한국기초과학지원연구원
KOREA BASIC SCIENCE INSTITUTE

다목적 이온빔 발생장치 개발 현황과 중성자 연구시설 추진 계획

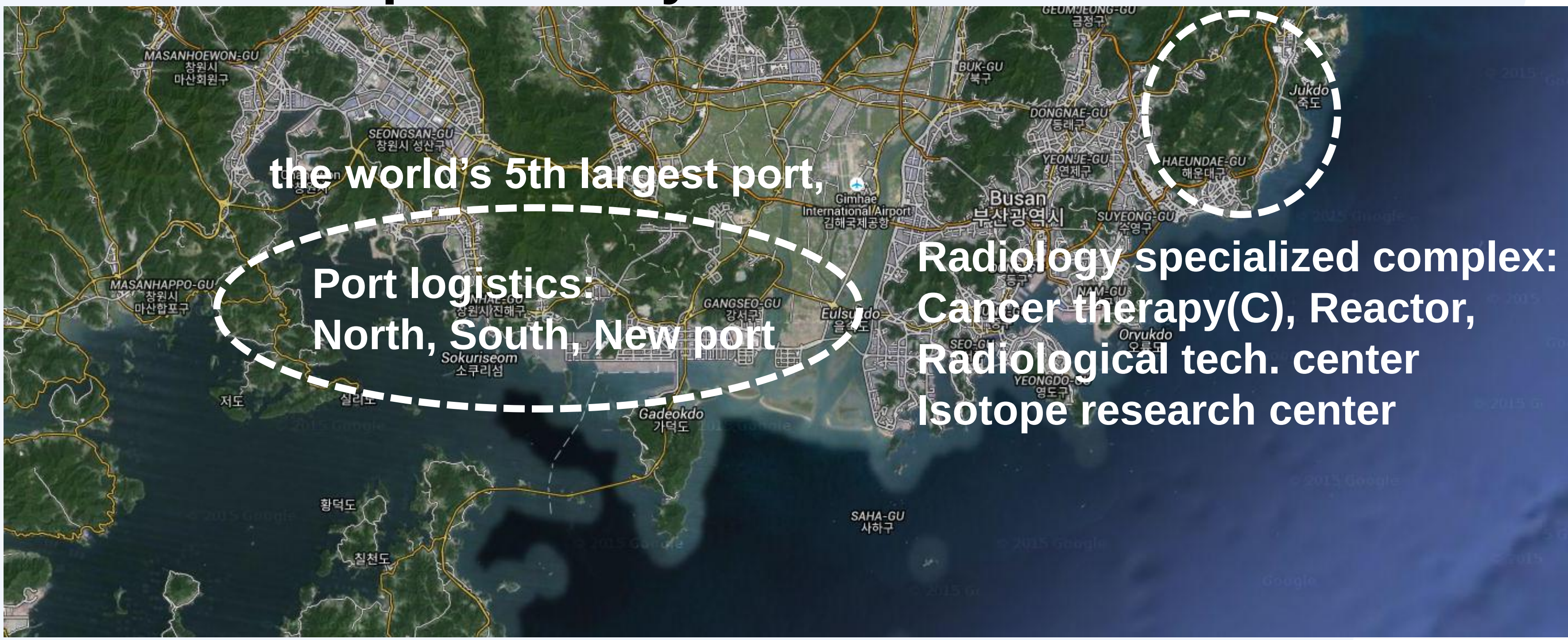
2016/10/26

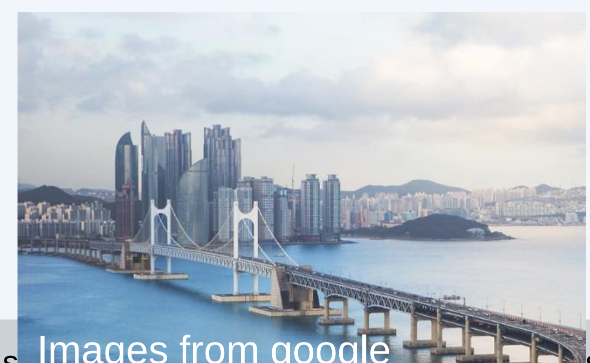
원 미 숙
Busan Center, Korea Basic Science Institute

Contents

Motivation

Busan metropolitan city





Images from google

Motivation

Research issues of KBSI (Busan center) specialized for Busan metropolitan city

Neutron Radiography based on accelerator

(Left) x-ray, (Right)Neutron imaging
Courtesy of Paul Scherrer Institute

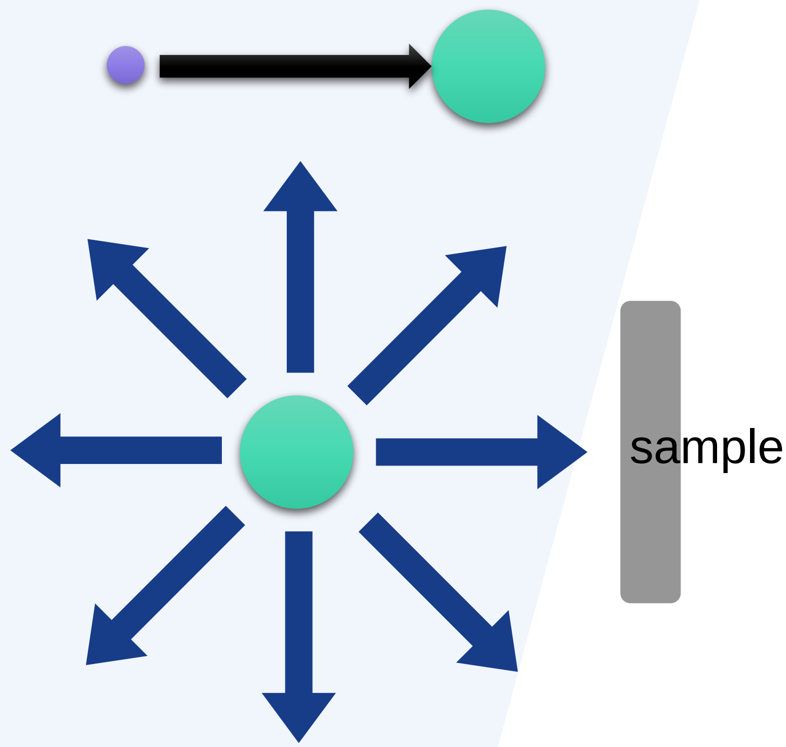
Cancer therapy based on accelerator

Particle cancer therapy using heavy ion (C)
Courtesy of nature.com(SIMENS)

Concept of neutron production: Inverse kinematics

Conventional reaction for neutron generation

$$^{3}H(d,n)^{4}He$$
$$^{2}H(d,n)^{3}He$$
$$^{7}Li(p,n)^{7}Be$$
$$\vdots$$



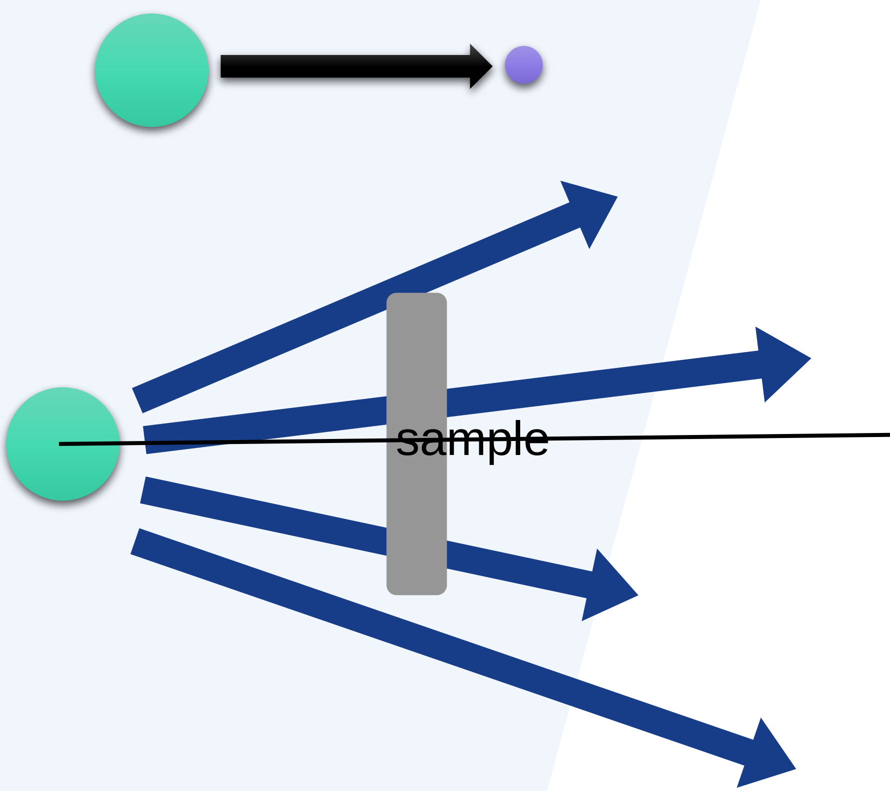
Normal kinematics: light particle interact with heavy element target. the produced neutron will be go to all direction.

- Most of neutrons are "wasted"
- Not proper to radiography

Concept of neutron production: Inverse kinematics

Inverse kinematics
for neutron generation

$$\boxed{p(^7Li,n)^7Be}$$



Inverse kinematics: the produced neutron will be go forward.
Production angle is limited about 30 degree and high intensity neutron beam.

Concept of the neutron production for radiography employing heavy ion linear accelerator.

- Most of neutrons are straight-forward
- Proper to radiography

Neutron yield by inverse kinematics

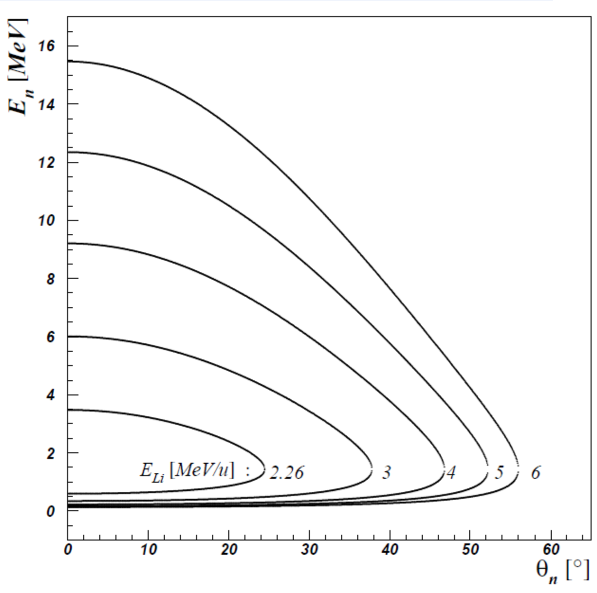
Requirement for KBSI Neutron radiography facility

→ Higher than 1pmA of $Li^{2\sim3+}$ beam intensity

→ ~2.5 MeV/u (17.5 MeV) of beam energy

→ Lower neutron incident angle

→ High efficiency detector for fast neutron detection



Fast Neutron Yield

$$Y_n = F_{Li} \cdot \rho \frac{N_A}{Z} \cdot L \cdot \sigma$$

Y : Neutron yield

F_{Li} : Flux of lithium ion beam (2.1×10^{13})

ρ : Density of hydrogen

N_A : Avogadro constant

Z : Atomic number of hydrogen

L : Target length

σ : Cross-section of reaction

Li energy (MeV/u)	Max. angle (deg)	Cross-section (barn)	Neutron flux (n/cm^2 sec)	Max. neutron energy (MeV)
2.26	24.4	0.536	5.2×10^{13}	3.4

J. Park and J. Ahn, Sae-Mulli, 54, pp.171, 2007

Overview of KBSI Accelerator Project

Motivation

- Fast neutron radiography facility
- Achievement: High-yield neutron flux
- Implementation: Inverse kinematics
- Requirements: Li ion beam + hydrogen target
- Pros.: effective and compact

28 GHz SC ECR ion source

- 3solenoids+1 Hexapole SC magnet
- LHe re-condensing cryostat
- 28 GHz-10 kW gyrotron
- Large bore plasma chamber
- Output beam: 84 keV (12keV/u)

KBSI Accelerator Systems

LEBT System

- enable to separate the ions from IS
- satisfy the RFQ input condition: beam acceptance, current, size and etc.
- 1dipole+3solenoids+2quadrupoles
- 2 diagnostic chambers

Linear Accelerator

- Reference particle: Li^{3+}
- Freq.=165 MHz
- Output beam :
  ~ 3.5 MeV@RFQ
  ~ 18 MeV@DTL

KBSI Accelerator System Layout

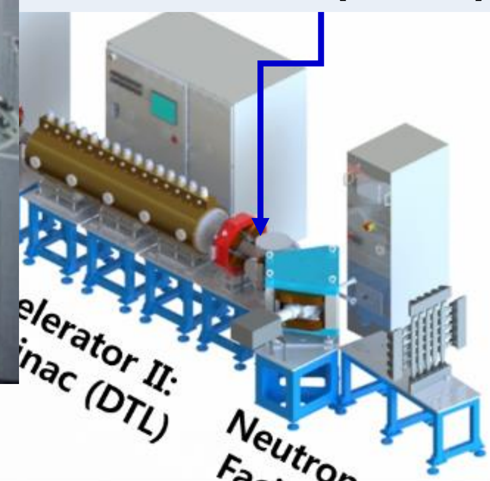
Heavy ion accelerator employing 28 GHz superconducting ECR ion source

ed analytic instruments

~ 500 keV/u (3.5 MeV)

Neutron application

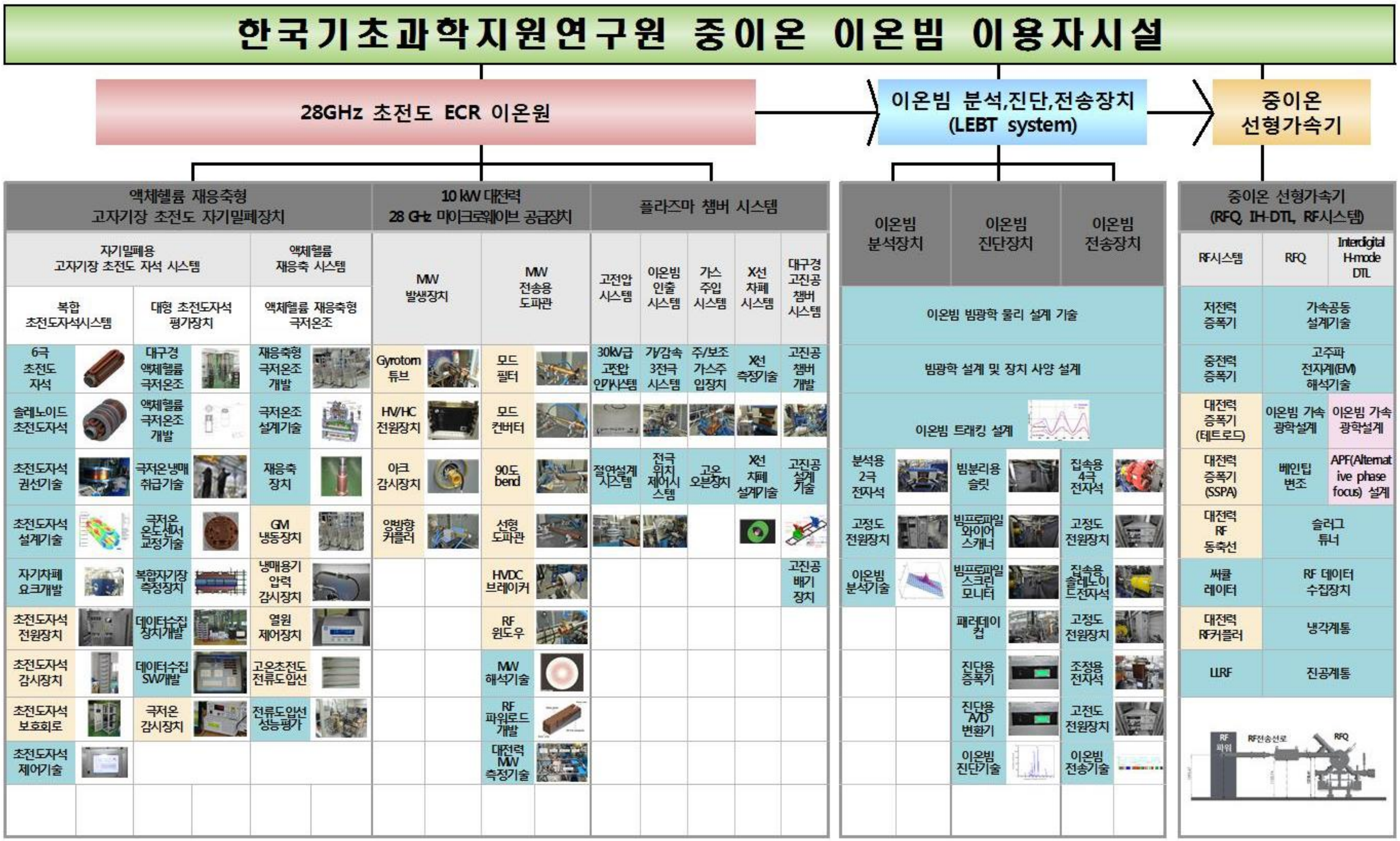
ation: ~ 2.7 MeV/u (18 MeV)



$p(^{7}Li, n)^{7}Be$ Inverse kinematics →

Neutron production

개발 전략

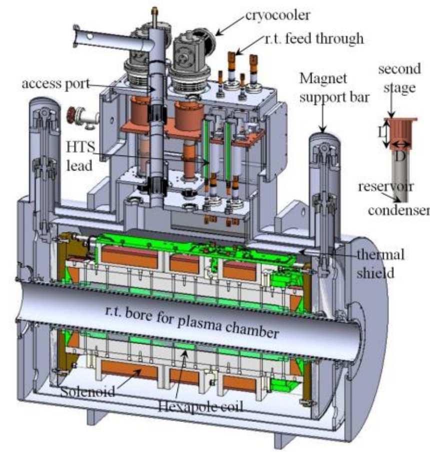


	한국기초과학지원연구원이 개발하고 국내 중소기업과 공동제작하여 확보한 기술 및 장치
	국내에서 제작이 불가능하여 도입한 장치
	향후 자체기술로 개발 예정 장치

SC-ECRIS

28 GHz MW system

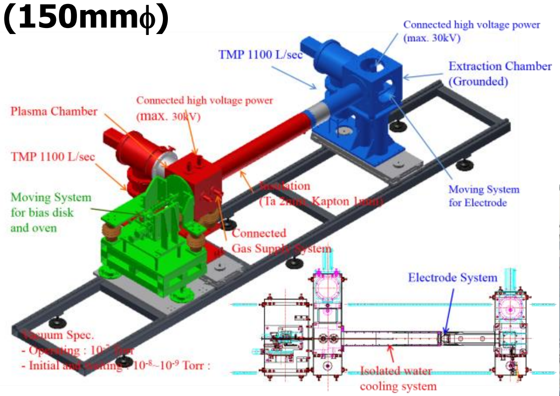
No boil-off LHe cryostat



- 4 GM cryocoolers
- 4 LHe recondenser
- HTS current lead: 300 A (6ea), 500 A (2ea)
- temperature monitor: 7 cernox sensors
- level monitor: 2 LHe level sensors

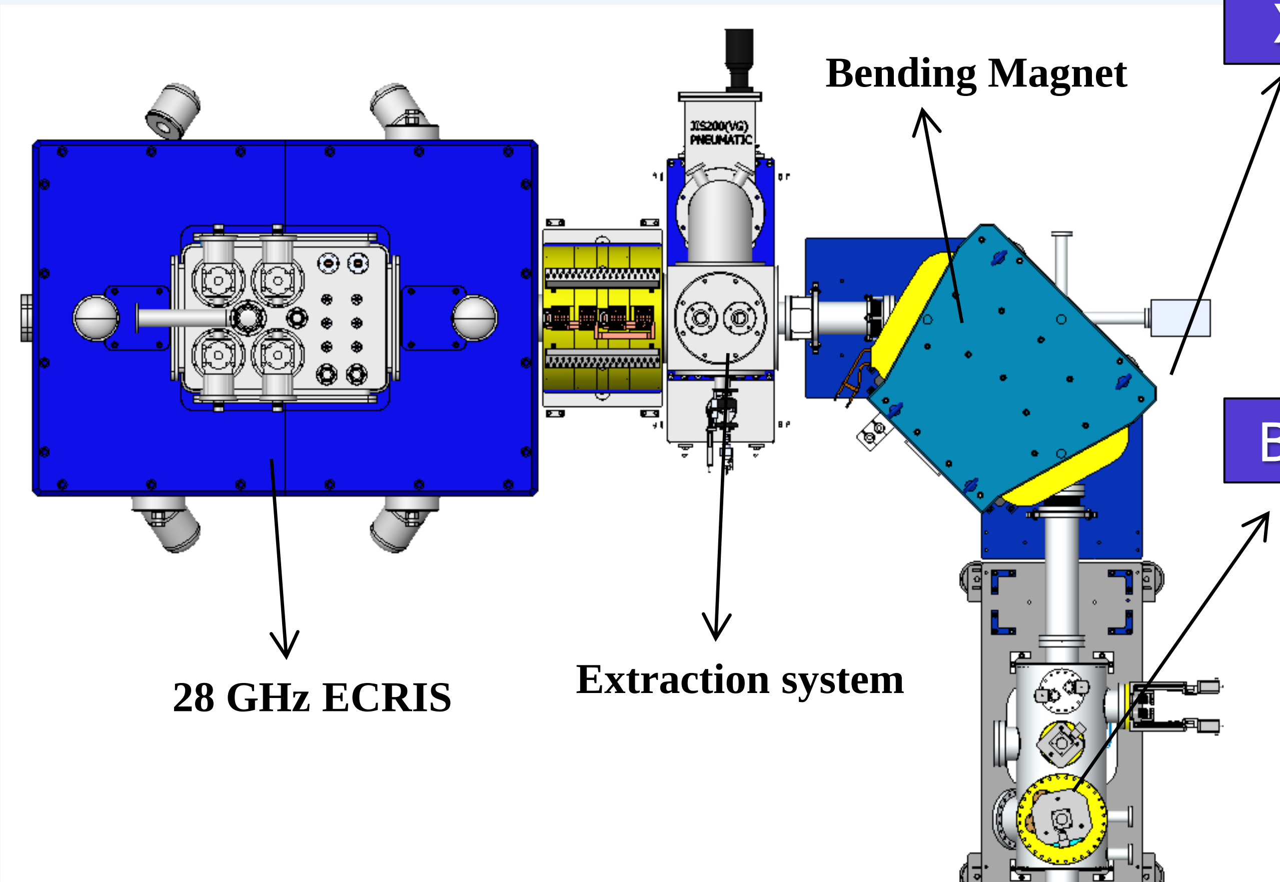
플라즈마 챔버/Extraction System

Large diameter plasma chamber (150mmϕ)

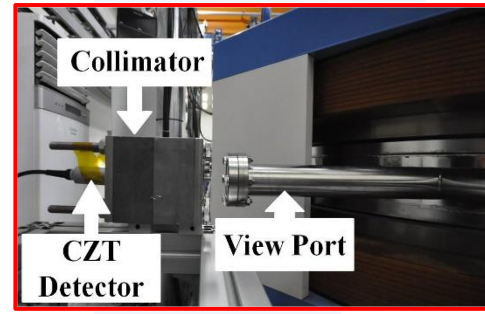


SC Magnet

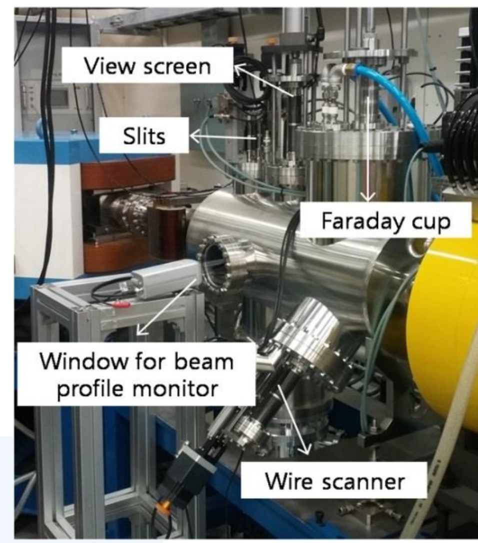
Beam measurement system in LEBT



X-ray detection system



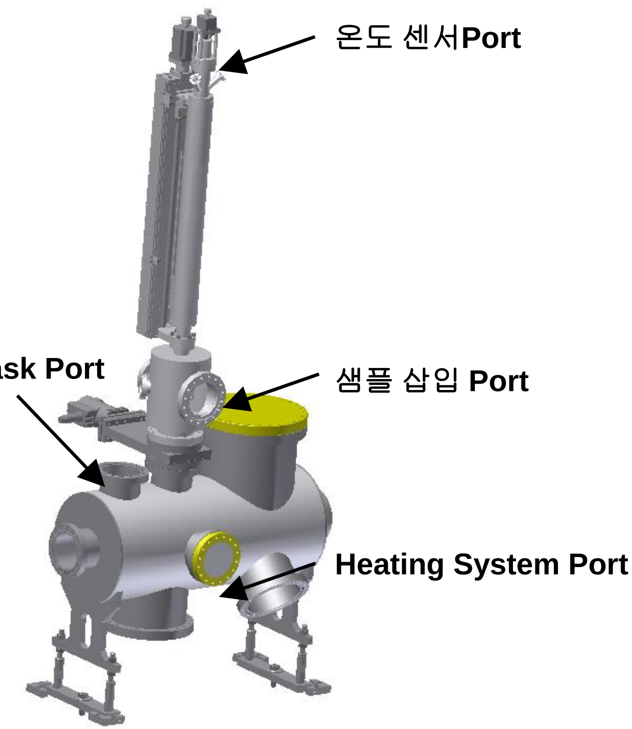
Beam diagnostic system



- Extracted beam spectrum are analyzed using dipole magnet
- Also, x-ray from plasma chamber are measured with x-ray detection system
- Diagnostic tools are ready to evaluate the ion beam quality.

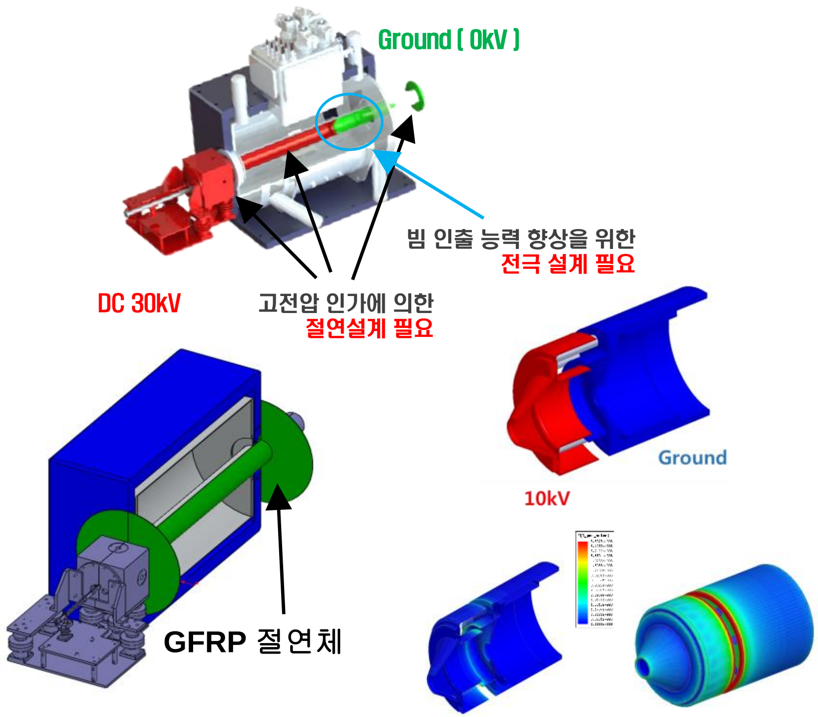
이용자 활용을 위한 기반 장치 구축

이온주입 전용챔버 개발 및 운영



-샘플 스테이지 냉각 시스템 도입으로 이온주입 중 상온 구현
-샘플 Heating gun을 이용한 온도 조절
-Grid & Mask와 샘플 스테이지 무빙을 통한 샘플 내 이온주입 편차 개선

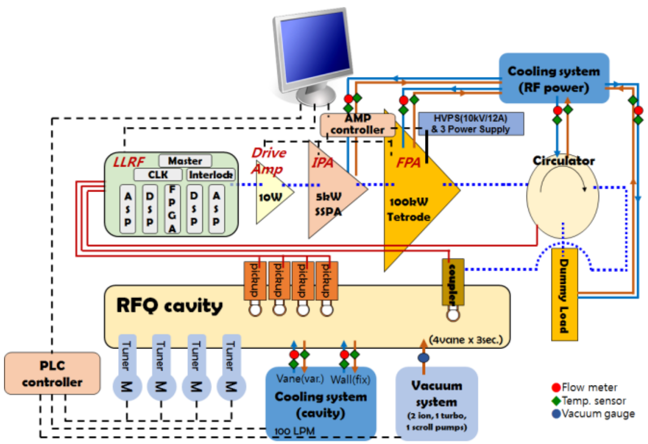
고전압 이온빔 가속부 성능향상 설계



- ANSYS를 이용한 빔 인출 능력 향상을 위한 인출 전극 절연 파괴 개선 및 인출 전극 형상 최적 설계를 통한 유지보수

RFQ 중이온 선형가속기용 Power Amplifier

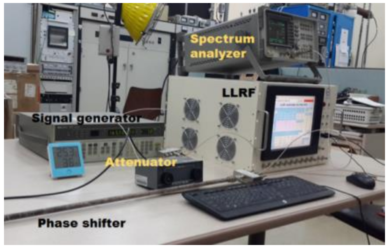
10 kW, 165 MHz RF 증폭기 개발



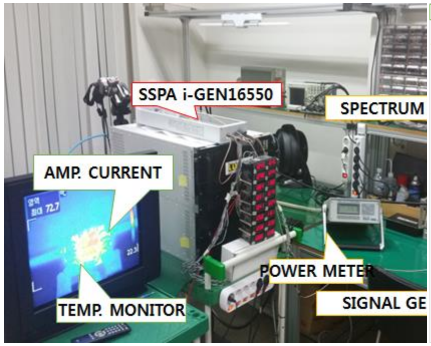
RF amplifier 제작

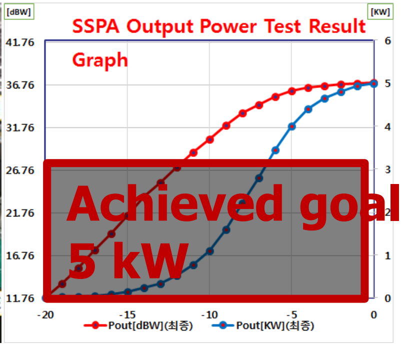
- Frequency and Band-width : 165[MHz] ±5[MHz]
- Stabilities : Output < ±1[%], Phase < ±1[Degree]

LLRF SW/HW 개발



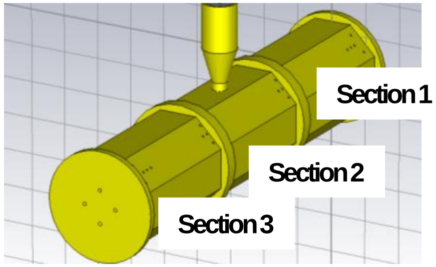
SSPA 개발

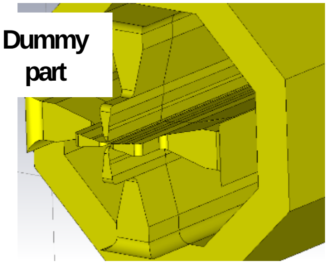




RFQ

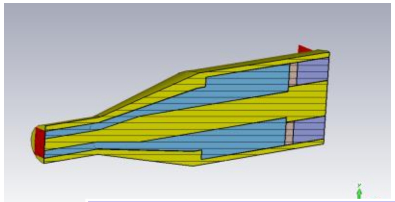
가속공동 섹션 별 튜닝을 위한 더미개발

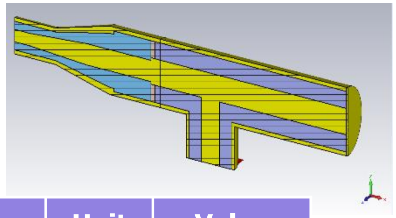




- 전체 튜닝에 앞서 각 Section 별 튜닝 필요
- 각 Section 별 튜닝을 위해 dummy part 필요
- Dummy part 는 2개로 3 section 이 공유

10 kW RF 파워공급을 위한 파워커플러 개발

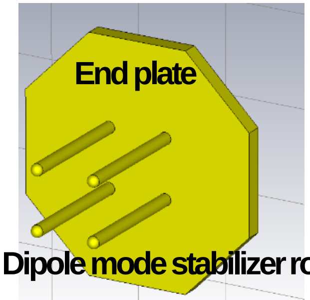


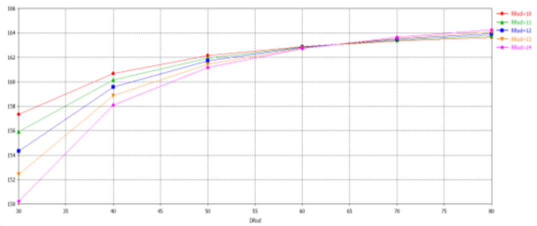


Parameter	Unit	Value
Resonance Frequency	MHz	165
Return Loss @165MHz	dB	-57.9

-Outer Conductor/Inner Conductor Impedance Matching
-T junction (λ/4) 도입을 통한 Resonance Frequency Matching

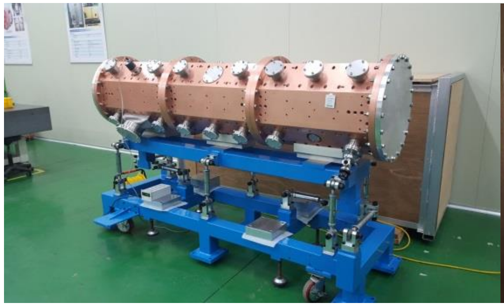
Dipole mode stabilizer 개발

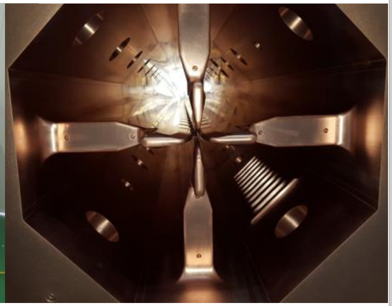




- RFQ 가속공동의 주파수특성 향상을 위한 mode stabilizer 적용
- Mode stabilizer: quadrupole모드에 영향을 주지 않고 dipole 주파수만 조절, 위치-길이-크기 최적화 연구

RFQ Design 및 제작



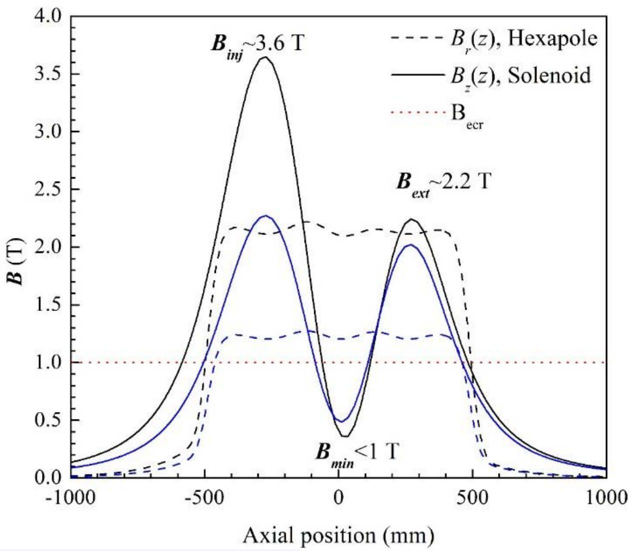


- KBSI RFQ consists of 3 section
- RF power coupler: 1
- Slug Tuner: 29

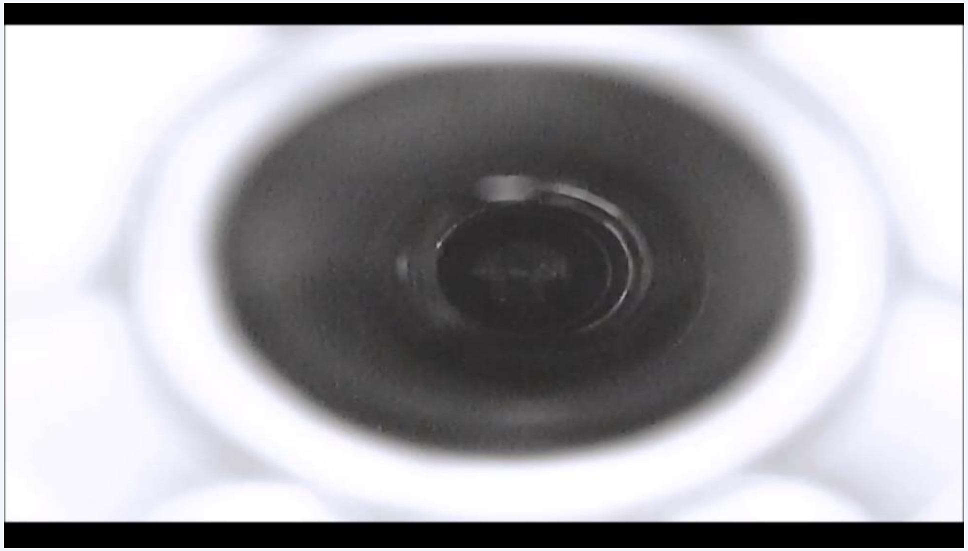
Operation of 28 GHz SC ECR ion source

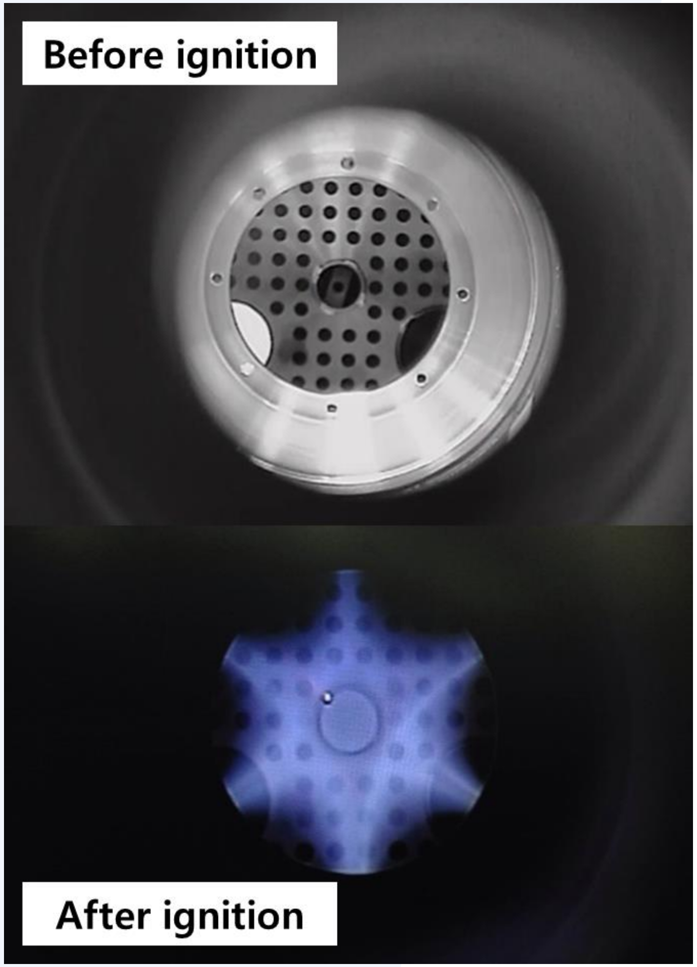
- The first ECR plasma ignition was performed in August 2014
- The first ion beam was extracted from the 28 GHz ECR ion source in 2015
- Optimization of ECR ion source with various conditions is under way (2015)
- Further optimization study about ECR ion source will be conducted

ECRIS for first plasma ignition		
Gas type	Ready	Ar
SC magnet	Ready (limited)	Solenoid was qualified
		HP was limited yet (83% of design)
Plasma chamber	Ready	~ 10^{-8} Torr (Before gas injection)
		~ 10^{-6} Torr (After gas injection)
Microwave	Ready	28 GHz, below 1 kW



First plasma ignition

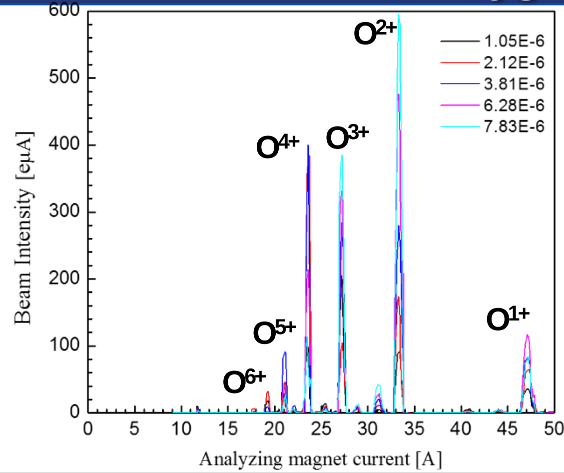




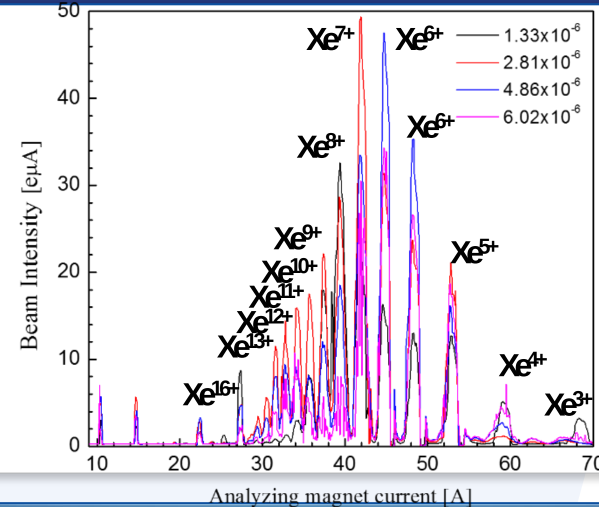
First ECR plasma ignition: All of apparatuses were ready as of August, 2014

First ion beam extraction (as of 2015)

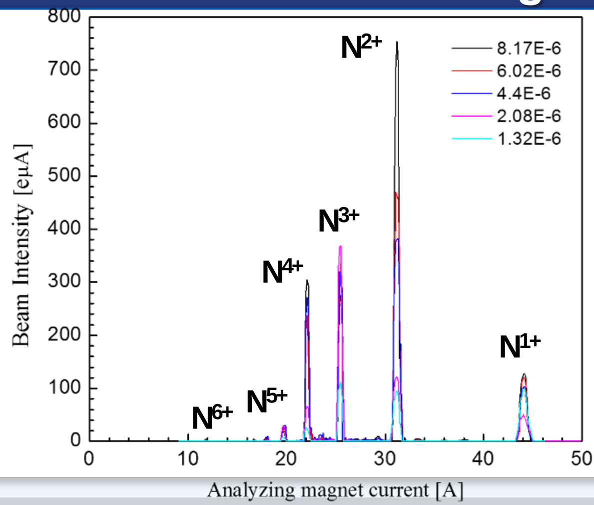
Extracted ion beam: Oxygen



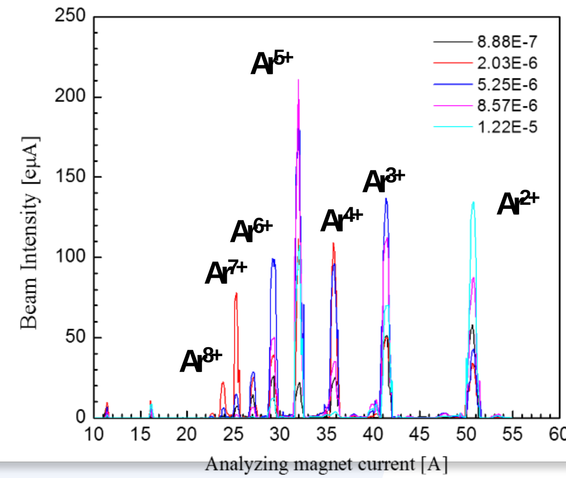
Extracted ion beam: Xenon



Extracted ion beam: Nitrogen

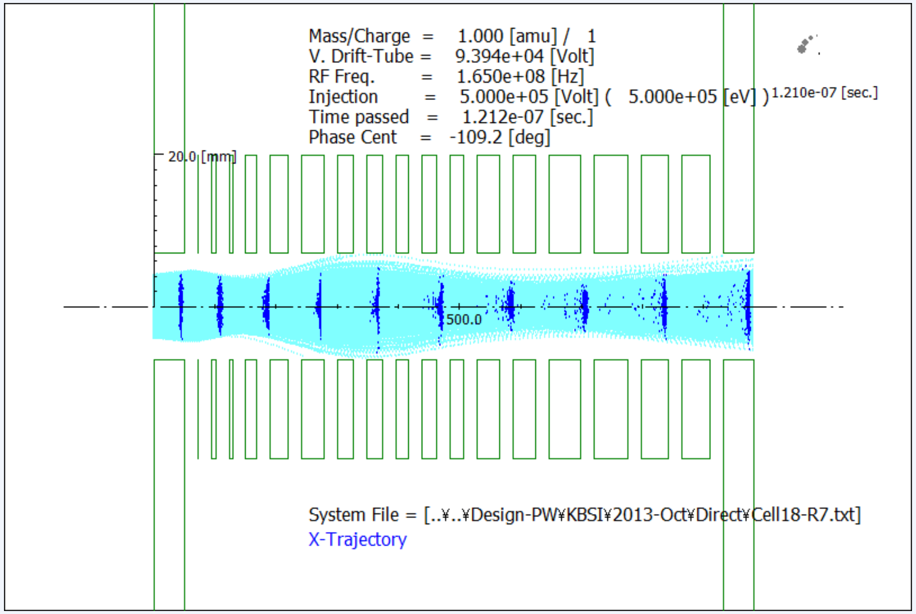


Extracted ion beam: Argon

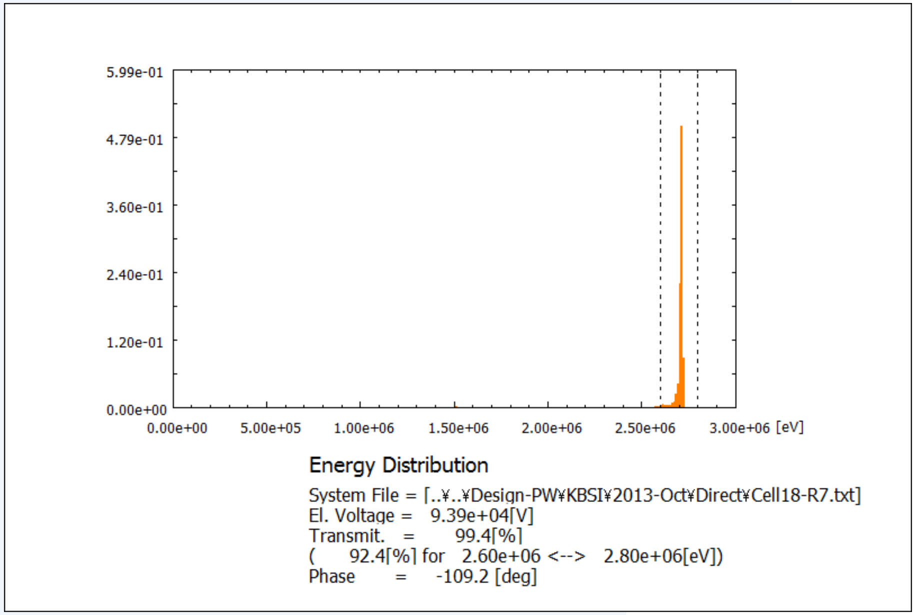


Beam dynamics simulation - preliminary study

Particle trajectory



Energy distribution

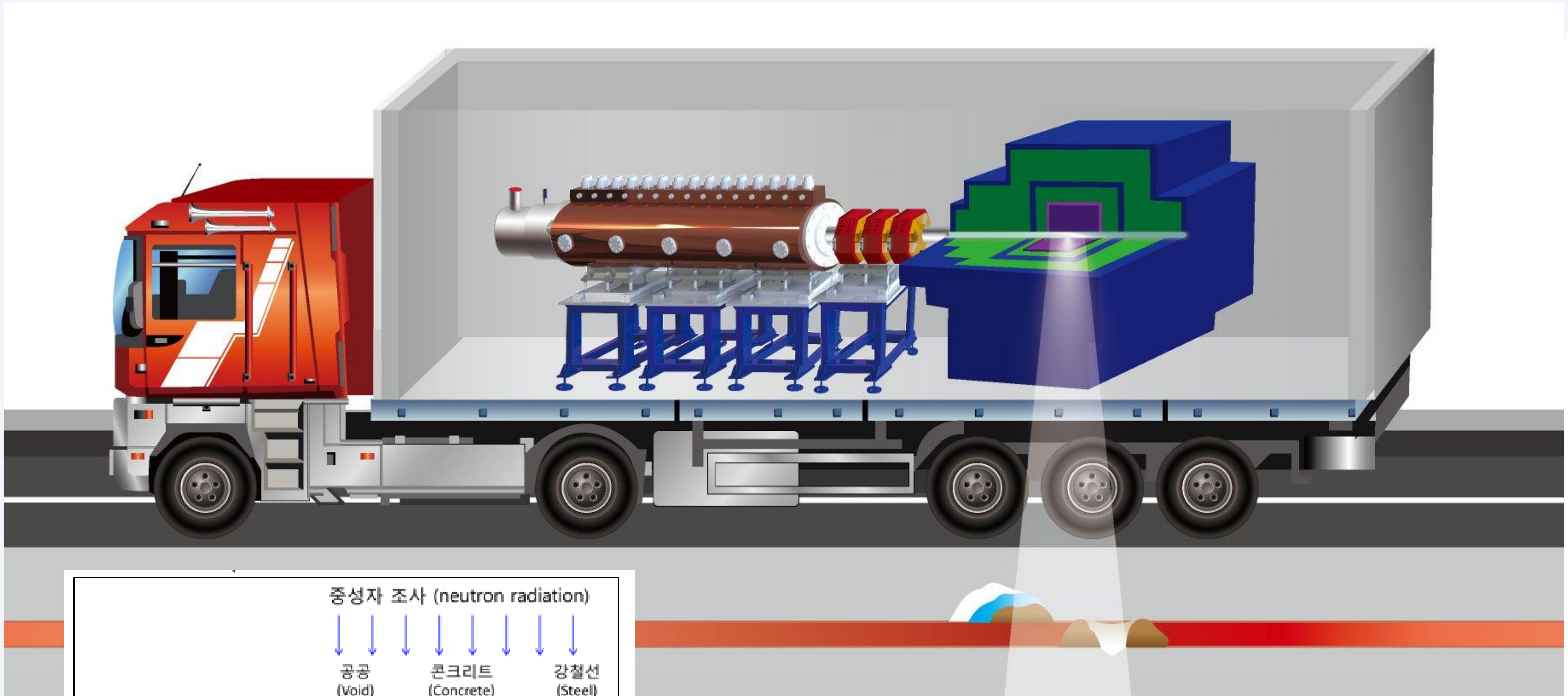


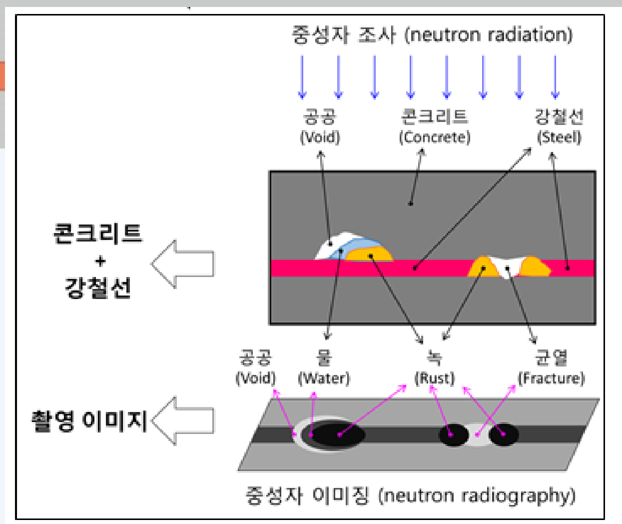
- Total length of DTL: < 2.3 m
- Particle transmission rate: > 92%
- Beam energy: 2.7 MeV/u
- Further design and study for DTL is under way

Courtesy of Dr. S. Ogata @ Atelier Modeling

KBSI KOREA BASIC SCIENCE INSTITUTE

구조물 진단용 차세대 이동형 **NDT** 플랫폼 구축 사업기획





가속기 기반 이동형 중성자 비파괴
검사장치 개략도

(개발 ①) 입자빔 가속장치 개발

- 이온원 : 양성자빔 인출 > 1 mA
- 가속시스템 : 가속에너지 < 7 MeV, 이동형 선형가속 시스템 개발
  빔 전송 시스템: 가속빔 측정장치, 빔 전송장치 개발(타겟전송)

(개발 ②) 중성자발생 및 차폐기술개발

- 이동형 중성자 발생장치 및 검사장치 (검출기)의 중성자 빔 정지를 위한 차폐 기술
  - BPE(Borated polyethylene)/PE (Polyethylene)를 이용한 고에너지·경량 중성자 차폐 개발
  - Graphite를 이용한 중성자 차폐 보조 기술 개발
  - 납을 활용한 감마선 차폐 기술 개발

(개발 ③) 검출기 및 이미징 기술 개발

- 고분해능 중성자 검출장치 개발(분해능 <30 mm 이하)
  - 픽셀크기 30x30 mm^2 이하의 넓은 FOV (Field of view, 화각)를 갖는 플라스틱 섬광체 기반 대면적 이동형 중성자 검출장치 개발
  - 중성자 반응 단면적이 큰 Gd 또는 Li 기반 섬광체를 활용한 CCD 타입 고 분해능 이동형 중성자 검출장치 개발
- 다양한 구조의 교량 및 콘크리트 내 중첩 강재 판독을 위한 중성자 영상검사장치 (X-ray 라미노그라피 영상기술을 활용)

(개발 ④) 이동형 기술 개발

- 진공 및 고전압 측정/차폐 시스템 및 운영 기기(전원, C-arm 등) 운반용 이동 수단 개발

(개발 ⑤) 구조물 안전진단 기술 개발

- 교량·도로 구조물의 NDT 장비 안전진단 활용 기술 개발
  - 구조물 안전진단을 위한 장비 최적화 기술 개발
  - 중성자 발생 및 차폐 안전성 확보 기술 개발
- 교량·도로 구조물의 NDT 수집데이터 결과 분석 및 평가 기술 개발
  - 교량·도로 구조물 NDT 이미지 결과 분석 기술 개발
  - 안전진단 적용을 위한 NDT 이미지 결과 데이터 분석 기술 개발

(개발 ⑥) 현장적용 및 운용기술

- 구조물의 안전도 평가 기술 개발
  - 구조물 내부 건전성 평가를 위한 상태평가 지표 및 정량화 기술 개발
  - 구조물 내부 상태평가 기반 안전성 평가 및 지표 기술 개발
- 교량·도로 구조물에 현장 적용 가능한 실용화 기술 개발
  - 교량·도로 구조물의 조사 위치, 방법, 주기 등 최적 점검 프로세스 개발
  - NDT 장비의 현장평가 사용성 최적화 개발

Future plan

- Optimization of ECR ion source by system overhaul
- Beam diagnosis under LEBT operation
- Beam acceleration using RFQ LINAC
- Engineering design of Drift Tube LINAC
- Development of neutron radiography facility
- New building for heavy ion accelerator for ion beam user

Future plan: Heavy ion beam utilization building

- Construction: 2015-2018
- 1 Main accelerator and beam utilization building, 1 supporting building

Members of ion beam application research team