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The Status and Future Plan of the PEFP

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on behalf of the Proton Engineering Frontier Project

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❑ Contents

PEFP Proton Engineering Frontier Project

❑ Introduction

- The PEFP is focusing on Proton Beam Utilization not Neutron Beam Utilization at this 1st phase.

- Original plan proposed to government in 2002 is 1GeV Spallation Neutron Source.

- Future extension plan for spallation neutron source is being planed now.

- Neutron source using 100MeV proton beam at the one of beamlines of the PEFP is being considered.

❑ Overview

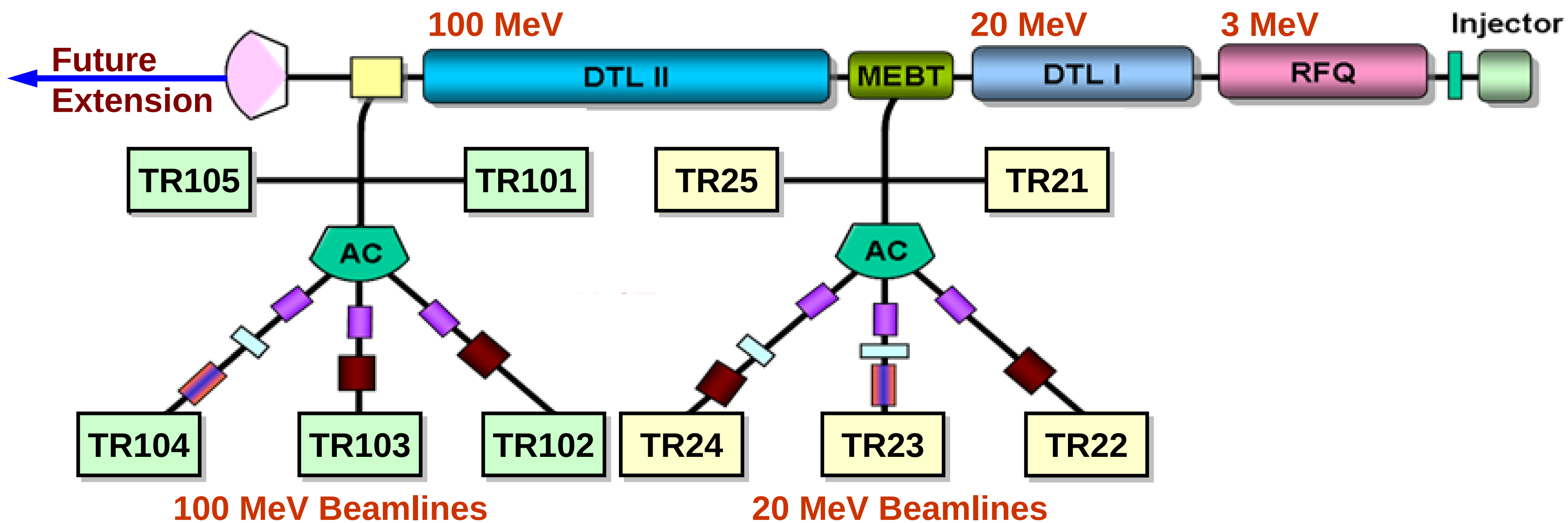
- **Project: Proton Engineering Frontier Project (PEFP)**
  21C Frontier R&D Program, MEST, Republic of Korea

- **Objectives:**
  - To develop a High Power Proton Linac (100MeV, 20mA)
  - To develop Proton 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 : Land, Buildings & Supporting Facilities)

❑ Schematics of PEFP Accelerator & Beamlines



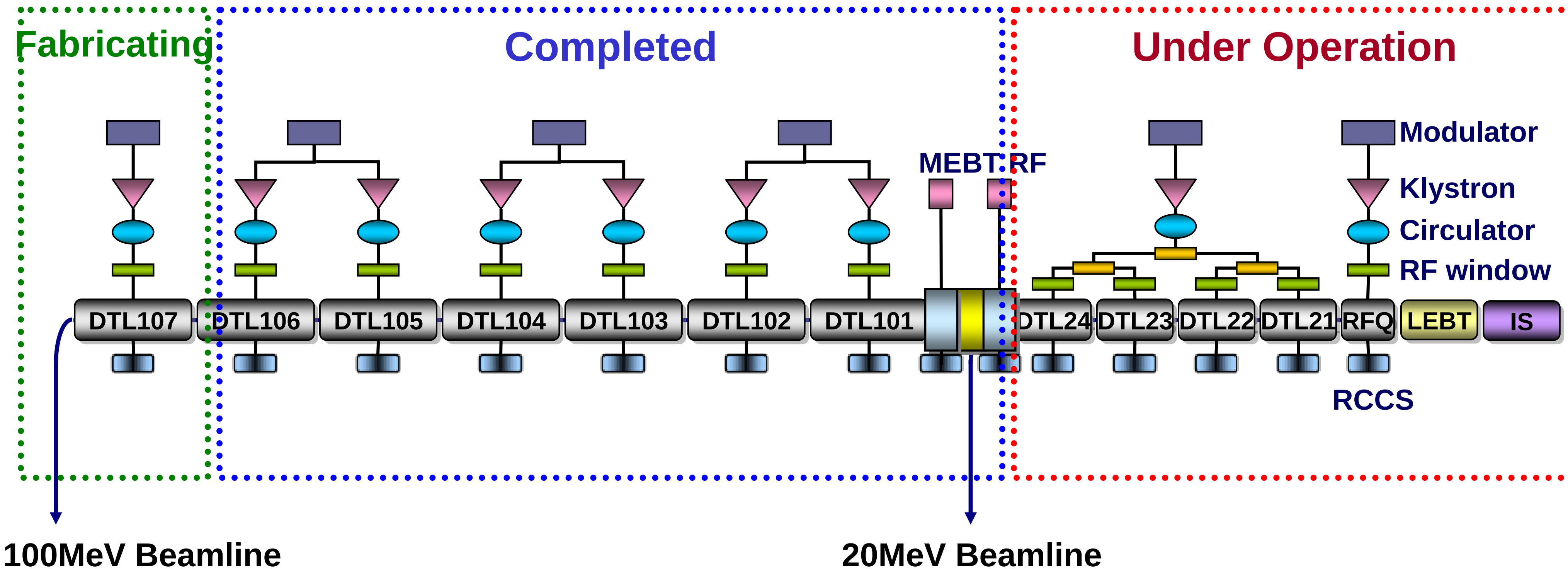
Features of the PEFP linac

- 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
  - Beam to be distributed to 3 BL via AC

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

❑ Status of Accelerator Development

❖ 20MeV; Fully developed & installed and under routine operation
❖ 6 tanks up to 91 MeV; Fabricated, partly tested & prepared
❖ 1 tank (91~102 MeV); Under fabrication

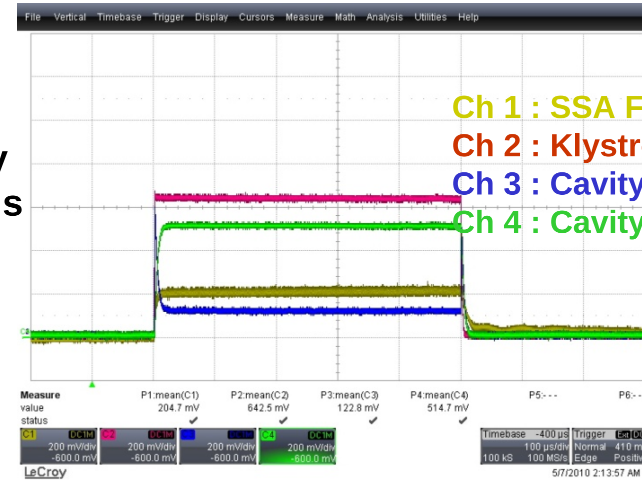


❑ 3MeV RFQ Test

❑ Set up for Test of RFQ

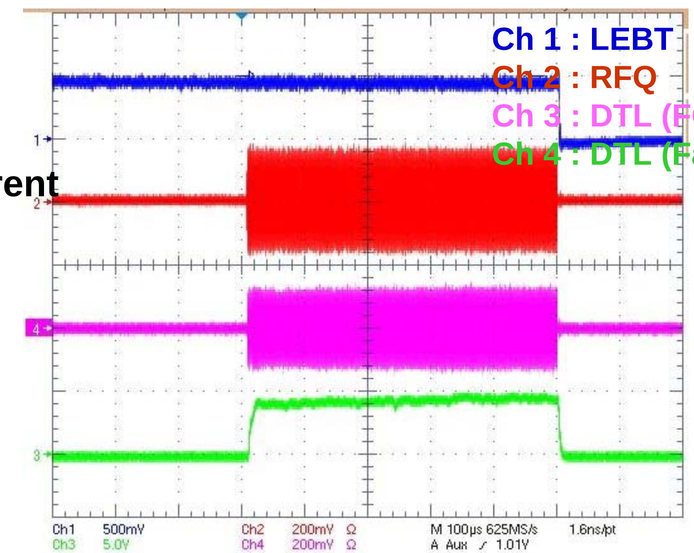
❑ Results of the RF & Beam test

RF Power
inside cavity
440 kW, 500us



< Cavity field signal >

Beam Current
500us



< Beam current signal >

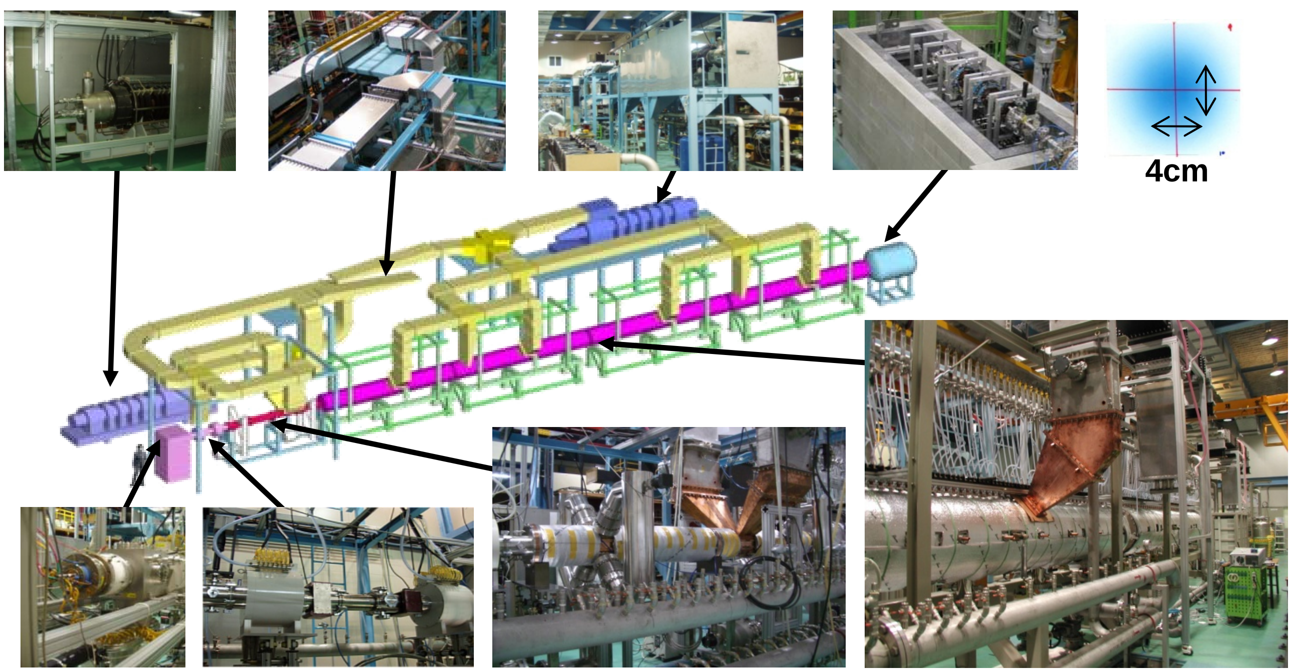
❑ Remarks of RFQ test

- RFQ have been fabricated and tuned. (Aug., 2005)
- Full Peak Power RF test has been done. (Oct., 2005)
- Beam test up to 20mA has been done. (Mar., 2008)
- Routinely used for the beam acceleration. (Now)

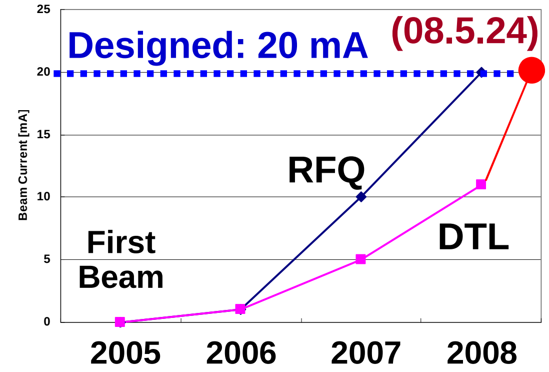
❑ PEFP 20 MeV Linac Performance

PEFP Proton Engineering Frontier Project

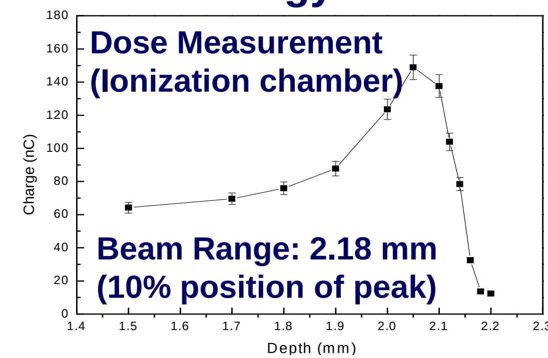
- **Extracted first beam (July 2005)**
- **Obtained operation license (June 2007)**
  - **Avg. current: 0.1 μA, Rep. Rate: 0.1 Hz, 4 hrs/week**
- **Started beam service (June 2007)**
- **Achieved designed performance (May 2008)**



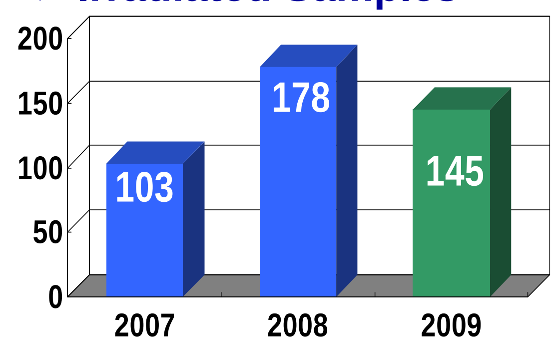
❖ Beam Current 20.2 mA



❖ Beam Energy: 20.33 MeV

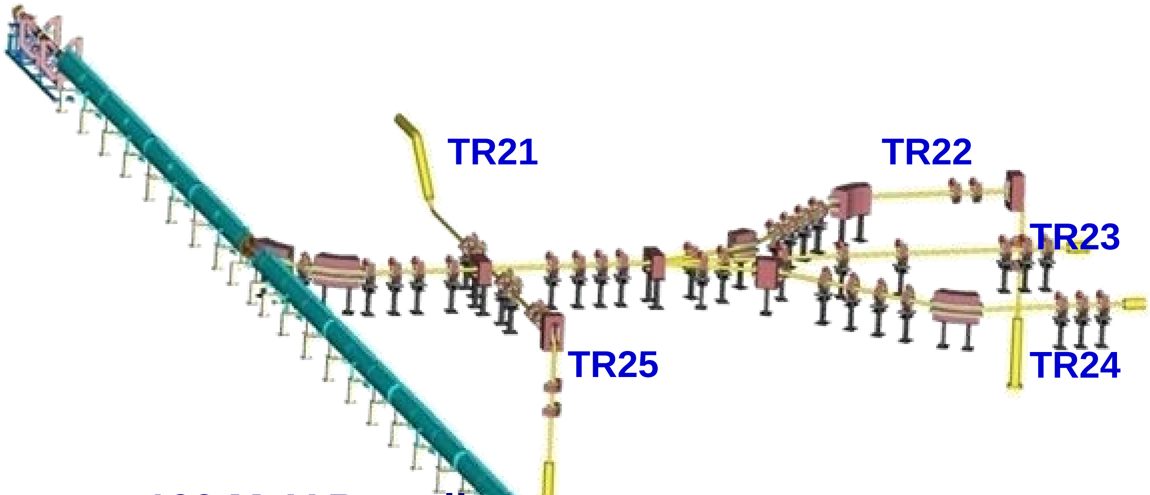


❖ Irradiated Samples



❑ Beamline Development

- ❖ Completed design of beamlines by reflecting user's requirement
- ❖ Developed components (BM, QM, ACM & beam instruments)

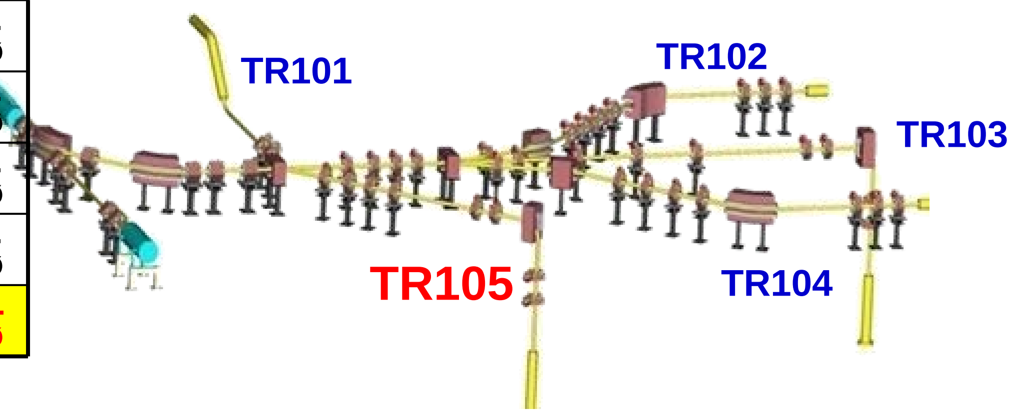


20 MeV Beamlines

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR21	Semiconductor	60Hz	0.6mA	Hor. Ext. 300mmØ
TR22	Bio-Medical Application	15Hz	60μA	Hor. Ext. 300mmØ
TR23	Materials, Energy & Environment	30Hz	0.6mA	Hor. Ext. 300mmØ
TR24	Basic Science	15Hz	60μA	Hor. Ext. 100mmØ
TR25	Radio Isotopes	60Hz	1.2mA	Hor. Vac. 100mmØ

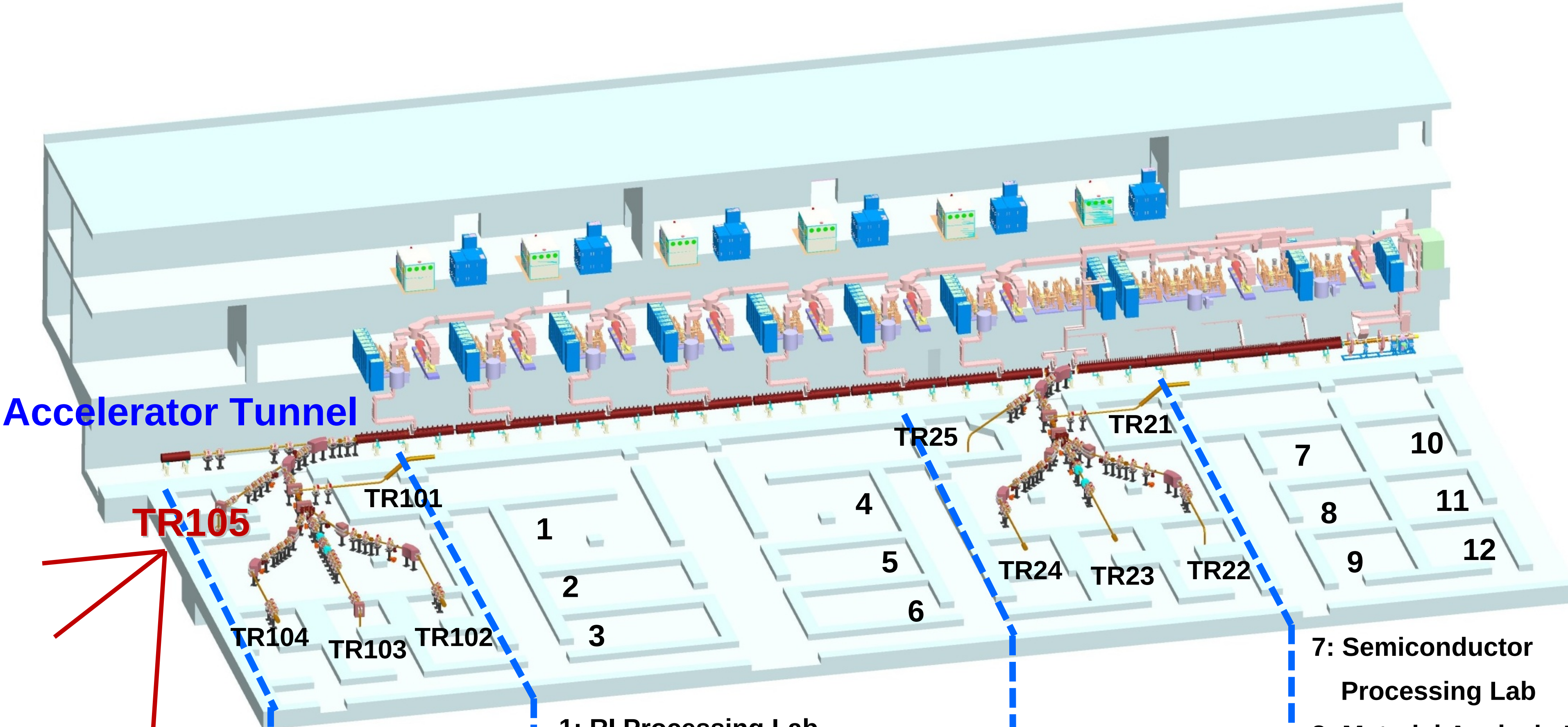
100 MeV Beamlines

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR101	Radio Isotopes	60Hz	0.6mA	Hor. Ext. 100mmØ
TR102	Medical Research (Proton therapy)	7.5Hz	10μA	Hor. Ext. 300mmØ
TR103	Materials, Energy & Environment	15Hz	0.3mA	Hor. Ext. 300mmØ
TR104	Basic Science Aero-Space tech.	7.5Hz	10μA	Hor. Ext. 100mmØ
TR105	Neutron Source Irradiation Test	60Hz	1.6mA	Hor. Vac. 100mmØ



❑ Layout of Accelerator Tunnel & Experimental Hall

PEFP Proton Engineering Frontier Project



Extension For Neutron Source & Instruments

100MeV Beam Lines

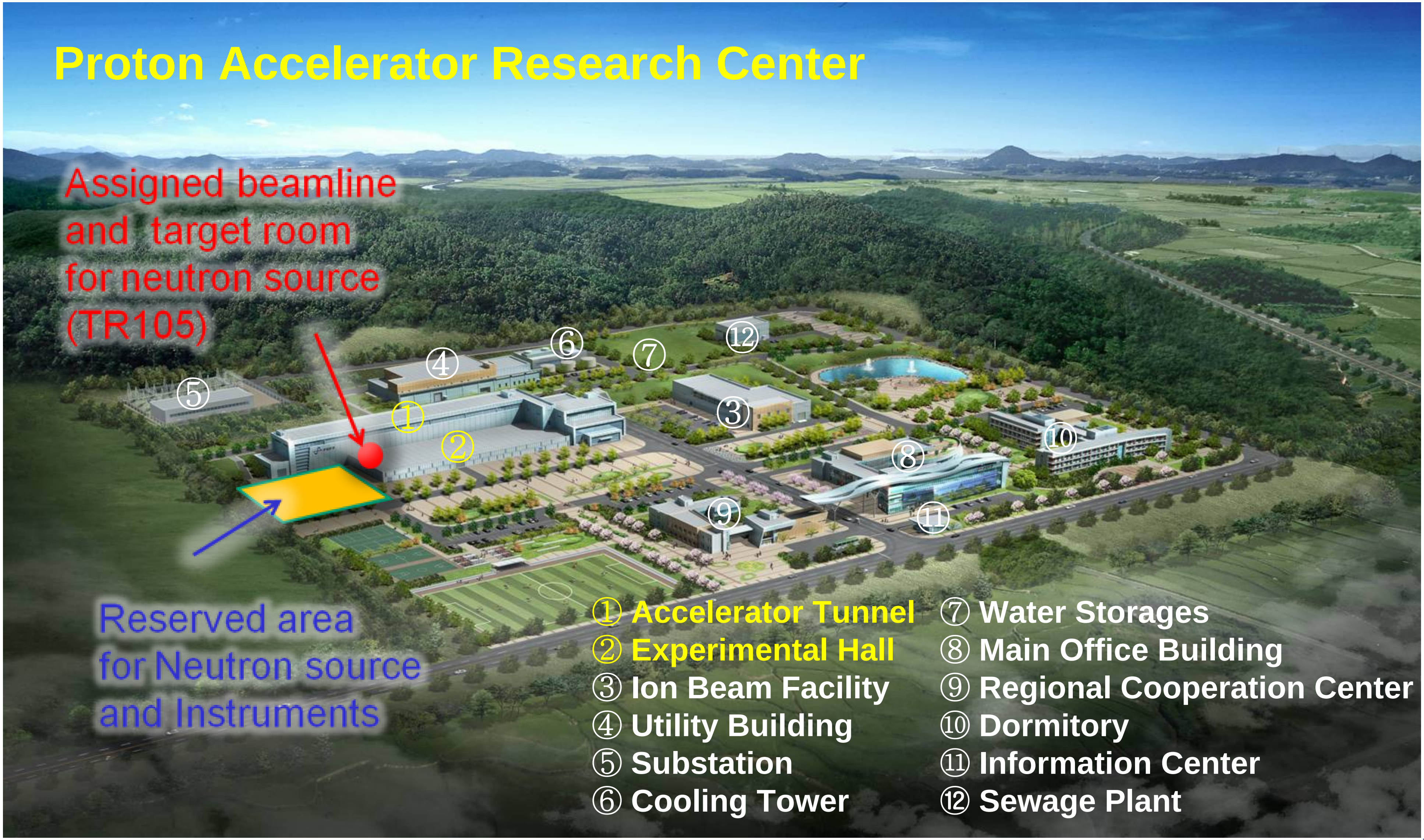
1: RI Processing Lab
2: Bioengineering Lab
3: Biocell Analysis Lab
4: Activation Analysis Lab
5: Basic Science Lab
6: Radio-Medical Lab

20MeV Beam Lines

7: Semiconductor Processing Lab
8: Material Analysis Lab
9: Nano-processing Lab
10: Detector R&D Lab
11: SRF Lab
12: RCS Lab
13: Target Instrument R&D

❑ Site Plan and Preparation for the PEFP

PEFP Proton Engineering Frontier Project

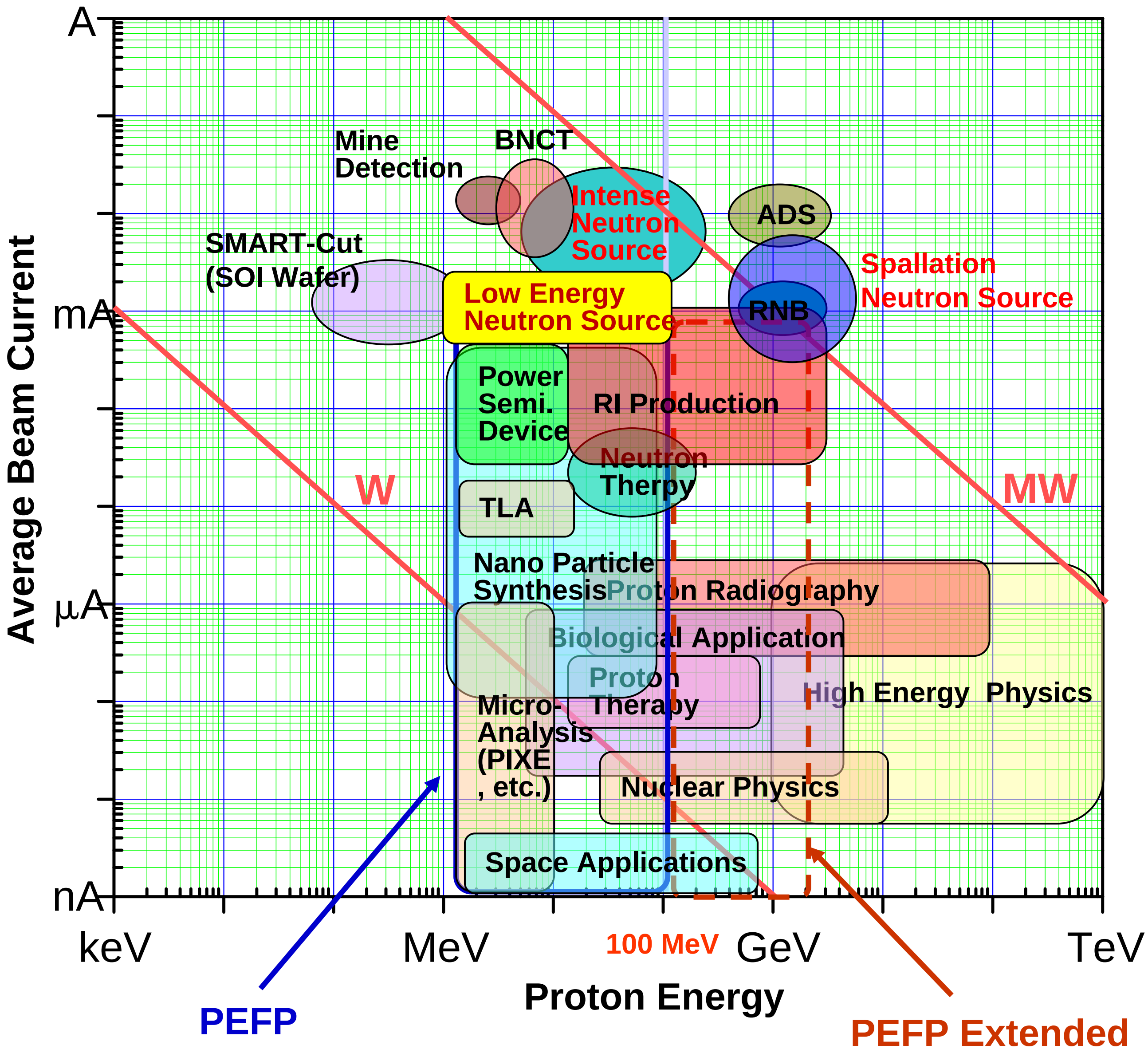


Aug. 5th, 2010

The Bird's-eye view of construction site

Construction of accelerator related building will be started in September.

❑ Application Fields with Proton Beams



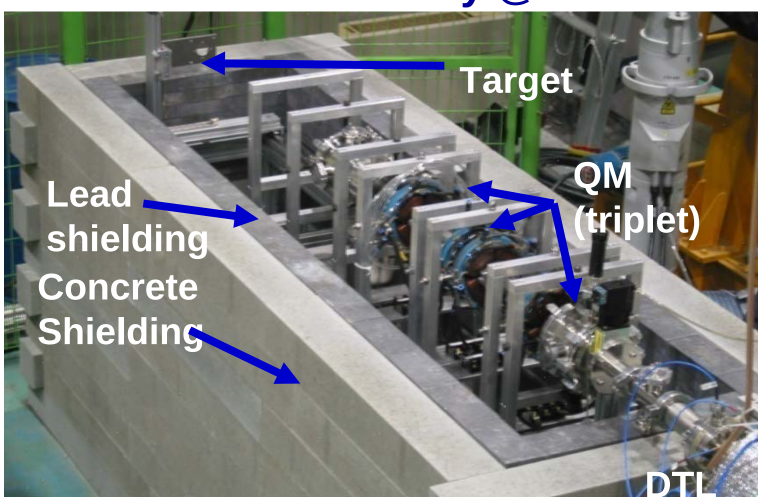
- **Industrial applications**
  ion-cut, power semiconductor devices
- **Medical applications**
  BNCT, RI production, proton therapy
- **Biological applications**
  mutation of plants and micro-organisms, micro-beam system, etc.
- **Space applications**
  radiation tests of space components and radiation effects, etc.
- **Defense applications**
  mine detection, proton & neutron radiography
- **Intense neutron source**
  radiation damage study, nuclear materials, target & modulator development, etc.
- **MW beam utilization areas**
  - Spallation Neutron Sources
  - Muon Source
  - Radioactive Nuclei Beams
  - High Energy Physics (mesons, neutrinos)

❑ R&D Program using Proton Beam

❑ User Program Development (2003~)

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

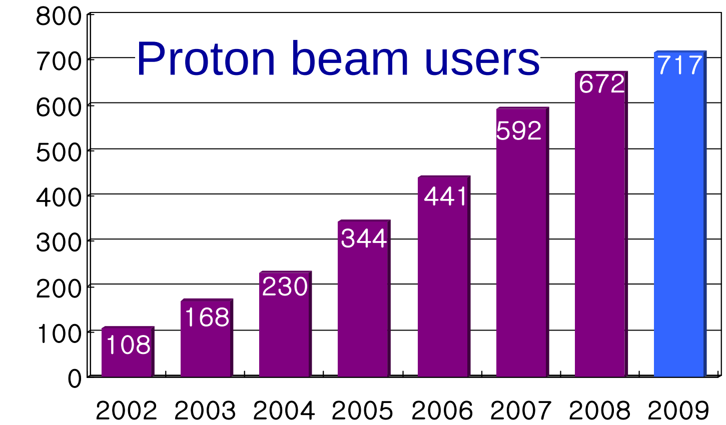
❖ 20 MeV Beam Facility @ KAERI



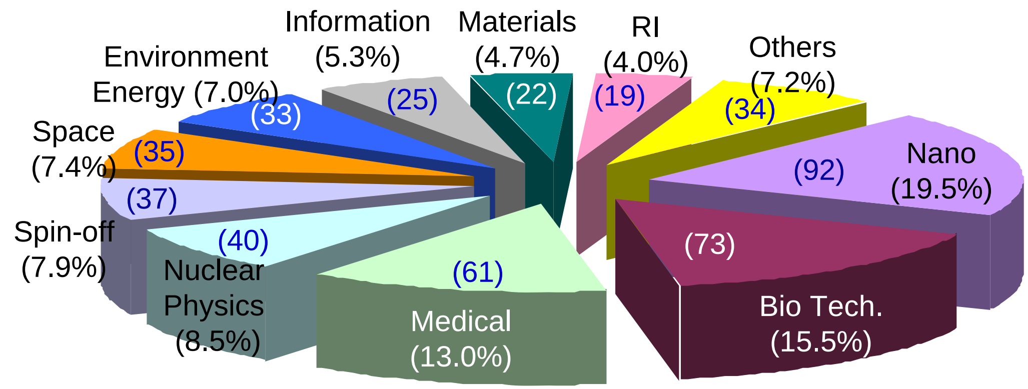
❖ 45 MeV beam facility @ KIRAMS*

❑ Status of PEFP User Program

❖ **Goals for the user program;**
- **Build up a strong community of proton beam users**
- **Diversify R&D fields by using proton beams**

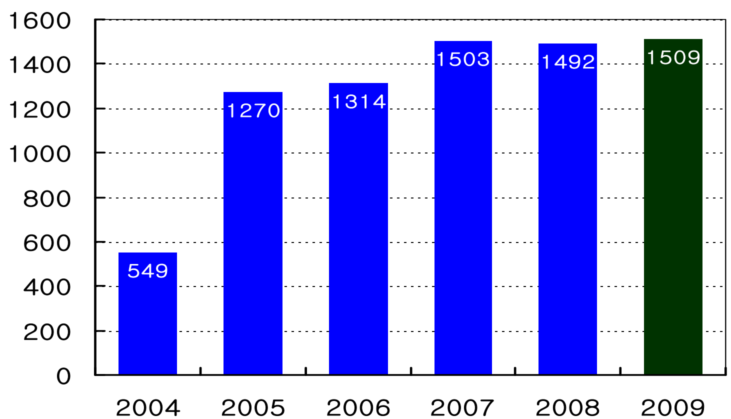


❖ User Distribution (R&D Fields)

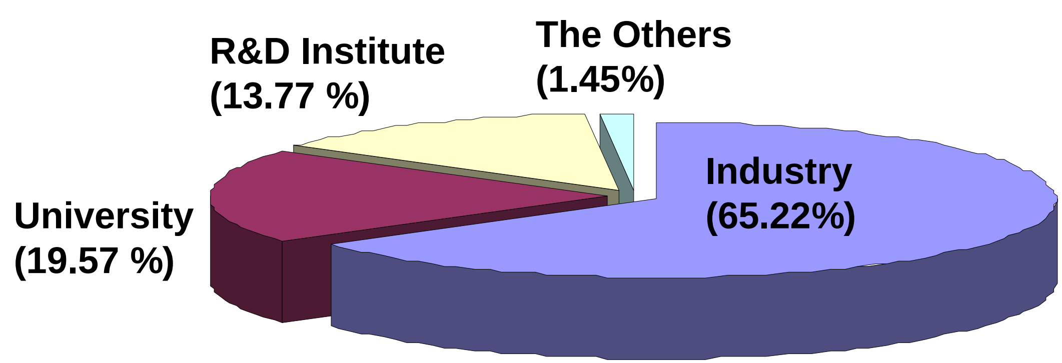


❖ Irradiated Samples

(20 MeV Linac, MC-50 @ KIRAMS, Ion Implanters)



❖ User Distribution (138 Institutions)

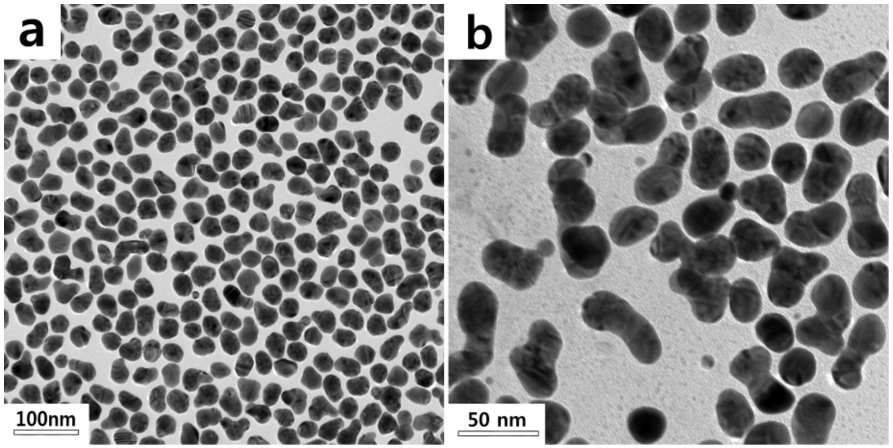


❑ R&D Activities (I) – Nano

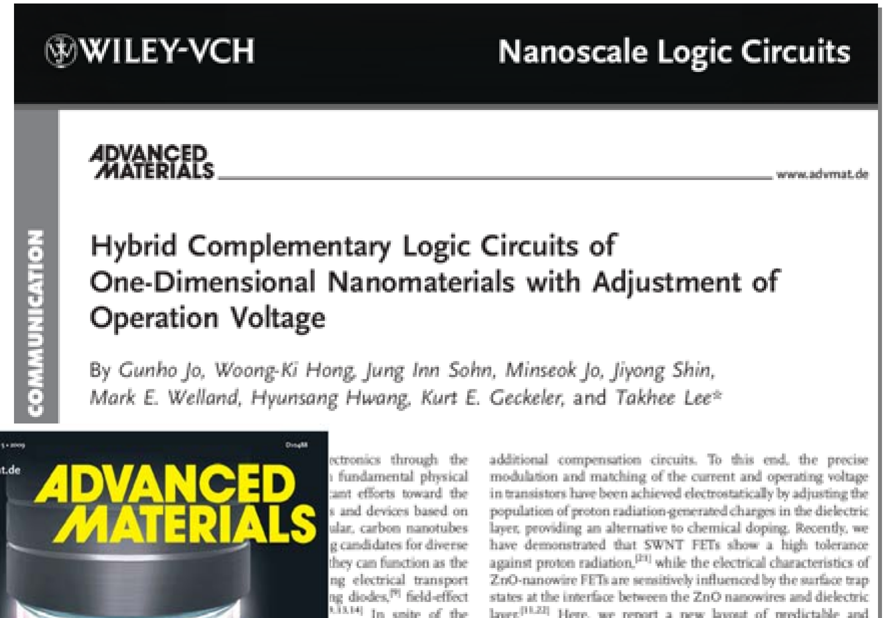
❖ Fabrication of metallic nano-particles
❖ Gold, Platinum, Silver

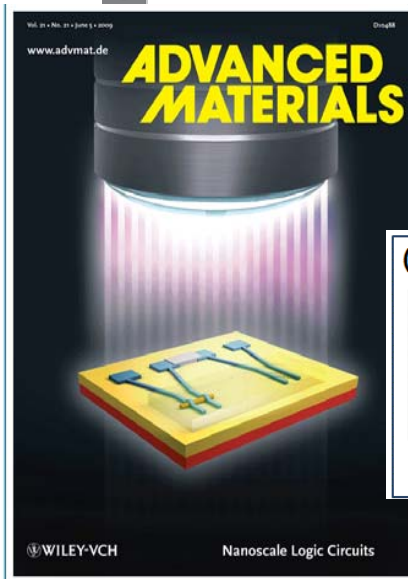
❖ Fabrication of Hybrid Nano-Logic Device
- n-type nanowire + p-type nanotube

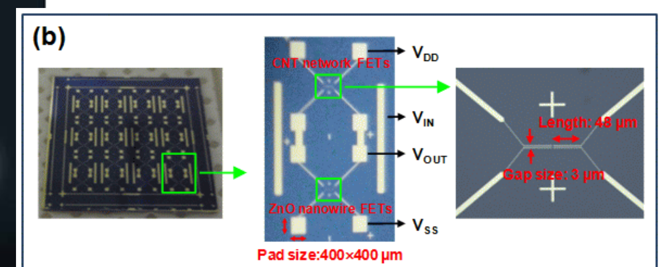
❖ Silver nano particle (SEM Images)



❖ Silver nano crystal (Flower) formation





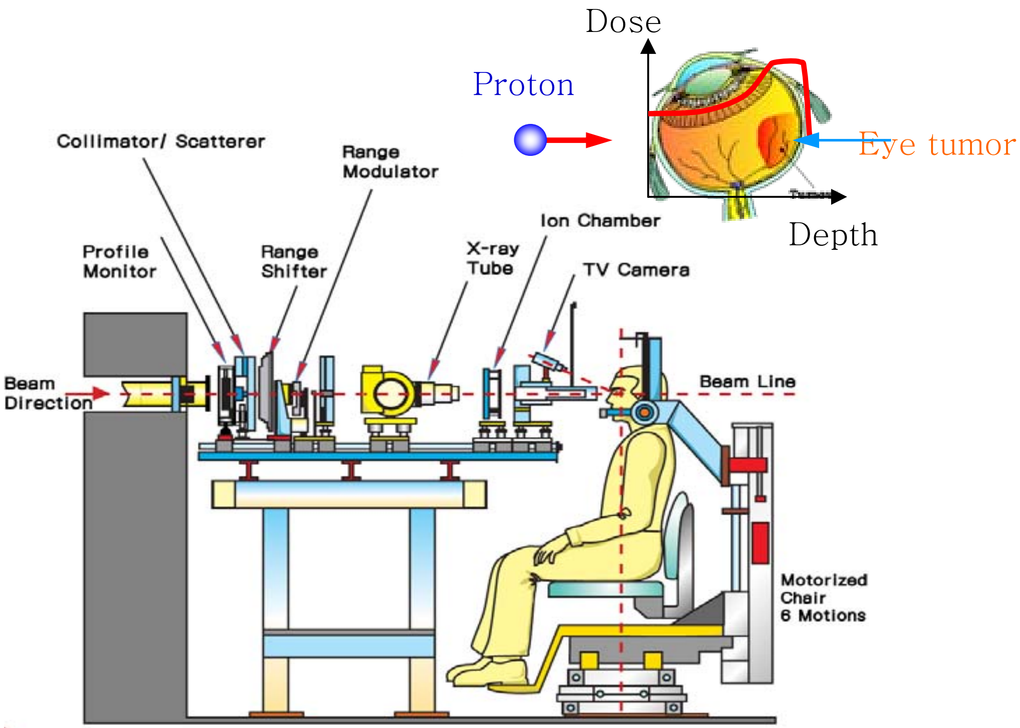


❑ R&D Activities (II) - Medical Utilizations

❖ Low Energy Proton Therapy

- ❖ **Proton therapy machine & technology**
- ❖ **Basic study of proton therapy**
- ❖ **Facility for radiation biological R&D**
- ❖ **Study of proton therapy for eye tumors**

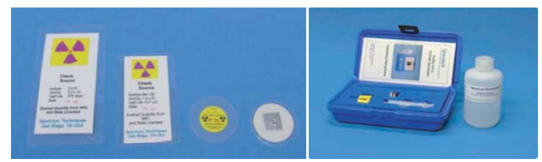
❖ Principle of Eye therapy

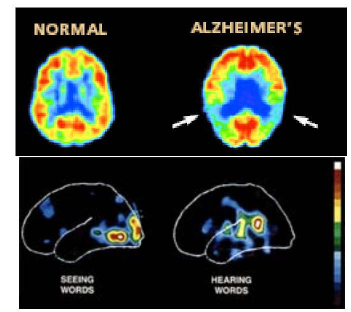


❖ Medical RI Production

- ❖ **Medical RI production using high energy (100MeV) and high current proton beam**
- ❖ **Mass production of many kinds of RI**
- ❖ **Substitution for imported RI**

❖ RI products and their applications





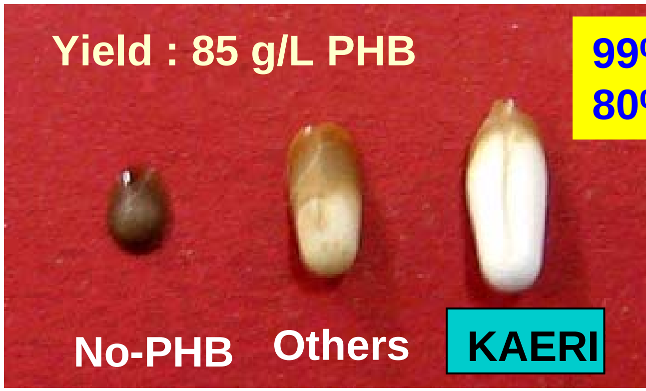
❖ Medical RI available

Proton Energy	R I
Low energy (<20MeV)	F-18, C-11, O-15, N-13, Pd-103
Medium Energy (30~100MeV)	Tl-201, Ga-67, I-123, I-124, In-111, Co-57
High Energy (>100MeV)	Al-26, Mg-28, Si-32, Be-7, Na-22, Ge-68, Sr-82, Tc-95, Cu-67

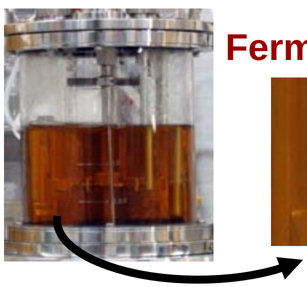
❑ R&D Activities (III) – Bio

❖ Biodegradable Plastic

- ❖ Mutant breeding of microorganism
- ❖ PHB production using E-coli



99% PHB content
80% autolysis



Fermentation !!

Yield : 60-70g/L PHB

Biodegradable Plastic Knife

❖ Mutation Studies

- ❖ Mutant Breeding of Vegetables
- ❖ Plant breeding of Flowering Tree

Technology transfer was performed at 2008

Chinese cabbage transferred to company

Mutants of radish (M3)

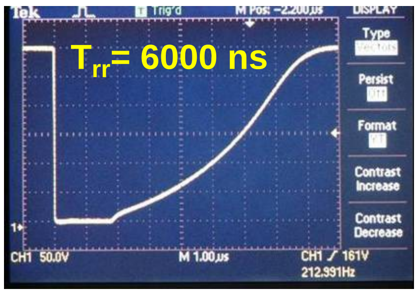
Lagerstroemia indica

❑ R&D Activities (IV) – Semiconductor

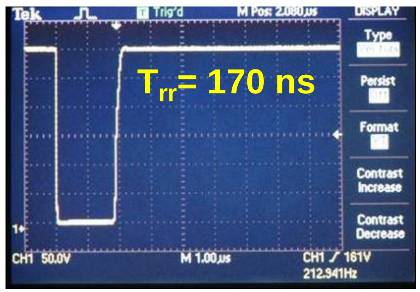
❖ Power Semiconductor

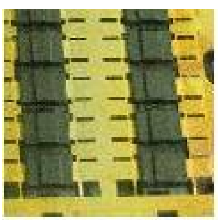
- ❖ Control of minority carrier lifetime
- ❖ High power & speed power semiconductor
- ❖ FRD, IGBT, BJT, etc.

❖ Minority Carrier Lifetime (1/35)



Proton Irradiation





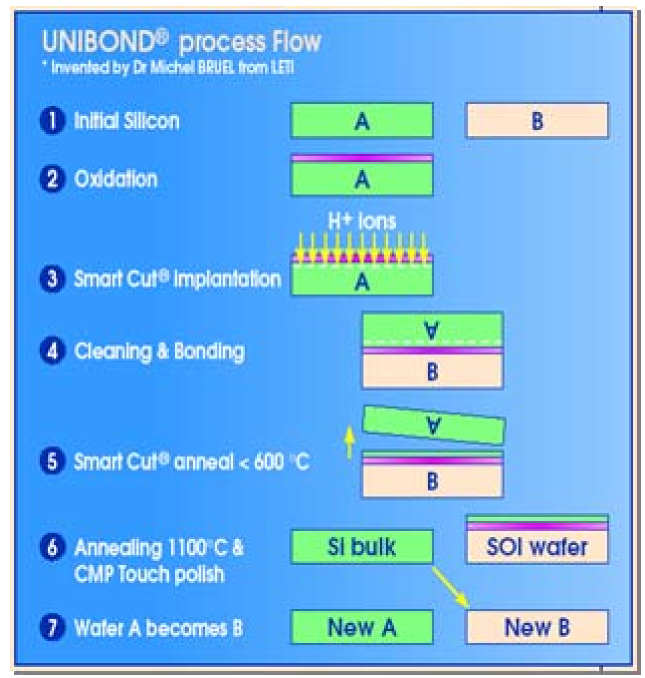
FRD
(Fast Recovery Diode)

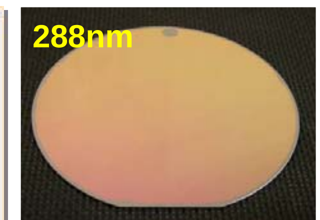
IGBT
(600V, 5A)
And Power IGBT

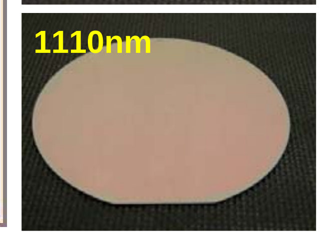
❖ Ion-cut Technology

- ❖ Development of Ion-cut technology
- ❖ Manufacture SOI and GOI wafers
- ❖ Thin layer of compound semiconductor

❖ Ion-cut Technology



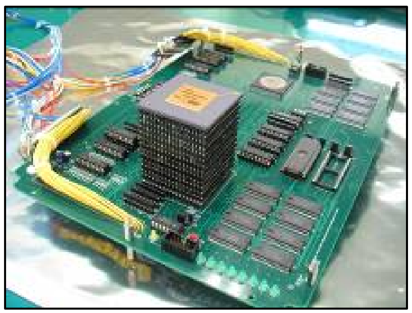


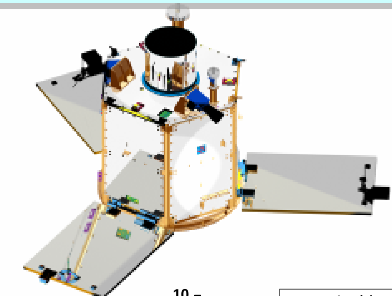


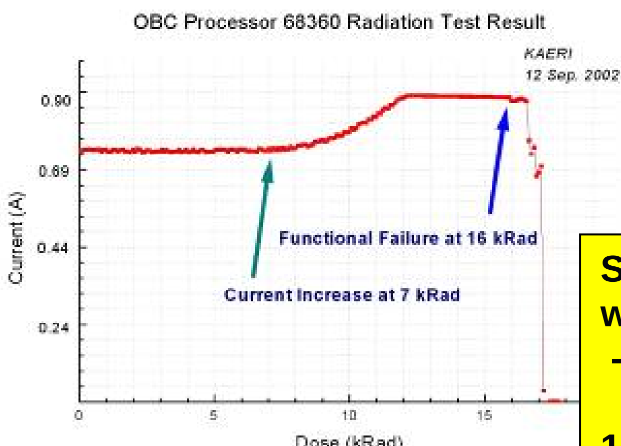
❑ R&D Activities (V) – Others

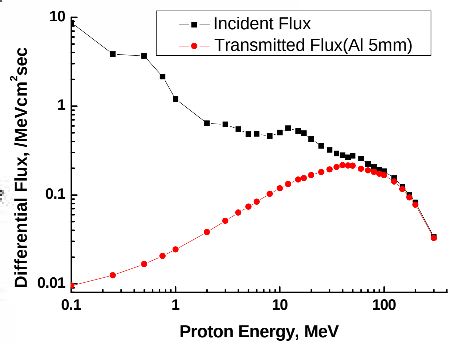
❖ Space Radiation Test

- ❖ Radiation hardness test of semiconductor devices for space crafts
- ❖ Total Dose Effect, Single Event Effect, etc.





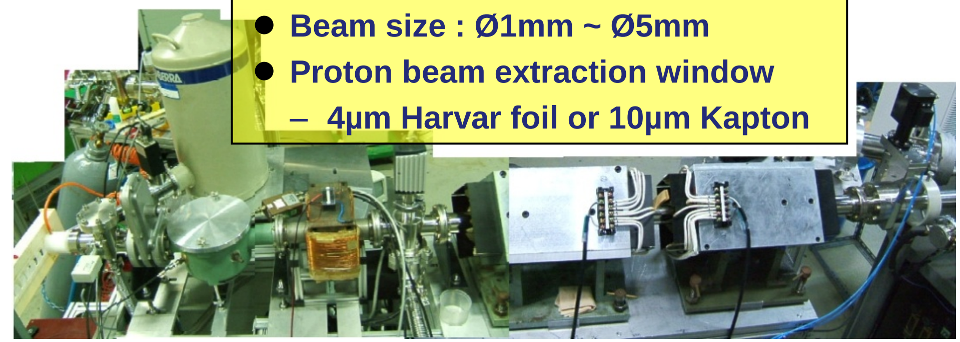




Space environment of MACSAT with 5mm Al shielding
-> total radiation dose 400 rad for 3 years
1000% margin -> 4 krad

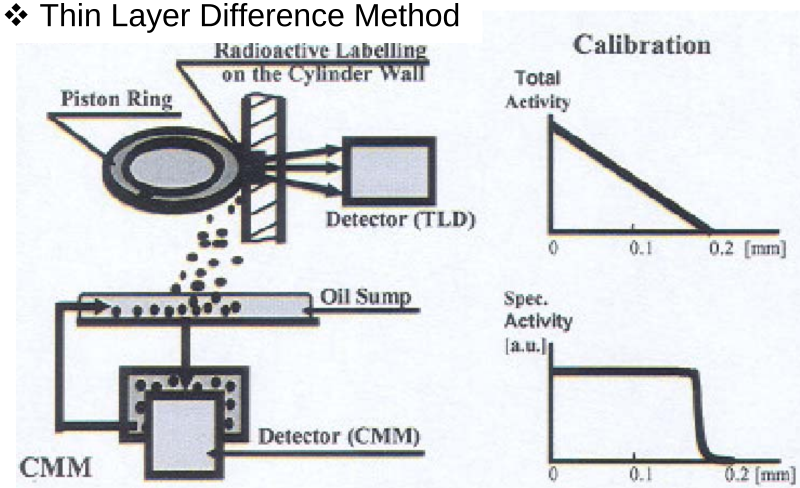
❖ External PIXE

- Beam intensity : 0.5~20nA variable
- Beam size : Ø1mm ~ Ø5mm
- Proton beam extraction window
  - 4μm Harvar foil or 10μm Kapton



❖ TLA (Thin Layer Activation)

❖ Thin Layer Difference Method



❖ Concentration Measurement Method

❑ Activities for the Future

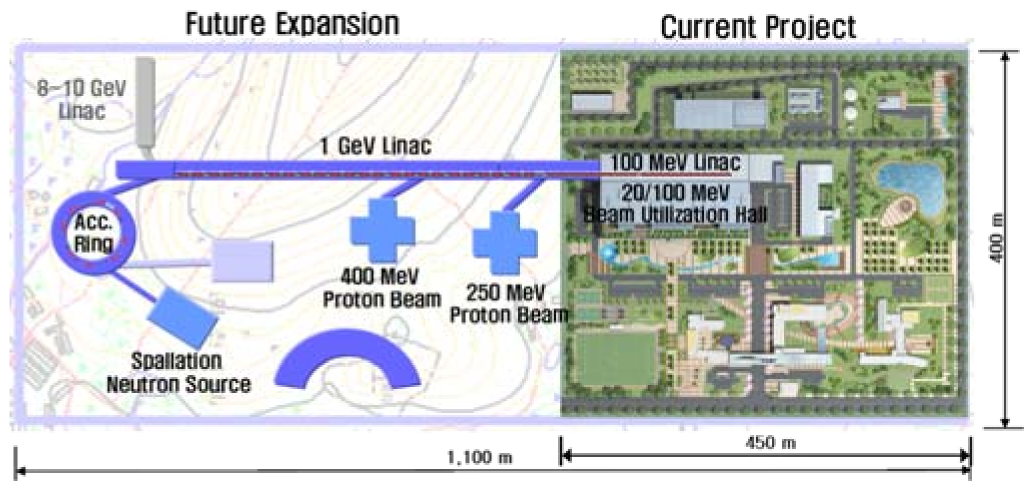
❑ Two Extension Options of the PEFP

Proposed by Science & TEchnology Policy Institute (Feb, 2009)

: in a research report on "*Long-term Planning for Proton Engineering Frontier Project*"

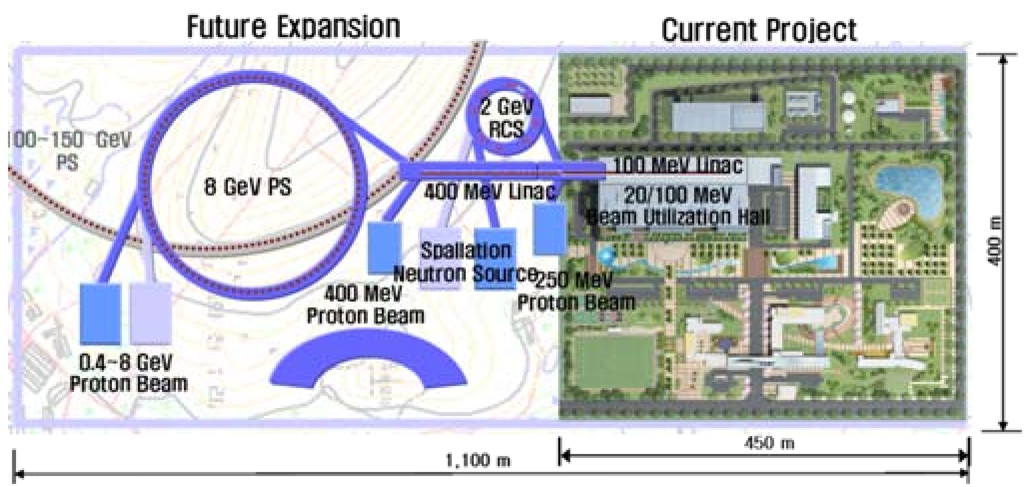
❖ Option 1

- **1 GeV Linac + Accumulation Ring**
  - ⇒ 2 MW Spallation Neutron Source
  - ⇒ 250, 400, 1000 MeV Proton Beam



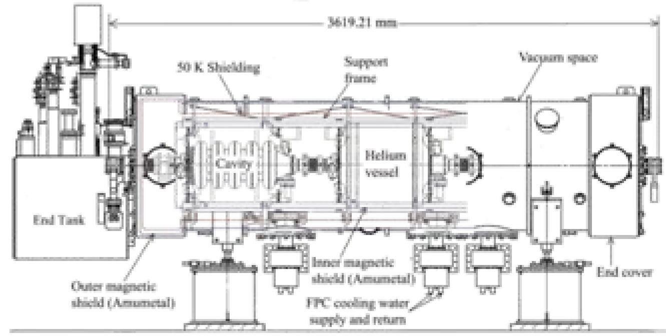
❖ Option 2

- **200 MeV Linac + 2 GeV RCS**
  - ⇒ 0.5 MW Spallation Neutron Source
  - ⇒ 250 MeV Proton Beam
- **400 MeV Linac + 8 GeV PS**
  - ⇒ 8 GeV Proton Beam

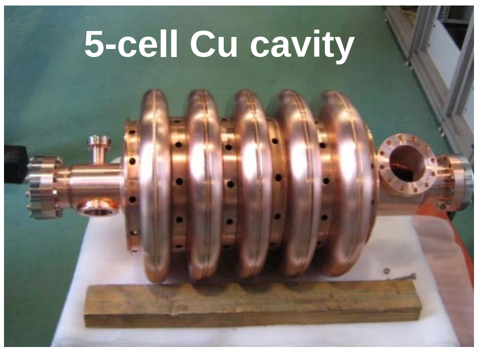


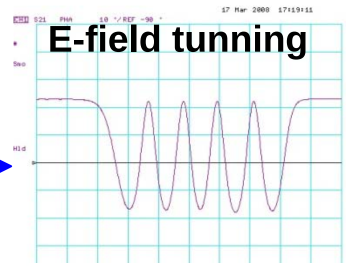
❑ Superconducting Linac Development

- β=0.42, RF: 700 MHz
- SC Cavity, RF coupler, Tuner, Vacuum Vessel, etc.
- Fabricated & tested a warm module (Cu Cavity)
- Fabricated and tested a 2-cell cold module (Nb Cavity)

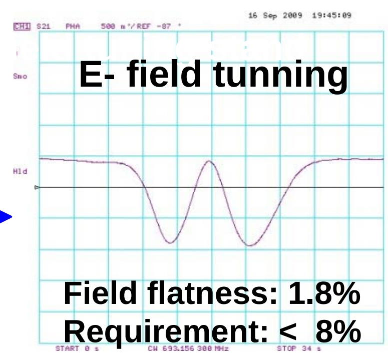


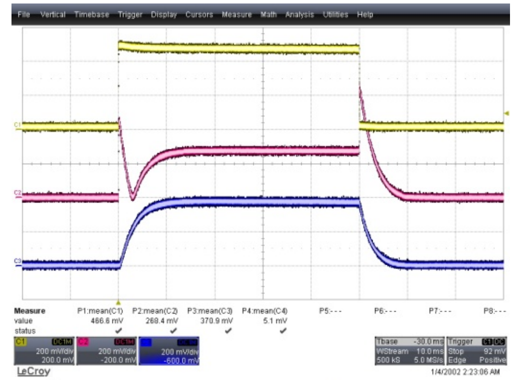
< Designed SRF module >

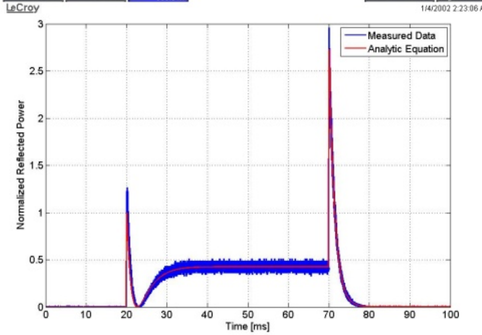




Field flatness < 1.43 %

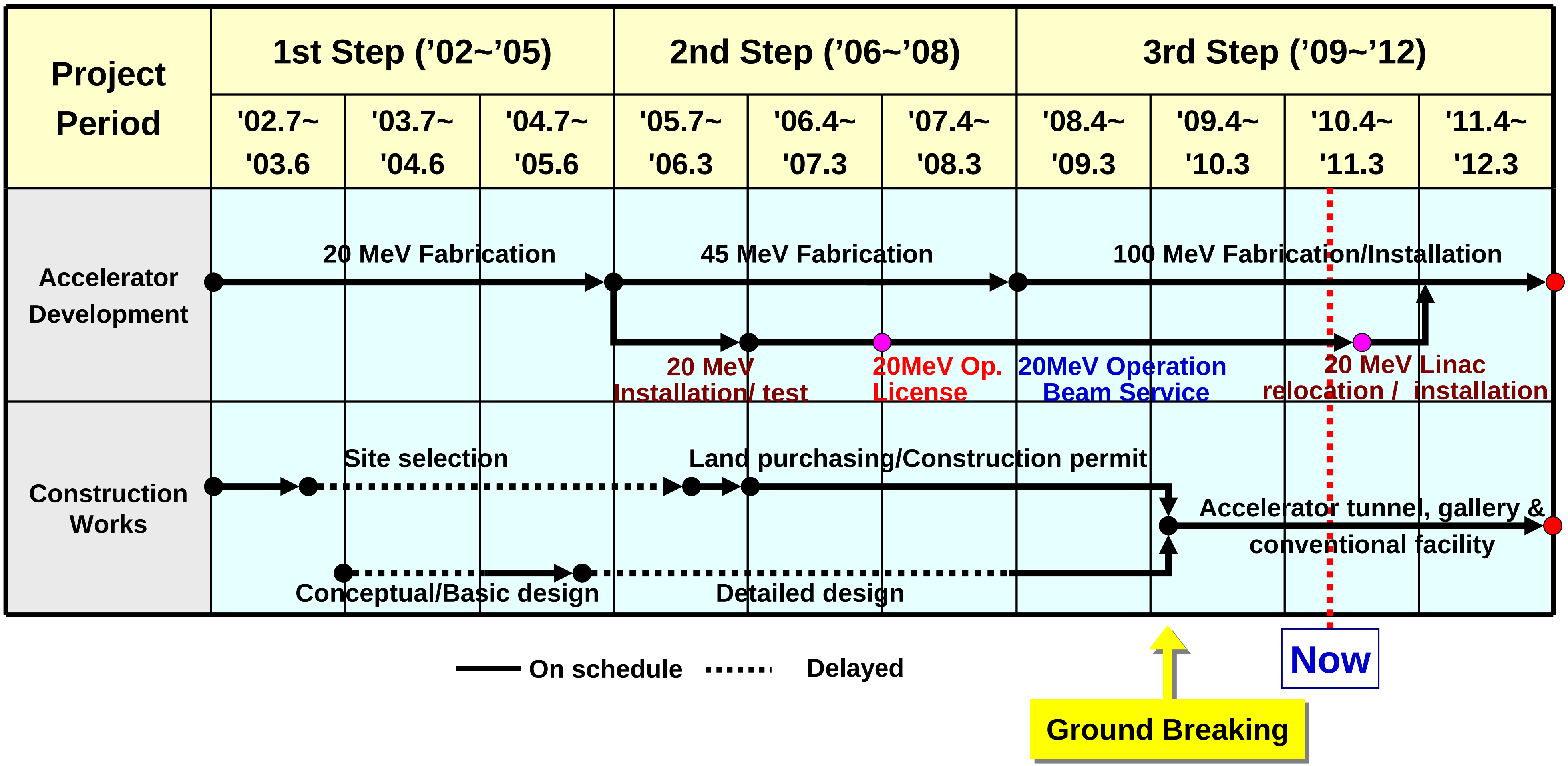






Eacc ~ 1.8 MV/m
(Available RF power limit)
Q0 ~ 3.7E7

❑ Project Schedule

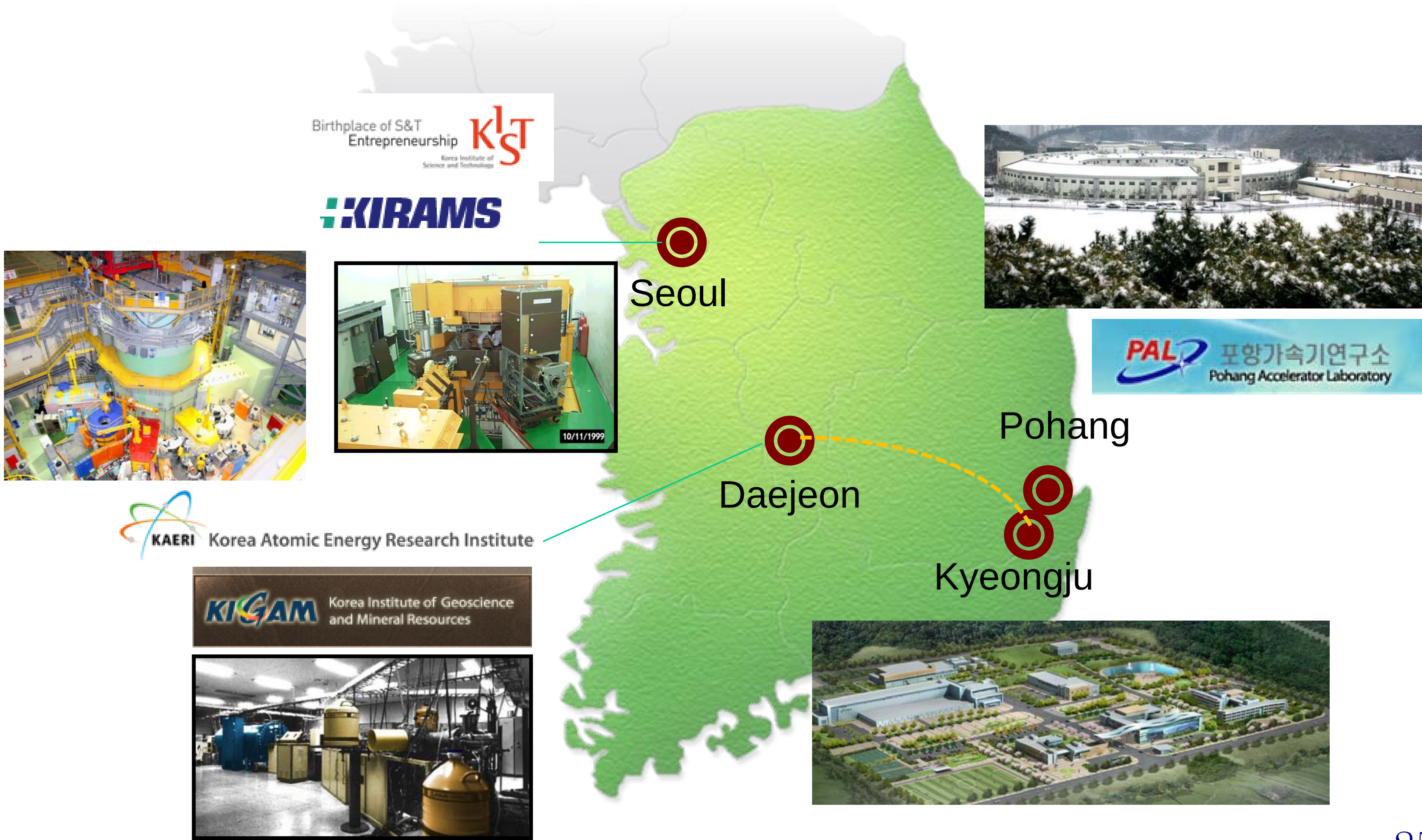


* delayed due to an interruption in connection with the site selection issue of Korean nuclear waste repository

❑ Neutron Sources in Korea

- Reactor Based Neutron Source
  - HANARO
- Accelerator Based Neutron Sources
  - KIGAM Neutron Facility
  - MC-50 Neutron Beamline
  - Pohang Neutron Facility

❑ Facilities for Neutron Sources



❑ HANARO (High-flux Advanced Neutron Application Reactor)

PEFP Proton Engineering Frontier Project

- Constructed in April 1995
- Application Fields : - Neutron Beam Application, - Fuel & material Irradiation
  - Neutron Activation Analysis, - Radioisotope Production
  - Neutron Transmutation Doping, - Ex-core Neutron-Irradiation Facility
  - 3-Pin Fuel Test Loop (under construction)
  - Cold Neutron Beam Application (under Construction)

Type	Open-tank-in-pool
Maximum thermal power	30 MW
Coolant	Light water
Reflector	Heavy water
Fuel material	U_3Si in aluminum matrix, 19.75 w/o enriched
Absorber material	Hafnium
Secondary cooling	Cooling tower
Reactor building	Confinement

❑ HANARO Neutron Research Facility

Construction & Utilization

Full Utilization

Cold Neutron Facility

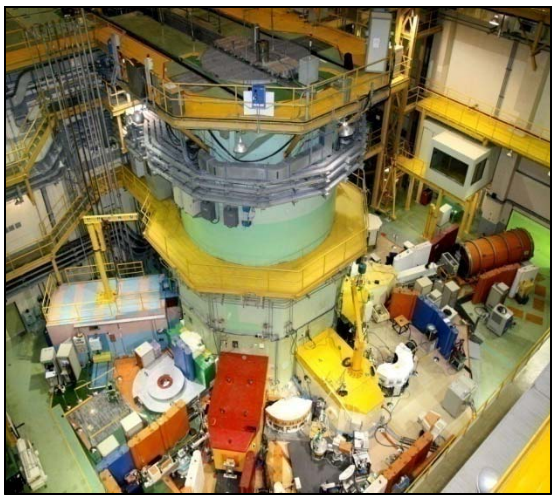
(2003~2010)

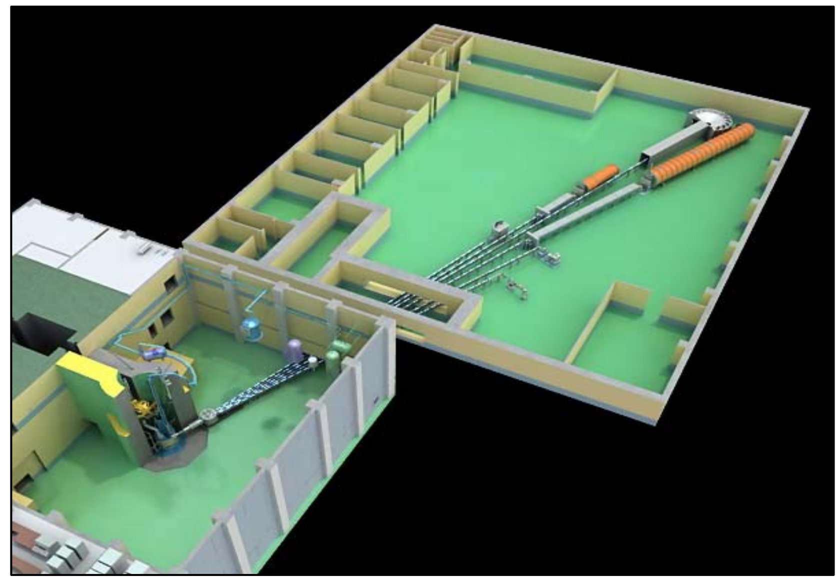
2010

Thermal Neutron Instruments

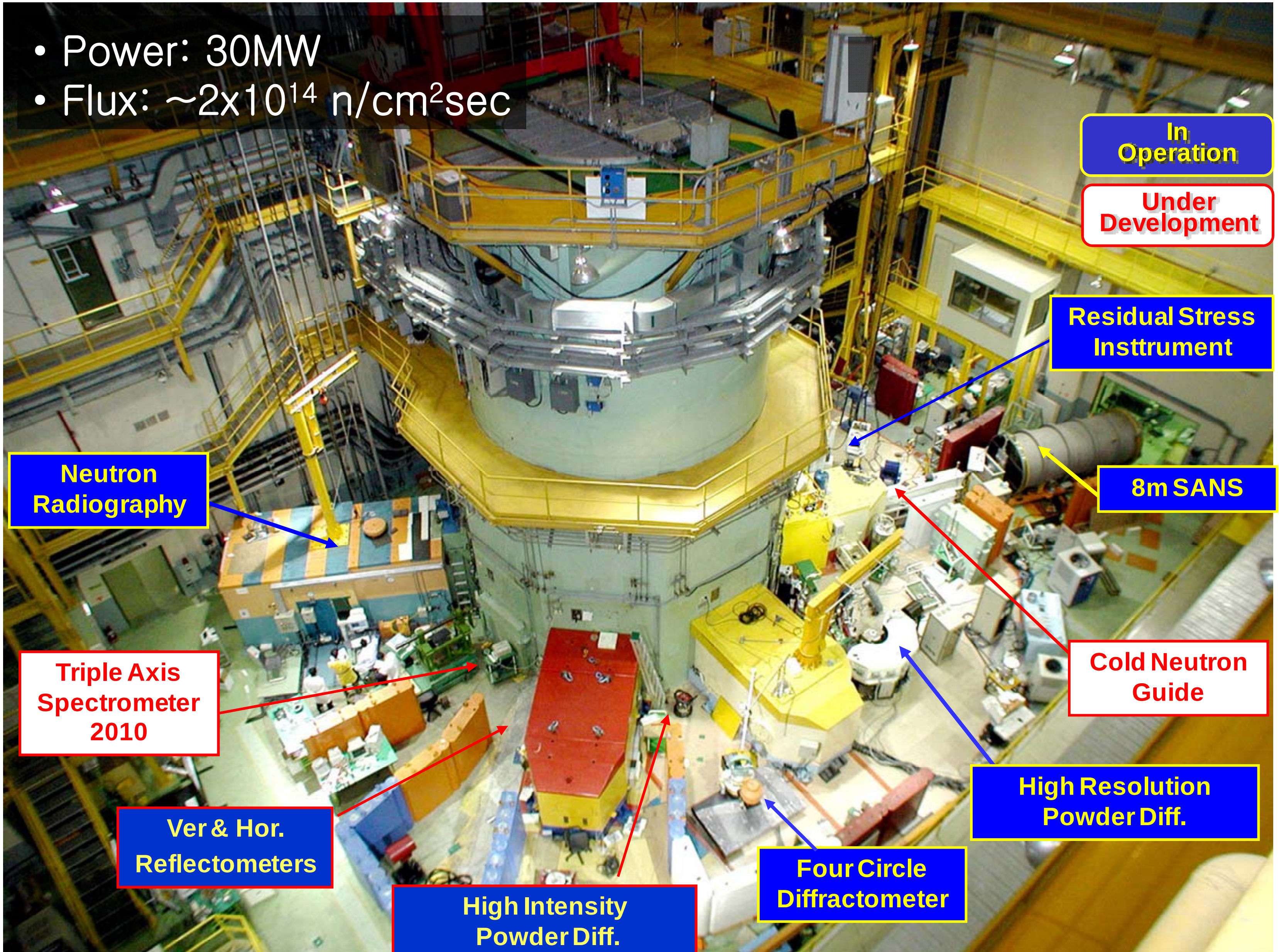
HANARO Reactor (30 MW)

1995





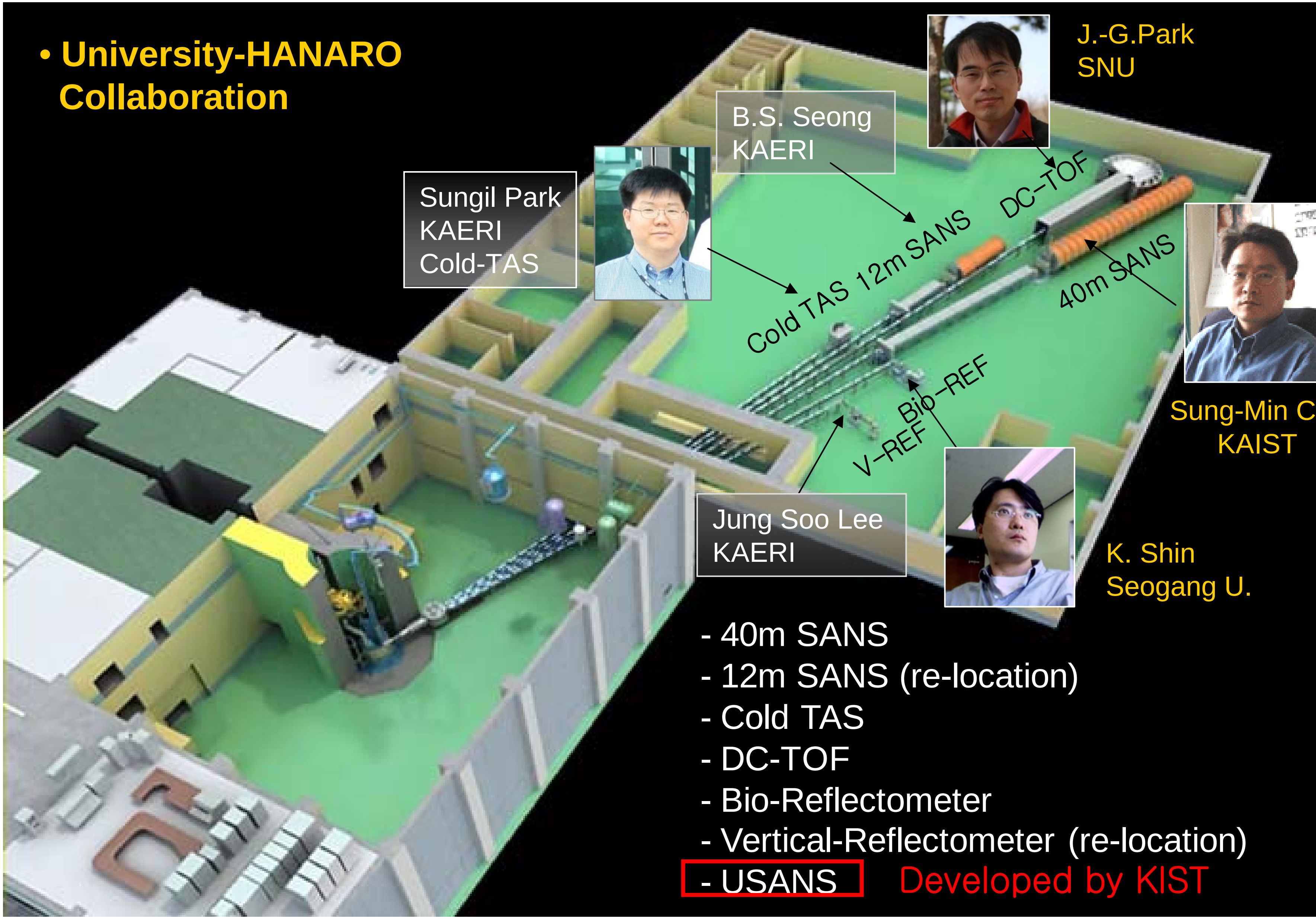
❑ HANARO Thermal Neutron Instruments In Reactor Hall



❑ HANARO's Cold Neutron Research Facility

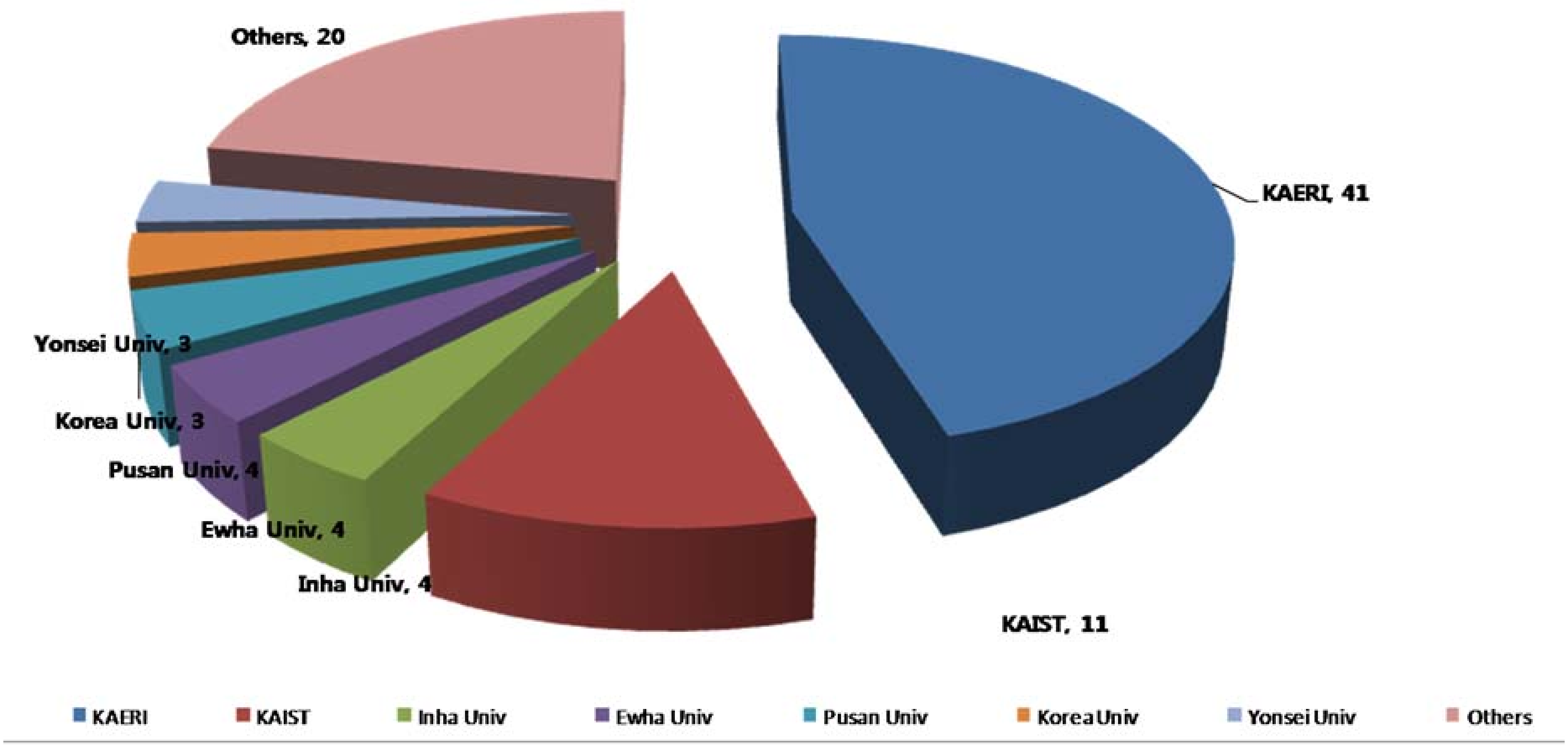
PEFP Proton Engineering Frontier Project

- **University-HANARO Collaboration**



- 40m SANS
- 12m SANS (re-location)
- Cold TAS
- DC-TOF
- Bio-Reflectometer
- Vertical-Reflectometer (re-location)
- USANS Developed by KIST

❑ HANARO Users in 2009

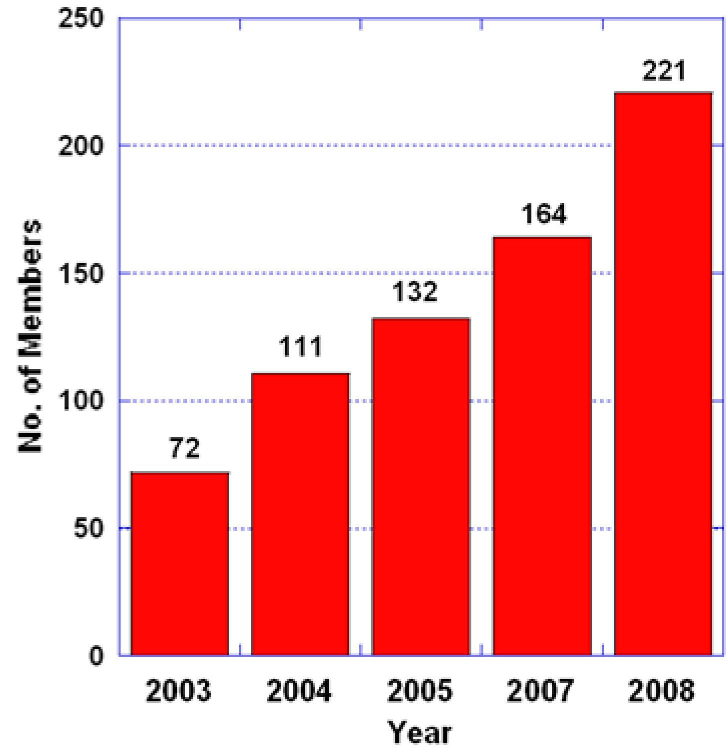


❑ Korean Neutron Beam Users Association (KNBUA)

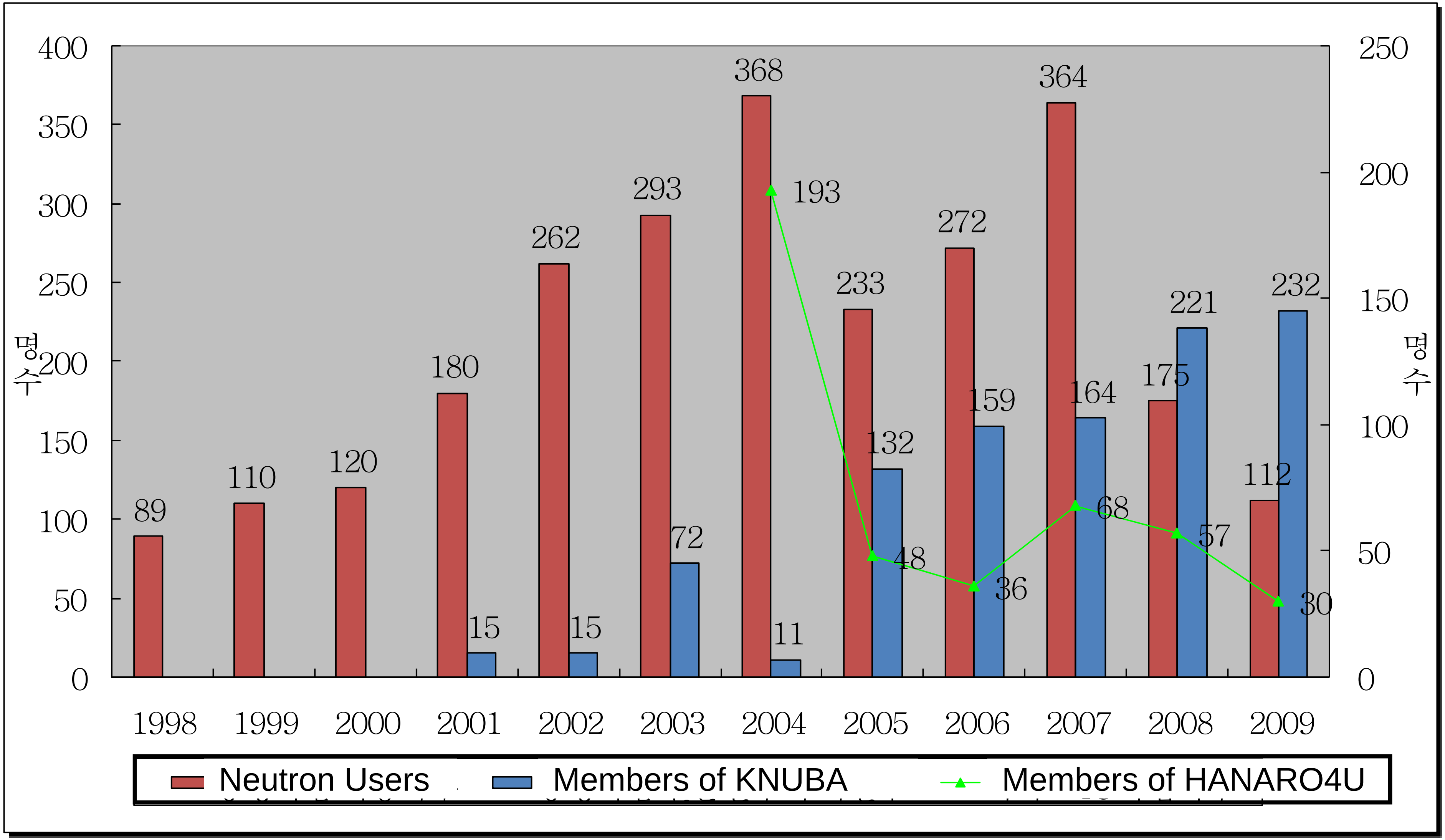
KNBUA
The Korean Neutron Beam Users Association

President : Mahn Won Kim (KAIST)
Secretary : Sung-Min Choi (KAIST)

Elastic Group 104	Low-Q Group 91	Inelastic Group 39	Radiography 22
J.S. Kim N.S. Shin H.M. Park C.H. Lee	H.D. Kim Y.S. Kim D.Y. Ryu B.S. Seong	J.G. Park J.H. Jeong S. Park	G.S. Cho J.H. Hwang H.H. Kim C.M. Shim

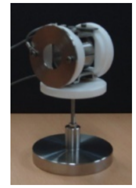


❑ Neutron Users in Korea



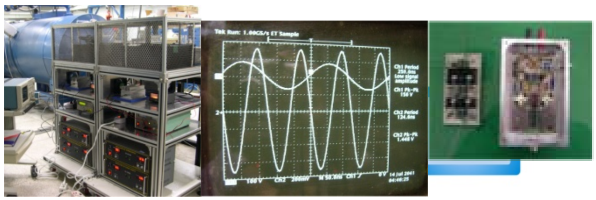
❑ KIGAM Neutron Facility

TOF system
(L=4.18m)
Neutron beam line

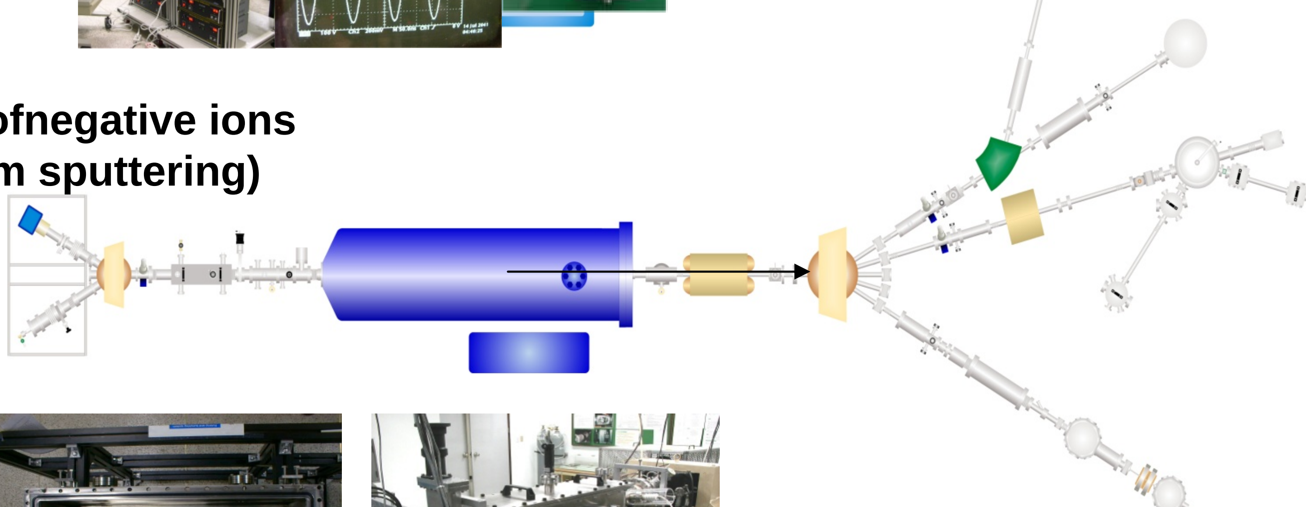


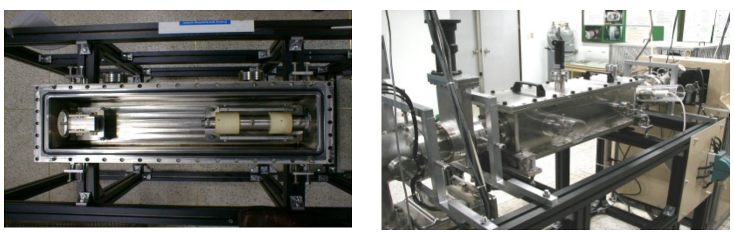
Time-pick-up
module

RF amplifier



SNICS
(source ofnegative ions
by cesium sputtering)





Beam pulsing system
(rep time : 125ns, pulse width : 1-2ns)

- KIGAM 1.7 MV tandem accelerator
- Beam bunching system

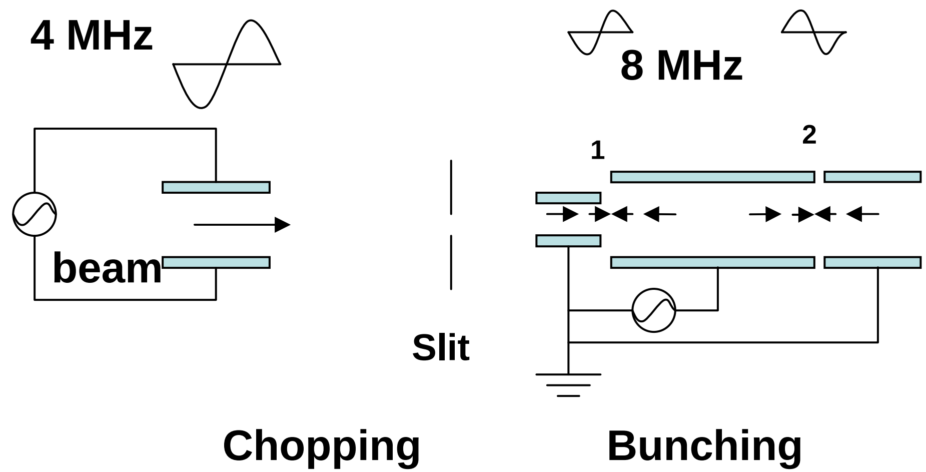
by Dr. K. D. Kim

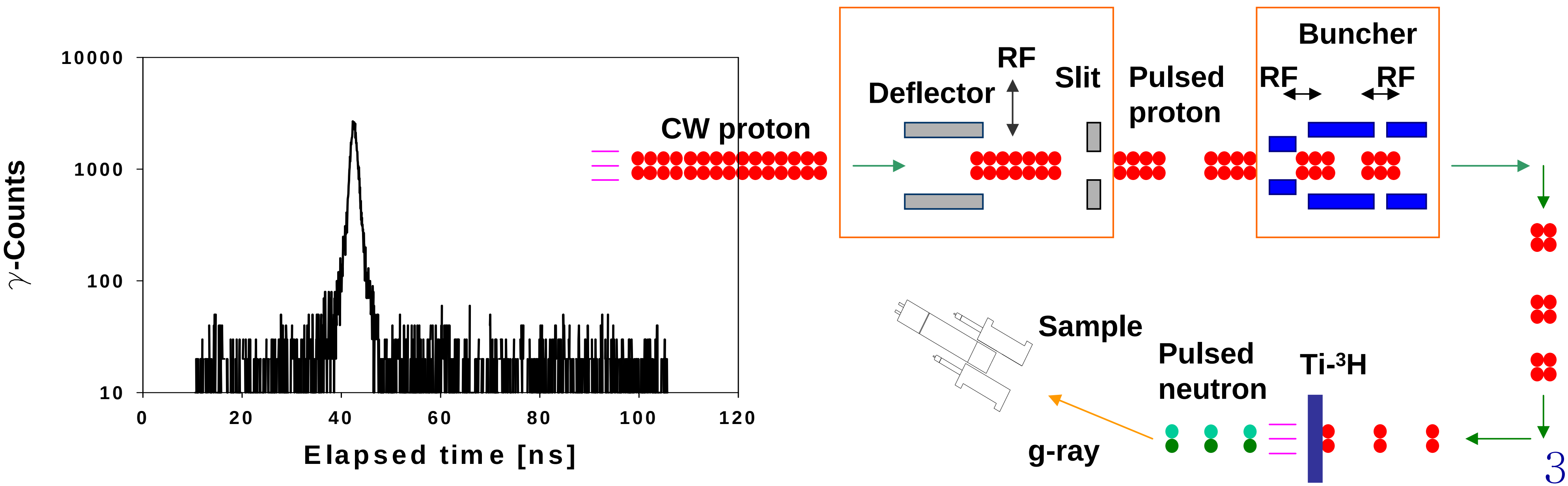
❑ KIGAM Neutron Facility

● **Beam bunching system**

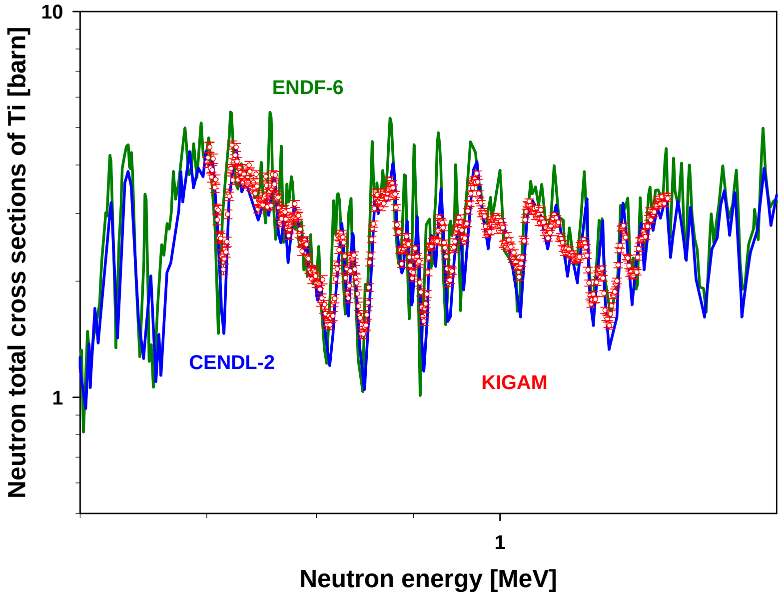
- Beam size : <8 mm
- Bunch width : 1 ~ 2 ns
- Bunching yield : <10 %
- Bunch repetition rate : 8 MHz

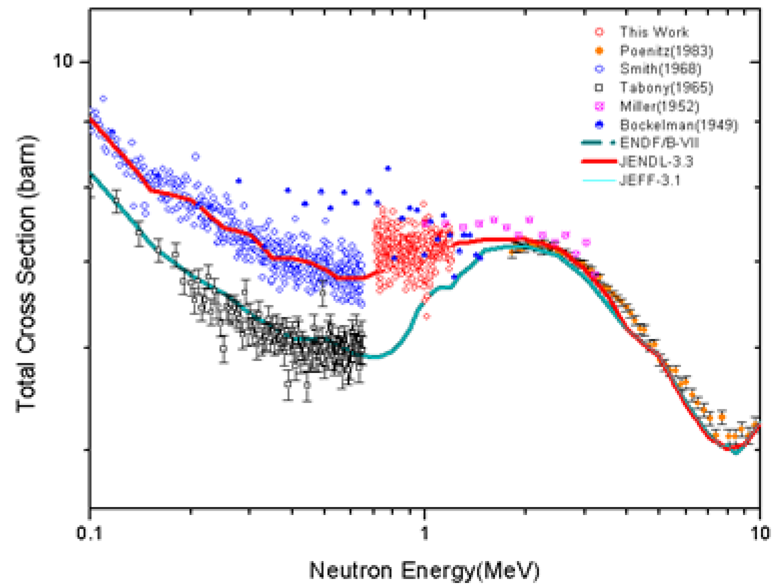
Principle of beam pulsing system

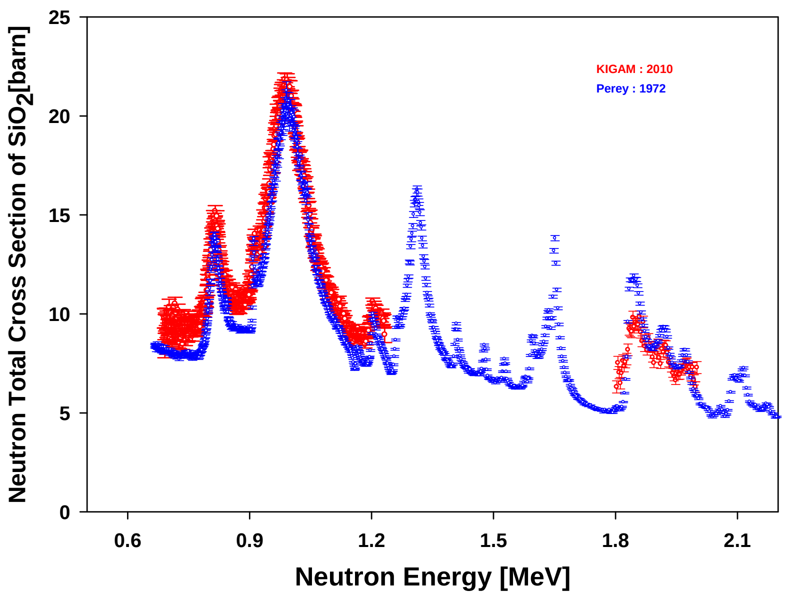


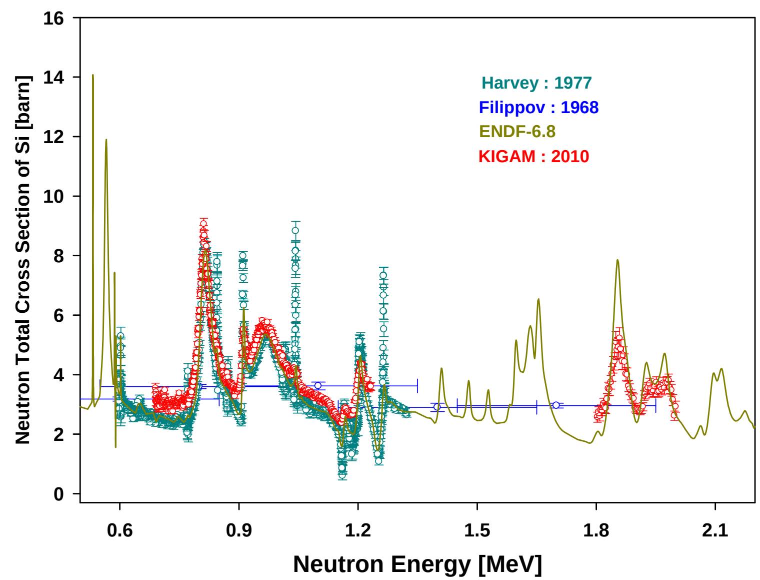


❑ KIGAM Neutron Facility









❑ Future Plan of KIGAM Neutron Facility

In 2010,

Construction of Mono-energetic Neutron Standards Facility

- Fabrication of D beam bunching system.
- Replace SNICS to Duoplasmatron source.
- Design and fabrication of long counter.
- Fabrication of movement system for flux monitor.

In 2011,

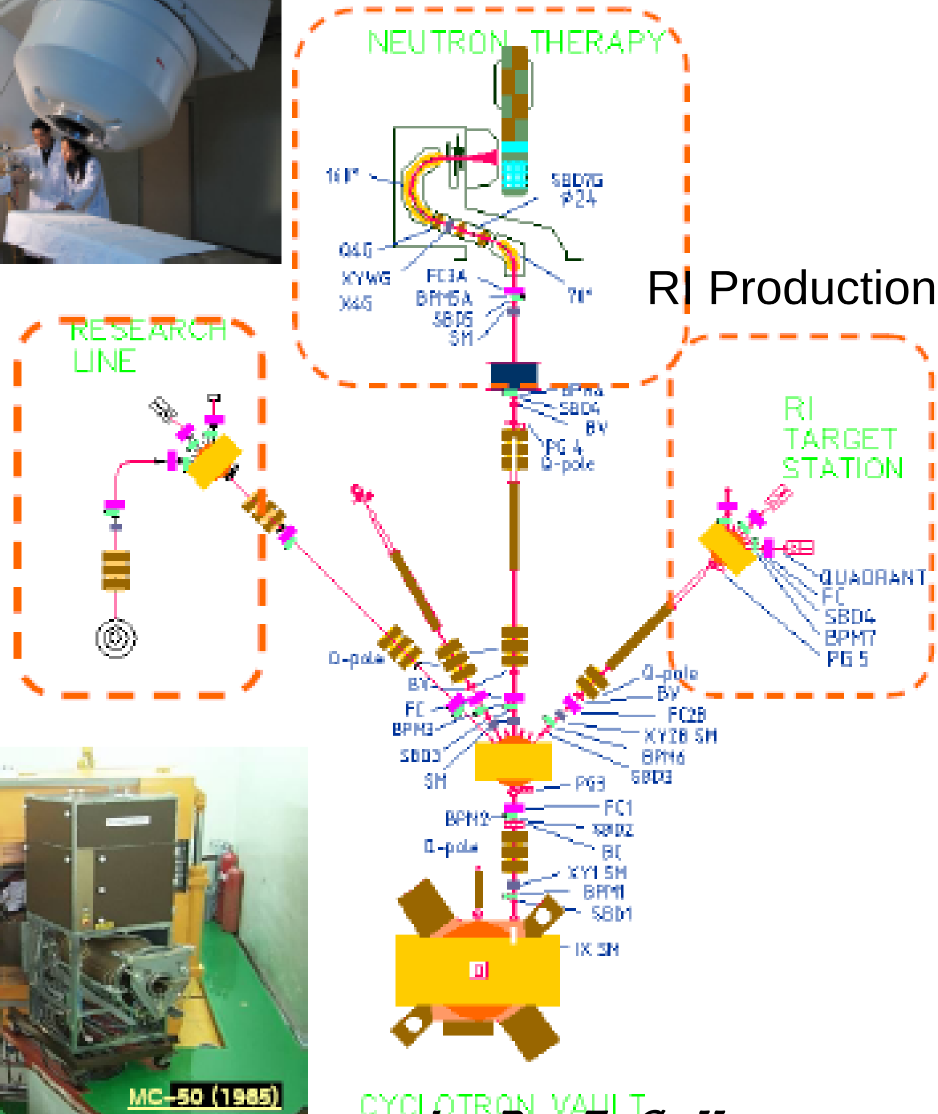
Nuclear Data Production on keV Energy

- Neutron capture cross section on Actinide material
- Measurement system of elastic scattering cross section

❑ MC-50 Cyclotron at KIRAMS

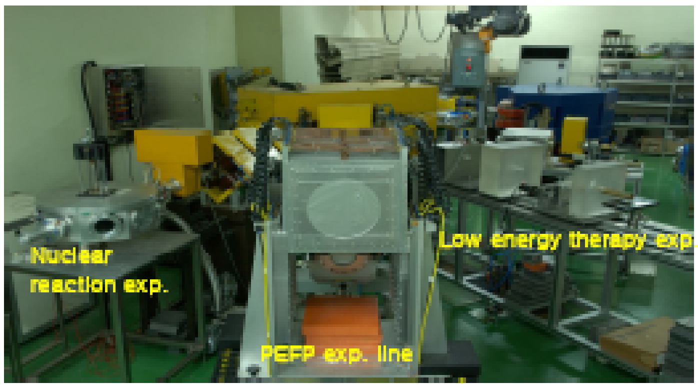
양성자 (proton)	20~51 MeV / 60 uA
중양성자 (deuteron)	10~25 MeV / 30 uA
He-3	20~70 MeV / 20 uA
He-4	25~52 MeV / 30 uA

Neutron exp. Hall (>10nA)

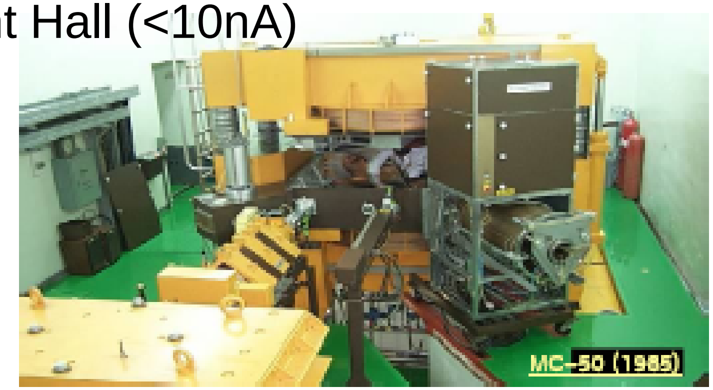


RI Production

• Imported in 1984 for neutron therapy



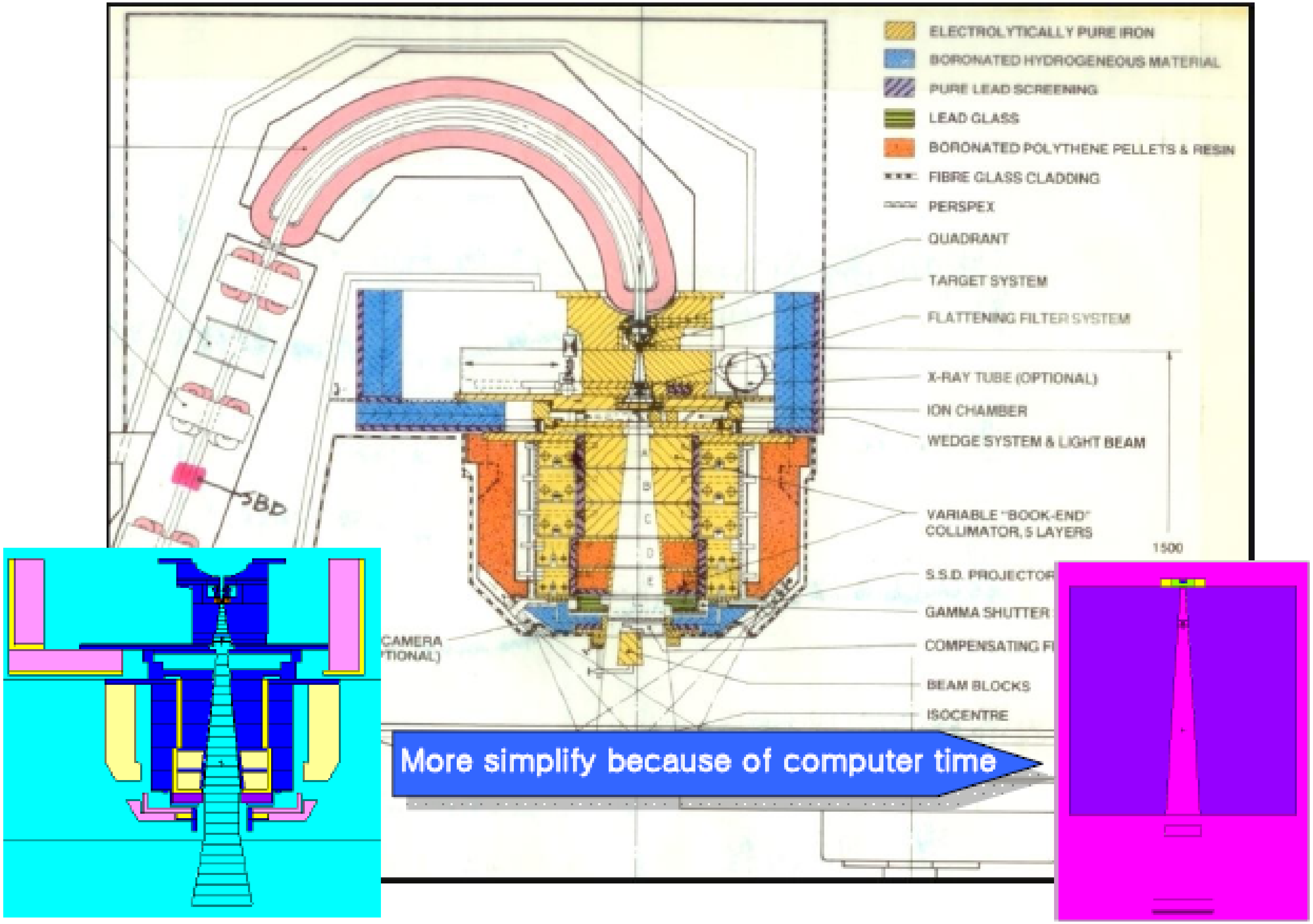
Beam utilization experiment Hall (<10nA)



MC-50 Cyclotron (Scantronics)

by Dr. T. G. Yang

❑ Gantry Modeling for Neutron Dose Estimate



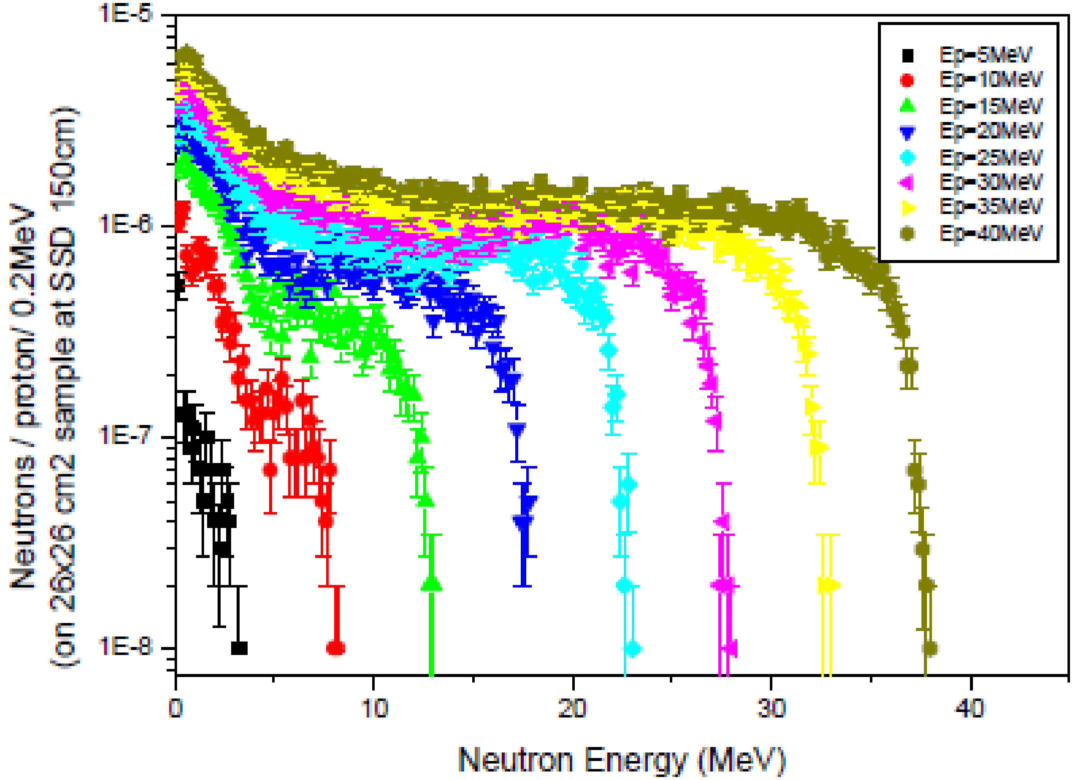
Ctm: 3657 min

Pentium 4, cpu 2.8Ghz, mcnpx nps:1e+8

Ctm: 784 min

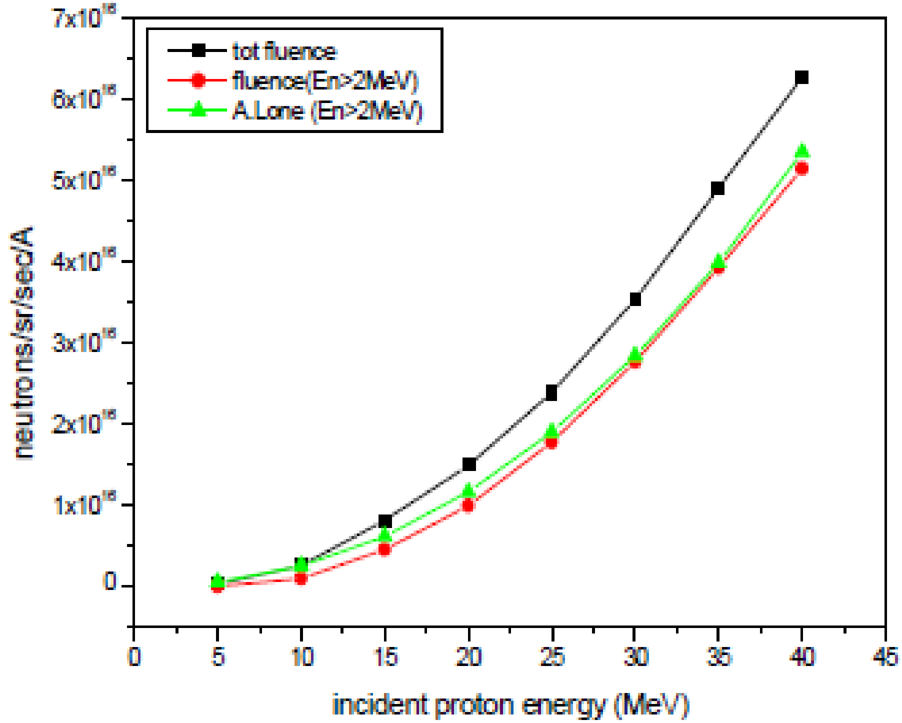
❑ Neutron Spectrum from Targets

Neutron spectra at each energy of incident proton



Be target thickness: range of proton
SSD: 150cm

Compare neutron yield with M.A.Lone (En>2MeV)

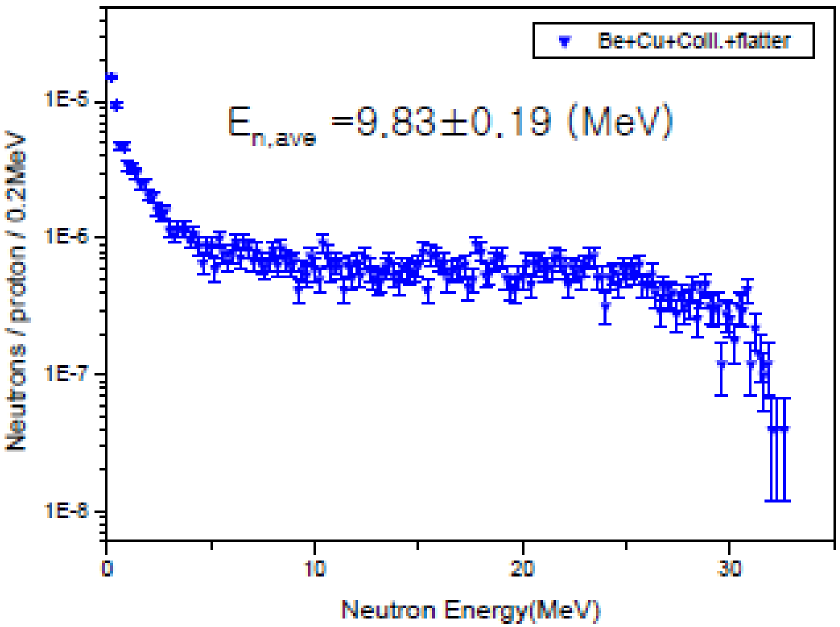


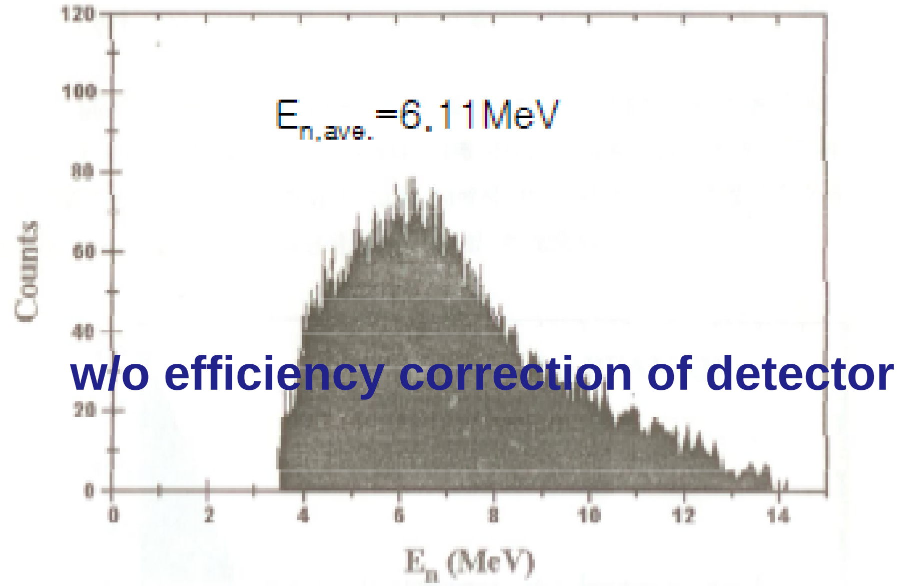
By M.A.Lone[ref], for En>2MeV

$$I_n = 1.6\times10^{13} E_p^{2.2} (n\cdot sr^{-1}\cdot s^{-1}\cdot A^{-1})$$

[Ref] M.A.Lone, NIM 189, 513-523 (1981)

❑ Comparison of Average Neutron Energy



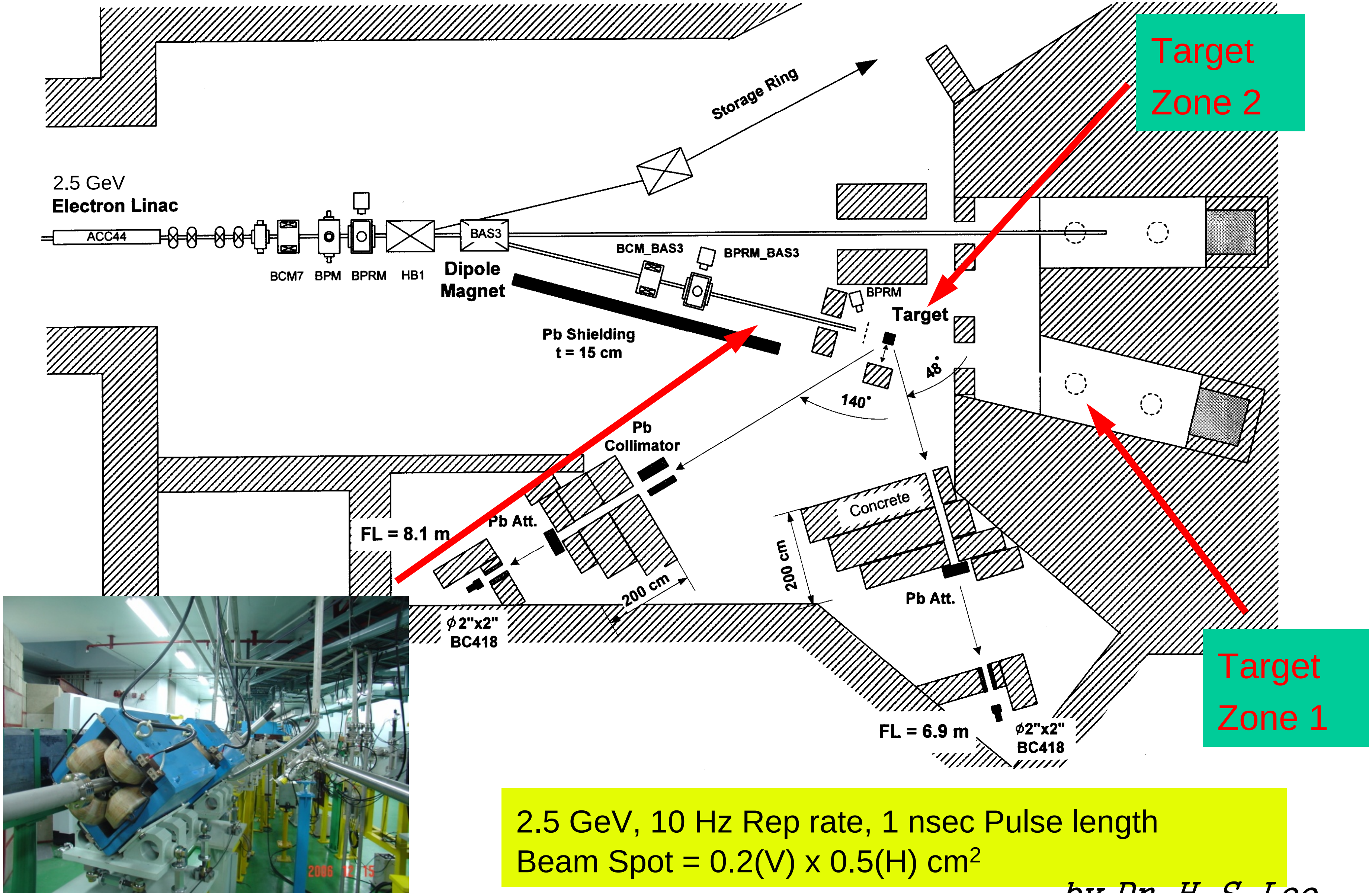


TOF spectrum.p(35MeV) +Be [3]

[3] Jong Seo Chai, et al. A study on the neutron beam energy measurement and development of neutron target system, KAERI/RR-1555/95

They obtained 6.11MeV as average energy of neutrons from TOF measurement of Be(p,n) reaction at Ep=35MeV[3]. When they converse TOF spectrum to Neutron energy spectrum, they did not consider the dependence of detection efficiency on neutron energy. Considering low detection efficiency of high energy neutron, the average neutron energy emitted from the reaction must be higher more than 6.11 MeV.

❑ PAL-PHERF (Pohang High Energy Radiation Facility)



2.5 GeV, 10 Hz Rep rate, 1 nsec Pulse length
Beam Spot = 0.2(V) x 0.5(H) cm^2

by Dr. H. S. Lee

❑ Neutron Spectra and Yields

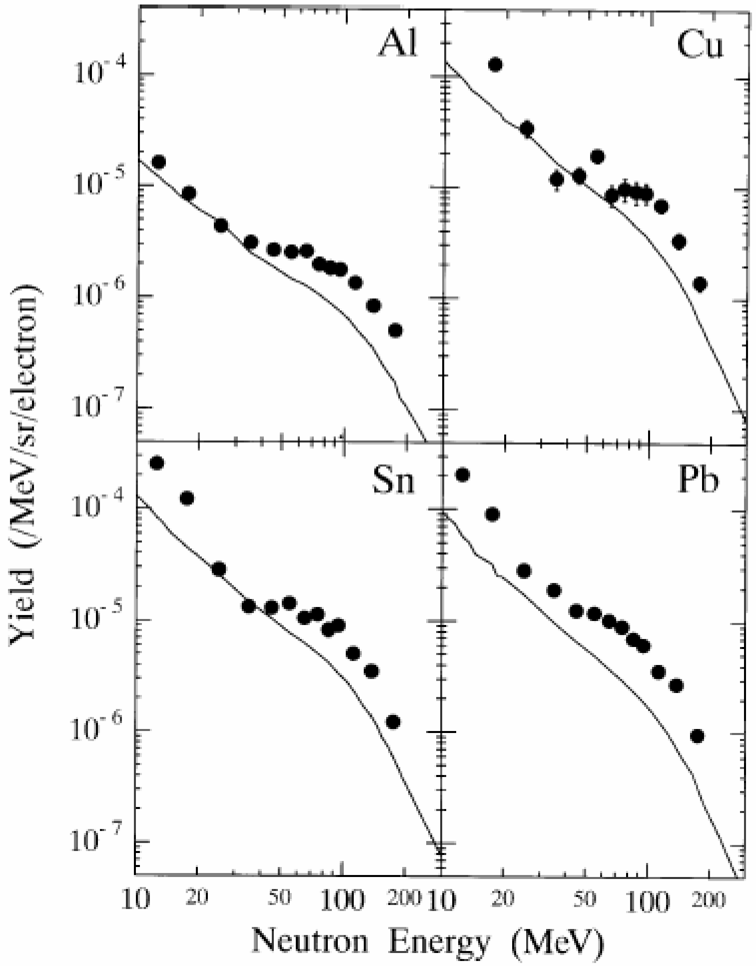


Fig. 6. Measured and calculated neutron spectra at the upper surface of each target. The calculated values are predicted by a combination of EGS4, our modified PICA95 and LAHET2.7 codes.

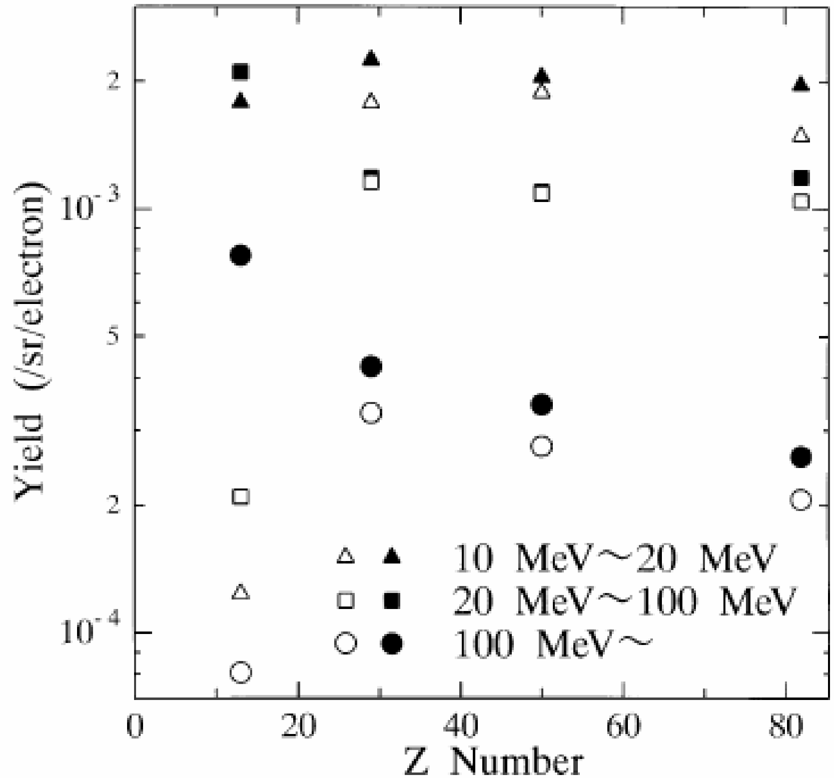
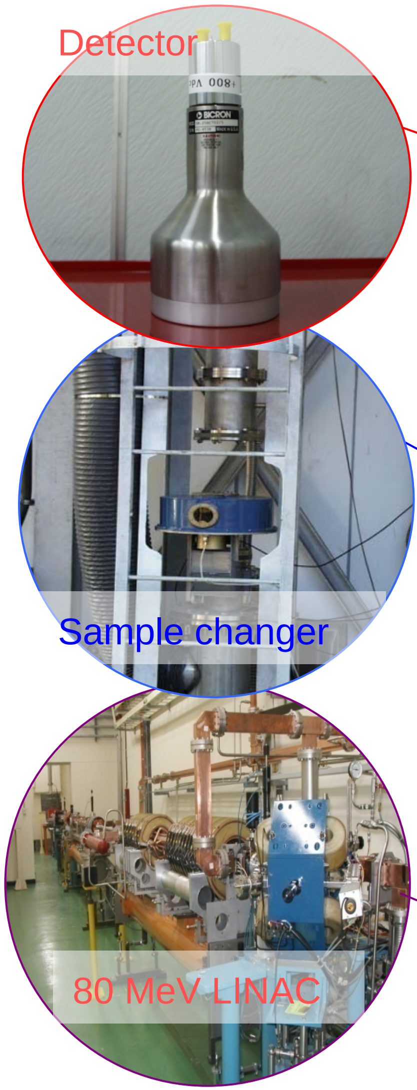


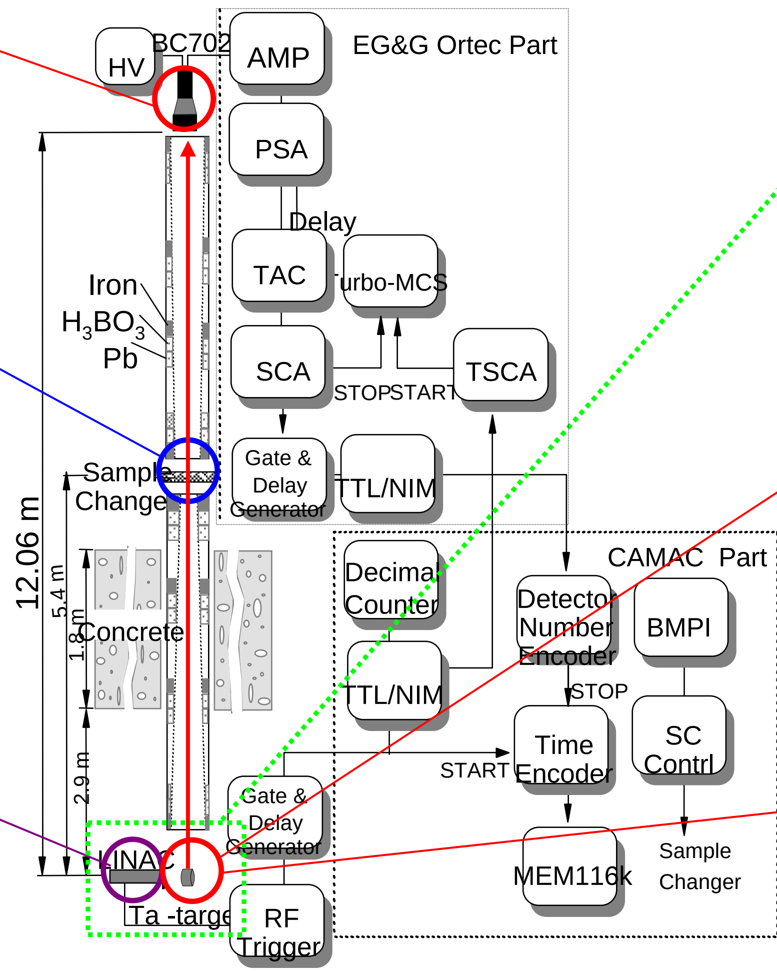
Fig. 7. Integrated neutron yields for three neutron energy ranges as a function of the target's Z number. The solid symbols are for the neutron production yields in the infinite-size targets, and the open symbols are for the emitted neutron yields from our finite-size targets.

❑ PAL-PNF (Pohang Neutron Facility)

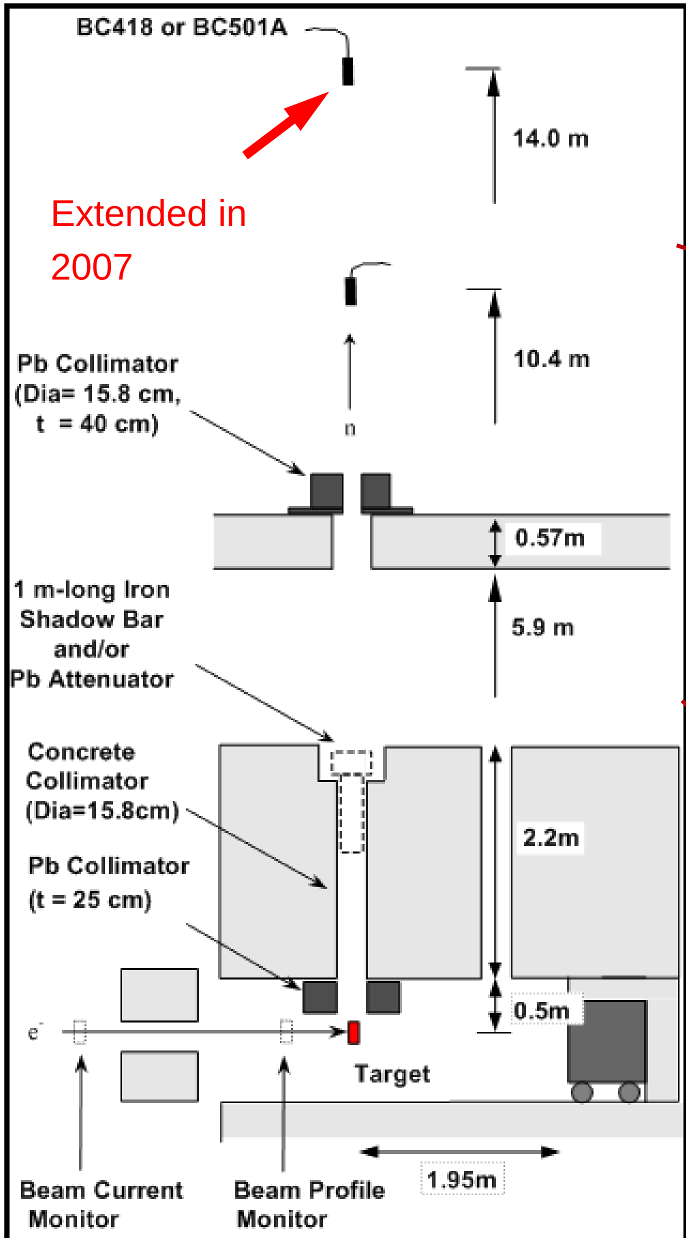
PEFP Proton Engineering Frontier Project

1) Electron Linear Accelerator (80 MeV,1 usec pulse)
2) Target System for low-E neutron
3) 12 m TOF Experimental Hall





❑ PAL-Neutron TOF at 90^{o}, 48^{o}, 140^{o}



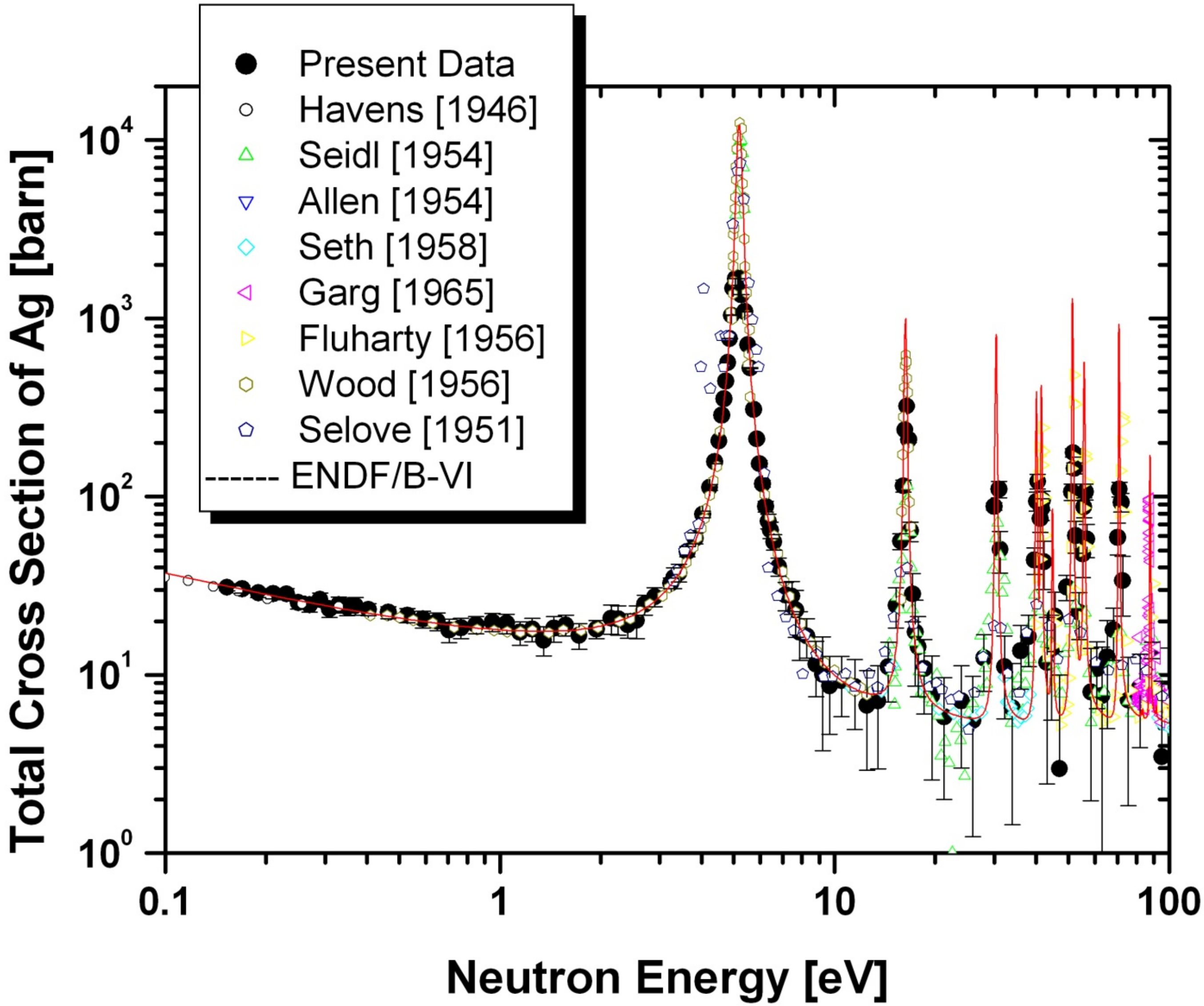
❑ Differential photo-neutron yields

Dependence on target conditions :

Atomic number, Target thickness

Experimental setup (90^{o} case) .

❑ Total Cross-Section of Ag^{nat}



❑ Promotion of accelerator-driven neutron source in Korea

- Number of potential users in Korea
  >200 users for CW neutron source
  <10 users for pulsed neutron source

- Role of compact pulsed neutron source can be defined;
  Education & training
  Test of neutron instruments
  Promoting neutron science
  Development of users and experts
  Bridge to the spallation neutron source, etc.

- Have to be complementary to HANARO

- Collaboration with existing R&D groups for pulsed source internally as well as internationally

❑ Collaborations

- PEFP : CSNS, SNS, J-PARC, Tsinghua Univ., CYRIC, RCNP, MEGAPIE, etc.
- PLS : KEK, Spring-8, Tsinghua Univ., JAEA, etc.
- KIST : SNS, HANARO, etc.

2008	❑ ORNL-KIST Joint Symposium ❑ MOU with ORNL in Neutron Sciences
2009	Spallation Neutron Sources Session at the 13th ICABU (International Conference on Accelerator and Beam Utilization
2010	Workshop for Spallation Neutron Sources

2007-2010	❑ KIST-USANS Construction at KAERI-HANARO (beam line: CG4B) ❑ Advisor : M. Agamalian (ORNL-SNS) & John Barker, C. Glinka (NIST)

by Dr. M. H. Kim

❑ Technical Issues

- Accelerator and proton beam

  20MeV / 100MeV / 1~2GeV proton beam

  few hundreds micro amp.

- TRM

  Target

  Moderator

  Reflector

- Neutron Instruments

  TOF, SANS, etc.

- Measurement of fast neutron as well as thermal neutron

❑ Summary

➢ **100 MeV, 20 mA Proton Linac & Beamlines**

- **20 MeV Linac :**
  - **- Completed & In beam service**
  - **- Achieved designed beam energy & current**
- **Higher energy part:**
  - **- 20~91 MeV DTL : fabricated and tested**
  - **- 91-100 MeV DTL : under fabrication**
- **To relocate the 20 MeV linac to the site from September 2011**
- **To complete the 100 MeV linac & beamlines by March 2012**

➢ **Construction Work**

- **Under leveling the site along with excavation**
- **To start foundation work in July 2010, construction work will be started next month, accelerator & experimental hall to be completed by March 2012**

➢ **Beam Utilization & Applications**

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

❑ Summary

- **Activities for the Future (a Spallation Neutron Source)**
  - **R&D in SCL, RCS, RF Power Source, Spallation Neutron Target**
- **For the accelerator-driven neutron source using 100 MeV proton linac**
  - **one beamline is assigned to the neutron source**
  - **possibility using 20MeV proton beam at 105 beamline for compact neutron source**
- **Accelerator-driven compact neutron sources in Korea**
  - **KIGAM, KIRAMS, PAL have been established neutron facilities by using their own facilities**
- **Users for the neutron sources in Korea**
  - **User community has been grown up last 10 years continuously.**
  - **Their interests will be expanded to accelerator-driven pulsed source from reactor based CW source**
  - **User community will contribute to the promotion of new neutron source of Korea in near future.**


Thank you very much
for your attention!