Applications of Ion Accelerator

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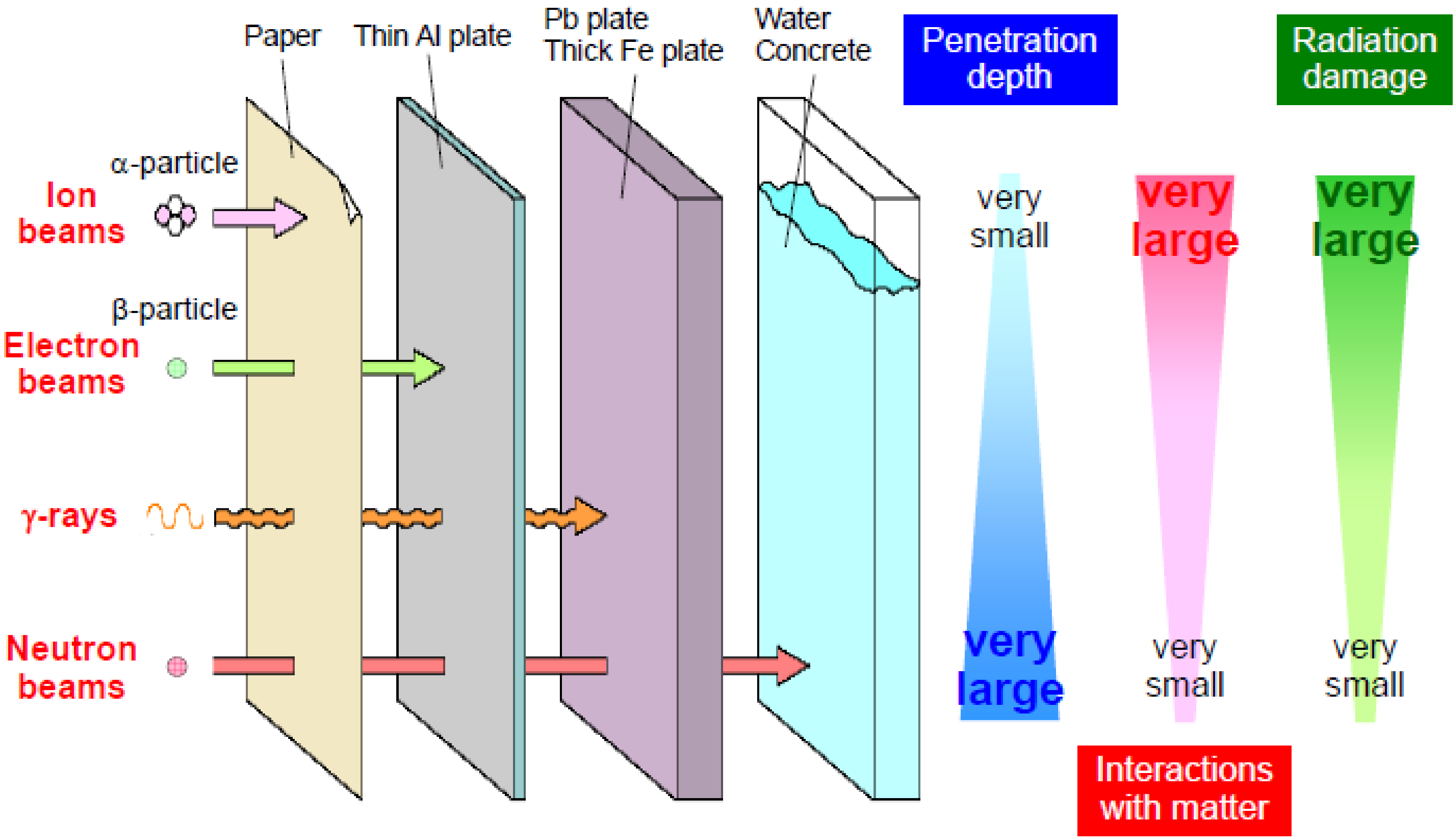
Indo-Japan Accelerator School at IUAC, 2/16-18 2015

	Subject
1.	Overview on Applications of Medium Energy Ion Accelerator *Including the comparison with other quantum beams* *from AFAD2009-2015*
2.	RI for Industrial use and RI medicine
	Novel Materials
	Bio/Agriculture
	Medical (Introduction)
3.	South Asia Standard Model for Hadron Cancer Therapy Driver based on Ideal Digital Accelerator

Effects of High Energy Quantum Beams penetrating Materials



By courtesy of Dr. Yamaki (JAEA-Takasaki) (KEK-NM Accelerator School in 2014)

Fundamental Problems for Humankind or Earth in 21st Century and Direct Contribution of High Energy Quantum Beams for their Resolution

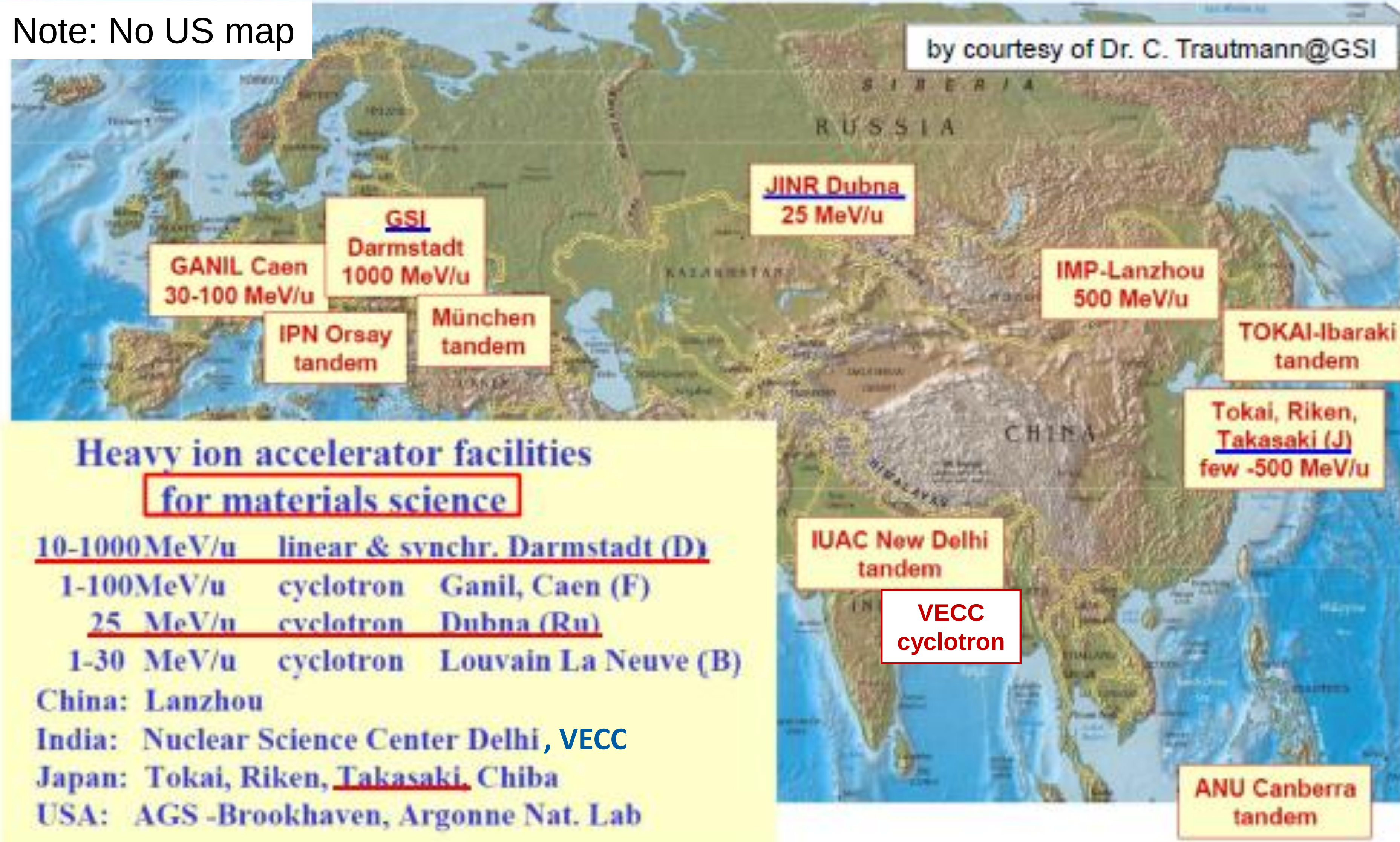
This table is written based on the presentations at the past AFADs.

Quantum beam species	Environment	Energy	Water	Food	Life care	Quality of life
Electron	Enhancing chemical treatment of contaminated gas and sludge in a large scale		Sterilization/ sanitation of contaminated water in a large scale	Pest control of fruits in a commercial scale (as a x-ray converter)	•*Cyber knife* •*Intensity Modulated* Radiation Therapy (IMRT)	A lot of industrial product with a long his.
Proton					•Cancer therapy driver •BNCT driver •Radio isotope medicine	as a compact neutron driver
Heavy ions	Mutation (*) of root nodule bacteria trapping N(**) in soil, by increasing its capability by a factor of ten ** N_2O (global-warming gas) which has larger effects by a factor of 300 than CO_2	•Mutation (*) of microorganism, by increasing its photosynthesis oil production capability •Mutation(*) of crop plant for bio fuel •Fuel cell		Mutation (*) of crop plant Keeping/increasing production/hain climate change	•Cancer therapy driver •Materials for medical use	•Novel materials aiming industrial applications •RI tracer

➢Heavy ion mutation, which is a kind of accelerated evolution in organisms, must be distinguished from gene-transplant technology.

Worldwide Large Accelerators & Tandem Facilities

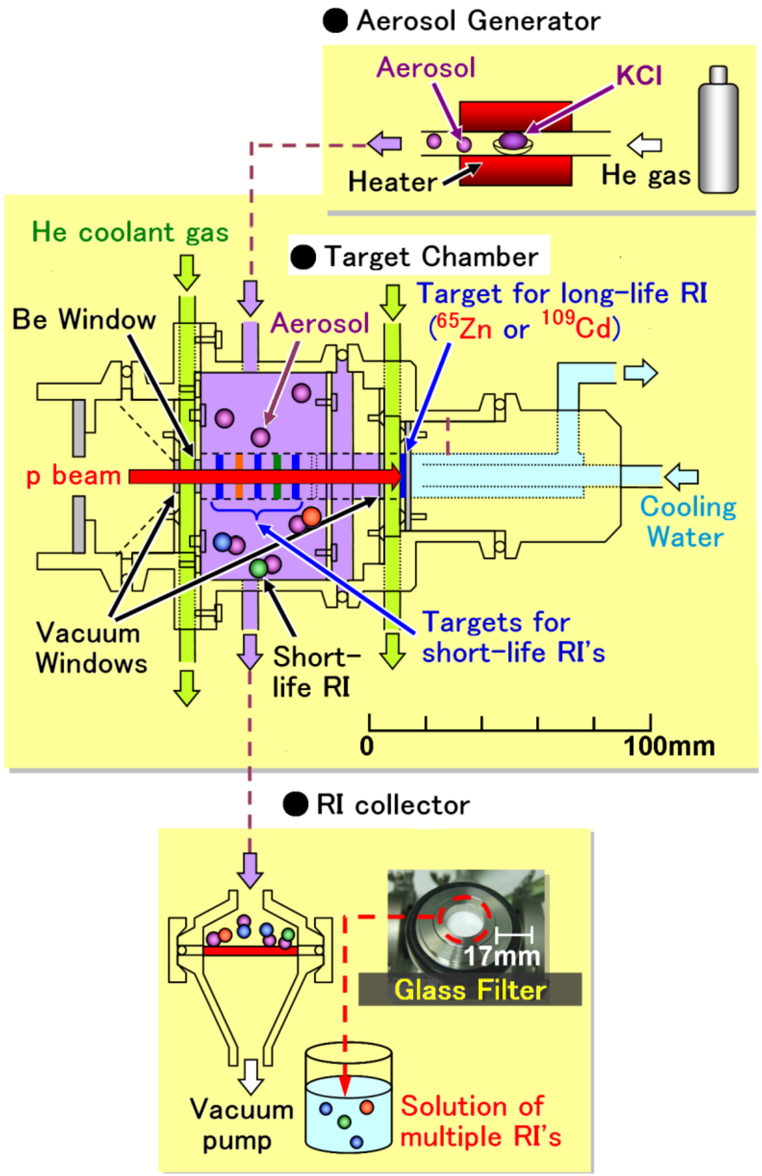
Note: No US map



Production of long-life nuclides at RIKEN (by Kambara at JAAWS 2010)

Nuclide	Half Life (days)	Production Reaction
^{7}Be	53	$^{7}Li(p,n)$
^{48}V	15.97	$^{48}Ti(p,n)$
^{52}Mn	5.591	$^{52}Cr(p,n)$
^{54}Mn	312	$^{54}Cr(p,n)$
^{65}Zn	244.3	$^{65}Cu(p,n)$
^{67}Cu	2.58	$^{70}Zn(p,\alpha)$
^{83}Rb	86.2	$^{81}Br(\alpha,2n)$
^{85}Sr	64.84	$^{85}Rb(p,n)$
^{88}Y	106.7	$^{88}Sr(p,n)$
^{89}Zr	3.27	$^{89}Y(p,n)$
^{92m}Nb	10.15	$^{92}Zr(p,n)$
^{95m}Tc	61	$^{95}Mo(p,n)$
^{99}Rh	16	$^{99}Ru(p,n)$
^{109}Cd	462.6	$^{109}Ag(p,n)$
^{139}Ce	137.6	$^{139}La(p,n)$
^{175}Hf	70	$^{175}Lu(p,n)$
^{177}Ta	2.357	$^{177}Hf(p,n)$
^{203}Pb	2.161	$^{203}Tl(p,n)$
^{206}Bi	6.243	$^{206}Pb(p,n)$

Short-life nuclides are also produced.



Industrial applications of the RIKEN cyclotrons T.Kambara (RIKEN)

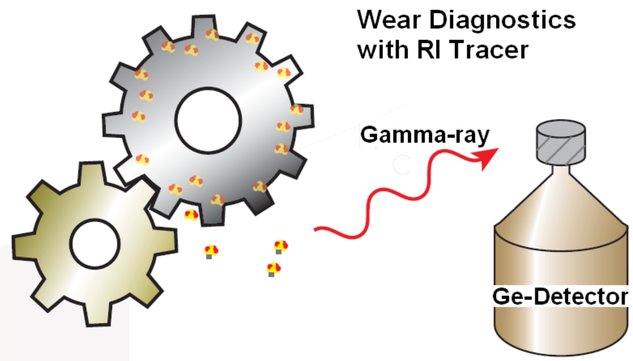
■**At RIBF, ion beams including RI beams are utilized for industrial applications.**

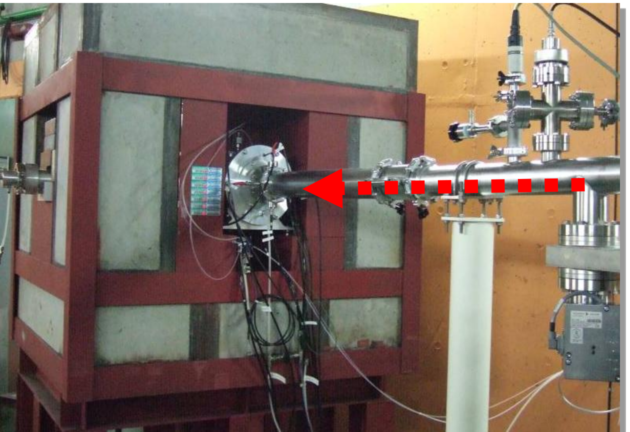
■Three nuclides (Zn-65, Cd-109 and Y-88) produced at AVF and RRC are distributed for charge.

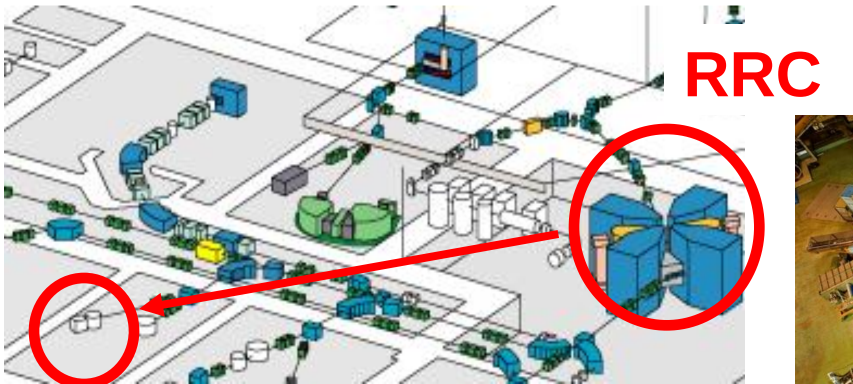
■Industrial use of ion beam and RI beam has been started since 2009.

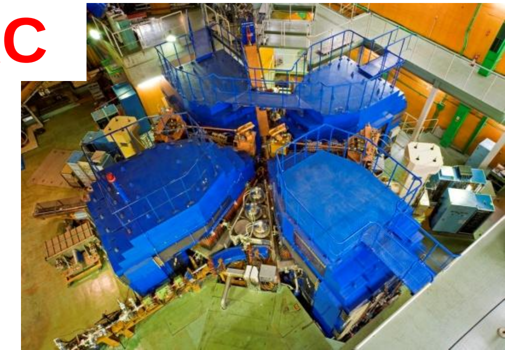
Nuclide	Cd-109		Zn-65	
	Order	Quantity (MBq)	Order	Quantity (MBq)
FY2007 (Nov.-)	1	5	2	12.1
FY2008	6	33	7	38.7
FY2009	3	25	16	116.1
FY2010(Apr.-Nov)	3	20	12	52.4
Total	6	83	7	219.3

- Development of radiation-tolerant Power MOS-FET bored on satellites Simulation of cosmic-rays with Kr-86 beam from RRC (36 MeV/u).
- Wear diagnostics of machine parts using RI-beam implantation









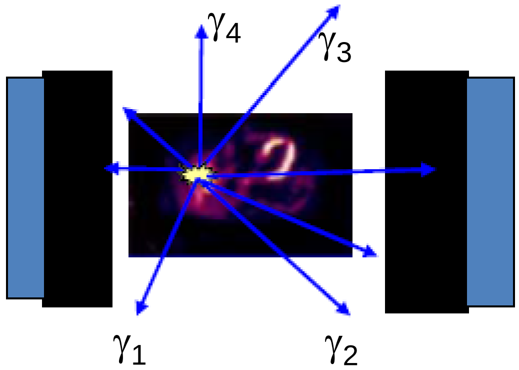
RI Nuclides for PET and SPECT

Nuclide

^{201}Tl 73 h
^{67}Ga 78 h
^{111}In 2.8 d
^{99m}TC 6h

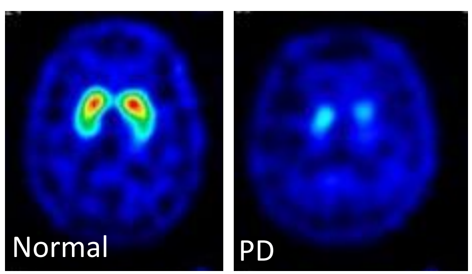
- So-far this nuclide had been provided from 5 nuclear reactors in the world.
- Unstable operation due to unscheduled shutdown.

SPECT
(Single-Photon Emission Computed Tomography)



Single-photon emission at a time

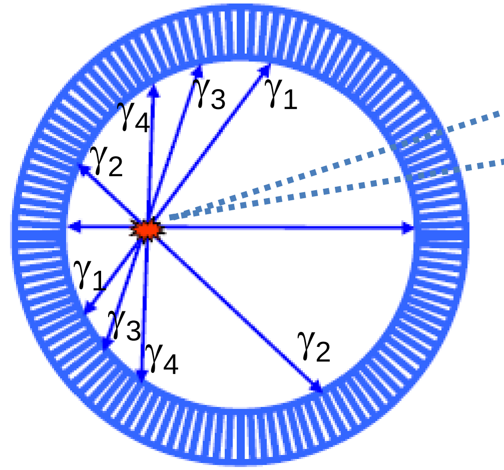
Parkinson's disease



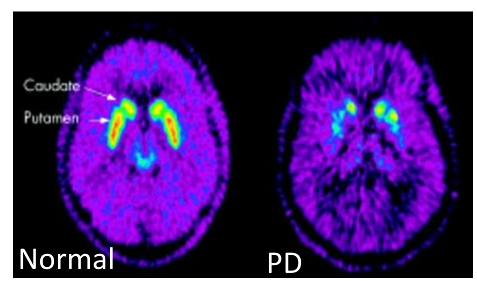
^{99m}Tc-TRODAT-1

(林口總院核子醫學科 張秀萍, 林昆儒)

PET
(Positron Emission Tomography)



$e^{+} + e^{-} \rightarrow 2\gamma$



^{18}F-FDOPA PET

(Applications of positron emission tomography (PET) in neurology, 2004)

Nuclide

^{11}C 20 min
^{13}N 10 min
^{15}O 2 min
^{18}F 110 min

by Ting Shien Duh at AFAD2015

Maybe, Accelerator research institutes have nothing to do, because Cyclotron industry in the world is well matured.

Compact AVF cyclotrons lineup

Sumitomo Heavy Industries, Ltd.

HM - 30

P 30MeV
For PET/SPECT Radioisotopes Production, BNCT

HM - 20

P 20MeV / D 10MeV
For FDG Delivery, PET Research

HM - 12

HM-12S (Self-Shield)

P 12MeV / D 6MeV
For PET Clinical / Research

HM - 10

P 10MeV / D 5MeV
For PET Clinical / Research with Self-Shield

HM - 7

P 7MeV / D 3.8MeV
For FDG Clinical / O-gas Study with Self-Shield

by Tsutsui (Sumitomo Heavy Industry) at KEK-NM Accelerator School in 2014

Modification of Bulk Materials

Target Materials

- Nonliving Materials
  - Organic
    - Polymer
  - Inorganic
    - Metal
    - Crystal
    - Ceramic
    - Semicondutor
    - Magnetic material
- Living Materials (Living tissues)
  - Human body (mamaml body)
  - Cancer tissue
  - Plant (damage -> Mutation)
  - Microorganism (damage -> Mutation)

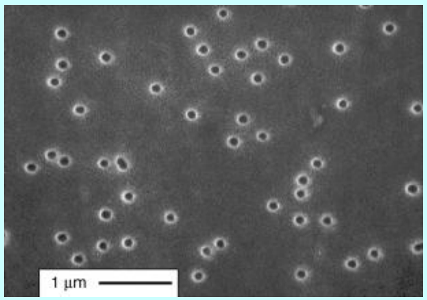
Self regeneration

Materials with Novel Function

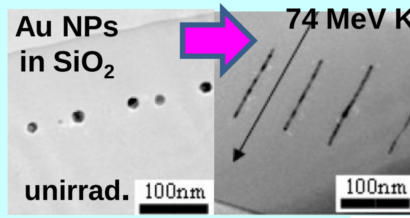
・Creation of Ion track of nm size in diameter by a single swift heavy ion
・ realization of non-equilibrium phase due to electron excitation of several tens of keV/nm

Filter with open holes of nm size

Diameter ← ion species
Depth ←energy
Hole number ← number of ions

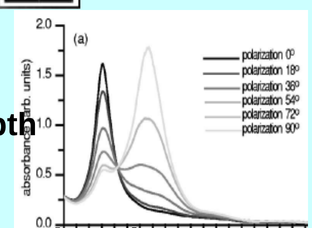


Overlized deformation of nano-particle



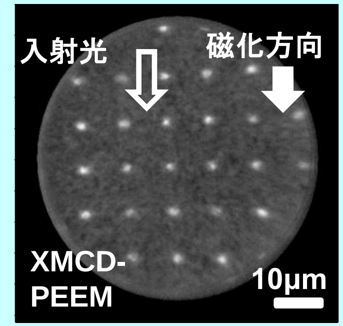
プラズモン光吸収
偏光角度依存性

Anisotropic nano-complex
・polarizer with nm depth
・anisotropic magnetic material
・control of plasmon wavelength



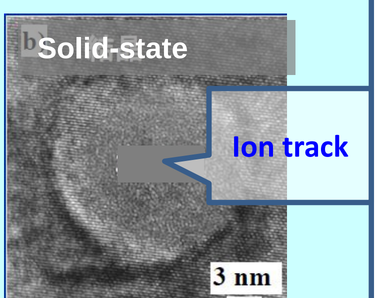
Ion irradiation induced ferromagnetization

Irradiated area has ferromagnetics.



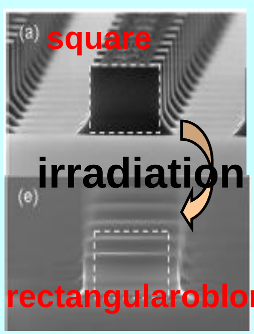
3D nano-circuit

β-$FeSi_2$: solid-state
Ion track: metal
→ 3D nano-circuit



Control of micro/nano-structure

Microstructure in Si

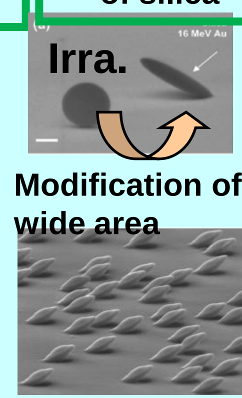


Micro-groove in glass

before：1.8μm

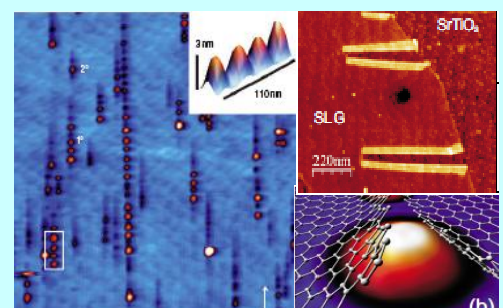
after: 5μm

Micro-sphere of silica



Modification of wide area

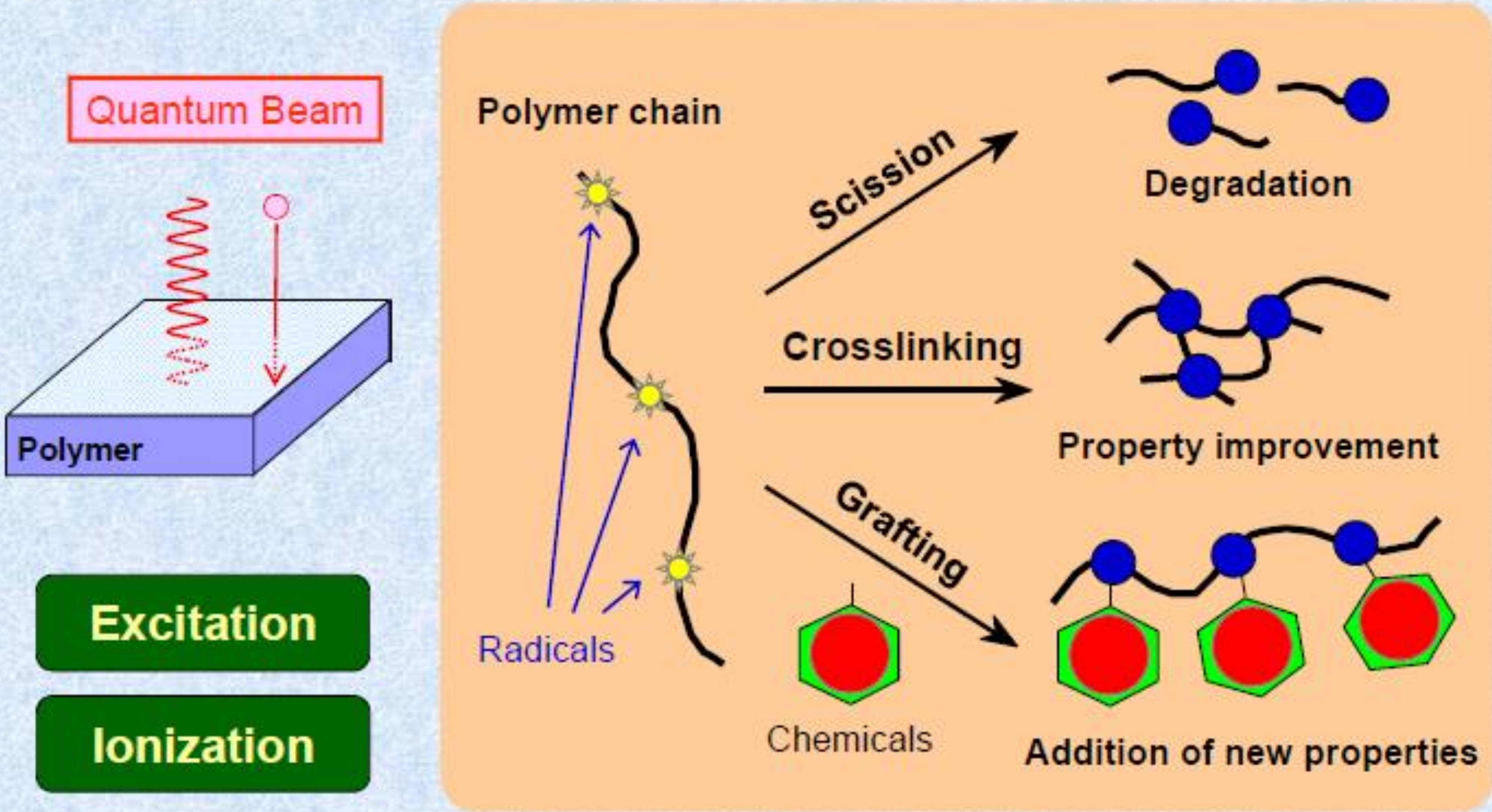
小角入射による連続ヒルロックの形成とグラフェンの折り畳み



substrate：$SrTiO_3$

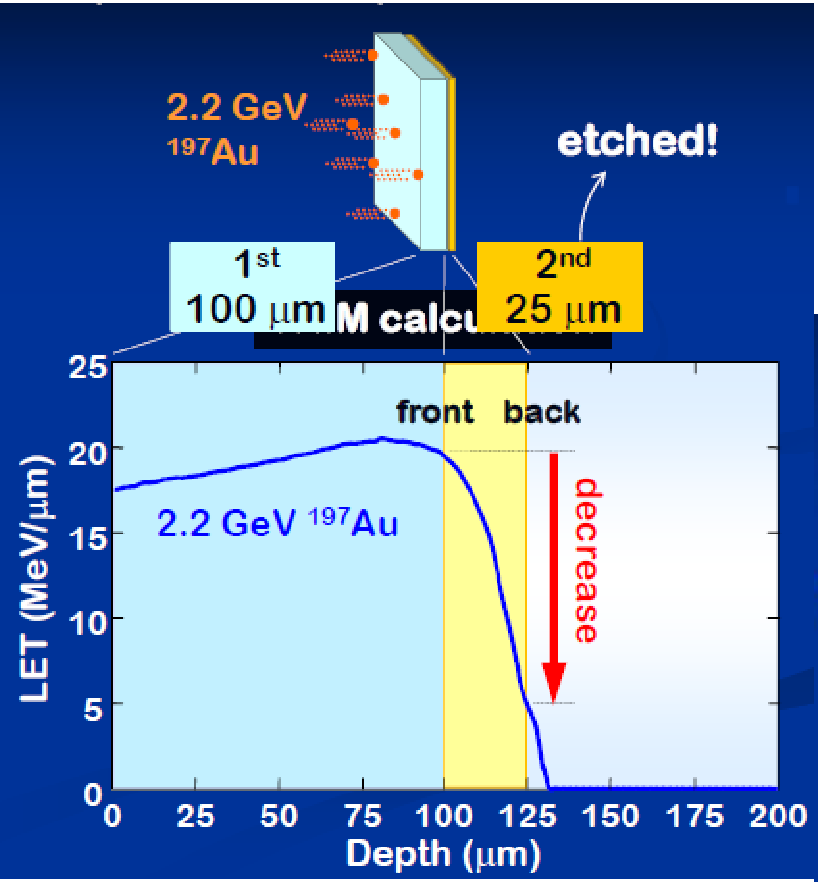
by H. Amekura (NIMS in Japan)

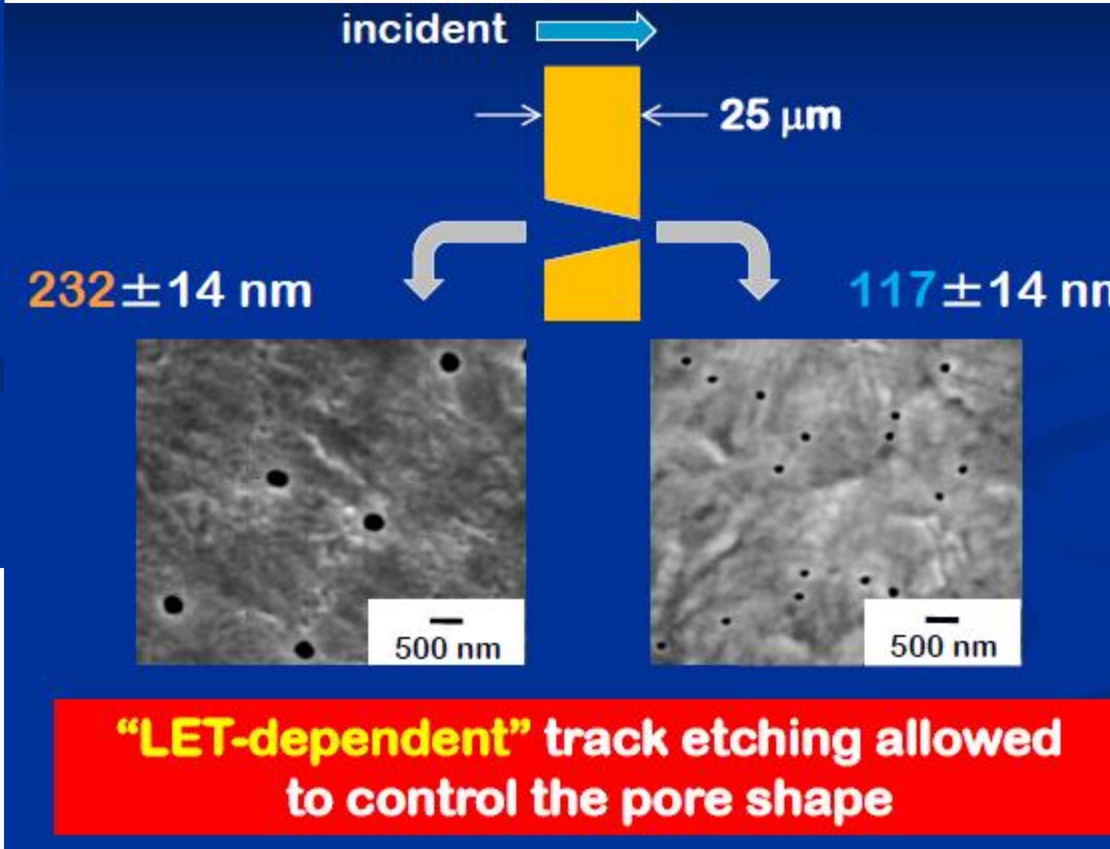
Polymer



Quantum Beam
Polymer
Excitation
Ionization
Polymer chain
Radicals
Scission
Degradation
Crosslinking
Property improvement
Grafting
Chemicals
Addition of new properties

Control of Ion Track





by Yamaki (JAEA-Takasaki) at KEK-NM Accelerator School in 2014

Mutant Variety Database

Joint FAO/IAEA Programme
Database of Mutant Variety and Genetic Stocks

understandable

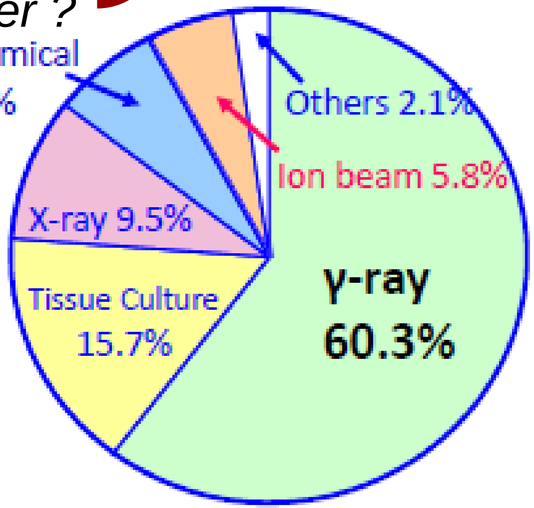
understandable

(FAO/IAEA Database, October 2011)

Country	No. of cv. Total	Rice	Barley	Wheat	Maize	Soybean	Chrysanthemum
All countries	3212	815	304	252	89	170	277
China	808	290	7	162	47	79	21
Japan	481	222	10	7	0	30	56
India	329	59	13	4	0	7	46
Russia	215	6	29	36	5	9	17
Netherland	176	0	1	0	0	0	80
Germany	171	0	66	2	0	1	34
USA	139	36	13	4	0	0	1

for beer ?

Bangladesh	44
Indonesia	29
Korea	35
Pakistan	53
Thailand	20
Viet Nam	55



More than half varieties with ion beams created by using TIARA

Mutagen (Japan)

H. Nakagawa, TechnoInnovation No.68(2007)

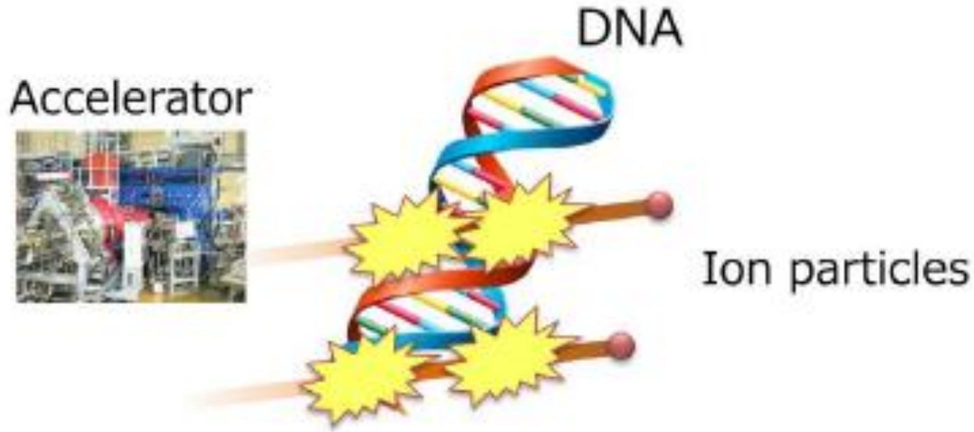
Energy deposition: Gamma-rays vs Ion Beams

Gamma-rays
(electromagnetic wave)

Produce ionization sparsely along their track (Low-LET radiation)

LET: ~0.2 keV/μm

Ion Beams
(energetic particles)



Produce dense ionization along the track of ion particles (High-LET radiation)

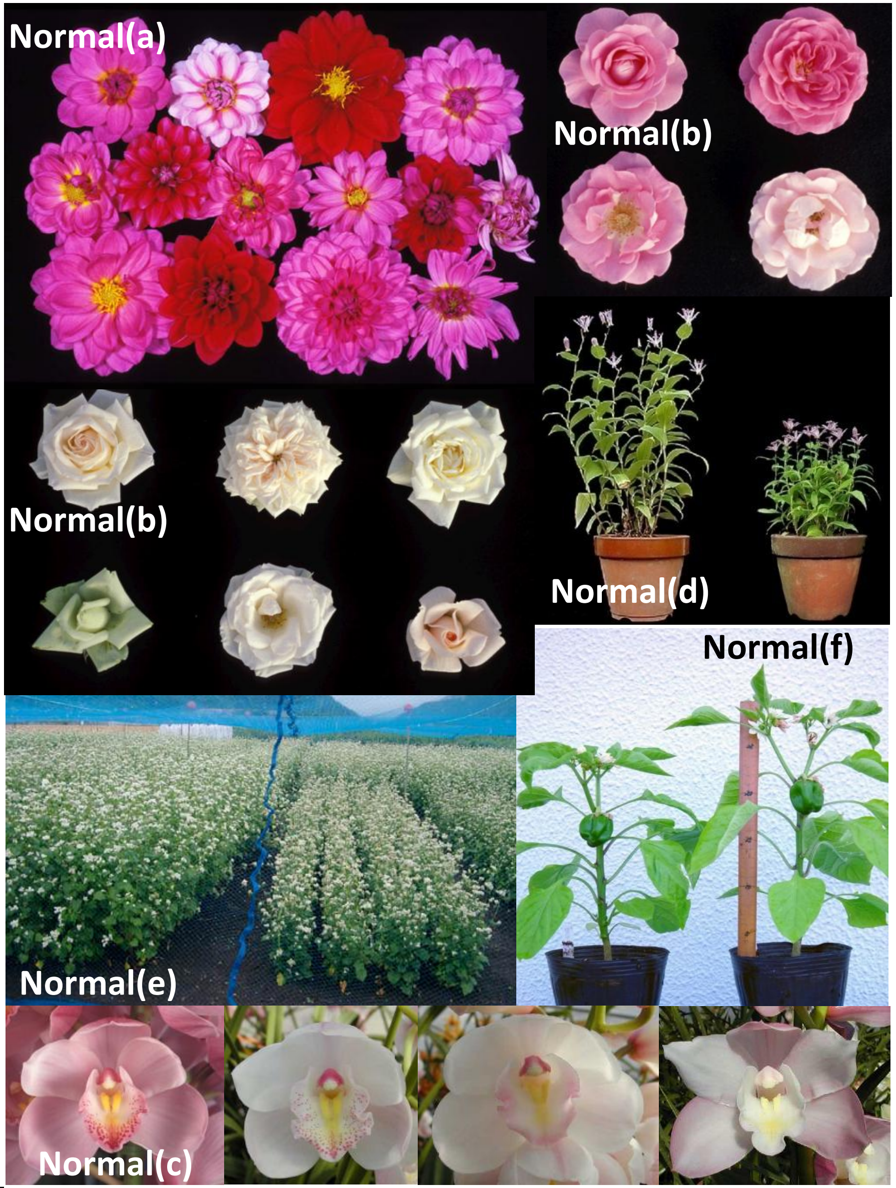
LET: 1 ~ 2,000 keV/μm

Does the ion beam induce different mutation?

by Hase (JAEA-Takasaki) at KEK-NM Accelerator School in 2014

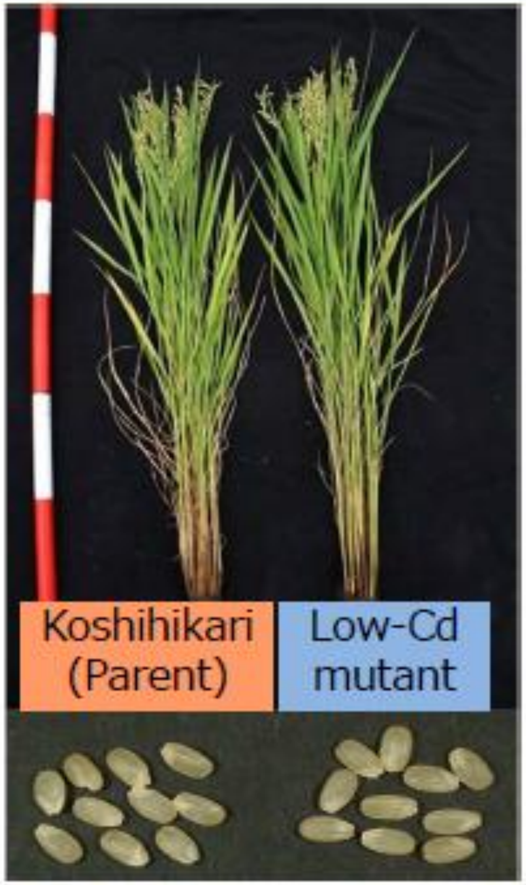
Mutants developed from the RIKEN beam

Mutant phenotype	Plant material	Mutation rate (%)
Sterile		
Verbena	Stem	09-2.8
Cyclamen	Tuber	6.7
Eucalyptus	Shoot primordia	9.3
Color and shape		
Petunia	Ovary	1.0
Dahlia[a]	shoot	20.3-50.1
Rose[b]	Dormant scion	43.1-51.7
Chrysanthemum	Stem	4.5-14
Torenia	Leaf and stem	1.6-18.8
Orchid[c]	shoot	5.0-6.3
Variegation		
Petunia Hybrida	Stem	1.8
Dwarf		
Tricyrtis hirta [d]	Embryogenic callus	10.8
Millet	Dry seed	0.1
Buckwheat[e]	Dry seed	0.6
Pepper[f]	Dry seed	1.3

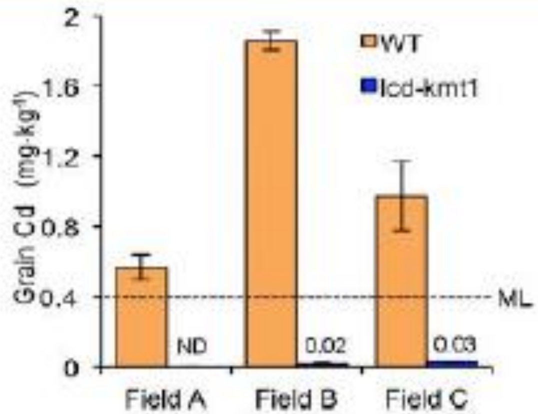


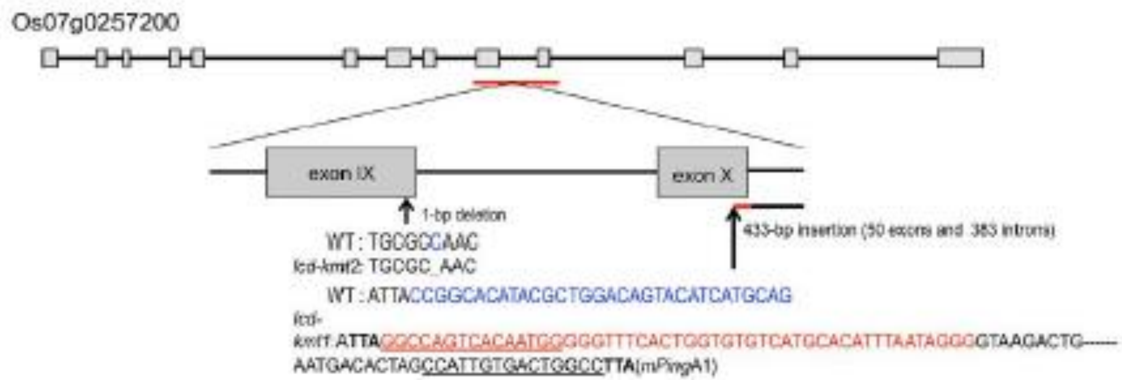
by HYoshida (RIKEN) at JAAWS2010

Mutation Breeding of Crop Plant



~3,000 M2 plants derived from ~3,000 M1 seeds irradiated with 40 Gy of carbon ions were screened.





Three independent mutants on the *OsNRAMP5* gene involved in Manganese transport

lcd-kmt1 1-bp deletion
lcd-kmt2 Transposon(*mPing*) insertion
lcd-kmt3 227-kb deletion

Ishikawa S. et al., PNAS 2012

by curtesy of Hase (JAEA-Takasaki) at KEK-NM Accelerator School in 2014

Mutation of Microorganism

Botryococcus (autotrophic alga) creating Oil as a result of photosynthesis

- Colonial green algae live in fresh water
- Green to Brown, Size: 30-500 μm
- The oil of *B. braunii* is hydrocarbon （→ petroleum)
- Oil is secreted out of a cell under some pressure
- Oil contents: 30-75%（dry weight)

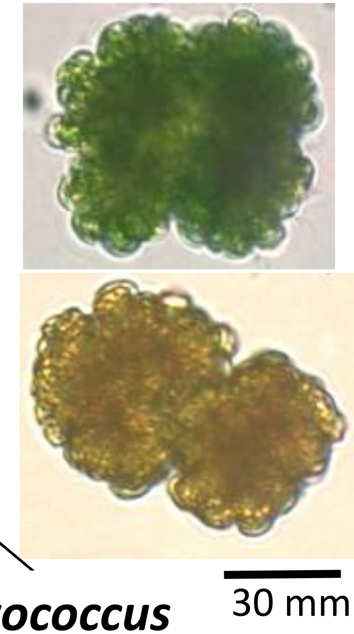
Two problems to prevent industrialization:

(1) Growth is very slow

(2) Capability of hydrocarbon production is not enough

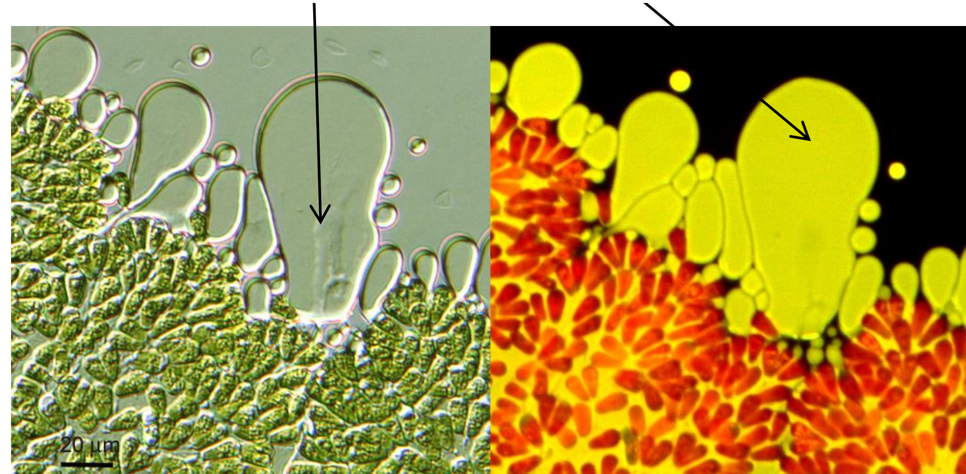
- Gene transfer technique is not established.

Possibility of Gene Modification by quantum beams



Oil

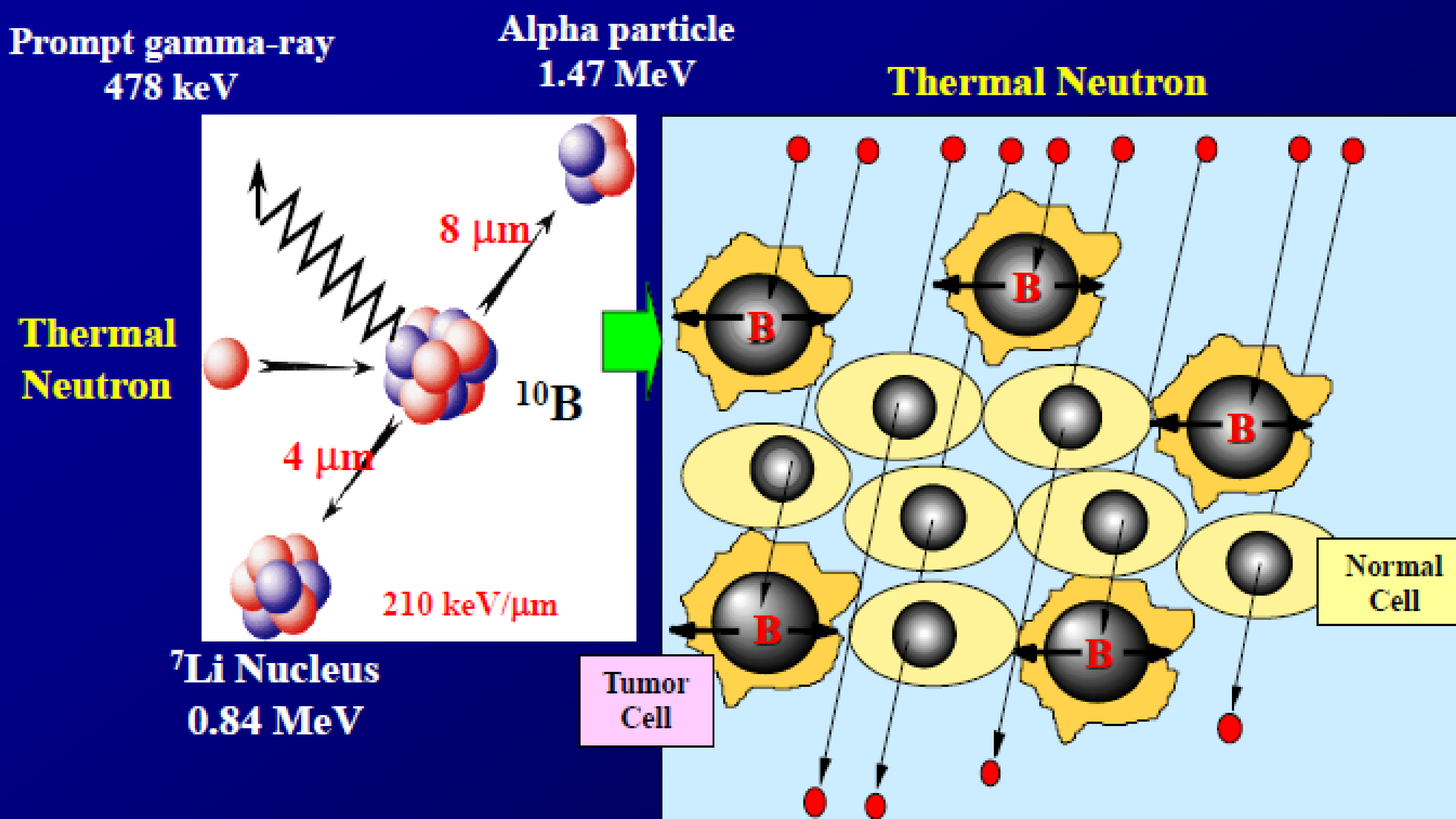
Micrograph of *Botryococcus*



by courtesy of Prof. Suzuki (Univ. Of Tsukuba) (AFAD2014)

BNCT Principle

Sumitomo Heavy Industries, Ltd.



Alpha particle in the cancer cell will destroy only that cancer cell

by Tsutsui (Sumitomo Heavy Industry) at KEK-NM Accelerator School in 2014

Variation of Proton Driver for BNCT (Boron Neutron Capture Therapy)

Conventional fission reactor base BNCT at JAEA

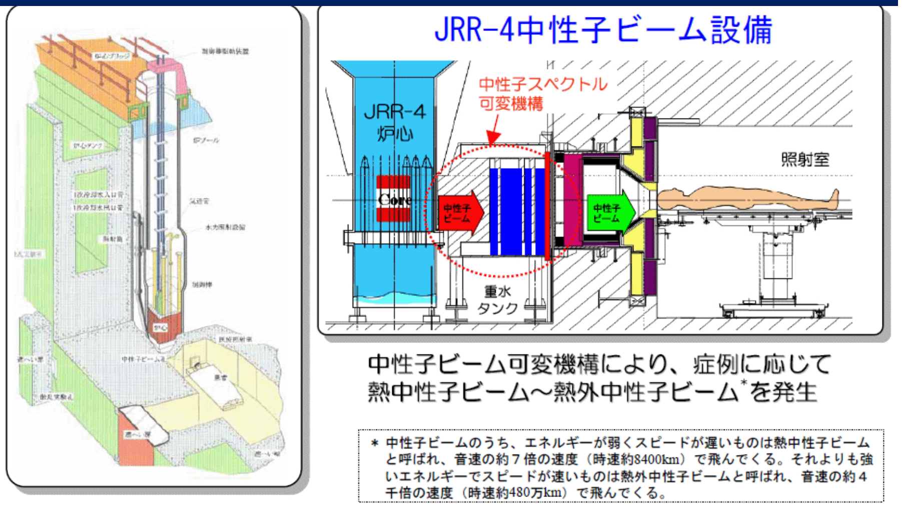
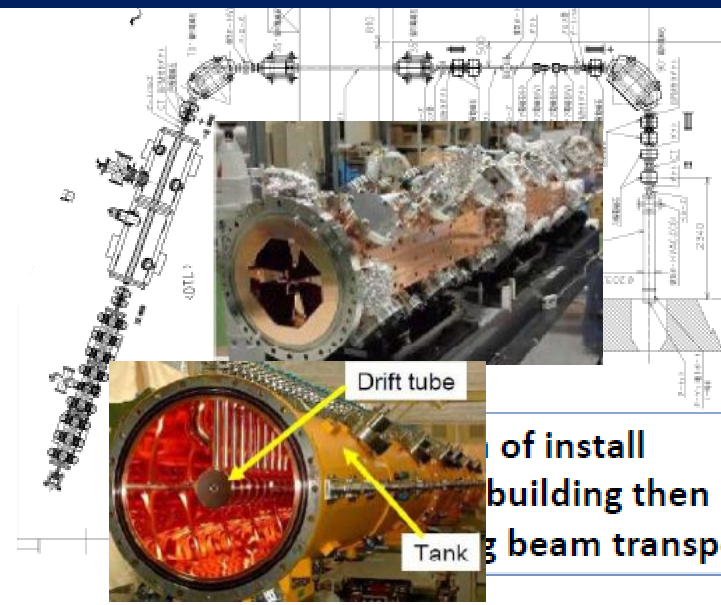


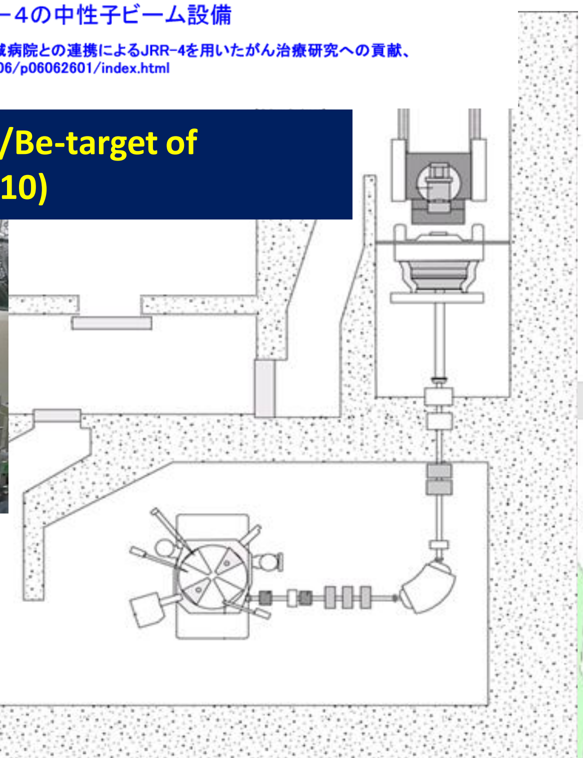
図3 JRR－4の中性子ビーム設備

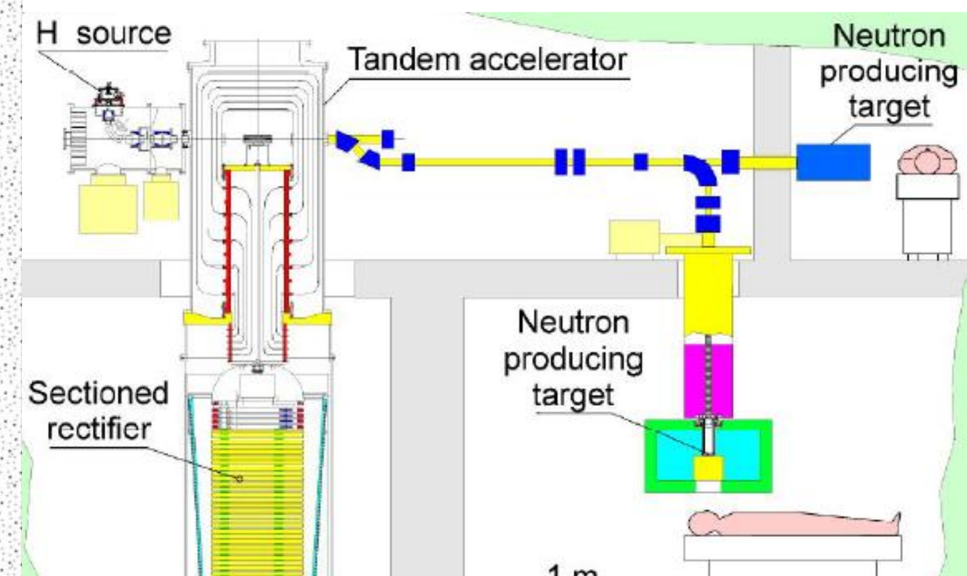
［出所］(独)日本原子力研究開発機構：地域病院との連携によるJRR-4を用いたがん治療研究への貢献、http://133.188.30.70/02/press2006/p06062601/index.html

8 MeV Linac driver/Be-target at Ibaraki in Japan (AFAD2012)



30 MeV Cyclotron driver/Be-target of Sumitomo H.I (JAAWS2010)





2 MeV ES driver/Li-target in Russia (JAAWS2010)