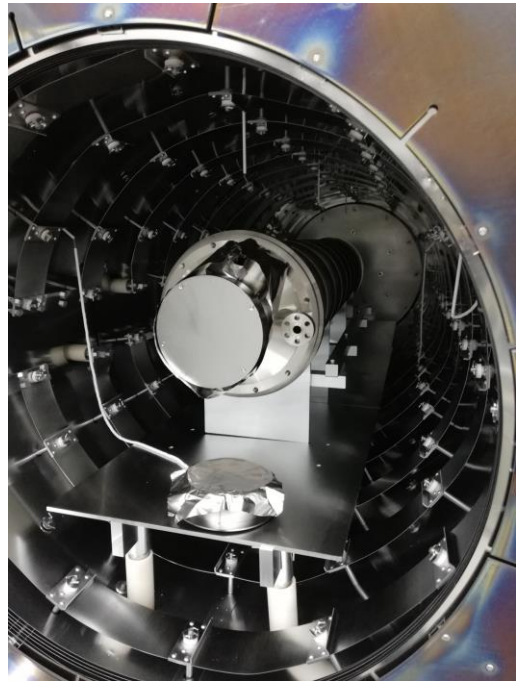
- 1st 800C heat treatment
  - ➢De-gassing of cavity
  - ➢One important target is Hydrogen
- 2nd 800C heat treatment
  - ➢Much better vacuum condition
  - ➢Less absorption on cavity surface
  - ➢“H” start to rise after 2 hours, due to temperature rise of cryo-pump.
- 120C, N-infusion
  - ➢Normal N-injection procedure
  - ➢3.3Pa N2 injection for 48 hours.

First N-infusion for 9-cell cavity



※ Eacc for reference measurement was limited by F.E.

This cavity will be installed into STF cryomodule.

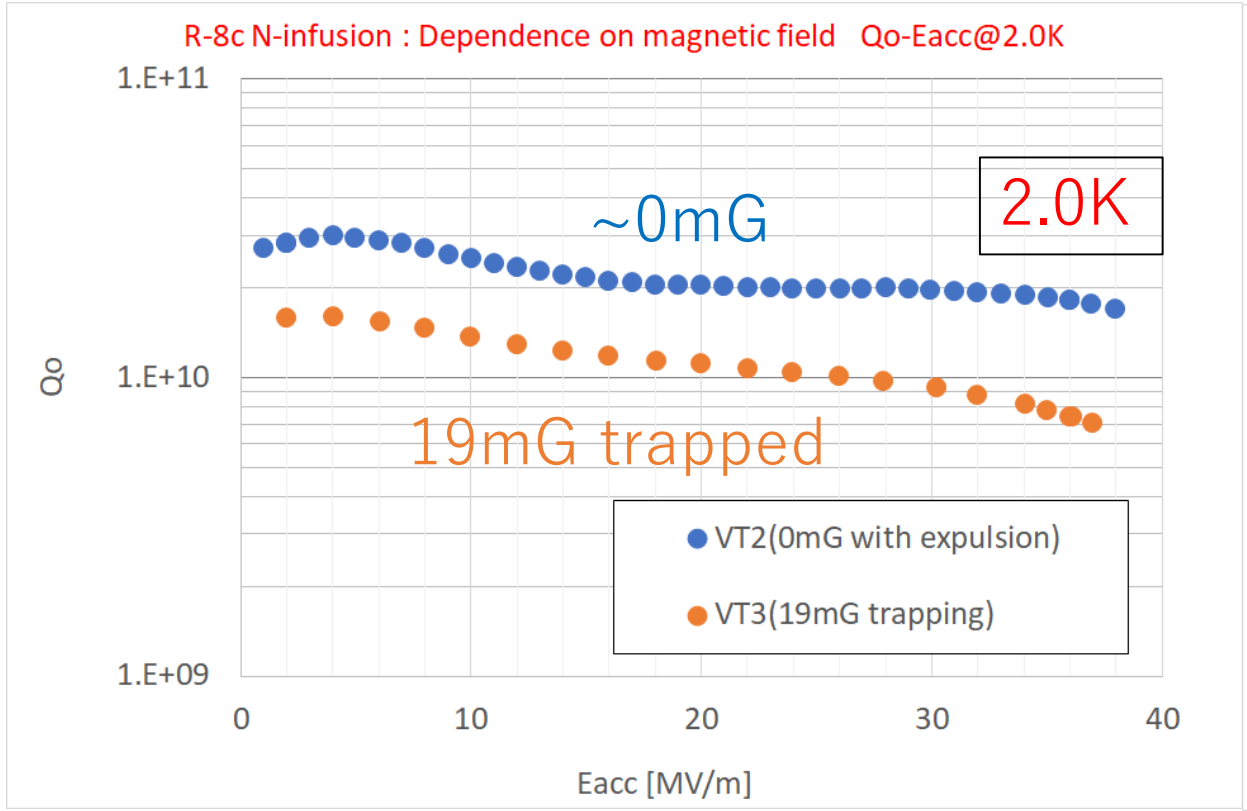


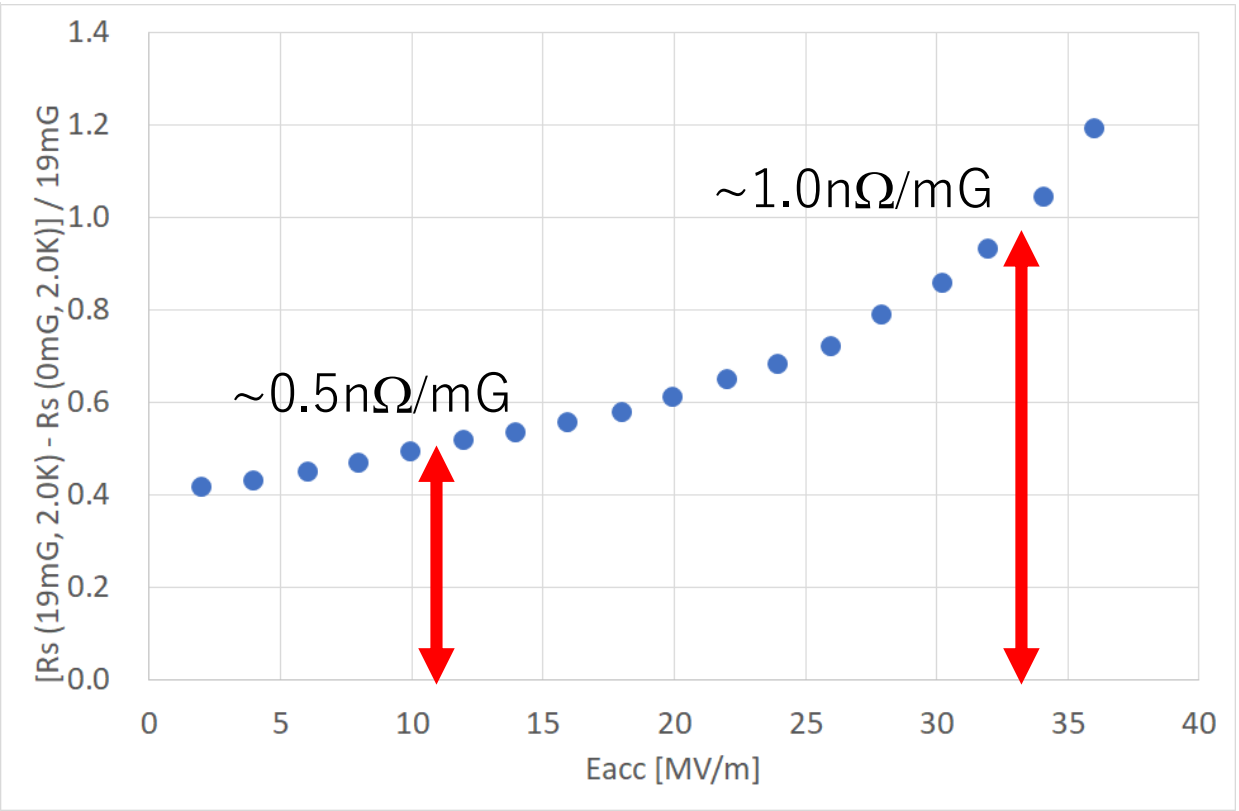
- **Max Eacc = 37MV/m**
- **Quench : 1-cell, 120deg.**
- **Final field emission onset Eacc = 20-21MV/m**

- **Improvement of Qo ?**
- **Magnetic field inside VT dewar was not controlled for 9-cell cavities.**

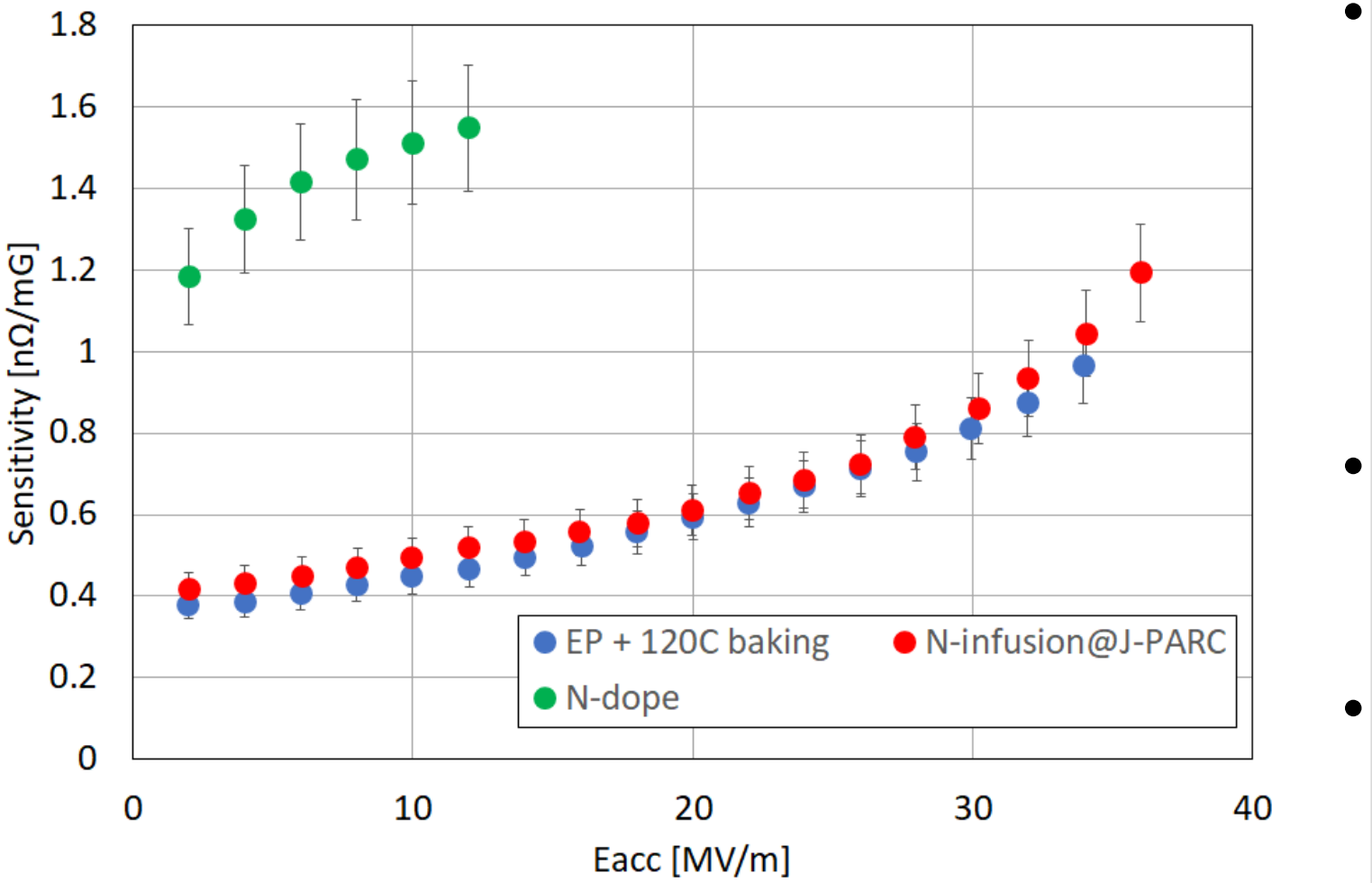
Sensitivity to flux trapping (N-infusion@J-PARC)

VT2: 0mG with expulsion condition ⇒ ~0mG
VT3: 20mG was applied and almost trapped ⇒ 19mG trapped (5% expulsion)





Comparison of sensitivity[nΩ/mG]



- We did sensitivity measurement for
  - N-infusion@J-PARC
  - standard recipe(final EP + Baking 120C, 36h)
  - N-doping@KEK
- Both of N-infusion/baking cavity shows very similar sensitivity behavior.
- Sensitivity is ~1nΩ/mG at Eacc~35MV/m.

Summary

- KEK has carried out N-infusion study for realize high-Q/high-Gradient performance of SRF cavities.
- New clean furnace was constructed at KEK. It has been used for N-infusion studies.
- Roughly half of N-infused cavities show degradation of Q.
- “Two step 800C + 120C N-infusion” may help to realized successful N-infusion.
- First trial for 9-cell cavity showed good results.
- We will continue study to find more stable condition and more reliable SRF performance.