February 5, 2014
CLIC Workshop 2014@CERN, Switzerland

Compact short-pulsed X-band linac based neutron source

○M. Uesaka[1], K. Tagi[1], K. Dobashi[1], T. Fujiwara[1]
M. Yamamoto[2] and
H.Harada[3]
Nuclear Professional School/Dept. Nucl. Eng.&Manage., University of Tokyo, Japan
Accuthera Inc., Japan
JAEA, 2-4 Shirane Shirakata, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan

CONTENTS

1. Decommission of Experimental Reactor “YAYOI”
2. R&D of X-band electron linacs
3. New Accelerator based Neutron Sources
4. High Precision Nuclear Data Analysis for Fuel Debris Evaluation

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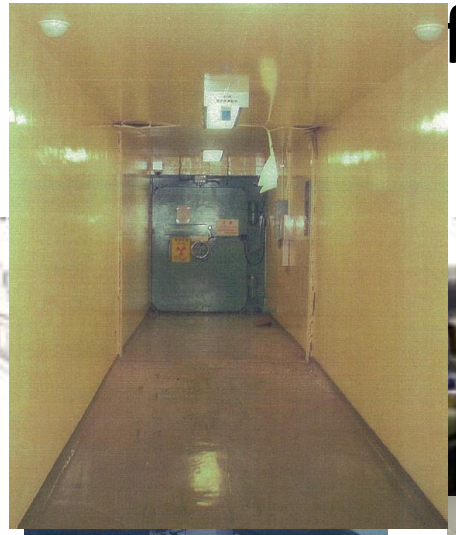
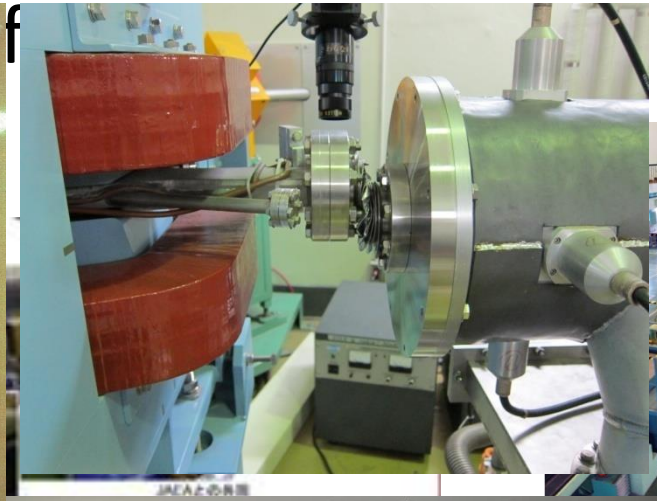






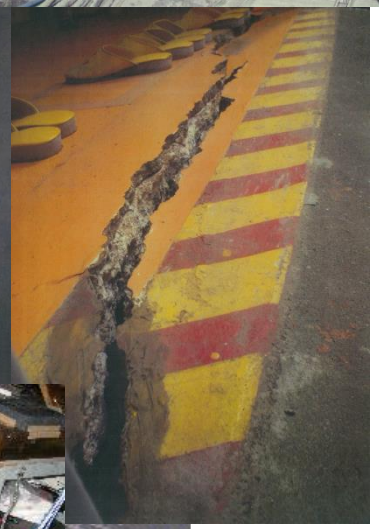




Categorization of Special Nuclear Material

Unirradiated		Category I	Category II	Category III
Plutonium		2kg or more	Less than 2kg but more than 500g	500g or less but more than 15g
U-235	Enriched to 20% 235U or more	5kg or more	Less than 5kg but more than 1kg	1kg or less but more than 15g
	Enriched to 10% 235U but less than 20% 235U		10kg or more	Less than 10kg but more than 1kg
	Enriched above natural, but less than 10% 235U			10kg or more
U-233		2kg or more	Less than 2kg but more than 500g	500g or less but more than 15g

Irradiated — Type of nuclear material	Category
Material irradiated in a reactor but with a radiation level equal to or less than 1 Gy / hr at 1 meter unshielded	Same category as unirradiated
Radiation level from the fuel exceeding 1 Gy / hr at one meter unshielded	May be reduced by one category level
Depleted or natural uranium, thorium or low-enriched fuel (less than 10% fissile contents)	II

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1. Decommission of Experimental Reactor “YAYOI”
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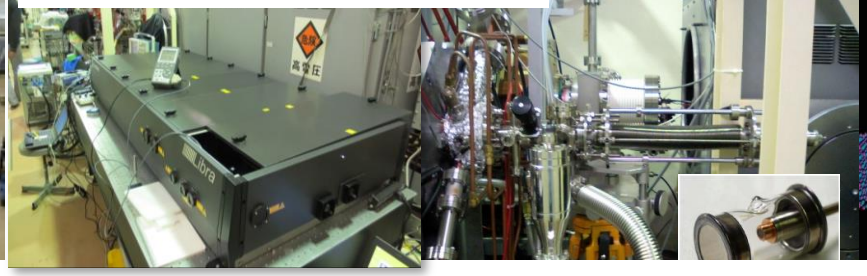
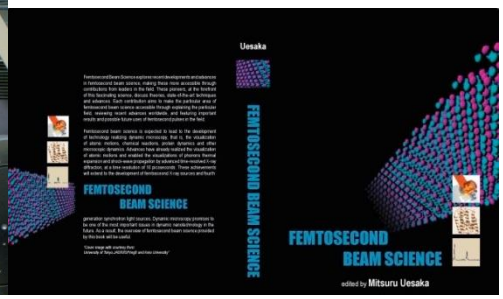
Staged Development of Compact Accelerator at University of Tokyo

S-band (2.856 GHz) Linear Accelerators

Er Fiber Laser for Photoinjector



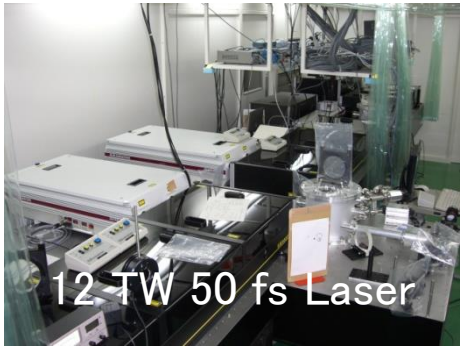
Femtosecond Beam Science, Imperial College Press



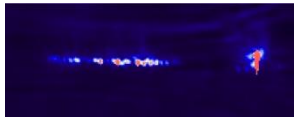
Picosecond Time-resolved Linac-Laser Synchronization System for Radiation Chemistry

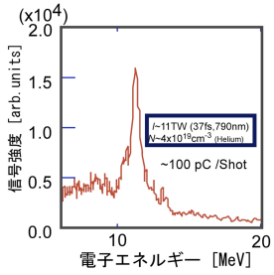
Compact/Portable X-band(9.3,11.424GHz) Linac X-ray Sources for Medicine and NDT

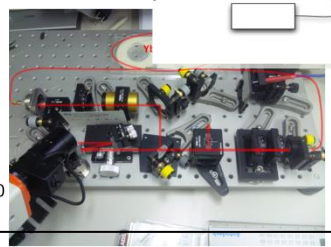
Laser Acceleration

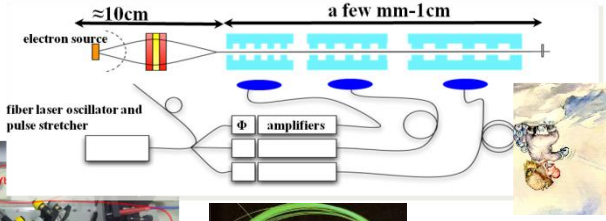


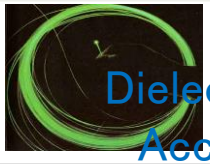
Laser Plasma Acceleration





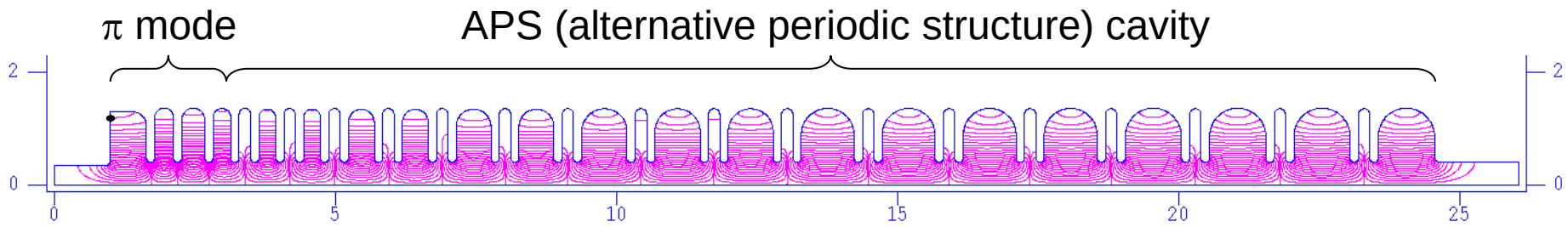




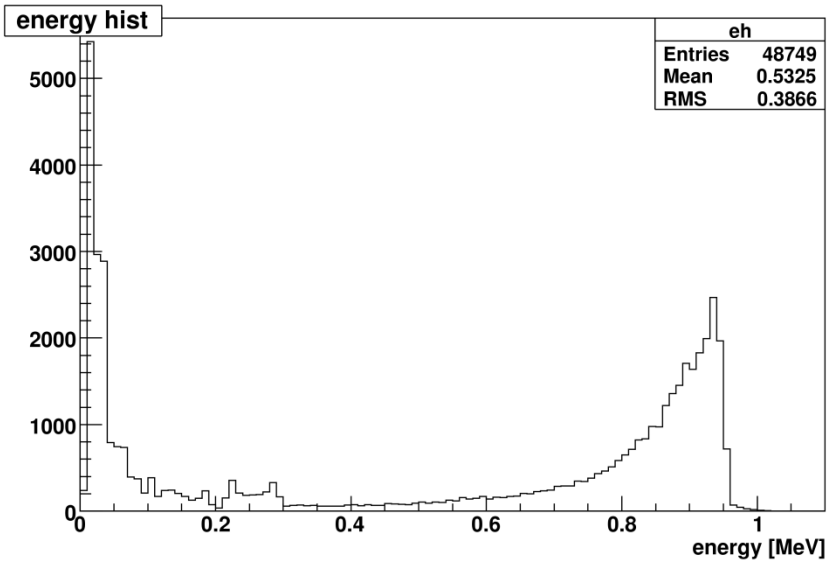


Dielectric Laser Acceleration

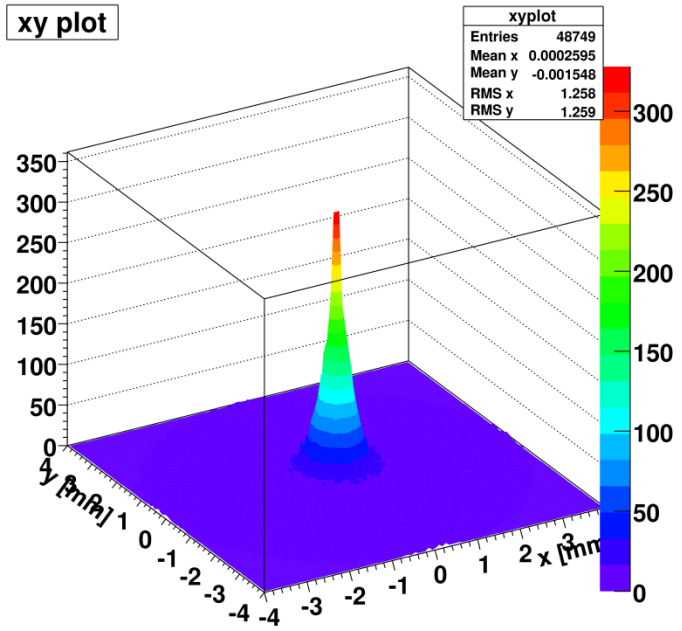
Cavity design of accelerating tube



Cut view of the Acc.tube with electric field (SUPERFISH calculation data)

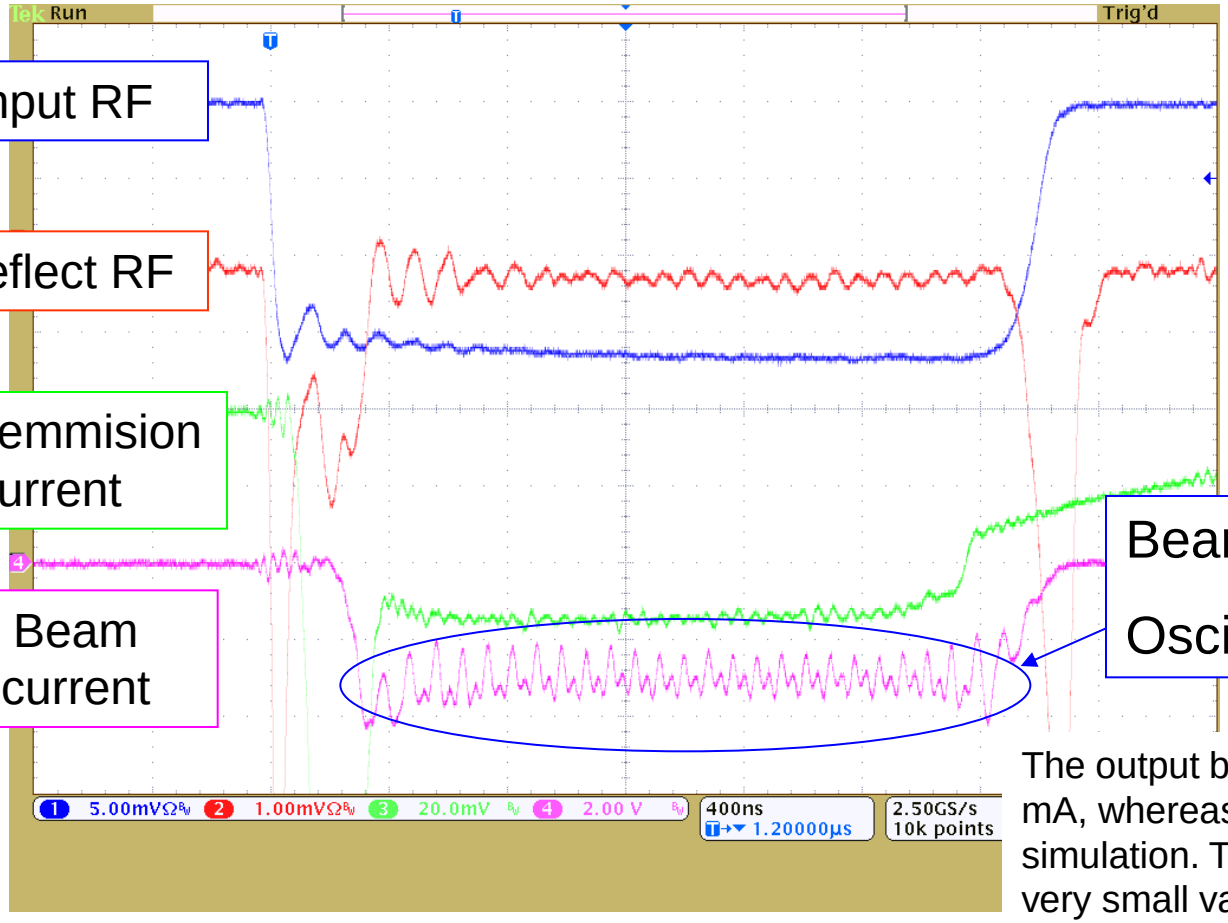


Energy spectrum of accelerated beam (GPT simulation data)



Beam size (GPT simulation data)

Beam current measurement



Input RF

Reflect RF

Gun emmision current

Beam current

Beam current : 60 mA

Oscillation : 100 MHz

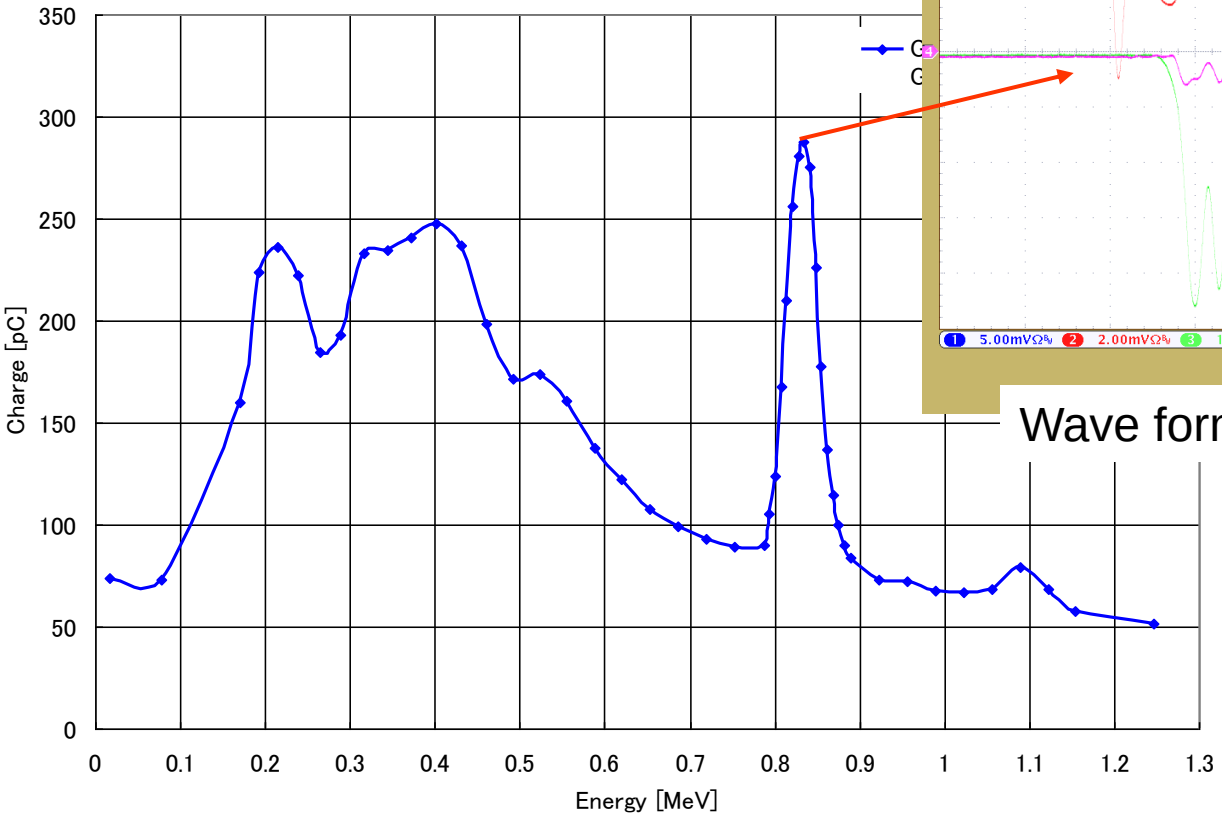
The output beam current was about 60 mA, whereas it was 200 mA in the simulation. The measured value was very small value. In addition, we detected an oscillation of beam current in a pulse

The wave form of beam current

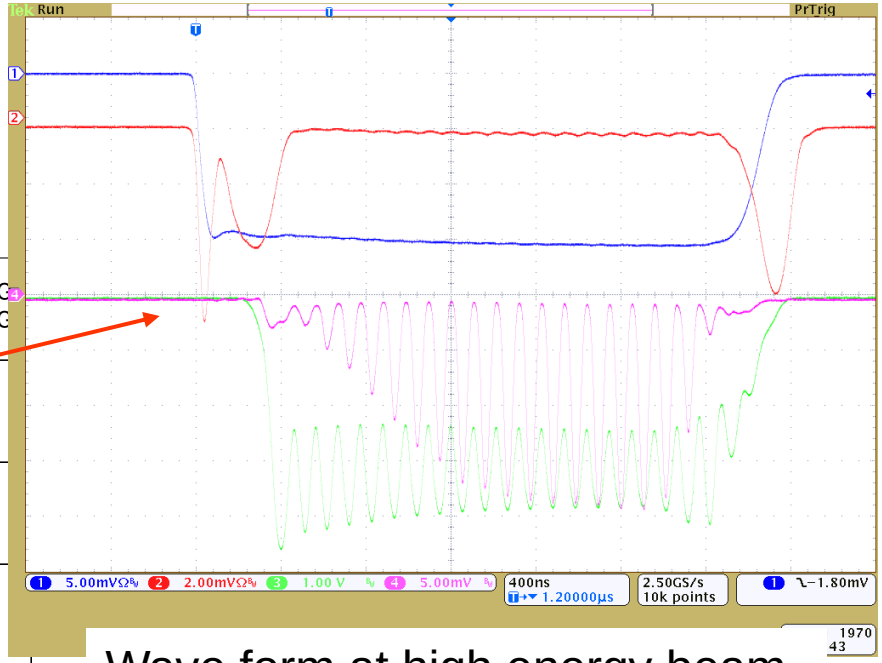
(Gun HV : 20 kW , RF power : 218 kW)

Result of energy spectrum measurement

We confirmed 950 keV accelerated beam.



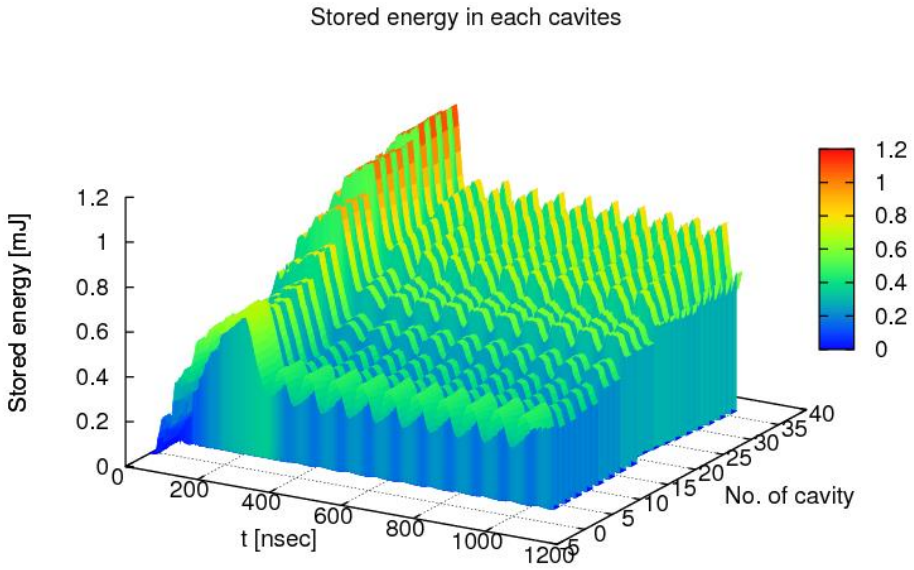
Beam energy spectrum



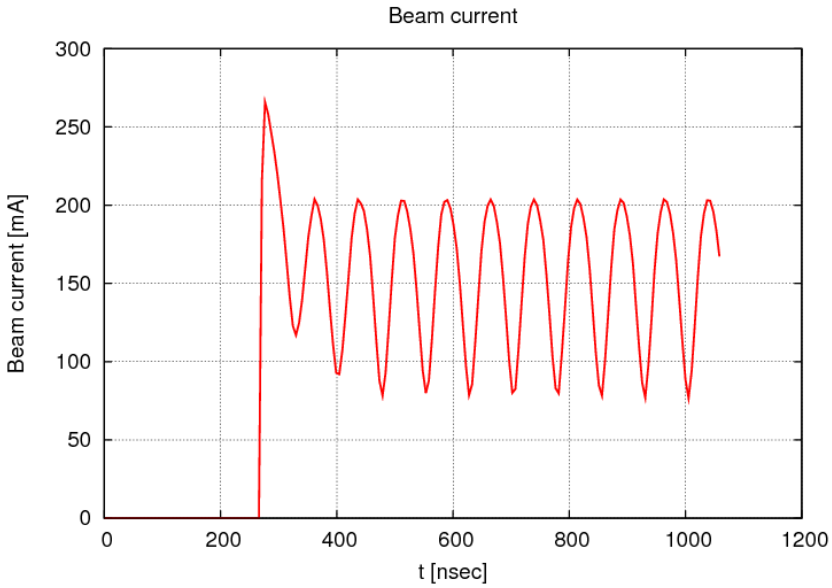
Wave form at high energy beam

Equivalent circuit analysis & Calculation result

3. Transient analysis



Time variation of stored energy in each cavity



Time variation of output beam current

Beam oscillation is found in the equivalent circuit analysis

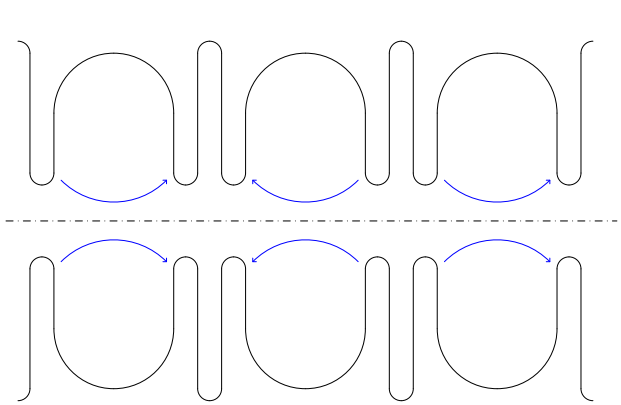
Feature of side couple cavity

Advantage(compare with APS-cavity)

- High shunt impedance
- Can change easily the electric field distribution

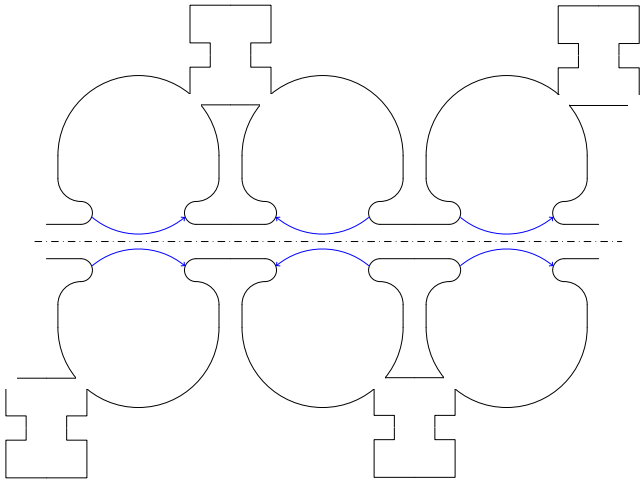
Drawback (compare with APS-cavity)

- 3D structure



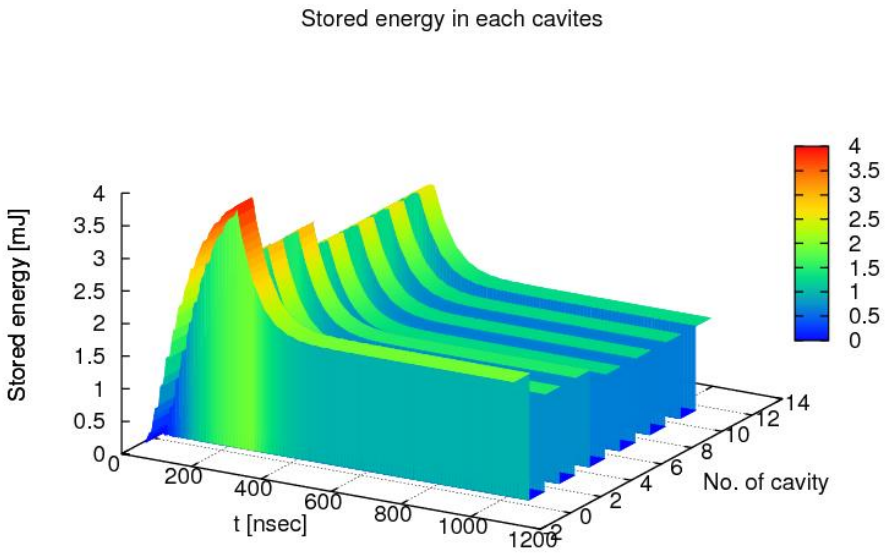
On-axis APS structure

New design

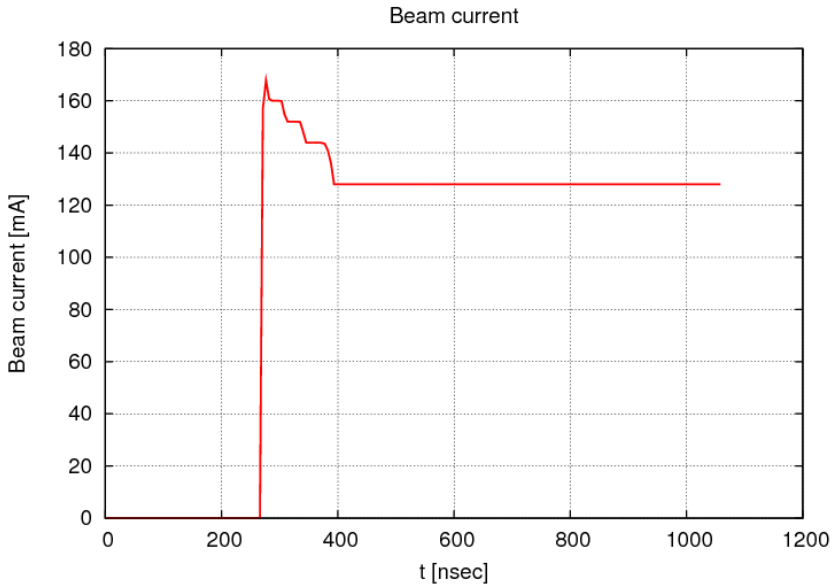


Side couple structure

Equivalent circuit analysis
(side couple cavity)



Time variation of stored energy in each cavity



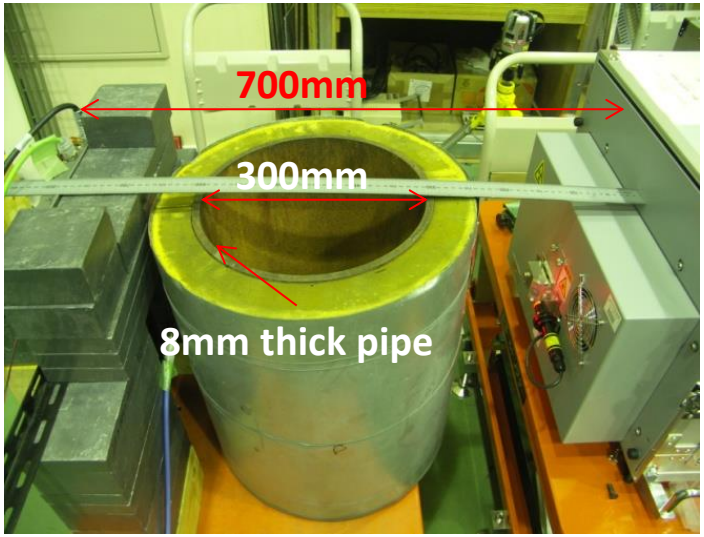
Time variation of output beam current

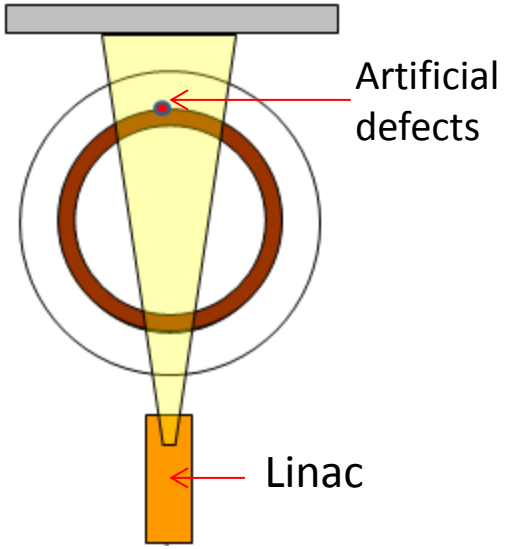
In the cavity, the stored energy is in a steady state.

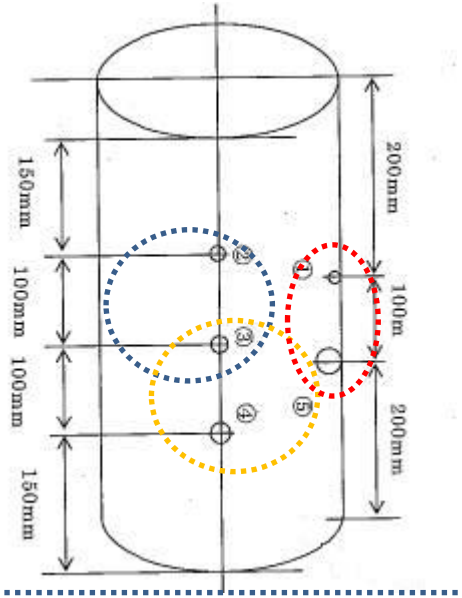
Beam current does not oscillate.

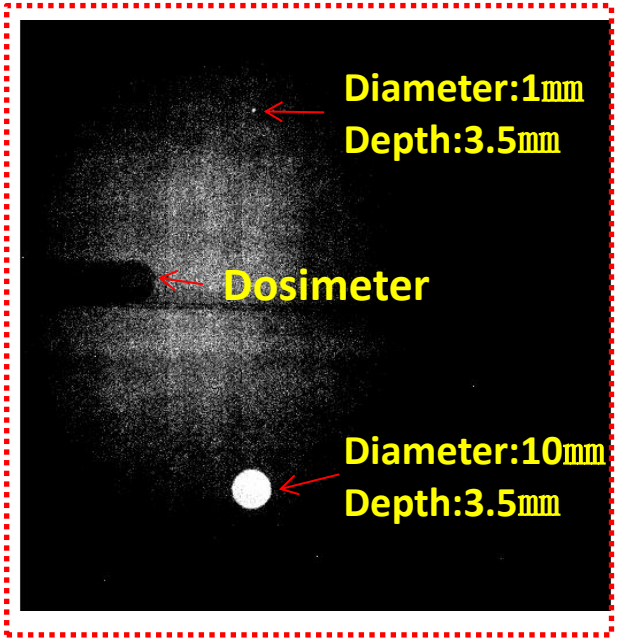
Test by X-band 950keV Linac

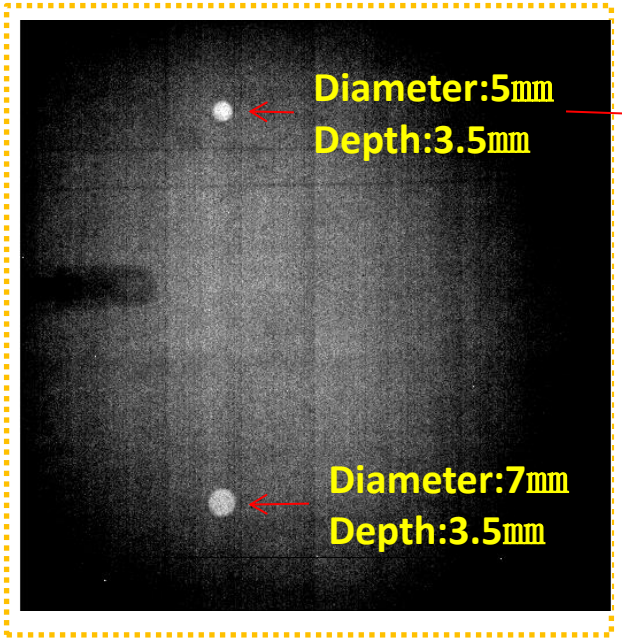
— Measurement time: 1s —

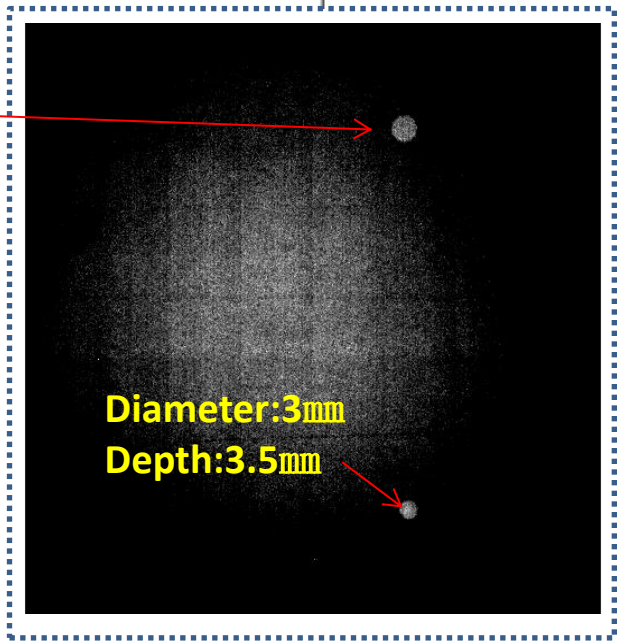






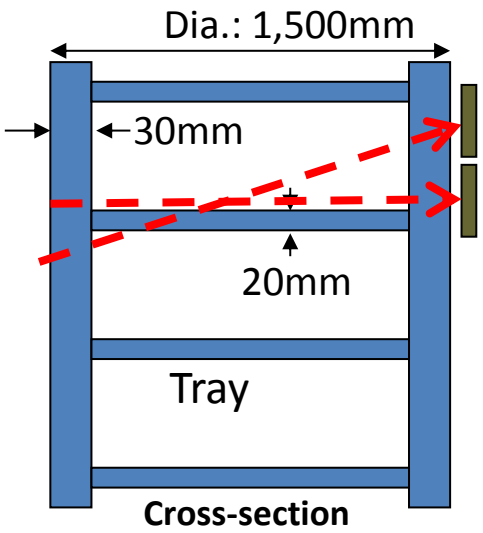






First On-site Transmission Test

Nitric Acid Distillation Tower

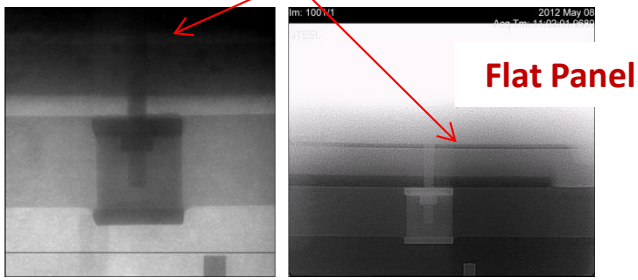


Imaging Plate

Flat Panel

Inner structure can't be seen by 350kV X-ray tube.

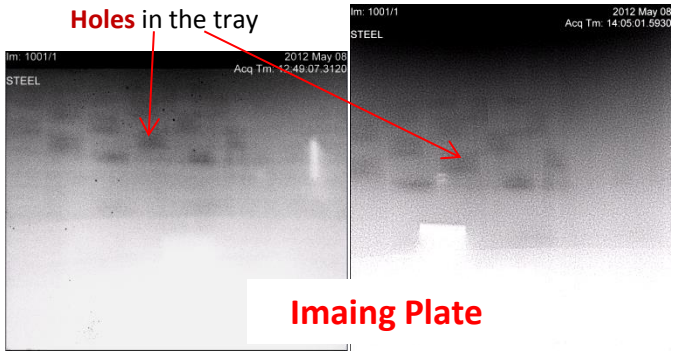
Gap between tray and support



20s test time by flat panel detector

90s test time by imaging plate

Holes in the tray



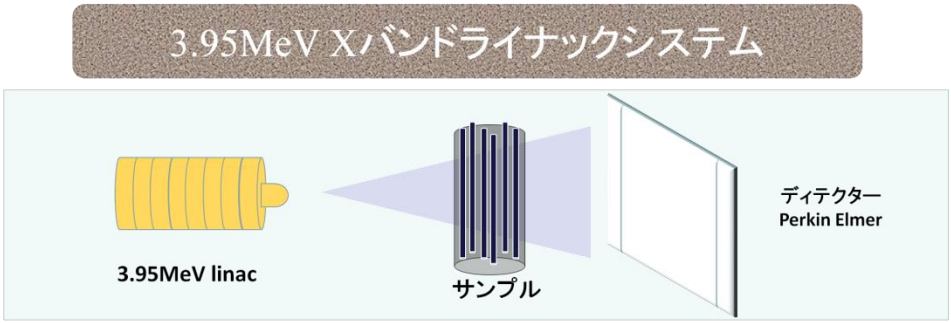
10min by imaging plate

30min by imaging plate

→ **First Successful On-site Obervation of the inner holes by 0.95MeV X-band linac X-ray source.**

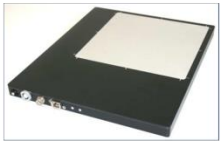
Transmission inspection in situ for bridges by portable 3.95MeV X-band linac X-ray source

"1h measurement time by conventional 300keV X-ray source became 1s" at University of Tokyo



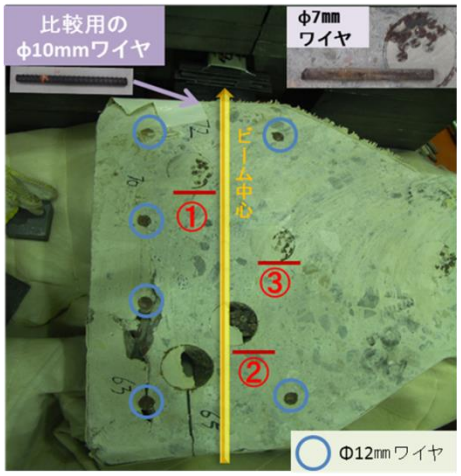
装置仕様	
RF加速空洞共振周波数	9.3 [GHz] ±25 [MHz]
加速管全長	50 [cm] 以下
X線発生強度	2,000 [mGy/min]以上　at 1 [m]
RF発生源	9.3[GHz]マグネトロン パルス幅4[μs] 繰返数200[PPS]
電子銃出力電流	パルスピーク電流　300 [mA]以上
ターゲット遮蔽体	タングステン合金材
パルス出力	出力　3,000 [kW] 以上
出力方式	コンデンサ充電スイッチング方式
X線ヘッドユニット重量	62kg
コリメータ重量	80kg
高周波源ユニット重量	62kg
HVPS,制御ユニット重量	116kg
加速器パラメータ	
ビーム電流	95 mA 以上
入力RF電力	920 kW
加速管方式	Side coupled Structure
電子ビーム収束方式	RF集束方式
加速セル数	Half 1+full 20
セル間カップリング	3%
フィリングタイム	0.23 μsec
シャントインピーダンス	110-130 MΩ/m (レギュラー部)
電子銃電圧	20 kV
電子銃方式	三極管

	Perkin Elmer
	Scintillator + photodiode
Total pixel	1024 × 1024
Pitch	200μm 400μm with 2x2 Binning
Total area	204.8 x 204.8 mm²
Scintillator	Gd_2O_2S:Tb
Capable radiation energy	20 keV – 15MeV

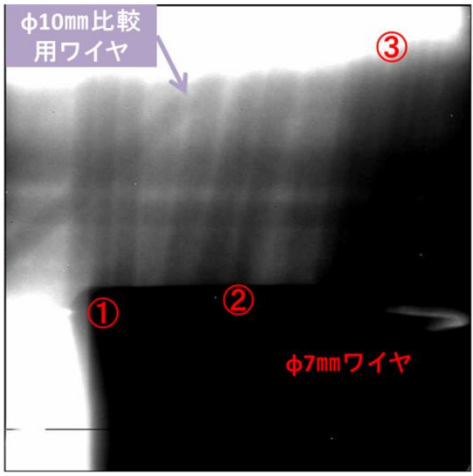


Perkin Elmer XRD-0820

40cm橋桁サンプル

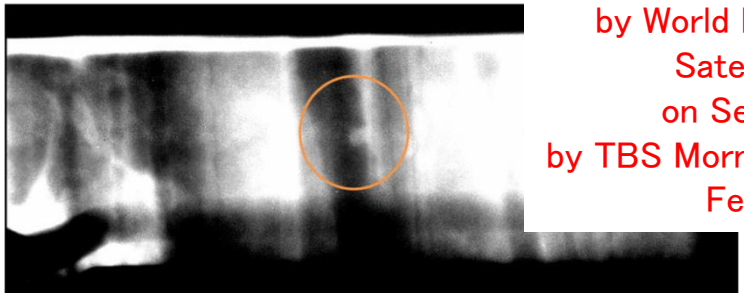


X線画像（積算時間5s）



Measurement time: 5s at 50Hz (about 1s at 200Hz)

φ12mmワイヤ中3mmのダメージ



ON AIR
by NHK on April 19
by World Business Satellite
on Sep.18
by TBS Morning News in
Feb.

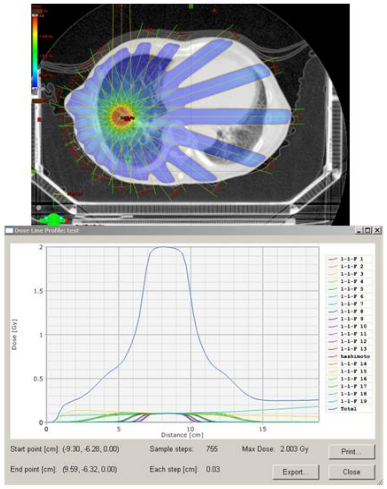
Repetition rate: 50Hz200Hz
Current: 90mA(100mA)

measurement time: 5s

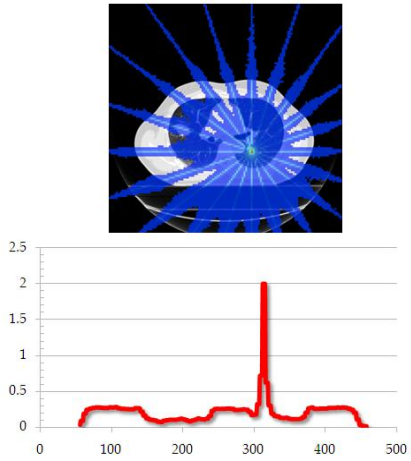
X-ray Micro-beam Pinpoint 4-dimensional Therapy System

Robot system
Real Time Dynamic Tracking

Compact X-band(9.3GHz) linac
（50cm, 6MeV)

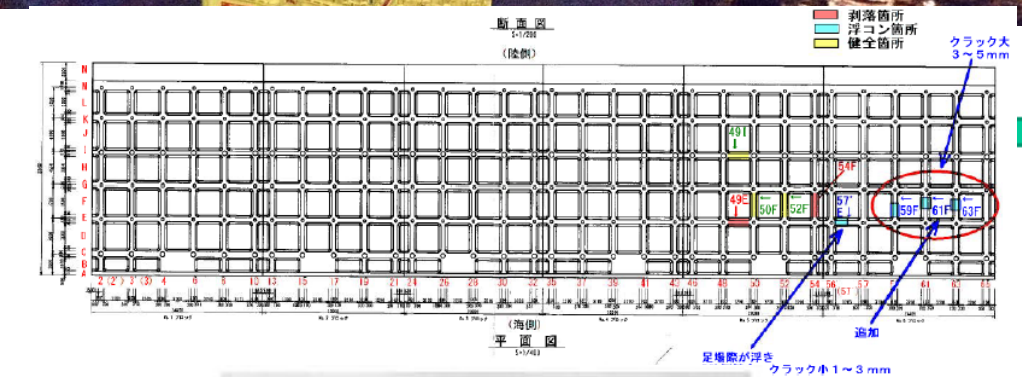


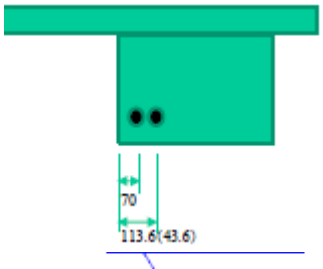
Conventional

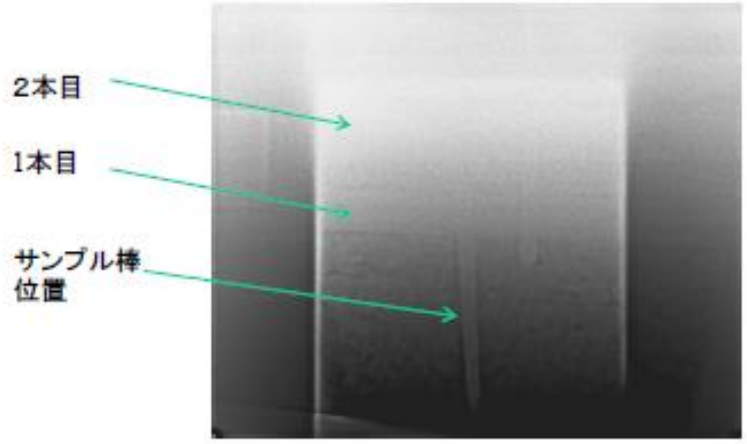


X-ray Micro-beam (1mm)

On-site Inspection of Reinforced Concrete Pier of Chemical Plants on Jan.8,9,10, 2014







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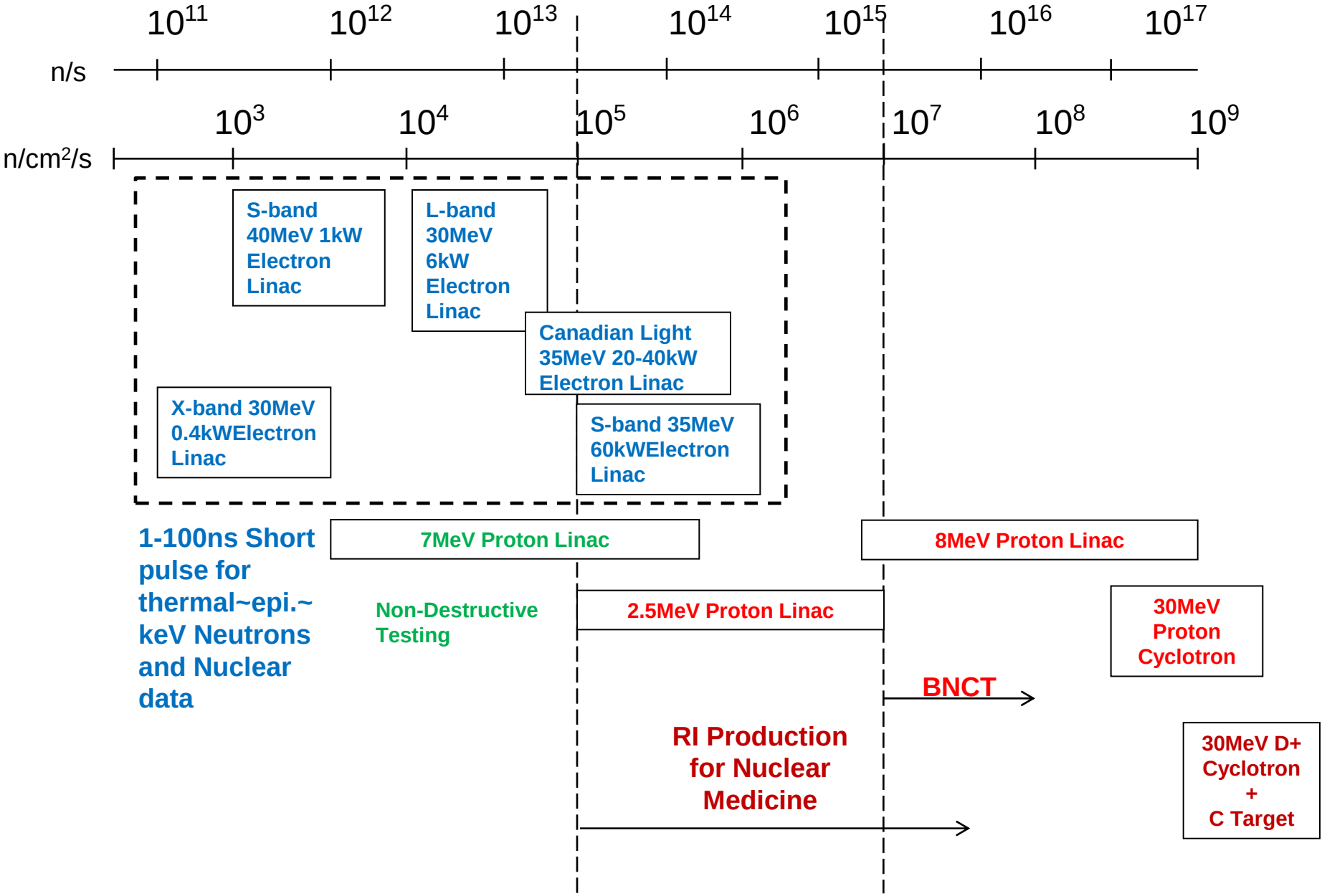
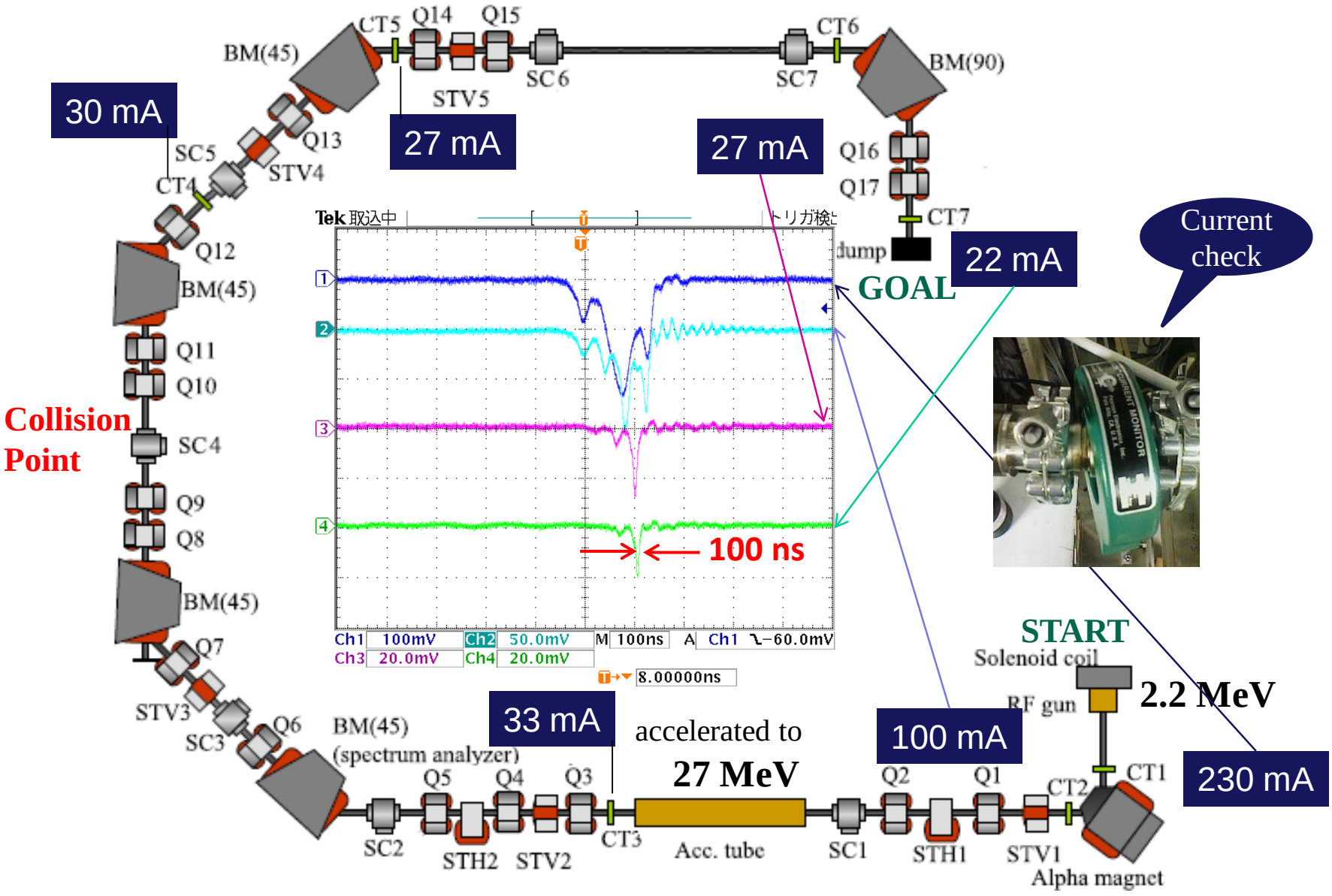
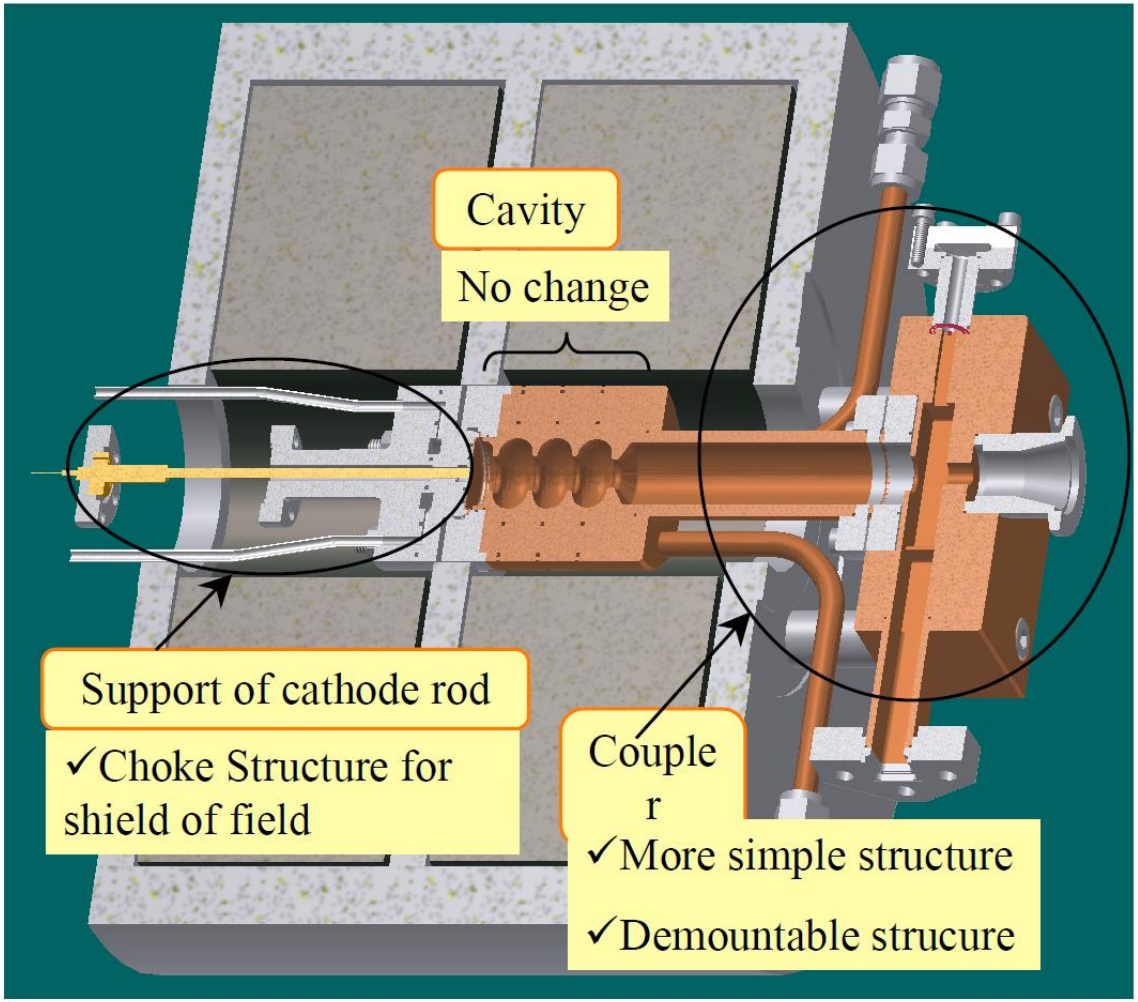
Intensity and Application of Compact Accelerator Neutron Sources



Acceleration up to 27 MeV with 22 mA in 2009



Thermionic RF Gun for Multi-bunch Low Emittance Electron Beams



Replacement to electron gun (20keV) and buncher (2/3 π mode) for reliable high beam power

Property of buncher

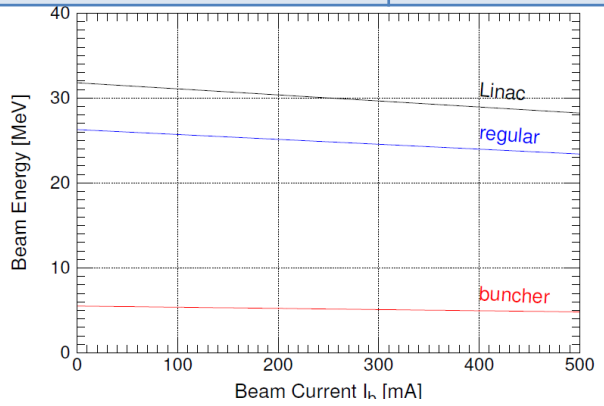
Cell Number	30
Tube Length	0.26 m
Q_0	6000
Shunt impedance	85 MΩ/m
Group velocity	%
Decay constant	0.5 Naper/m

Property of RF source

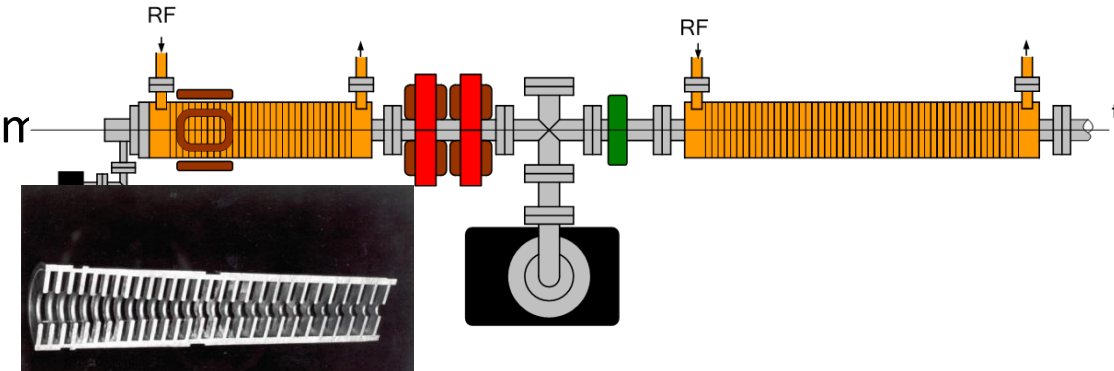
Pulse width	30
Power in buncher	6 MW
Power in accelerator tube	35 MW

Property of accelerator tube

Cell Number	60
Tube Length	0.524 m
Q_0	6593
Shunt impedance	95.6 MΩ/m
Group velocity	3.97 %
Decay constant	0.478 Naper/m

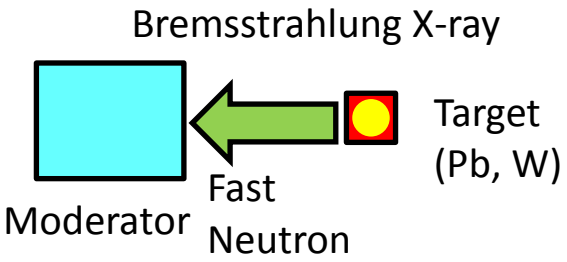


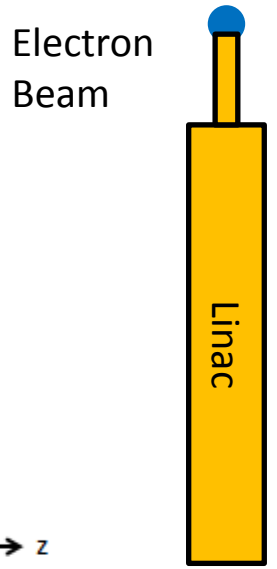
- Combination of 20 keV thermal electron gun and 5 MeV accelerator
- Peak Beam current: 250mA (Beam energy: 30MeV・Pulse width: 1μsec)
- Beam Power: 0.375kW (50pps)

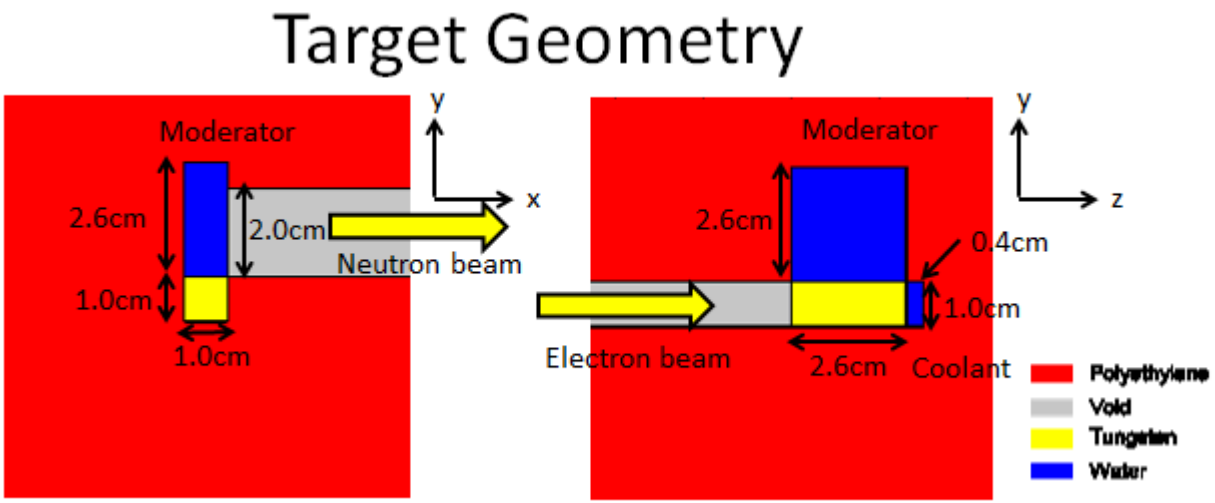


Design of target and moderator for neutrons

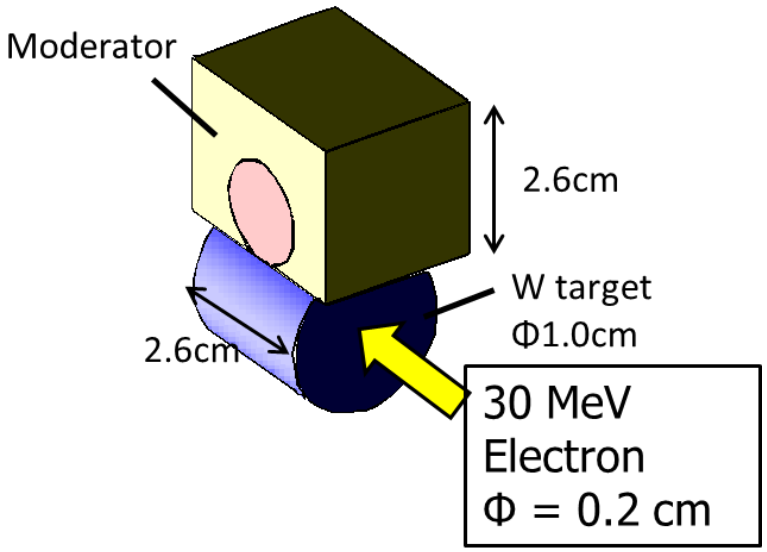
- Neutron generation
  - Photoneutron effect
  - Tungsten as target material
- Compact Moderator
  - To make pulse width short for measuring high energy and to make flight path short for brief measurement
- Shielding
  - Neutron … PE with 5% Boron
  - Photon…Lead



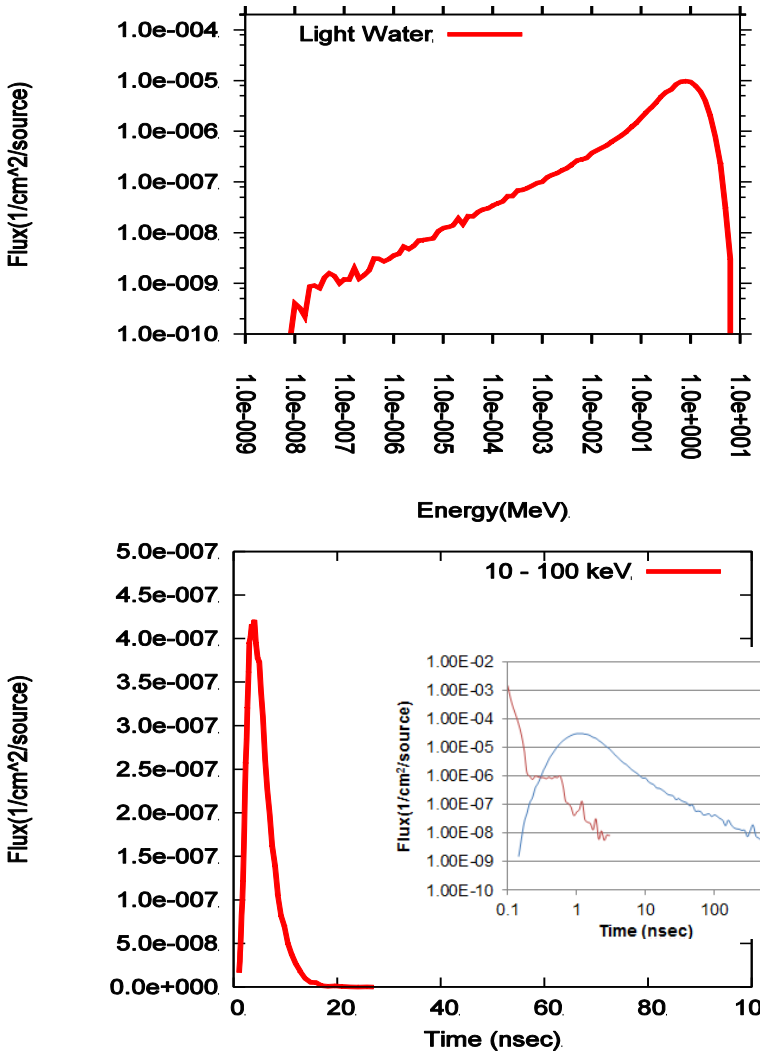




Spectrum and pulse shape of neutrons



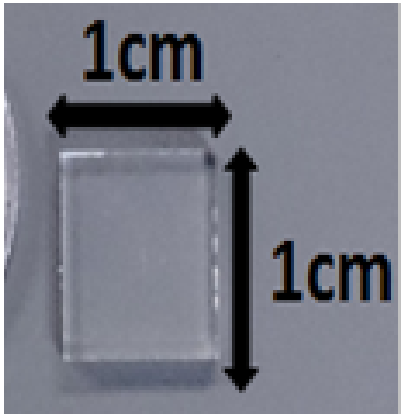
Beam Power	375 W
Target intensity	1.3×10^{11} n/s
Pulse width behind moderator (10 – 100 keV neutron)	6.66 ns
Neutron flux at measurement point (5m TOF)	1.1×10^{3} n/cm^2/s



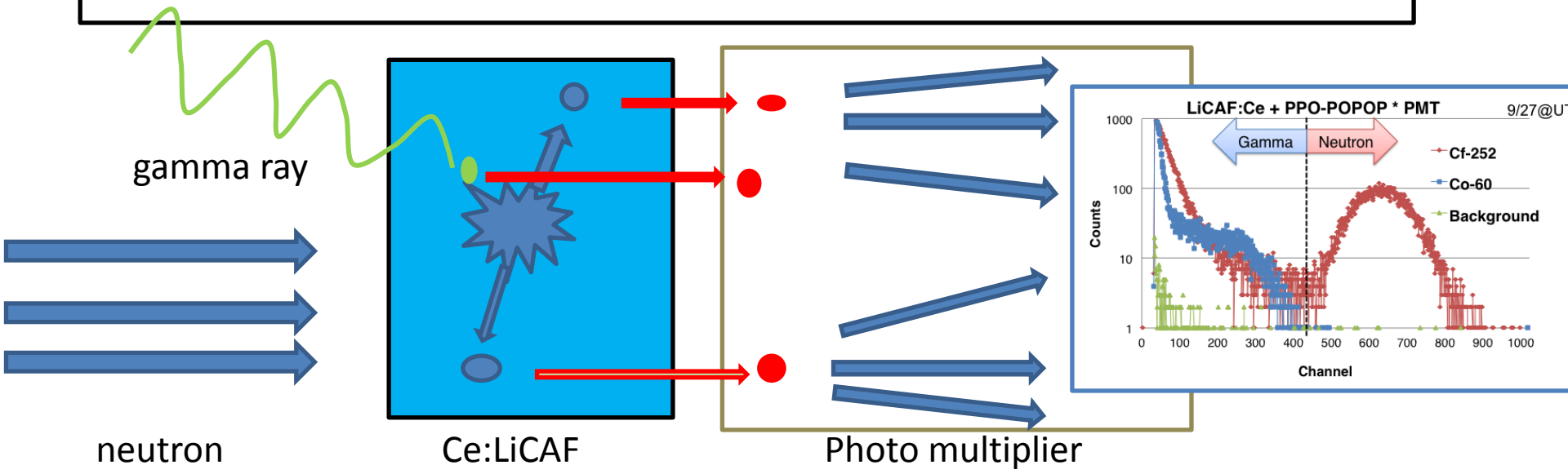
Ce:LiCAF

$Ce^{3+}:LiCaAlF_6$

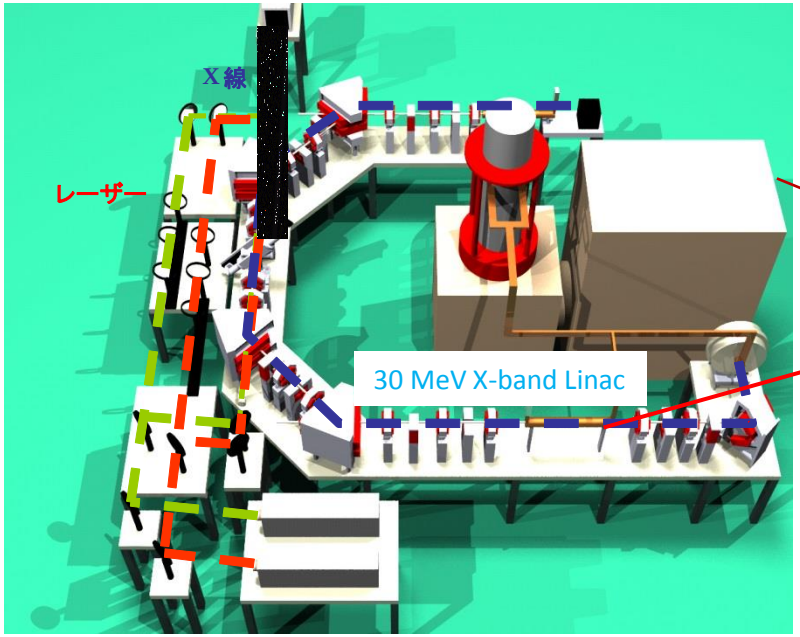
Characteristics



- solid → high density
- detecting neutron (6Li + n → α + T)
- short deexcitation time



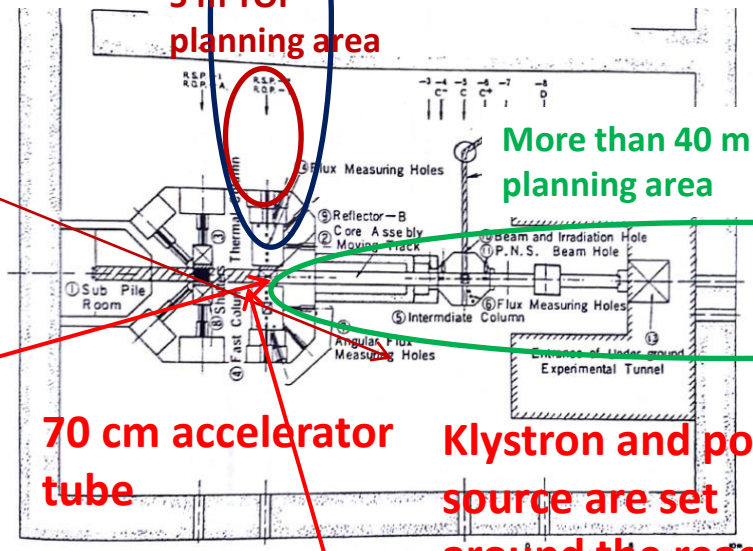
Existing X-band 30 MeV electron linac will be moved for neutron source



More than 10 m TOF planning area

5 m TOF planning area

More than 40 m TOF planning area

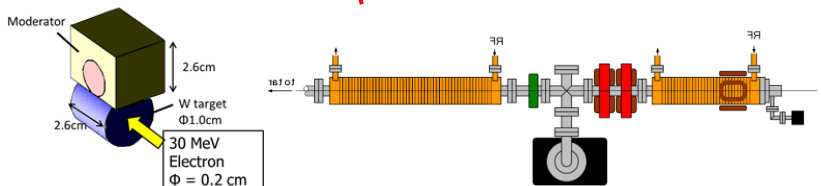


70 cm accelerator tube

Klystron and power source are set around the reactor

20 keV electorn gun + 5 MeV buncher+30 MeV structure

+ Neutron target



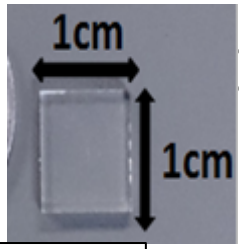
Peak Beam current: 250mA

(Beam energy: 30MeV・Pulse width: 1μsec)

Beam Power: 0.375kW (50pps)

(S-band 30MeV⇒1kW(Hokkaido Univ.))

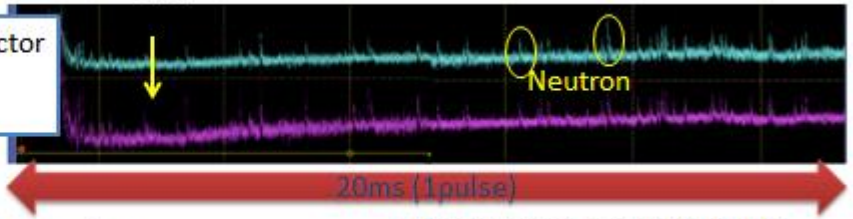
Experimental configuration in Phase I



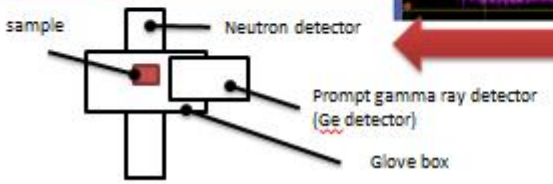
Ce:LiCAF

10-0.1eV
0.1eV

High speed scintillation detector
Time resolution 100ns
Ce:LiCAF

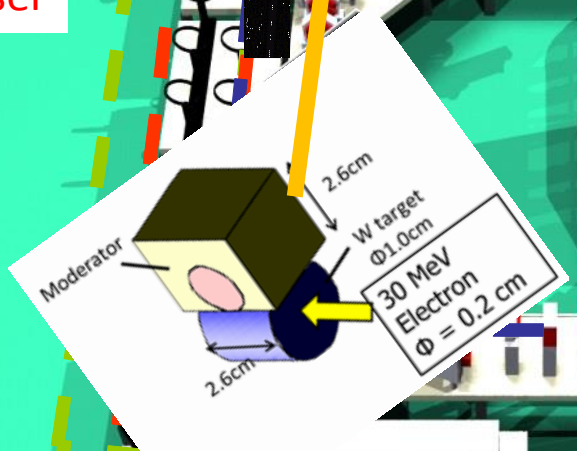


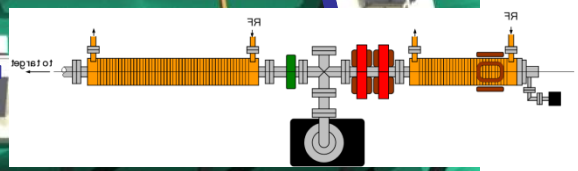
Measurement sample(J-PARC)

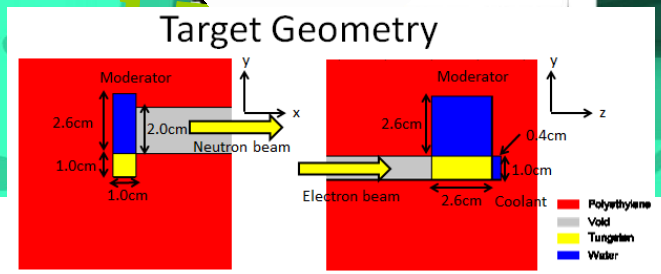


X-ray

Laser





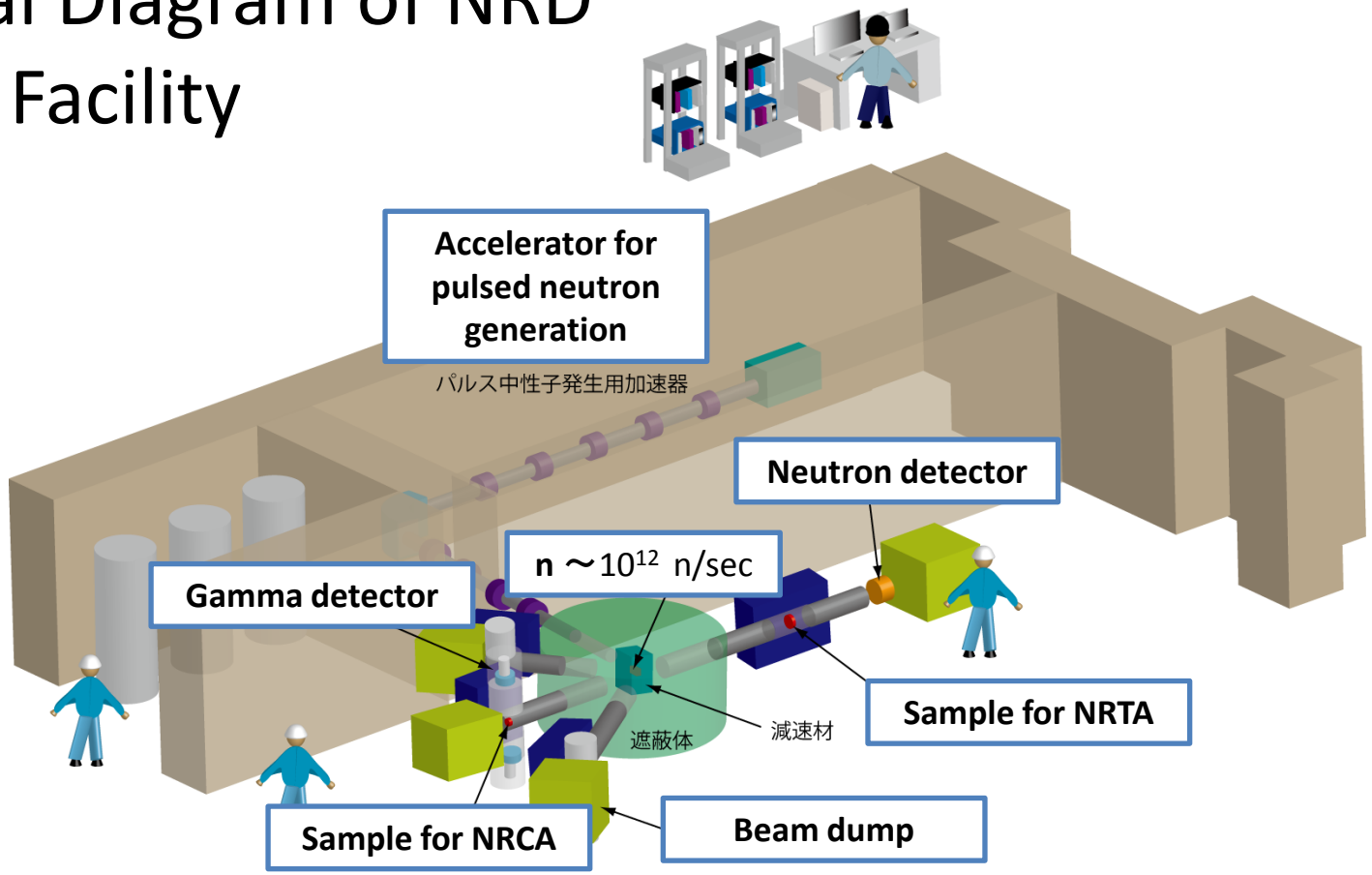


CONTENTS

1. Decommission of Experimental Reactor “YAYOI”
2. R&D of X-band electron linacs
3. New Accelerator based Neutron Sources
4. High Precision Nuclear Data Analysis for Fuel Debris Evaluation

Conceptual Diagram of NRD Facility

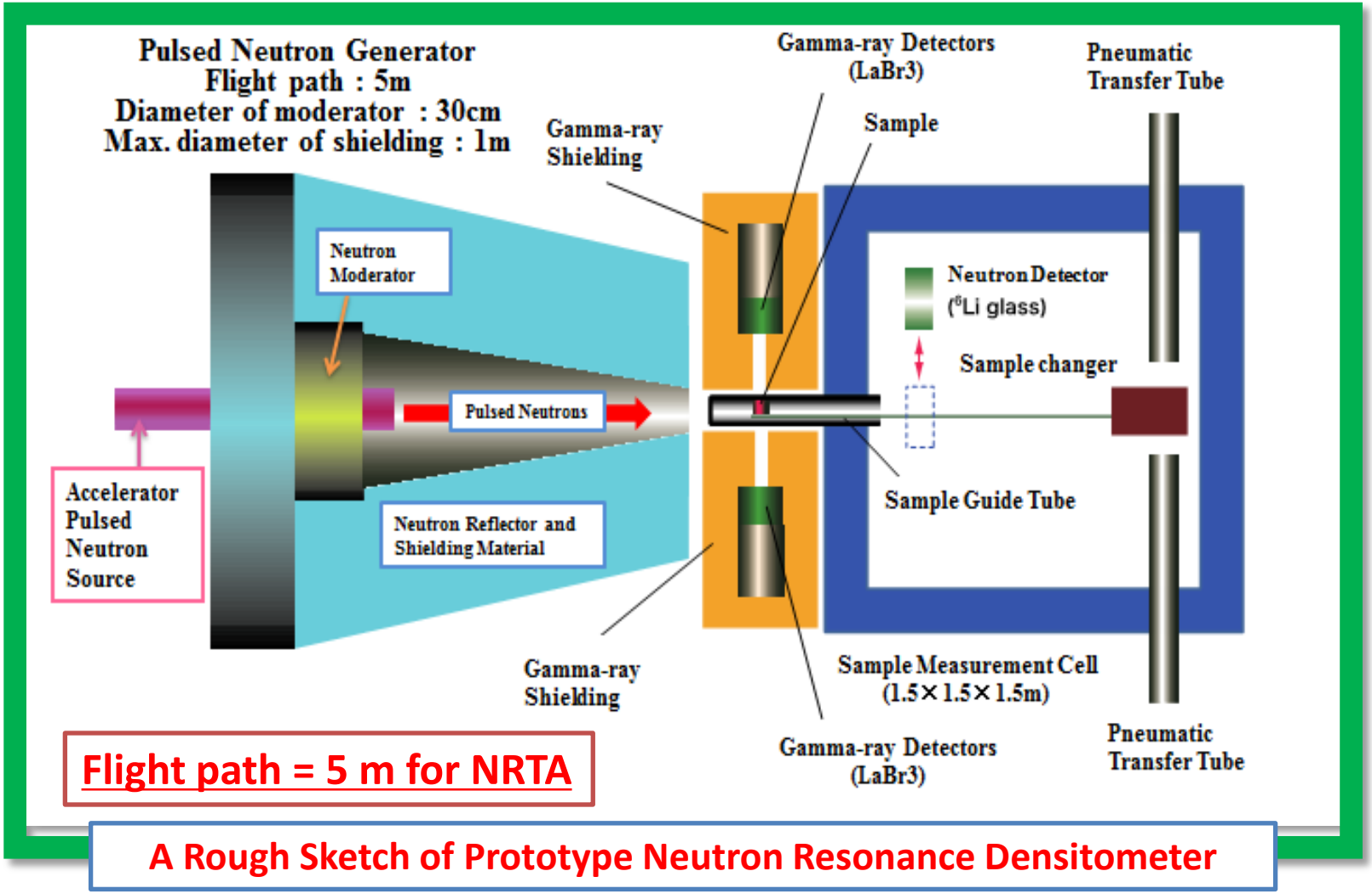
Hideo Harada (JAEA)



- By NRTA, 3-7 kg of small sized MF will be measured within 20 min. (The 3-7 kg: a MF area of 300-700 cm^2 and a thickness of 10 g/cm^2).
- By NRCA, 30 g of MF including 10^9 Bq (mainly ^{137}Cs) will be measured within 1 hour for each beam line.

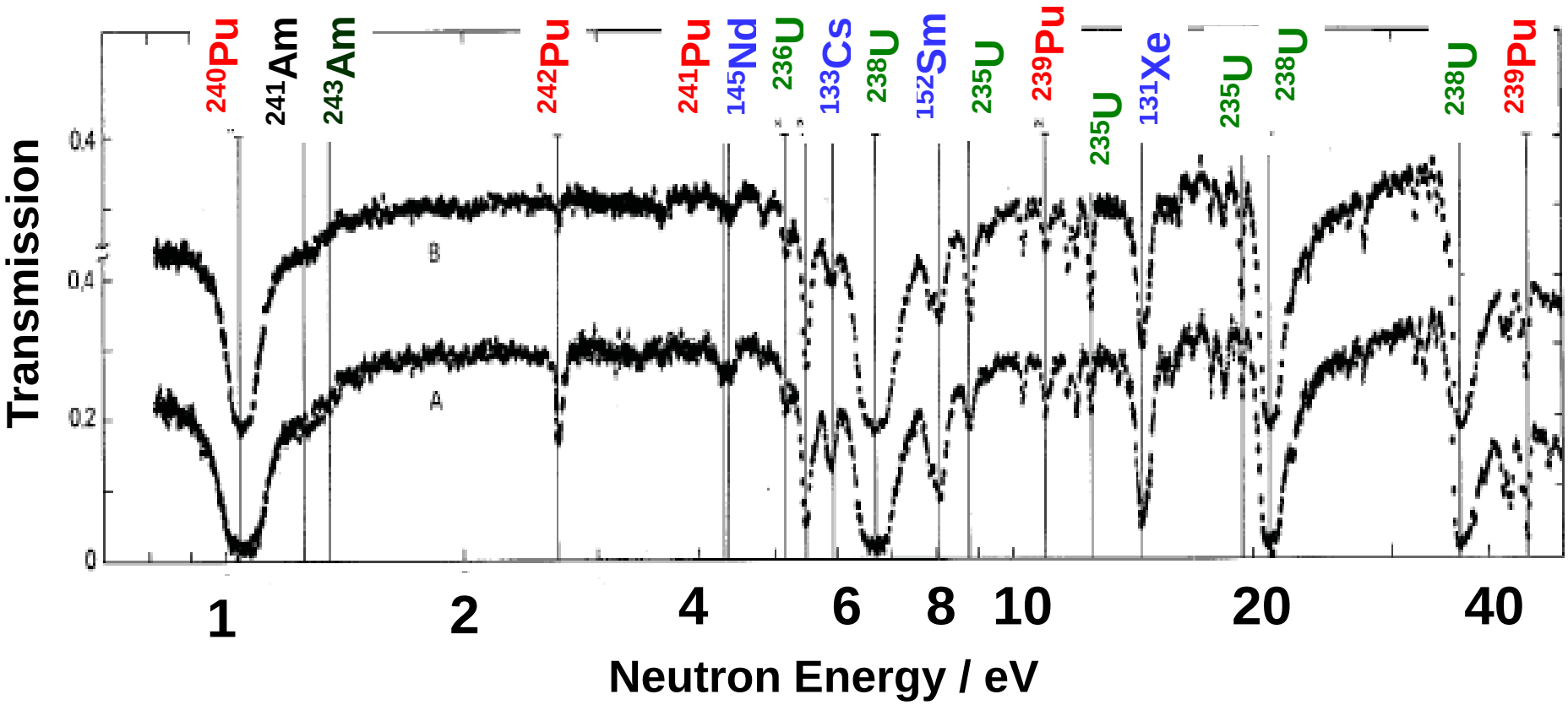
TOF Measurement by Small Pulse Neutron Source

Hideo Harada (JAEA)



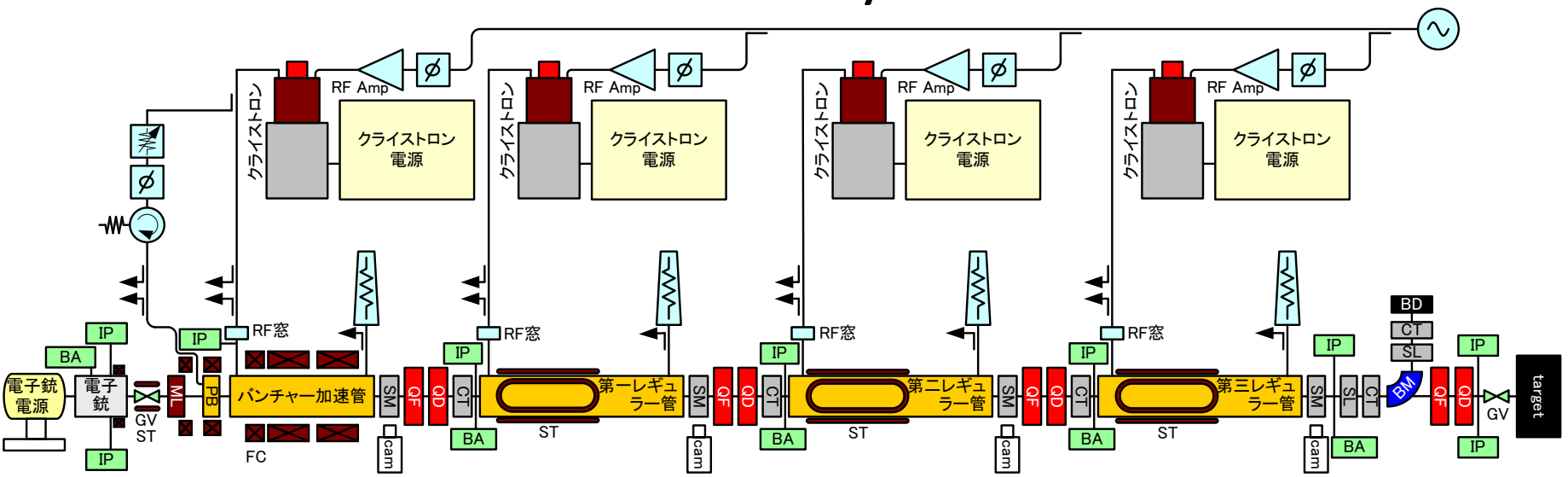
A Rough Sketch of Prototype Neutron Resonance Densitometer

Typical NRTA Data of Nuclear Materials



Behrens et al., Nucl. Techn. 67 (1984) 162

Plan of S-band 50 kW Linac System in the 2nd Term



Beam energy	35 MeV
Beam current	0-324 mA (continuously variable)
Pulse width	0.1-20 µsec (variable)
Repetition	0-250 (continuously variable)
Beam power	40 kW (Generally) 56 kW (Max)
Frequency	2856 MHz (S-band)
Tube Length	1.9 m (traveling-wave type)

Klystron

Type	Toshiba E3783
Peak Power	4.5 MW
Pulse width	20 µsec
Repetition	250 pps

Beam Power [kW]	Rep. Rate [pps]	RF Power [kW]	Aux. [kW]	Cooling [kW]	Total [kW]
1	4	4	20	24	48
10	44	40	20	60	120
40	178	160	20	180	360
56	250	225	20	245	490

Summary

- Decommissioning project of research reactor “Yayoi” of Univ. Tokyo is under way.
- We are developing X-band 30 MeV electron linac neutron source and TOF measurement system and to start the experiment this summer. They are going to be installed in the “Yayoi” room.
- Electron injector of X-band 30 MeV linac is revised for large current and higher stability.
- Application of the system is to measure the nuclear data at first. We plan to get more accurate nuclear data for analysis of the fuel debris at Fukushima (F-1), nuclear transformation at ADS and design of new reactors in future.
- Both S-band and X-band linacs are expected to be short-pulsed (1ns-1μs) neutron source for the nuclear data study.

Thank you for your attention.