Development of FFAG Accelerators in Japan

Yoshiharu Mori
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FFAG R&D Activities in Japan

- KEK
  - POP FFAG 0.05-0.5MeV(1MeV):2000
    - proof-of-principle, scaling(DFD),proton, MA rf cavity
  - 150MeV FFAG :2006
    - scaling(DFD),prototype for particle therapy, 100Hz
- Kyoto Univ., RRI
  - ADS(Accelerator Driven System) project, FFAG+Reactor:2007
    - 3 rings (Injector(2.5MeV spiral), booster(20MeV DFD), main ring(150MeV,DFD)
- NEDO project/site KURRI
  - ABNS(accelerator-based neutron source) for BNCT (boron neutron capture therapy):2008
    - ERIT (emittance/energy recovery internal target): FFAG proton strorage ring + internal target, 11MeV proton+ Be target, ionization cooling

History of FFAG Proton Accelerator

- 1953: Basic concept by Ohkawa

  Proton FFAG accelerator was not successful until recent

  →**difficulty in fabricating RF cavity with variable frequency & high gradient field**

- 1998：Development of RF cavity using Magnetic Alloy

  Grant-in-Aid for Scientific Res. by MEXT：Y. Mori, KEK

- 2000：Development of Proton FFAG Accelerator

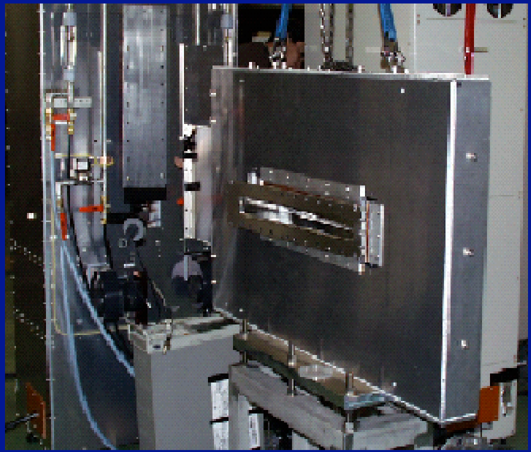
  Grant-in-Aid for Scientific Res. by MEXT: Y. Mori, KEK

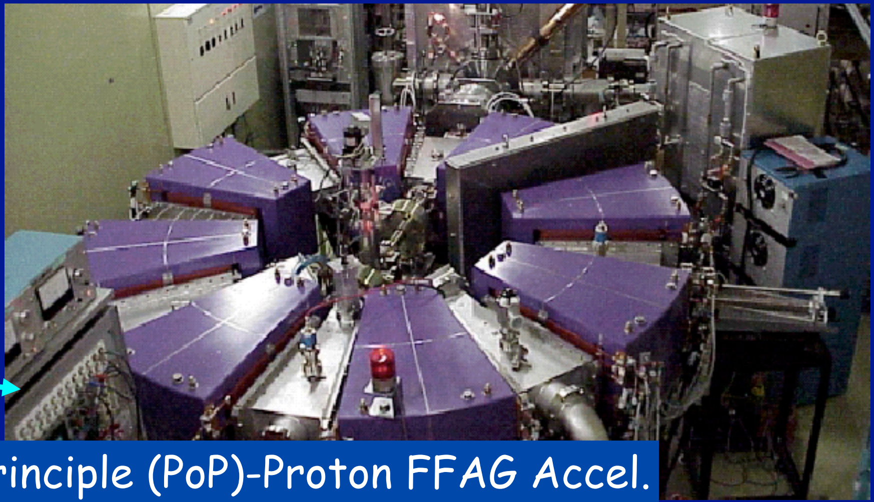
- 2005：Development of 150MeV multipurpose FFAG accelerator

  100Hz Operation!

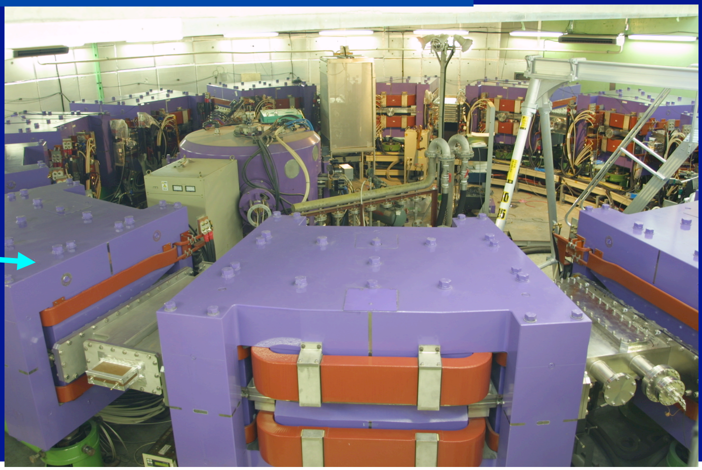
  Grant-in-Aid for Creative Basic Res.

RF Cavity



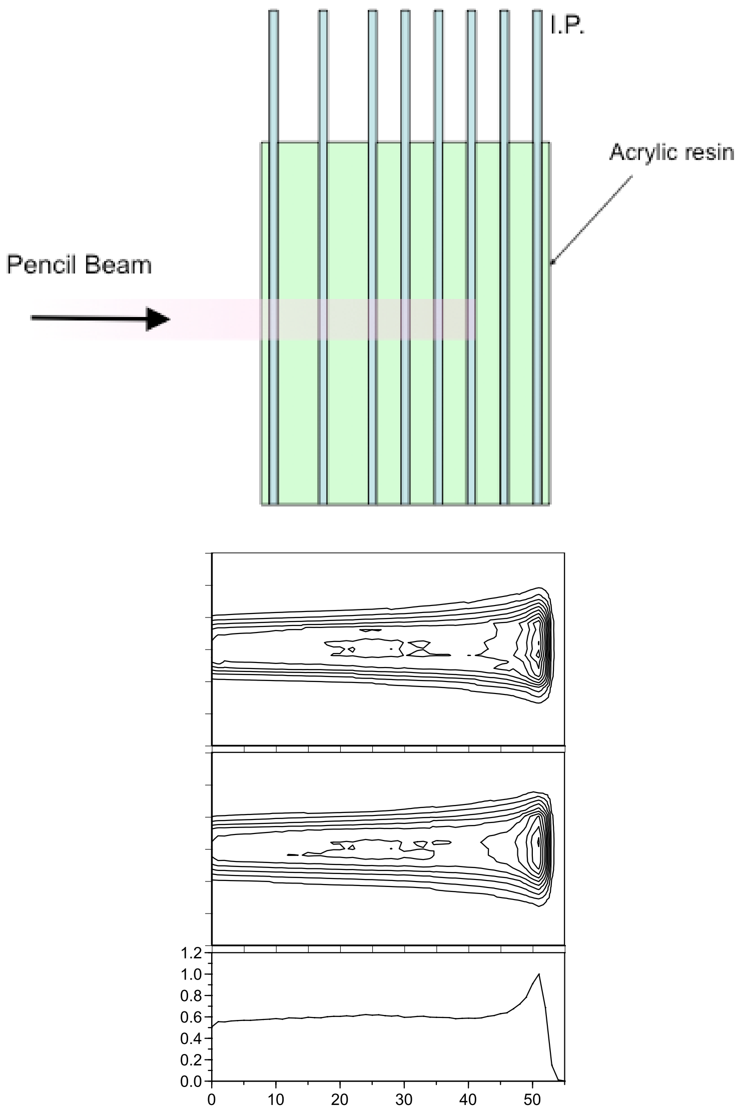


Proof-of-Principle (PoP)-Proton FFAG Accel.

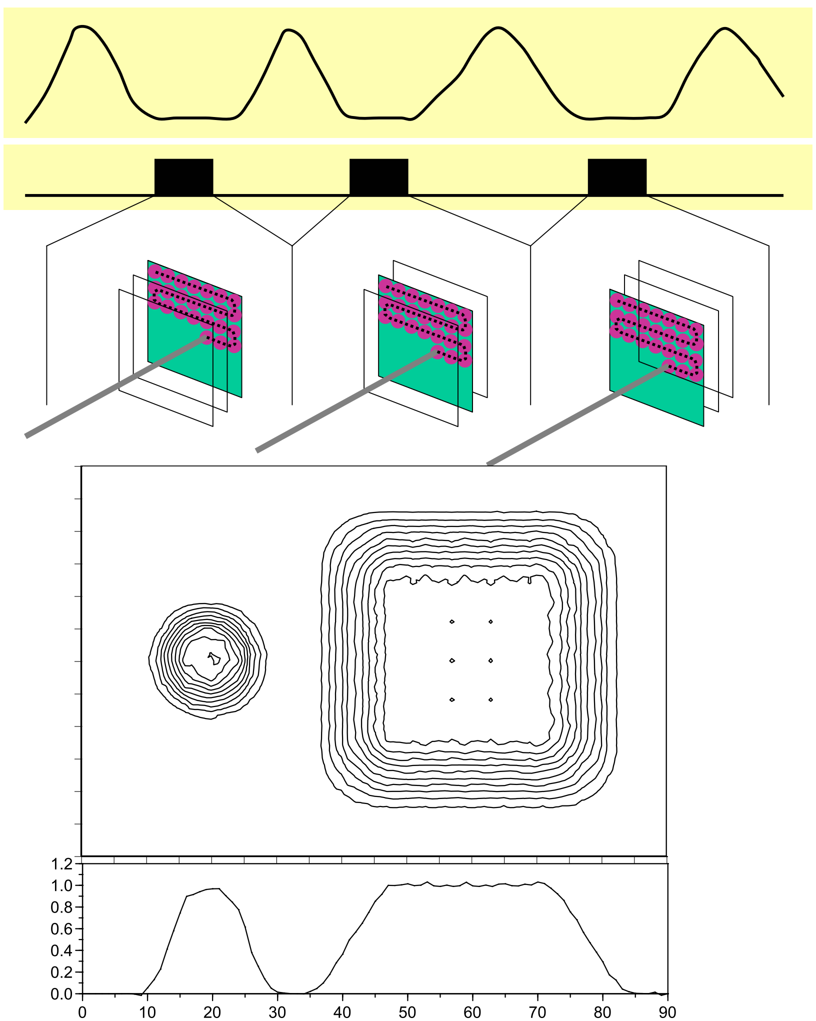


150MeV FFAG

Fast spot scanning exeriments & simulations



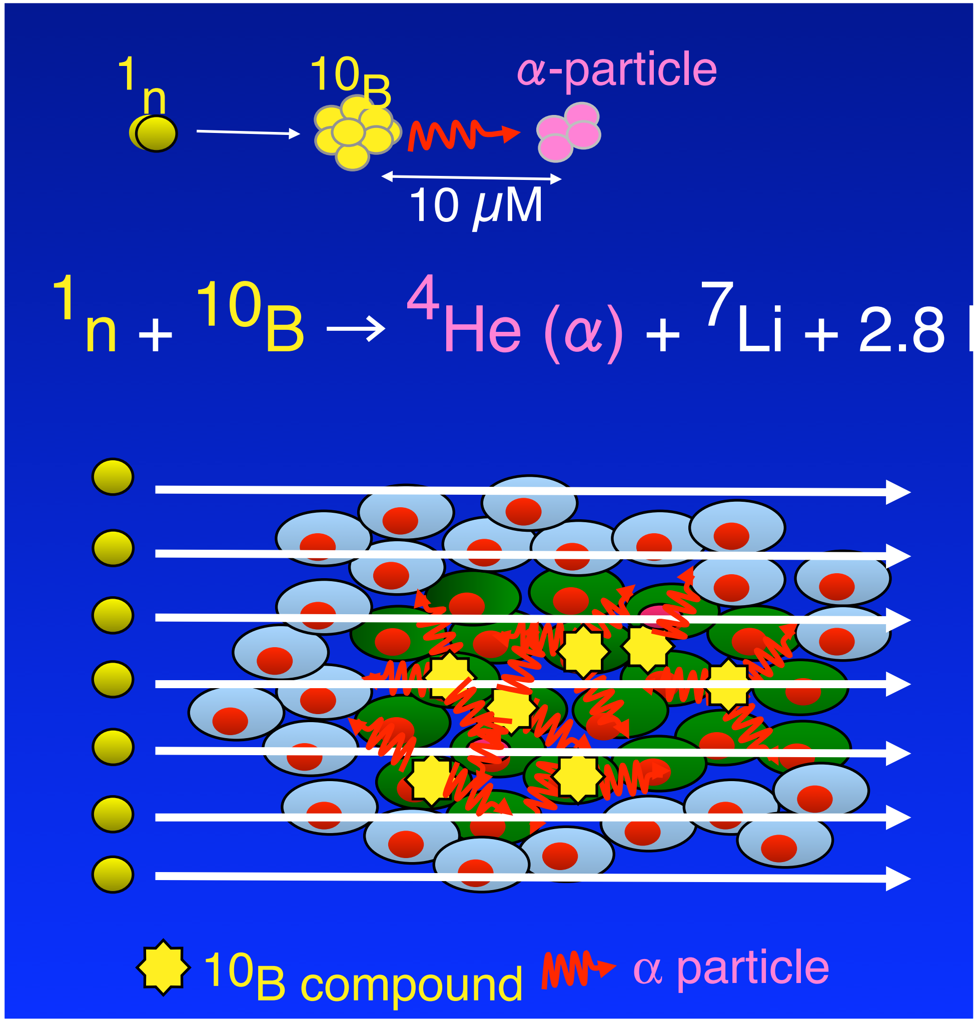
呼吸同期に対応するスキャンニング照射



multipurpose FFAG with 100Hz operation

Neutron Source for BNCT

- ***Requirements***
  - *Large neutron flux*
    > 1x10⁹ n/cm²/sec at patient
  - *Low energy spectrum*
    thermal/epi-thermal neutron



Nuclear reactor only can provide these neutrons.

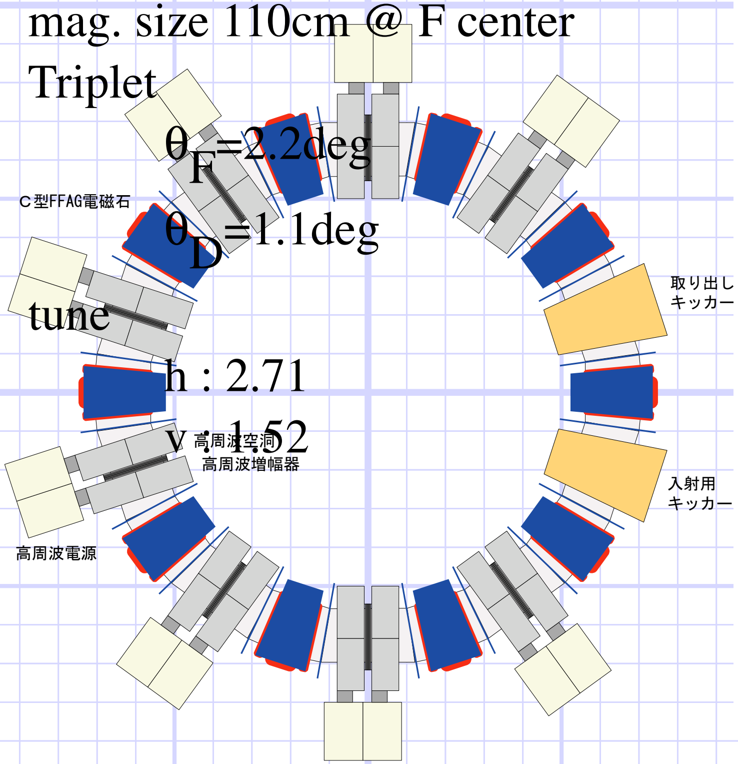
Limited to extend the use of BNCT widely in society.

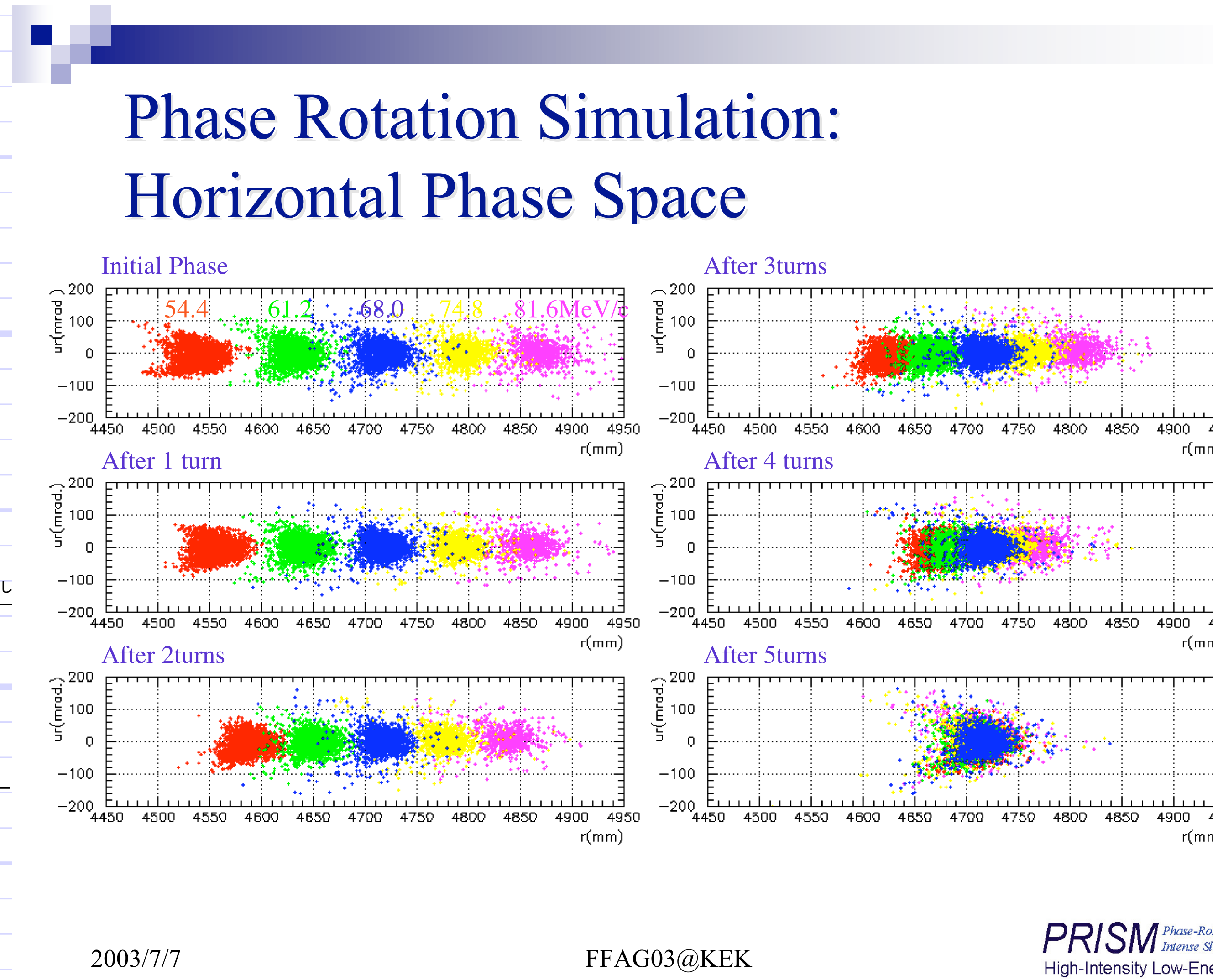
FFAG R&D Activities in Japan

- PRISM project <-- Dr. Arimoto
  - Mu-e conversion: Muon phase rotation ring
- Mitsubishi Elect. Co.
  - table-top electron accelerator
    - X-CT:FFAG+synchrotron hybrid
- Others
  - Collaboration btw Fukui Univ. & Kyoto Univ.
    - Dev. FFAGs & education

PRISM project

N=10
k=5(4.6-5.2)
F/D(BL)=6
r0=6.5m for 68MeV/c
half gap = 17cm
mag. size 110cm @ F center
Triplet
θ_F=2.2deg
θ_D=1.1deg
tune
h : 2.71
v : 1.52



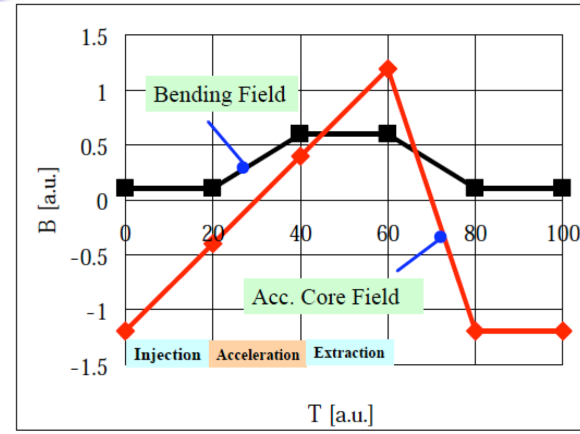


Mitsubishi Elect. Co (MELCO)

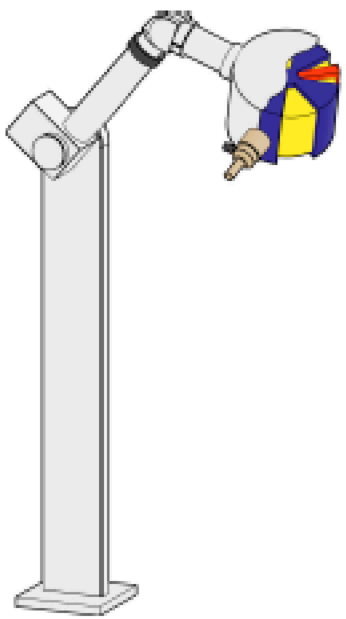
Application of LAPTOP Accelerator

- X-rays irradiation
- X-rays radiation therapy
- X-rays CT

Acceleration Scenario



Basic parameters



Proto-type Machine

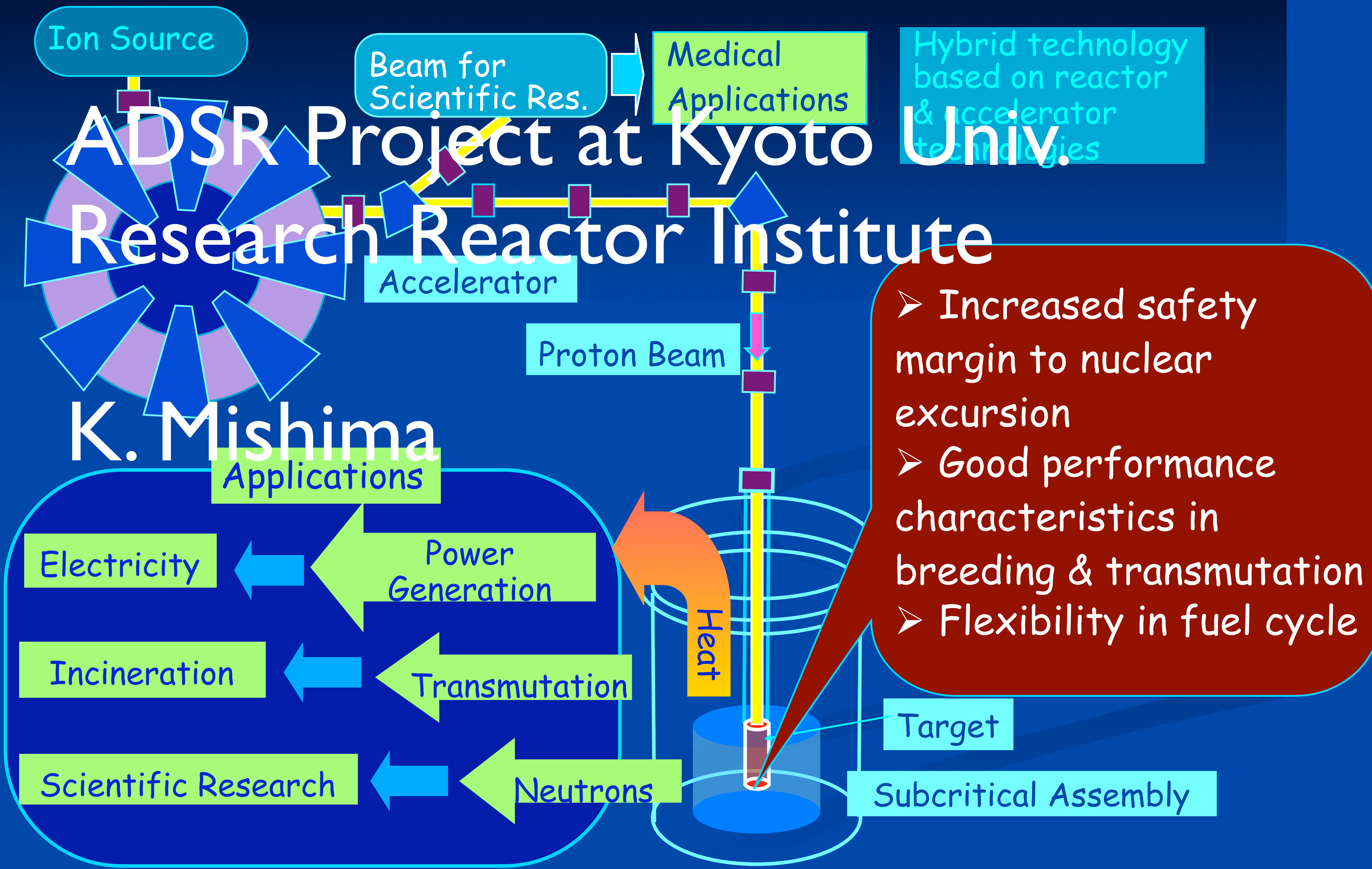
Injection Energy	50 [keV]
Acceleration Energy	6 [MeV]
Injection Radius	0.1 [m]
Extraction Radius	0.125[m]
K value	2～3
Magnet	Spiral Sector Magnet
Repetition	1 [kHz]
Duty	2 [%]
Energy after injection	50～250[keV]

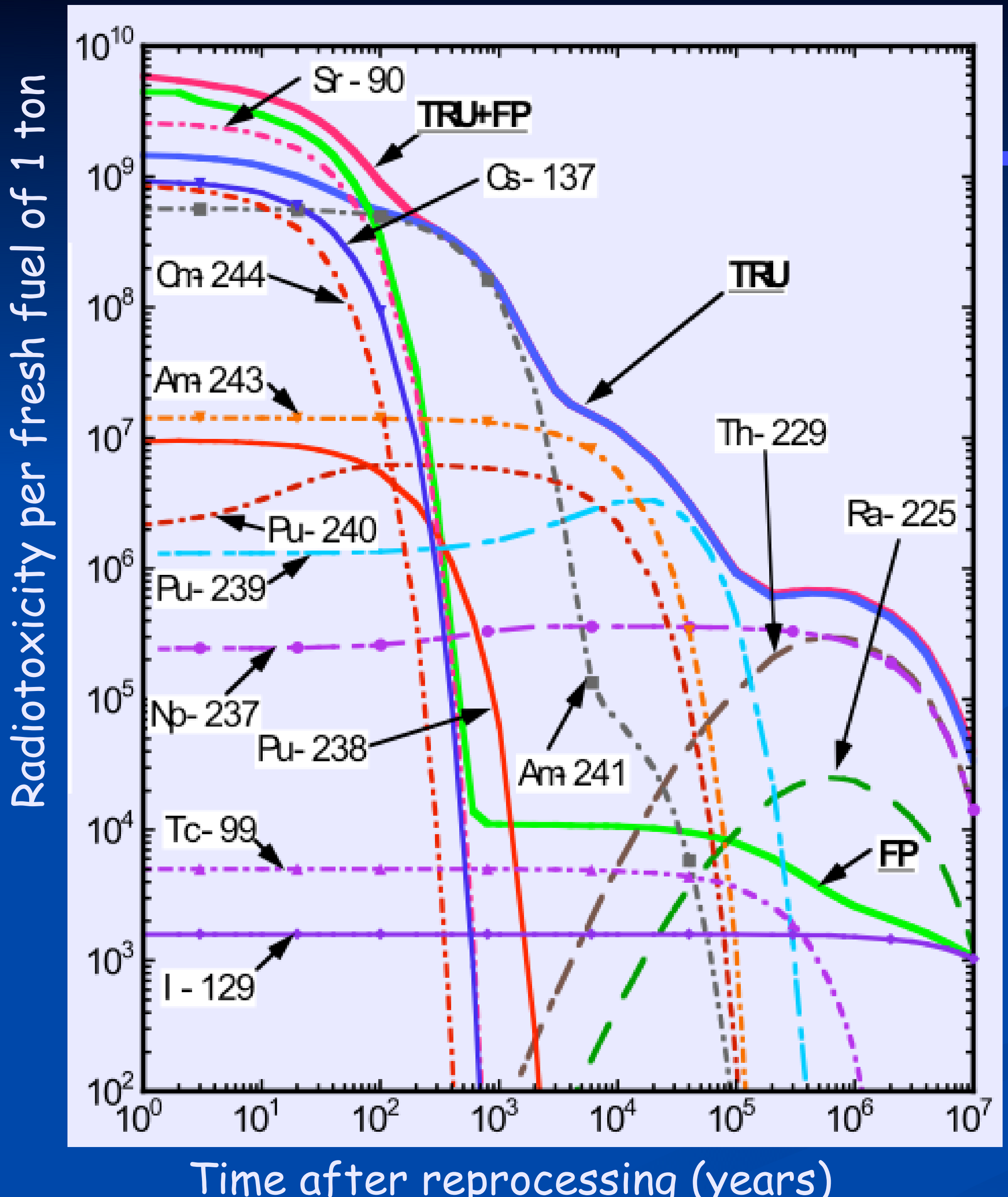
combination of FFAG and synchrotron
-->compact ring(small orbit excursion)

Accelerator-driven Subcritical Reactor (ADSR)

ADSR Project at Kyoto Univ. Research Reactor Institute

K. Mishima





Radiotoxicity

- Radiotoxicity: ratio of the mass of nuclide to the permissible limit of annual intake

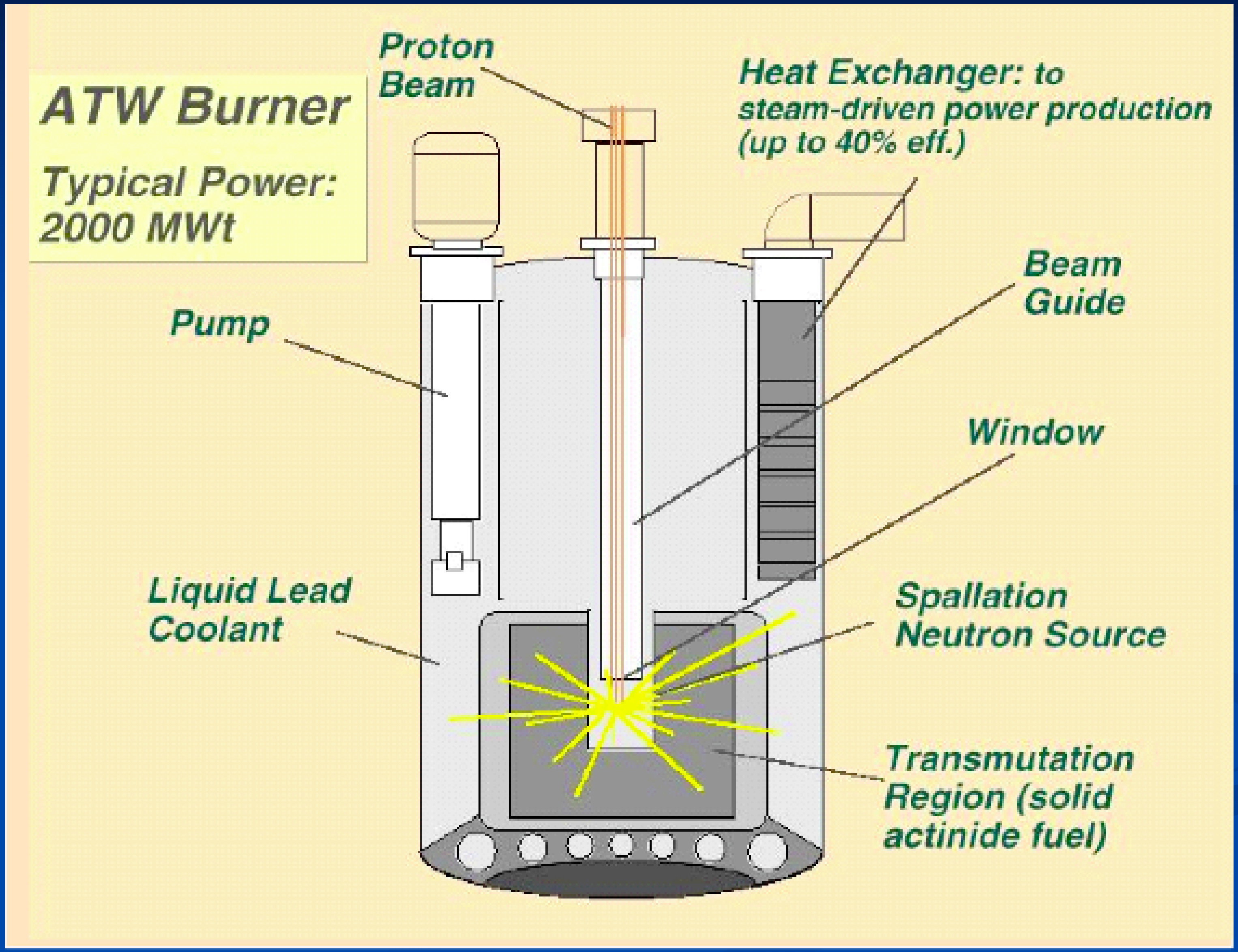
- Raiotoxicity of FP's is dominant within 100 years after reprocessing, and that of MA's thereafter

Half-lives:

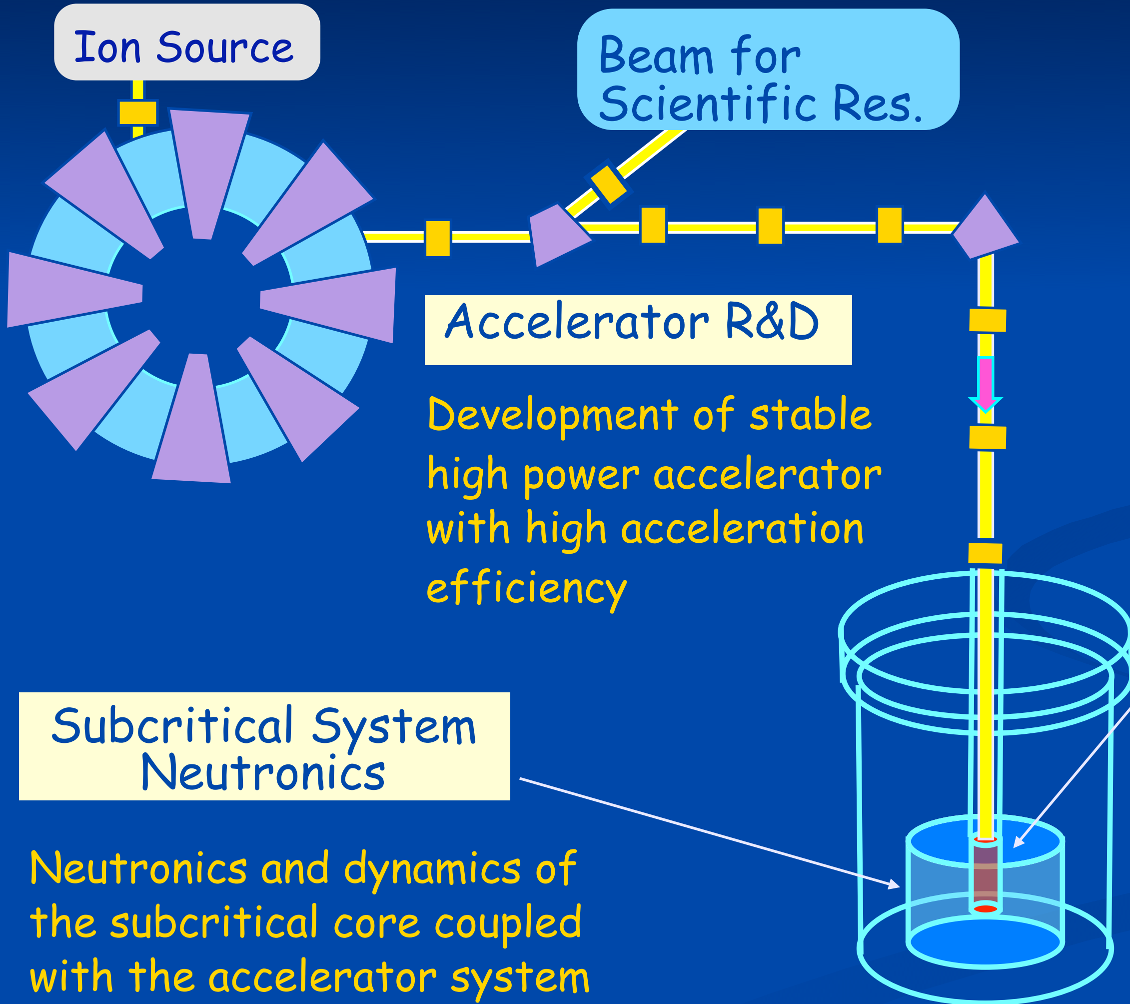
Sr-90	28yrs.
Cs-137	30yrs.
Np-237	2.14 M. yrs.
Am-241	433yrs
Am-243	7370yrs.

☆Long term risks could be reduced if MA's are reduced

Example of Accelerator-driven Transmuter



Subjects on ADSR



Accelerator R&D

Development of stable high power accelerator with high acceleration efficiency

Thermal-hydraulics

Heat removal from target & reactor core at very high thermal load and thermal stress analysis

Material Research

Energy-dependent irradiation effects & development of new reactor materials

Subcritical System Neutronics

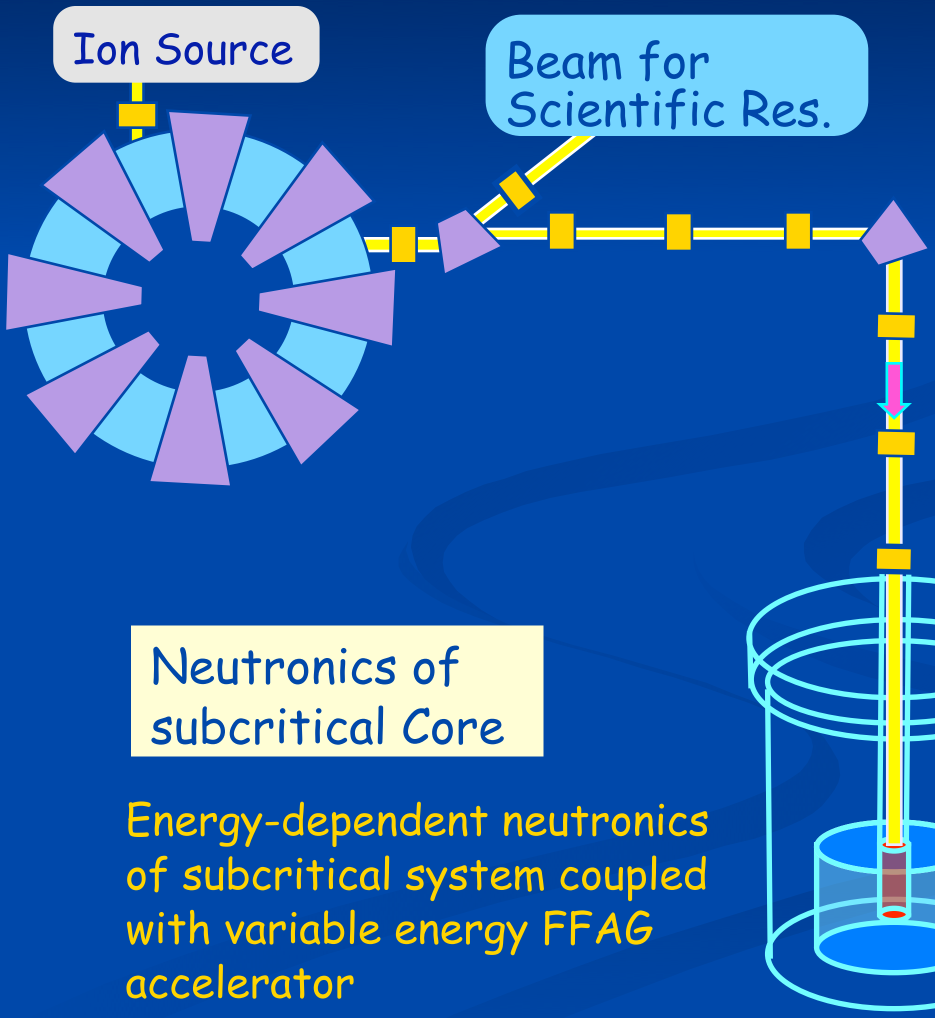
Neutronics and dynamics of the subcritical core coupled with the accelerator system

Feasibility Study on ADSR Using FFAG Accelerator

(FFAG: Fixed Field Alternating Gradient)

Accelerator R&D

Development of variable-energy FFAG accelerator with high acceleration efficiency



Neutronics of subcritical Core

Energy-dependent neutronics of subcritical system coupled with variable energy FFAG accelerator

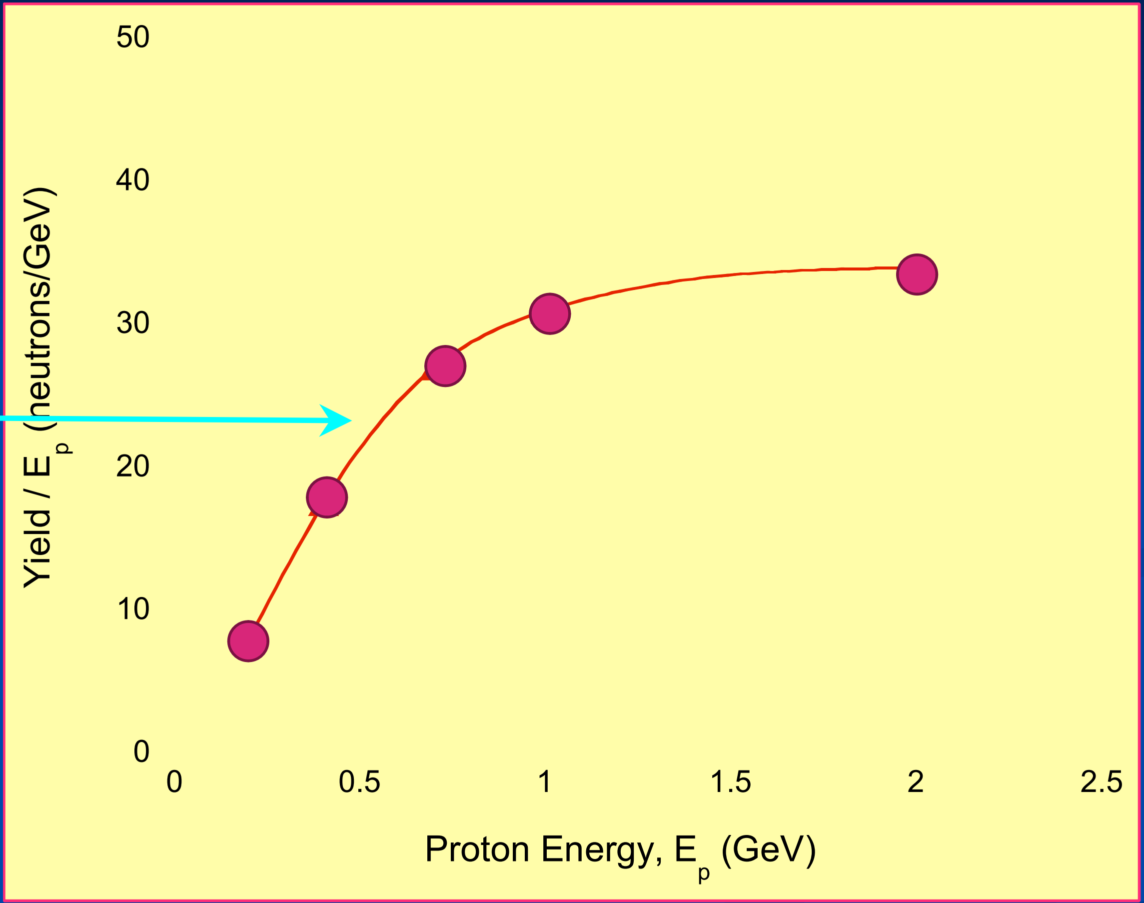
Main Feature of Proposed ADSR

ADSR Power $\propto \dfrac{S}{1-k_{eff}}$

Control of S
- Control by beam current
- Control by beam energy

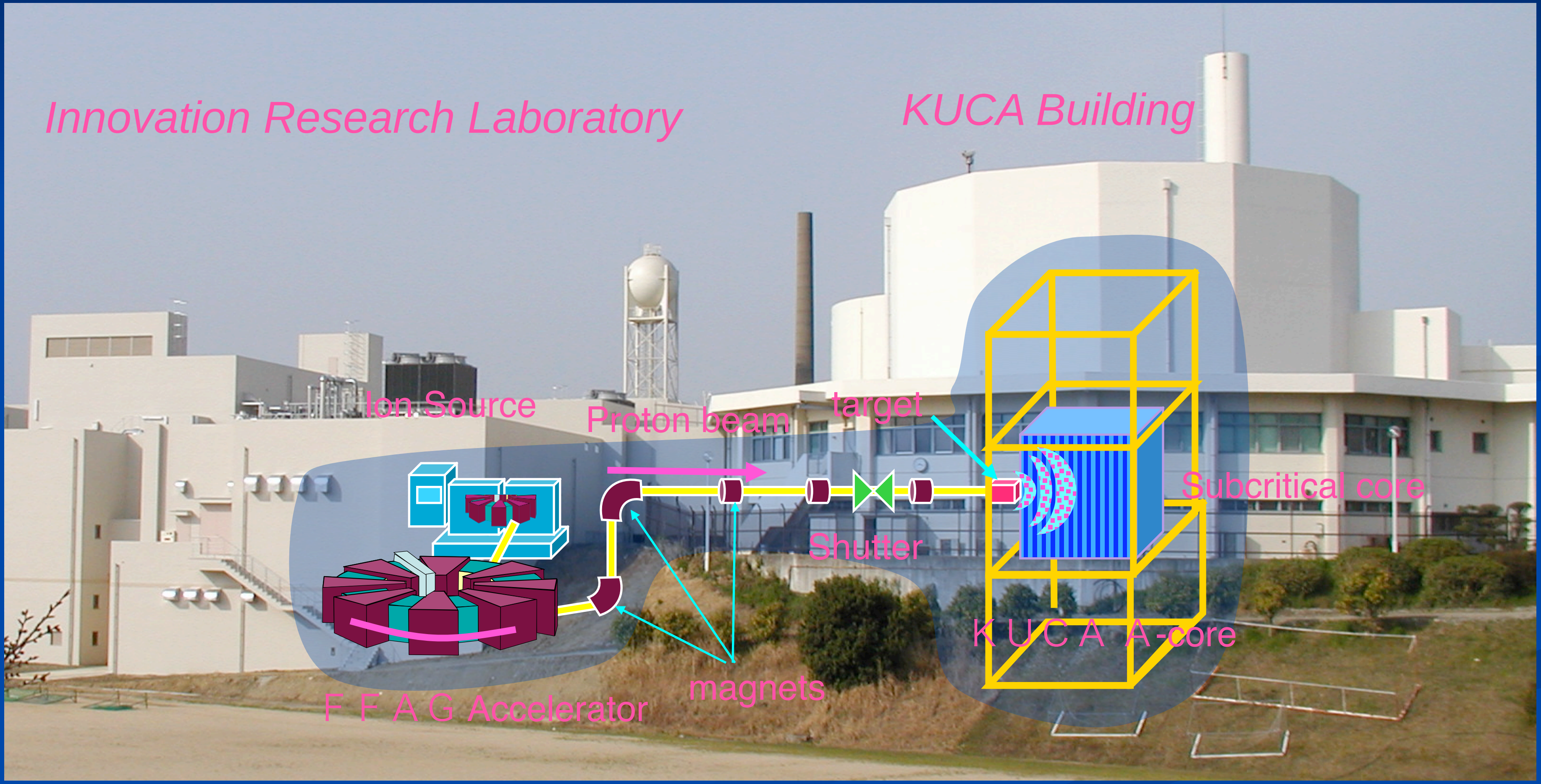
Variable-energy FFAG accelerator
- Control by beam energy & beam current

Spec. of FFAG accelerator
- Energy : 2.5～150 MeV
- Current: ～1 mA



Subcritical core: Thermal neutron system

Concept of FFAG-KUCA Experiment on ADSR



Advantage of FFAG

- Fast acceleration
- DC magnetic field allows the beam acceleration only by RF pattern. No needs of synchronization between RF and magnets.
- High average current with large repetition rate and modest number of particles in the ring
- Space charge and collective effects are below threshold.
- Large acceptance
- Transverse (hor.)>10,000mm.mrad
- Longitudinal dp/p>10%

Comparison between Synchrotron and FFAG

	FFAG	Synchrotron
1. Magnetic field	static (fixed)	varying with time
2. Closed orbit	moving	fixed
3. Focusing	strong	strong
4. Duty factor (Repetition cycle)	large～10-50% (max.～1kHz)	small～1% (～50Hz)
5. Space charge instability	not critical	severe

Problems to be solved to develop FFAG synchrotron

＊Complicated magnetic field → 3D Codes (TOSCA, etc.)

＊RF system: high acceleration＋rapid tuning

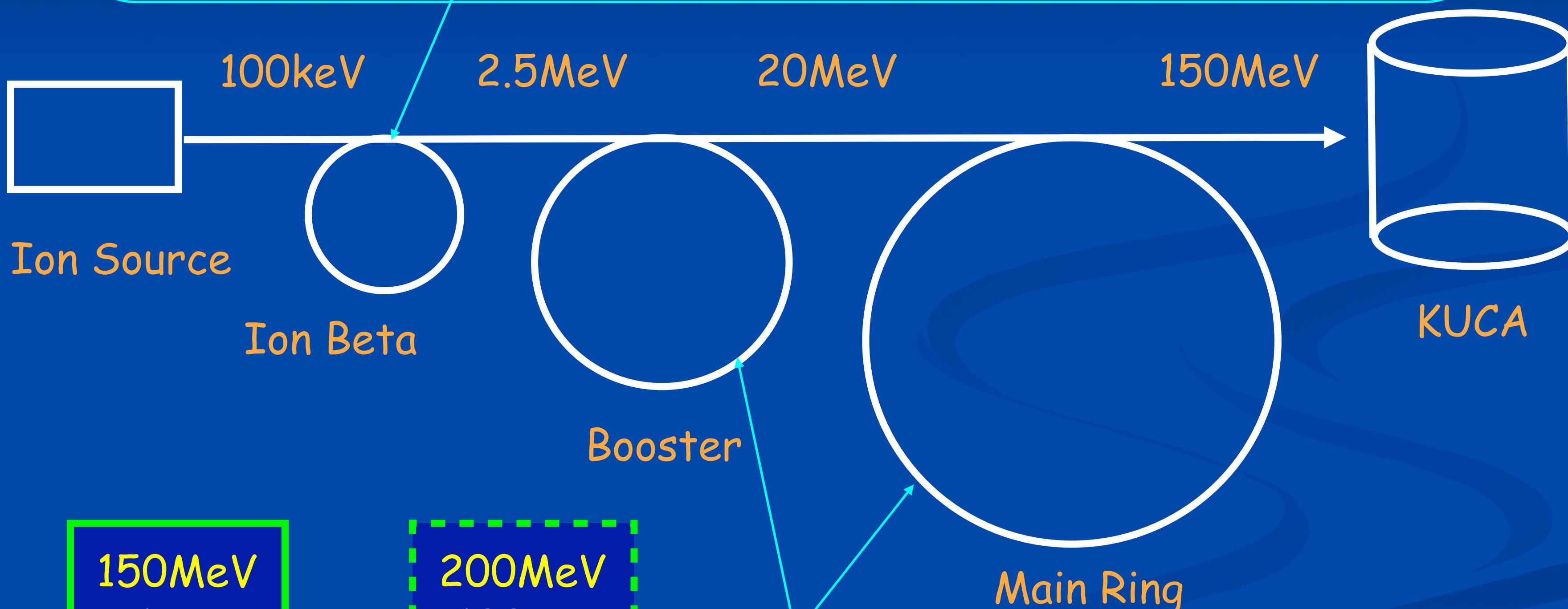
→Development of high gradient & broad band RF cavity

Beam Specifications of FFAG Accelerator

Beam Species	**H+**
Energy	**20 – 150 MeV**
Average Beam Current	**1κA**
Pulse Repetition Rate	**120Hz**

Configuration of FFAG Accelerator Complex

- Spiral focusing: 1st for ion accelerator in the world
- Acceleration by induction core: 1st for ion accelerator in the world
- Magnetic field by multi-coil: 1st in the world
- Continuous injection by static field: 1st in the world



150MeV
1mA
120Hz

→

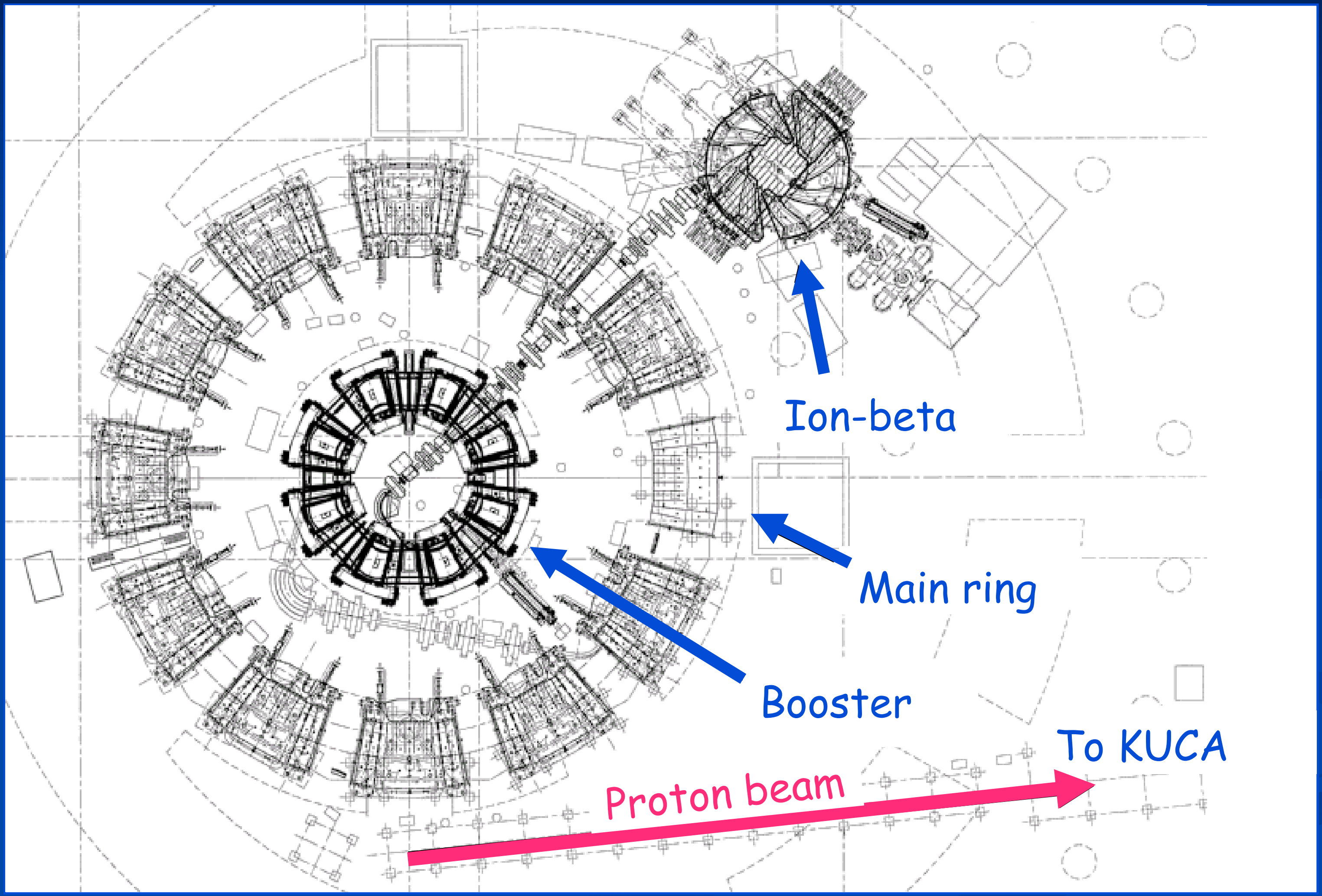
200MeV
100mA
1kHz

Similar design as precursory KEK FFAG accelerator to save design cost

System Parameters of FFAG Accelerator

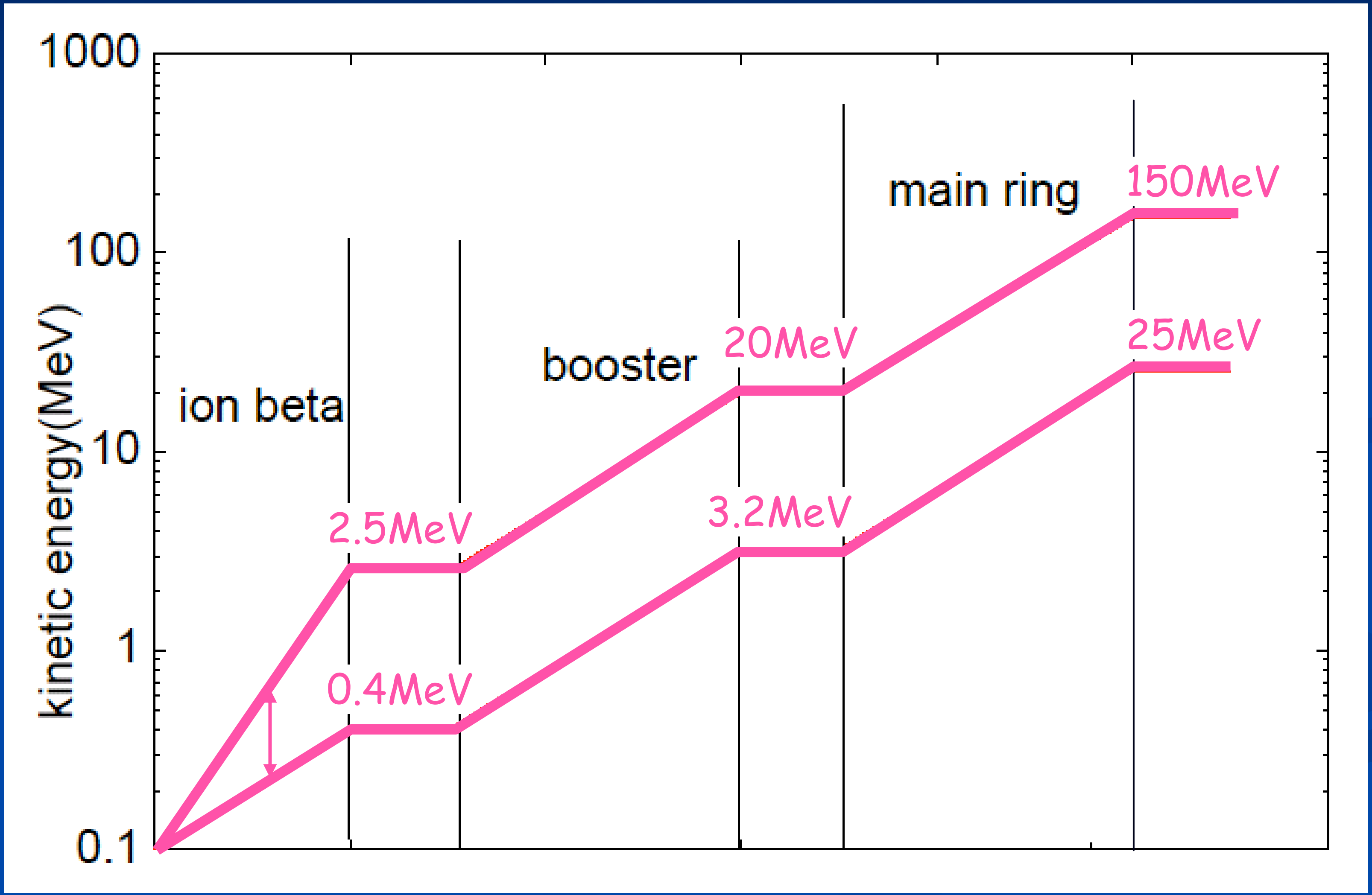
	Ion Beta	Booster	Main Ring
Focusing	Spiral	Radial DFD	Radial DFD
Acceleration	Induction	RF	RF
Number of Cells	8	8	12
k-value	2.5	4.5	7.6
Injection Energy	100keV	2.5MeV	20MeV
Exit Energy	2.5MeV	20MeV	150MeV
Pext/Pinj	5.00	2.84	2.83
Injection Orbit	0.60m	1.42m	4.54m
Exit Orbit	0.99m	1.71m	5.12m

Layout of FFAG Accelerator Complex



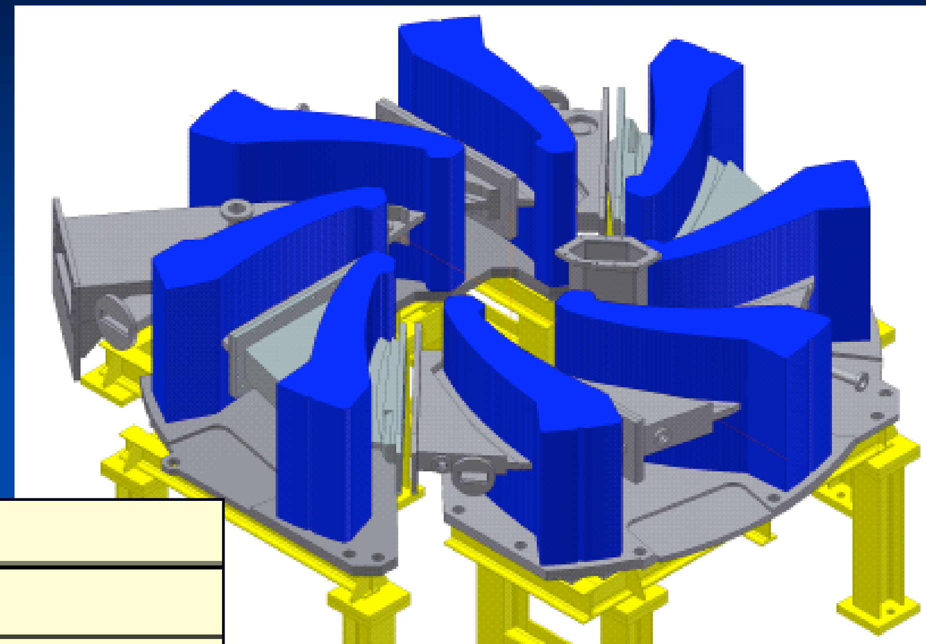
Variable Energy FFAG Accelerator Complex

Extraction proton energy can be varied by changing k-value of Ion Beta

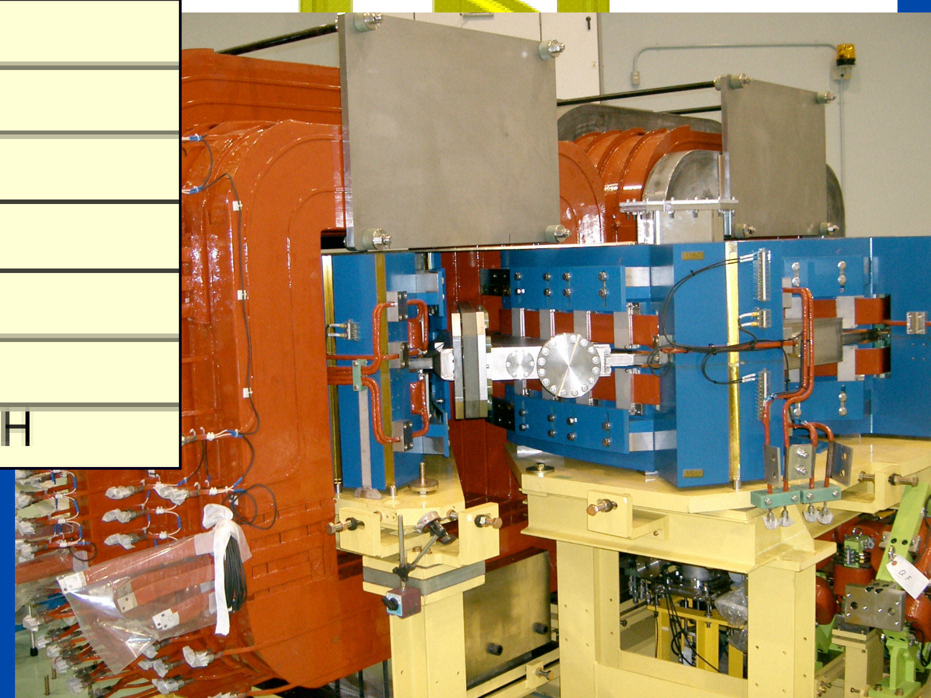


Ion-Beta - Spiral Type FFAG Accelerator

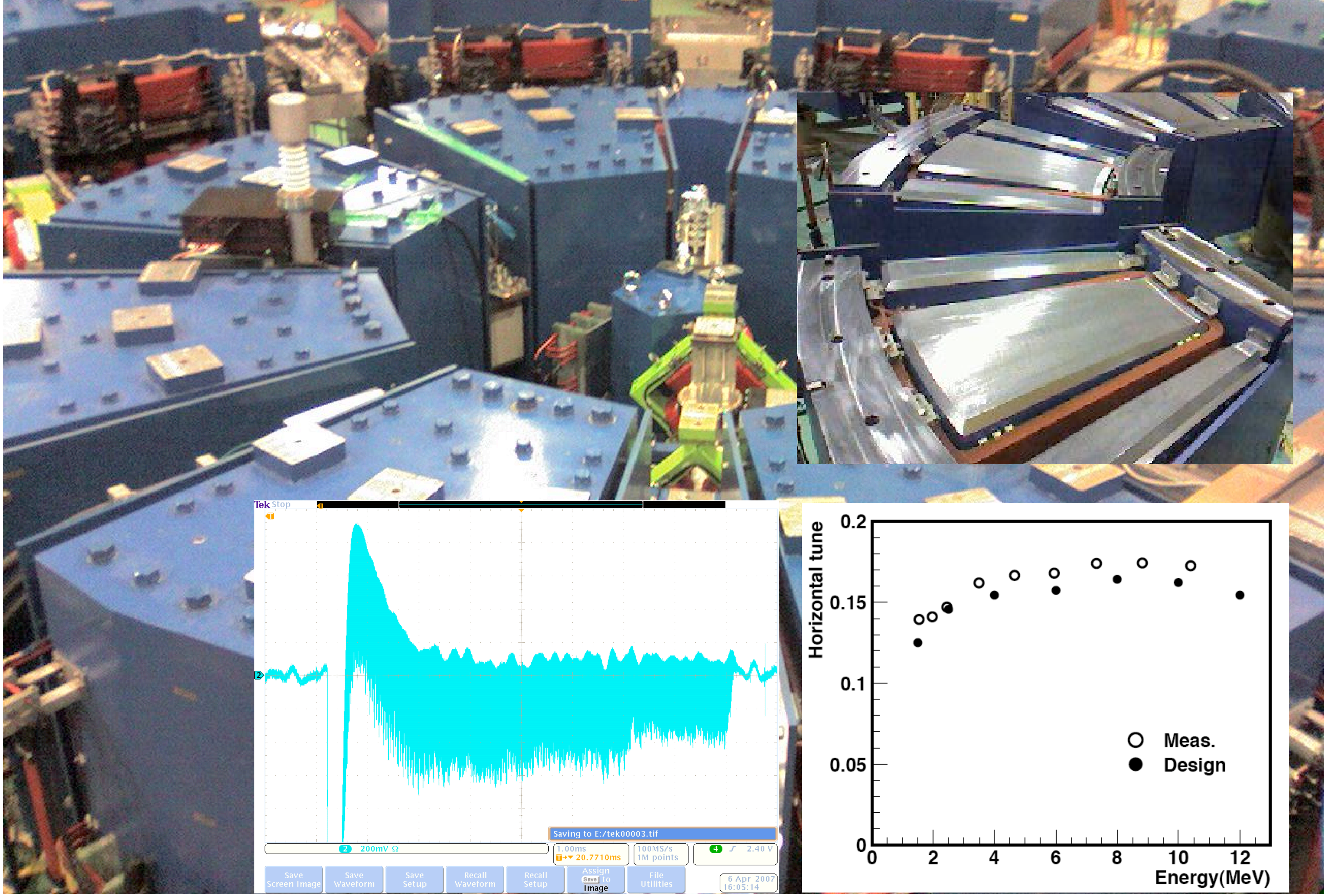
uFocusing by spiral magnetic field
uMagnetic field shaping with multi-coil magnets
◆ Acceleration by induction core



item	specs
Energy	2.5 MeV
<I>	0γ 2μA
Rep. rate	120Hz-1kHz
Pulse length	1γ 5μs
k	2
spiral angle	42 degree
tune	(1.85, 0.80)
Size	3500Wx6000Dx2500H

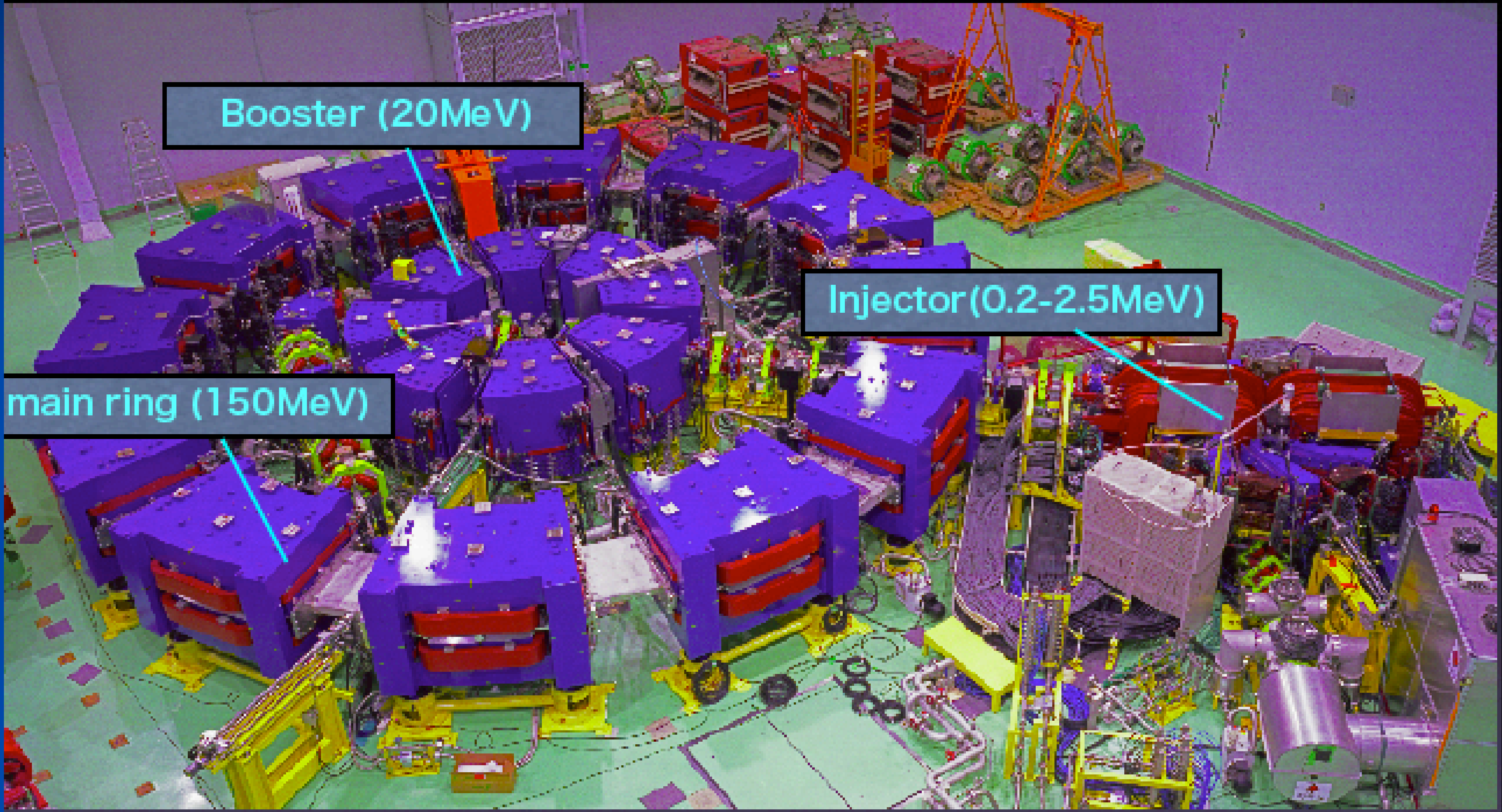


Booster



Tek Stop
Saving to E:/tek00003.tif
200mV Ω
1.00ms
20.7710ms
100MS/s
1M points
2.40 V
Save Screen Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Assign Save to Image
File Utilities
6 Apr 2007
16:05:14
Horizontal tune
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
Energy(MeV)
Meas.
Design

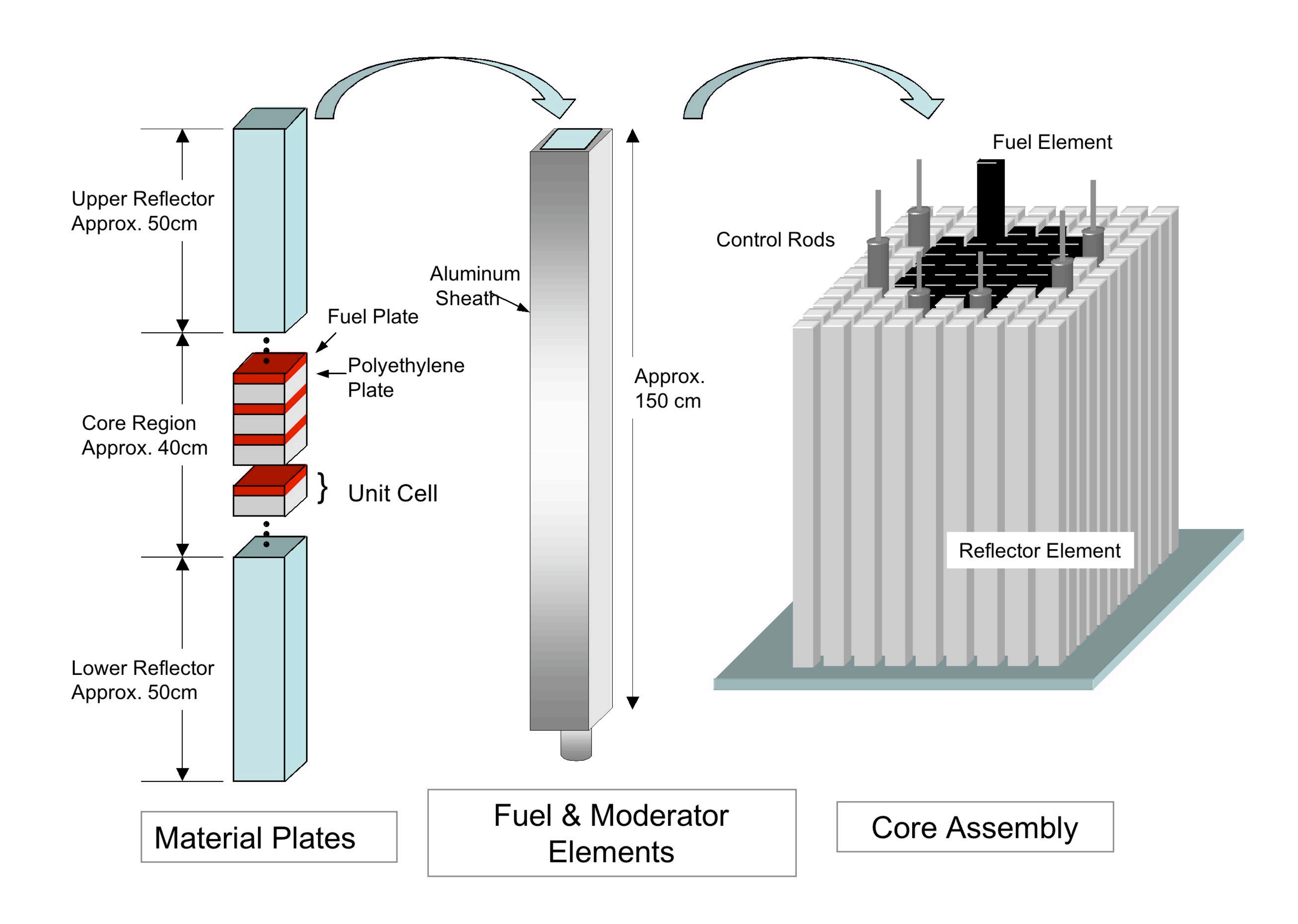
FFAG complex at KURRI



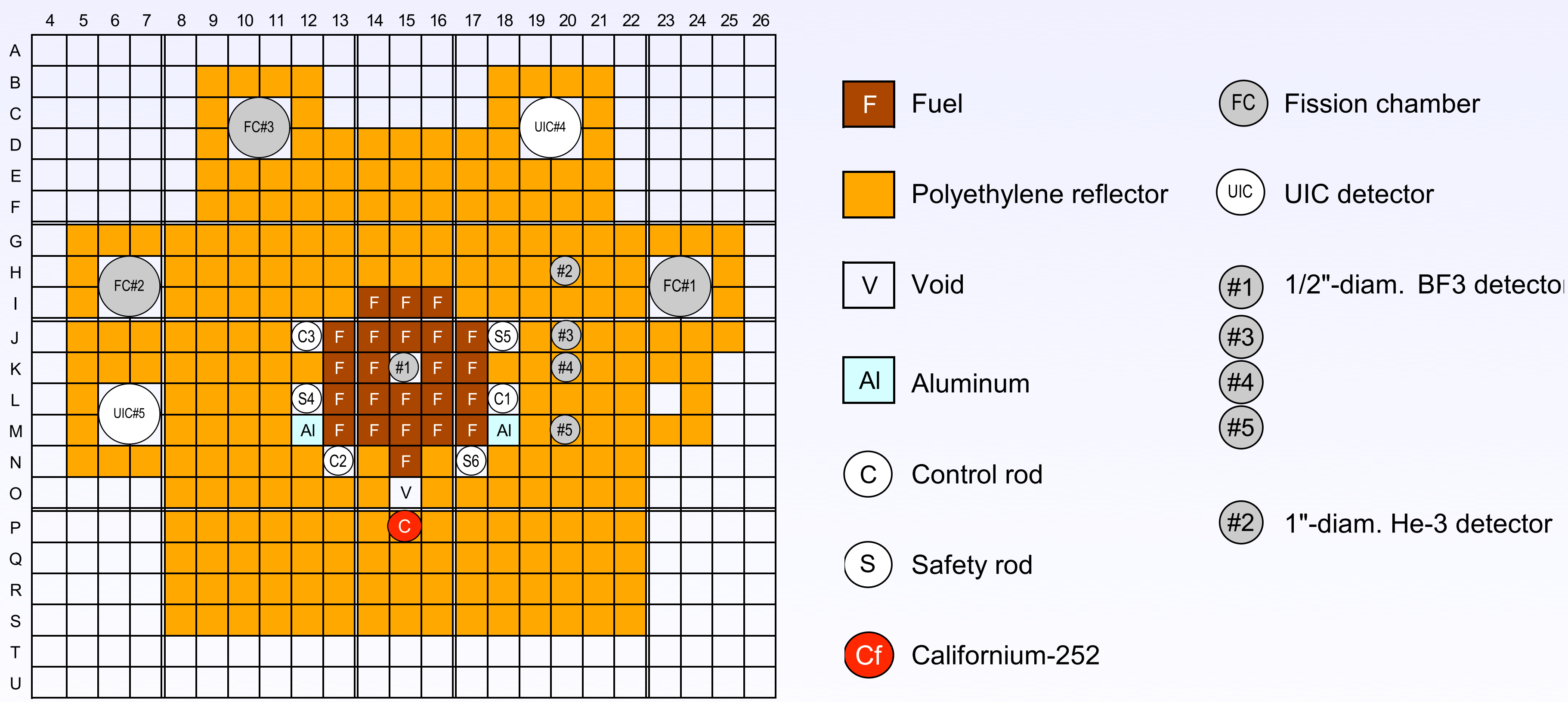
Neutronic Study of Subcritical Core

KUCA-A Core - solid moderated and reflected -

Concept of KUCA A-Core Set-up



Example of Core Configuration in KUCA-A Core



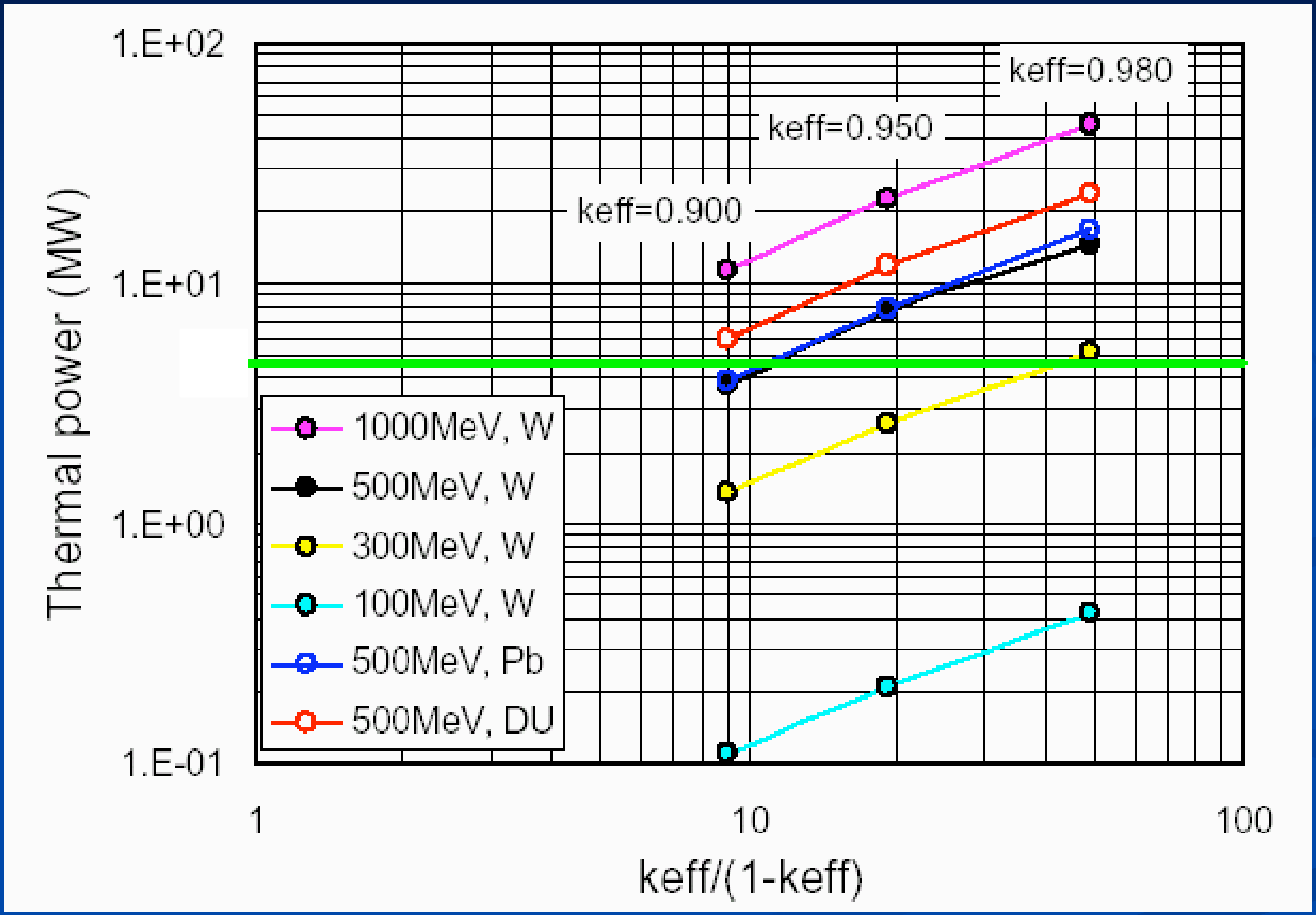
Previous Results of R&D for ADSR

- Characteristics of ASDR depends significantly on neutronics in the subcritical core

- Neutronic design of ADSR requires much higher accuracy in calculations
  ∵ neutron multiplication $\mu 1/(1\text{-}k_{eff})$

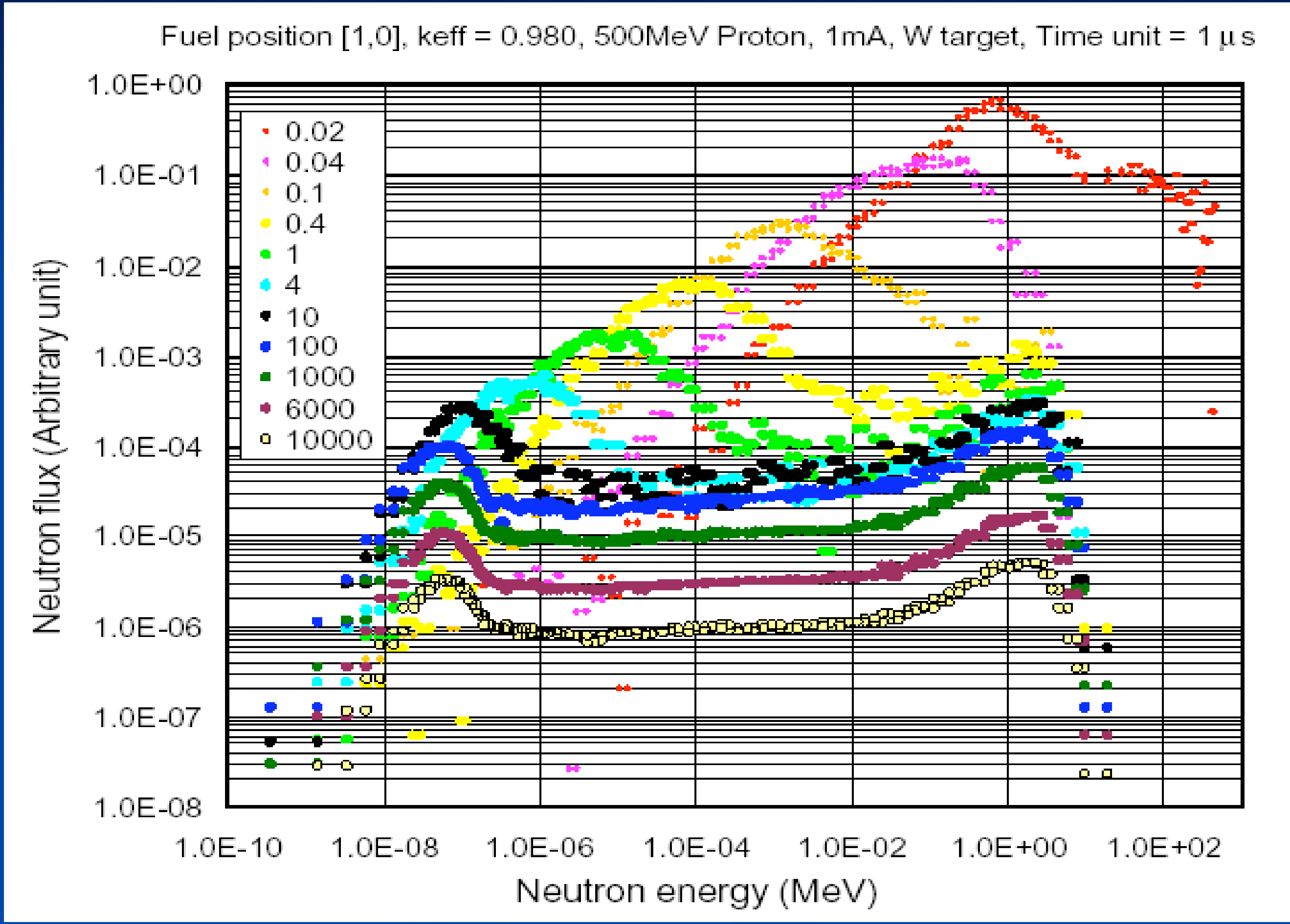
- Method for analyzing ADSR dynamics should be developed
  ・Monte-Carlo calculation taking account of delayed neutrons

Calculated Thermal Power of KUR-type ADSR

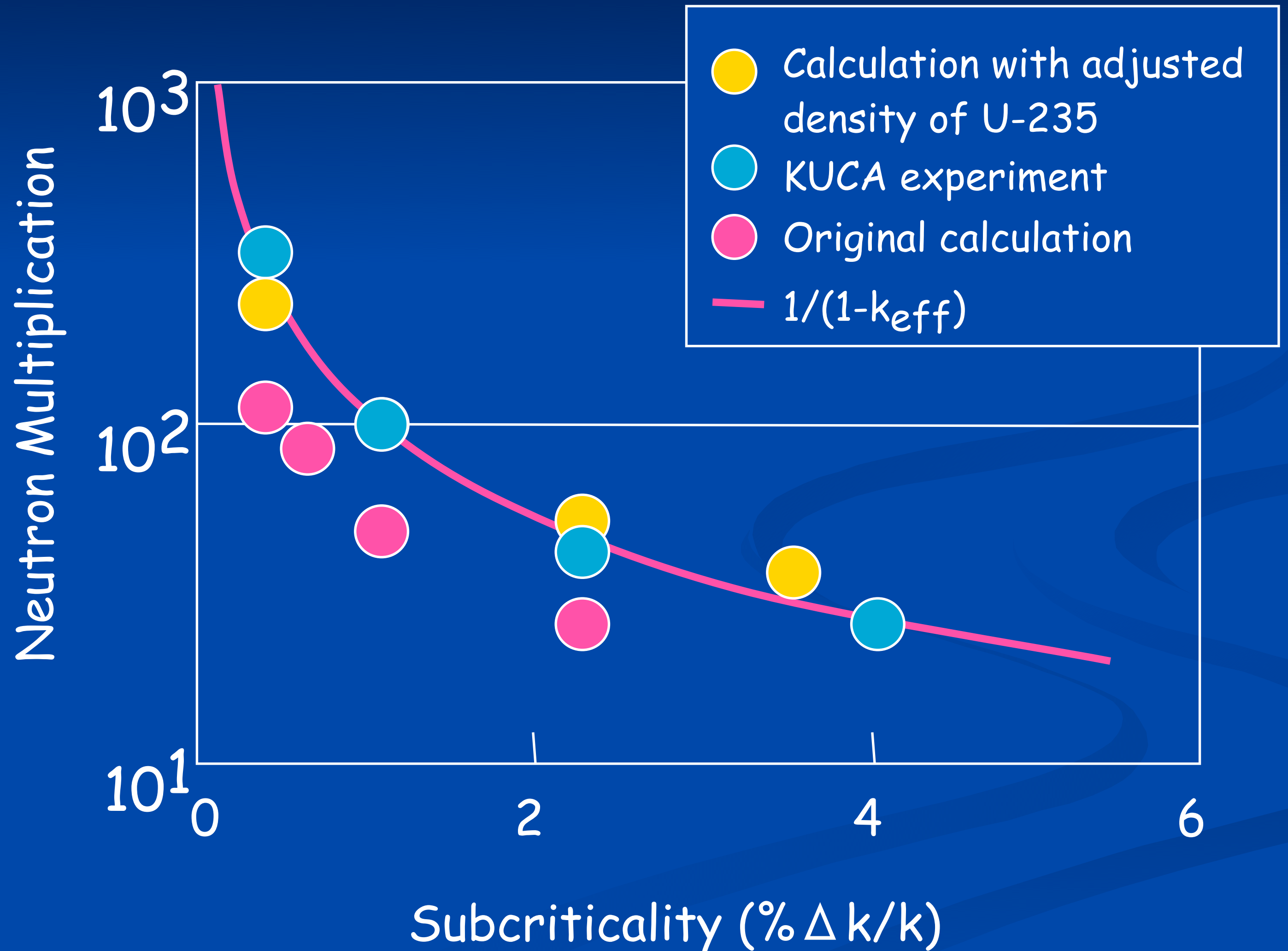


Thermal power of KUR-type ADSR (proton beam current=1mA) as a function of target material and effective multiplication factor

Temporal variation of neutron spectrum in ADSR after injection of pulsed proton



Comparison of Neutron Multiplication between Experiment and Calculation

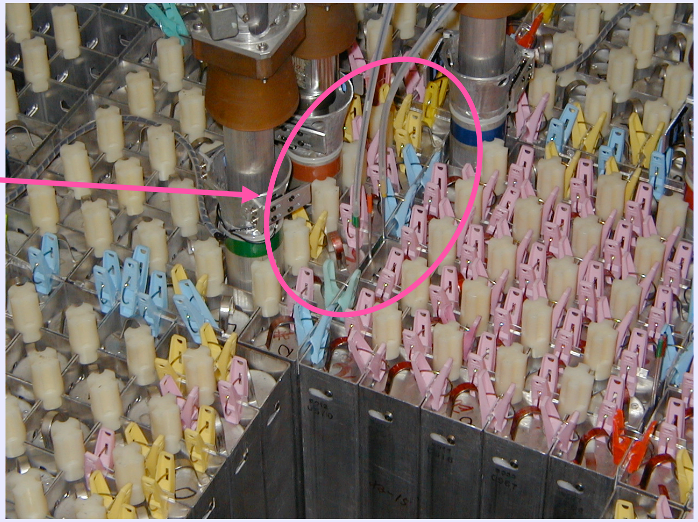


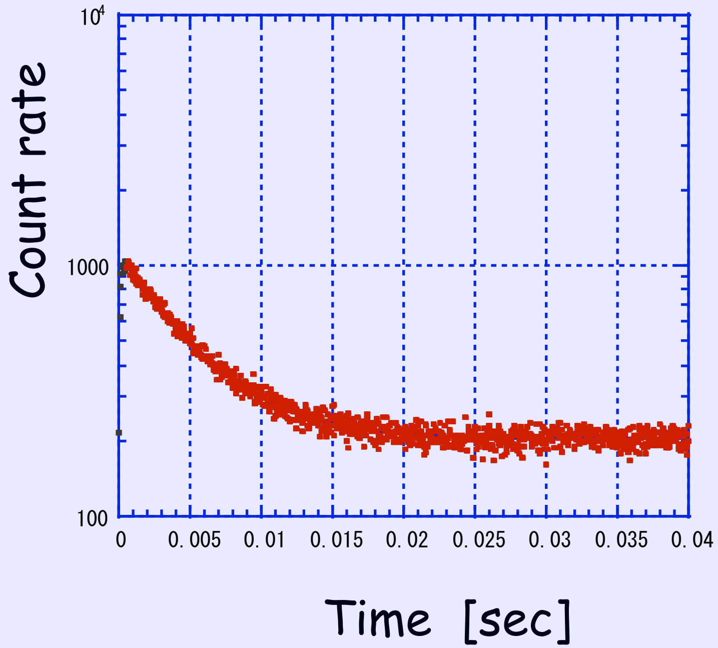
Objectives of Present Neutronic Study on ADSR

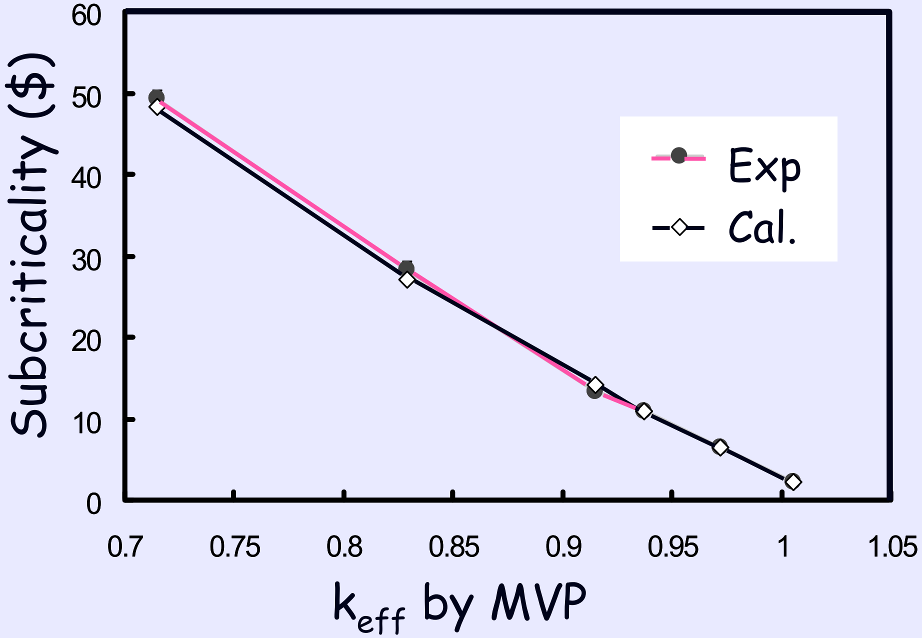
- KUCA Preliminary Experiment Using 14MeV incident neutrons
  - Measurement of subcriticality and neutron decay constant in subcritical enriched-U and mixed U/Th thermal neutron systems
  - Optimization of neutron beam collimator
- Analysis of preliminary KUCA experiment using continuous energy Monte-Carlo codes MVP, MCNP and MCNP-X
  - Evaluation of criticality of enriched-U and mixed U／Th thermal neutron systems
  - Evaluation of prediction accuracy of criticality and subcriticality by analyzing critical and subcritical KUCA experiments
  - Comparison of prediction accuracy between MVP, MCNP and MCNP-X codes
- ADSR experiment using coupled FFAG accelerator and KUCA
  - Measurement of neutronic characteristics of ADSR

Subcriticality Measurement by Pulsed Neutron Method

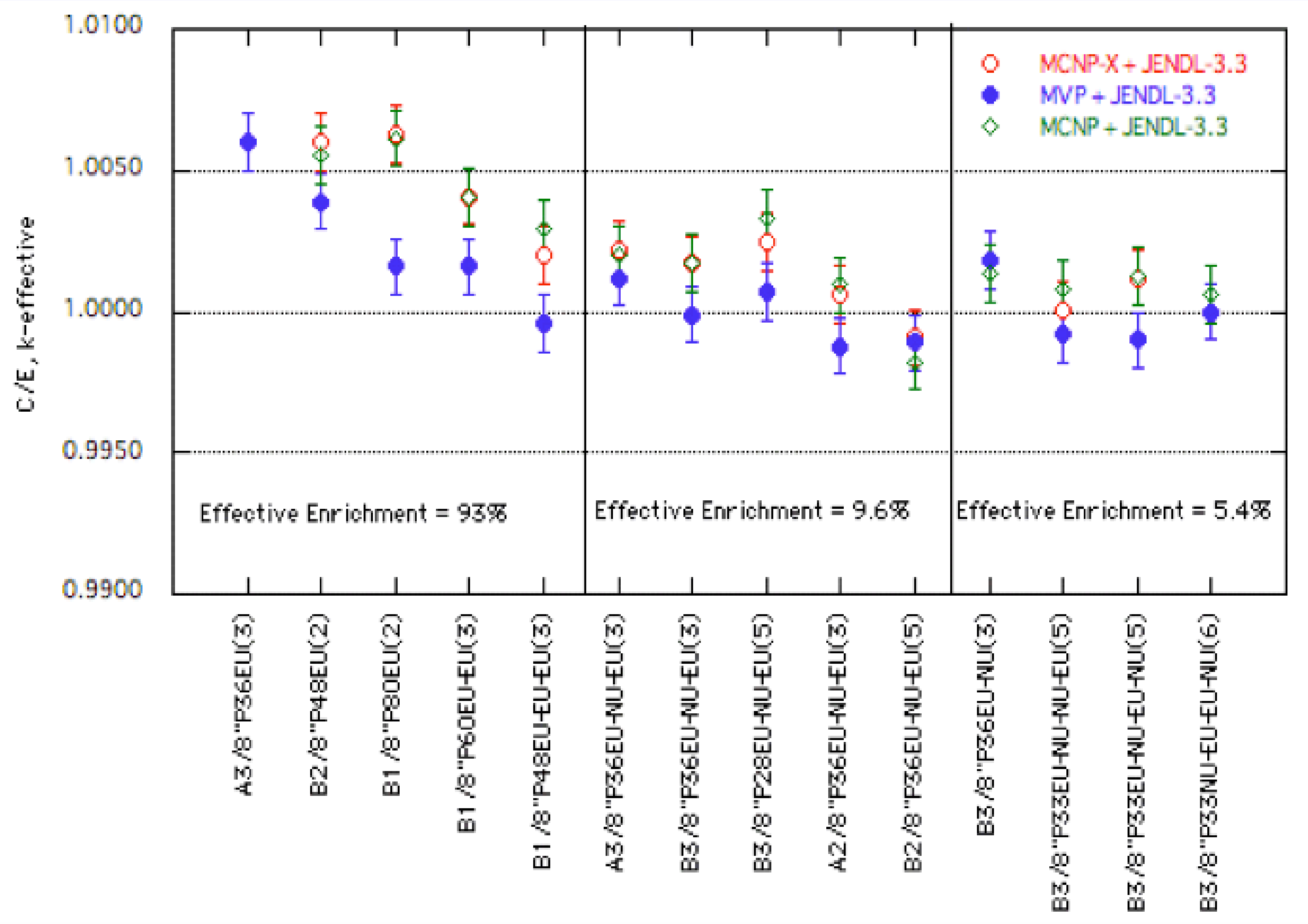
Optical Fiber Detector







C/E ratio for k_{eff} in solid moderated cores obtained by MVP, MCNP and MCNP-X codes



Status of accelerators (commissioning)

- Injector (Spiral-induction FFAG)
  - completed. Jan.2006.
  - E=1.2MeV (because of limited core voltage) : I=50nA
- Booster
  - completed. Jun. 2006
  - E=11.5MeV, I=0.8nA
- Main Ring: still in commissioning stage
  - accidental failures : Electricity-line off caused by severe thunder storm

    Injector core power supply : 36 IGBTs (2kV-1600A each) were broken.
    Insulating rectifier, High voltage breakdown (ion source etc.)
    Nov.2006 -Feb.2007

Status of accelerators (commissioning)

- Main Ring:
  - RF cavity

    Replace MELCO type(amorphous core) with KEK type (FINEMET core).

    Disturbed B-field (amorphous MA, not FINEMET)
  - Inadequate power supply for main D magnets

    I=700A -> I=1300A: Inadequate operational tunes (Qv=1)
  - Elect. current: half of the requested one - design mistake
  - Vacuum chamber

    Wrong design: horizontal beam apertures are very limited.(almost nothing)

Conclusions

- Basic research on ADS has been performed using KUCA driven by 14 MeV pulsed neutrons:
  - Subcriticality
  - neutron flux (reaction rate) distribution
  - fast neutron spectrum
  - neutron noise analysis
- Results of preliminary experiments have been analyzed by MVP, MCNP and MCNP-X codes.
- In FY2007, new experiment will start at KUCA coupled with a 150 MeV FFAG accelerator.
- Material and thermal-hydraulic R & D should be needed.

Intense Neutron Source Project for BNCT(Boron Neutron Capture Therapy)

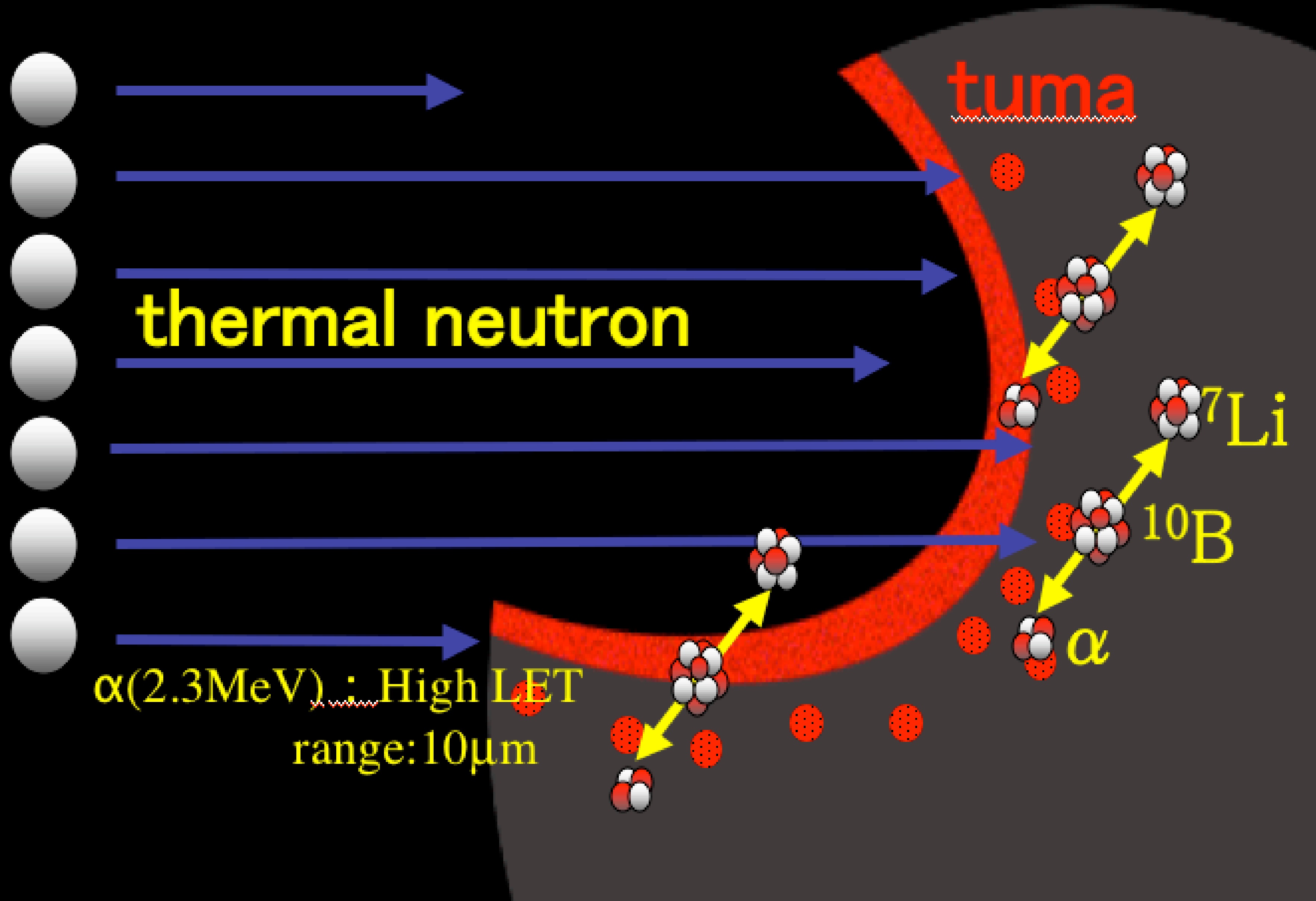
FFAG-ERIT

neutron source-NEDO project

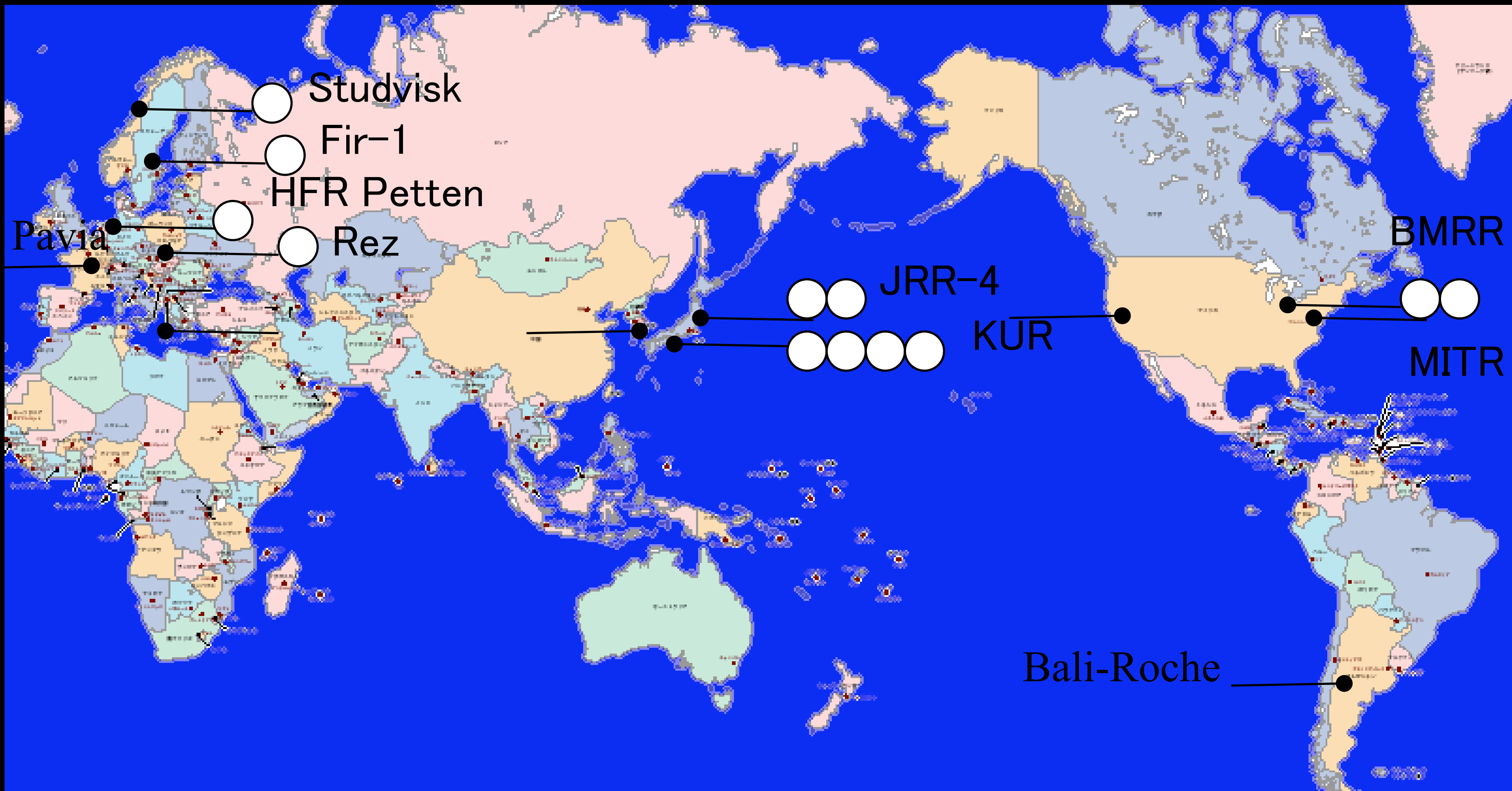
Purpose of Project (NEDO 3-year project:2005-2007)

- Development of a prototype of compact accelerator-based thermal/epithermal neutron source for boron neutron capture therapy
- Perforemance
  - Neutron flux enough for 1 hour treatment
  - thermal/epithermal neutron flux : $\phi \backsim 1 \times 10^9$ n/cm^2/sec @patient

Principle of BNCT



世界における中性子捕捉療法治療施設

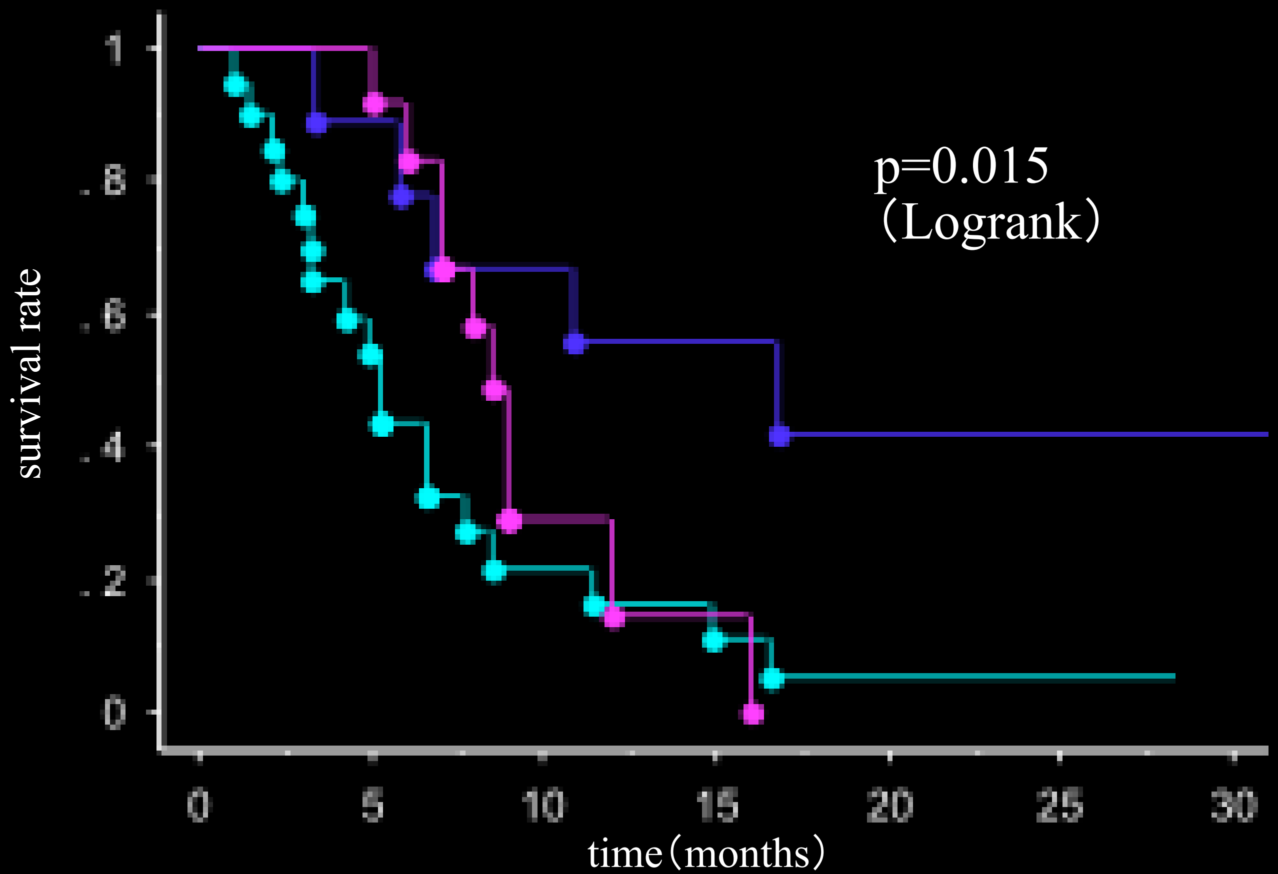


限られた研究用原子炉での臨床研究に留まっている

Department of Neurosurgery
University of Tsukuba

Progression-Free Survival

gliobrastomer



BNCT **Proton** **X-radiation**

PFMST	13.4m	8.5m	5.1m

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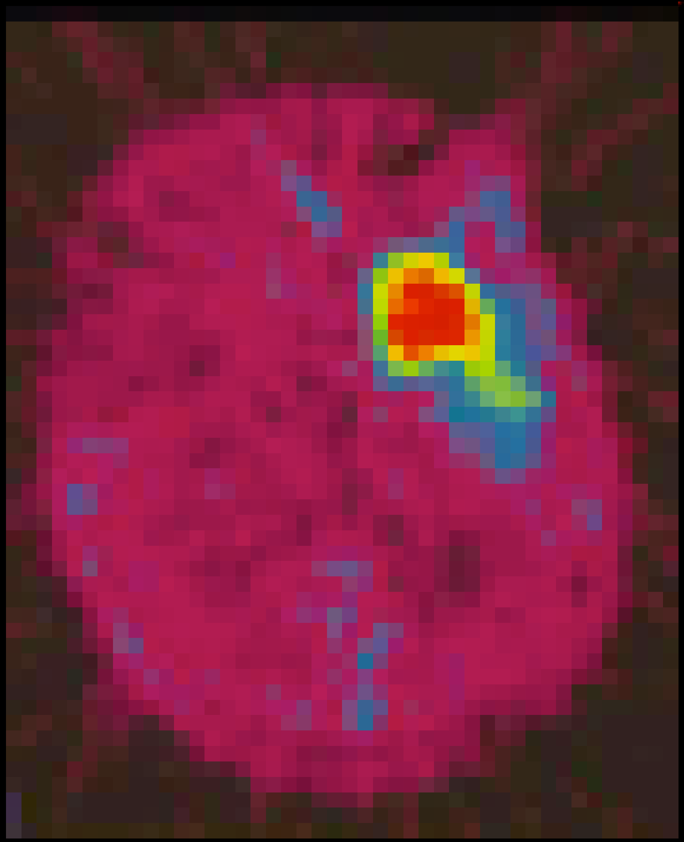
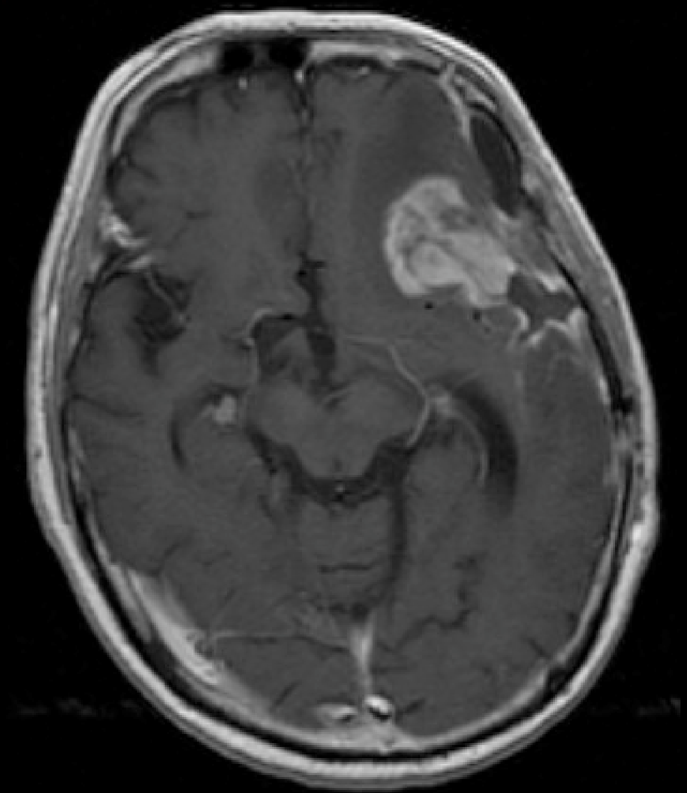
University of Tsukuba

^{18}F-BPA-PET

BPA-PET (T/N 7.8)



Pre BNCT T1Gd

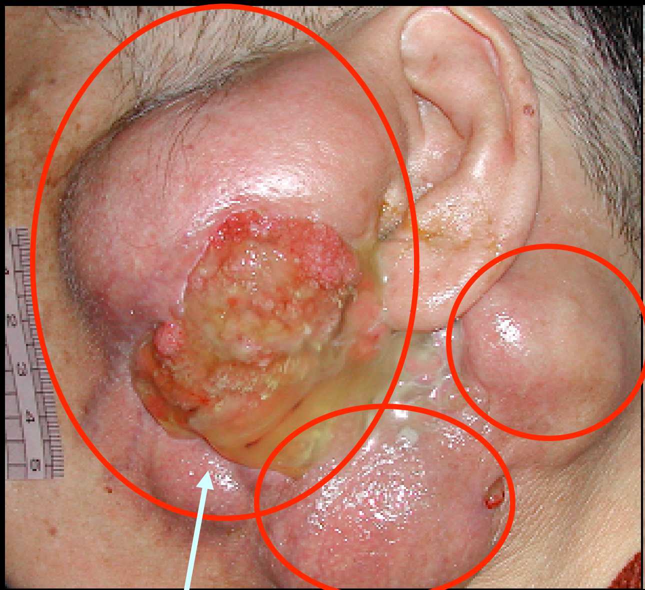


T/N : T / Normal Brain ratio

BNCT : parotid gland tumor

Department of Neurosurgery
Unive
大阪大学　歯学部

照射前



著しいがん細胞の
成長により体内に
止まらず皮膚をも
破りさらに増大

二回照射直後

絶大なるがん細胞縮小の
効果を得ただけでなく
他の放射線治療では
成し得ない、
皮膚の再生を確認。

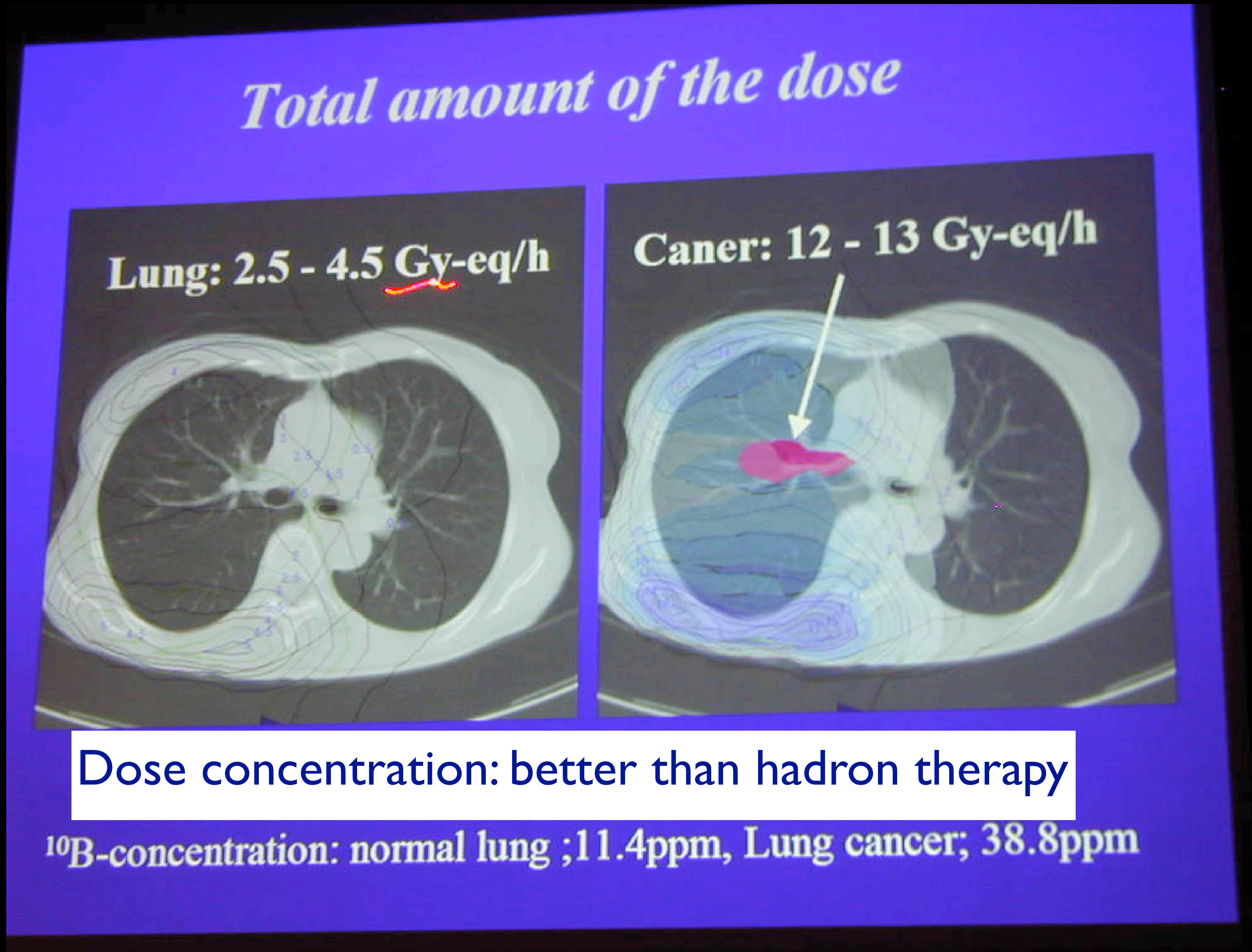
三回照射五ヵ月後

腫瘍はほぼ完全に縮退。

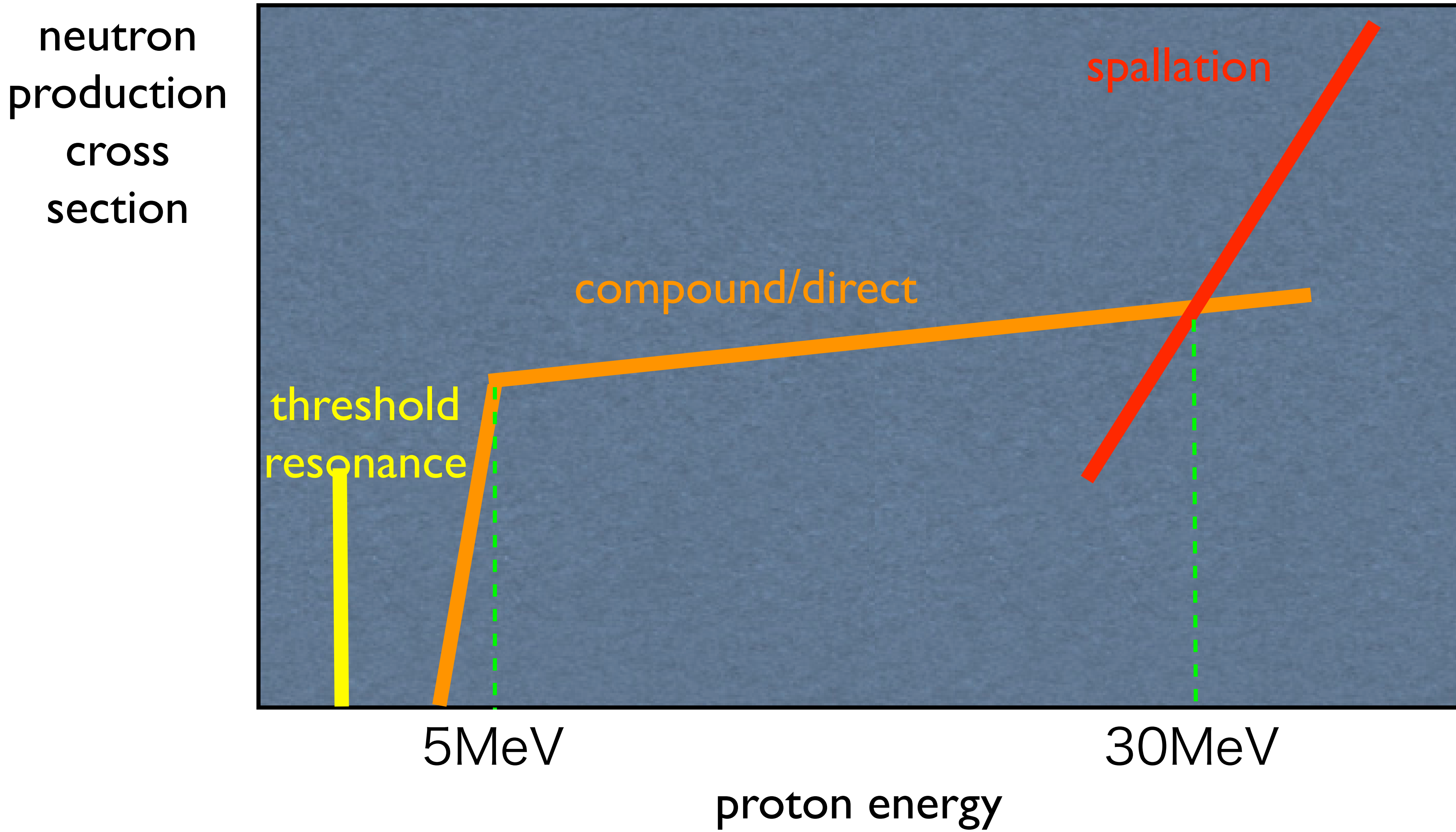
高いQOLを達成。

lung , liver etc.

SKY PerfecTV!
サイエンス　チャンネル
‘03，３月２日　18:00　放映
Japan Science and Technology Corporation（JST)


Total amount of the dose
Lung: 2.5 - 4.5 Gy-eq/h
Caner: 12 - 13 Gy-eq/h
Dose concentration: better than hadron therapy
10B-concentration: normal lung ;11.4ppm, Lung cancer; 38.8ppm

Neutron production process



Problems of ordinary accelerator-based neutron source: scheme with external target

- Beam(proton) energy
  - feasible with ordinary acclerator technology
    - Light nuclei (compound nucleus) low energy ~10MeV
    - Heavy nuclei (spallation) high energy >50MeV
- Beam current
  - technically difficult
    - Light nuclei (compound nucleus) high intensity >10mA
    - Heavy nuclei (spallation) medium intensity >0.5-1mA
- Neutron production target
  - technically difficult
    - Large heat load beam power >10kW
    - Large radiation damage
- Gamma-ray irradiation prohibits for treatment
  - Problems for high energy reaction(cf. spallation) :
    Large gamma-ray production from target/moderator →
    Difficult for shield

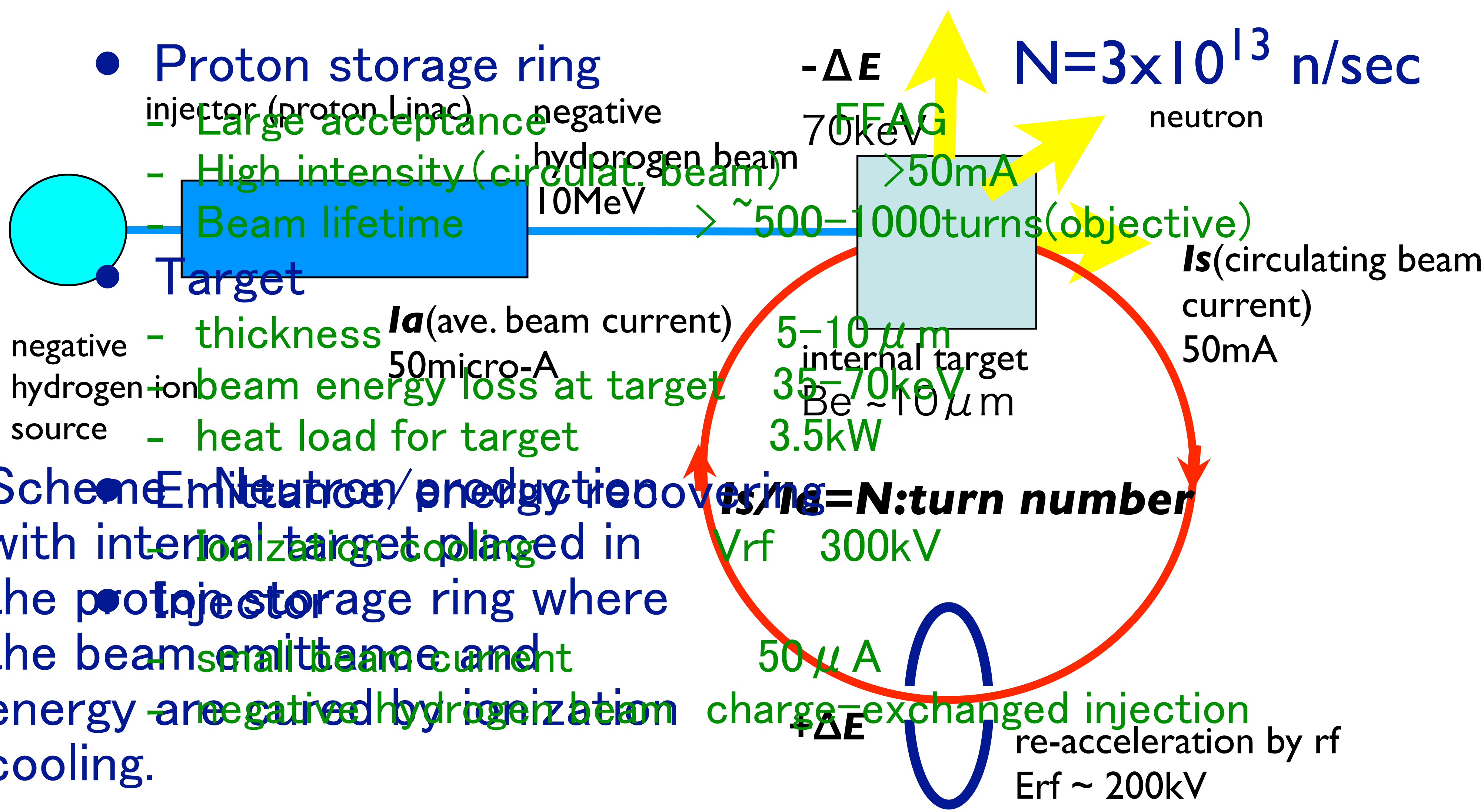
Example of ABNS(accelerator-based neutron source) with external target

- Taskaev et al. (Budker Inst. Russia) ICNCT-12, 2006,Kagawa.
  - Threshold resonance (compound)　Li, Ep=1.9MeV
  - Electro-static accelerator　2MV
  - Beam current　∽10mA
  - Lifetime of target　one/day (thermal errosion)
  - γ ray production　E=489keV
    - Thin target　1 γ /1neutron　OK
    - Thick target　>>1 γ /1neutron　problem

ABNS with internal target
FFAG-ERIT

FFAG Accelerator with Emittance/Energy Recovery Internal Target

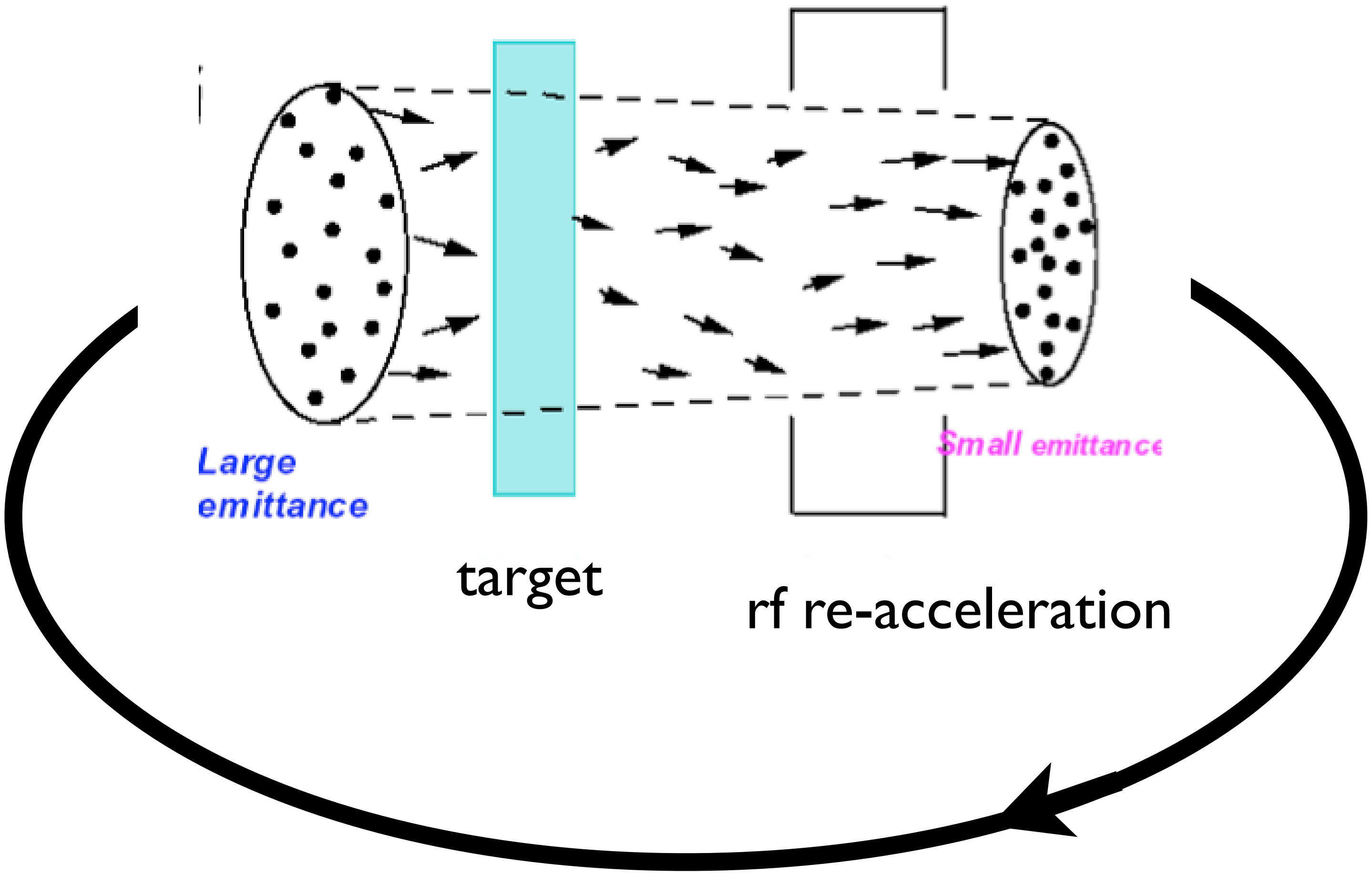
Y.Mori, Nucl. Instr. Meth., PRS, A562(2006) 591-595.



- Proton storage ring
  - Large acceptance
  - High intensity (circulat. beam) > ~500–1000turns(objective) >50mA
  - Beam lifetime
- Target
  - thickness 5–10 μm
  - beam energy loss at target 35–70keV
  - heat load for target 3.5kW
- Neutron production N=3×10^{13} n/sec
- Emittance/ energy recovering
  - Ionization cooling Vrf 300kV
- Injector
  - small beam current 50 μA
  - negative hydrogen atom charge-exchanged injection

Scheme with internal target placed in the proton storage ring where the beam emittance and energy are cured by ionization cooling.

Ionization Beam Cooling



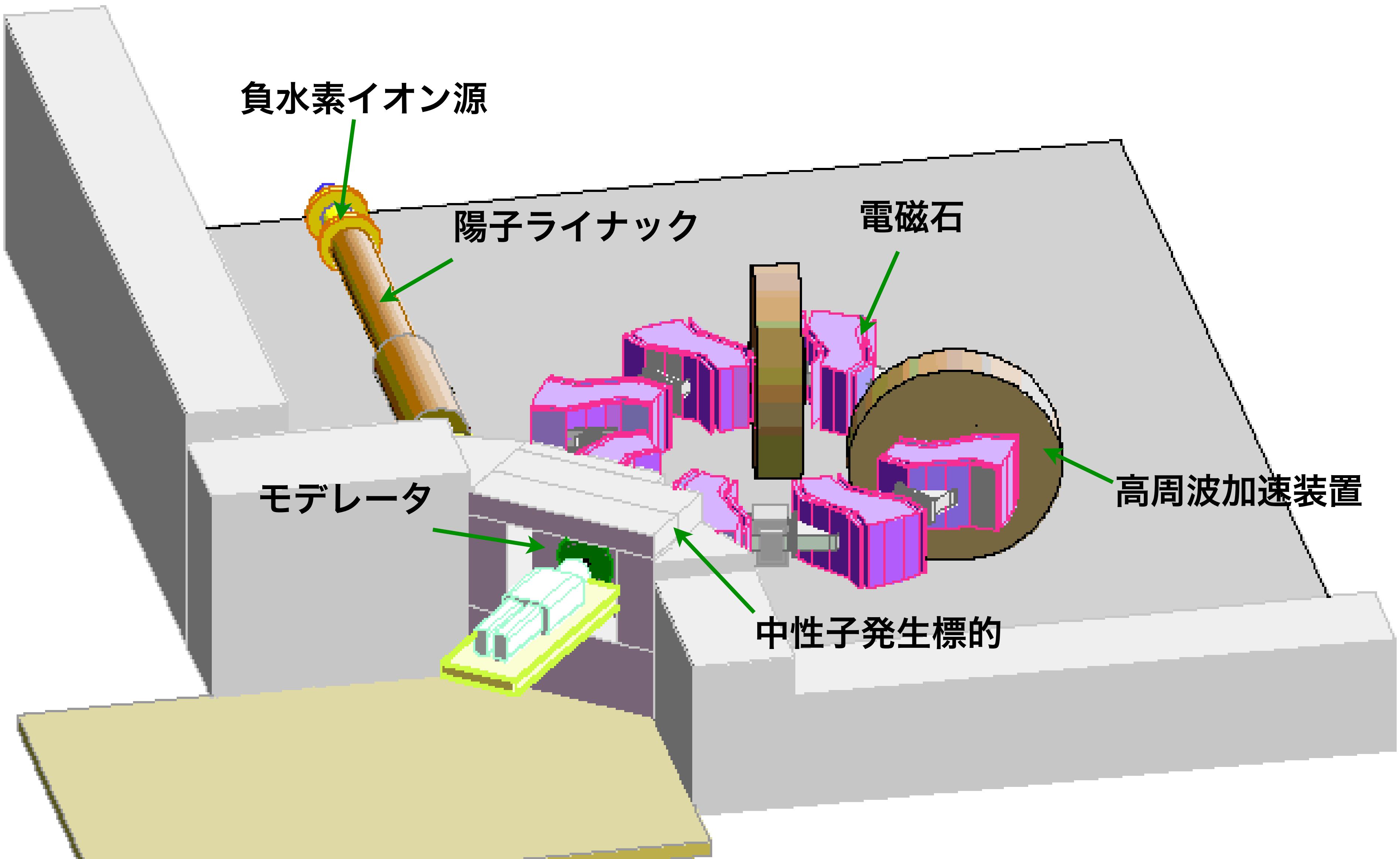
- 3–dimension energy loss :cooling
- recovery of beam energy :rf acceleration
- competition :multiple scattering(heating process)
  - equilibrium beam profile

ABNS with FFAG-ERIT:characteristics

- Large beam current/beam power
  - circulating beam
    - ciruculating beam current(beam power) >50mA(500kW) 10times more than those for external target
- Low loads for the target and injector
  - heat load/radiation damage with thin target
    - heat load ~kW -> radiation cooling :Temeprature ~650C
    - radiation damage 0.1dps
    - Lifetime >month
  - small beam current for injector
    - required beam current circ. beam current／circu. turn number
    - beam current 50 μ A(1000turns)
- Small gamma-ray production
  - thin target, no cooling medium and no beam dump at target region
- multi-target & -directional irradiations
- Small radiation shielding
  - modest beam current
    - small buildings and low infrastructure cost

ABNS with FFAG-ERIT

リングレイアウト鳥瞰図（照射室側から）



Performance

- FFAG-ERIT ring
  - circ. beam current 70mA
  - number of turns 1000ターン
- Injector
  - beam energy 11MeV
  - averaged beam current 70 μ A
- Neutron production target
  - Be,10 μ m Lifetime>one month
- Modearotr
  - thermal+epithermal 10^9 n/cm^2/sec
  - γ・fast neutron Nuclear reactor level（IAEA）

Design issues of ABNS with FFAG-ERIT(I)

- Beam optics and dynamics
  - Acceptance
    - Av>500mm.mrad(rms)
    - dp/p>+-5%(full)
  - Beam lifetime : ionization cooling
    - >1000 turns
- Larege aperture magnet
  - accuracy, fringing filed
    - <10-3, gap:15cm
- rf cavity
  - frequency
    - ~20MHz(harmonic number ~5)
  - rf voltage
    - >200kV
- Target
  - heat load
    - <6.6W/cm^2
  - homogeneous beam profile
    - off center beam injection

Design issues of ABNS with FFAG-ERIT(II)

- Injector
  - beam current
    - NH ion source
      - av. beam current >100 μA (20–200Hz, duty ~2%)
    - Linac
      - av. beam current >70 μA (20–200Hz, duty ~2%)
- Moderator
  - optimized design
    - neutron flux at patient
      - 10^9 n/cm^2/sec
    - reduction of fast neutrons (E>100keV) & γ rays

Beam focusing of FFAG
Spiral sector & Radial sector

Spiral sector :

Small size
Small beam focus for vertical plane
Difficult of operational tunes

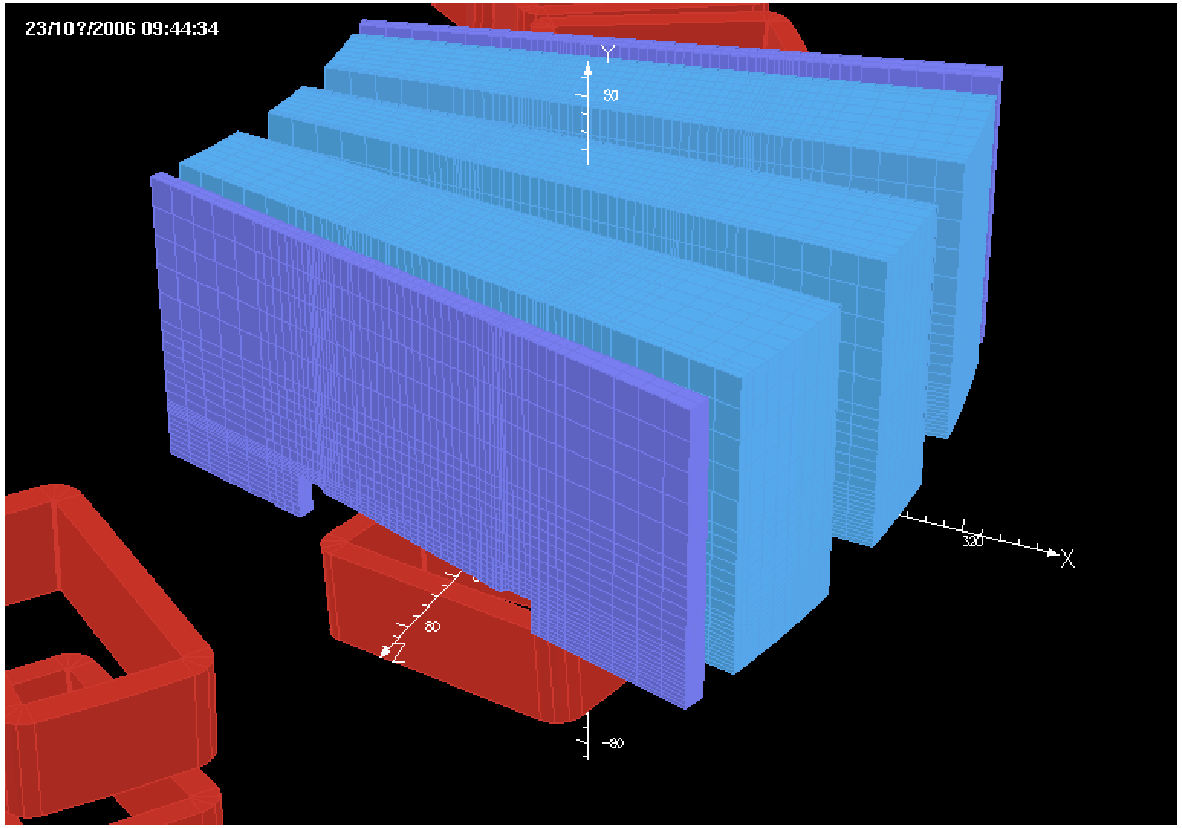
Radial sector :

Large size
Large beam focus for vertical plane
Change of operational tunes : feasible

We choose Radial Sector (FDF).

Radial sector FFAG

FDF lattice
Cell num. = 8
F-Mag. = 6.4[deg],
D-Mag. = 5.1 [deg],
F-D gap 3.75[deg],
F-Clamp gap = 1.9[deg],
Clamp thick = 4[cm]
Mean radius = 2.35[m]



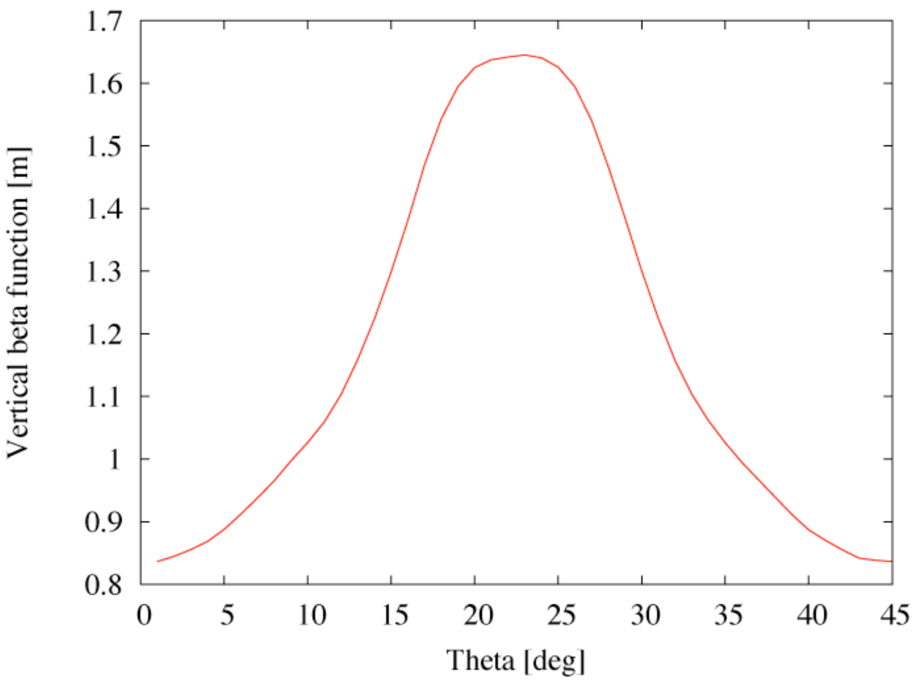
$n_x \sim 1.75$, $n_y \sim 2.23$
FD ratio ~ 3

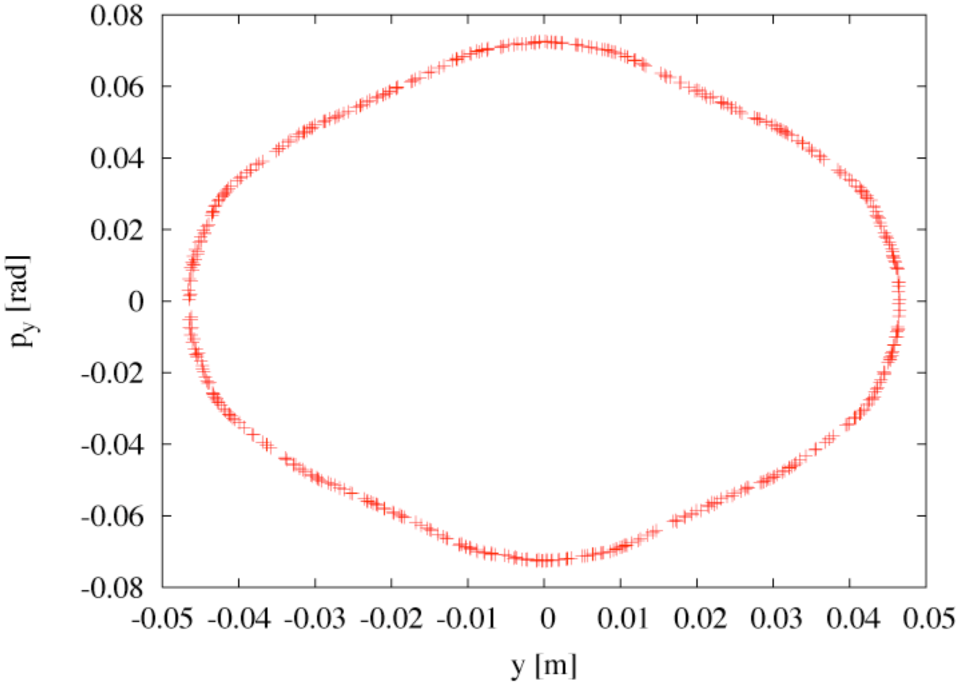
Radial sector (FDF) FFAG Ring
parameters

beam energy	11 MeV
ave. radius	2.35 m
most ext. radius of magnet	3.06 m
Fmagnet	
field strength	0.825 T
AT	58500 AT
orbit length(@ave. radius)	26.25 cm
mass	4.1 ton
Dmagnet	
filed strength	0.727 T
AT	54500 AT
orbit length(@ave. radius)	20.92 cm
mass	3.4 ton

Vertical beta function & acceptance

Beam tracking simulation with TOSCA field map



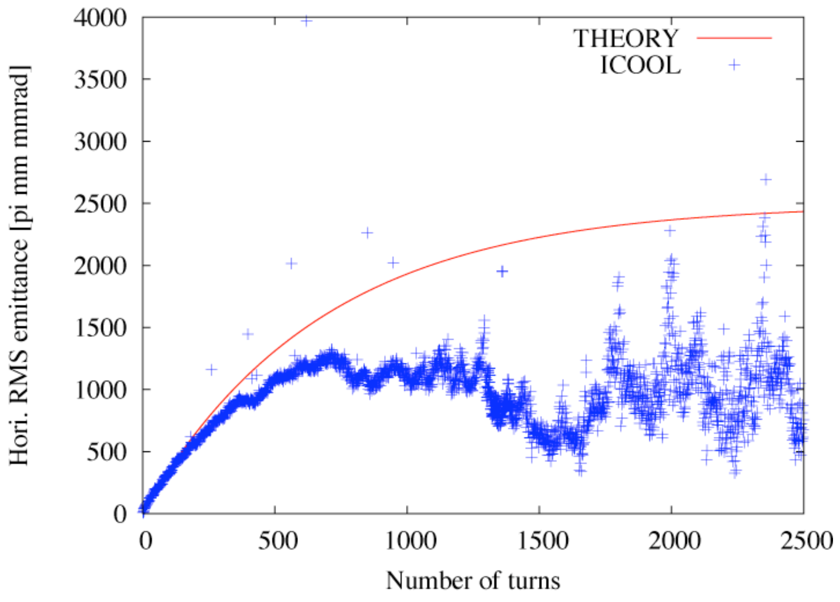


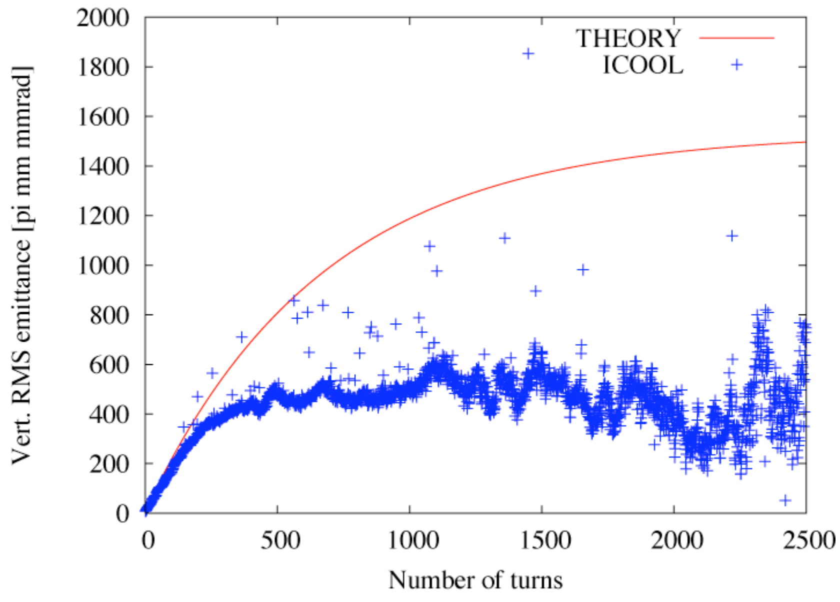
Vertical beta function@target ~ 0.83 [m]

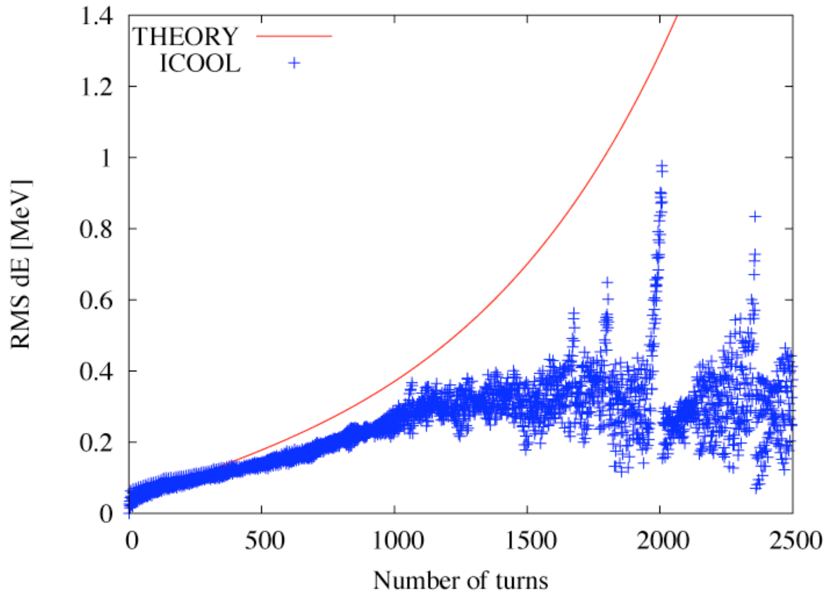
Vertical acceptance ~ 3000π [mm-mrad]

(Horizontal acceptance > 7000π [mm-mrad])

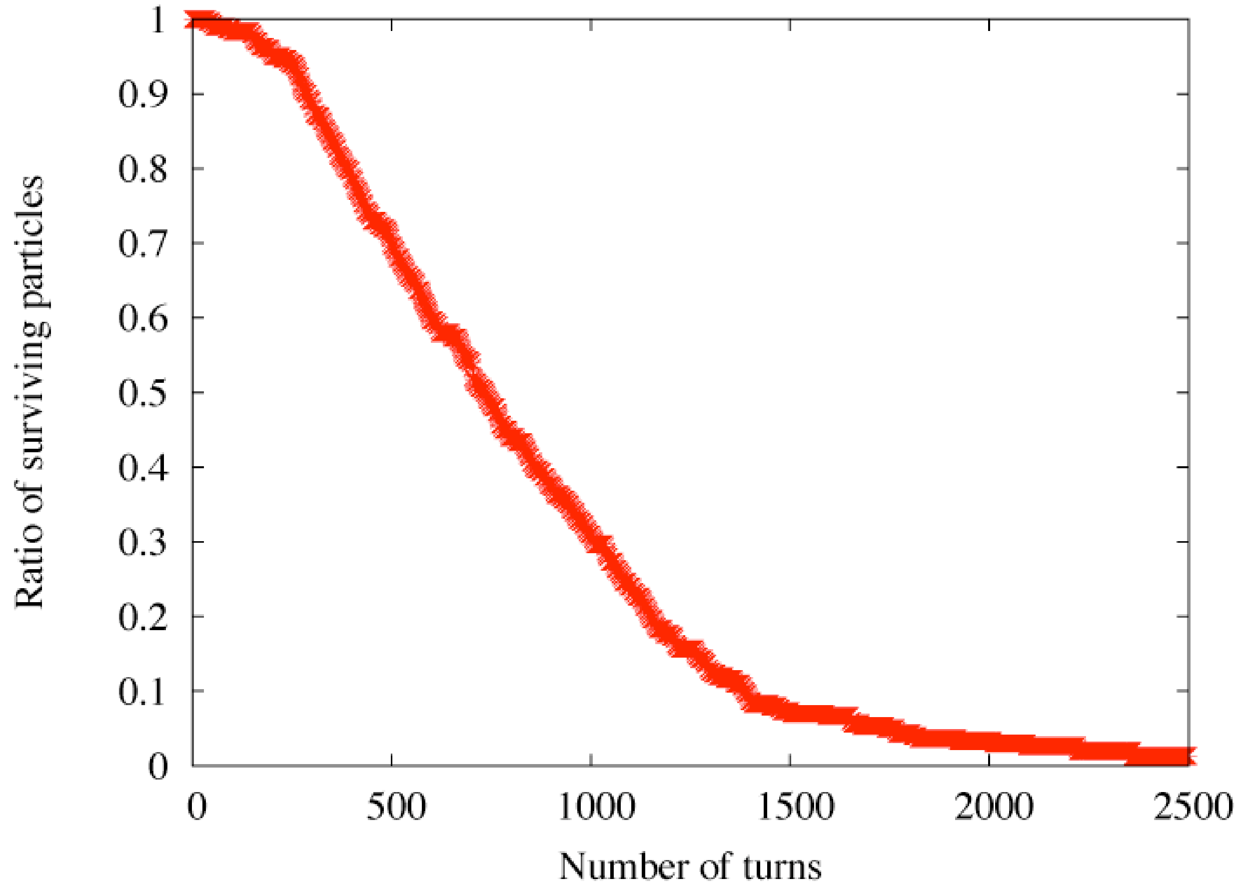
RMS emittance / energy spread







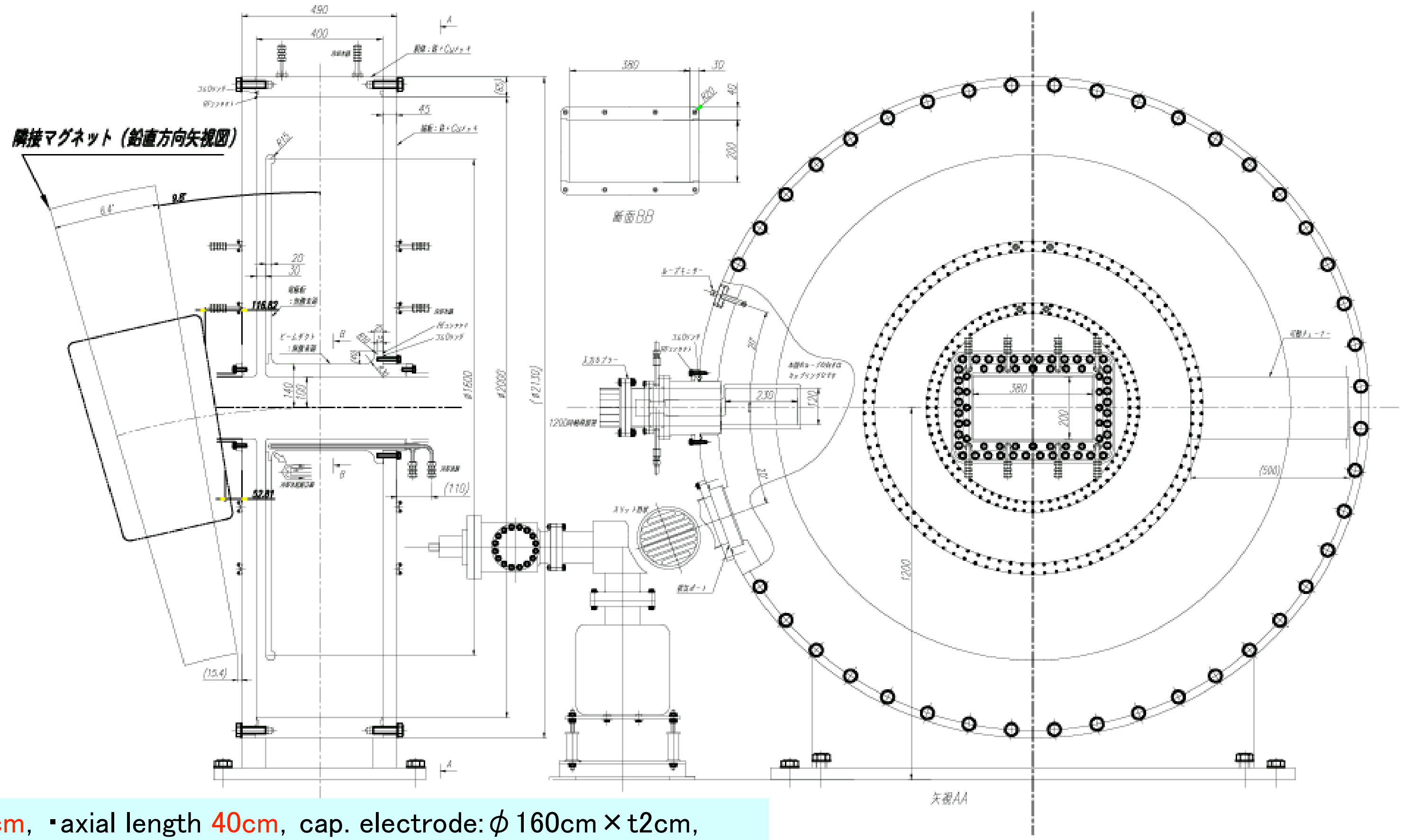
Number of survivals



Ave. turn numbers for beam survival ~ 910 turns

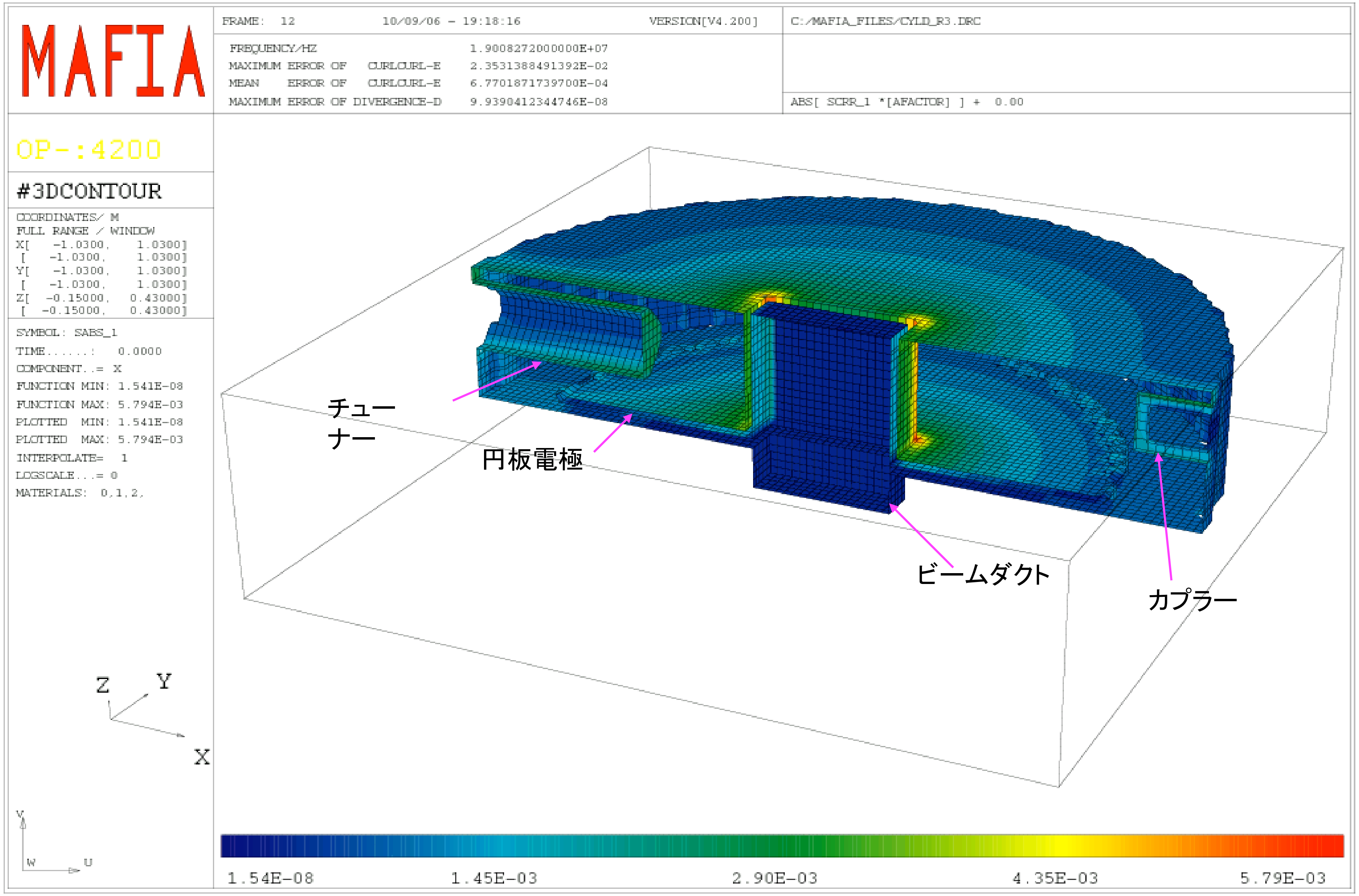
ERIT rf cavity – basic design

(図5) ERIT空洞の基本設計図



- Inner diameter φ200cm, ・axial length 40cm, cap. electrode: φ160cm×t2cm,
- gap btw cap. electrode and cavity end plate 3cm,
- tuner: φ20cm×L50cm,
- beam duct : w38cm×h20cm,
- coupler :diameter 12cm×L30cm, φ2cm

Field map and surface current



RF cavity for ERIT -cold model

Q(measured) ~6000: 66% of MAFIA result
->surface roughness

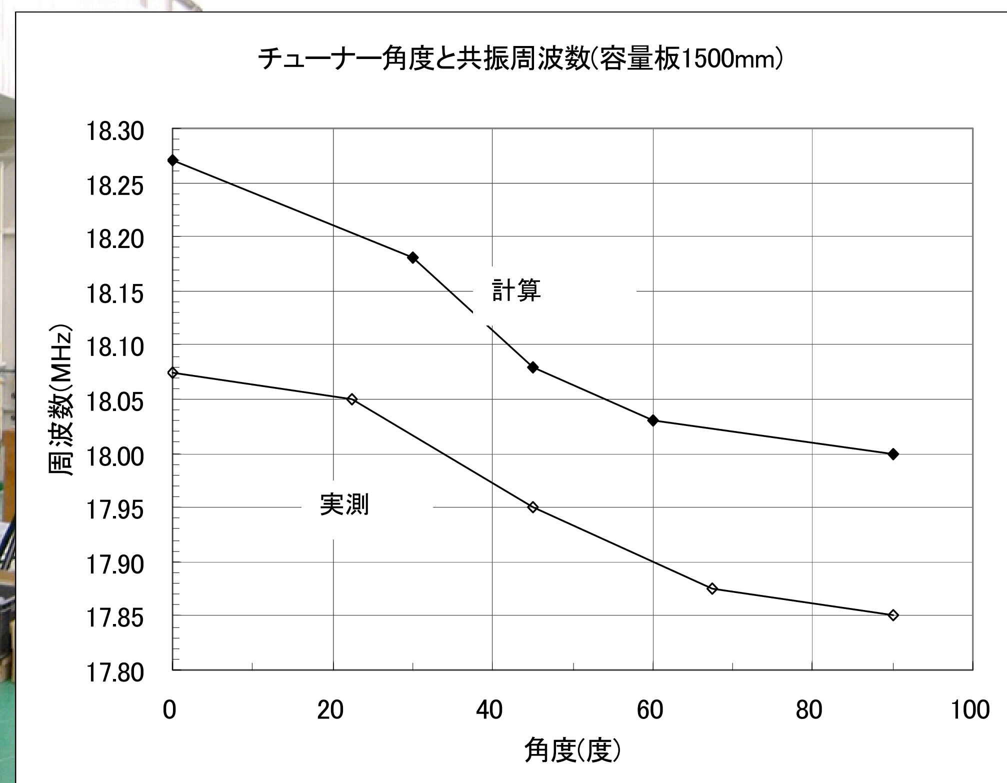
共振周波数の測定
2006/3/14

角度	共振周波数
度	MHz
0.0	18.075
22.5	18.050
45.0	17.950
67.5	17.875
90.0	17.850
周波数幅	0.225

容量板　φ1500　を取り付けた状態

測定方法
①端板のN型コネクターにφ1.7mmで径150mm程度のループを
　密結合で挿入

②ネットワークアナライザーでチューナー各位置での共振周波数を
　（アンテナのインピーダンス補正は無し）

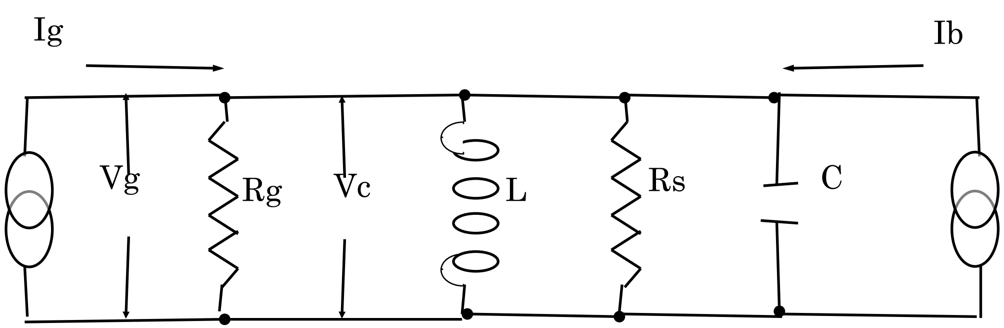


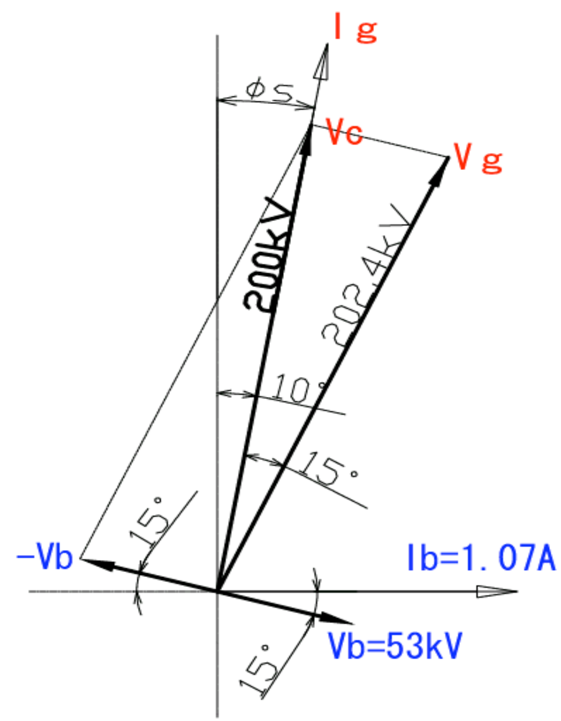
Beam Loading

- Admittance/rf power

$$Y=\frac{1}{R}\left\{1+j2Q_b\frac{(\omega-\omega_r)}{\omega_r}\right\},\frac{1}{Q_b}=\frac{1}{Q_g}+\frac{1}{Q_0}$$

$$P_g=\frac{(1+\beta)^2}{8\beta R_s}\left(V_c+\frac{2R_sI_{b0}}{1+\beta}\sin\phi_s\right)^2$$

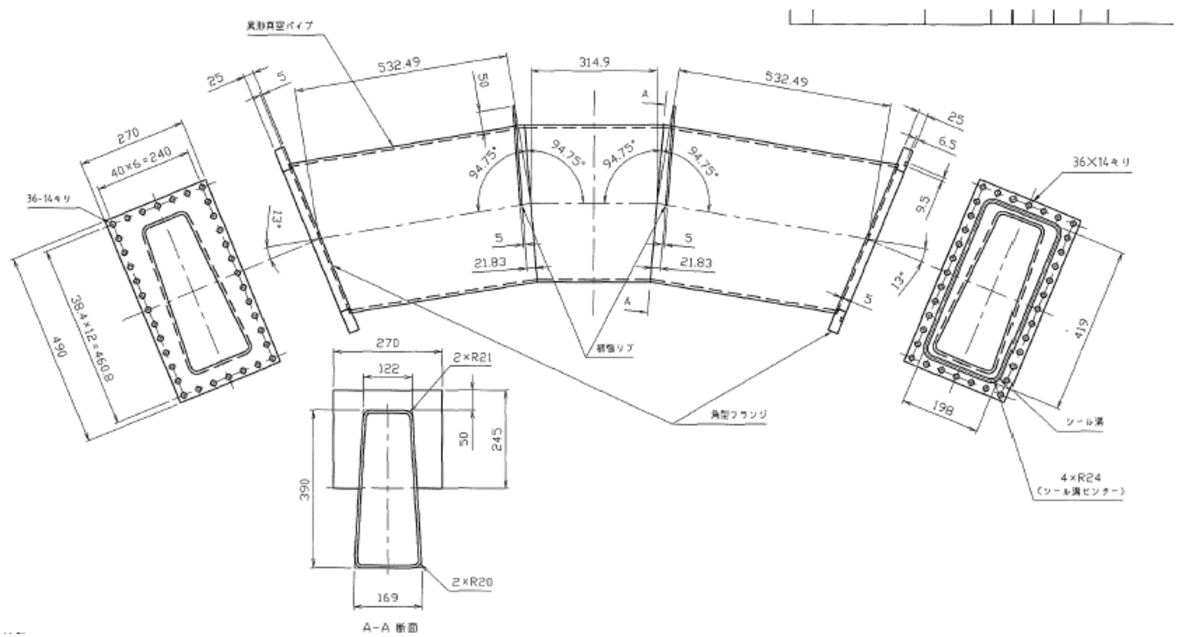


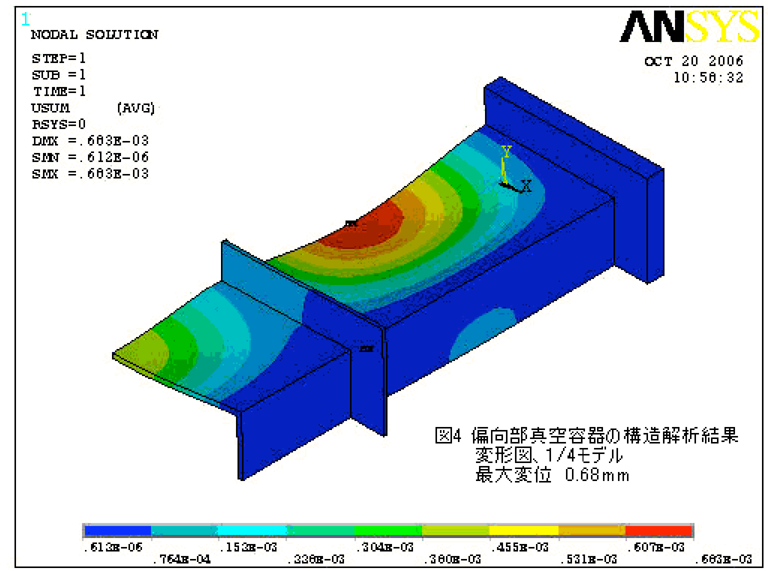


Ave. rf power ~60kW (duty 30%)
Peak rf power ~210kW

Vacuum duct

sag <1mm　→ thickness 7mm+ 5t rib





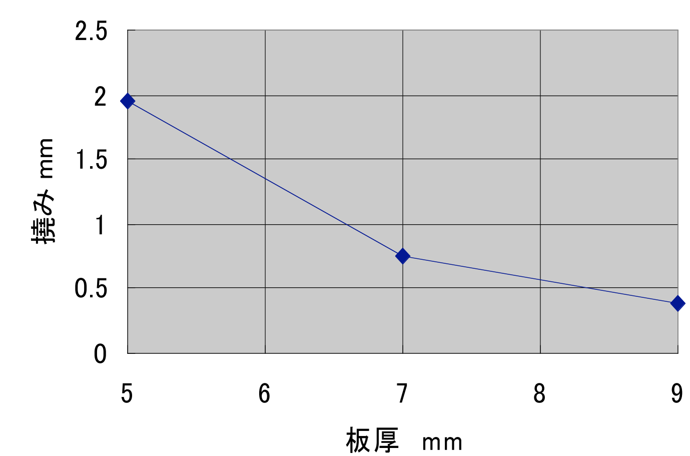


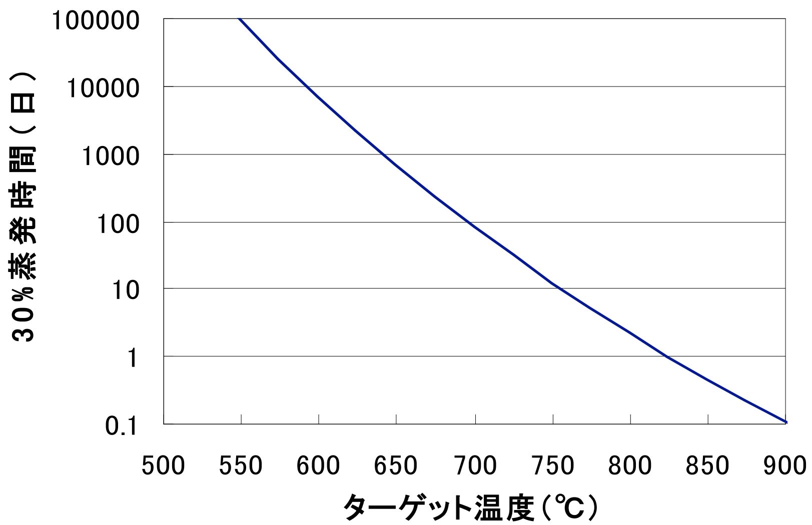
図3.1 直線部真空容器の撓み

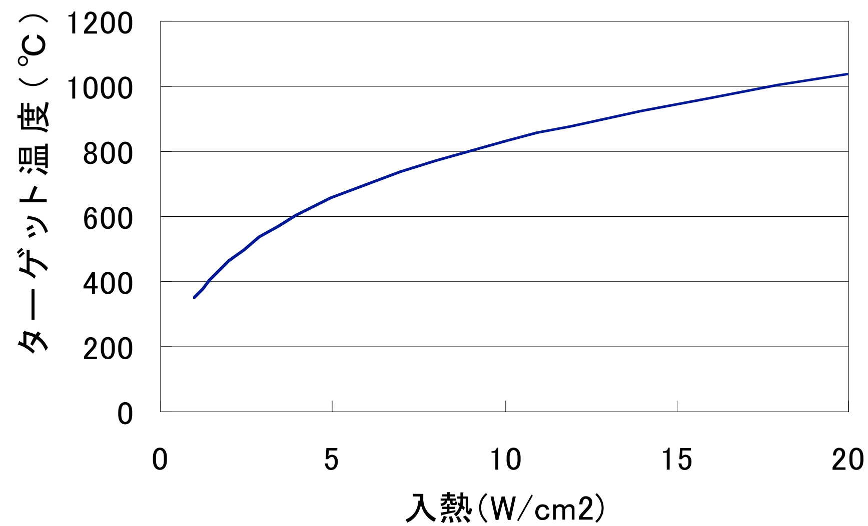
Neuron production target lifetime

- Lifetime is mainly determined by evapolation.

  → Low temperature operation(<650C) is essential.

- Heat power density <6.6W/cm2 for 3 months operation.



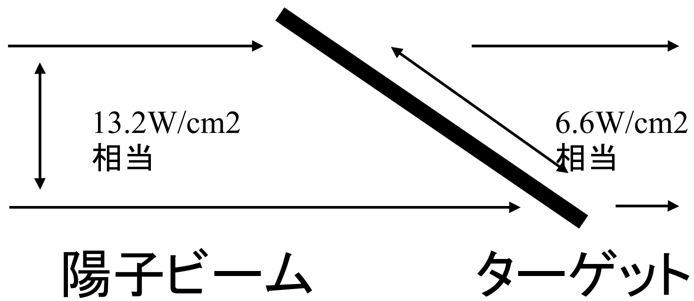


Lifetime(30% evaporation) and temperature

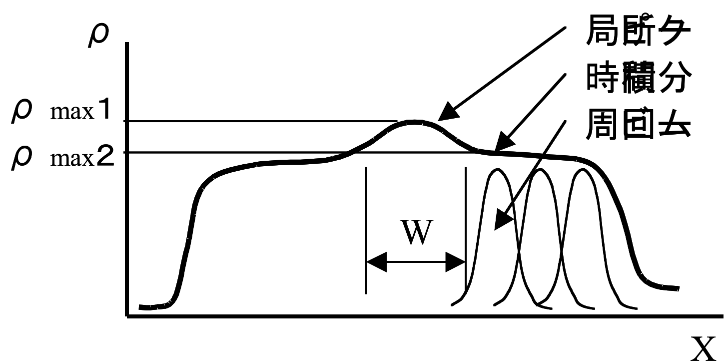
target temperature as a function of input heat power density

Target layout & performance

- Tilted target : input heat power density ~1/2
- Beam profile distribution



Tilted target layout



Beam profile distribution

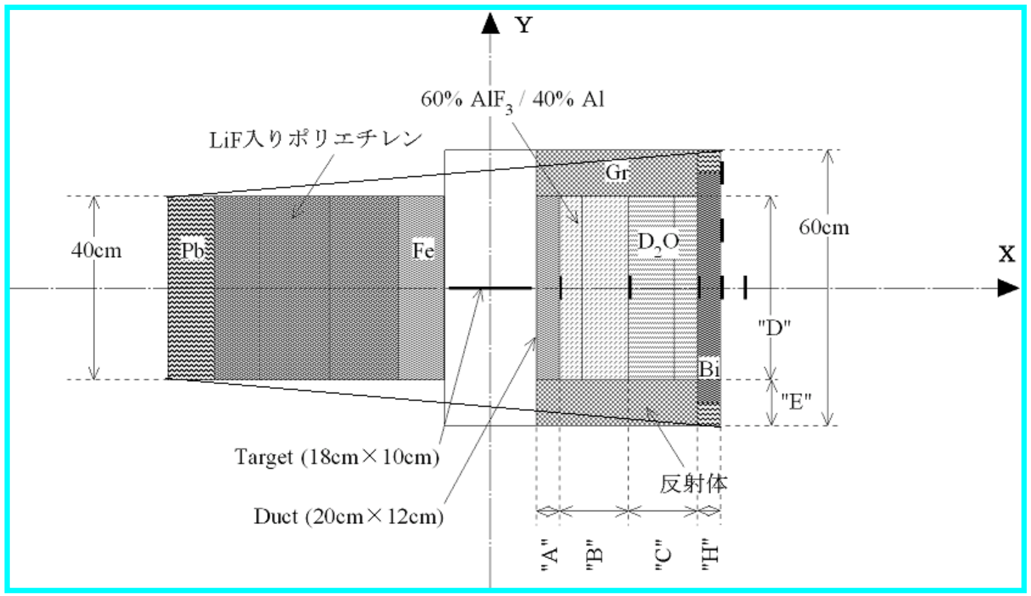
parameters

proton energy	11MeV
beam current	70mA
Be thickness	10 μ m
stopping power	6.46keV.um
energy loss	64.6keV
heat radiation	4523 W
beam size(H)	34cm
beam size(V)	10cm
target angle	30degree
irradiation area	14cm2
radiation factor	0.61
power density	6.6W/cm2
target temp.	720C
lifetime	38days

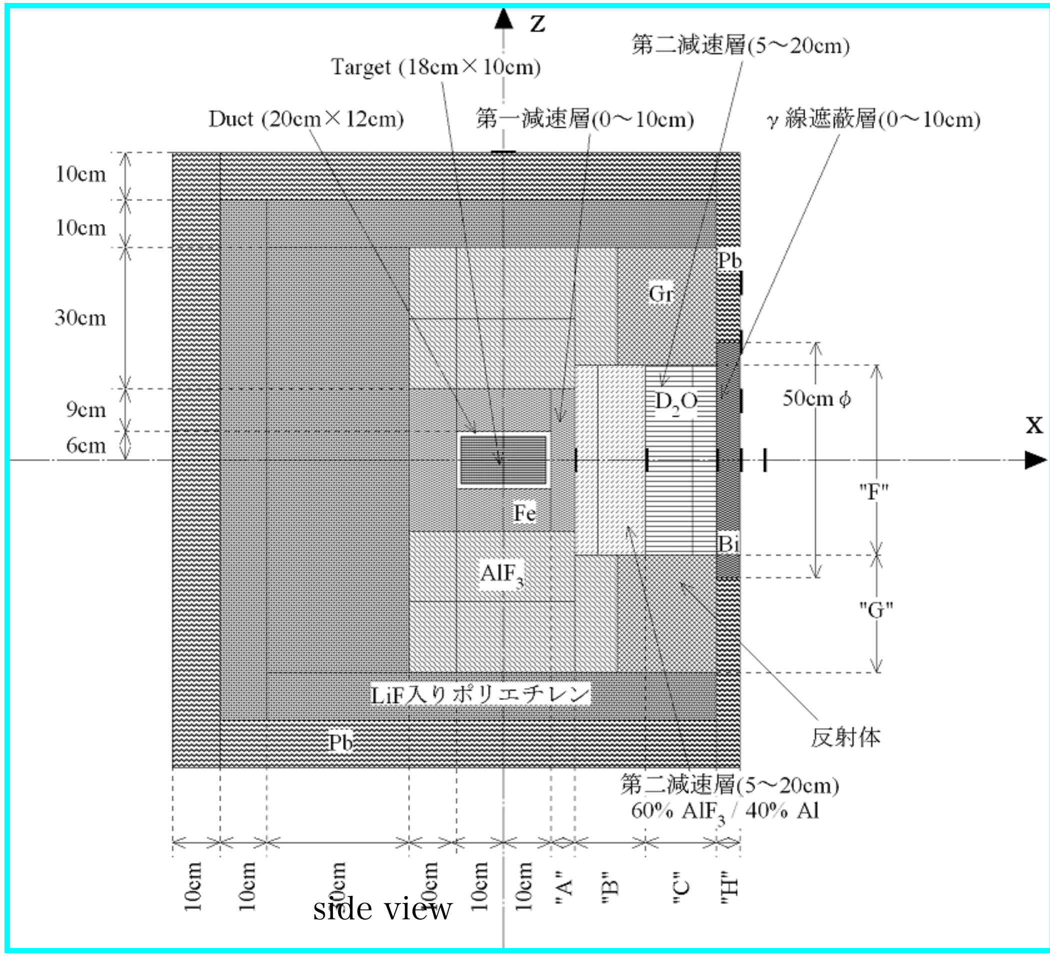
Moderator

basic layout

1st moderator：5～10cm, 2nd moderator：10～30cm,
3rd moderator：10～20cm, γ-ray shield ：5～10cm

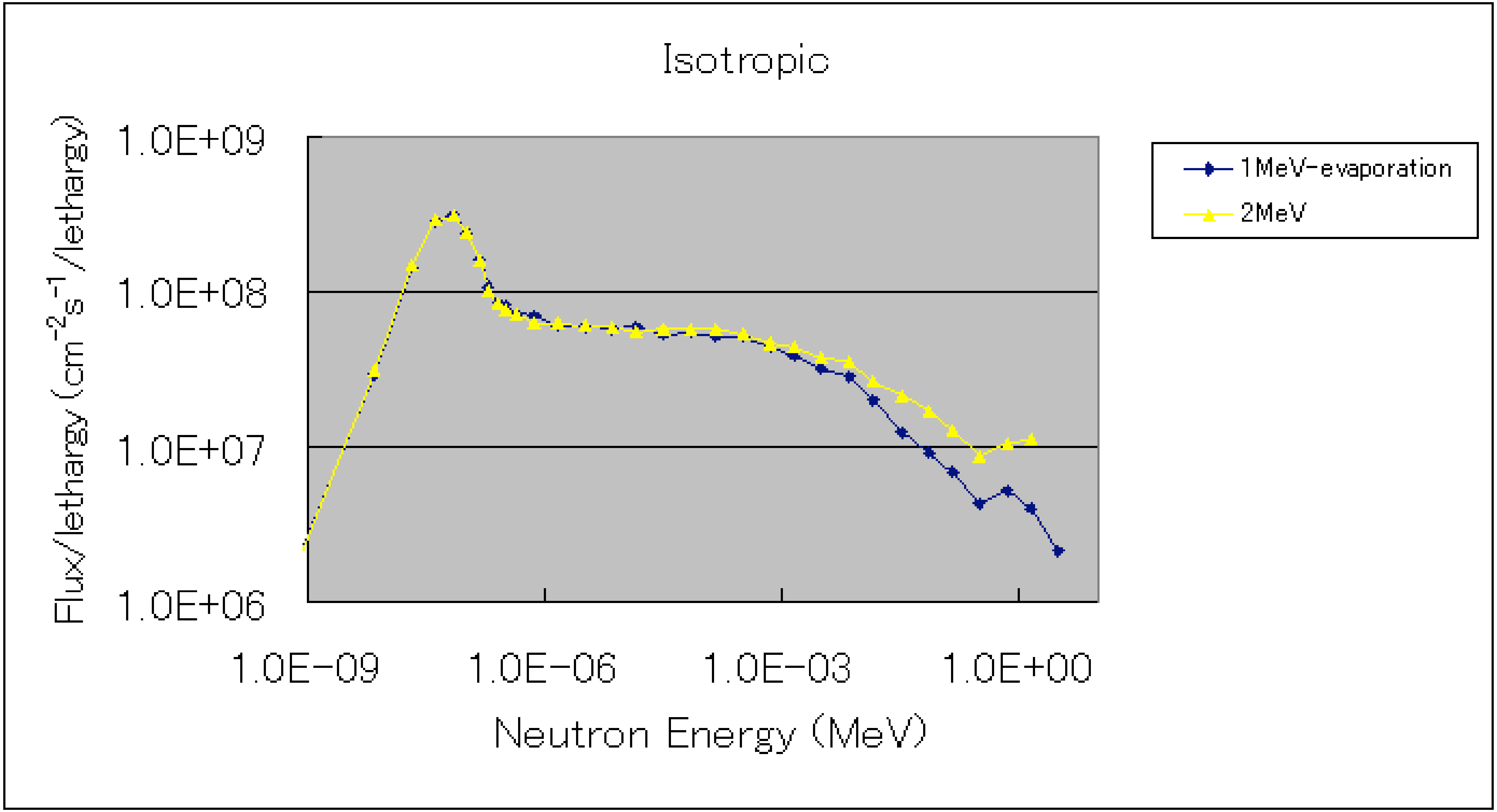


top view



side view

example (under optimization)



Summary of Moderator (in progress)

Thermal neutron flux : 7×10^8 ($cm^{-2}s^{-1}$)

Epi-thermal neutron flux : 5×10^8 ($cm^{-2}s^{-1}$)

Total (thermal + epi-thermal) : 1.2×10^9 ($cm^{-2}s^{-1}$) @ patient

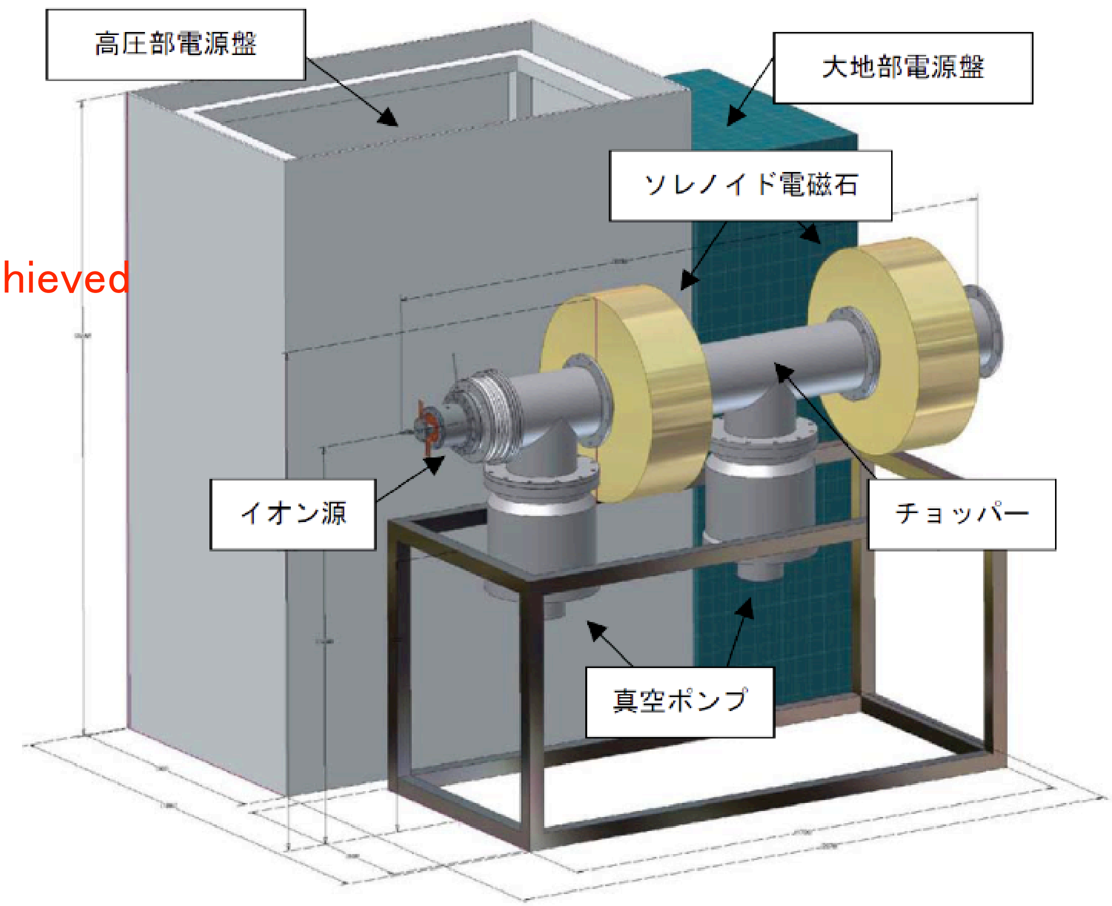
Contamination of fast neutron ; 2-2.5 times larger than IAEA standards, however, comparable with those from ordinary nuclear reactors(KUR, JRR4 etc.)

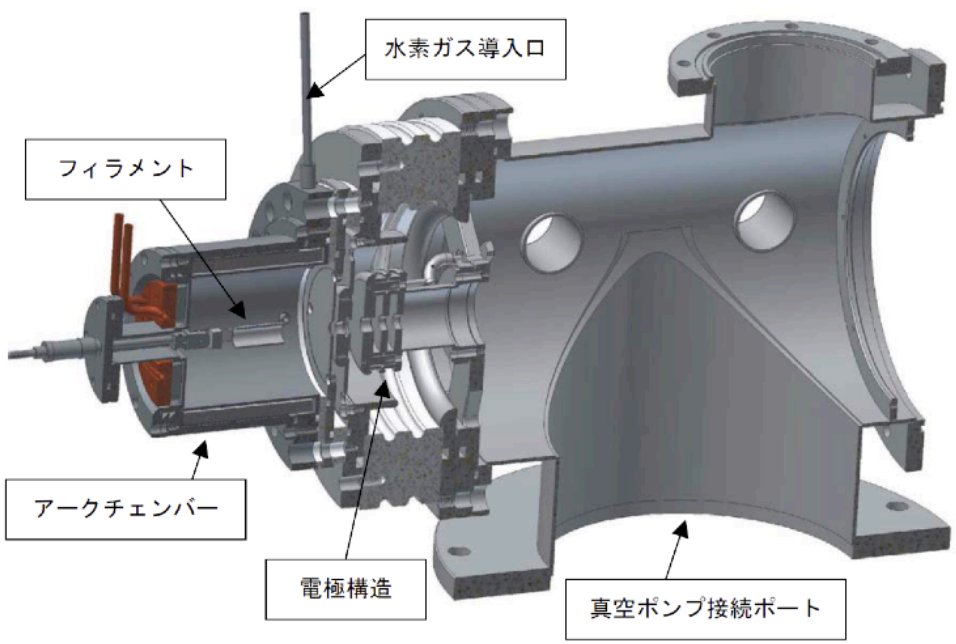
Contamination of γ-ray : lower than IAEA standards, however, not includes those from target nucleus.

Optimaization is in progress.

Ion Source

- particle: negative hydrogen
- extraction energy: 30 keV
- rep. rate：200Hz（goal：500Hz）
- beam duration：2%, maximu
- beam current：
  - 100 μ A（ave.）
  - 5mA（peak：goal10mA）
  - commissioning(12/12/06)　1mA(cw)achieved
- nor. emittance：<1πmm-mrad



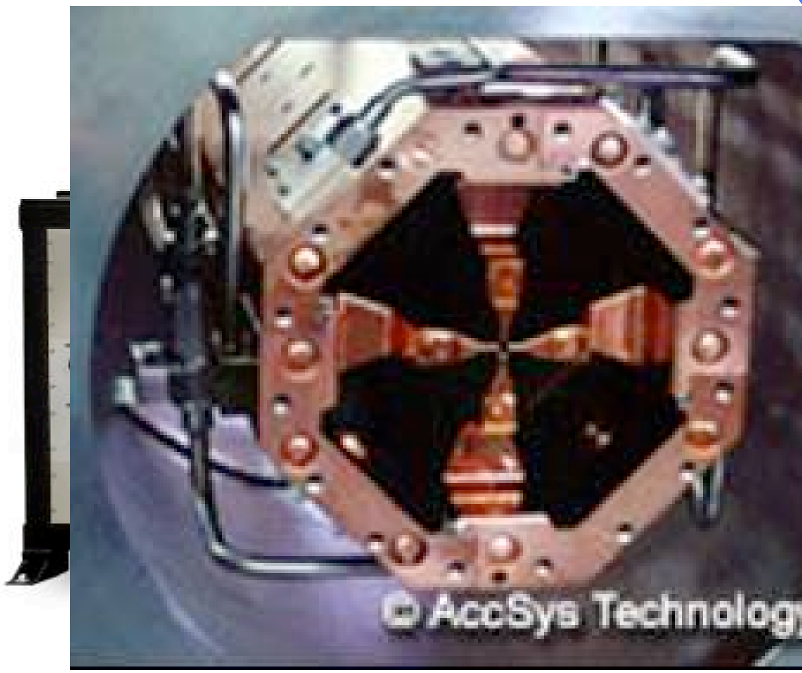


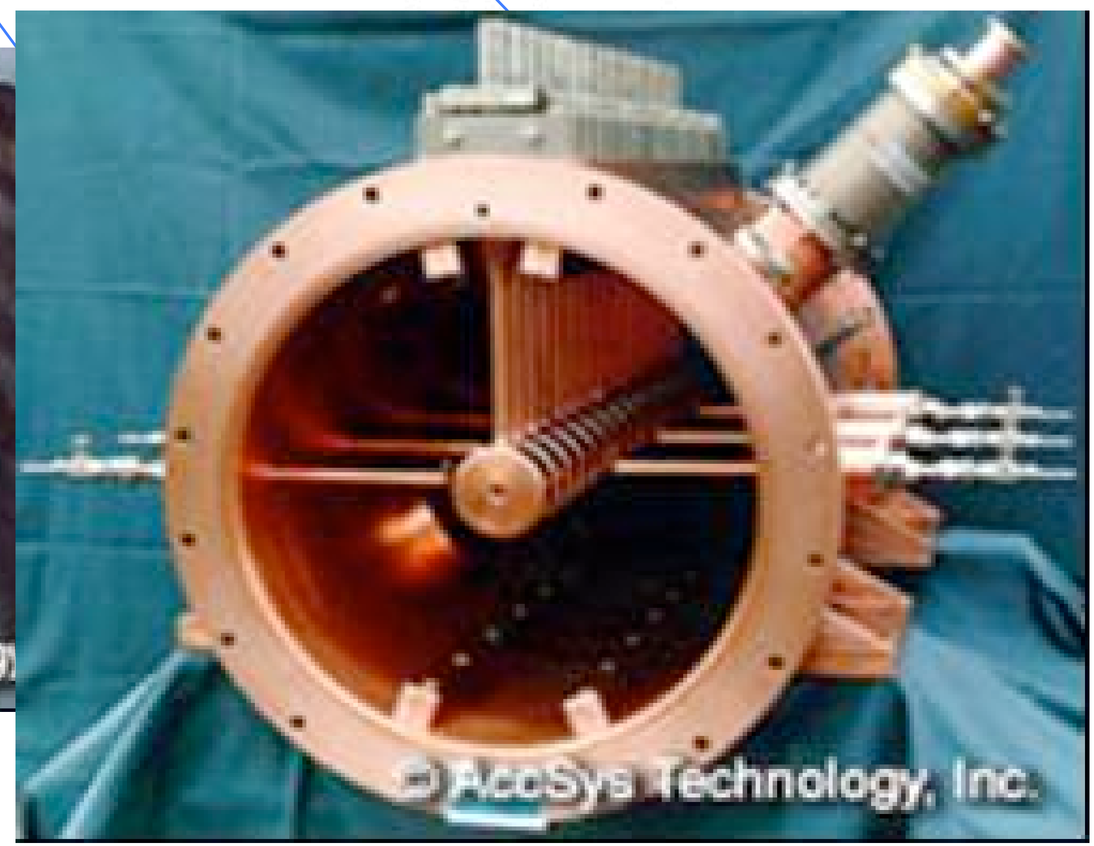
Proton linac

AccSys Inc. PULSAR-7

DTL

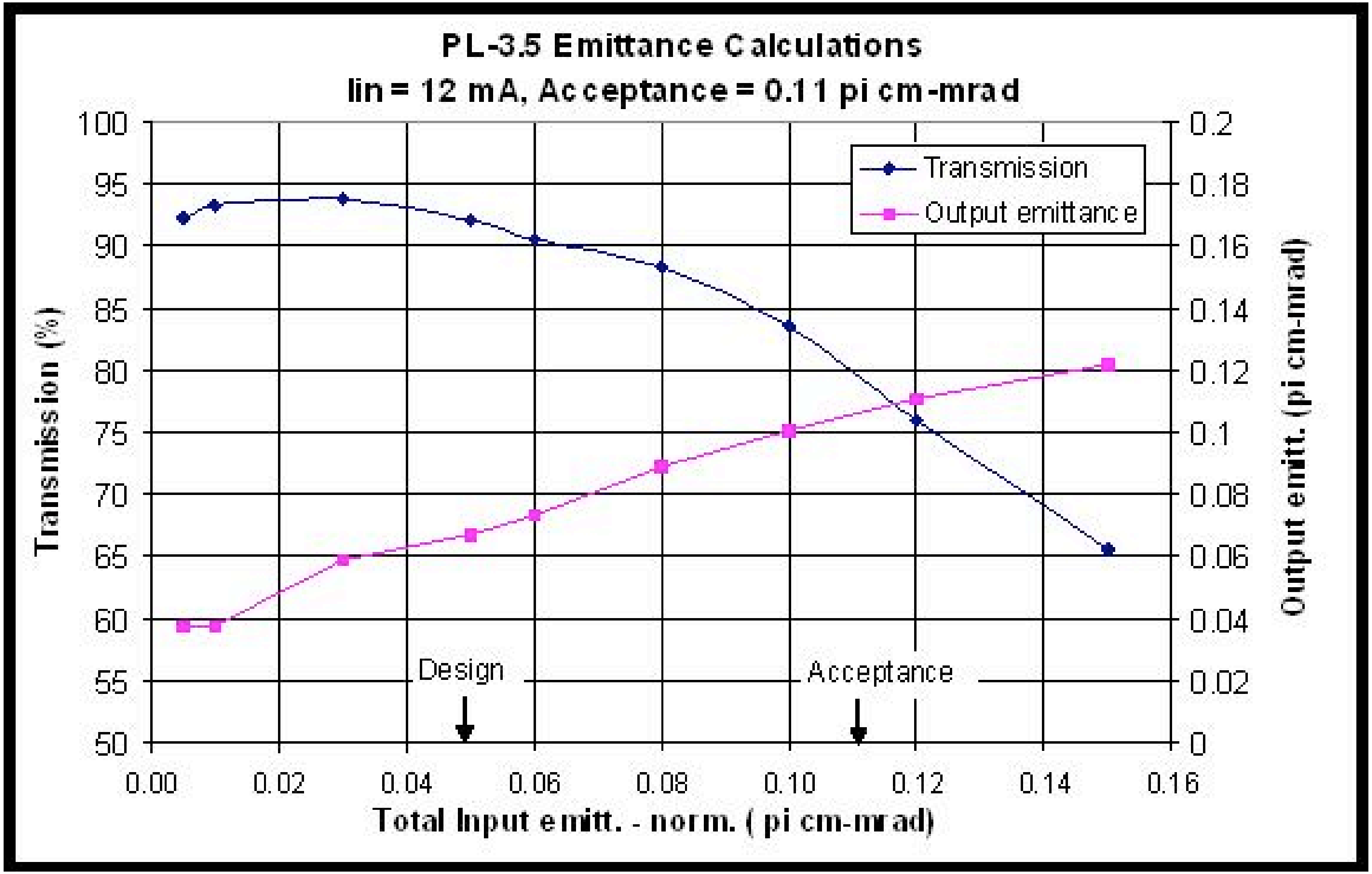
RFQ





PULSAR-7:developed for **PET**。
12/19/06:ビームcommissioning (@7MeV)

Proton linac



Summary of ABNS with FFAG-ERIT

- Physical design is completed. Fabrication is in process.
- Ion source is almost completed.
  - cw operation. beam current ~1mA。
- Proton linac
  - beam commissioning started：12/19/2006~
- Preparation of infrastructure(water, electricity etc.) at KURRI
- Completion (hope) : Sept. 2007

Next FFAG workshop in Japan

- November , 2007. Date will be fixed soon.
- Place: Kyoto University, Kyoto/Osaka area
- Support for participation (traveling etc.) ,especially for young scientists.