Dongnam Institute of Radiological & Medical Sciences
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Status of the DIRAMS C-band standing-wave accelerator for a radiotherapy machine

9th ASIA FORUM FOR ACCELERATORS AND DETECTORS
Daejeon Convention Center, 2018 Jan. 28-31,

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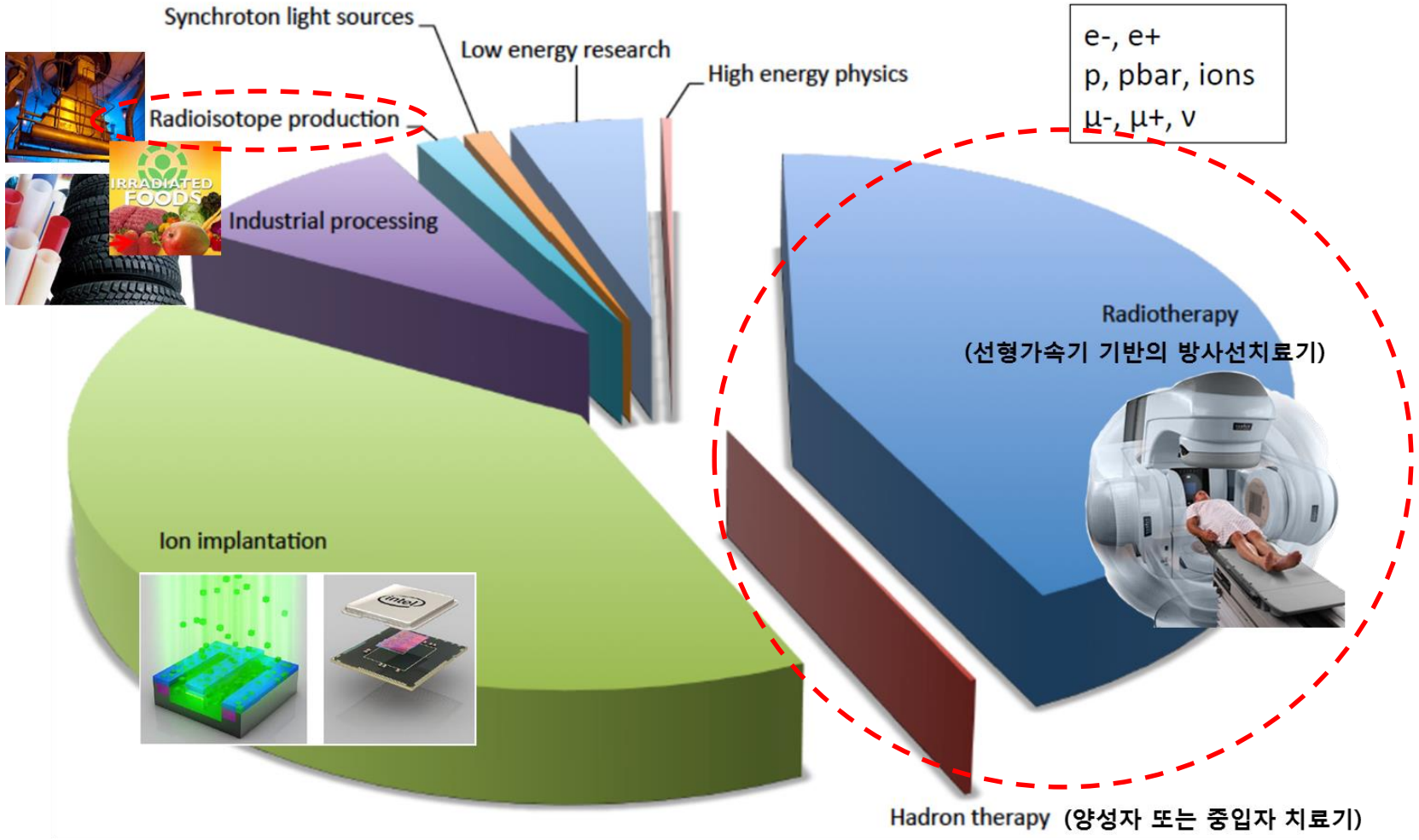
동남권 Dongnam Institute of Radiological & Medical Sciences
원자력의학원

Contents

30,000 Accelerators in worldwide

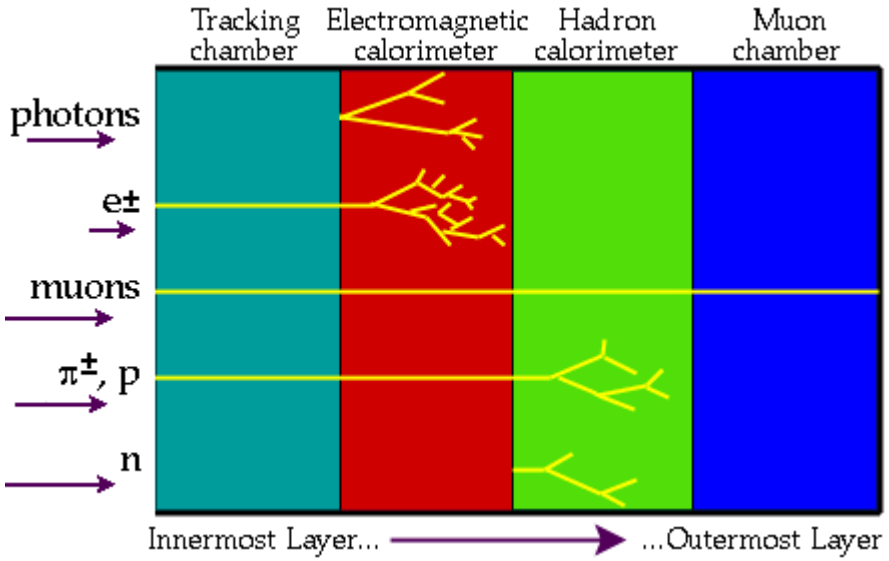
Picture from CAS2015(Austria), R. Bailey

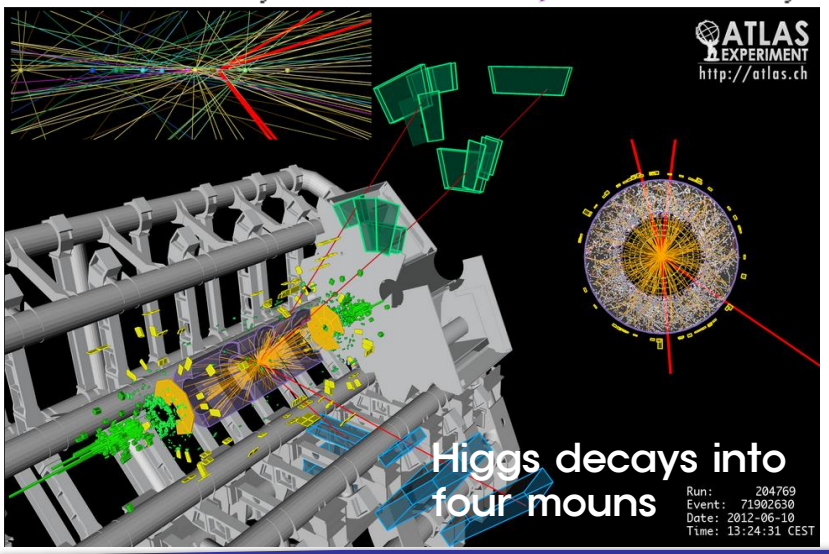


40 % of accelerators are used for the medical purpose!

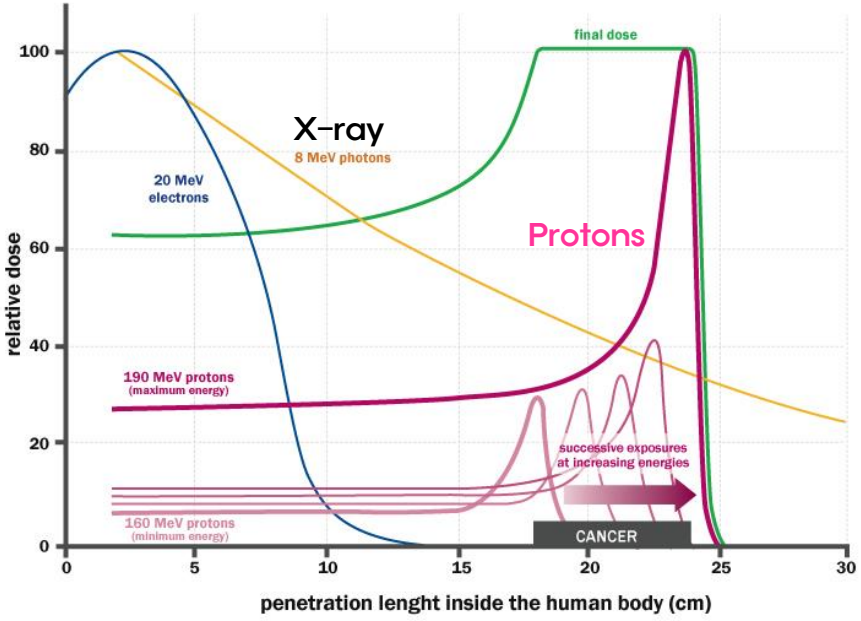
Particle Interactions

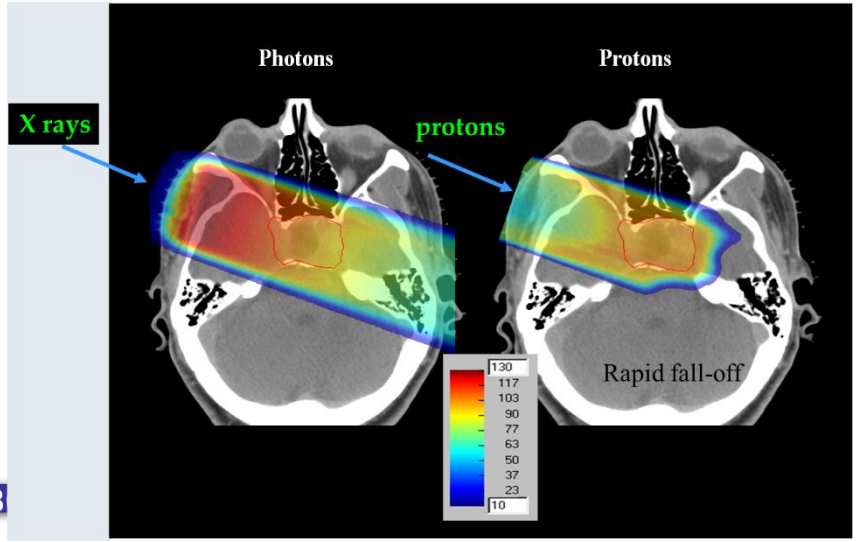
Particle physics application





Medical application





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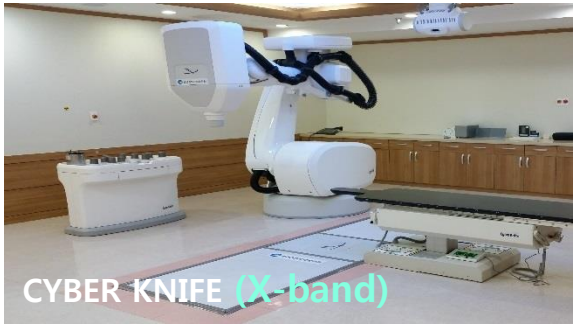
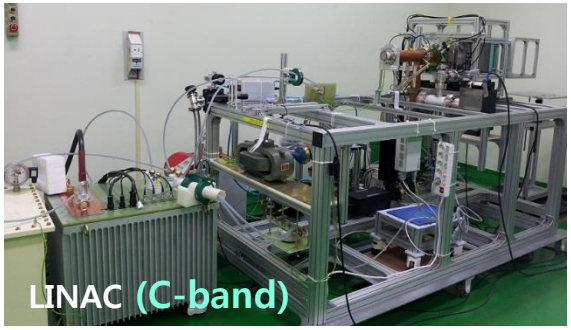
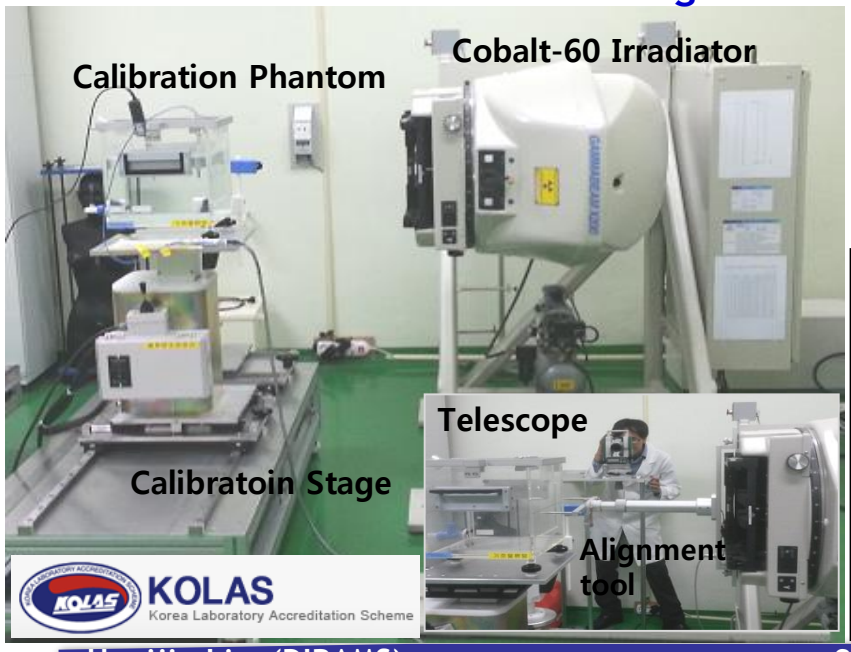
Commercial linac for patients treatment



R&D of linac

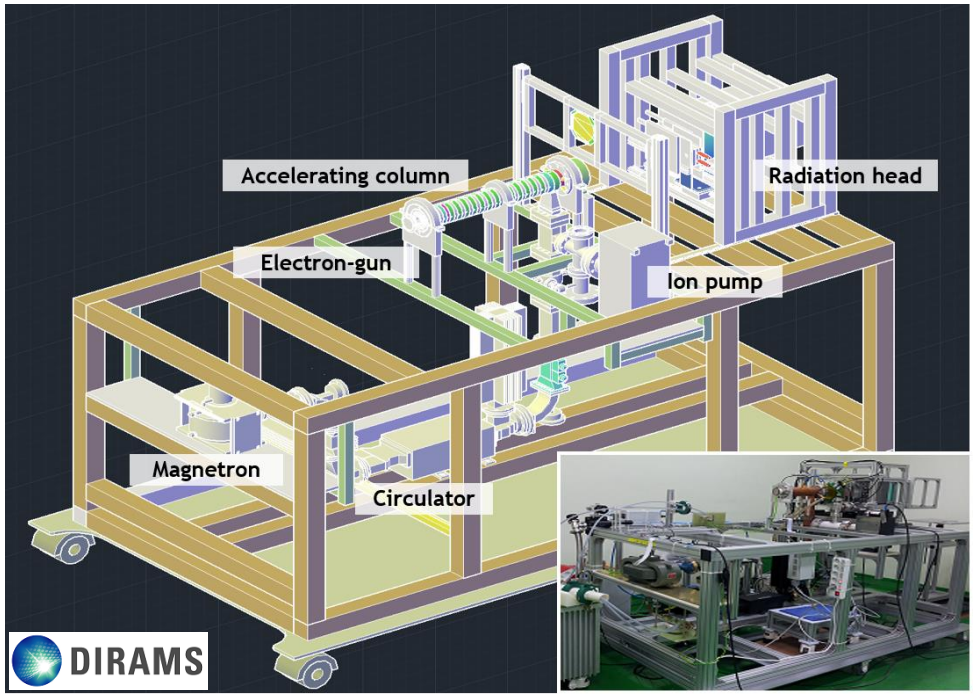


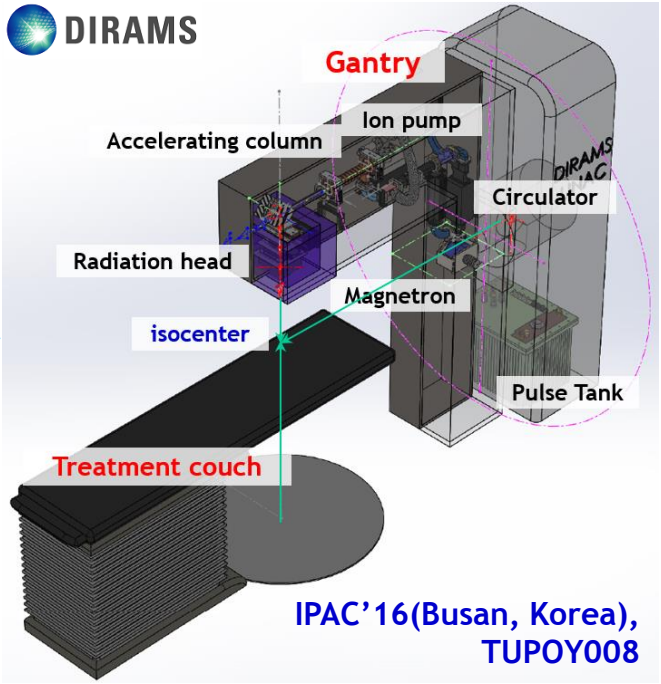
Accreditation KC14-297 : Ionizing Radiation



- **Opening 2010, Jul. 16.**
- Research for medical use of radiation : medical, biotechnology, chemistry, physics, environment etc.
- Providing medical services and radiological emergency response.

Medical Linac R&D @ DIRAMS



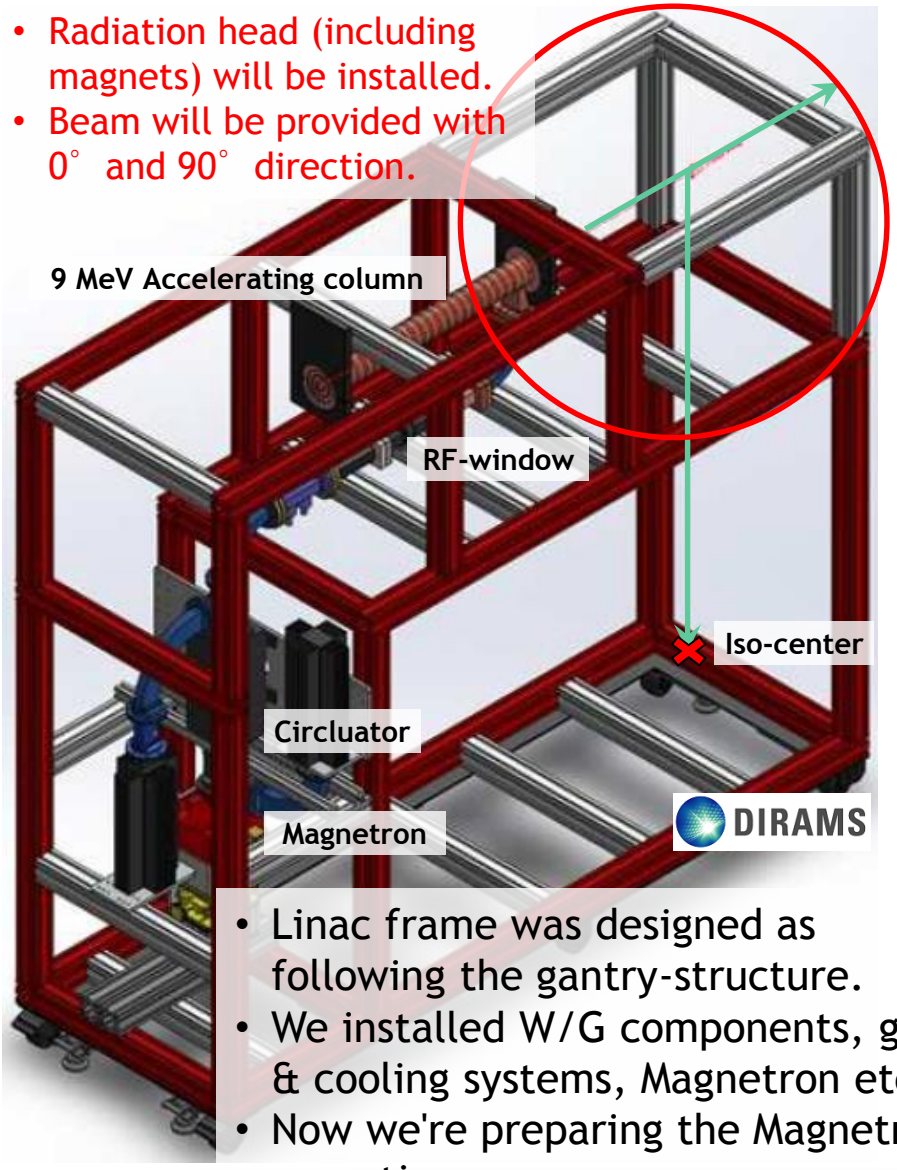


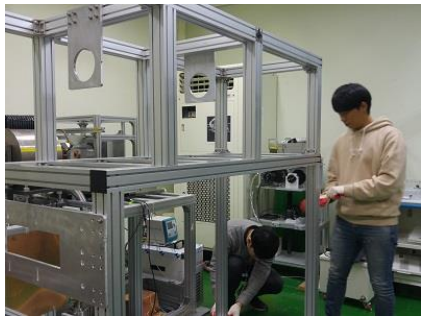
Design and Construction of C-band (5712 MHz) Linac

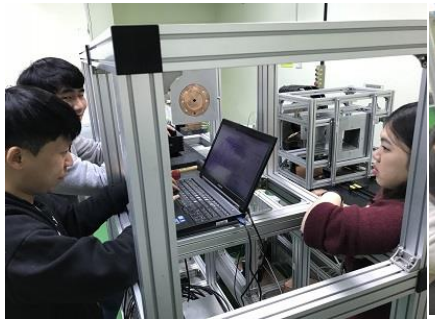
- Bi-periodic & on-axis coupled structure, π/2 mode SW operating.
- Accelerating the electrons up to 6 MeV using 2.5 MW RF power.
- Using the 6 MW pulse modulator which was designed and constructed with the thyratron-switched pulse-forming network.
- We are developing a radiotherapy machine consisting of a gantry, a support stand, a treatment couch, a control console, etc.
- Now we're constructing the 9 MeV linac located in the gantry-like frame.

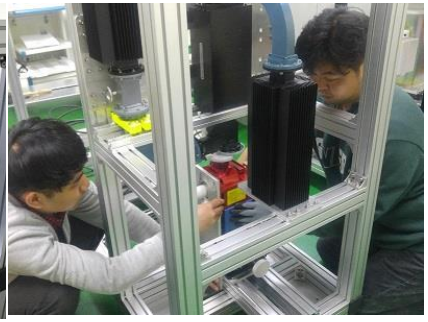
Construction of 9 MeV C-band Linac (2018. Jan. 26)

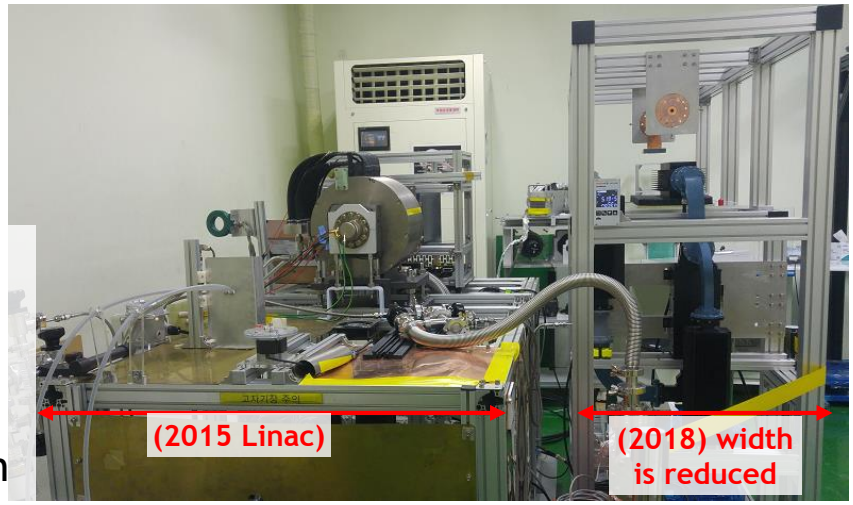
- Radiation head (including magnets) will be installed.
- Beam will be provided with 0° and 90° direction.





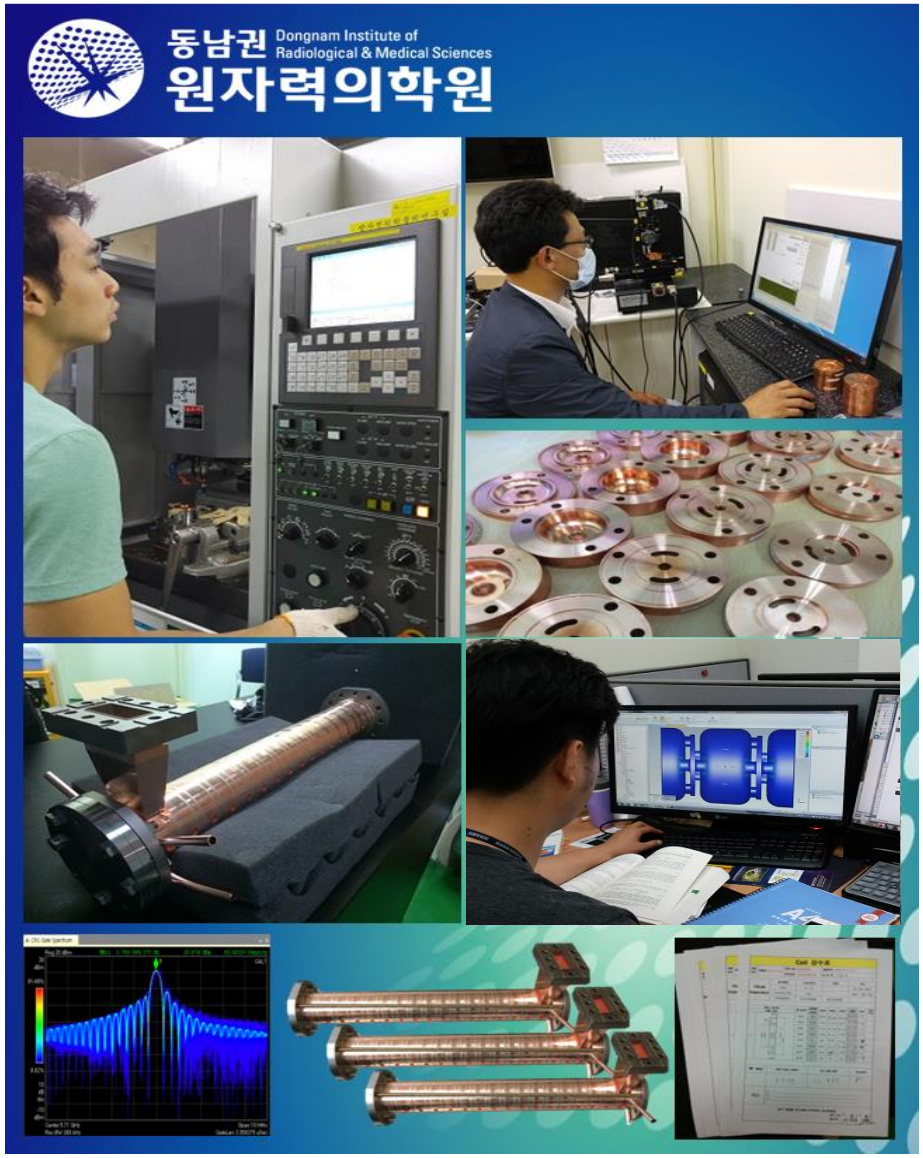


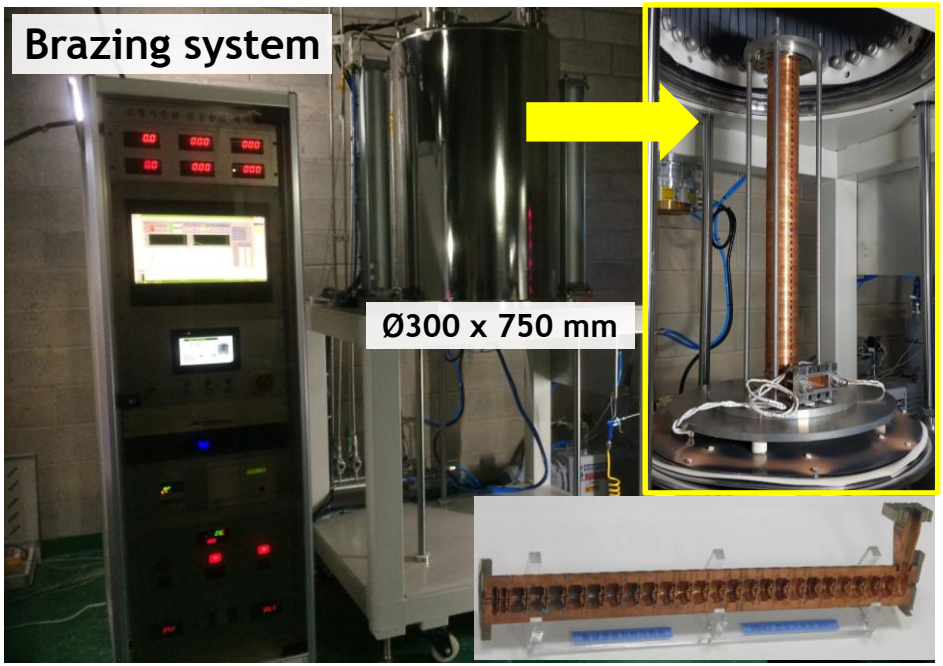


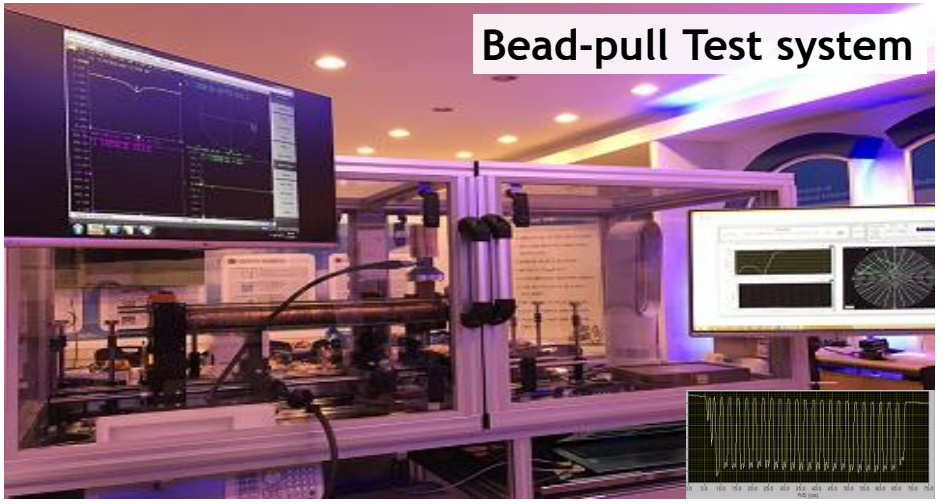


- Linac frame was designed as following the gantry-structure.
- We installed W/G components, gas & cooling systems, Magnetron etc.
- Now we're preparing the Magnetron operation.

Accelerating Column

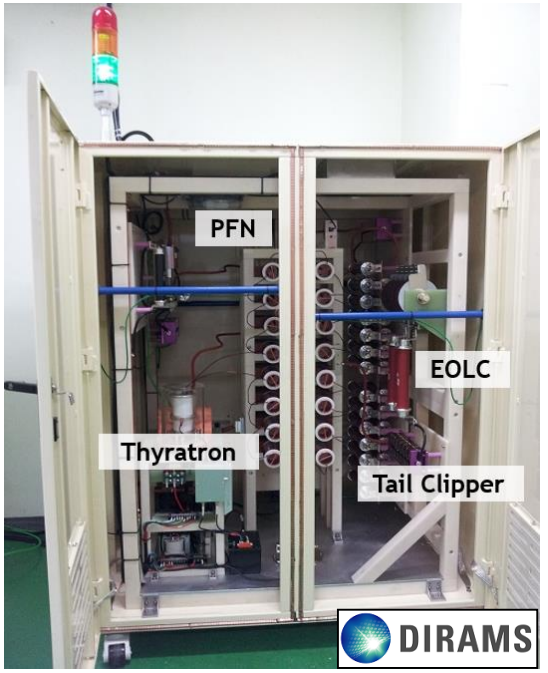


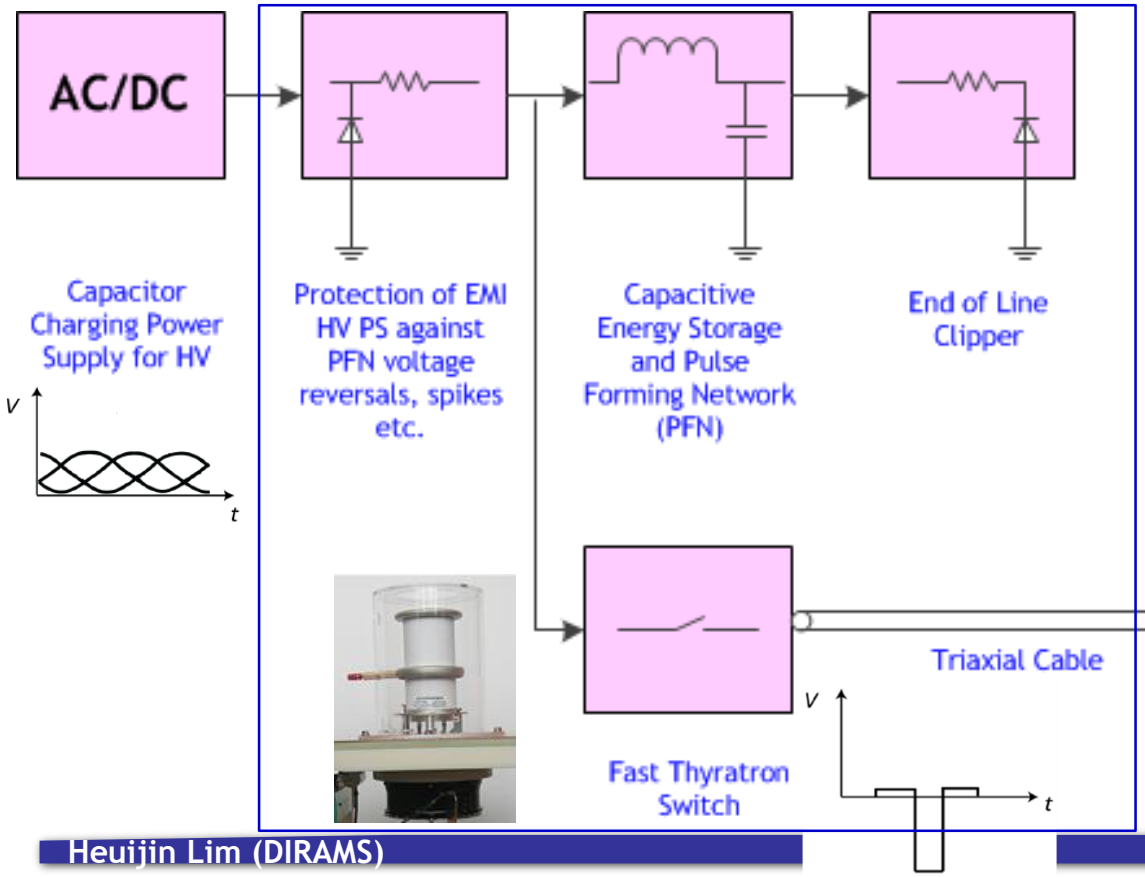




Pulse Modulator

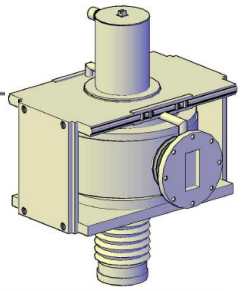
- **6MW** Pulse Modulator (Average ~ 12 kW)
  - ✓ For Magnetron, up to 50 kV & 120 A
  - ✓ For Electron gun, up to 20 kV & 1A
  - ✓ Pulse width ~ 4 us and rate up to 250 Hz
  - ✓ Using thyratron-switched pulse-forming network





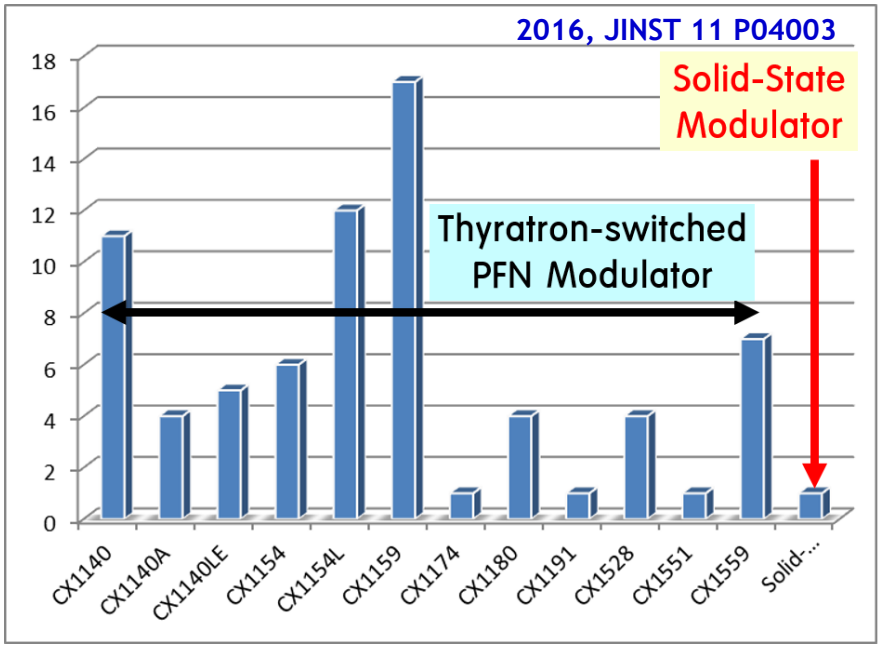
Pulse Transformer

Electron gun



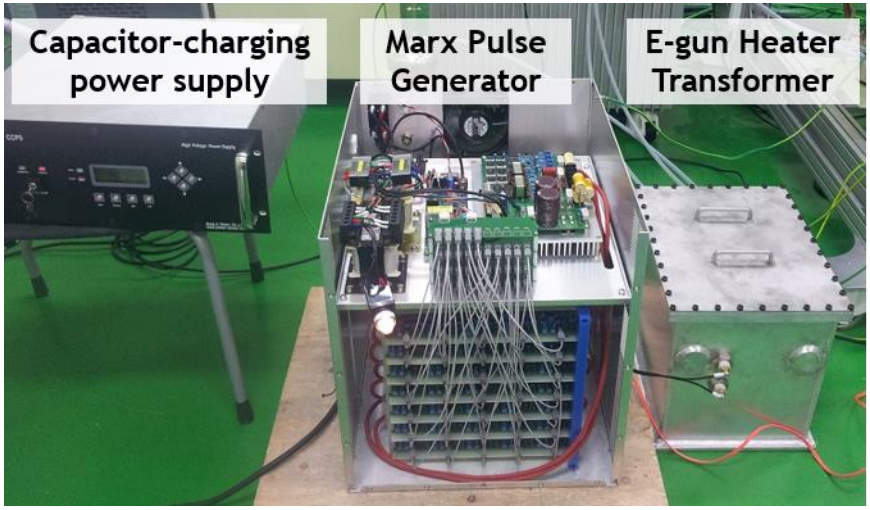
Solid-State Pulse Modulator

For commercial medical linacs



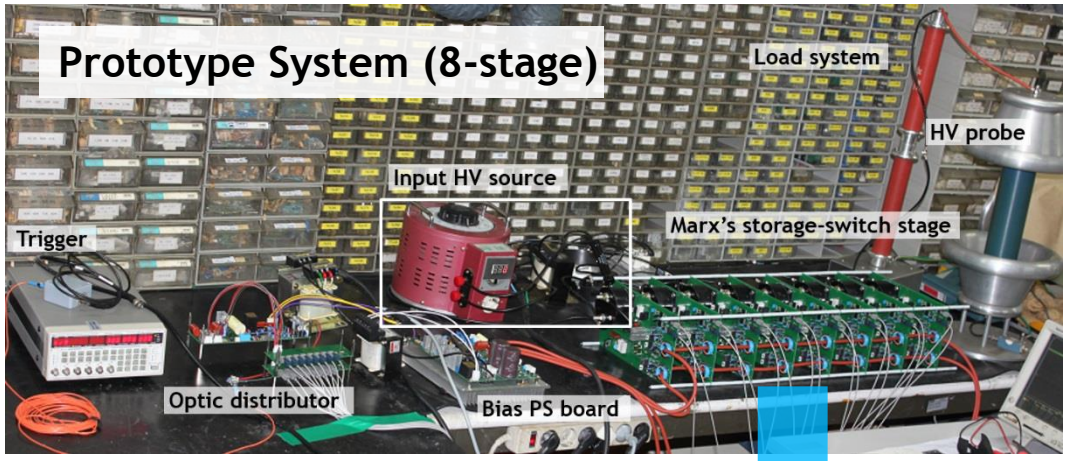
- Medical linacs (from Elekta, Siemens and Varian) are mostly using the thyratron-switched PFN modulator.
- The solid-state modulator is only used in the TomoTherapy® Hi-Art® Treatment System (2013 Jan. data)
- Still not actively using the solid-state modulator.

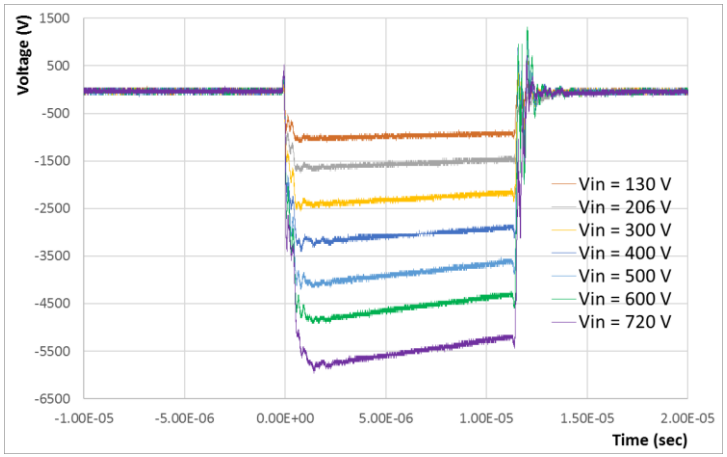
Low power solid-state pulse modulator for a linac electron-gun (2016, JINST 11 P04003)



- Developed the low power solid-state pulse modulator based on the Marx generator.
  - ✓ Operation for a linac electron-gun
  - ✓ Output HV : 5 – 25 kV (P_{peak} = 25 kW)
  - ✓ Repetition Rate : 1 – 300 Hz
  - ✓ Pulse width : 4 – 10 μs
  - ✓ N of Storage-switch stages = 35
- We are now developing the high power pulse modulator.

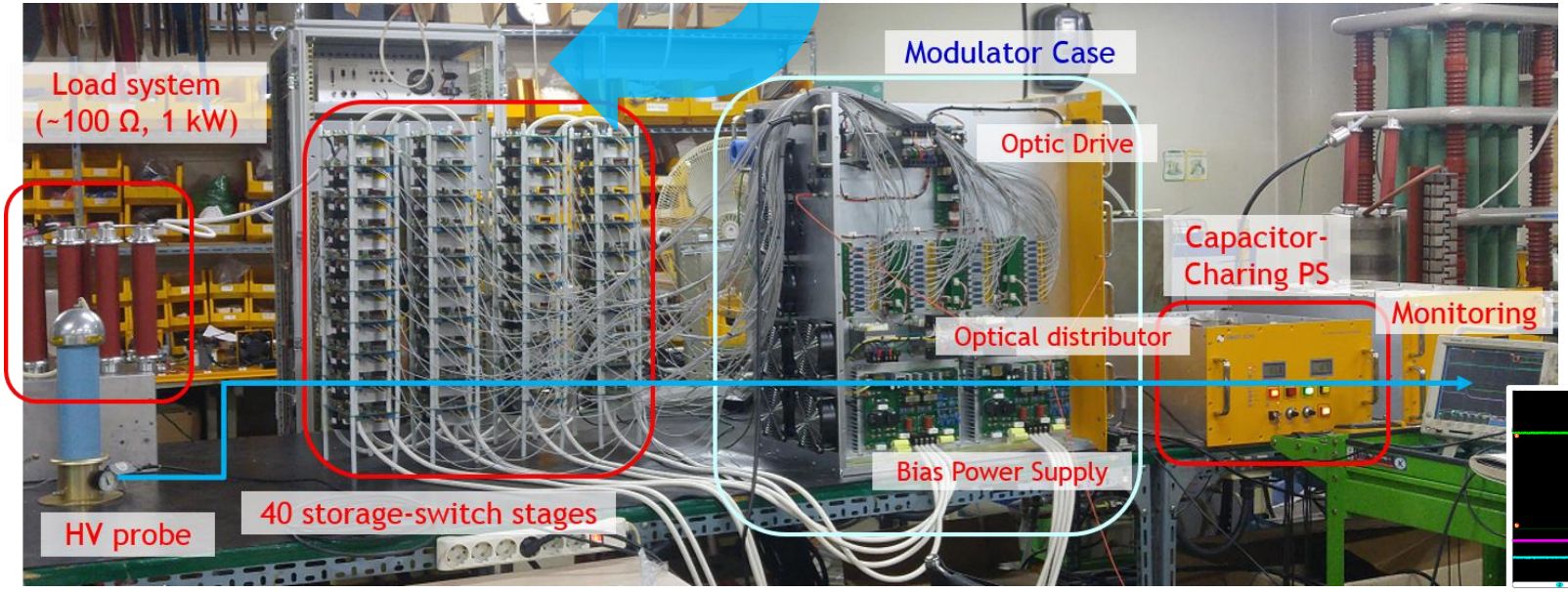
6 MW SS Modulator for Magnetron

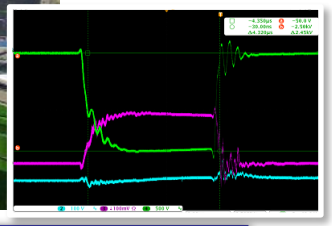




(2017, IEEE Trans. Plasma, Vol. 45, No. 10)

40-stage Marx-geneator (25 kV, 240 A, 4-10 us)

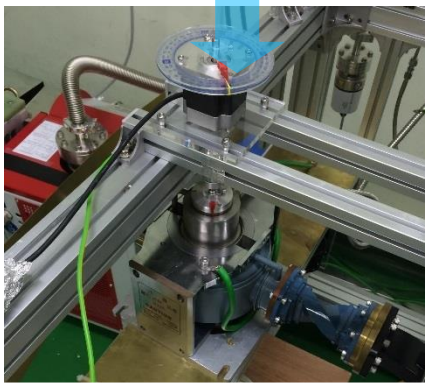


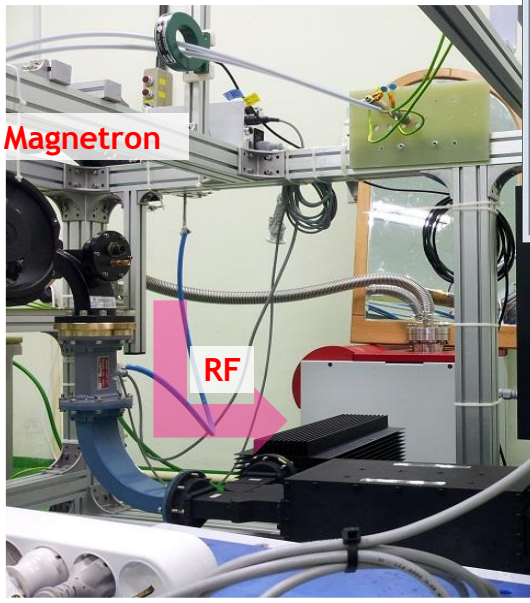


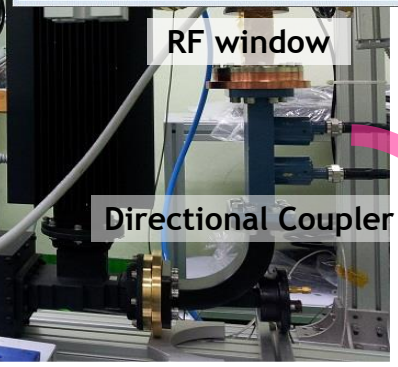
Auto Frequency Control System

Web Server ← Data

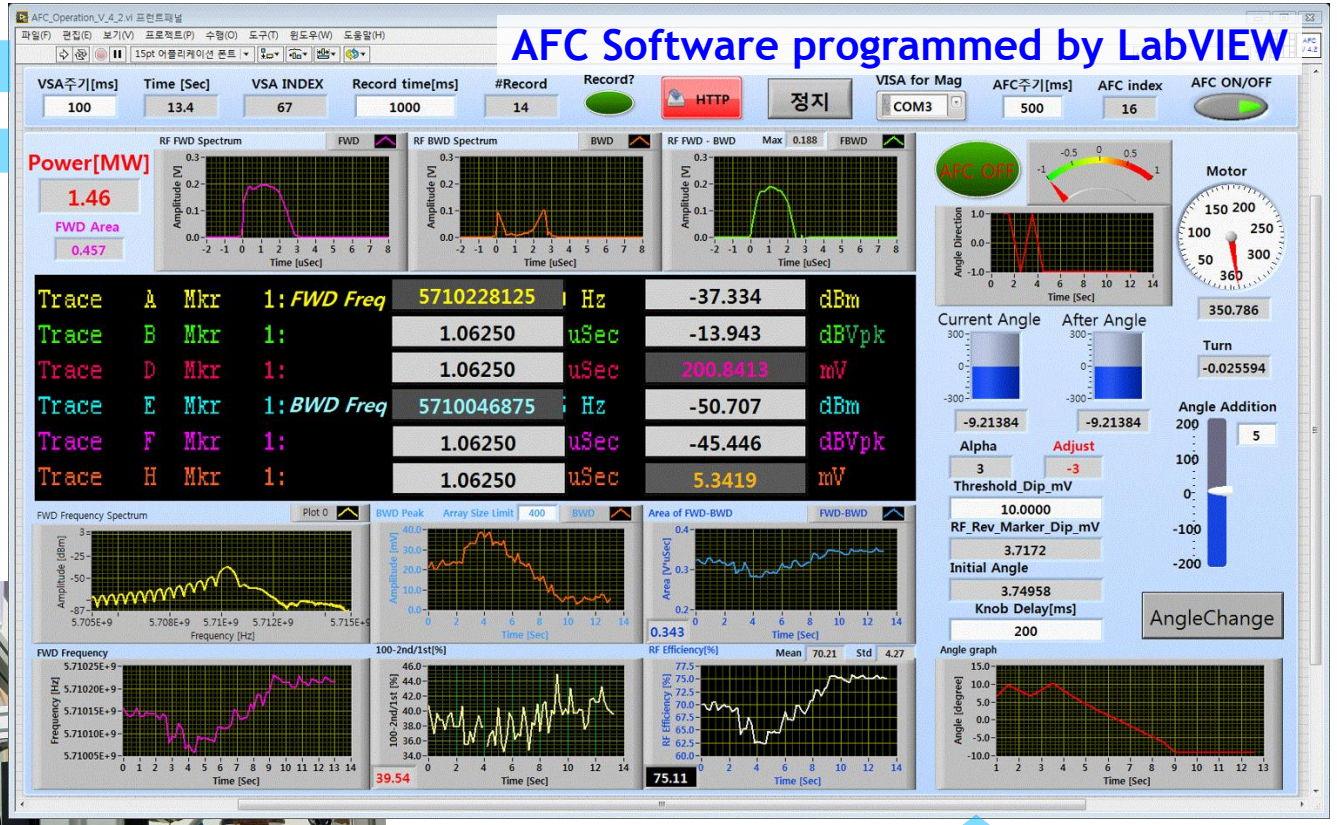
Motor-control





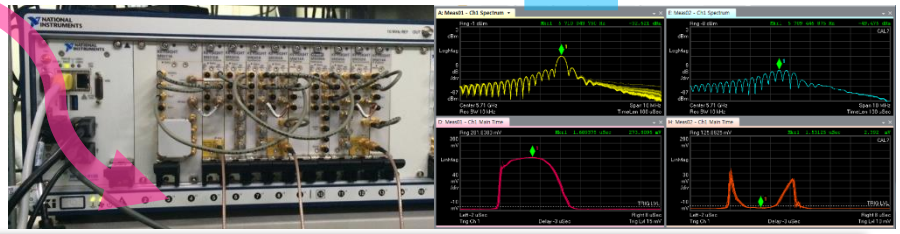


AFC Software programmed by LabVIEW

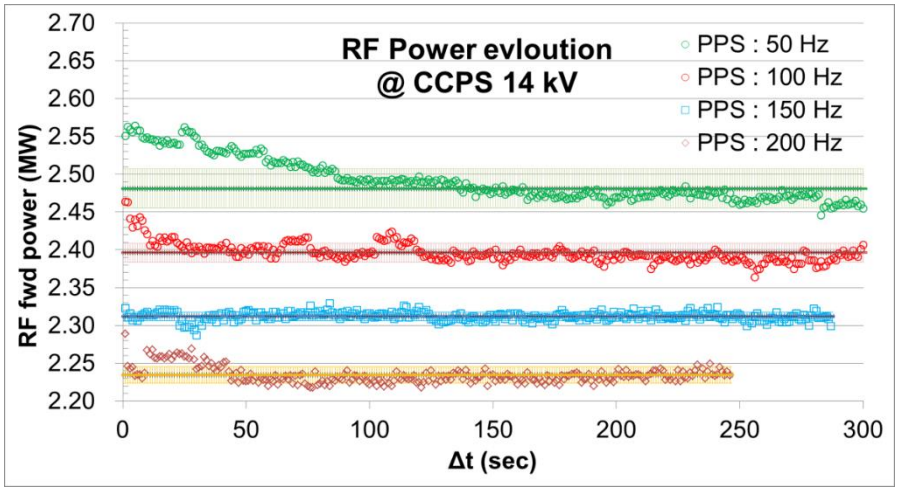


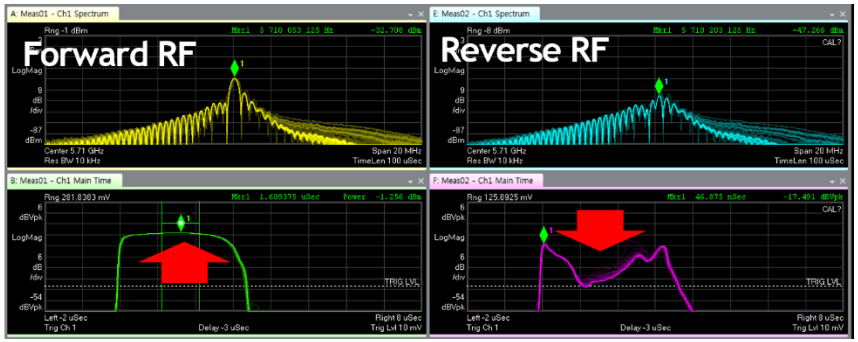
ICABU 2017 (Korea)

Vector Spectrum Analyzer

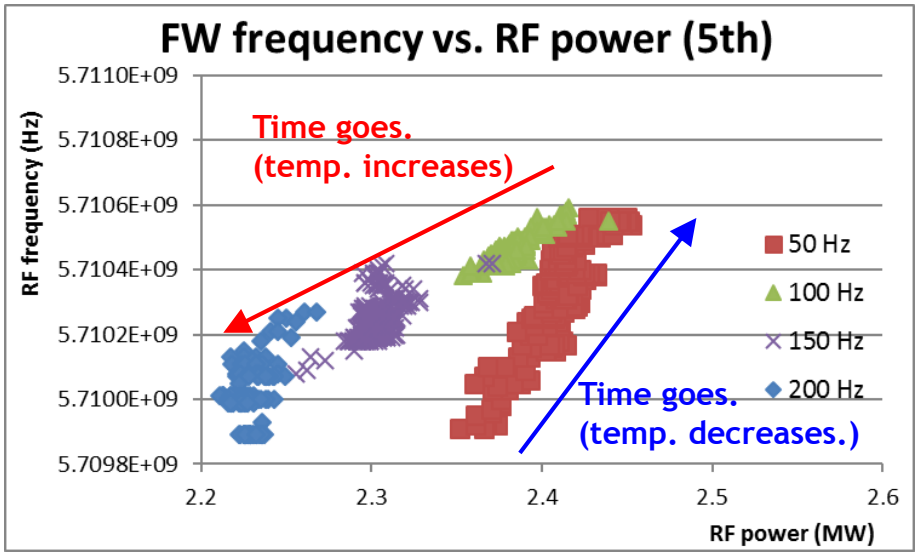


Linac Operation with AFC



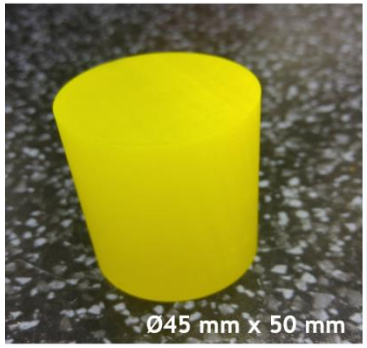


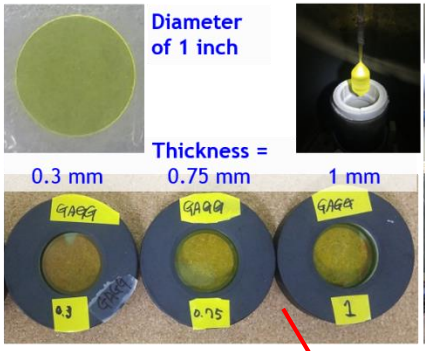
(ex) Operation cycle (with each run of 20 min) :
100 Hz → 150 Hz → 200 Hz → 50 Hz

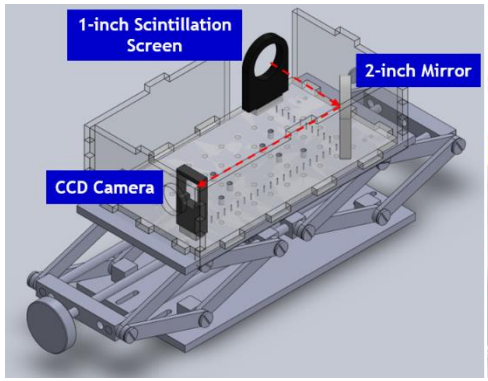


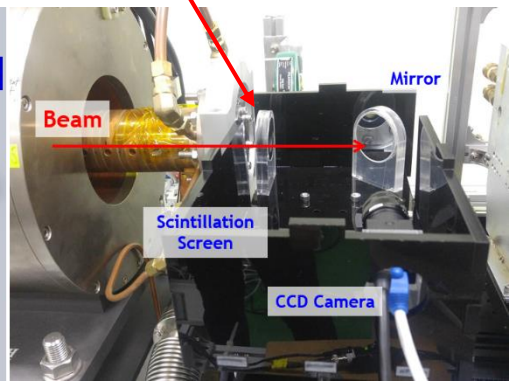
- If Reverse RF power is higher than threshold, AFC tunes the magnetron RF frequency to minimize the Reverse RF power.
- If the resonant frequency of the accelerating column changes due to the heat or other reason, the Reverse RF power can increase. In this case, AFC immediately can control it (< 500 ms).
- Therefore, the operation stability (for long-time run and high repetition rate) shows less than 1 %.

Beam Profile Measurement

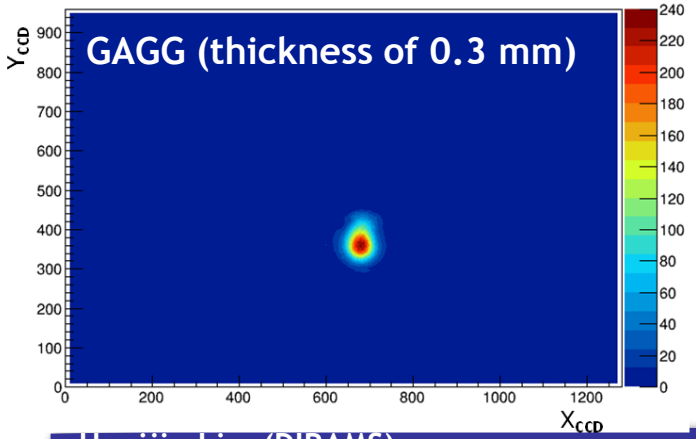


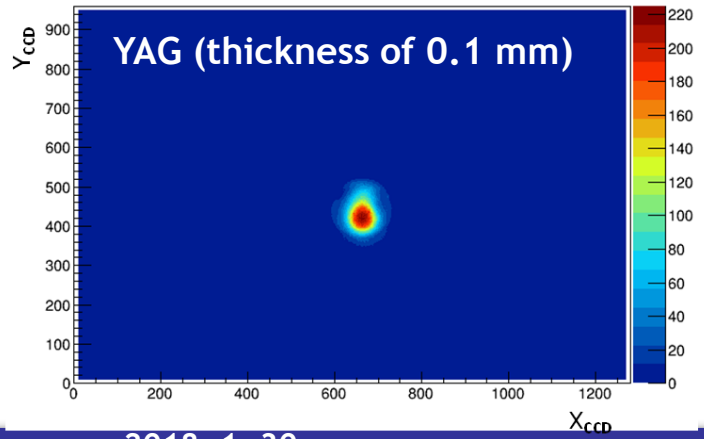






- GAGG($Gd_3Al_2Ga_3O_{12}$:Ce) inorganic scintillator
  - ✓ Recently developed by Tohoku group, Japan. In addition, we easily can get the domestics product.
  - ✓ High light yield of ~46,000 γ/MeV and fast decay time of 68-92 ns.
  - ✓ Applied to the beam-profile measurement.
- We built the protable system for the real-tim beam-profile monitoring (size : 176x316x108 mm^3) including the software (C++, ROOT).

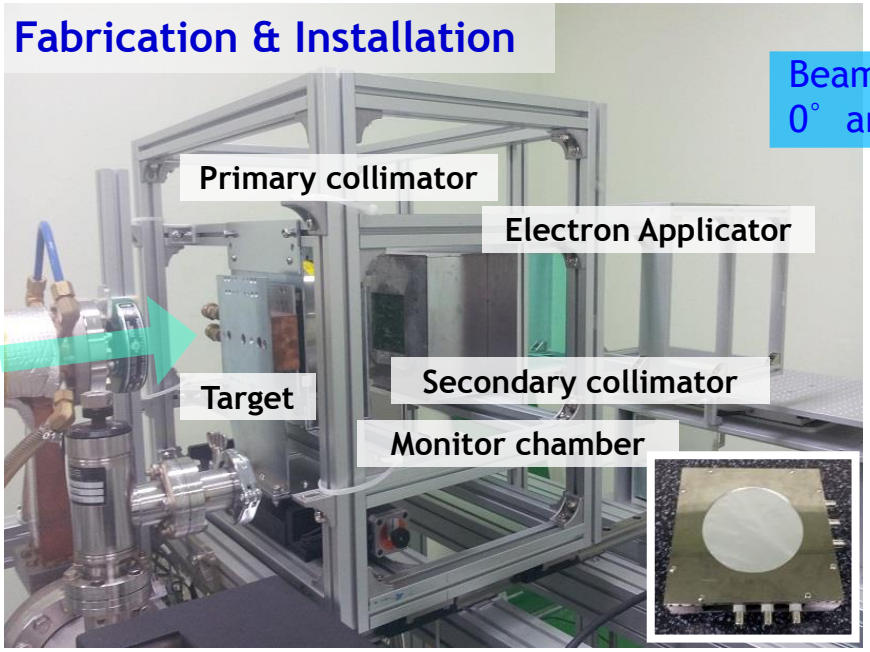




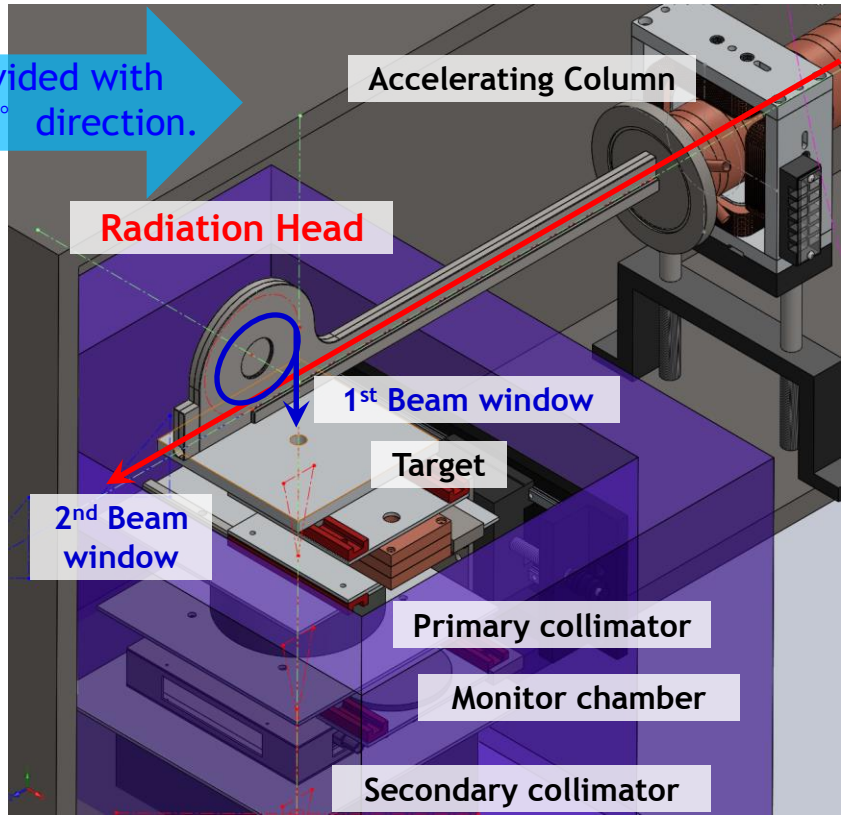
→ GAGG profile results are compatible with the YAG results.

Radiation Head

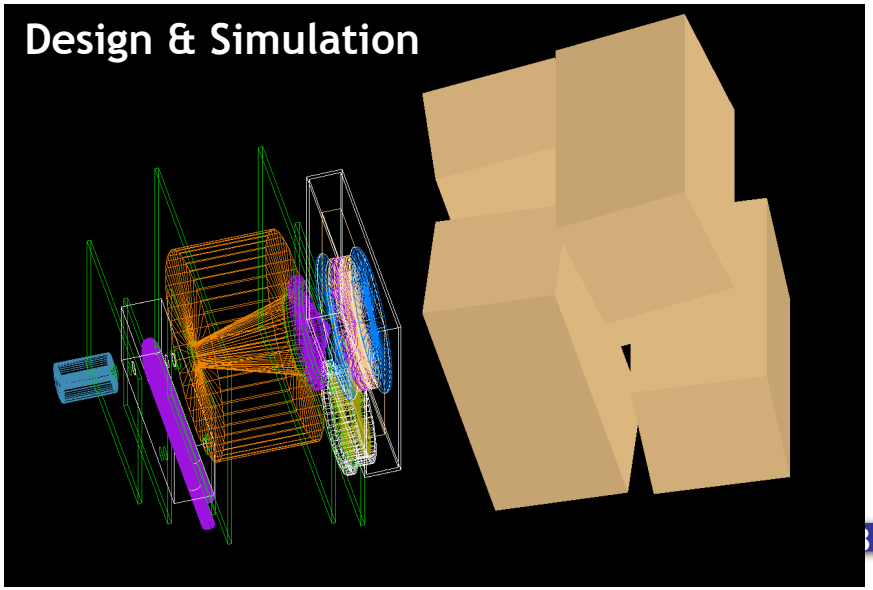
Fabrication & Installation



Beam provided with 0° and 90° direction.



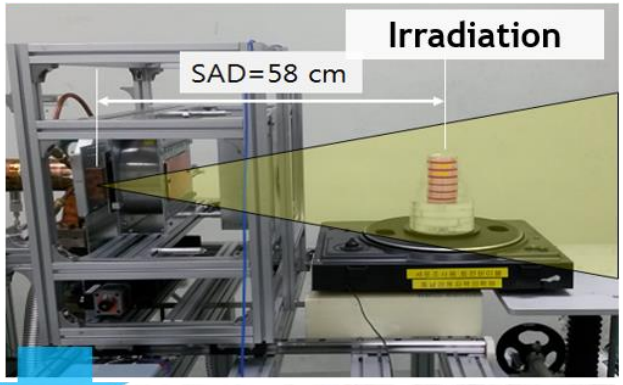
Design & Simulation

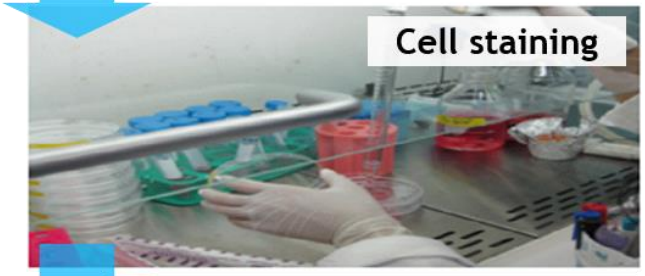


- The e-beam pass out of the vacuum into the air through a beam-window(titanium foil).
- X-ray beam is produced in the tungsten target.
- The monitor chamber is used for the dose measurement, that finally is used for the beam operation and interlock system.

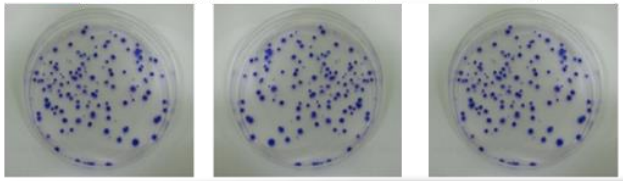
Pre-clinical study

Procedure

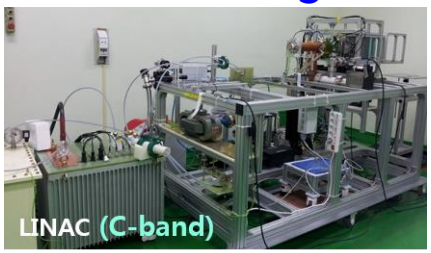


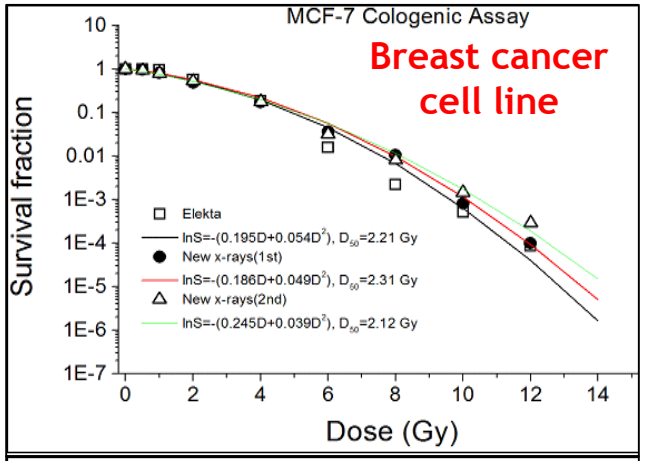


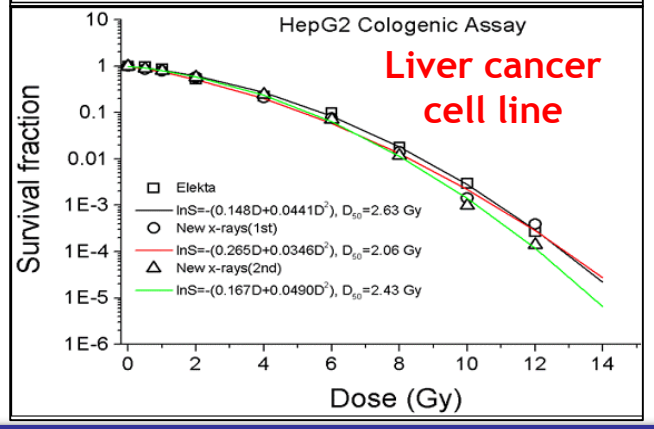
Clonogenic assay and analysis

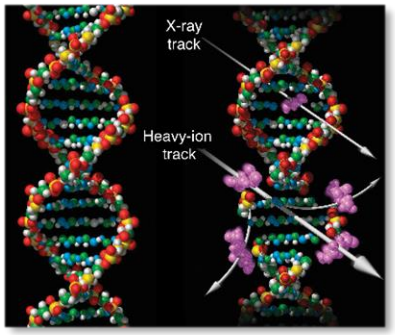


→ The following irradiators at DIRAMS used for this study.



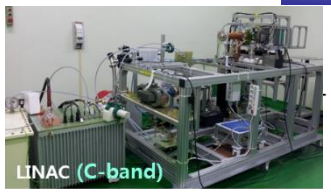


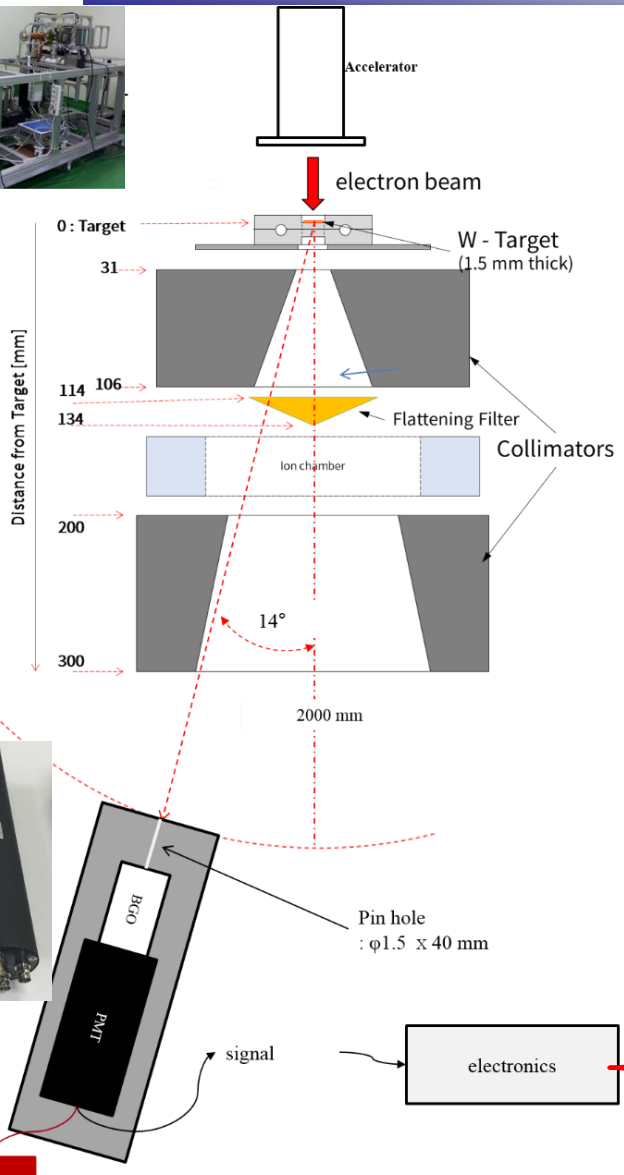


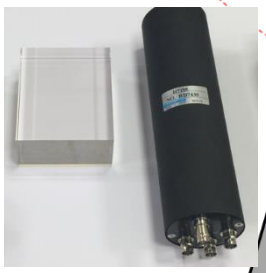


- Exponential decrease of the survival fraction as a function of dose.
- Verification of the biological effect of X-ray beam using the human cancer cell line.

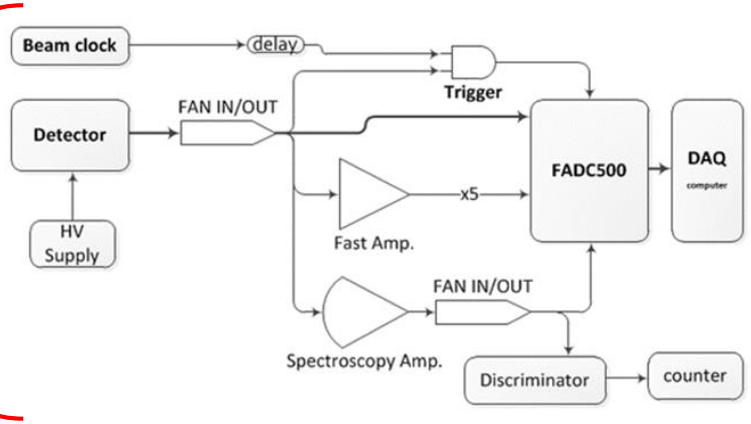
Bremsstrahlung Spectrometer





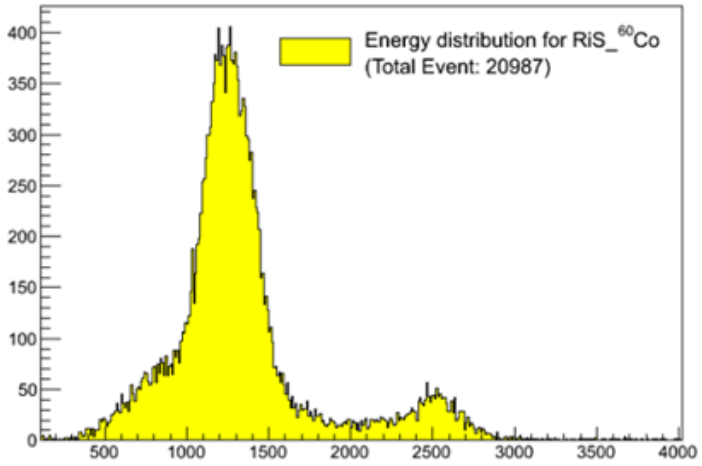


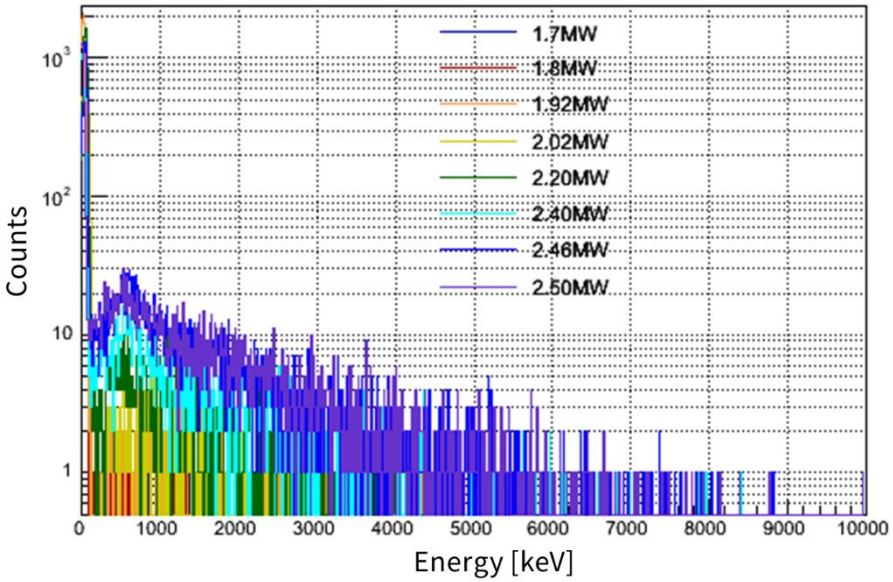
- Determination of the **X-ray energy distribution** from our medical Linac.
- **BGO (Bismuth Germante, $Bi_4Ge_3O_{12}$)**
  - ✓ Inorganic scintillator(Size : 40 x 80 x 100 mm^3)
  - ✓ Decay time : 300 ns
  - ✓ Light output > 8000 photons/MeV
- Linac condition
  - ✓ RF power : 1.5 ~ 2.5 MW
  - ✓ Electron beam current < 10 mA
  - ✓ W-target with 1.5 mm thickness
  - ✓ In order to reduce and reject the pile-up event, the detector position with pin-hole, the trigger configuration and the beam current were determined.



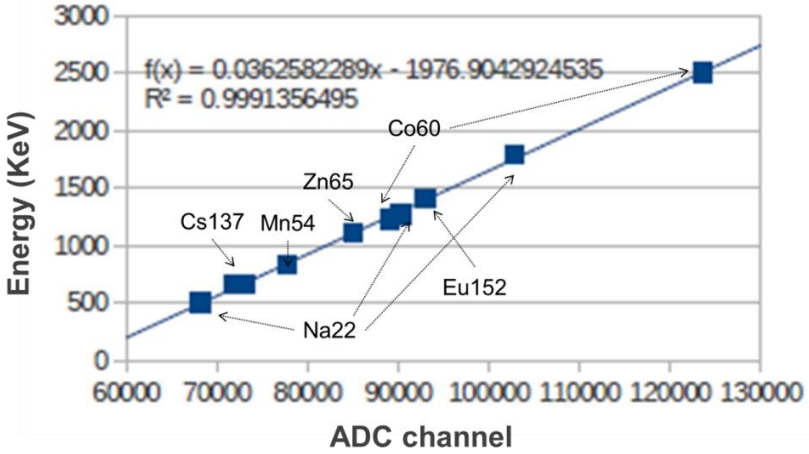
X-ray energy spectrum

ADC Spectrum for Co^{60}





Result of RI source test



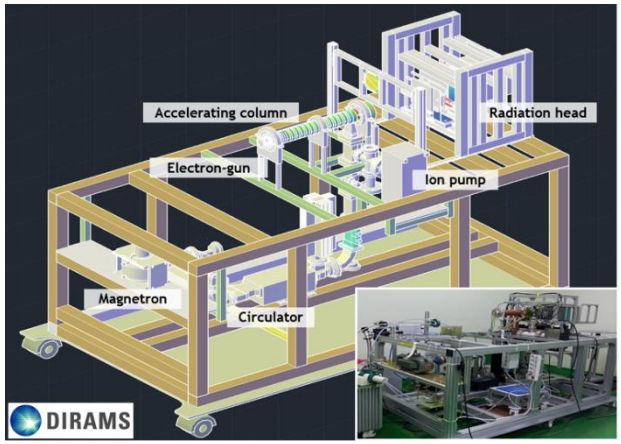
X-ray energy spectrum

- Measured with the RF power of 1.7 ~ 2.5 MW in DIRAMS Linac.
- Emax, (appox.)
  - ≥ 1.5 MeV @ RF 2.02 MW
  - ≥ 1.9 MeV @ RF 2.20 MW
  - ≥ 3.0 MeV @ RF 2.40 MW
  - ≥ 5.5 MeV @ RF 2.46 MW
- Therefore, we directly measured the energy spectrum using single photon event.

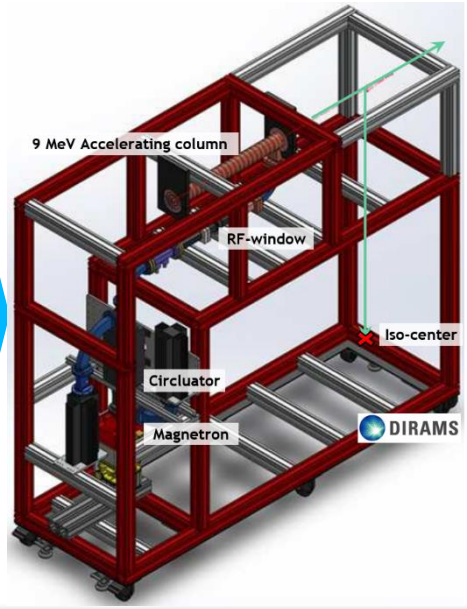
Conclusion

- Since the 6 MeV C-band Linac was constructed, it currently is used as an irradiator machine for biological effect study, radiation hardness study, also the development for sub-components and so on.
- We have the plan to generate the high dose of X-ray beam, that the precise measurement and the advanced study based on X-ray beam will be improved.
- Currently, we're preparing the 9 MeV C-band Linac which also will be verified for the gantry design in the radiotherapy machine.

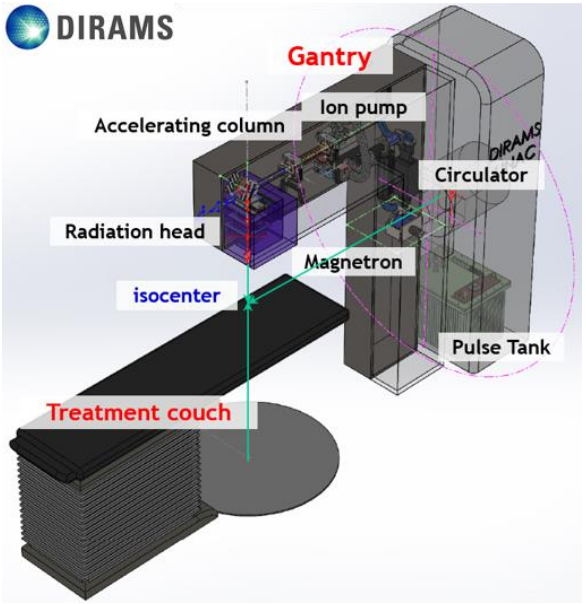
6 MeV C-band Linac



9 MeV C-band Linac



Radiotherapy machine



감사합니다.

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and a hope of the cancer patients.
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