TOSHIBA
Leading Innovation

RPTK201680016
HN-2016-3420

Applications of Accelerators from Basic Science to Industrial Use

December 13th, 2016

Kiyokazu Sato

TOSHIBA Corporation
Keihin Product Operations

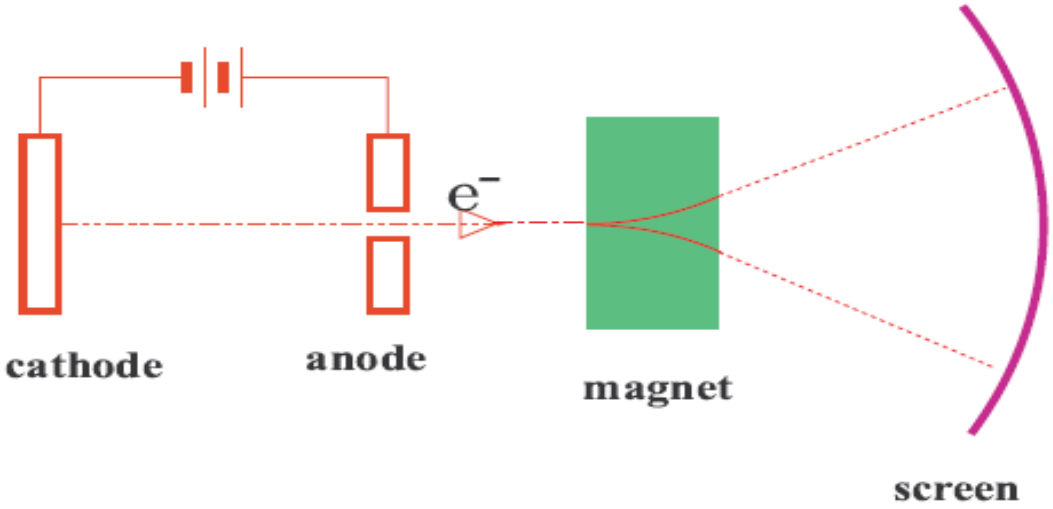
Contents

Contents

The first Accelerator

Cathode Ray Tube

< few tens keV (1eV =e(1.6E-19C) x 1V [J])

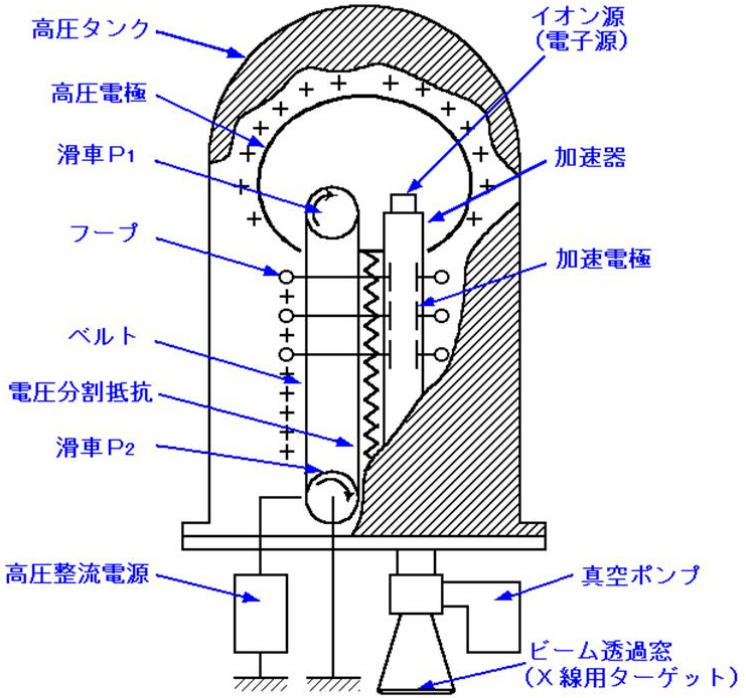


∗ Discovery of X-ray Röntgen in 1895
∗ Discovery of Electron J.J.Thomson in 1897

The first Physics Experiment by using Accelerator

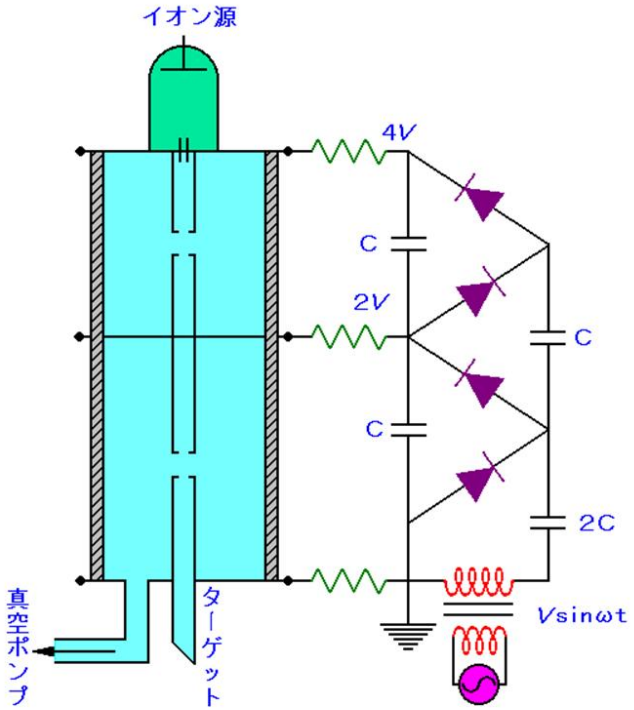
Improvement of Energy

High Voltage DC Accelerators < few tens MeV



Van de Graaff Accelerator in 1931

[出典] 江藤 秀雄ほか：放射線の防護、丸善、 p.234(1982年12月)



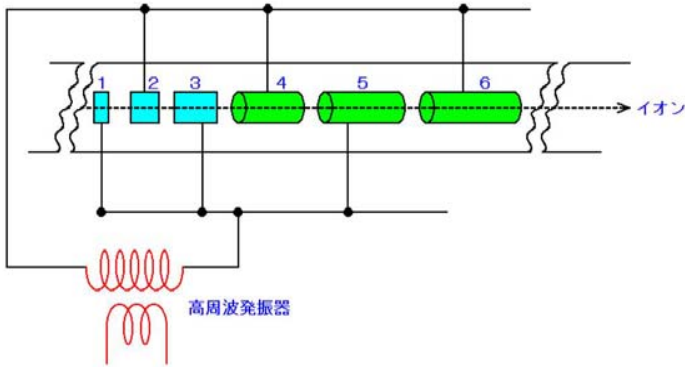
Cockcroft-Walton Accelerator in 1932

[出典] 石川 友清(編)：放射線概論、通商産業研究社(1991年4月)、p.59

* The first artificial nuclear Transmutation $^{1}_{1}P + ^{7}_{3}Li \rightarrow ^{4}_{2}He + ^{4}_{2}He$
  D. Cockcroft and E. T. S. Walton in 1932

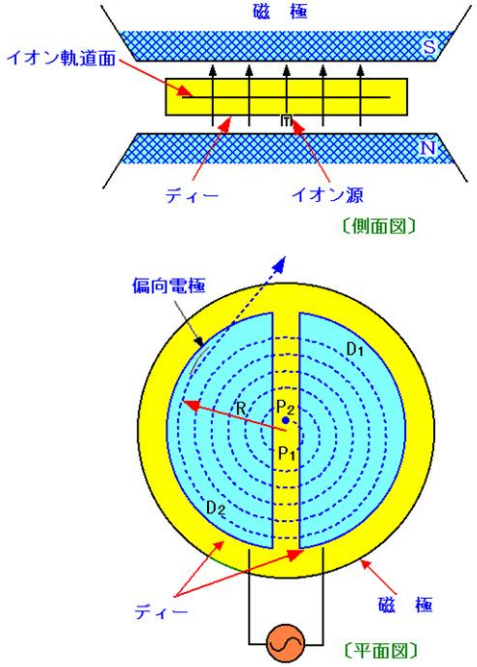
Improvement of Energy

RF Accelerators　～GeV～TeV



Linear Accelerator in 1928

［出典］江藤 秀雄ほか：放射線の防護、丸善、p.229(1982年12月)



Cyclotron in 1931

［出典］石川 友清（編）：放射線概論、通商産業研究社（1991年4月）、p.64

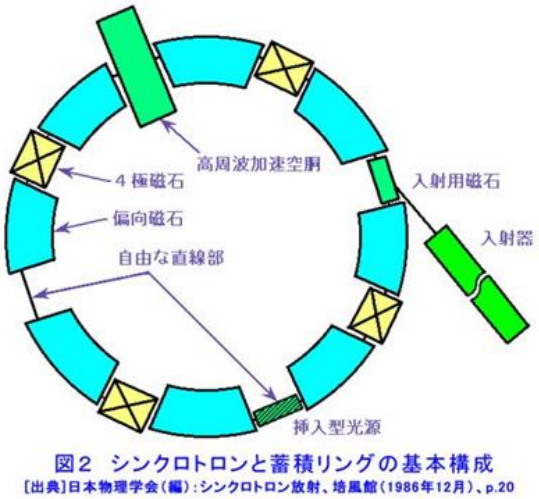
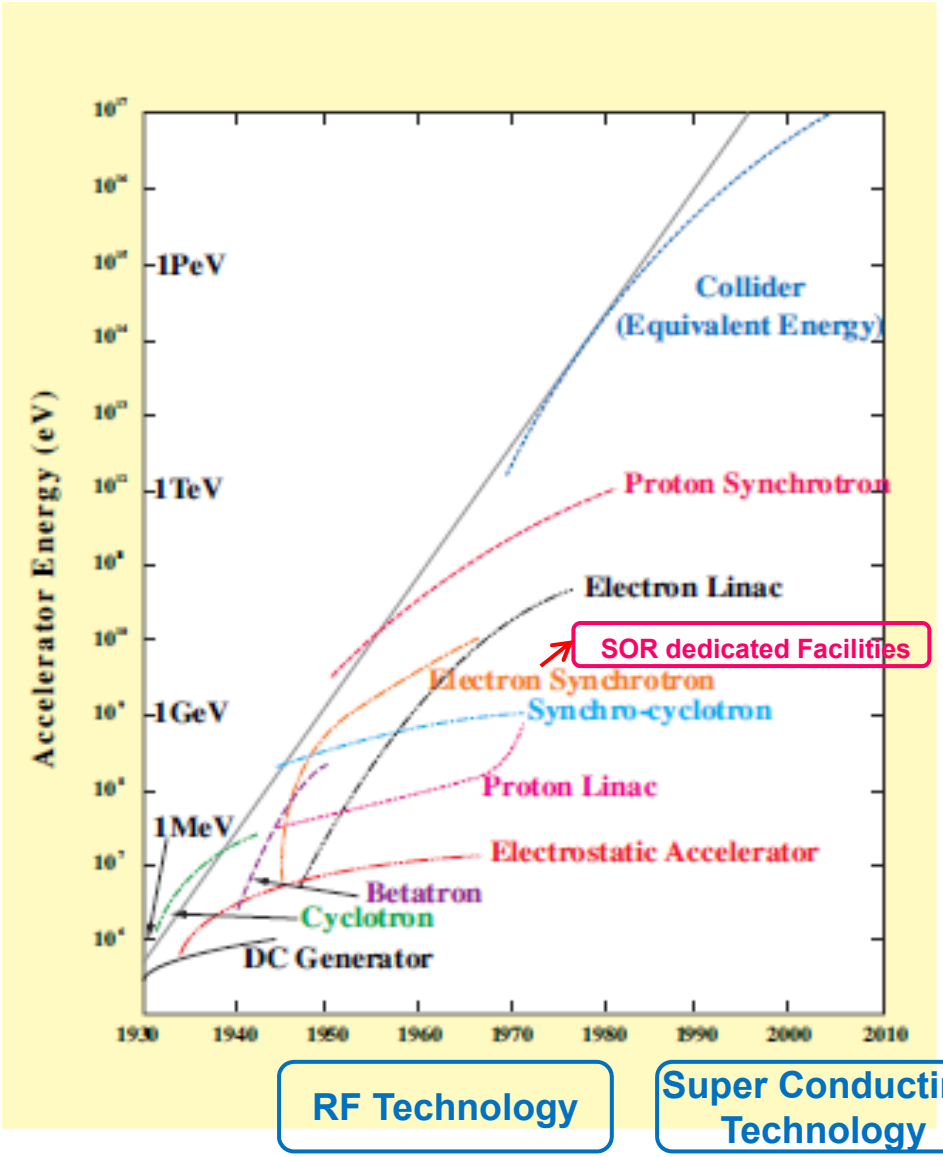


図2 シンクロトロンと蓄積リングの基本構成
［出典］日本物理学会（編）：シンクロトロン放射、培風館（1986年12月）、p.20

Synchrotron in 1945

＊Generation of artificial radio active Isotopes　E.O Lawrence　in 1930s

Livingston Chart



Energy has increased
about 50-times in every 10 years

SOR dedicated Facilities have
been constructed since 1975

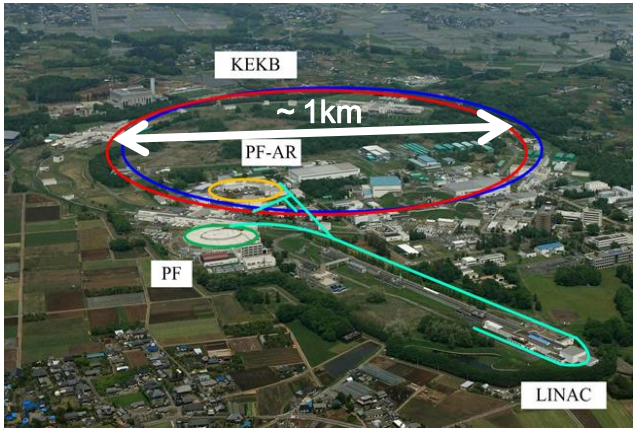
Contributed important Discoveries

- Elementary Particle
- TRans-Uranium
- Giant Resonance
- 3D Structure of
  Photosynthetic Reaction Center

etc.

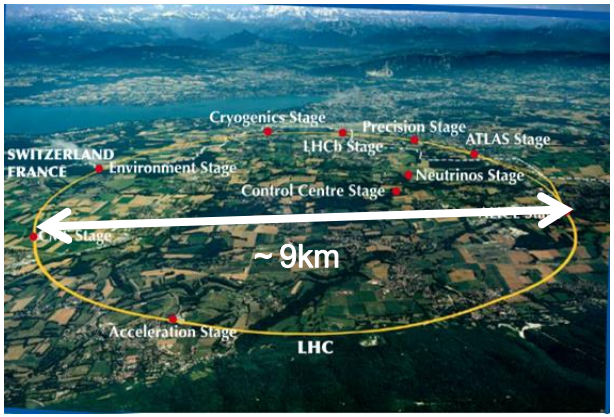
Recent Achievement

∗ Experiment of CP violation at B-factory : e+, e- collider



Source : KEK https://www2.kek.jp/accl/topics/topics100830.html https://www2.kek.jp/accl/introKEKB/gaiyo.html

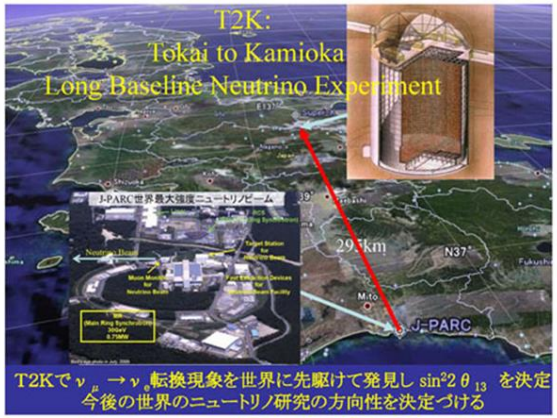
∗ Discovery of Higgs Boson at LHC : p, p collider



Source : CERN http://passeport-big-bang.web.cern.ch/sites/passeport-big-bang.web.cern.ch/files/passeport_bigbang-en-pour_web.pdf
http://home.cern/sites/home.web.cern.ch/files/image/update-for_the_public/2016/07/0508014_02-a4-at-144-dpi.jpg

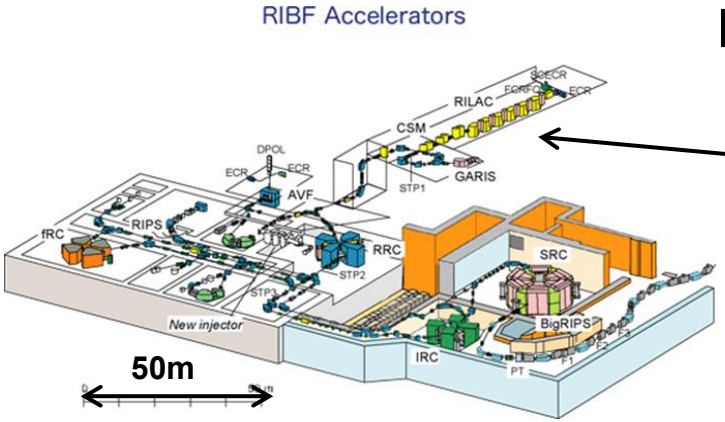
Recent Achievement

* T2K-Experiment (Precise Experiment of Neutrino Oscillation) from J-PARC to Super-Kamiokande



Source : KEK https://www.kek.jp/ja/Research/IPNS/T2K/ https://www2.kek.jp/ja/news/press/2009/J-PARC50GeV2.html

* Discovery of Nihonium (Z=113) at RIBF

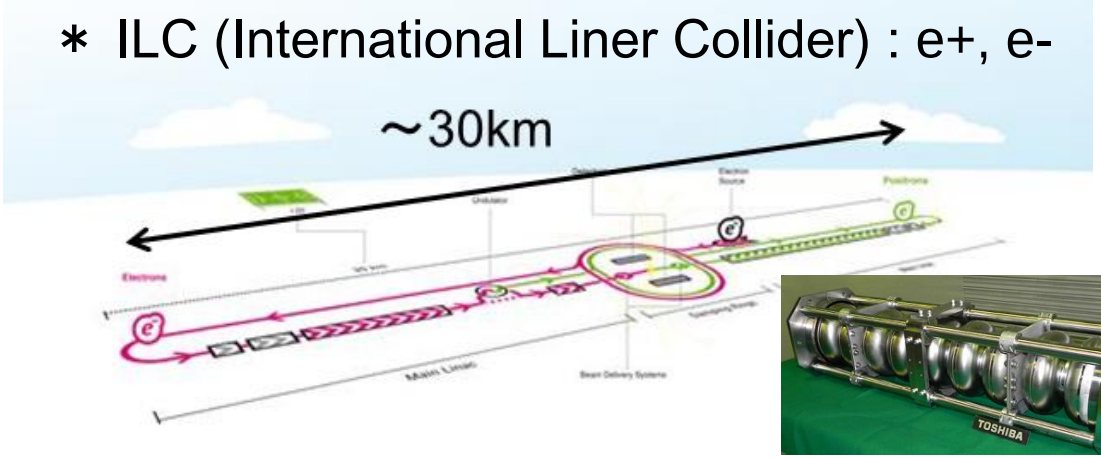


Heavy Ions up to U

Source : RIKEN http://www.nishina.riken.jp/RIBF/accelerator/overview.html http://www.nishina.riken.jp/facility/RILAC.html

Future Plan and new Concept

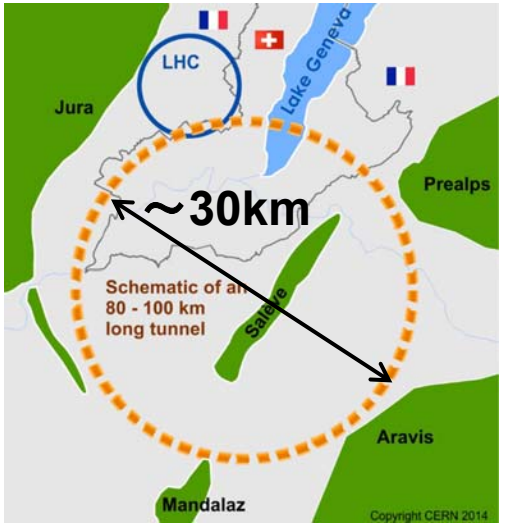
＊ ILC (International Liner Collider) : e+, e-



Source : KEK
https://ilc.kek.jp/Images/schematic_20070129_hires.jpg

SC-Cavity
Eacc>30MeV/m

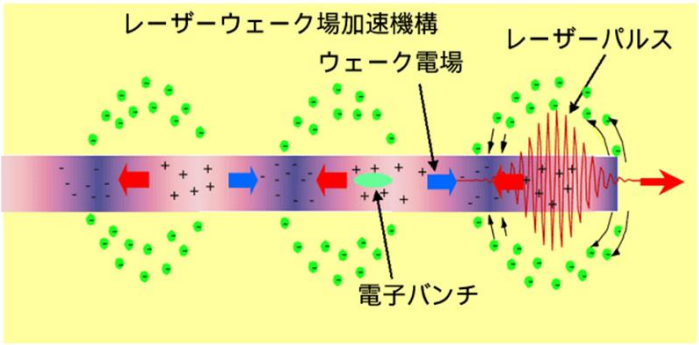
＊ FCC (Future Circular Collider)
p, p

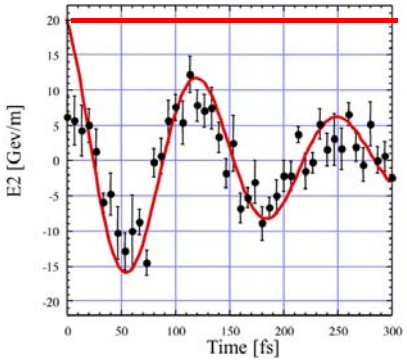


Source:CERN
https://cds.cern.ch/images/OPEN-PHO-ACCEL-2016-002-1

Improvement by Scale-Up is being saturated

＊ New Concept (Laser Plasma Acceleration, etc.)





20GeV/m

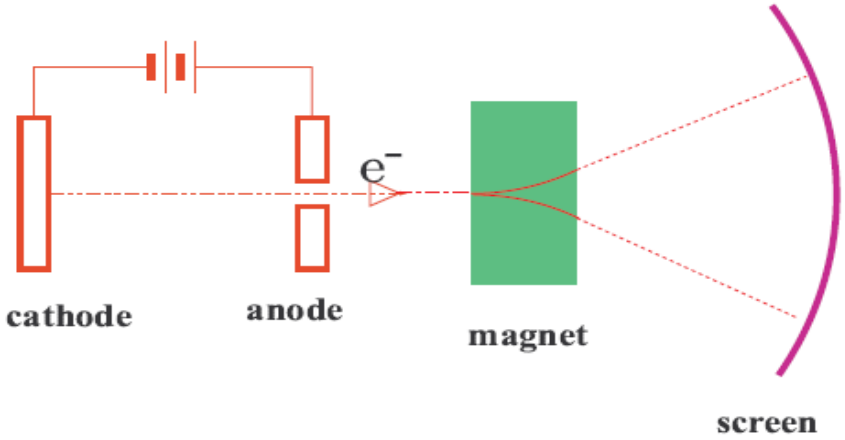
Source : KEK https://www2.kek.jp/ja/newskek/2003/mayjun/laser.html

Contents

Early Applications

Cathode Ray Tube

< few tens keV (1eV =e(1.6E-19C) x 1V [J])



∗ Medical Use

X-ray Picture by Wilhelm Röntgen in 1896

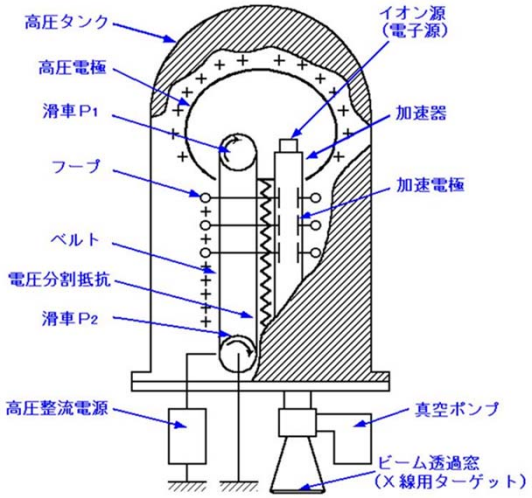
Source : Wikimedia
https://commons.wikimedia.org/wiki/File:X-ray_by_Wilhelm_R%C3%B6ntgen_of_Albert_von_K%C3%B6lliker%27s_hand_-_18960123-02.jpg

∗ Electronics
- Braun Tube in 1897
- Diode in 1904, Triode in 1906
- Magnetron in 1920, Klystron in 1937

Early Applications

Use of MeV-class Electron and Proton in 1930's～1950's

- ＊Radiotherapy using high Energy X-ray
- ＊ X-ray Examination for Industrial use
- ＊Radiotherapy using high Energy Proton
- ＊Production of Isotopes



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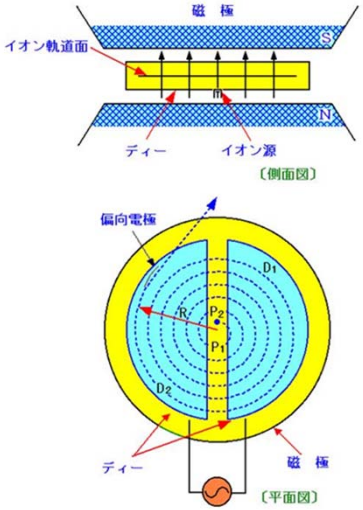

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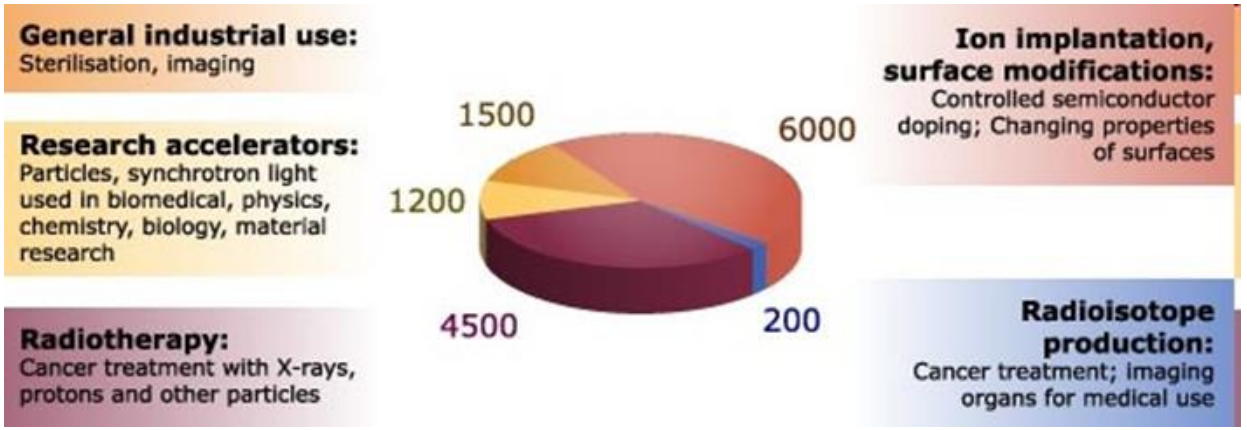
Wide Applications in the 21st



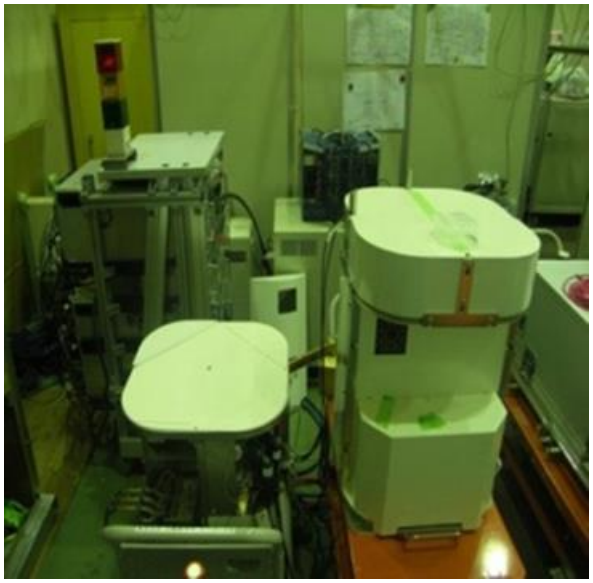
World Accelerators in 2008 (Medical X-ray diagnostic devices are not included)

Source : Robert W. Hamm, “Industrial Accelerators”, Reviews of Accelerator Science and Technology, Vol.1, 2008.

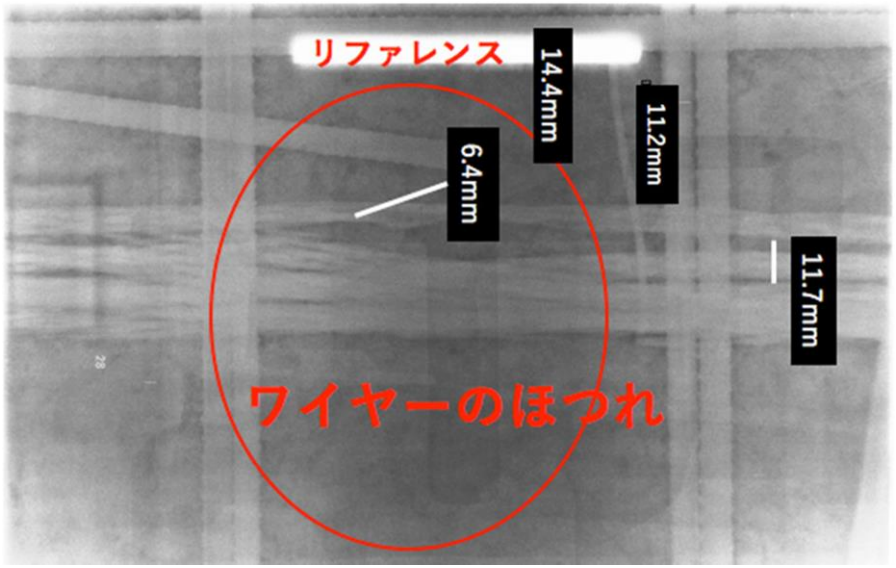
- Ion Implantation, Surface Modification : Semiconductor
- Radiotherapy : X-ray, Electron, Proton, Heavy-Ion, Neutron
- NDI : Industrial Products
- Processing : Tire, Film, Cable Insulation
- Sterilization : Medical Tool, Food
- Radio Isotope Production : Nuclear Medicine
- Mutation : Blue Rose, Grain
- Archeology : Radiocarbon Dating by AMS
- Structure Analysis : New Pharmacy, New Material

Wide Applications in the 21st

＊NDI : few 100s keV ～ few MeV Electron Accel.



Portable X-band linac based X-ray source for diagnosis of the structural health of social infrastructure such as bridge.
The maximum X-ray energy is 950 keV.



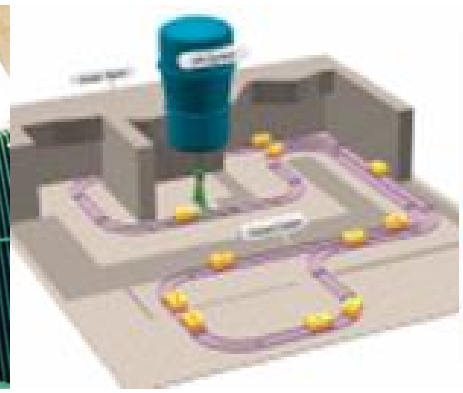
X-ray image of a part of a pre-stressed concrete bridge. Some wires were confirmed to be wasted by comparing the width (diameter) of each wire.

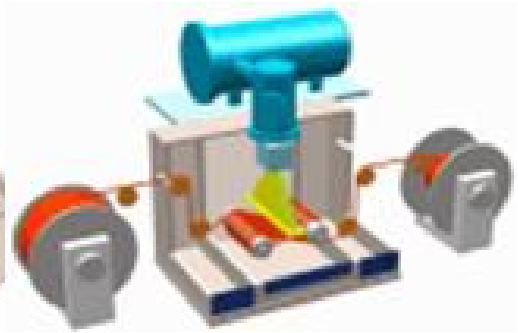
Source : M.Uesaka et al., “COMISSIONING OF ON-SITE INSPECTION AND STRUCTURAL ANALYSIS BY 950 keV X-BAND LINAC X-RAY SOURCE”, Proceedings of the 13th Annual Meeting of Particle Accelerator Society of JAPAN, p241, 2016.

Wide Applications in the 21st

∗ Processing, Sterilization : few100s keV~10MeV Electron

Source : NHV Co. http://www.nhv.jp/products/epsmain.html





Scan Beam type

Area Beam Type

∗ Radio Isotope Production : ~few10s MeV p, D

HM-20S Cyclotron System for PET

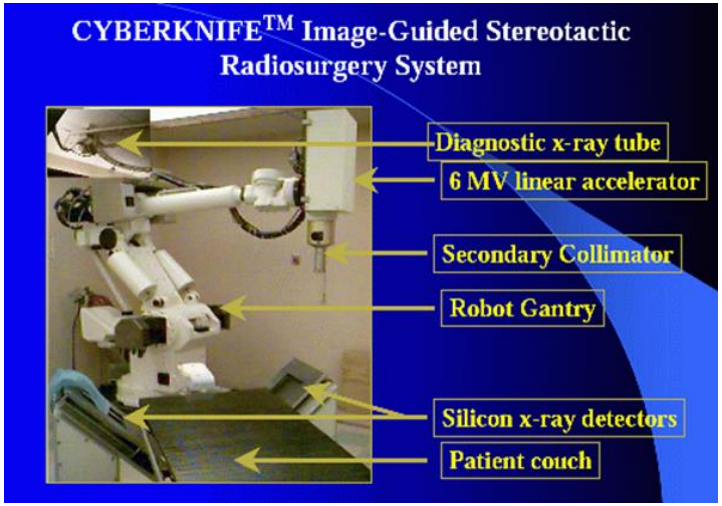
Source : Sumitomo Heavy Industries Ltd.

Wide Applications in the 21st

＊Ion Implantation, Surface Modification : 10keV～10MeV

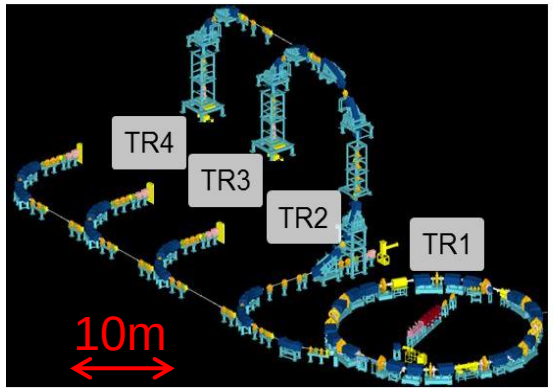
Source : ULVAC, Inc. https://www.ulvac.co.jp/products_j/equipment/applications/power-device/front-side_power-device/ion-implant_front-side/ih860dsic

＊Radiotherapy



X-ray(Photon) Therapy
: few MeV Electron Accel.

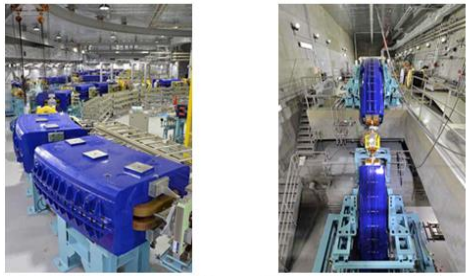
Source : Wikimedia
Wikimediahttps://commons.wikimedia.org/wiki/File:CyberKnifeSchematic2.png



Particle type	Carbon ion (C^{6+})
Facility area	3,009m^2, Gross floor: 6,999 m^2
Patients per year	Over 880
Beam Energy	430 MeV/n （design value）
Treatment Room	4 (H:2, H/V:2)
Irradiation Method	Scanning

Source : TOSHIBA

Accelerator



High Energy Beam Transport Line

Source : KCCH
http://kcch.kanagawa-pho.jp/newcenter/i-rock_en.html

Heavy Ion Therapy : few100s MeV/u (few GeV)

Wide Applications in the 21st

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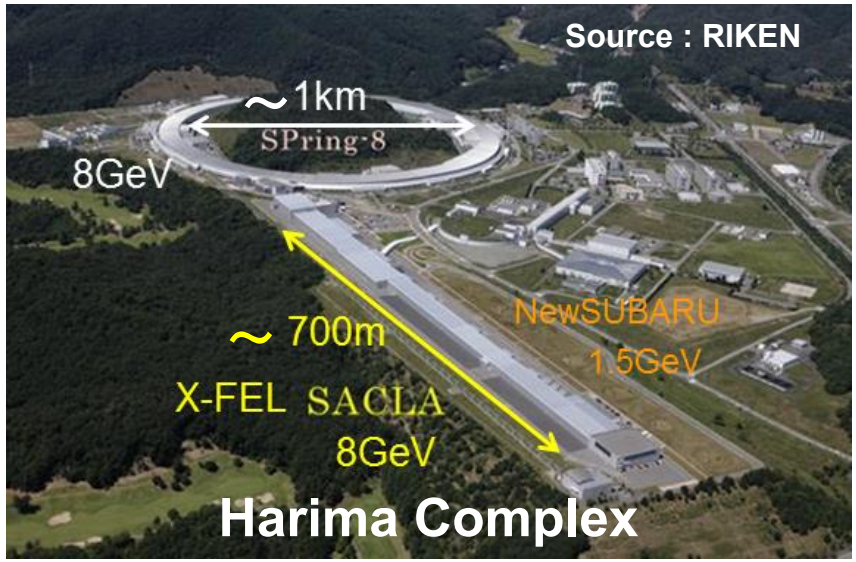
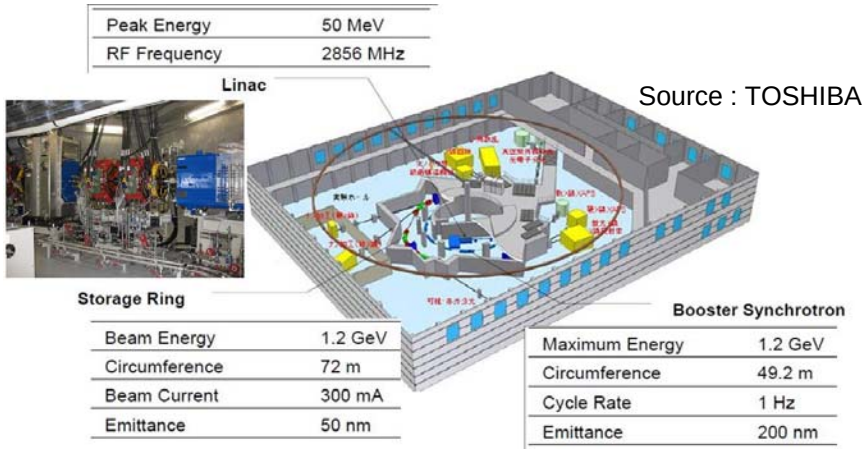
∗ Structure Analysis by using Photon (SOR, FEL)

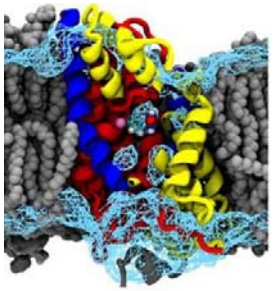




Source : TOSHIBA

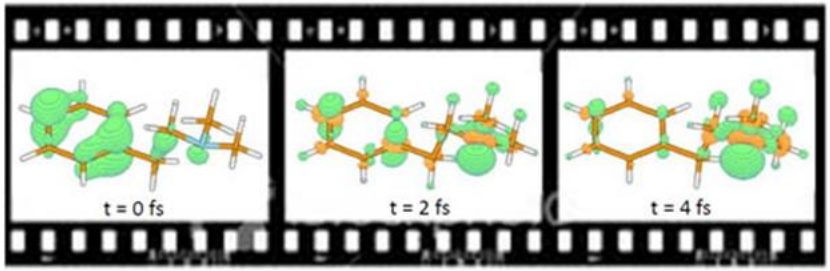
Aichi Synchrotron Radiation Center, 2012～

∗ Observation of
- Precise Structure of Matter
- Rapid (fs order) Movements of Electrons and Atoms



New Pharmacy
New Material

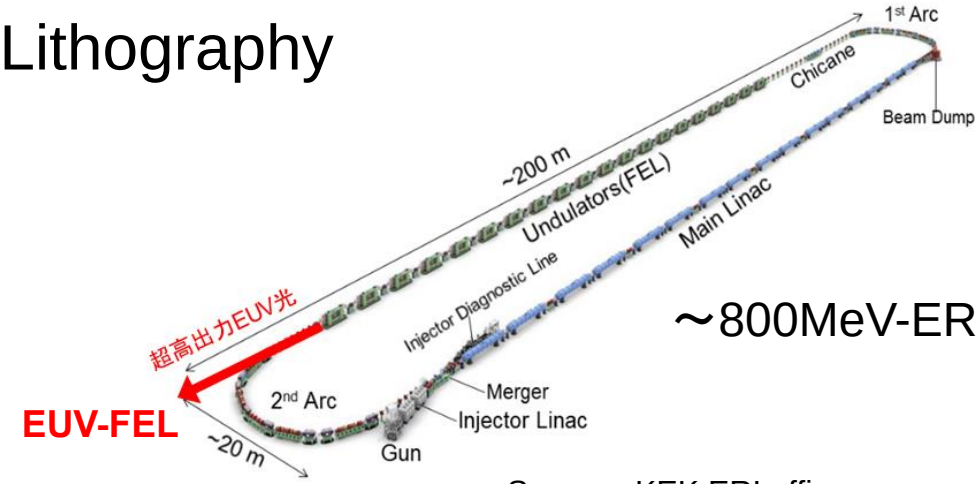
Source : MEXT-HP
http://www.mext.go.jp/a_menu/shinkou/ryoushi/detail/1316022.htm



Source : MEXT-HP
http://www.mext.go.jp/a_menu/shinkou/ryoushi/detail/1316021.htm

Expectation of high-intensity Photon Applications

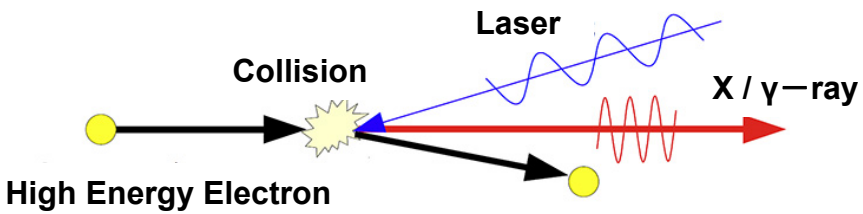
∗ EUV-Lithography



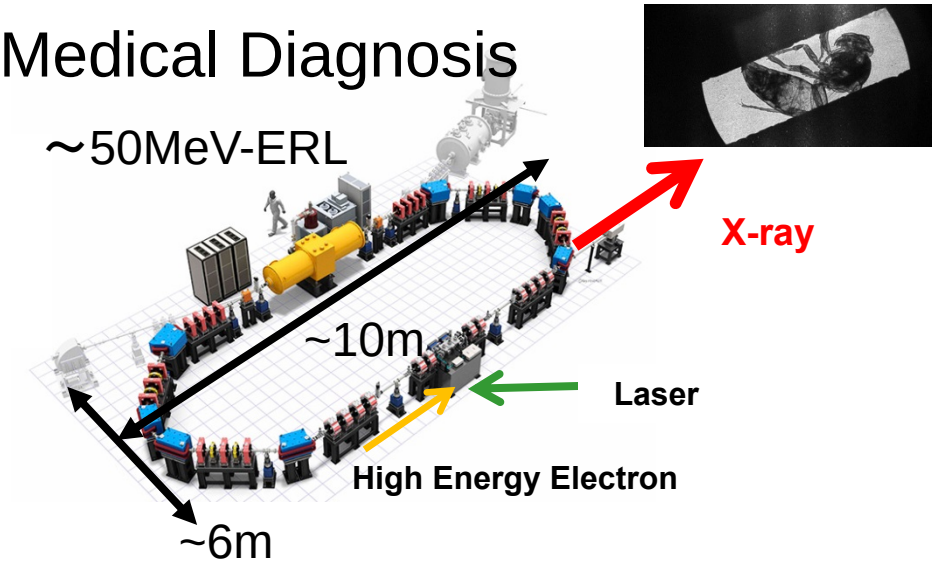
～800MeV-ERL

Source : KEK ERLoffice.

∗ High-resolution, real-time Medical Diagnosis



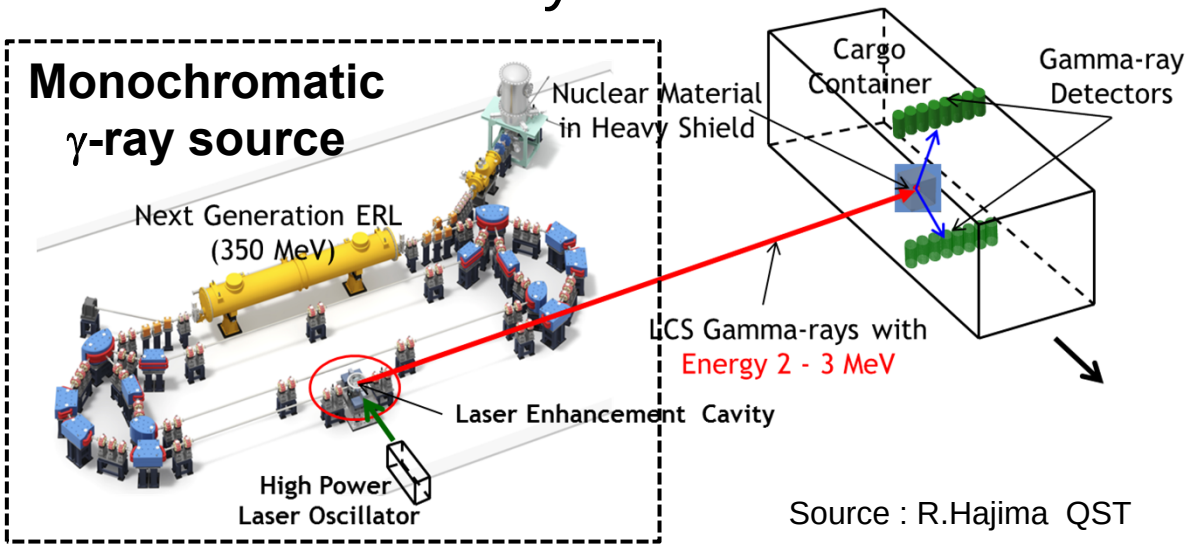
Laser Compton Scattering (LCS) point-source and monochromatic X-ray Source



Source : KEK https://www.kek.jp/ja/NewsRoom/Release/20150427150000/

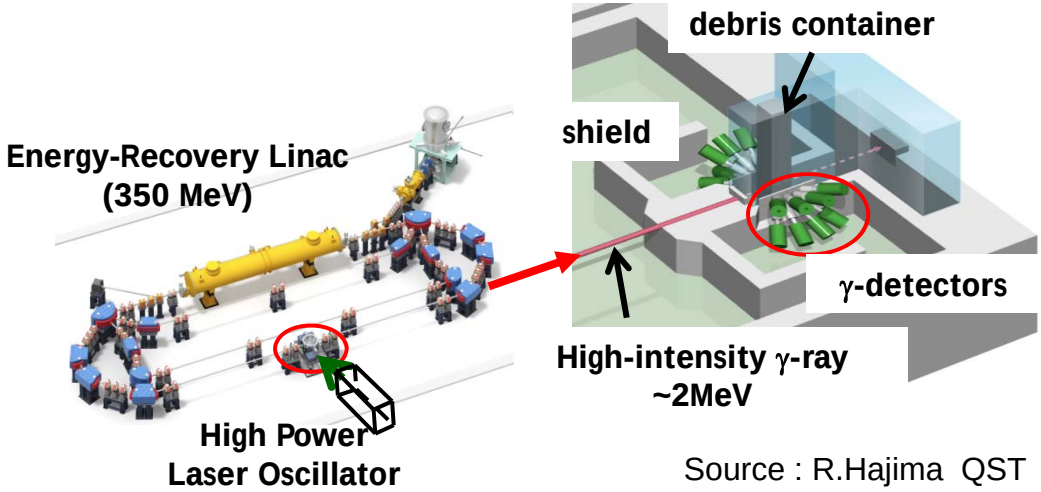
Expectation of high-intensity Photon Applications

∗ Nuclear Security : NDI inside Container at Port



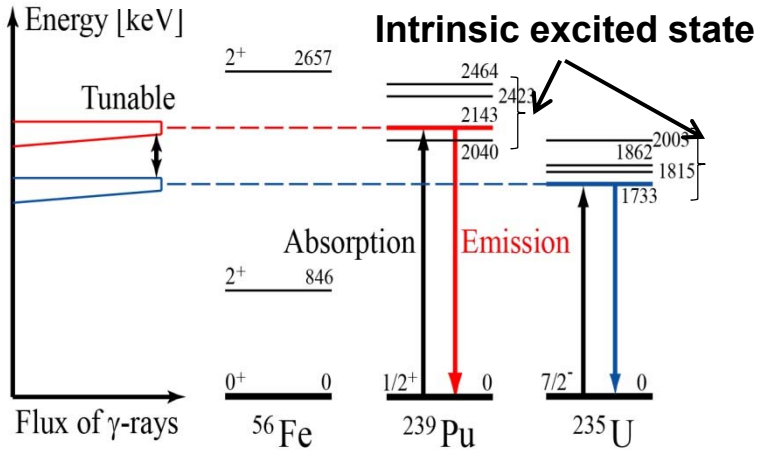
Source : R.Hajima QST

∗ Nuclide Identification in Debris



Source : R.Hajima QST

Nuclear Resonance Fluorescence



Contents

Summary

* Accelerator has been developed as strong tool of basic science.

* On the other hand, technology of accelerator has been applied for industrial and medical use since its early stage.

* Now, accelerator is very common in the society.

* Many companies in Japan have taken part in national projects and also have developed there own products.

* Continuous development of new applications is important to keep technology and motivation.

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