

International Topical Meeting on  
Nuclear Research Applications & Utilization of Accelerators  
Vienna, Austria, May 4-8, 2009

# Proton Engineering Frontier Project<sup>\*</sup>

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<sup>\*</sup> Supported by the Ministry of Education, Science and Technology of Korea.

## **I. Overview**

## II. Accelerator Development

## III. Beam Utilization & Applications

## IV. Activities for the Future

- ❖ **Project : Proton Engineering Frontier Project (PEFP)**  
21C Frontier R&D Program, MEST, Republic of Korea
- ❖ **Objectives :**
  - To develop a High Power Proton Linac (100MeV, 20mA)
  - To develop Beam Utilization & Accelerator Application Technologies
  - To Industrialize Developed Technologies
- ❖ **Period : July 2002 – March 2012 (10 years)**
- ❖ **Budget : 128.6 B KRW (Gov. 115.7 B, Private 12.9 B)**  
**(Gyeongju City : Site, Buildings & Supporting Facilities)**



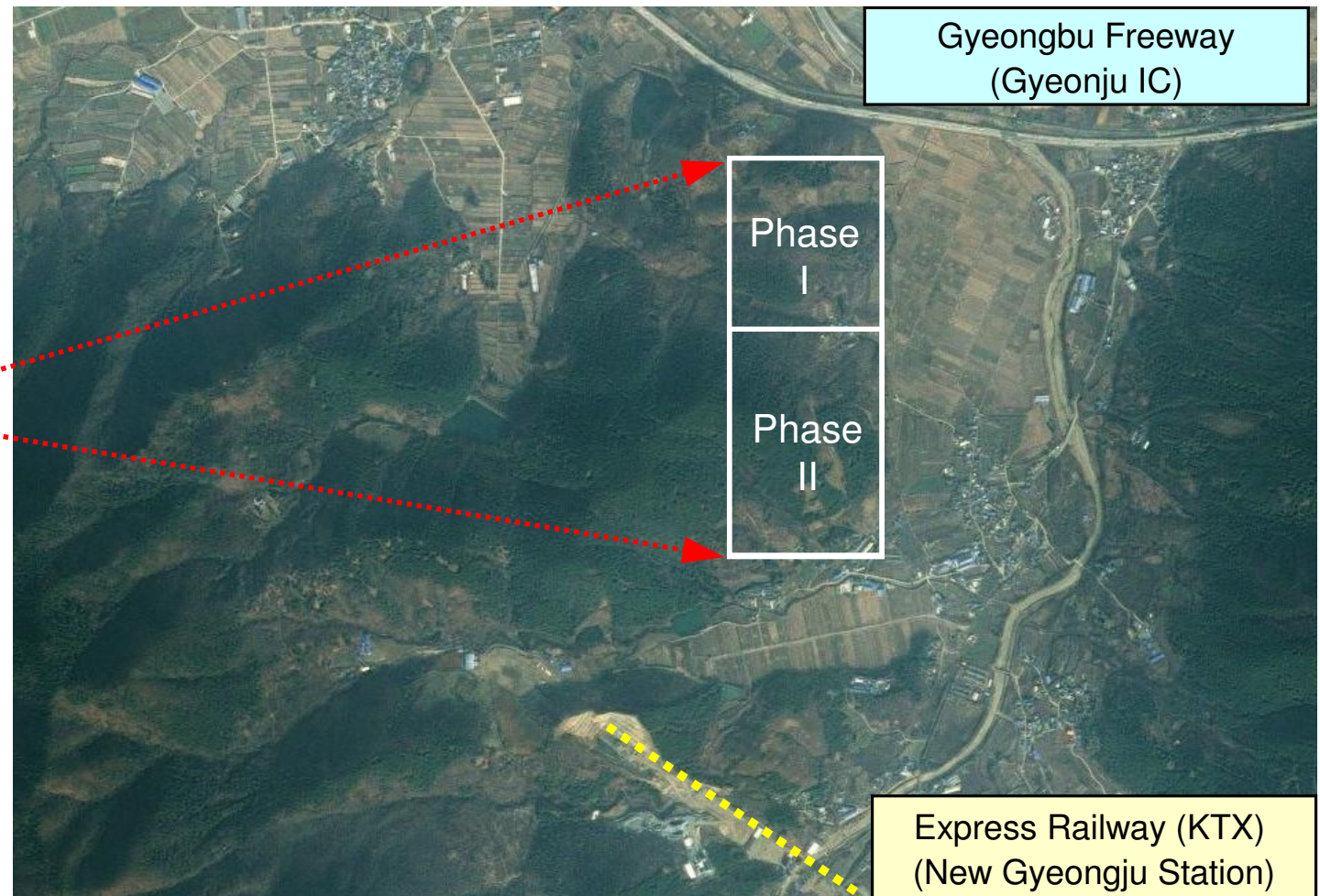
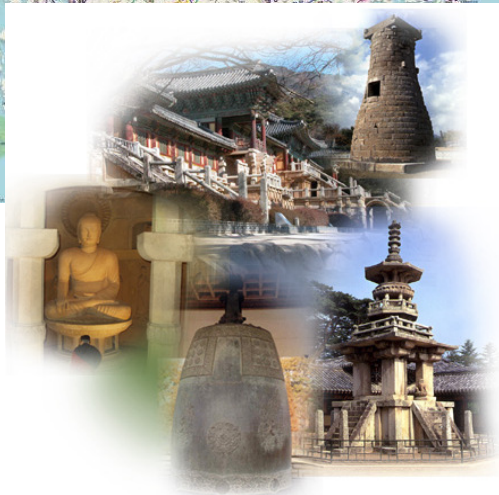
# Project History

Step	Year order	Calendar		What's done
		Year	Month	
I	1	'02	7	Approved and Lunched the Project
			9	Started 1 <sup>st</sup> year with 17 sub-projects
			12	1 <sup>st</sup> public subscription for the site (Daegu, Iksan, Yeonggwang, Choerwon, & Chuncheon)
		'03	4	Cabinet Council suspended the site Selection process and bound it to Nuclear Waste Storage Site
			5	2 <sup>nd</sup> public subscription for the site in conjunction with Nuclear Waste Storage Site
	2	'03	7	Started 2 <sup>nd</sup> year with 21 sub-projects
		'04	2	3 <sup>rd</sup> public subscription for the site in conjunction with Nuclear Waste Storage Site
	3	'04	7	Started 3 <sup>rd</sup> year with 23 sub-projects
		'05	2	Project assessment for the 1 <sup>st</sup> step
			4	Completed project plan for the 2 <sup>nd</sup> step
			6	4 <sup>th</sup> public subscription for the site in conjunction with Nuclear Waste Storage Site (Gyeongju, Kunsan, Yeongdeok, & Pohang)
			6	Signed the project contract for the 2 <sup>nd</sup> step (between KAERI & MOST)
II	1	'05	7	Started 1 <sup>st</sup> year of the 2 <sup>nd</sup> step with 18 sub-projects
			11	Gyeongju hosted the Project with 89% favorable residential vote
		'06	2	Selected Geoncheon as the project site in Gyeongju city
			3	Signed cooperation contract (between KAERI and Gyeongju city)
	2	'06	4	Started 2 <sup>nd</sup> year of the 2 <sup>nd</sup> step with 19 sub-projects
	3	'07	4	Started 3 <sup>rd</sup> year with 19 sub-projects
		'08	2	Completed project plan for the 3 <sup>rd</sup> step
III	1	'08	4	Project assessment for the 2 <sup>nd</sup> step
			4	Started 1 <sup>st</sup> year with 8 sub-projects
			5	Signed the project contract for the 3 <sup>rd</sup> step (between KAERI and MEST)
	2	'09	4	Started 2 <sup>nd</sup> year with 8 sub-projects

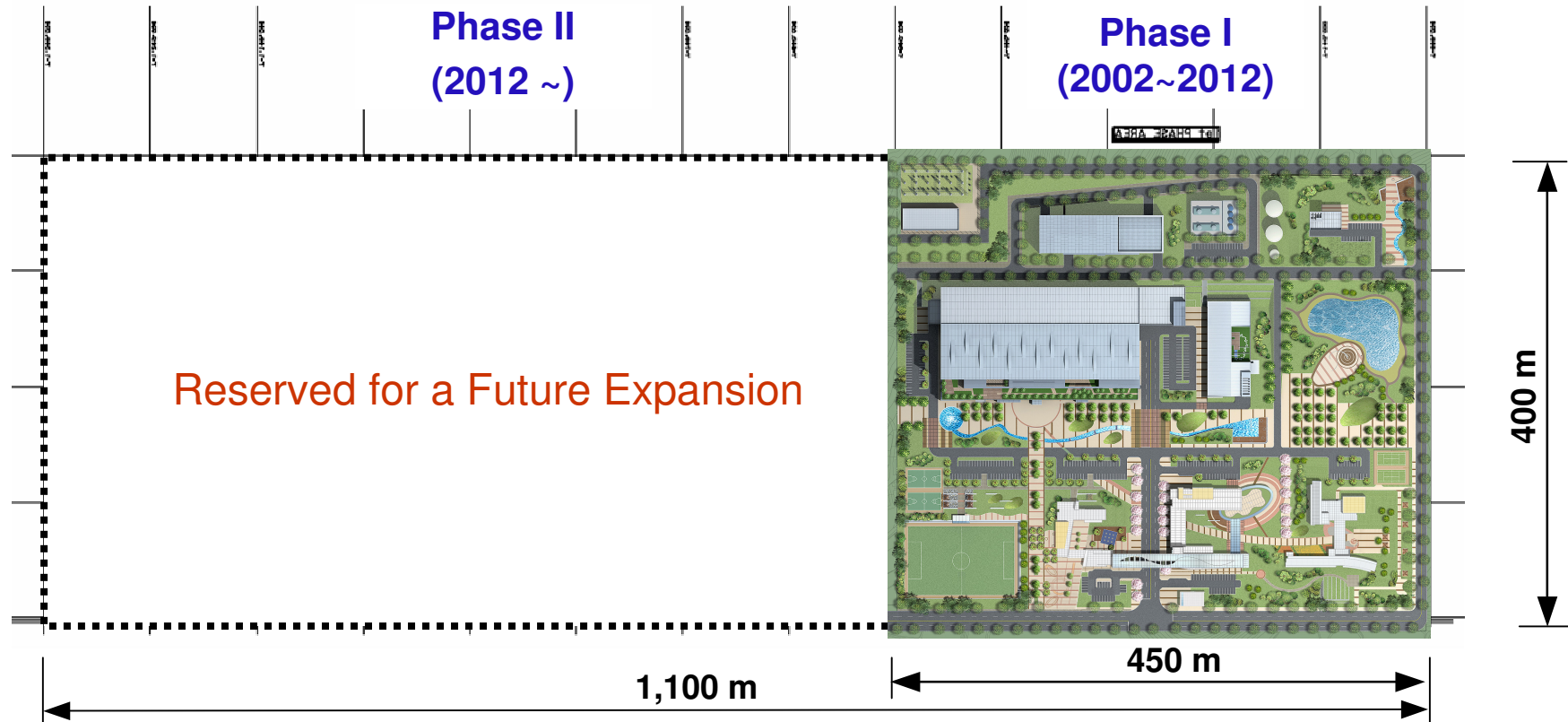


## □ Project Site

- ❖ Gyeongju provided the site (area: 440,000 m<sup>2</sup>)  
(The capital of Shilla dynasty for 992 years, from BC 57 to AD 935.)



## □ Site Layout





# □ Site Plan for the PEFP

## Proton Accelerator Research Center



□ Accelerator Tunnel

□ Experimental Hall

□ Ion Beam Facility

□ Utility Building

□ Substation

□ Cooling Tower

□ Water Storages

□ Main Office Building

□ Regional Cooperation Center

□ Dormitory

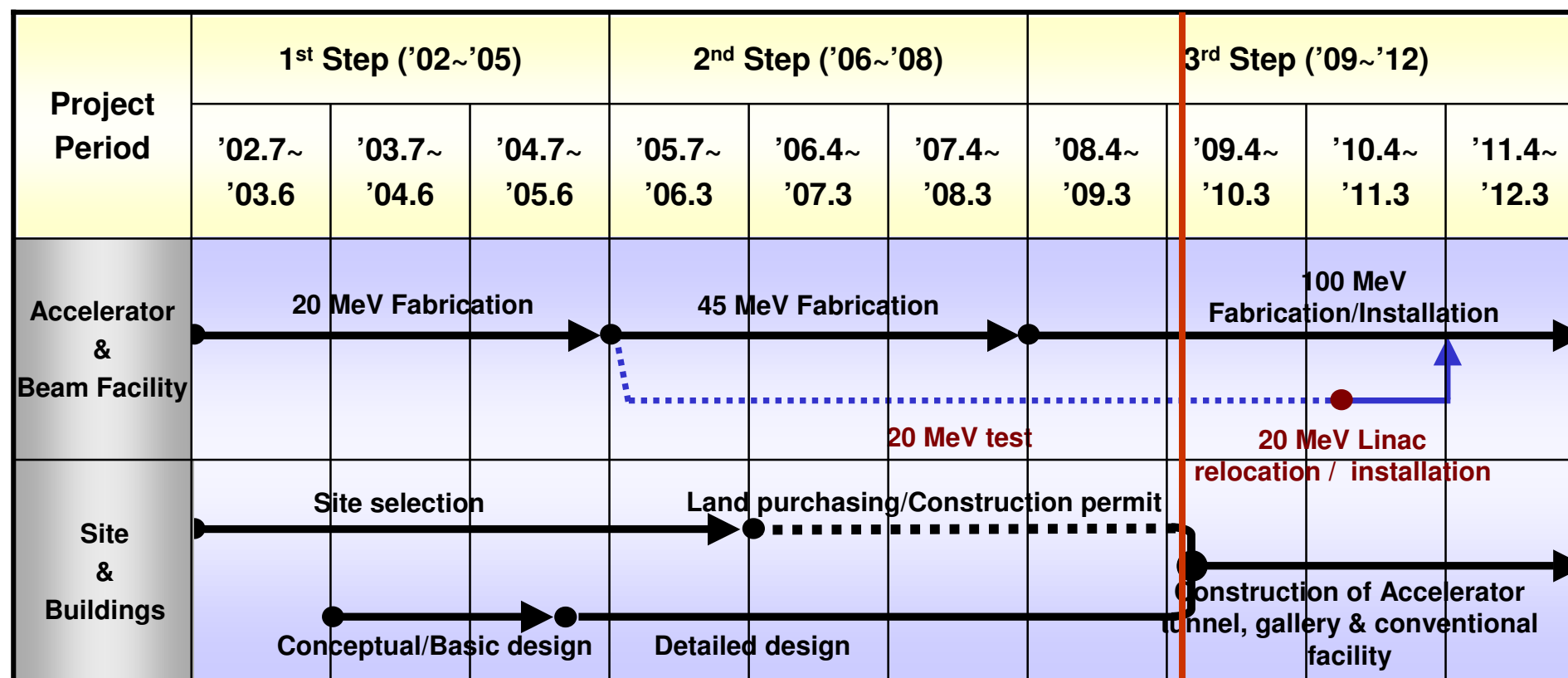

□ Information Center

□ Sewage Plant



# Project Schedule as of May 2009

Now

**Ground Breaking**

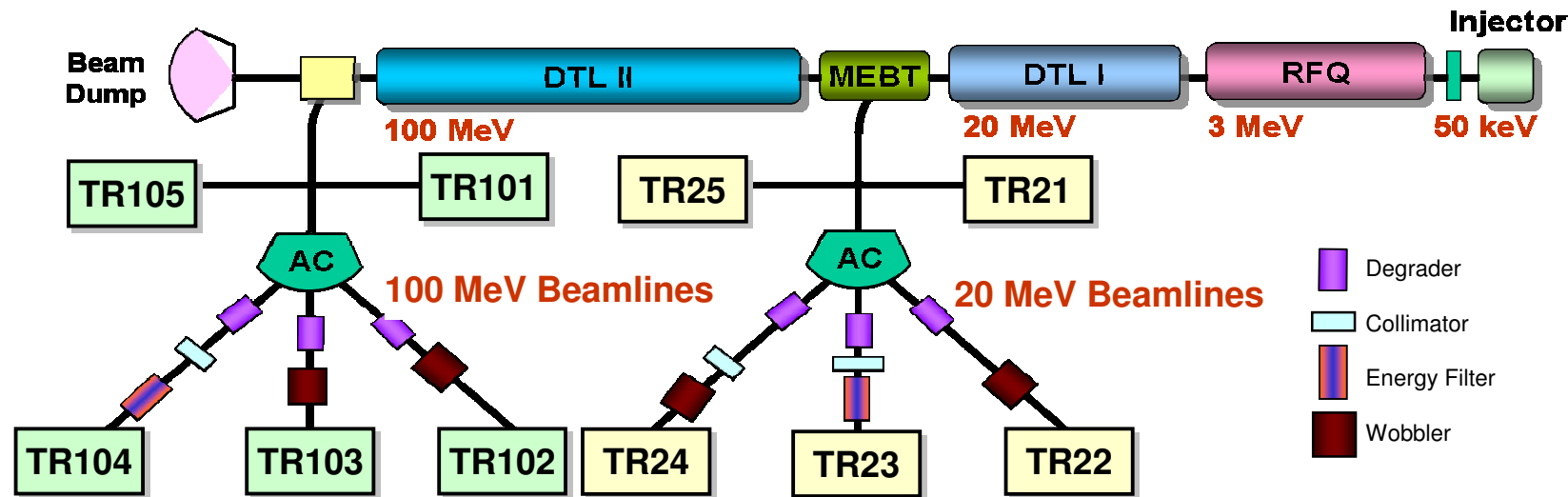
## I. Overview

## **II. Accelerator Development**

## III. Beam Utilization & Applications

## IV. Activities for the Future

# □ Schematics of PEFP Linac & Beamlines



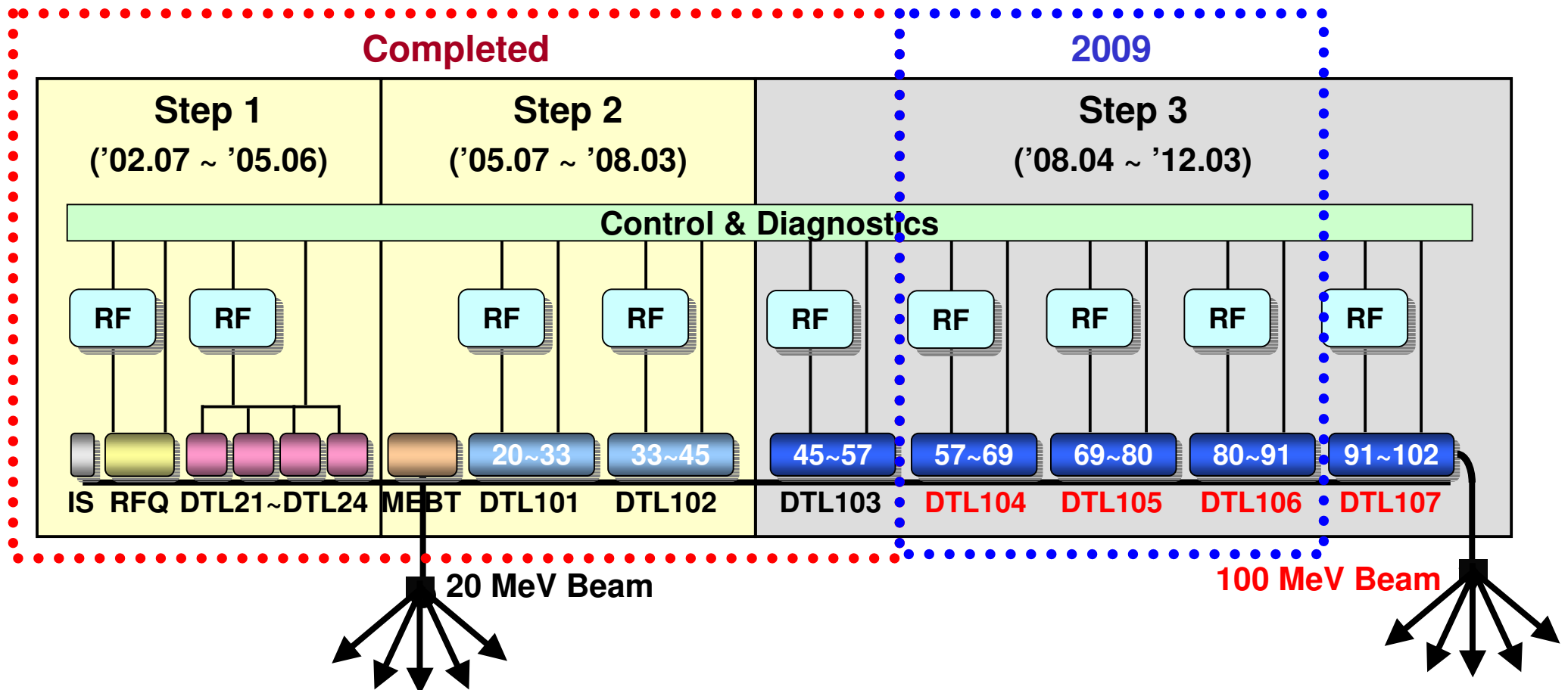
Parameter	DTL I	DTL II
Output Energy (MeV)	20	100
Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	<b>24</b>	<b>8</b>
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Beam Power (kW)	96	160

## Features of the PEFP linac

- 50 keV Ion Source (Duoplasmatron)
- 3 MeV RFQ
- 20 & 100 MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV



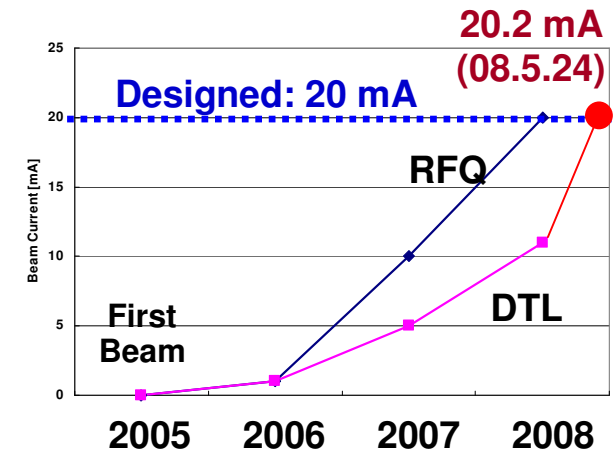
# □ Status of Accelerator Development



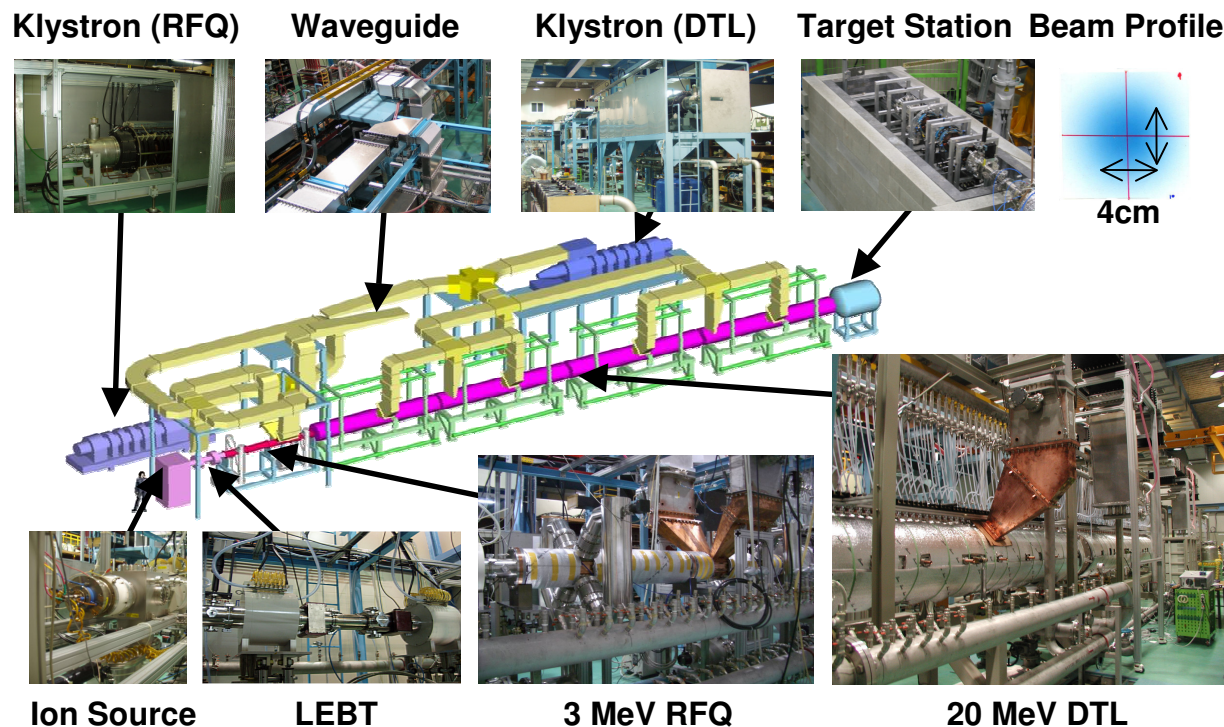
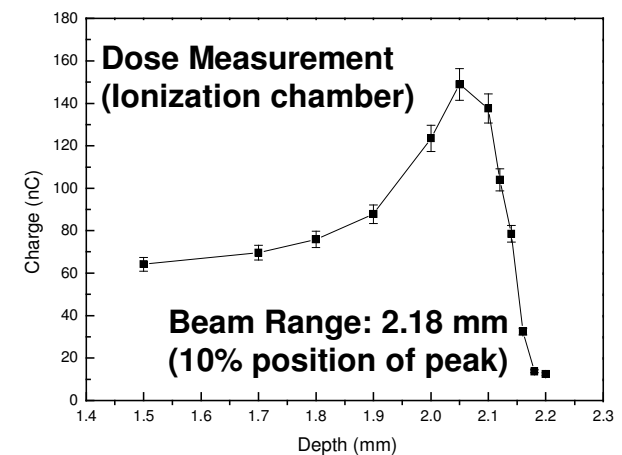
# PEFP 20 MeV Linac

- Extracted the first beam (July 2005)
- Obtained operation license (June 2007)
  - Avg. current: 0.1  $\mu$ A, Rep. Rate: 0.1 Hz, 4 hrs/week
- Started beam service (June 2007)
- Revised operation permit (April 2008)
  - Avg. current: 1.0  $\mu$ A, Rep. Rate: 1 Hz, 4 hrs/week
- Achieved designed performance (May 2008)

## ❖ Peak Beam Current

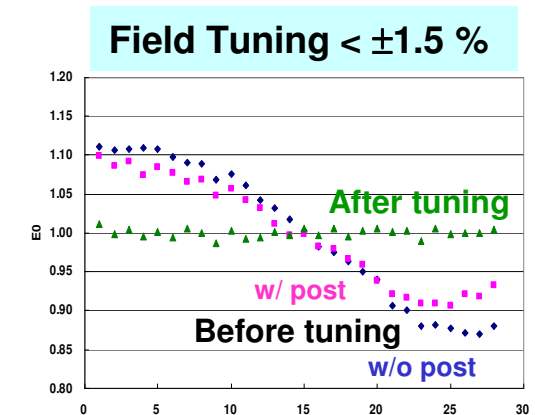
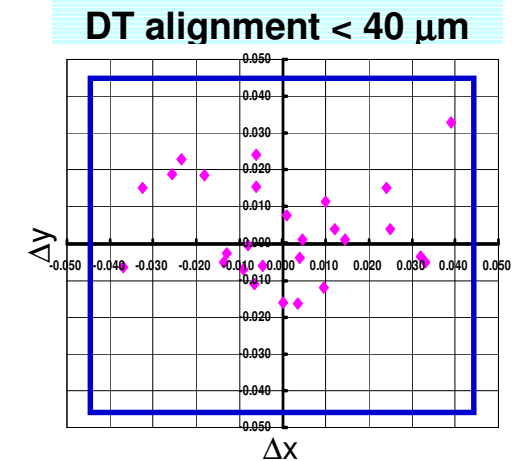
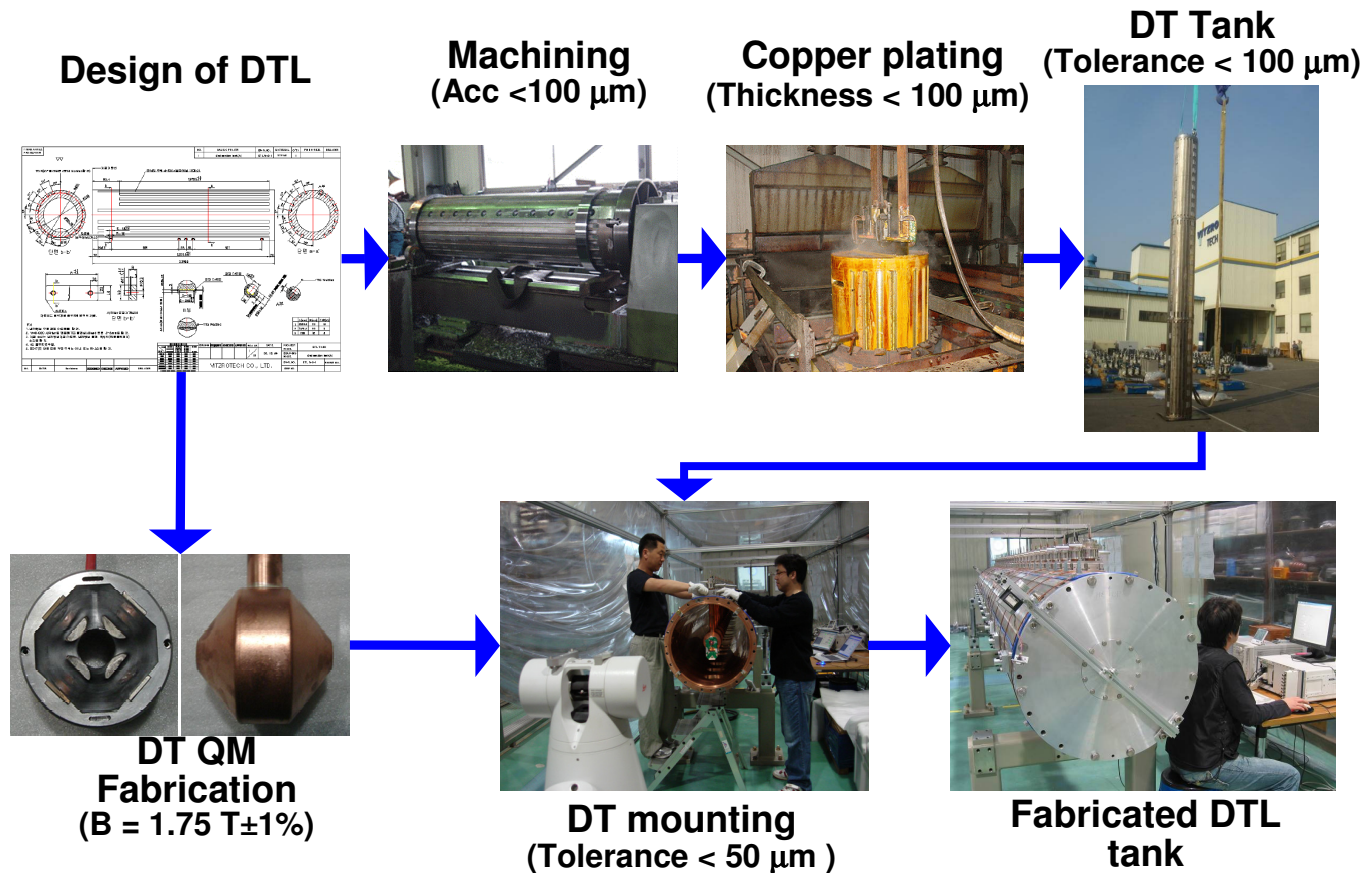


## ❖ Beam Energy: 20.33 MeV



# DTL Fabrication

- ❖ Established a full fabrication procedures
  - from design to field tuning, and low power test
- ❖ Fabricated up to 57 MeV : 3 DTLs



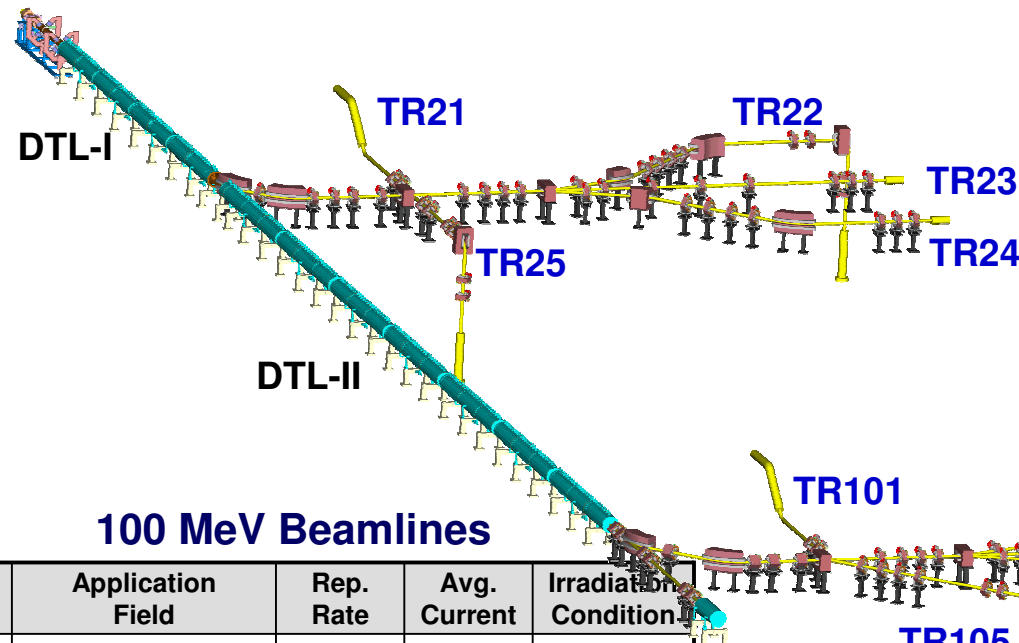


# Development of Beam Facilities

- ❖ Completed design by reflecting user requirements
- ❖ Developed components (QM, AC DM & beam instruments)

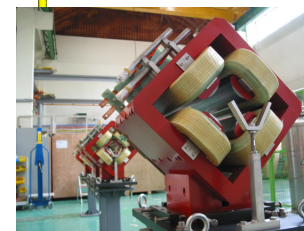
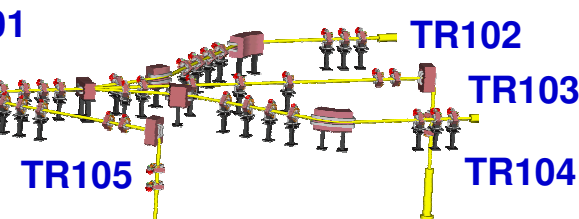
## 20 MeV Beamlines

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR21	Semiconductor	60Hz	0.6mA	Hor. Ext.
TR22	Bio-Medical Application	15Hz	60 $\mu$ A	Hor. Ext.
TR23	Materials, Energy & Environment	30Hz	0.6mA	Hor. Ext.
TR24	Basic Science	15Hz	60 $\mu$ A	Hor. Ext.
TR25	Radio Isotopes	60Hz	1.2mA	Hor. Vac.



## 100 MeV Beamlines

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR101	Radio Isotopes	60Hz	0.6mA	Hor. Ext.
TR102	Medical Research (Proton therapy)	7.5Hz	10 $\mu$ A	Hor. Ext.
TR103	Materials, Energy & Environment	15Hz	0.3mA	Hor. Ext.
TR104	Basic Science Aero-Space tech.	7.5Hz	10 $\mu$ A	Hor. Ext.
TR105	Neutron Source Irradiation Test	60Hz	1.6mA	Hor. Vac.



Quadrupole



AC Dipole

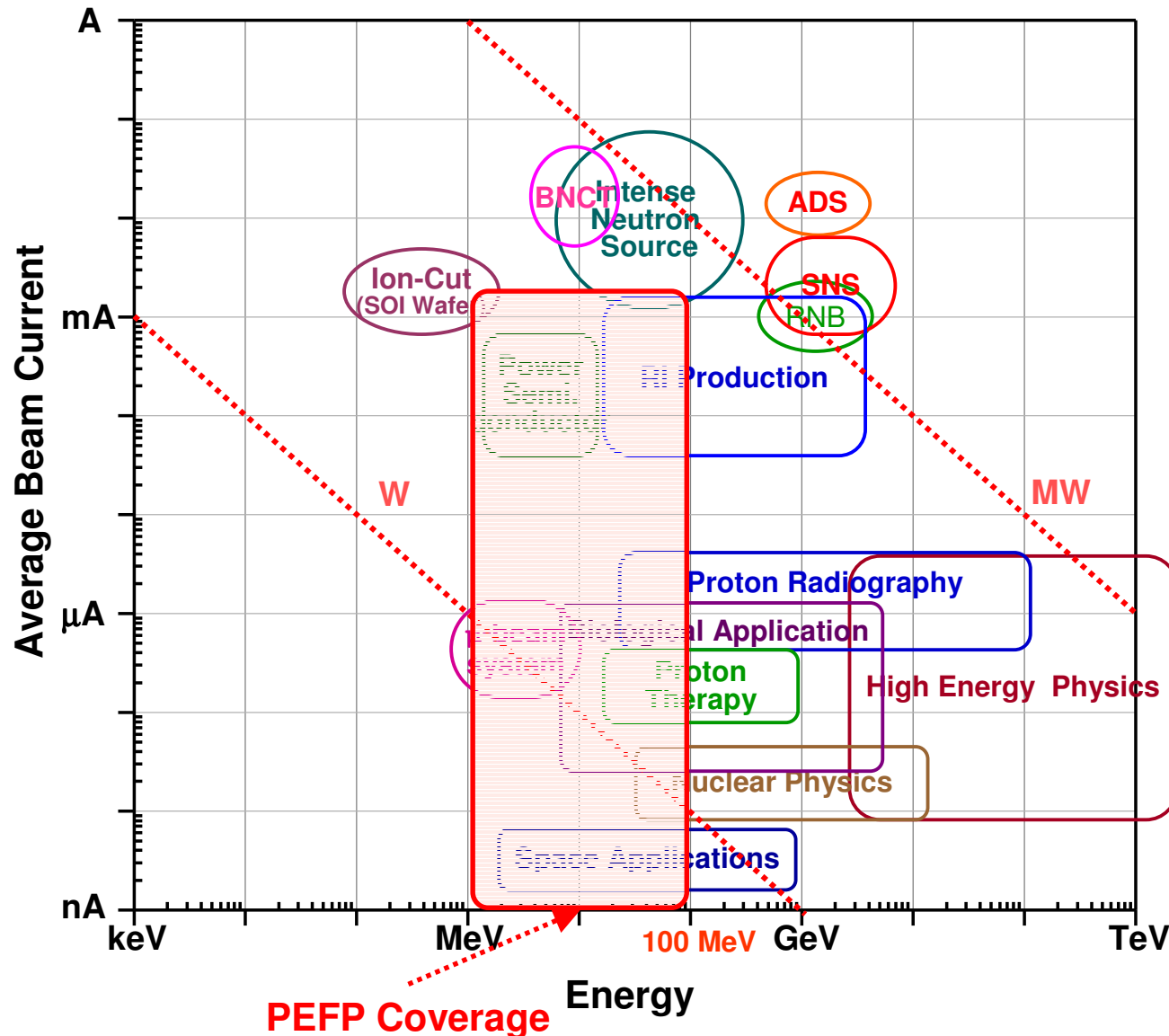
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# Utilization & Application Fields



- **Industrial applications:**  
ion-cut, power semiconductors
- **Medical applications:**  
RI production, BNCT, proton therapy
- **Biological applications:**  
mutation of plants and micro-organisms, micro-beam system
- **Space applications:**  
radiation tests of space components and radiation effects
- **Defense applications:**  
mine detection, proton & neutron radiography
- **Intense Neutron source:**  
radiation damage study, nuclear material test, target development
- **MW beams:**
  - Spallation Neutron Sources
  - Radioactive Nuclei Beams



## □ User Program Development

### ❖ Activities to develop users & user facilities

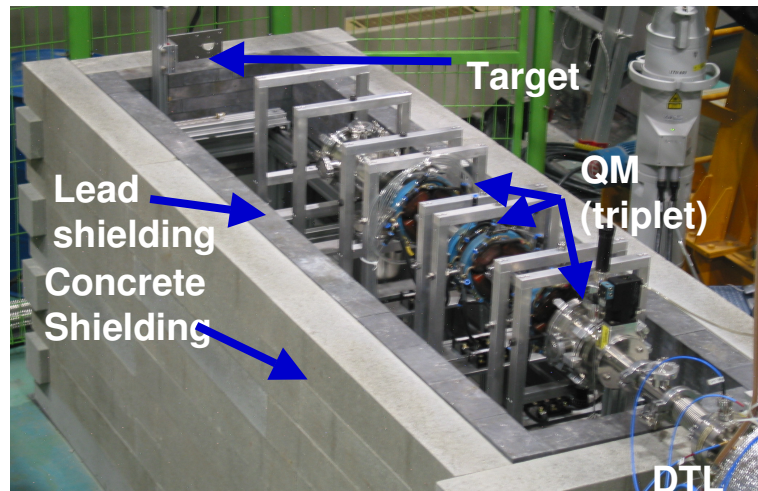
- Demands surveyed
- Developed and operated beam facilities
- Developed beam line components, instruments, etc.

### ❖ User Program Development (2003~)

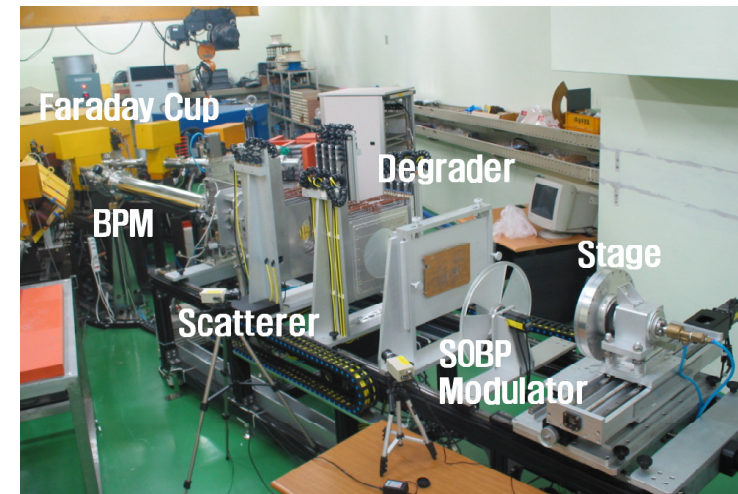
Research Fields	Sub-categories
Nano Science & Technology	Ion-cutting, Nano-particle shaping & fabrication, Carbon nano-tube, nano-wire, Nano-machining
Information Technology	High power semiconductor, Semiconductor manufacturing R&D, Proton lithography
Space Technology	Radiation hard electronic device, Radiation effect on materials
Bio-Technology	Mutation of plants & micro-organisms
Medical research	Low energy proton therapy study, Biocompatible material, Biological radiation effects, New RI production R&D
Materials Science	Proton irradiation effects with various materials Gemstone coloration
Energy & Environment	New microorganism development for bio fuel (ethanol, butanol), New materials for fuel cell ; electrolyte, nano catalyst, organic solar cell
Nuclear & Particle Physics	Detector R&D, Nuclear data, TLA (Thin Layer Activation)

## ❑ Beam Facilities Developed by PEFP

### ❖ 20 MeV Beam Facility @ KAERI



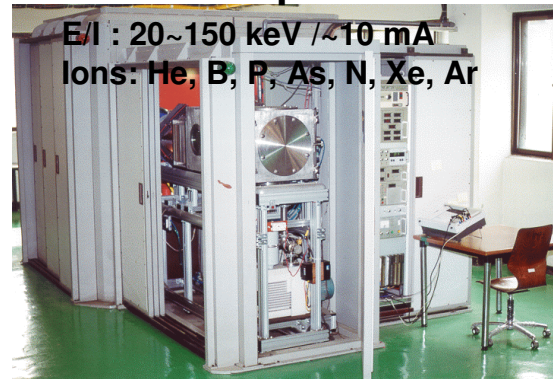
### ❖ 45 MeV beam facility @ KIRAMS\*



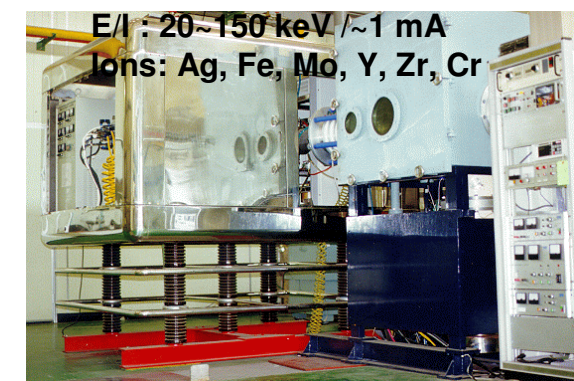
### ❖ Gaseous Ion Implanter



### ❖ Dual Ion Implanter



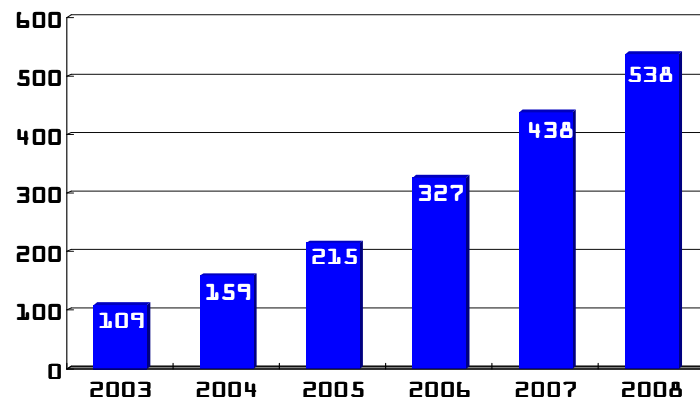
### ❖ Metallic Ion Implanter



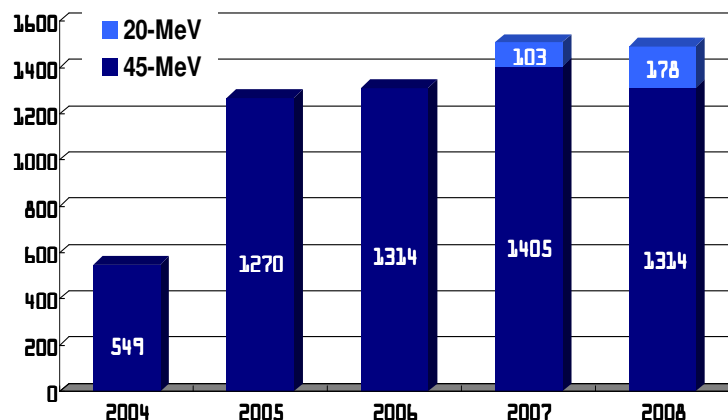
## □ Status of PEFP User Program

- ❖ Built up a strong community of proton beam users
- ❖ Diversified R&D fields by using proton beam

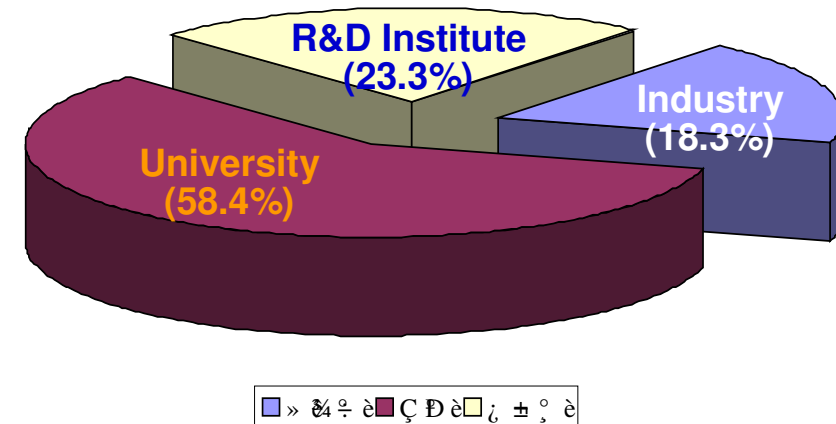
### ■ Proton Beam Users



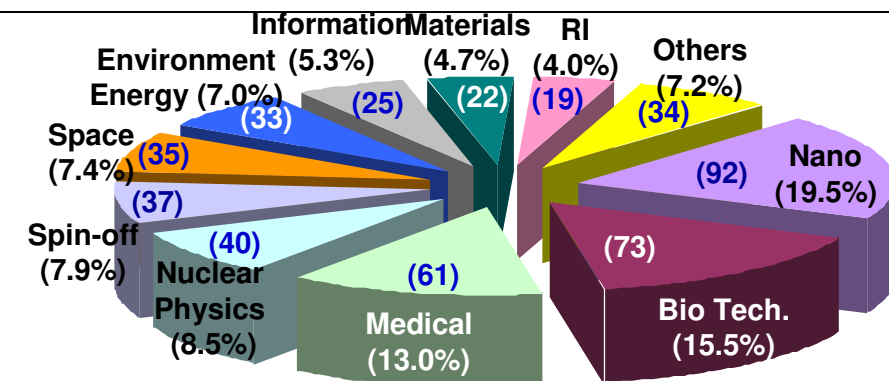
### ■ Irradiated Samples



### ■ User Distribution in Institutions



### ■ User Distribution in R&D Fields



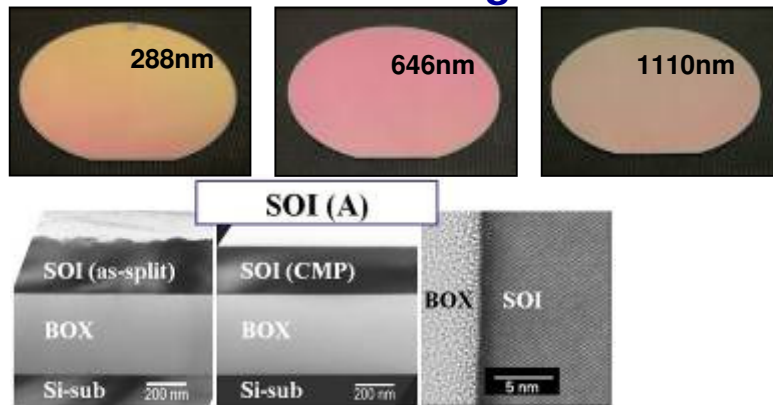


## □ R&D Activities (I)

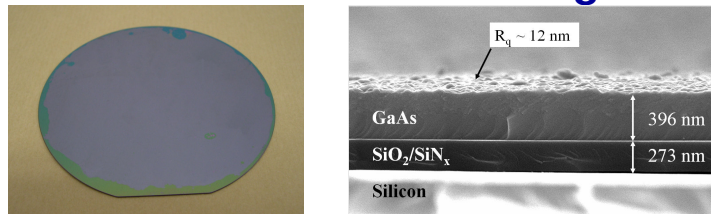
- ❖ Application of ion-cut technology
  - SOI (Si-on-Insulator) wafer fabrication
  - GOI (GaAs-on-Insulator) wafer fabrication

- ❖ Control carrier lifetimes of semiconductor
  - Improved switching speed of FRD & IGBT by more than 5 times

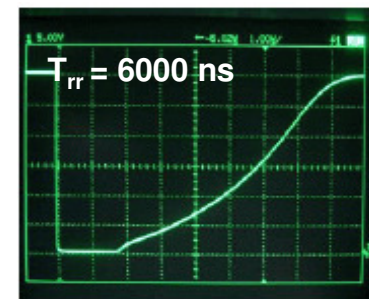
### ▪ SOI wafer & X-TEM Image



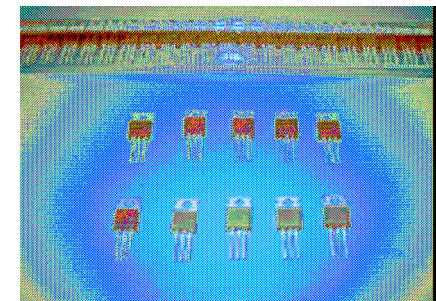
### ▪ 4" GOI wafer & FE-SEM image



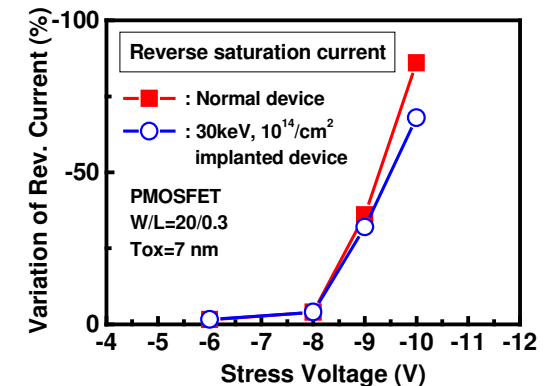
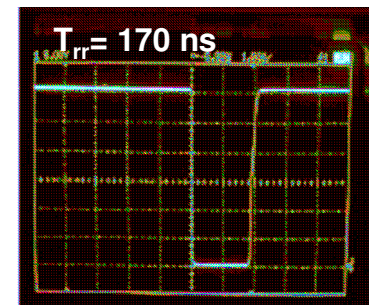
### Before irradiation



### 660V, 10A, IGBT



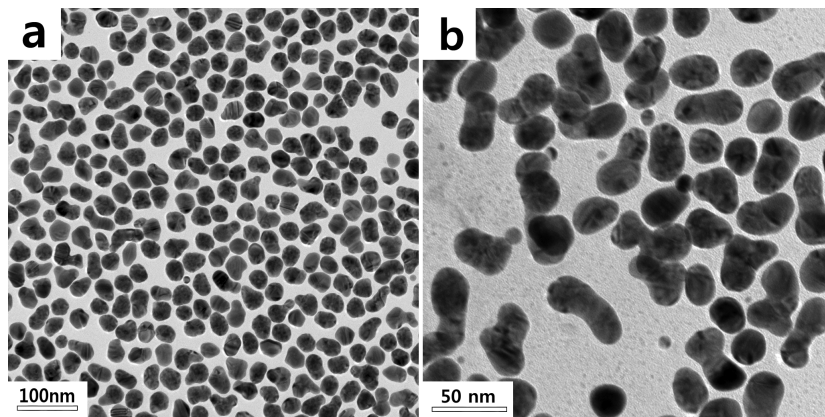
### After irradiation



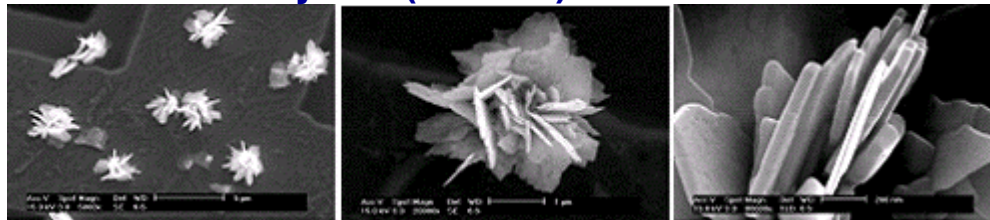
## □ R&D Activities (II)

- ❖ Fabrication of metallic nano-particles
  - Gold, Platinum, Silver, etc.

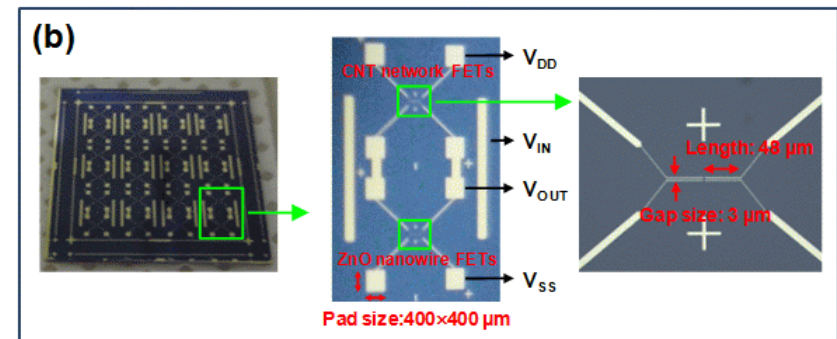
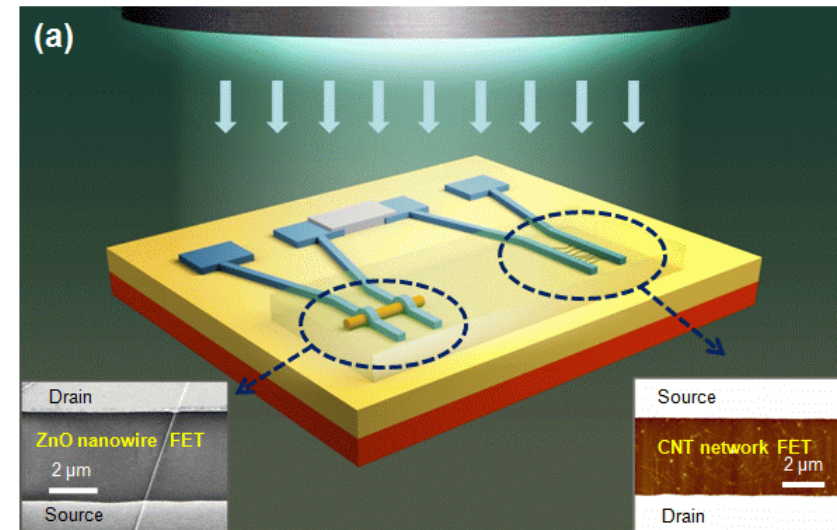
### Silver nano particle (SEM Images)



### Silver nano crystal (Flower) formation



- ❖ Fabrication of hybrid nano-logic device
  - n-type nanowire + p-type nanotube





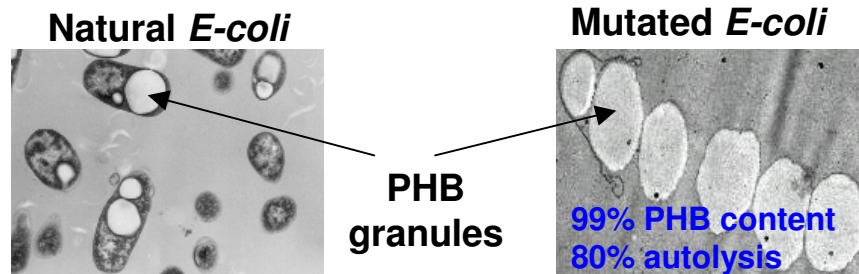
## □ R&D Activities (III)

### ❖ Developed mutants of plants, vegetables, mirco-organism

#### ▪ Developed New Chinese cabbage



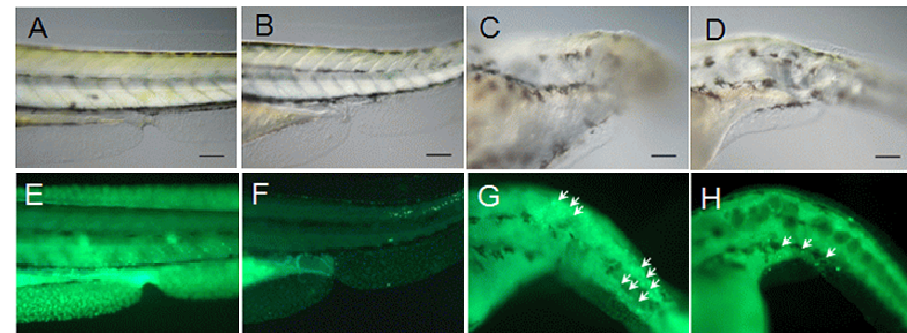
#### ▪ Mutated *E-coli* to produce PHB, PHBV



### ❖ Medical applications

#### ▪ Investigated mechanism

- blood vessel formation,
- vascular cell death of zebra fish



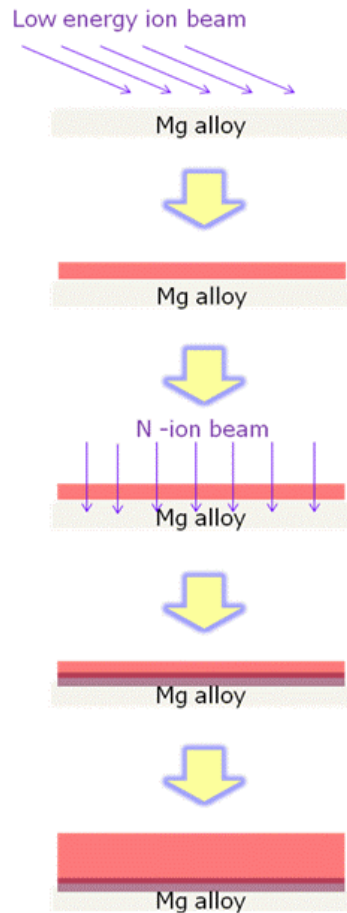
#### ▪ Radio Isotope production

Proton Energy	Radio Isotope
< 20 MeV	F18, C11, O15, N13, Pd103
30~100 MeV	F18, C11, O15, N13, Pd103, Ti201, Ga67, I123, I124, In111, Co57
> 100 MeV	Al26, Mg28, Si32, Be7, Na22, Ge68, Sr82, Tc95, Cu67

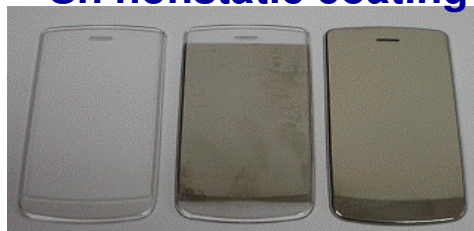
## □ R&D Activities (IV)

### ❖ Application of ion beam mixing

#### ▪ SiC film coating on Mg alloy



#### ▪ Sn nonstatic coating



### ❖ Application of accelerator technology

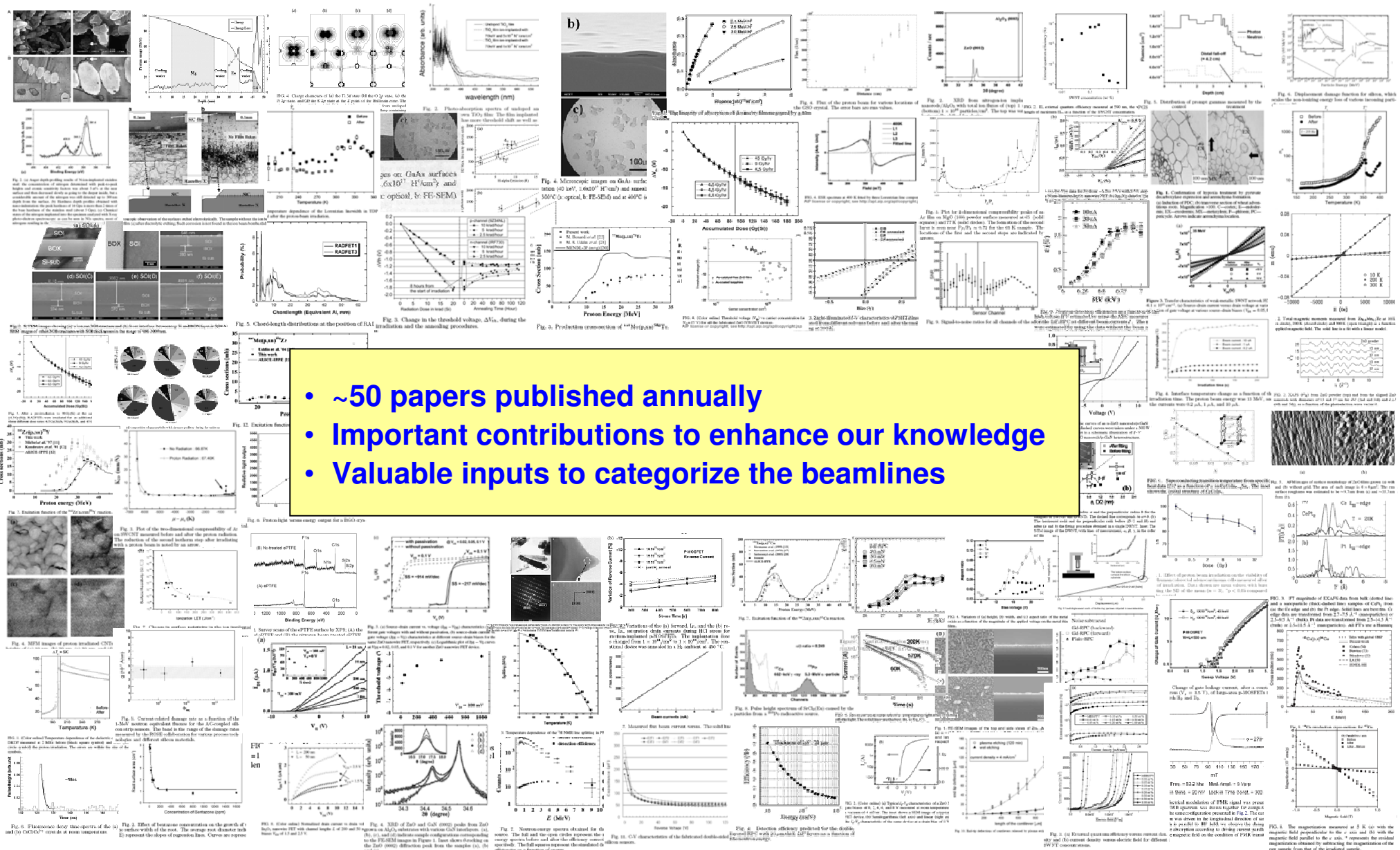
- Developed an ion implanter and installed @ Advanced Radiation Technology Institute
- Transferred industrial ion implanter tech



Energy	50 ~ 300 keV
Beam current	5 mA
Ions	H, He, N, Ar, Kr, Xe



# Papers published through the PEFP User Program

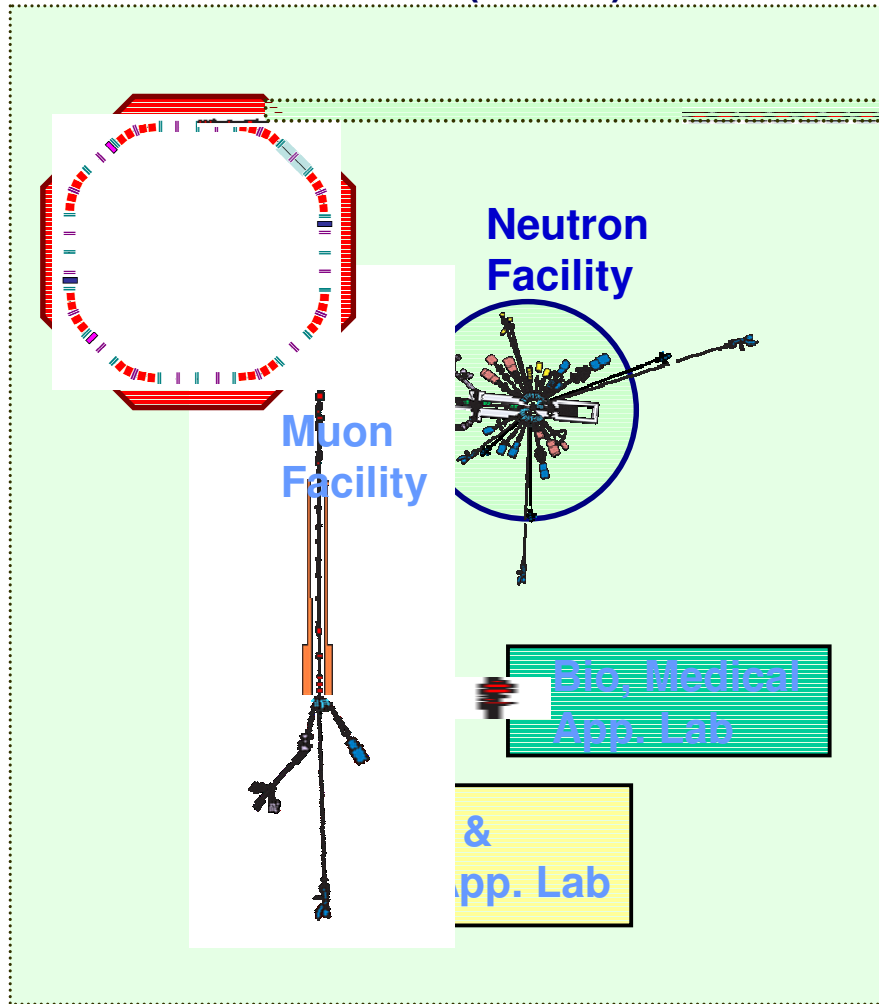


- ~50 papers published annually
- Important contributions to enhance our knowledge
- Valuable inputs to categorize the beamlines

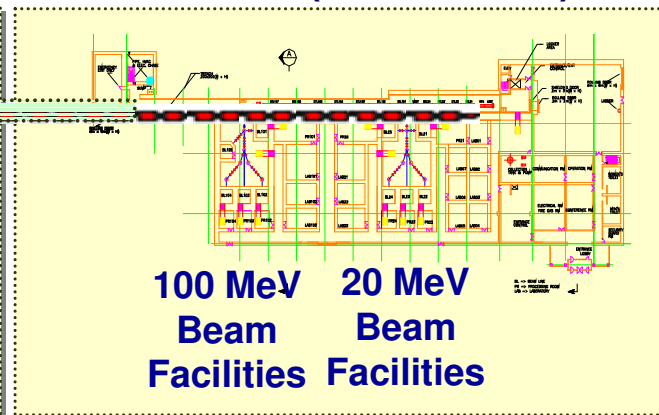
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## □ An Expansion Option of the PEFP

Phase II (2012 ~)



Phase I (2002 ~ 2012)



### Spallation Neutron Source

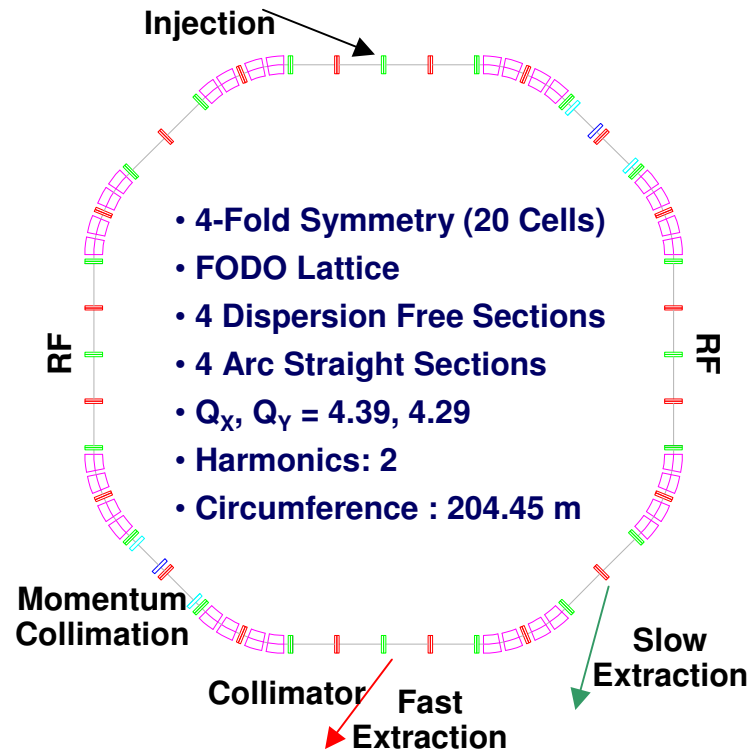
- 100 (200) MeV Linac + 1 (2) GeV RCS
- Beam Power : ~ 0.5 MW
- Slow Extraction (@ 450 MeV)

### R&D Activities

- 1(2) GeV Rapid Cycling Synchrotron
- Superconducting Linac (200 MeV)
- RF Source (700 MHz, 1 MW CW Klystron)
- Target (MEGAPIE)



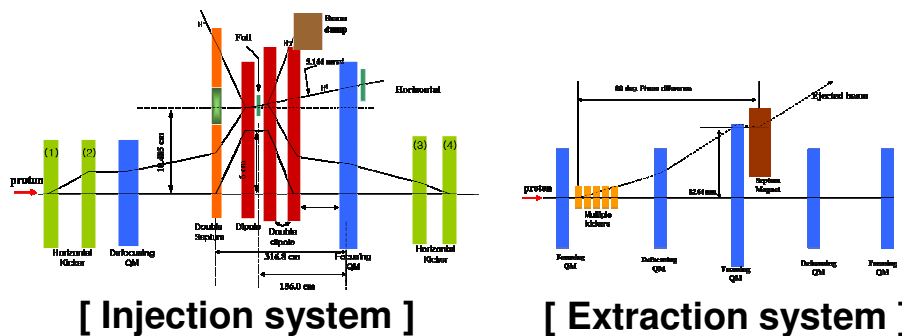
# □ Rapid Cycling Synchrotron



- Injection Energy: 100 (200) MeV
- Extraction Energy: 1 (2) GeV
- Injection : Charge Exchange
- Fast Extraction : Spallation neutron source
- Slow Extraction (~450 MeV): Medical application

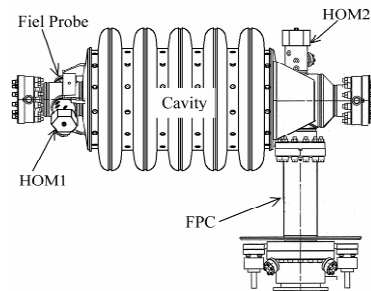
## ❖ Upgrade Path

	Injection [GeV]	Extraction [GeV]	Repetition [Hz]	RF [KV]	Beam Power [KW]
Initial	0.1	1.0	15	80	60
Upgrade #1	0.1	1.0	30	140	120
Upgrade #2	0.1	2.0	30	260	250
Upgrade #3	0.2	2.0	30	250	500

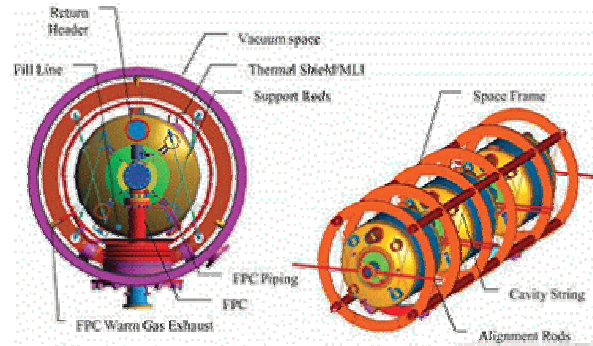


# □ Superconducting RF Linac

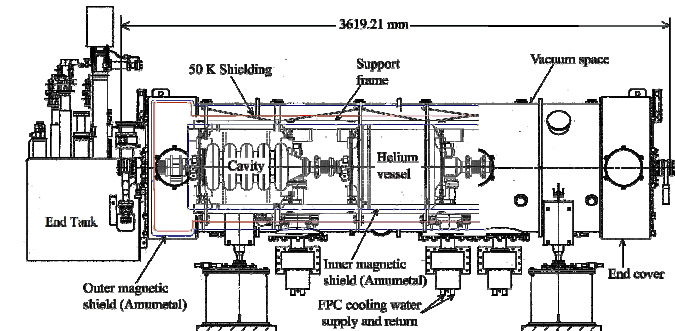
- $\beta=0.42$ , 5-Cell, RF: 700 MHz
- SC Cavity, RF coupler, Tuner, Vacuum Vessel, etc.
- Fabricated & tested a warm module (Copper Cavity)
- Cold module is being fabricated and tested



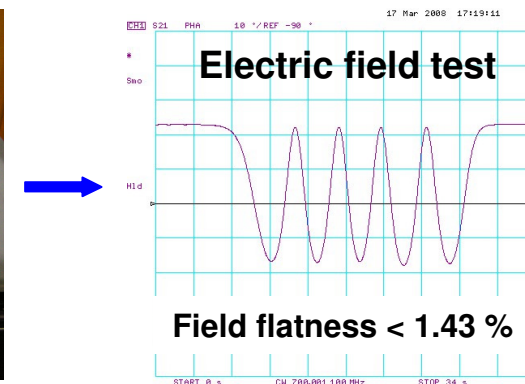
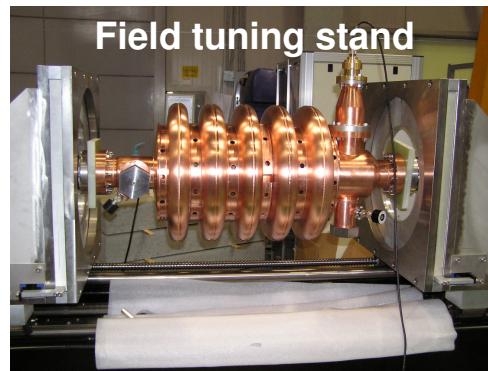
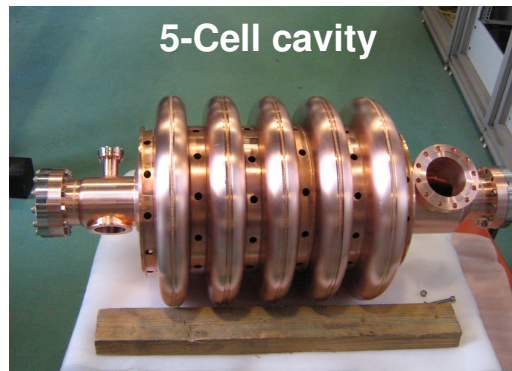
5-cell cavity with  
fundamental coupler



Thermal insulator



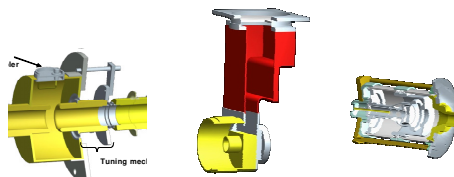
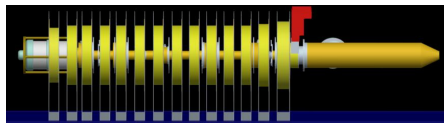
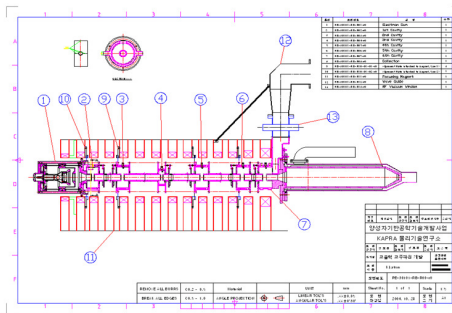
Designed SRF module



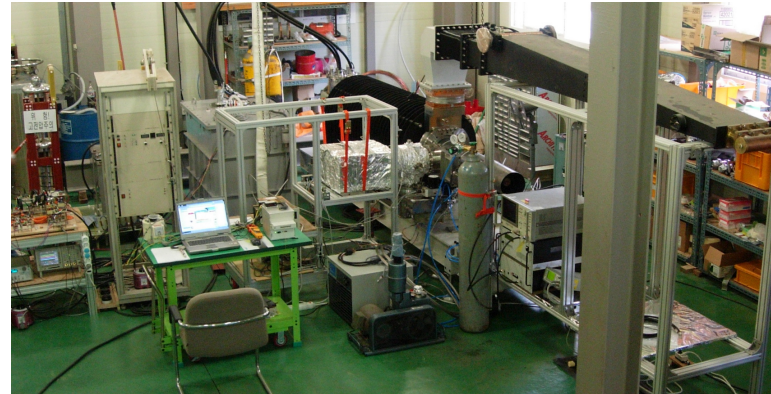
# □ High Power RF Source – MW Klystron

- Developed 700 MHz, 1 MW (CW) Klystron
- Established Full Processing Procedures  
(from design to test, & infrastructures such as test stand, baking furnace, etc.)
- Under Commercialization

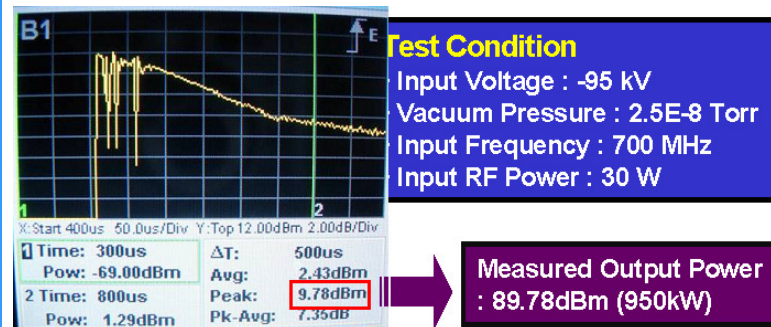
## Design & Fabrication



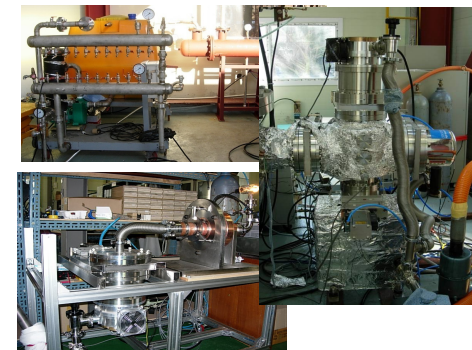
## Test Stand



## Test Result



## Infras @ KAPRA

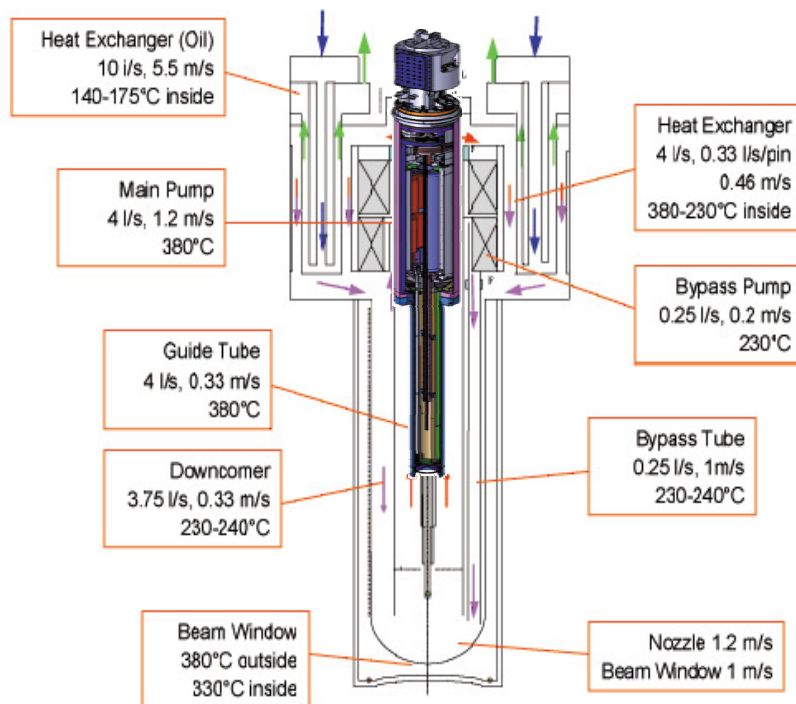




## □ Spallation Neutron Target

### ▪ MEGAPI (MEGAwatt Pilot Experiment)

Collaborating Institutes: PSI, CEA, CNRS, FZK, ENEA, SCK-CEN, JAEA, LANL, KAERI-PEFP



- '01.12 Joined MEGAPI collaboration
- '06.2 : Irradiated Pb-Bi target by SINQ at PSI
- '06.12 : Disintegrated the target system & analyzed the experiment
- '08. 8-11 : To perform the final cold test
- '09. 4-8: To dismantle target & move to Hotlab
- '10: To distribute PIE Sample
- '11.12.: To complete the MEGAPIE-I

## □ Summary

### ❖ 100 MeV, 20 mA Proton Linac & Beamlines

- 20 MeV linac :
  - Completed & In beam service
  - Achieved designed beam energy & current
- High energy part:
  - 20~57 MeV DTL : fabricated and tested
  - > 57 MeV DTL : to be produced as schedule
- To relocate the 20 MeV linac to the site in April 2011
- To complete the 100 MeV linac & beamlines by March 2012

### ❖ User Programs & Facilities

- Cultivated and fostered user programs in the wide range of research fields
- Produced promising outcomes including some industrialized

### ❖ R&D Activities for the Future (a Spallation Neutron Source)

- R&D in SCL, RCS, RF Power Source, Spallation Neutron Target

## □ The PEFP Members





Thank you very much  
&  
Welcome to the PEFP's Home

