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Operation of KOMAC 100-MeV Linac

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On behalf of the KOMAC Accelerator team

29 Sep., 2016
KOMAC, KAERI

KAERI

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Korea Multi-Purpose Accelerator Complex
양 성 자 가 속 기 연 구 센 터

Outline

KOrea Multi-purpose Accelerator Complex

- Introduction to KOMAC facility
- Operation of 100-MeV Linac
- Beam Line Development
- Operational Issues
- Summary

❖ Introduction to KOMAC facility

KOMAC Site : Gyeong-ju, Korea

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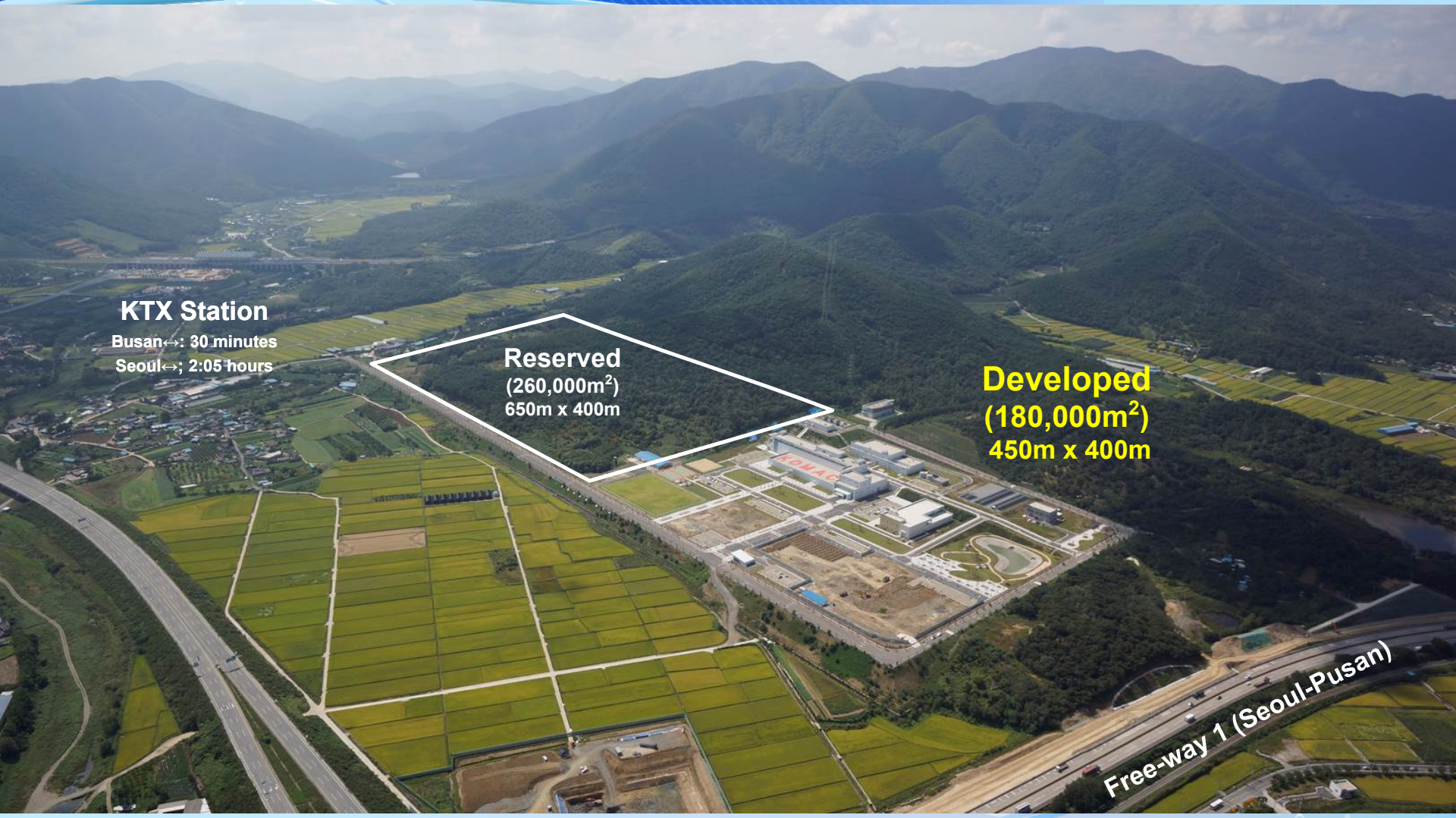

Main Facility of KOMAC

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Overview of Linac and Beam Lines

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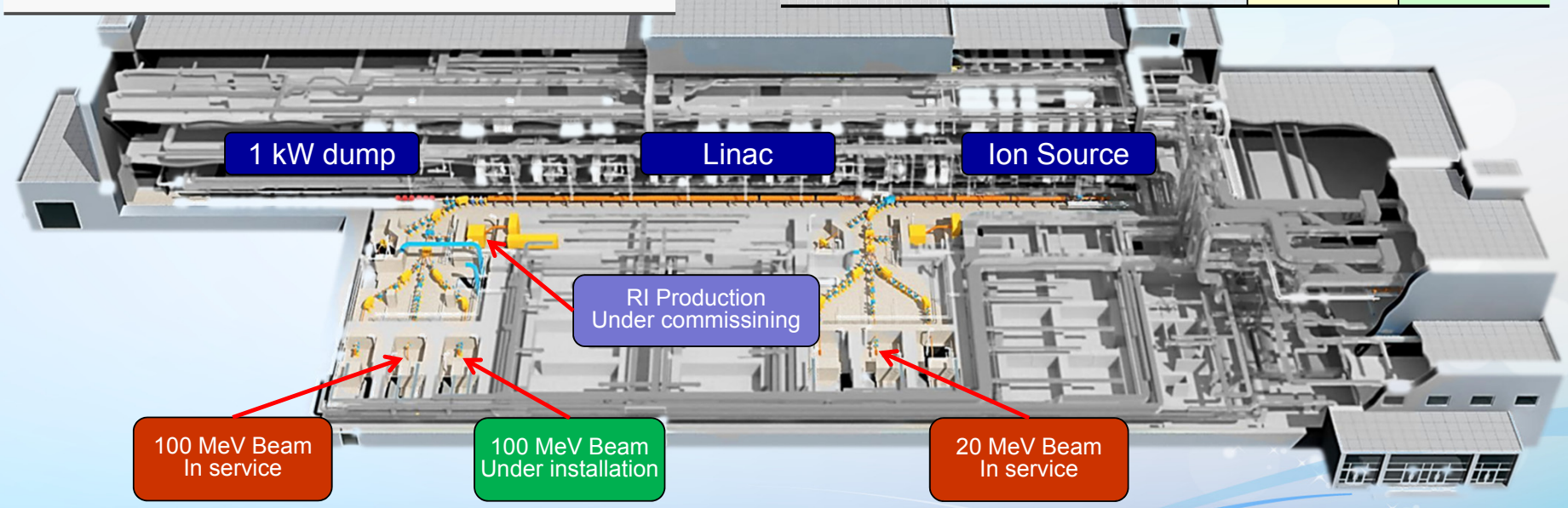
Features of KOMAC 100MeV linac

- 50-keV Injector (Ion source + LEBT)
- 3-MeV RFQ (4-vane type)
- 20 & 100-MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160



❖ Operation of 100-MeV Linac

Accelerator Development

- Developed proton linac technologies
  - 2.45 GHz Microwave ion source
  - 350 MHz 4-vane RFQ
  - 350 MHz DTL
  - 700 MHz Elliptical SC cavity for future extension
  - Digital LLRF and EPICS control system

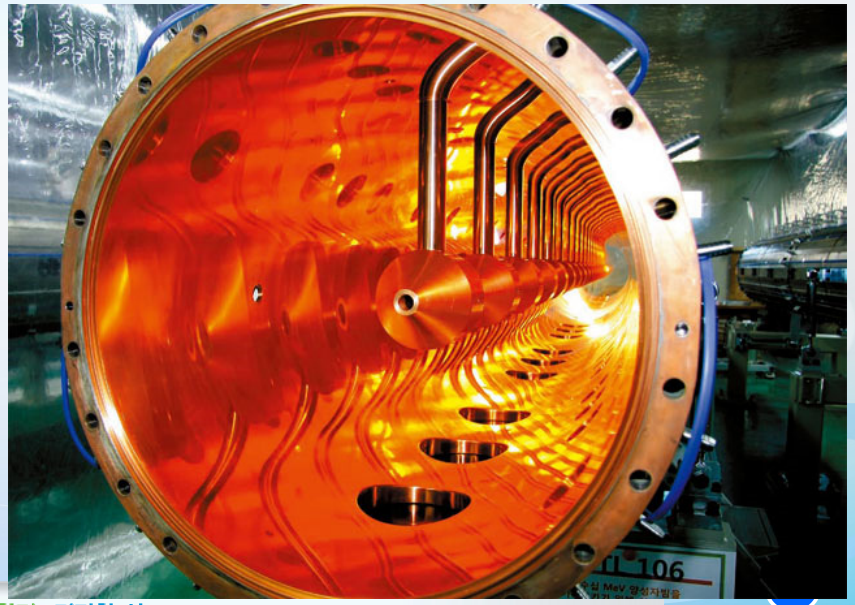
5-cell SCC prototyping

- Built KOMAC 100-MeV proton linac with the domestic companies

KOMAC Injector

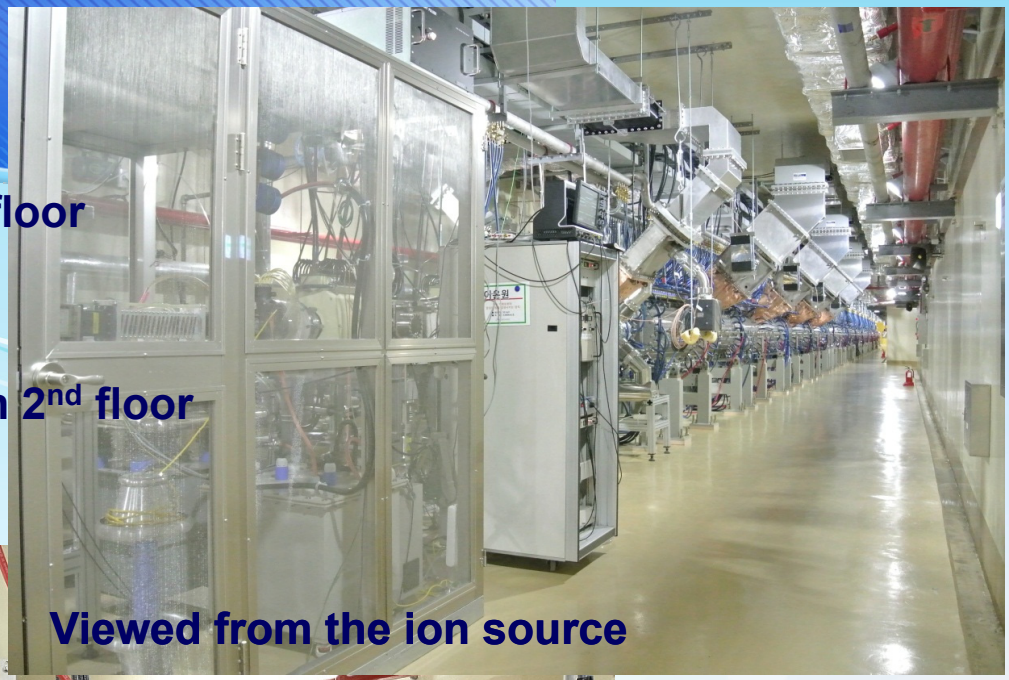
KOMAC RFQ

KOMAC DTL

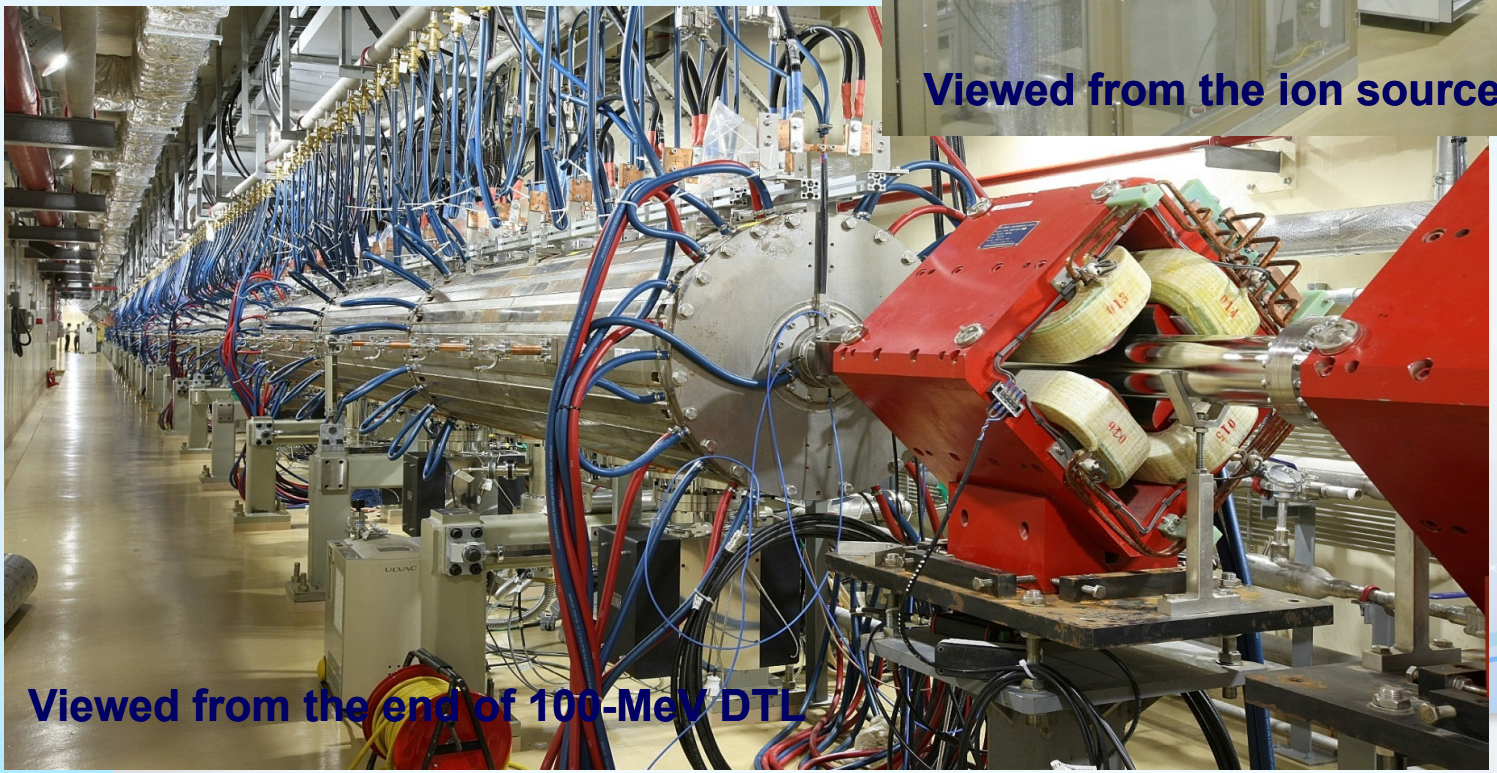


100-MeV Linac

- Linac and beam lines : installed in 1st floor
- Tunnel : 100 m
- 100-MeV linac : 75 m
- HPRF and cooling system : installed in 2nd floor



Viewed from the ion source



Viewed from the end of 100-MeV DTL

Linac Configuration

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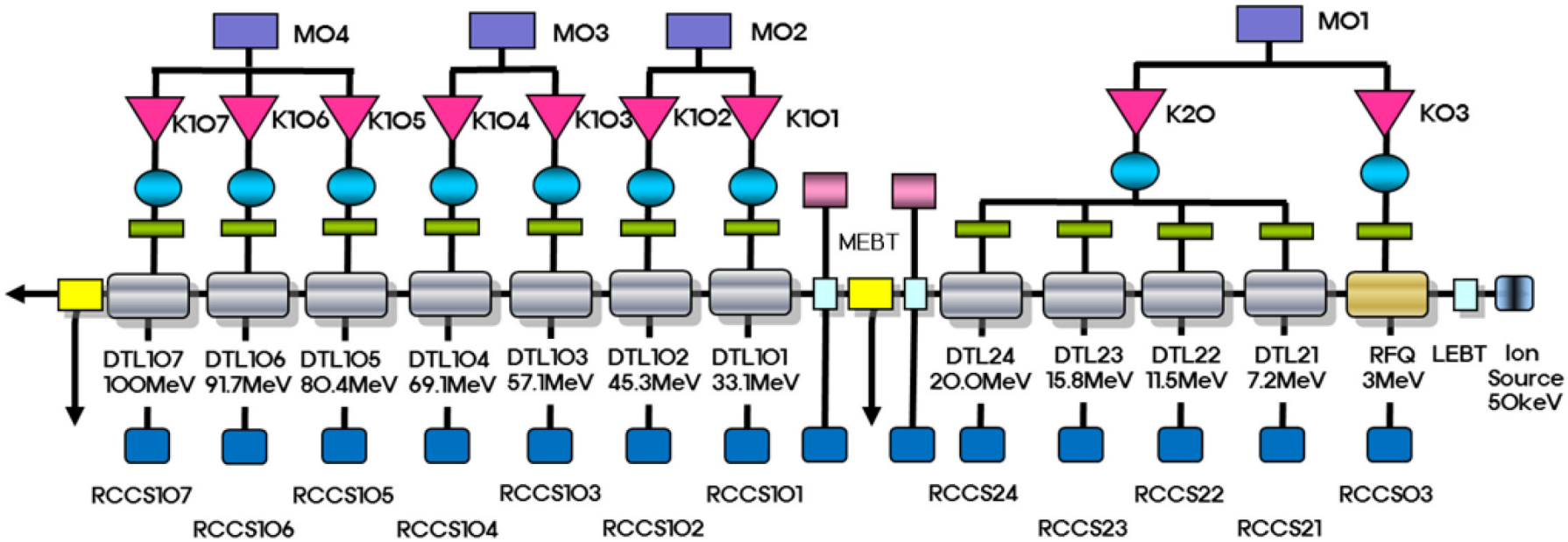
- 4 modulators drive 9 klystrons (350 MHz, 1.6 MW for each klystron)
- Single klystron drives first 4 DTL tanks (3 MeV ~ 20 MeV), works well so far
  - 3 Magic Tees with 1% power balance
  - Mechanical phase shifter @ each WG branch
- Modulators: 3 set of 5.8 MW and 1 set of 8.7 MW
- MEBT @20 MeV for switching magnet
- No MEBT between RFQ and DTL (as close as possible)



Target Room

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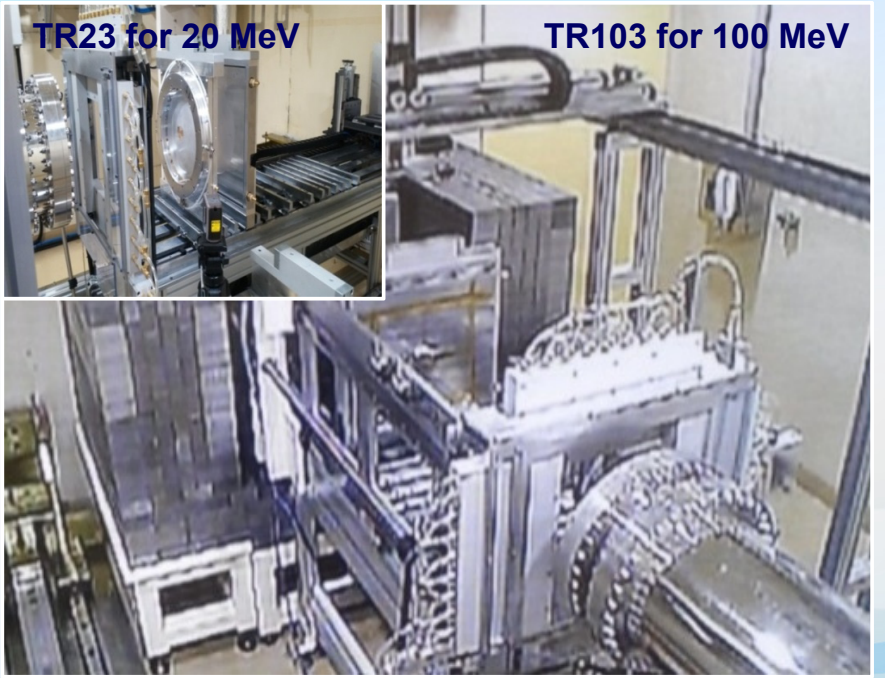
- 2 beam lines and 2 target rooms are installed and in services
  - 1 for 20 MeV, 1 for 100 MeV
- Irradiation: in air through 0.5-mm Al-Be alloy window

Beam line



Target room

High Power RF System

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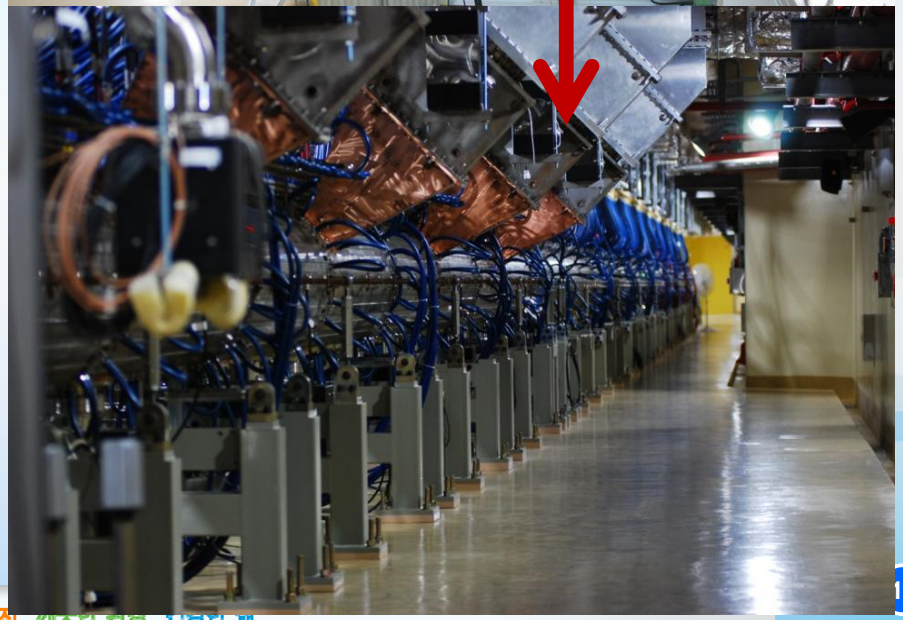
Modulators on 3rd floor



Linac in tunnel

Control Room & Operator

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- EPICS based control system
  - Accelerator / Utilities / PSIS / RMS are controlled in the main control room
- Accelerator team: Total 15 persons (7 Ph.D)

  Nuclear Eng. (5), Physics (4), Electrical Eng. (3), Control (2), Mechanical Eng. (1)
- Operators/shift : 2 for accelerator, 2 for beam service in target room

  Served as operator (~6 days / month)

Beam Commissioning

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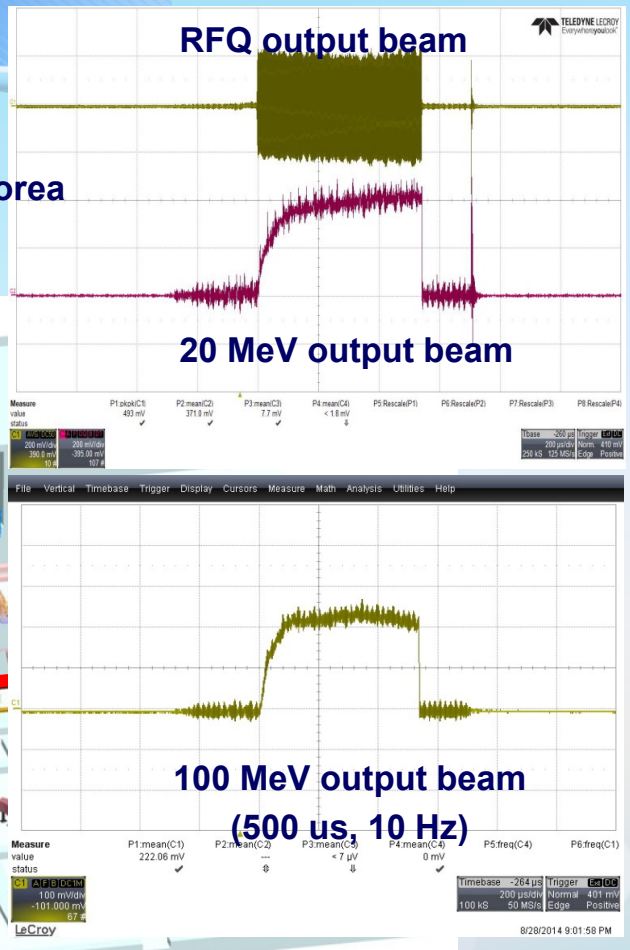
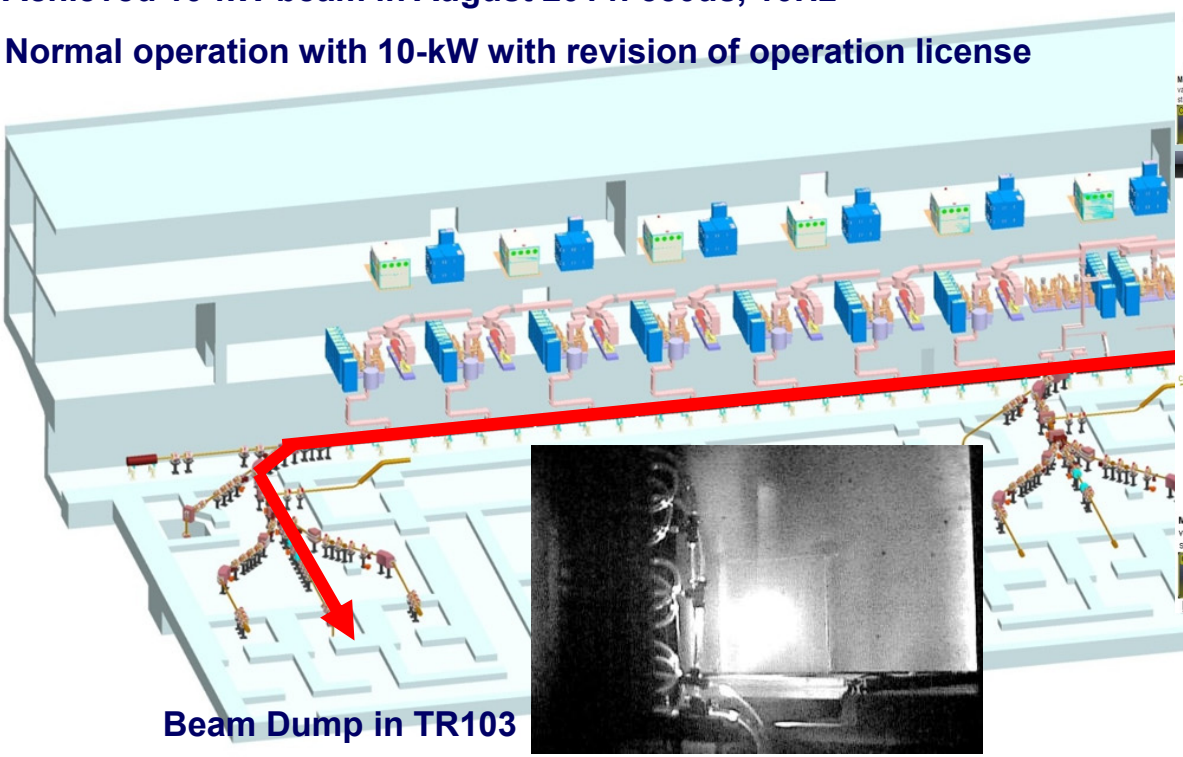
- Delivered 1-kW beam into TR103 in July, 2013
- Checked beam energy change by turning off 7 DTL tanks one-by-one
- Operation license by the Nuclear Safety and Security Commission of Korea
- Started user beam services for 1-kW beam from July 22, 2013
- Achieved 10-kW beam in August 2014: 550us, 10Hz
- Normal operation with 10-kW with revision of operation license

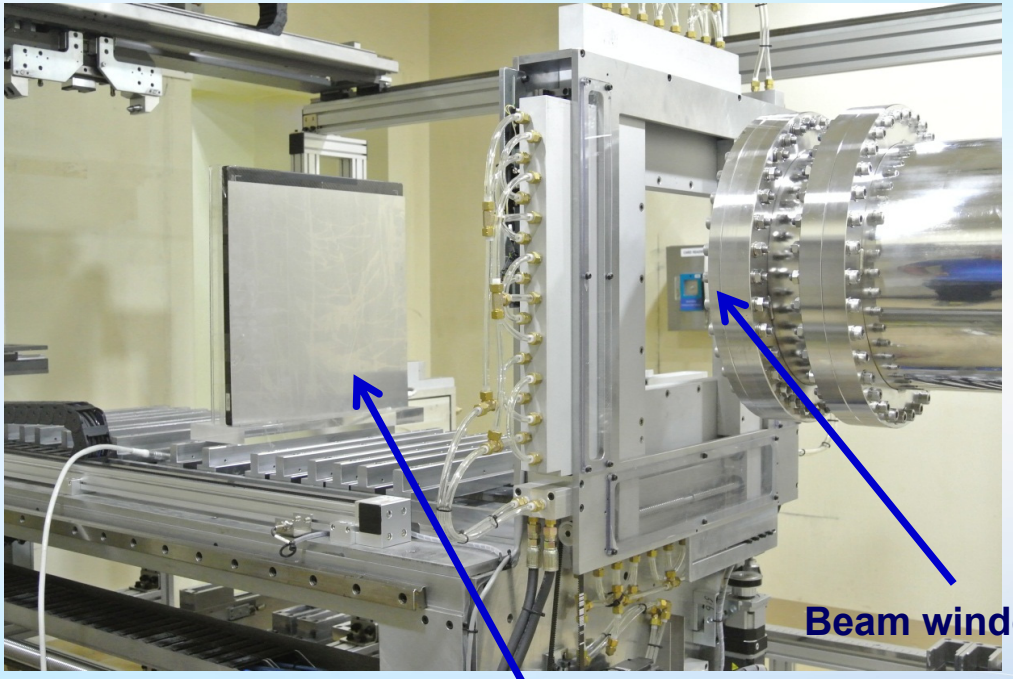


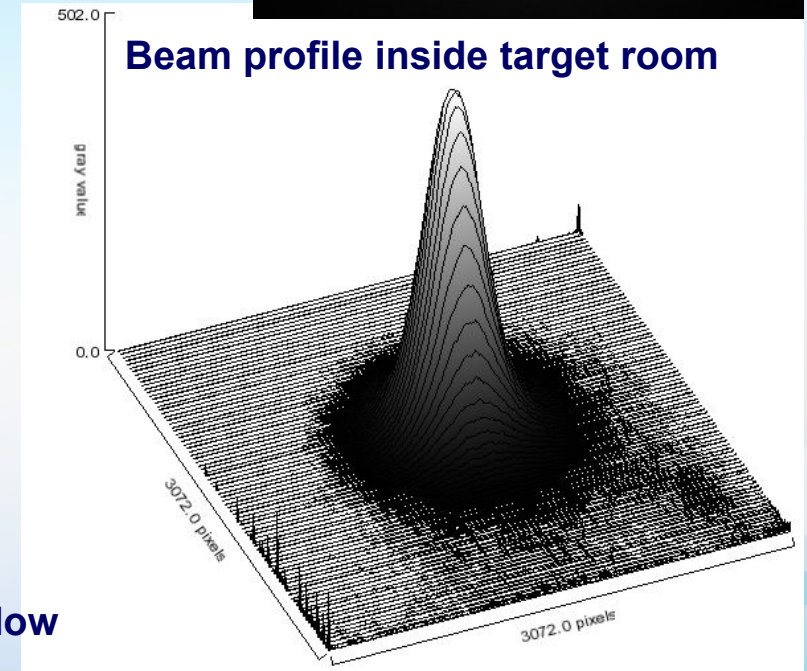


Beam Dump in TR103

Beam Profile at Target Room

- User requirement for beam size: max. 300-mm diameter
- Monitoring beam profile
  - Flat panel detector with CsI scintillator
  - Panel size 430 mm × 430 mm, pixel size 139 um





Beam rms radius : 25 mm

Summary of Operation History

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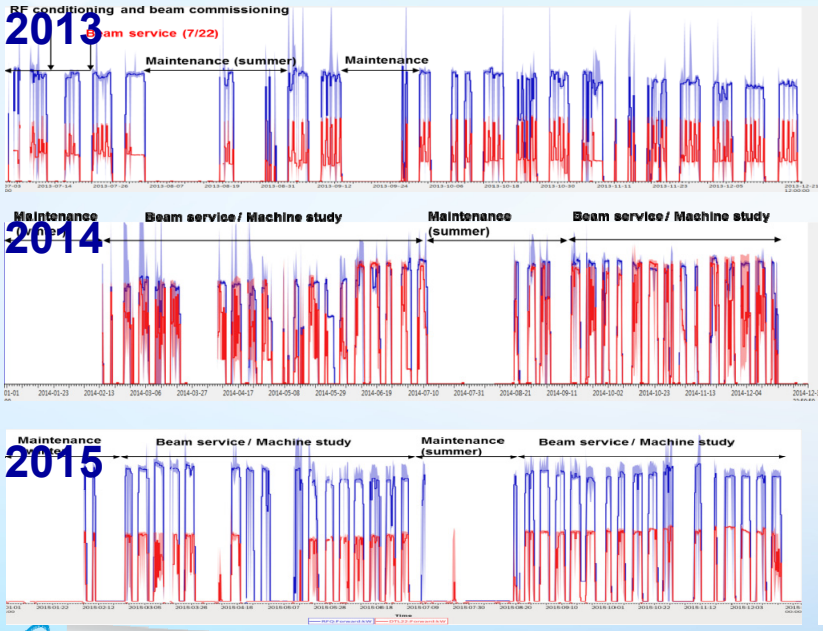
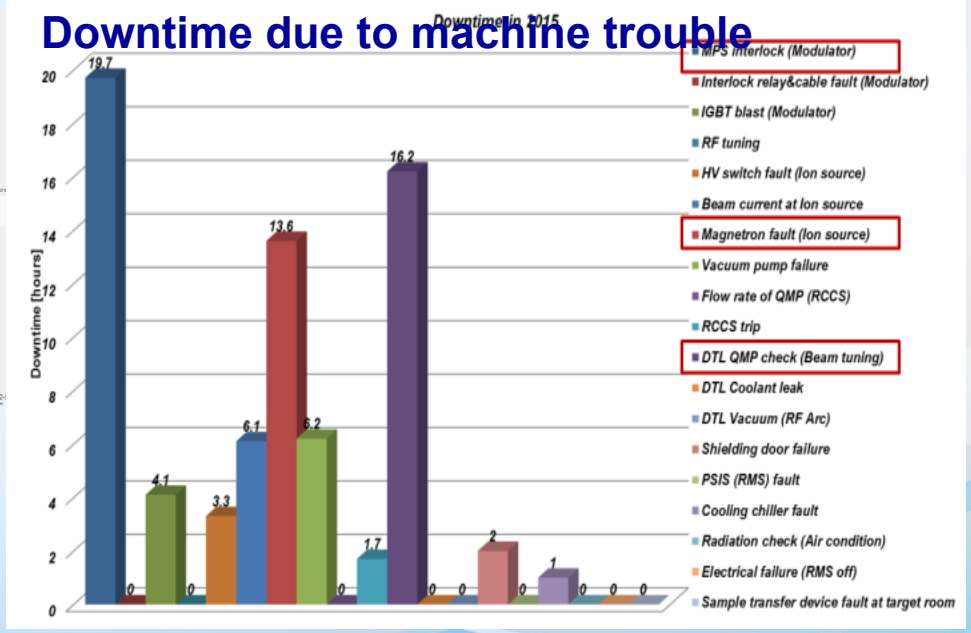
- ❖ Operated in weekly-based schedule through a yearly plan
  - ▪ Beam service: Monday 13:00 ~ Friday 12:00
- ❖ Operation statistics

	2013	2014	2015	2016	Sum
Operation hours	2,290	2,863	2,948	1,486	9,587
Beam service	432.7	700.9	704.1	408.5	2,246.2
Availability	82.0%	86.3 %	90.5%	94.3%	88.1%





Beam Service Stat. (July 2013 ~ Dec. 2015)

❖ Increasing beam time requests

Year	Research Projects			Beam Time (day)			Users
	Proposed	Served	Ratio(%)	Requested	Served	Ratio(%)	
2013	56	39	69.6	182	96	52.7	84
2014	121	103	85.1	275	203	73.8	223
2015	153	124	81.0	311	193	61.2	349
Sum	330	261	79.1	768	460	59.9	656

- **R&D Fields: Bio/medical(26.4%), Nano/Materials(26.4%), Space/Basic Sci.(22.6%) etc.**
- **Total number of treated specimen: More than 5000.**
- **KOPUA: Korea Proton Beam User Association (Self-organized user network)**
  - **PAC(Program Advisory Committee): Review proposals & Allocate beamtime**

❖ Beam line Development

Beam Requirement from User

- Users from various fields

  (nano/materials, bio/medical, space, basic science etc.)

- Requirements from users
  - Energy: 20 MeV ~ 100 MeV (controlled by DTL tank RF on/off)
  - Peak current: 0.1 ~ 20 mA (controlled by ion source and LEBT)
  - Beam size: 5 mm ~ 300 mm (controlled by QMs in beam lines)
  - Pulse width: 50 us ~ 5 ms
  - Number of pulses: 1 ~ over 10000
  - Dose uniformity: better than 5%
  - Pulse to pulse stability: better than 5%
  - Etc.

❖ Especially single shot operation after long preparation is not easy.

❖ In some cases, the irradiation conditions are not clear.
They decide the conditions during beam service.

Beam Line for RI Production

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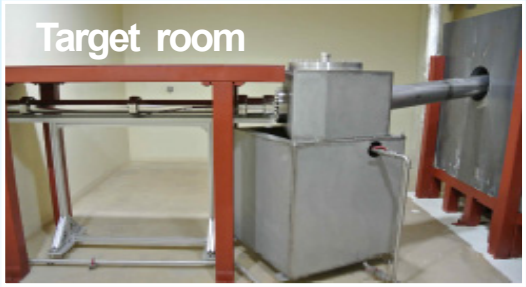
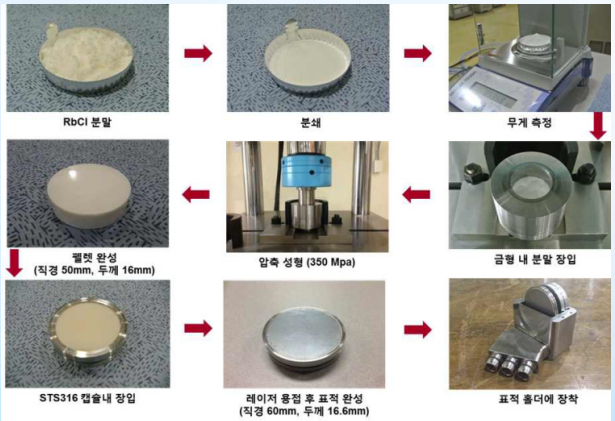
❖ RI Beamline: 100-MeV Proton

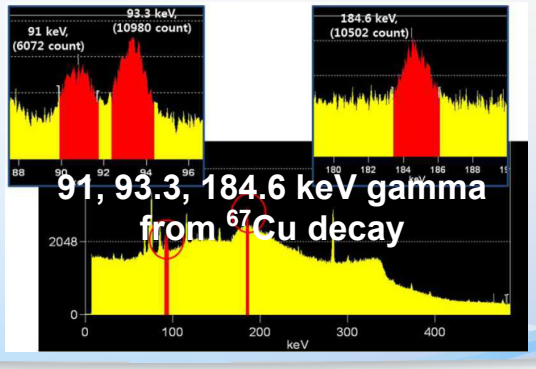
- **Application**
  - RI production: Cu-67, Sr-82, etc.
- **Proton beam**
  - Energy: 33 ~ 100 MeV
  - Beam power: 30 kW @ 100MeV
- **Status**
  - Completed installation: Dec. 2015
  - Under Commissioning
  - Operation: October 2016



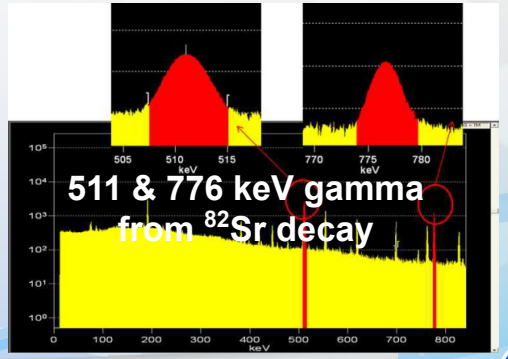
Target Preparation



$^{68}Zn(p,2p)^{67}Cu$



$^{nat}Rb(p,x)^{82}Sr$



Beam Line for Low Flux Application

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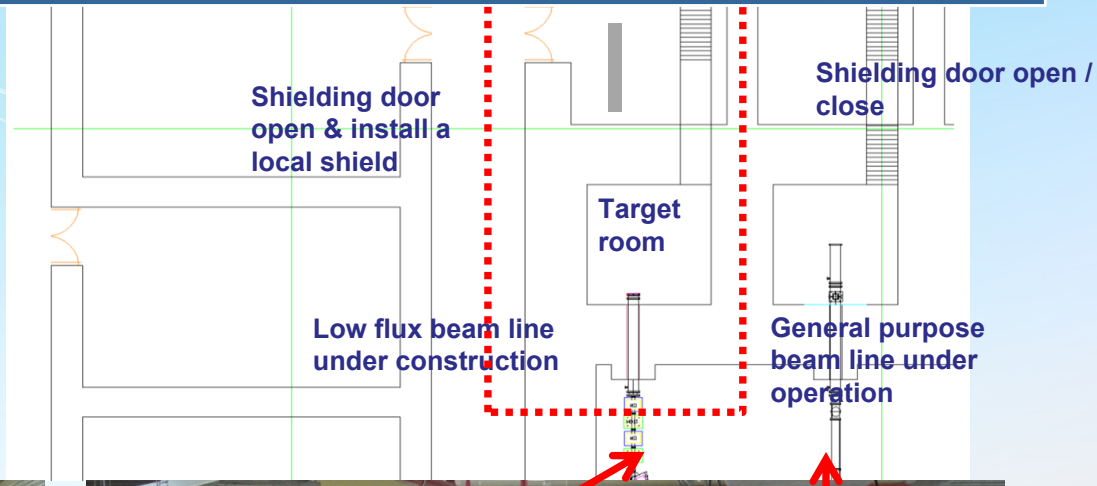
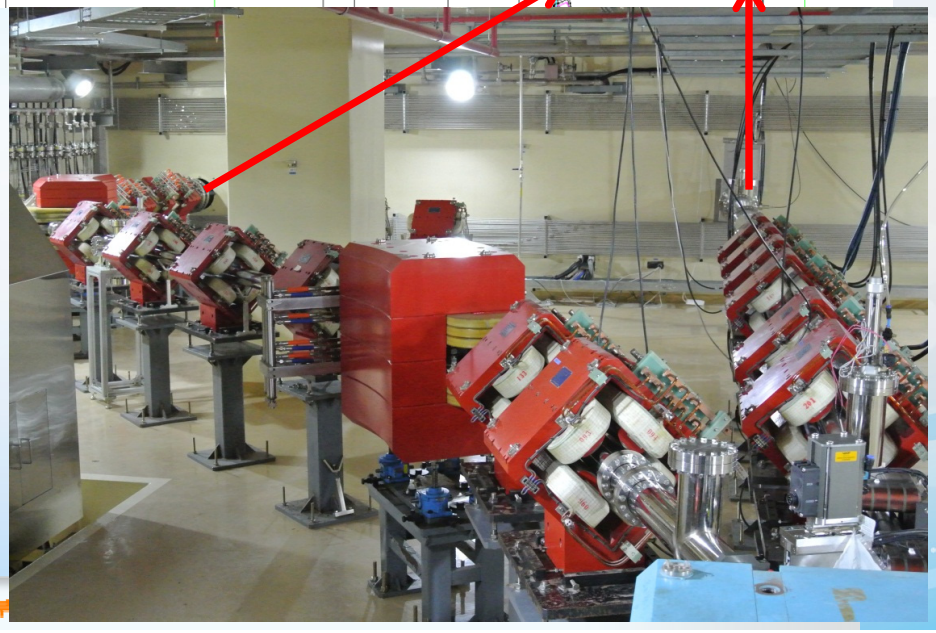
❖ Beamline for Low Flux Users: 100-MeV Proton

- Specification of the low flux beam line
  - Beam energy: max. 100 MeV
  - Flux: 10^8 p/cm^2 s
  - Target size : 10 cm X 10 cm
  - Two octupole magnets
  - Graphite collimator

- Shielding door: always open
- Add Local shield
- Increase the accessibility



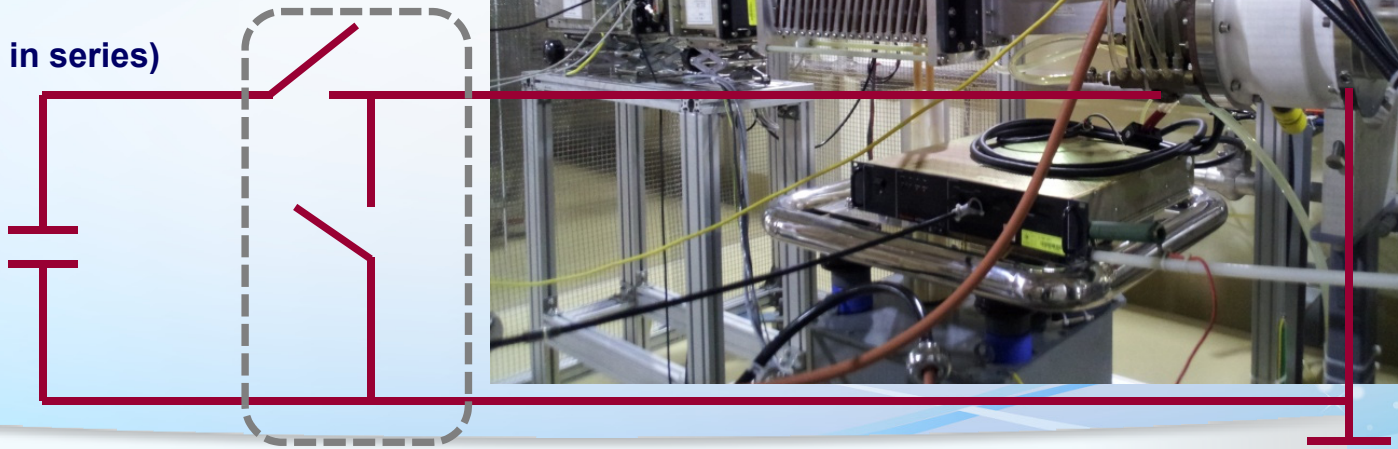


❖ Operational Issues

Ion Source 1 – HV Switch

- KOMAC ion source Requirement: 50 keV, 20 mA peak, 2.5 ms, 120 Hz (30 % duty)
- Operation mode: CW plasma, pulsed beam extraction
- Failure of the switch was a problem. Now fixed by adjusting gate drive timing and current limiting resistors.

Semiconductor switch
(push-pull type,
80 IGBTs connected in series)



Ion Source 2 – BN coating

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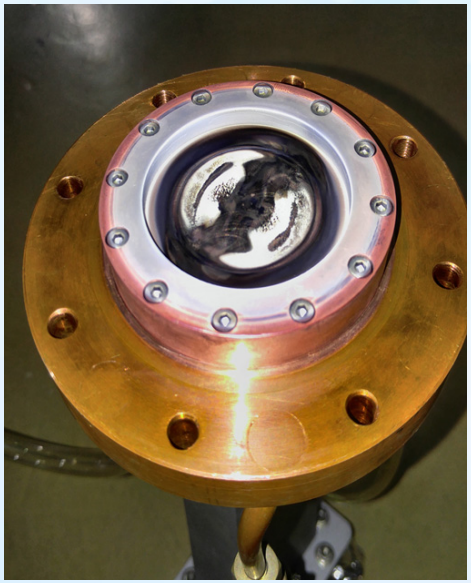
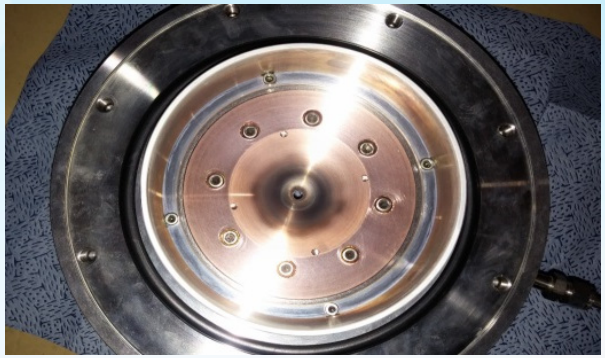
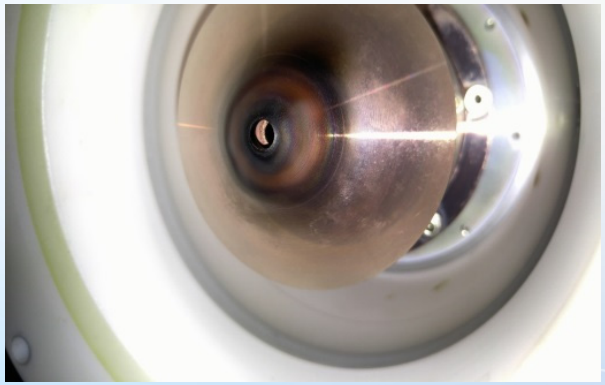
- CW plasma operation: electrode being coated with BN
  - BN from the microwave window
  - Frequent arcs between electrodes: Switch failure
- Preventive maintenance: overhaul after 500-hr operation

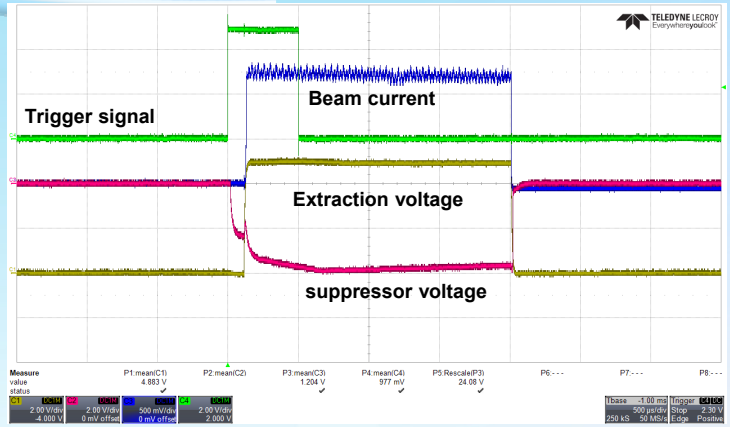


BN after 1,000 hour operation

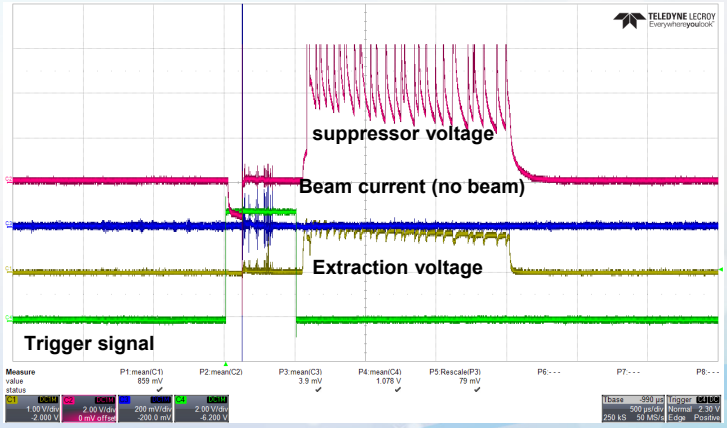




BN(insulator) coating on plasma electrode (upper) and extraction electrode (lower)



Normal operation waveform



Abnormal waveform due to coating

Ion Source 3 – Beam Current Ripple

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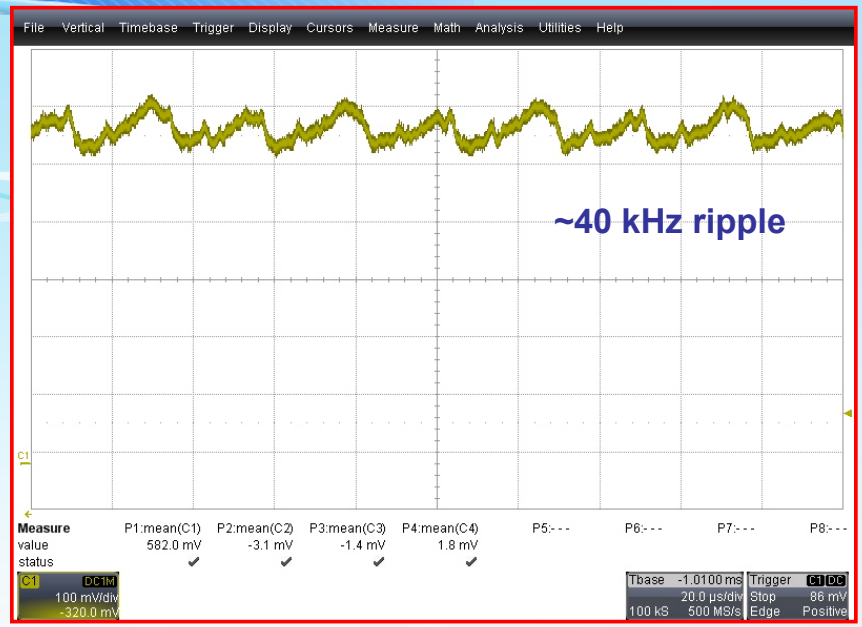
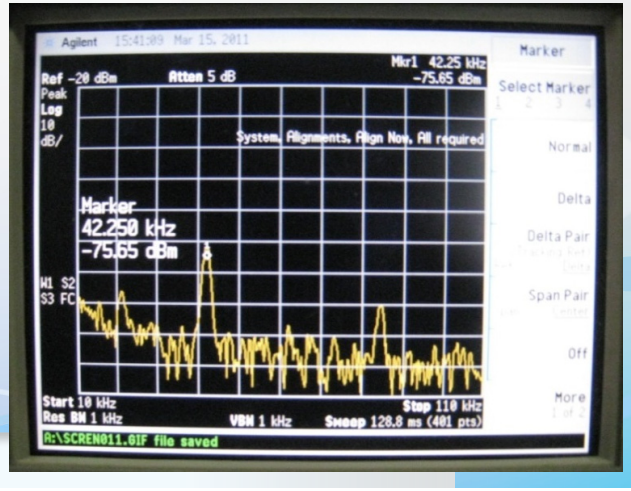
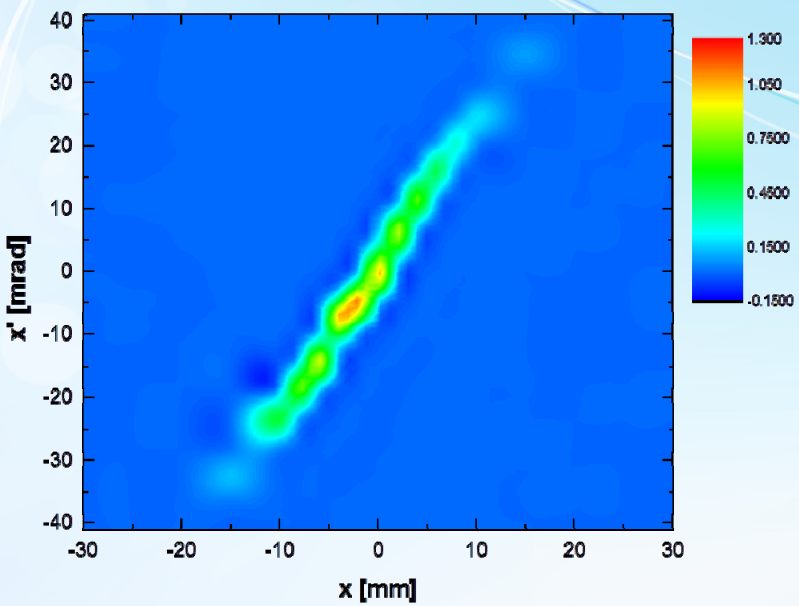
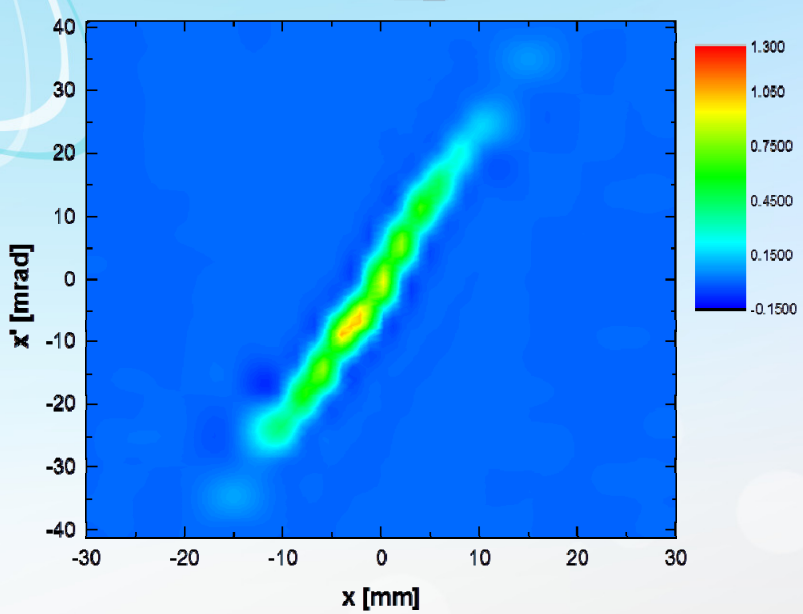


- Spectrum measurement at forward and reflected signal
  - 42.25kHz peak, regardless of magnet power supply status
- Microwave frequency depending on Power
  - 400W setting : 2.464250GHz
  - 310W setting : 2.462575GHz
- Magnetron power supply switching frequency : 20~22kHz



Ion Source 4 – Neutralization





Base pressure: 1E-7 torr
Measurement condition: 1.1E-5 torr hydrogen
Extraction voltage: 50 kV
Bias voltage: -2 kV
Normalized rms emittance: 0.318 π mm mrad

Base pressure: 1E-7 torr
Measurement condition
1.1E-5 torr hydrogen + 2.1E-5 torr krypton (1sccm)
Extraction voltage: 50 kV
Bias voltage: -2 kV
Normalized rms emittance: 0.249 π mm mrad

Measured at Test bench without beam focusing solenoid
Normalized rms emiitance reduced by ~20% with Kr adding

Ion Source Test Bench

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IS control rack
- HV PS
- Bias PS
- Magnet PS
- Gas flow control

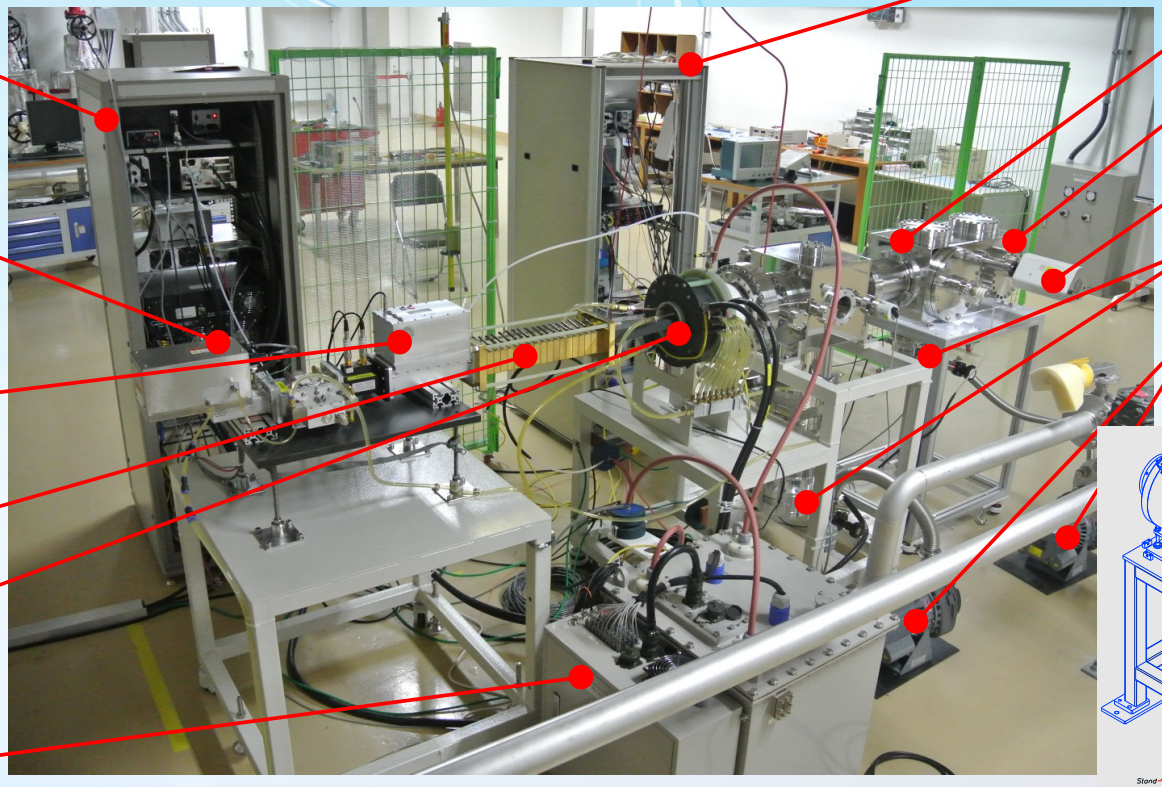
Magnetron

3-stub tuner

WG DC break

Ion source

HV switch
For extraction



Control rack
- Timing system
- Vacuum control
- Diagnostics

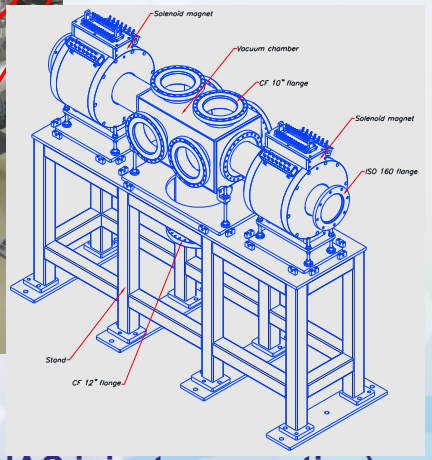
Diagnostic chamber

Faradycup

RGA

TMP

Scroll pump



Almost same as the one used for LINAC operation (source of spare parts for reliable LINAC injector operation)
Test bench for various operating condition, components tests and new design to improve the ion source
LEBT with two solenoid with a diagnostic chamber is under fabrication

Electroquadrupole in Drift Tube

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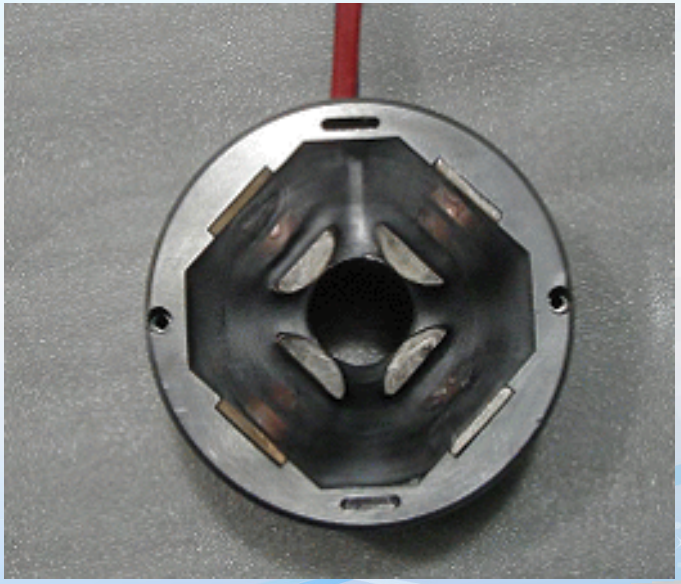
- DTQ of DTL (3 MeV ~ 20 MeV)
  - Limited space
  - Conductor: enameled wire (pool type magnet)
  - Yoke: Ni plating
  - Coaxial stem
- DTQ of DTL (20 MeV ~ 100 MeV):
  - Space is not a probleam
  - Conductor: hollow conductor (Normal water cooled magnet with epoxy molding)
  - Tri-axial stem

Pool type DTQ



DTQ with hollow conductor

DTQ Failure

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- Pool type magnet
  - Total 8 DTQs were failed in one 20 MeV DTL tank -> Failed DTQs were changed
  - Hardened enamel coating -> detached -> turn to turn short
  - Rust in the yoke
- At commissioning stage,
  - Low resistivity of the cooling water (by accident)
  - High radiation during beam test
- Change to permanent magnet or add coating by liquid type insulator

Current lead (enameled wire)

Rust covered on Yoke

DTL Vacuum

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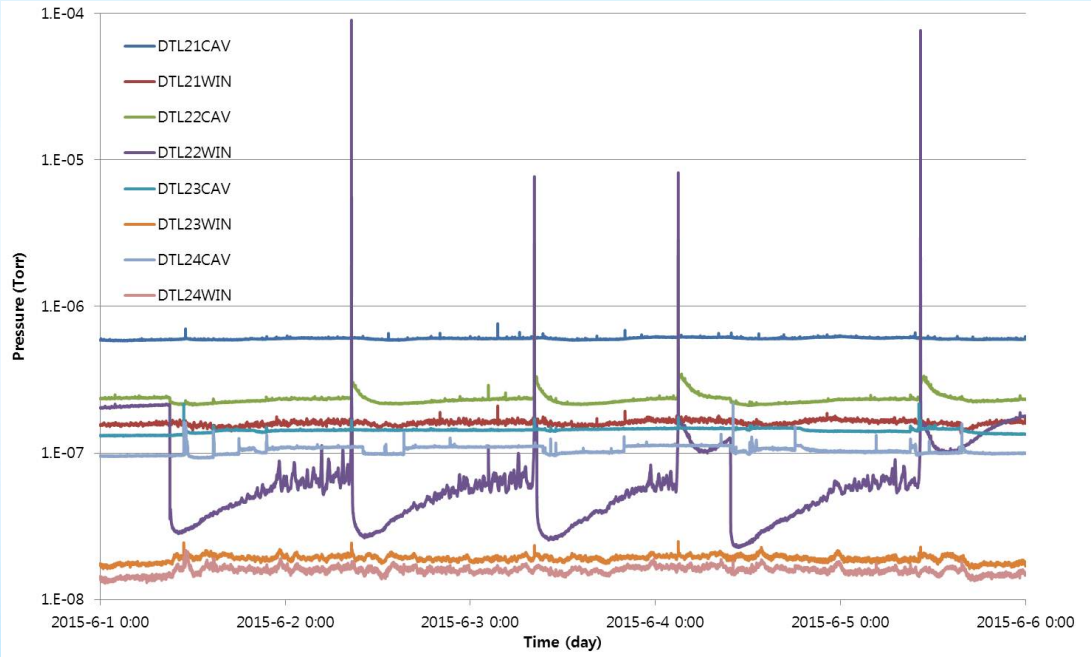
- Vacuum operation
  - 1 TMP + 3 IPs per DTL tank, 1 IP per DTL window
  - TMP: initial evacuation and turned off when ion pumps are operating
  - Normal vacuum level: 5 ~ 10 E-8 Torr
  - Occasional vacuum burst during operation with only ion pumps
- After TMP was turned on, vacuum bursts greatly reduced but not completely disappeared
- Change of 1 ion pump into 1 TMP is planned



Periodic vacuum burst when only ion pumps were operating

Shielding Door Issue

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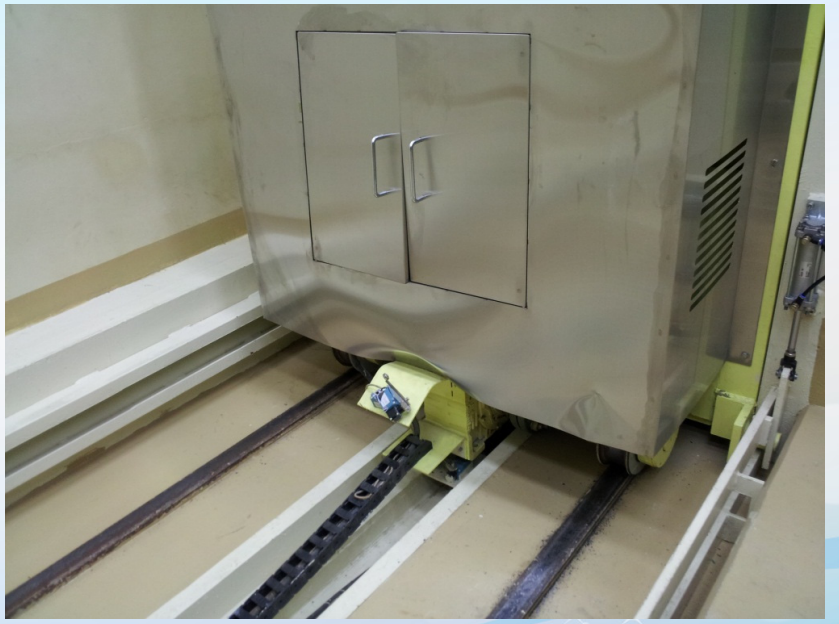
- Current beam service
  - Frequent shielding door operation (20~30 / day) -> failure in the shielding door system
  - Shielding door: Concrete 1.1 m + Steel 0.9 m -> 6 Ton
- Separate the low flux beam line (without shielding door operation)

Shielding door of 100 MeV target room



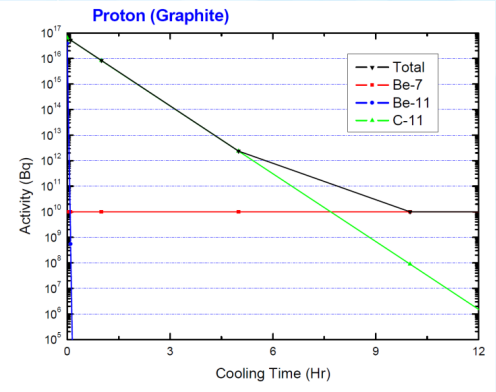
One example: Door controller failure

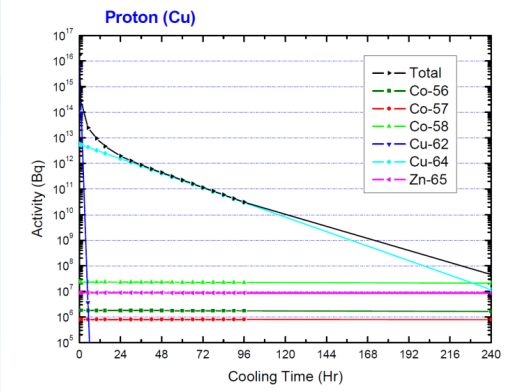
Beam Dump

KOMAC
Korea Multi-purpose Accelerator Complex
양성자가속기연구센터

- High power proton beam
  - Graphite is a good candidate with viewpoint of thermal and radiation issues
  - Neutron yield is less than 1/4 of copper, 1/2 of Aluminum

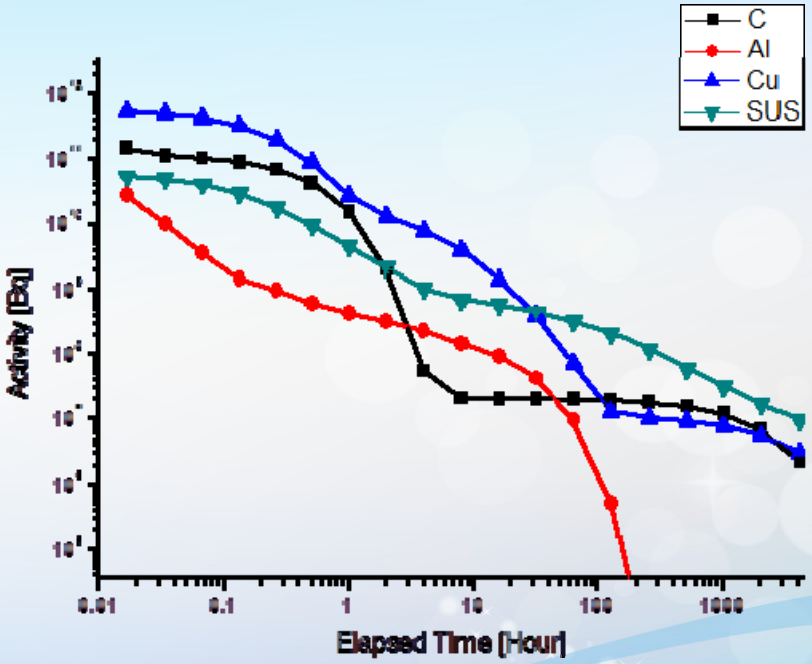
Radionuclides from graphite and copper





Neutron yield depending on proton energy

Proton Energy	Copper	Graphite	Aluminum
33 MeV	1.88E-02	7.69E-04	9.32E-03
100 MeV	2.29E-01	5.54E-02	1.25E-01

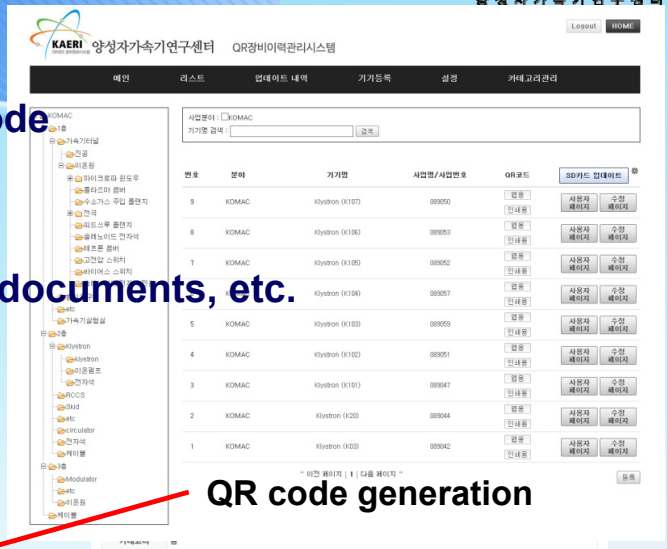


Residual radiation after 1hour irradiation (100 MeV, 1 uA)

History Management System

- History management system of the components by QR code
  - QR code & Tablet based system
  - Spare parts management, preventive maintenance
  - Including specification, maintenance history, drawing, documents, etc.

QR code scan with Tablet
(Possible scan distance depends on QR code size)



QR code generation

Component information

Summary

- Accelerator operation
  - Commissioned 100-MeV linac with 1 kW in 2013
  - Increased beam power to 10 kW in 2014 (30 kW in 2016)
  - Availability > 90% in 2015
  - Stable so far

- Beam service
  - Many users from various fields with complicated requirements
  - Beam line for RI production in 2016
  - Beam line for low-flux in 2017
  - Preparing beam lines one by one according to user demand

- Lesson learned
  - Multi-tanks driven by single klystron: works well
  - No MEBT between RFQ & DTL: good
  - High-duty ion source: BN coating problem
  - Pool type DTQ may cause long term reliability problem (water quality control essential)
  - Ion pump: not suitable for DTL when operated without TMP backup
  - Component history management system: good for operational efficiency

Thank you

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