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Status of Ion Sources at HIMAC

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Contents

1. Requirements
2. Production of carbon ions
3. Extension of the range of ion species
4. Two frequency heating
5. MIVOC with temperature control

NIRS
HIMAC

NIRS

- Budget: 14.6 Billion Yen
- Staff: 782 (permanent 340)
- Area: 133,000 m^2

Protection from radiation, and diagnosis and treatment of radiation injuries

Effects of radiation on the human body

Medical uses of radiation
Advanced imaging diagnosis & Radiotherapy

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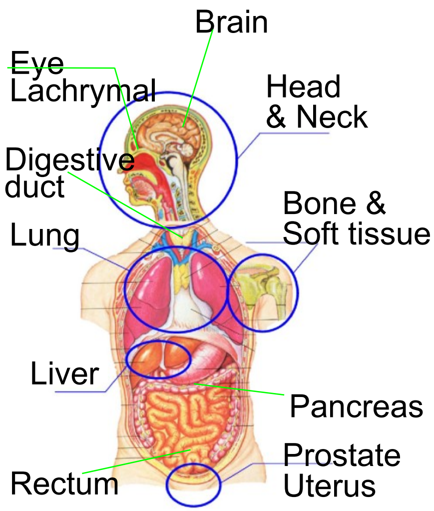
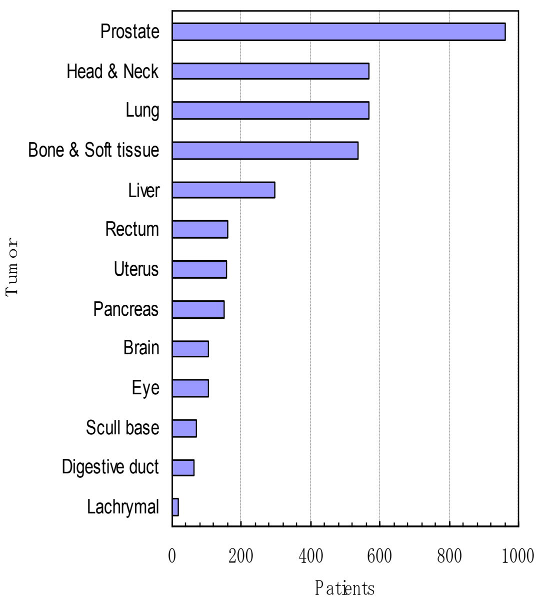
Research on heavy ion radiotherapy





Heavy Ion Medical Accelerator in Chiba (HIMAC)

Total 5497 various cancer patients have been treated with carbon beams since 1994.

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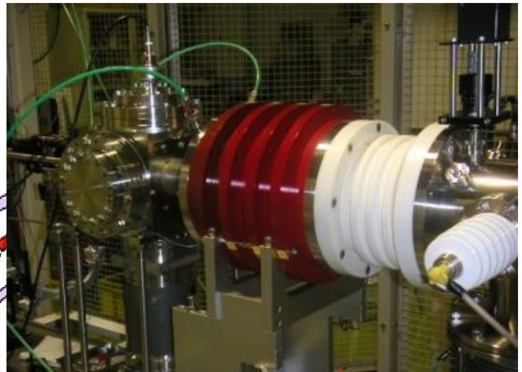
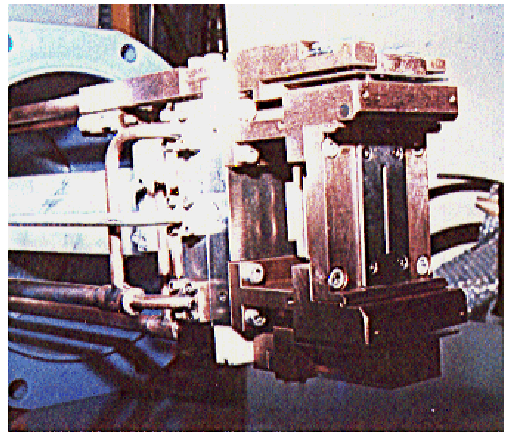
Ion sources at HIMAC

Kei2 ECRIS

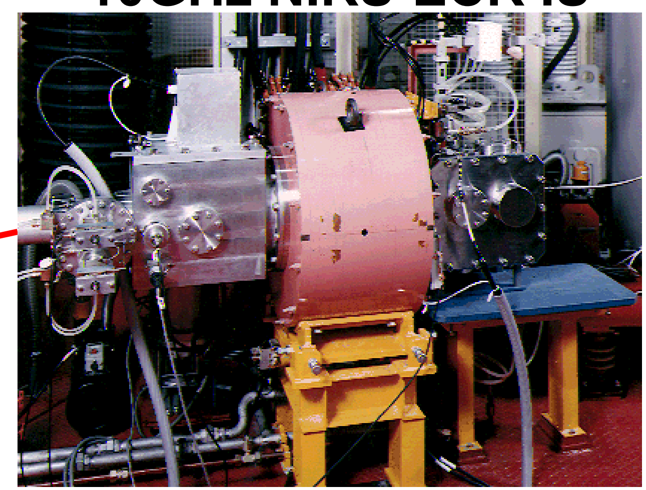


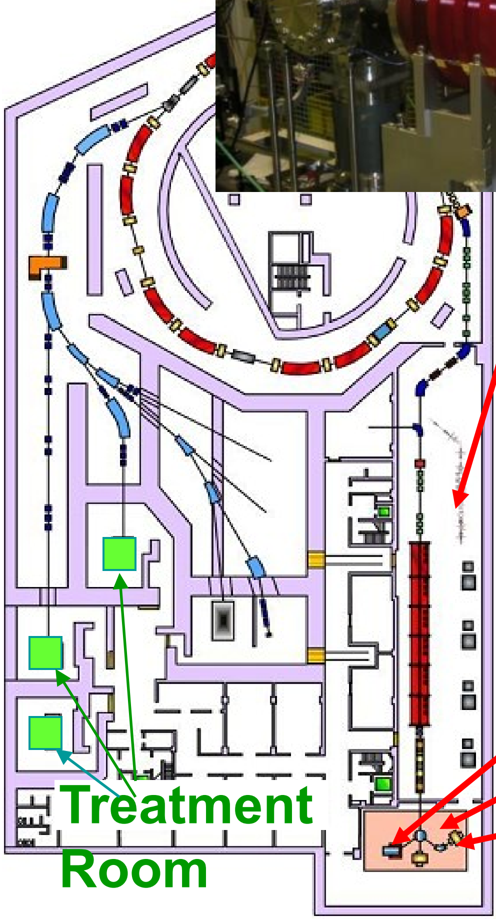
NIRS-PIG IS



18GHz NIRS-HEC ECRIS

10GHz NIRS-ECR IS





Requirements at HIMAC

1. Daily treatment

   HIMAC is dedicated to heavy ion radiotherapy.

   The production of carbon ion is the most important role for ion sources.

Roles of each ion source:

- Production of carbon ions for daily treatment

  > 10GHz NIRS-ECR

  > Kei-2 (starting 2011)

Requirements at HIMAC

2. Facility for research users

In addition, it has as a second essential task to operate as a facility for research uses. The extension of the range of ion species is also an important subject.

Roles of each ion source:

■Lighter metallic ions

> NIRS-PIG

–Spattering method for metallic material like Mg, B, … gasses with gas-mixing

■Lighter gaseous ions

> 10GHz NIRS-ECR

■Heavier ions

> 18GHz NIRS-HEC

–Gas feeding system for toxic gas (XClx, etc…)

–MIVOC method with temperature control system

–Other metal evaporation methods under development

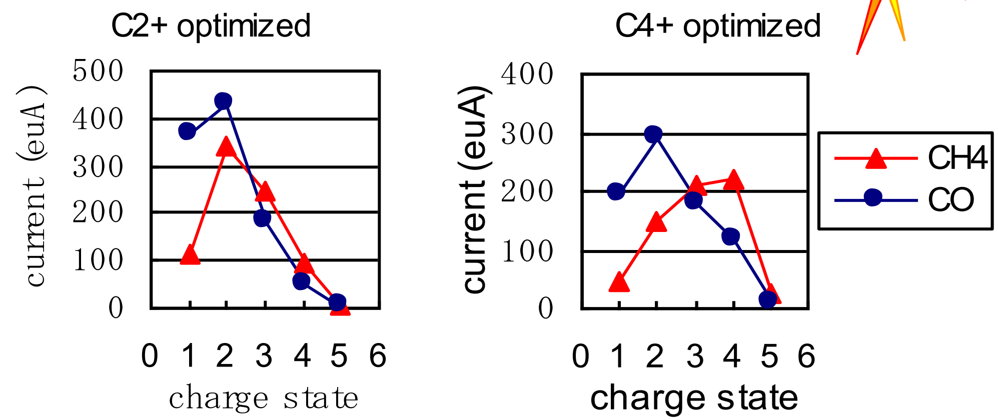
Difficulty for carbon ion production

- Gas mixing

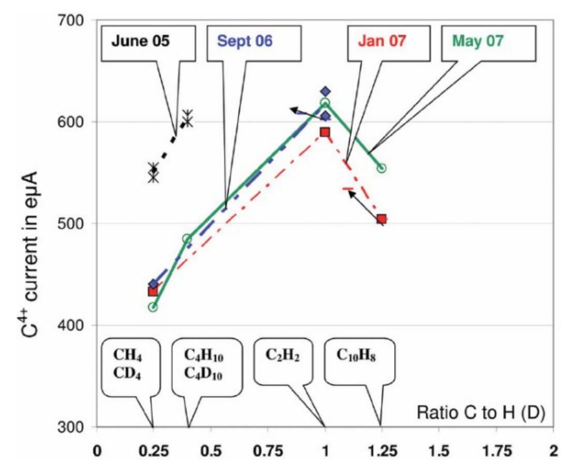
  In order to increase C^{4+} intensity, it's effective to feed hydro-carbonic C_xH_y gases.

  Experiments show: Carbon-hydrogen gases are the best. Gas mixing studies: C_2H_2 and C_4H_{10} are the best.

- In this case, the deposition of carbon on the wall surface causes serious effects.



1st observation of C_xH_y gas mixing effect at NIRS-ECR A. Kitagawa et al., Rev. Sci. Instrum. 71, 1061 (2000).



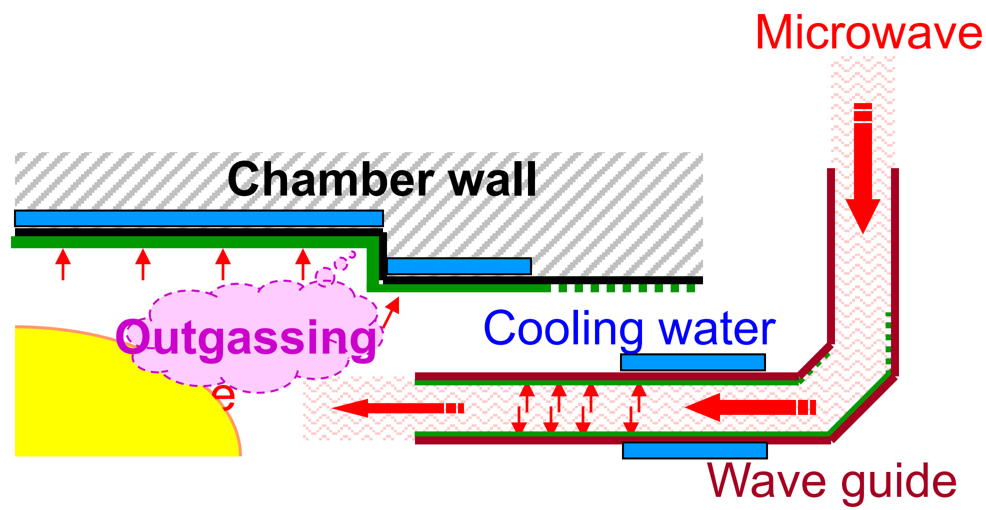
Experiences of gaseous compounds with different ratios of C to H.

A.G. Drentje, et al., IEEE Trans. Plasma Sci., Vol.36, No.4, 1502 (2008).

Harmful effect on the microwave feeding

Problem:

- Carbon production gives unavoidable depositions on surfaces
- More absorption of microwaves on the wall
- Lower microwave into the plasma
- To compensate the microwave power, but,
  - Higher total microwave power
  - Higher absorption
  - Higher wall temperature
  - Increasing outgassing from walls
- **As a result, decreasing reproducibility**

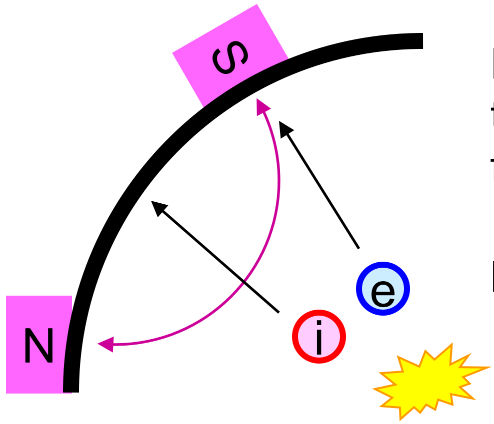


Solution:

- Improve the water cooling for
  - plasma chamber
  - puller
  - Waveguide
- Utilize pulsed operation

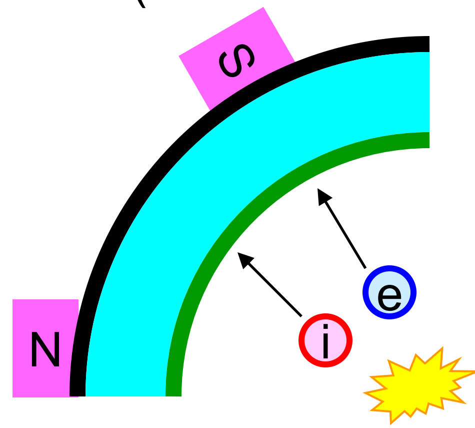
Decreasing of highly charged ions

A) Normal metallic wall



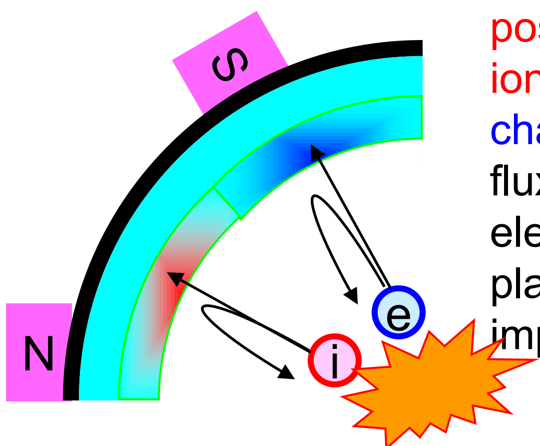
Electrons mainly escape toward to the magnetic field line.
Ions also escape to the perpendicular direction.

C) Carbon deposition (Adverse wall coating effect)



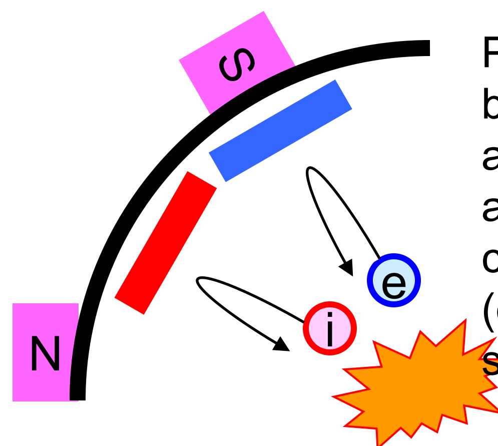
Carbon deposition on the wall prevents the form of potentials, thus the improvement is disappeared.

B) Dielectric wall (wall coating effect)



Positive and negative potential formed by positive charge-up of ion's and negative charge-up of electron's flux repel ions and electrons, thus the plasma confinement is improved.

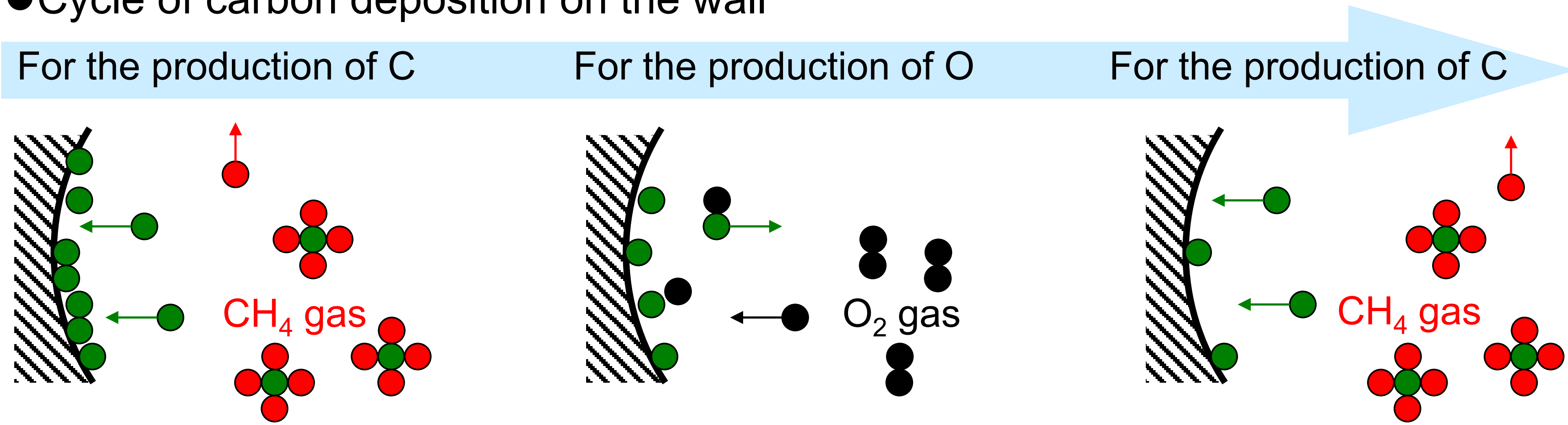
D) Multi biased electrode (against adverse wall coating electrode)



Positive and negative biased electrodes always repel electrons and ions even under the carbon deposition. (experimentally not yet shown)

Varying of the wall condition

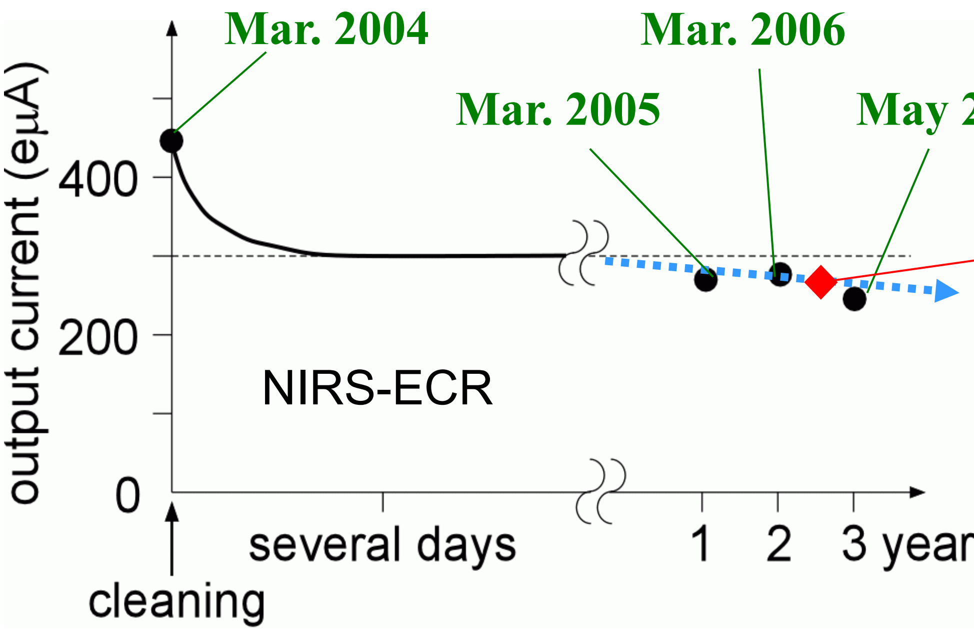
● Cycle of carbon deposition on the wall



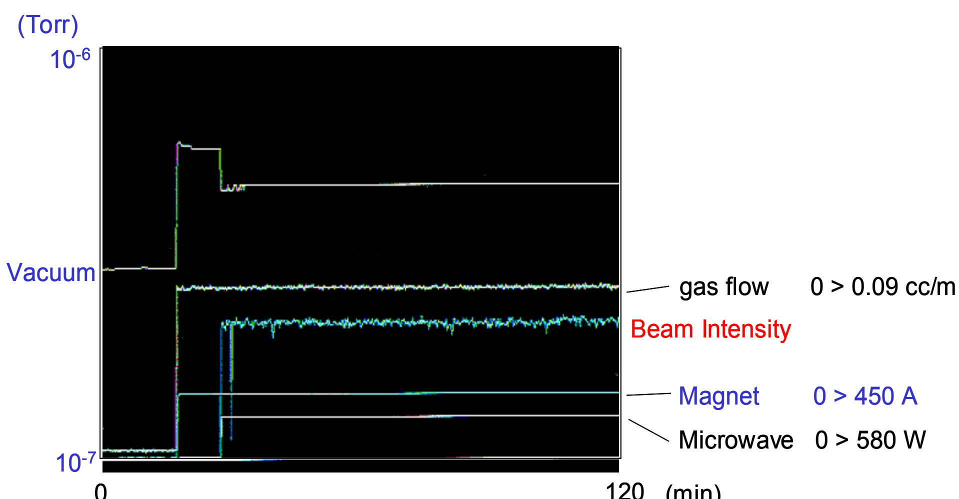
- Varying of amount of carbon deposition on the wall
  -> gives instability & bad reproducibility

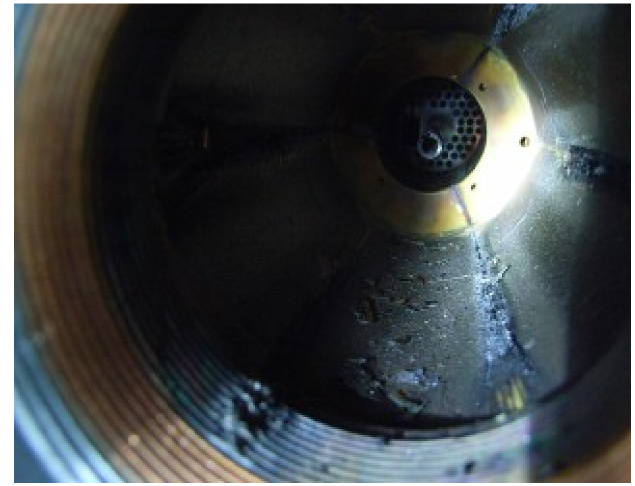
- Prevent change of gasses

Maintenance-free ion source



Variation in the beam intensity after starting the ECRIS





Mar. 2007

A. Kitagawa *et al.*, Rev. Sci. Instrum. **79**, 02C303 (2008).

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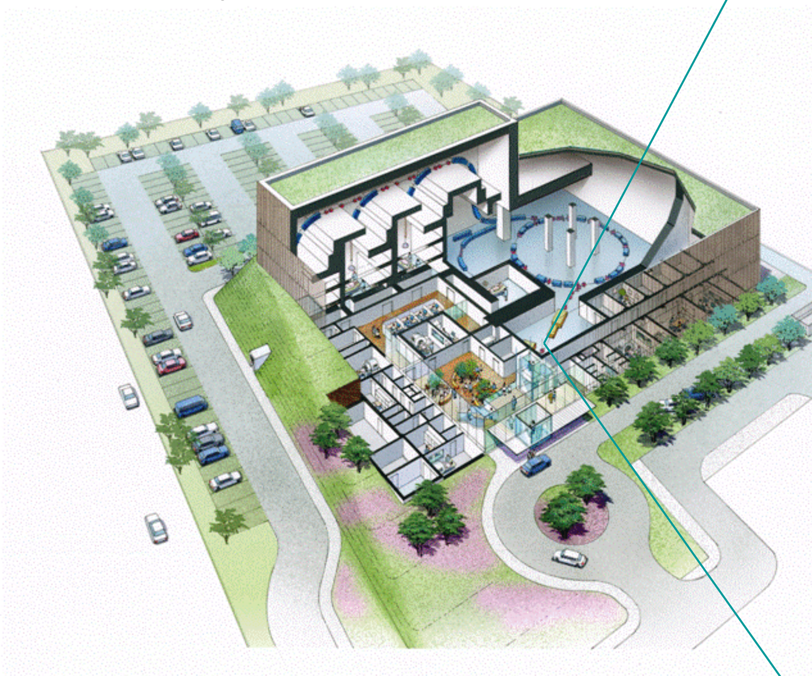
ECRIS for the new radiotherapy facility

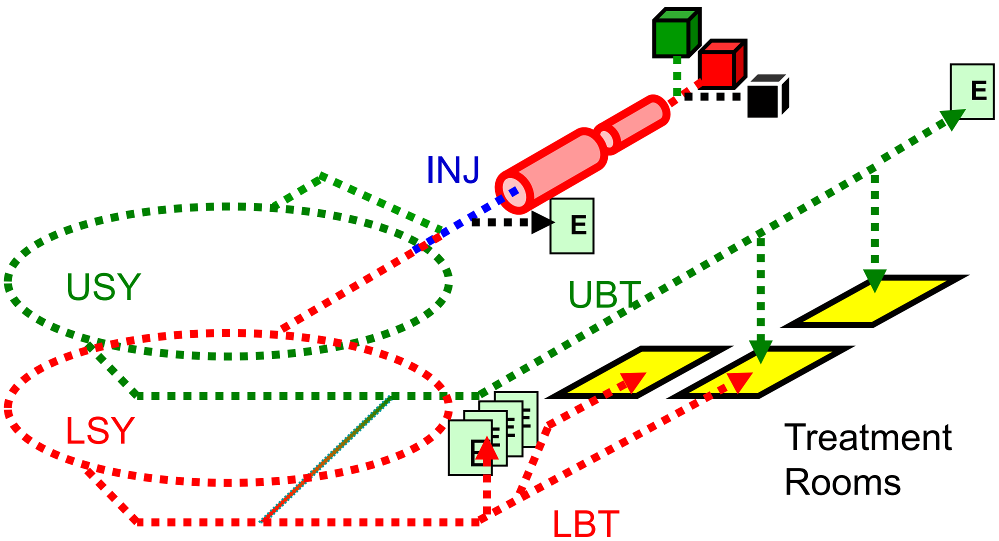
Gunma University
3rd facility in operation in Japan



See **MOPOT01** “Operation of KeiGM for the carbon ion therapy facility at Gunma University” by M. Muramatsu et al.

Typical operation schedule

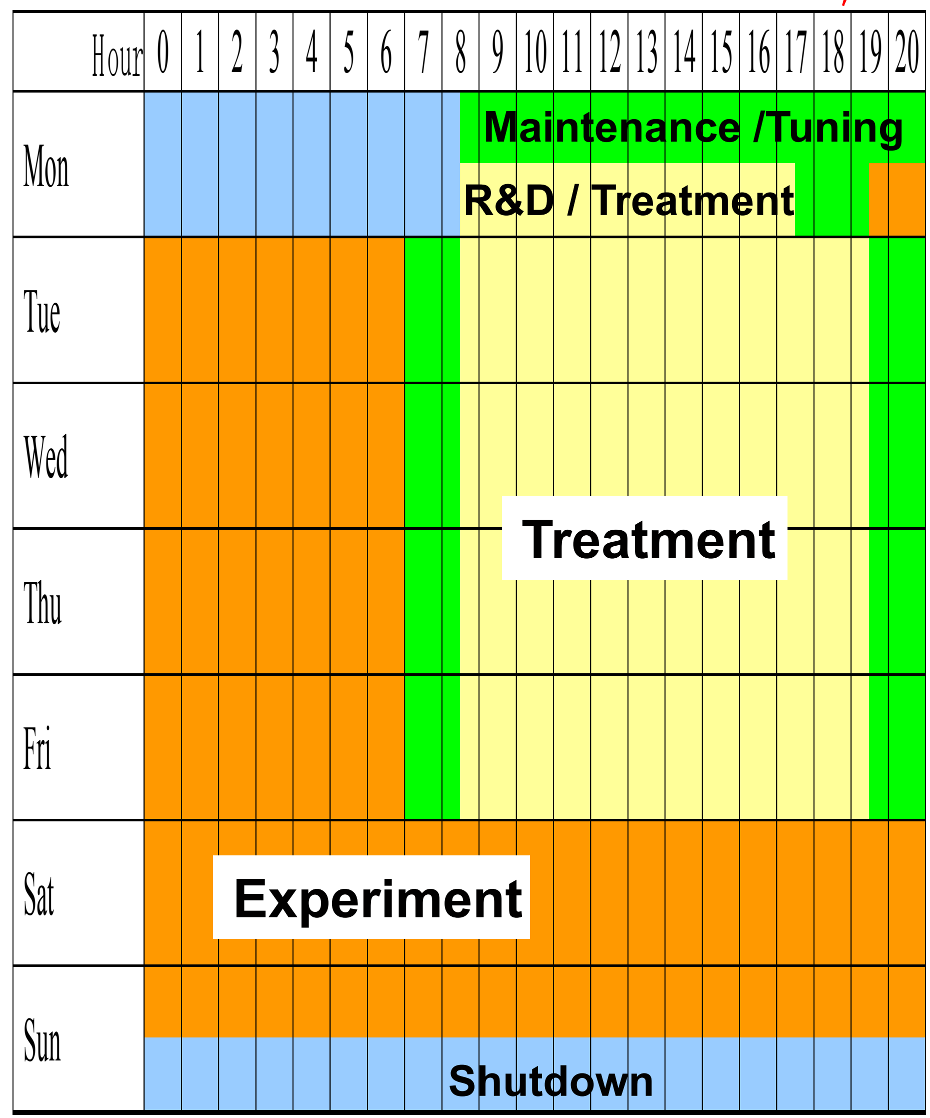
Schematic diagram of HIMAC



HIMAC can provide individual beams for three different users at the same time from three ion sources for experiments.
(However the parallel experiment is forbidden in the treatment time.)

-> Extension of the range of ion species

Weekly schedule



Scope for developments

Points of developments

- No ion source specialist is required for tuning.
- Ion sources are almost occupied for the daily operation
  -> short development time is only available.
- With the present ion sources' structure the required reproducibility and stability is fulfilled. New developments are in a way disturbing the situation.
- For developments one has to cope with 'dirty' plasmas and many contaminations in the available sources.

Improvement of CSD for heavier ions

Historical trials (succeeded)

1. Optimization of the extraction configuration[2-7,9]
2. Gas mixing [6,12,13]

Present priority

3. Two-frequency heating[6,7,14]
4. Biased electrodes[1,3,5,6,11]

Supplying of various ions

Present priority

1. MIVOC[9,15]

Future developments

2. IH oven
3. Electron bombardment for high temperature [8]

[1]Rev.Sci.Instrum.**65**,1087(1994).
[2]Rev.Sci.Instrum.**65**,1437(1994).
[3]Proc.12thECRIS,INS-J-182,259(1995).
[4]Rev.Sci.Instrum.**69**,674(1998).
[5]Proc.14thECRIS,CERN, 23(1999).
[6]Rev.Sci.Instrum.**71**, 1061(2000).
[7]Proc.EPAC, Wien, 1607(2000).
[8]Rev.Sci.Instrum.**73**, 545(2002).
[9]Rev.Sci.Instrum.**73**, 604(2002).
[10]Proc.15thECRIS, Jyvaaskylaa, 70(2002).
[11]Rev.Sci.Instrum.**75**, 1399(2004).
[12]Rev.Sci.Instrum.**75**, 1476(2004).
[13]Rev.Sci.Instrum.**77**, 03B701(2006).
[14]Proc.18thECRIS, Chicago, 92(2008).
[15]Rev.Sci.Instrum.**81**, 02A329(2010).

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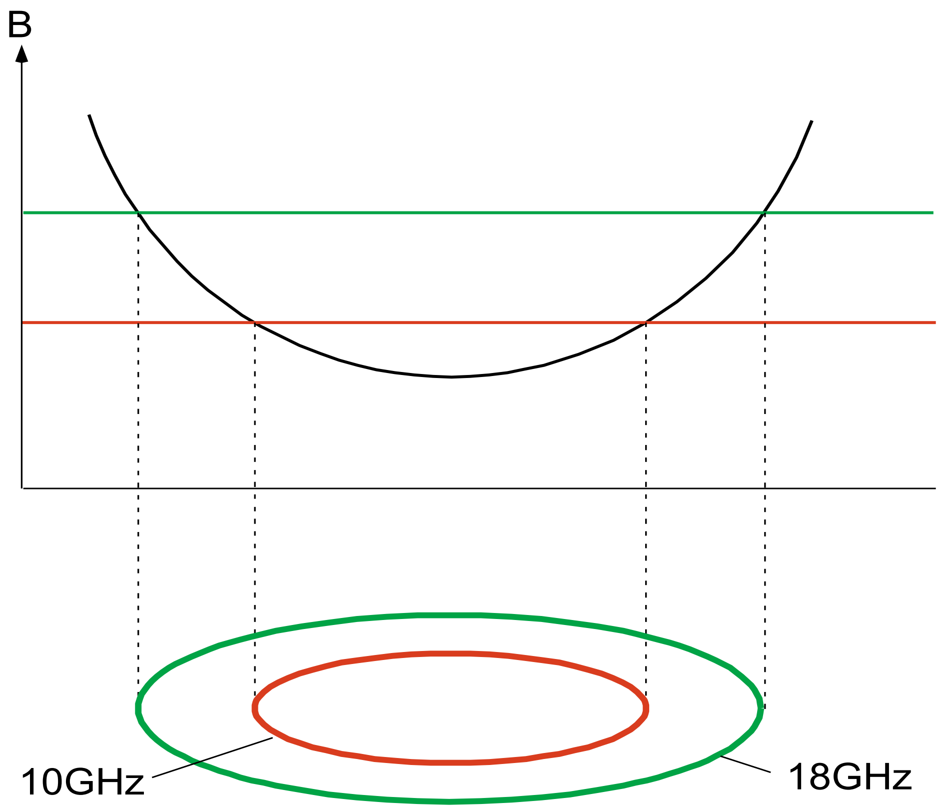
Original idea on two frequency heating

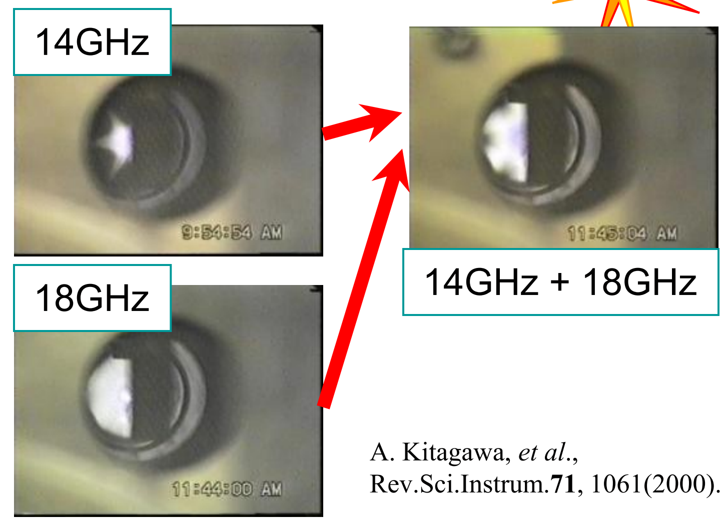


- The relation between the volume of the ECR region and the source performance has not been verified.
- However, several reports pointed out the possibility of improvement by increasing the amount of the ECR region, i.e., 2ω mode, volume ECR, two-frequency heating, and so on.
- We have also tested the two-frequency heating. It was expected that two different frequency microwaves are absorbed at each resonance regions in the minimum B structure of the magnetic plasma confinement.

Conclusion from former experimental results

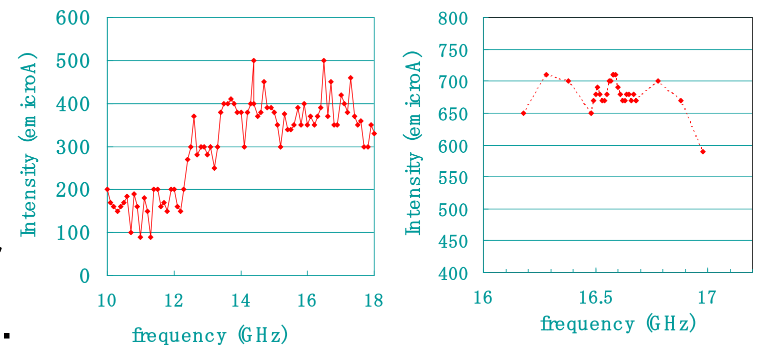
We obtained experimental results:

1. **Discrete fixed frequencies with high power**
   - By 14GHz Hyper ECR at INS with additional 10GHz or 18GHz.
   - Klystron amplifiers (KLY) were utilized (max. power was over 1kW).
   - ➢ Result suggested that microwave power of the order of 2kW was necessary.



A. Kitagawa, *et al.*, Rev.Sci.Instrum.**71**, 1061(2000).

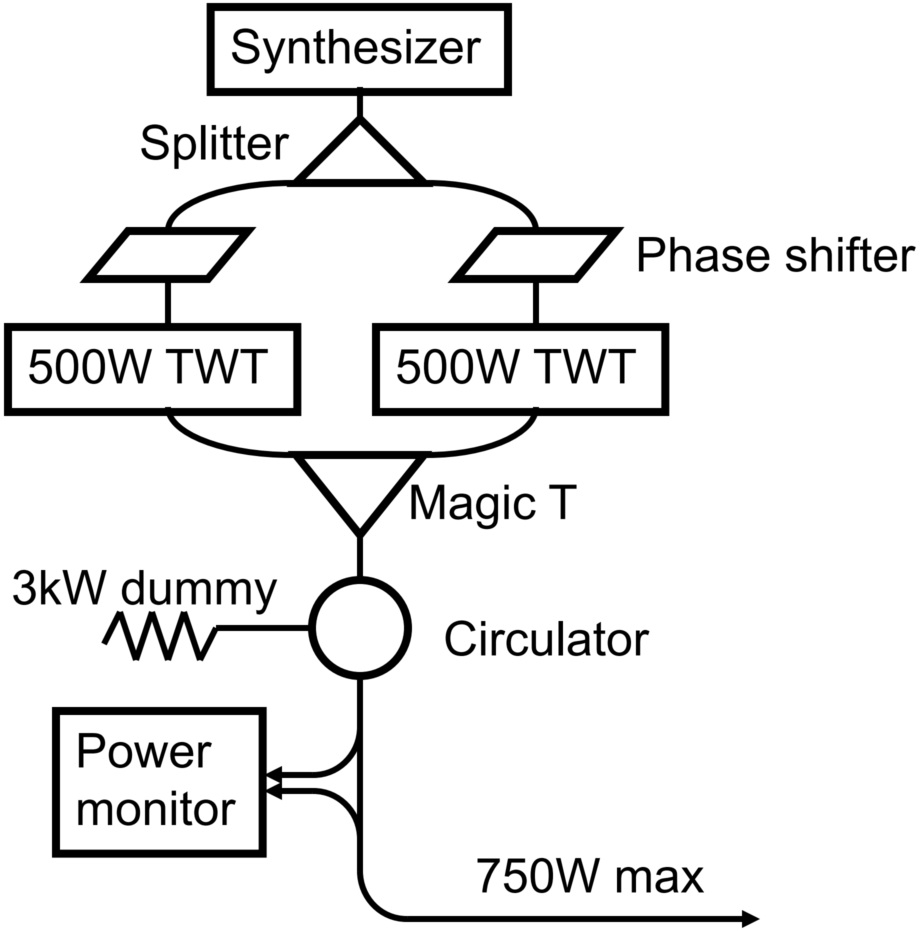
2. **Precise frequency control with small power**
   - 18GHz NIRS-HEC with additional 10-18GHz.
   - KLY for 18GHz (max. power was over 1kW) and Traveling Wave Tube amplifier (TWT) for 10-18GHz (max. power was less than 250W).
   - ➢ Result suggested precise frequency control was necessary.

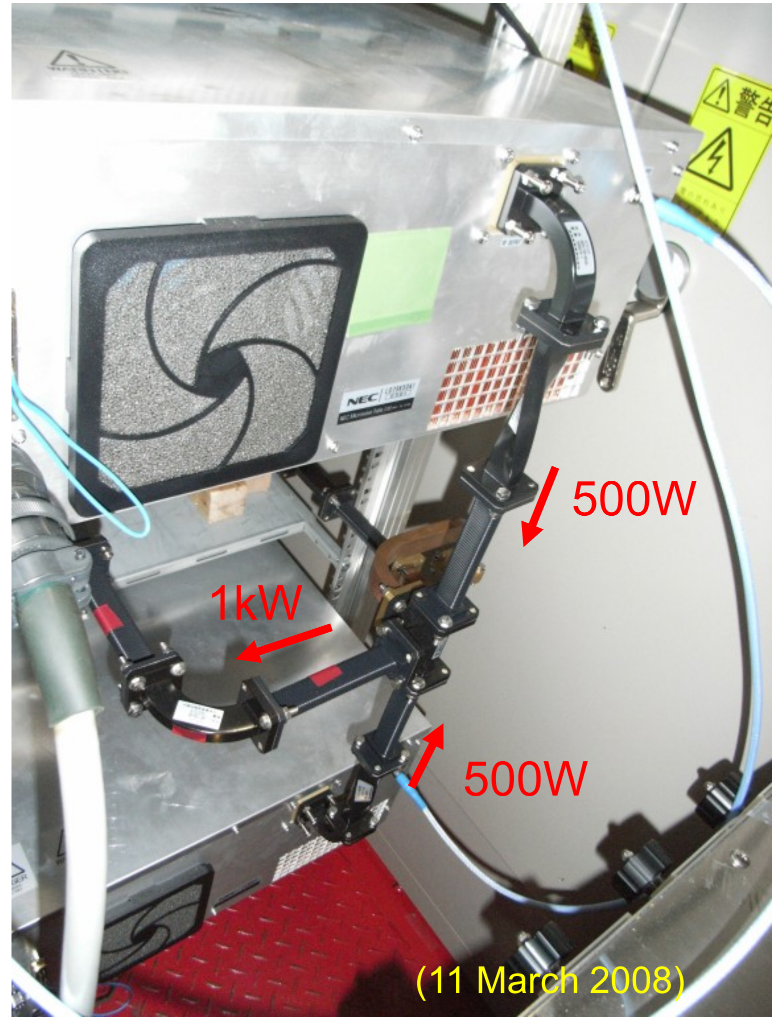


A. Kitagawa, *et al.*, Proc.EPAC, Wien, 1607(2000).

=> Question: How about enough power with precise frequency control?

The additional TWT microwave system





Frequency band width: 17.75 – 18.25 GHz

Maximum power: 750 W

(It's question the additional frequency is too close to the main frequency 18.0GHz?)

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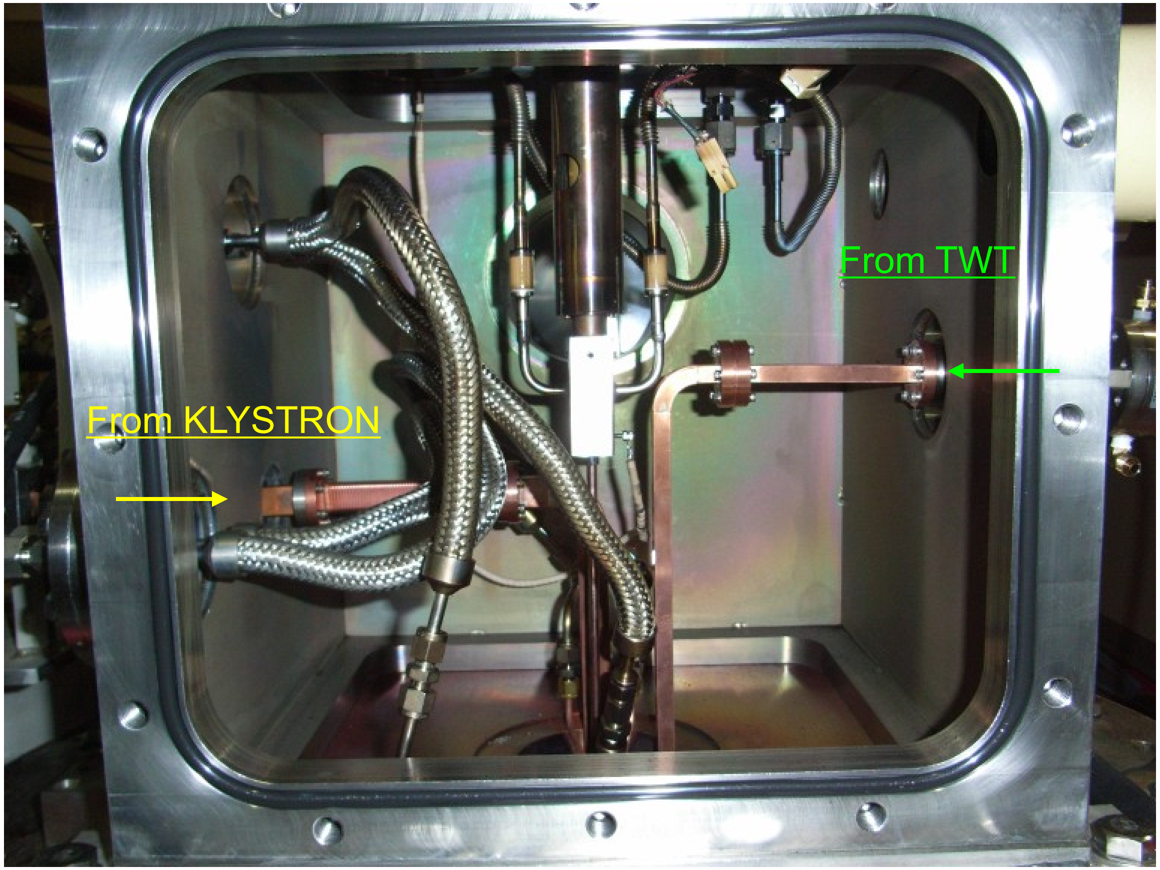
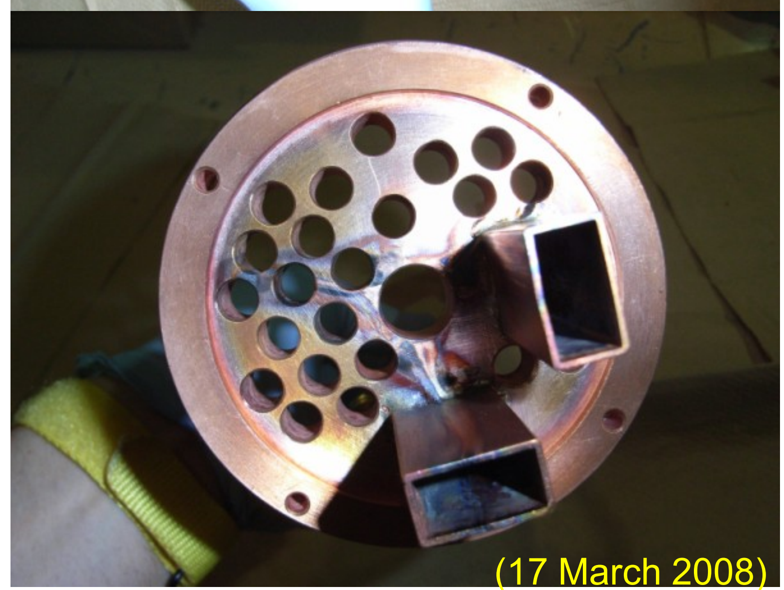
Setup of waveguides in vacuum chamber





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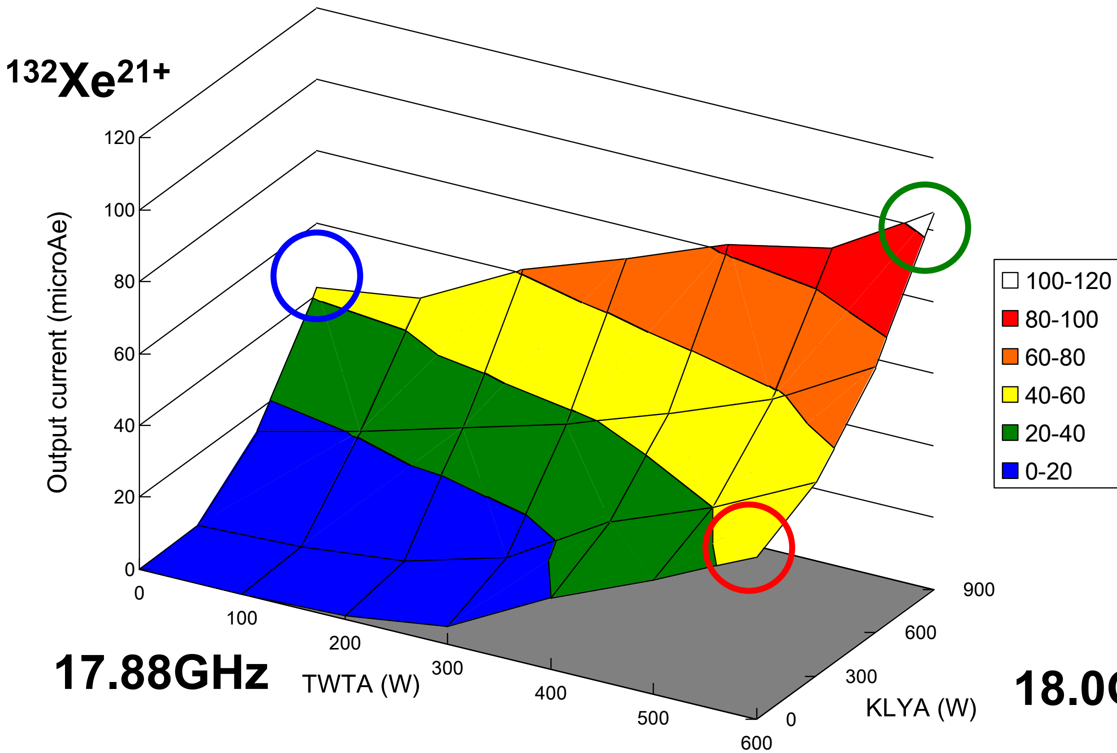
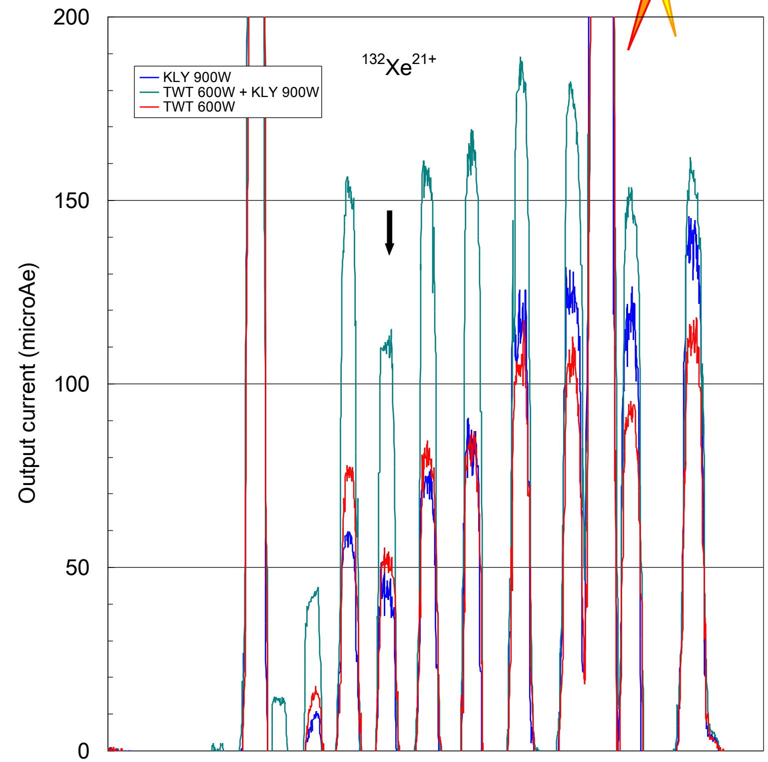
Calibration of microwave power from each amplifiers



17.88GHz

18.0GHz



- The intensity mainly depended on the total power, not on the balance of two frequencies.
- 900W by KLY has the same effect as 600W by TWT.

    -> Transmission efficiency from KLY is likely about 2/3 of TWT.
- The effect appears to be most important on the higher charge states, therefore further study needed.

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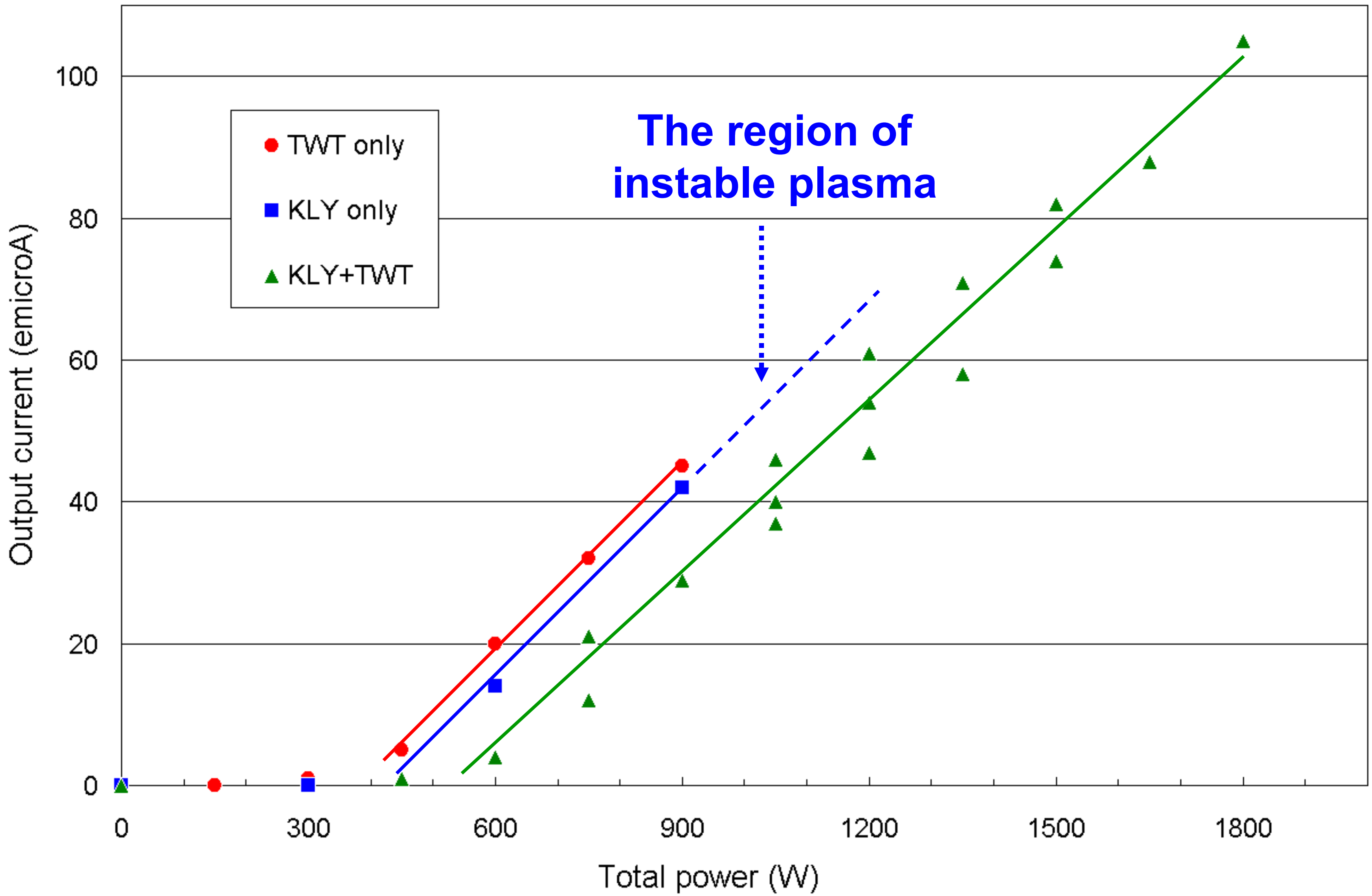
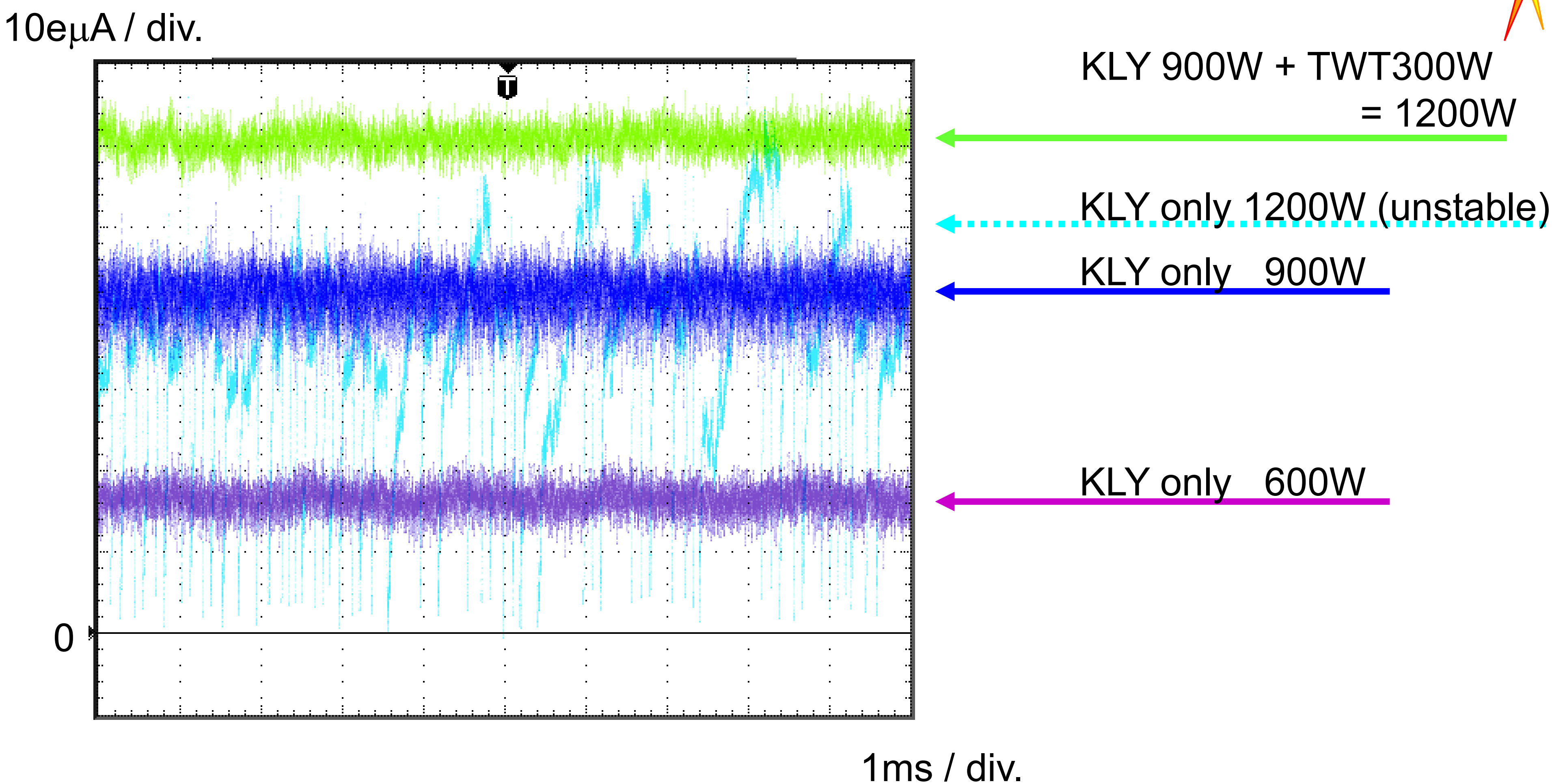
Dependence on total microwave power



Limitation of microwave power for instability



Conclusion:

•It seems two frequency heating is reducing the plasma instability.

Principle

Metal Ions from Volatile Compound method MIVOC is the method of obtaining vapors from the volatile compounds including the requested elements.

- Merit

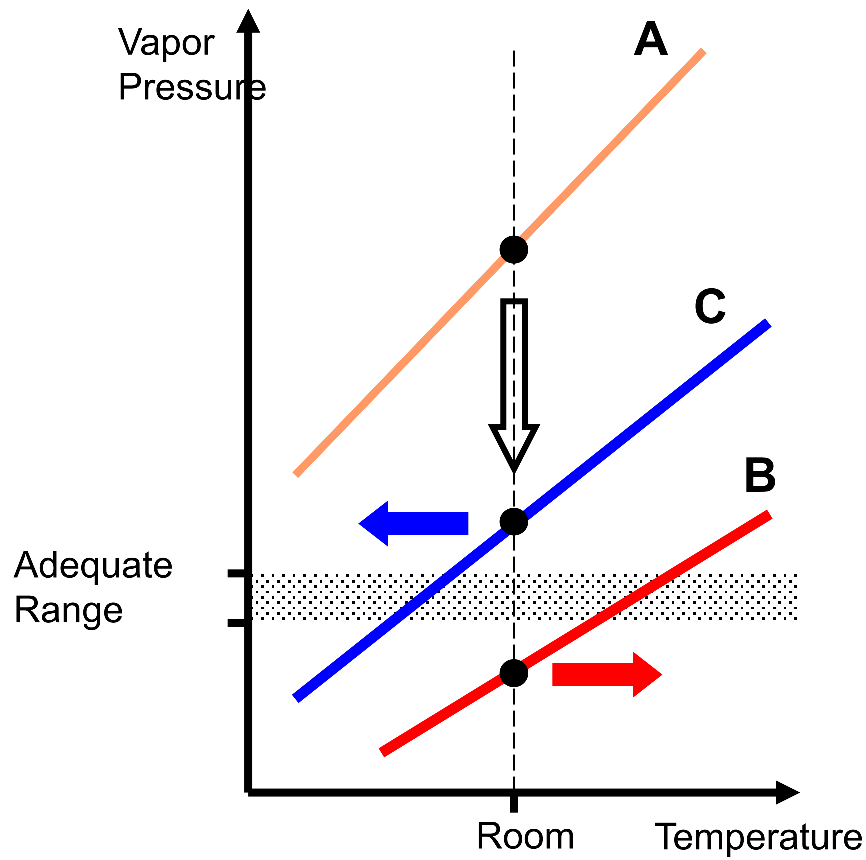
1. The material consumption rate is very low.
2. The equipment is small and easy.
3. The ion species can be changed without exposing the vacuum chamber to atmosphere.

- Weak point

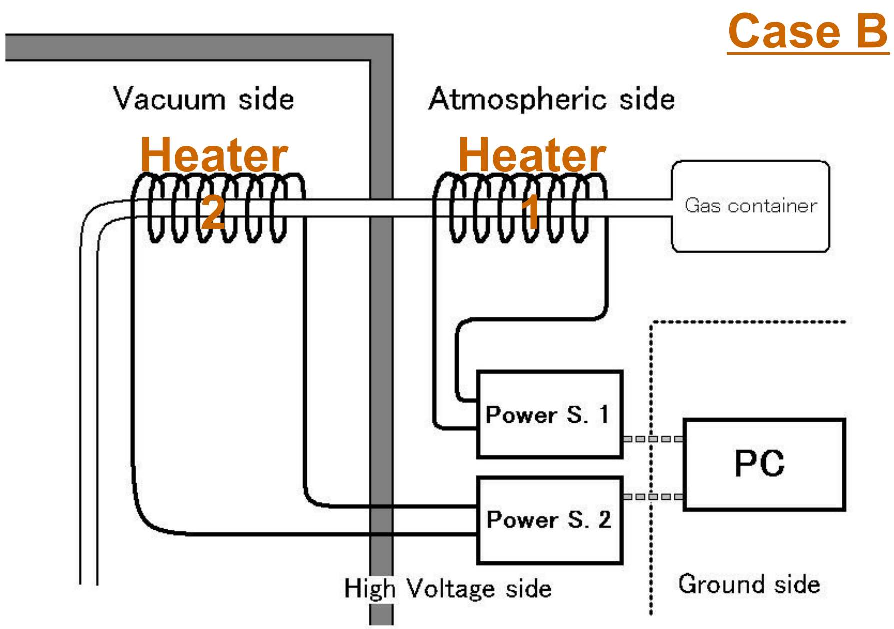
1. Signal-Noise ratio is bad.
2. The inside of ion source becomes dirty.
3. It is often difficult to find a compound with an appropriate vapor pressure.

We have solved the third problem by using a temperature control system

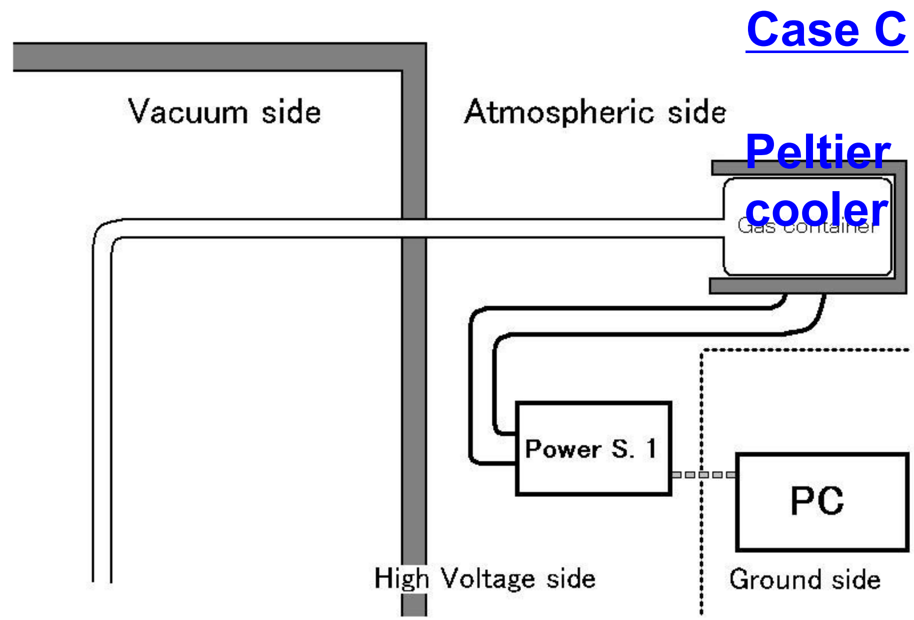
Schematic diagram of the gas-flow control



Description of device



Case B) Block diagram of the heating MIVOC system.



Case C) Block diagram of the cooling MIVOC system

Results

Ion	Compound	Output current (eμA)	Vapor pressure at 300K (Pa)	Case
$^{56}Fe^{9+}$	$Fe(C_5H_5)_2$	400	1.3	B
$^{57}Fe^{9+}$	$Fe(C_5H_5)_2$	50	1.3	B
$^{58}Fe^{9+}$	$Fe(C_5H_5)_2$	220	1.3	B
$^{59}Co^{9+}$	$Co[C_5H_4(CH_3)]_2$	210	5.3	C
$^{24}Mg^{5+}$	$Mg(C_5H_5)_2$	150	6.7	C
$^{48}Ti^{10+}$	$TiCl_4$	50	1.7k	A (with Heating)
$^{28}Si^{5+}$	$SiCl_4$	60	27k	A
$^{28}Si^{5+}$	$Si(CH_3)_4$	250	100k	A
$^{74}Ge^{12+}$	$Ge(CH_3)_2H_2$	42	100k	A

- It is now possible to select a wide-range of materials with a too high or low vapor pressure at room temperature.
- The consumption rate can be decreased for ‘expensive’ material or low quantities.

Summary

Carbon-ion production:

- Although the carbon depositions on the surface of all parts is unavoidable, the improvement of cooling system gave good stability and reproducibility.
- An almost maintenance free ion source for carbon ion radiotherapy has been developed.

Two frequency heating:

- Two frequency heating is reducing the plasma instability, so that the microwave power can be increased.
- The effect is mainly depending on the total power.

MIVOC method with temperature control:

- It is possible to select from a substantial wider range of materials.
- The consumption rate can be decreased for specific applications.