8th August, 2022
NAPAC 2022 at Albuquerque

Applications of Particle Accelerators

Mitsuru UESAKA,
Chairman, Japan Atomic Energy Commission
Professor of Emeritus, the University of Tokyo

CONTENTS

- Downsizing of Accelerators

- Medical RI Production by Best Mix of Research Reactors and Accelerators

- Sustainable Social Infrastructure

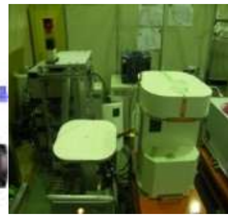
- Decommission of TEPCO Fukushima Daiichi Nuclear Power Station (FDNPS)

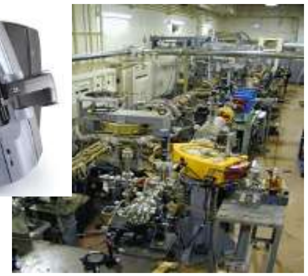
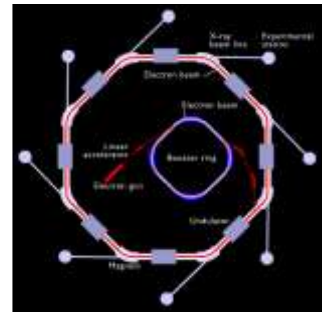
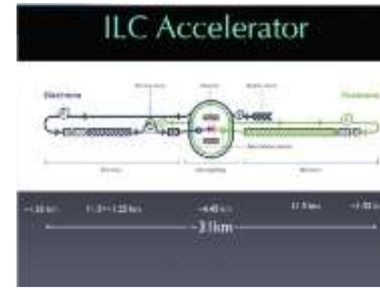
- Summary

Particle, Energy and Choice of Accelerators

100 keV 1 MeV 100 MeV 1 GeV 1 TeV

Electron

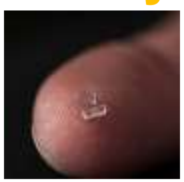



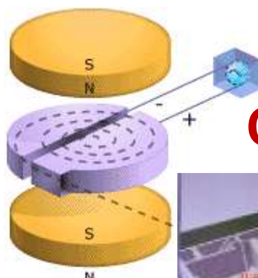




Linac

X-ray Tube

Linear Collider

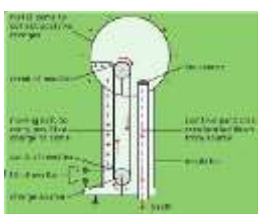


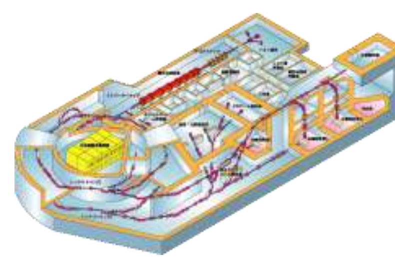
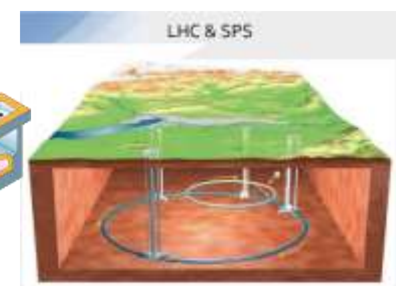



Cyclotron


Synchrotron

Ion

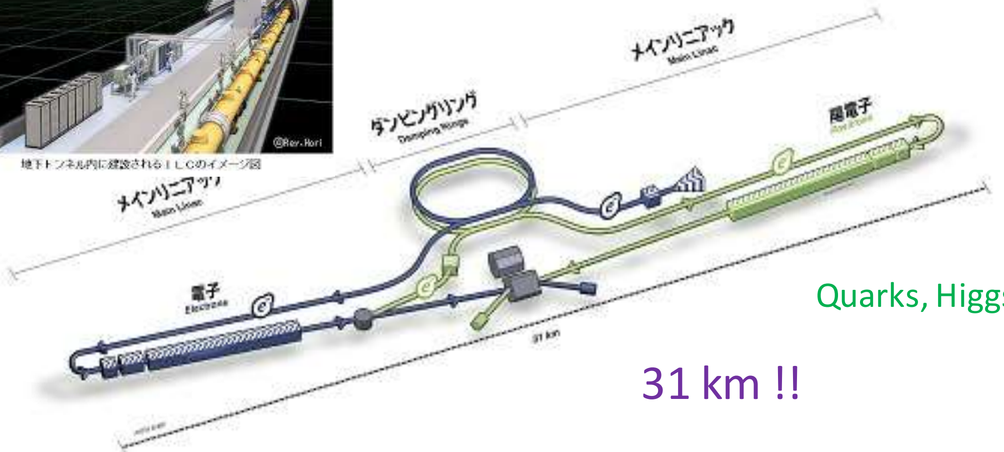


Electrostatic

Trials for Downsizing of International Linear Collider

地下トンネル内に建設されるＩＬＣのイメージ図

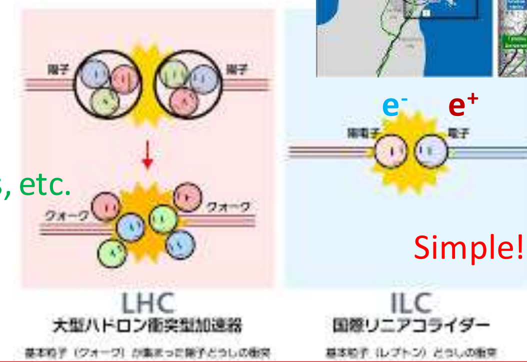


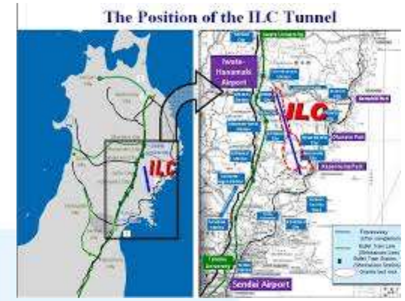
ILC Schema | Khwww.forre-one.de

31 km !!

Proton

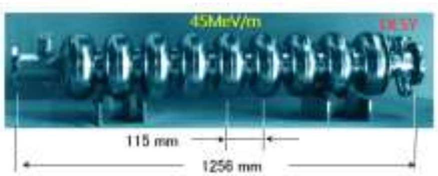
Quarks, Higgs, etc.





Alternatives

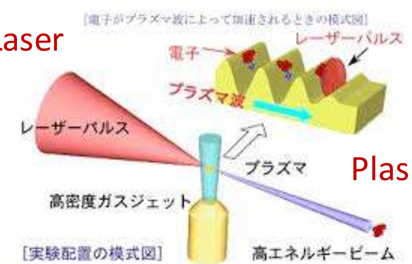
Superconducting Linac



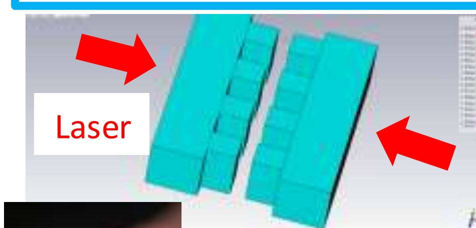
X-band (11.424GHz) Linac

11.424 GHz

Laser Plasma Accelerator



Optical Laser Dielectric Accelerator



Downsizing of Medical Accelerators by Advanced Technologies

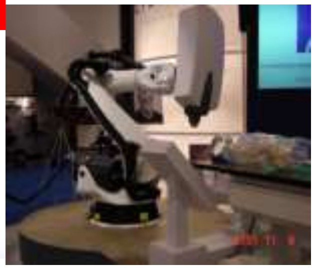
Electron Linac with S/C/X-bands

http://w ww.varian.com/

http://w ww.accuray.com/

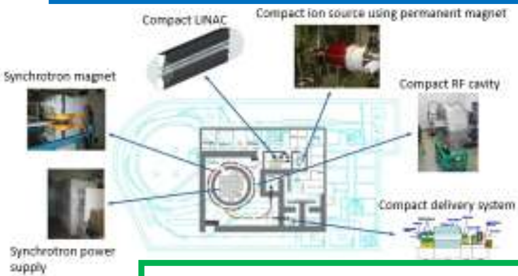
http://w ww.mhi-global.com/index.html

http://w ww.accuray.com/



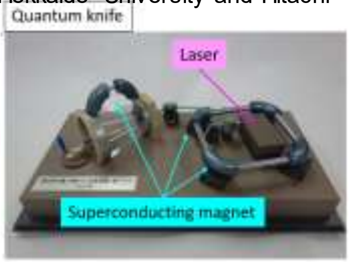
http://w ww.accuthera.com/

Synchrotron with Layout / SC



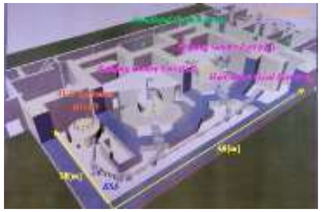
https://w ww.toshiba.co.jp/about/press/2015_11/pr1001.htm

Hokkaido University and Hitachi



Quantum Knife of QST

http://www.nirs.go.jp/ENG/core/ace/index.html



Cyclotron with SC / Layout

http://w3.ai-hosp.or.jp/ptc/proton_therapy_center.html

Review of Accelerators for Science and Technology, Vol.2(2009),p.154

J-PARC

LANSE

Neutron Source and BNCT

RANS of RIKEN

Cyclotron based BNCT at Fukushima

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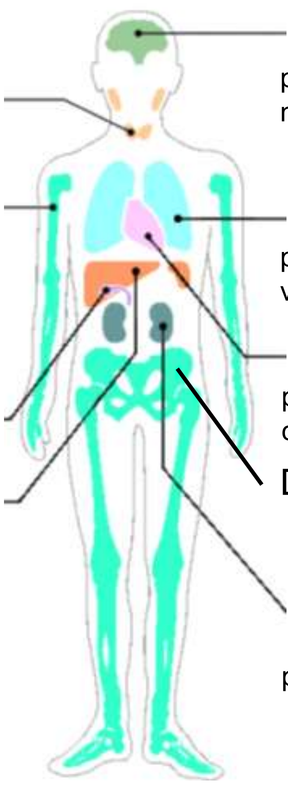
Clinical Nuclear Medicine

Uses of atomic energy for imaging of diseases and care for patients



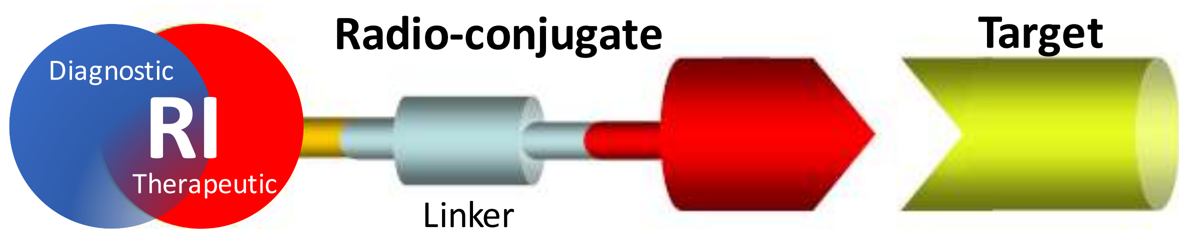
	radioisotope	purpose
gamma-emitting RI	$^{99}Mo/^{99m}Tc$, ^{123}I, ^{201}Tl, ^{67}Ga, ^{111}In, ^{89m}Kr, etc.	SPECT 1) imaging
positron emitting RI	^{18}F, ^{11}C, ^{15}O, ^{13}N ^{68}Ga, ^{89}Zr, etc.	PET 2) imaging
beta-emitting RI	^{131}I, ^{90}Y, ^{177}Lu, ^{64}Cu, etc.	thyroid diseases malignant lymphoma neuroendocrine tumor
alpha-emitting RI	^{223}Ra, ^{225}Ac, ^{213}Bi, etc.	prostate cancer with metastasis, etc.

1) SPECT: Single Photon Emission Computed Tomography
2) PET: Positron Emission Tomography

Theranostics is a concept of personalized medicine that combines diagnostics and therapeutics for **each patient**, using the **same** or **similar** diagnostic agent as the therapeutic agent, in order to 1) avoid harm to the patient and 2) ensure that the treatment is effective.

How it works?

Diagnostic or therapeutic isotopes bind to antibodies, peptides, or small molecules via chelation etc. Radio-conjugates bind specifically to antigens or receptors overexpressed on cancer cell membranes and emit radiation from those sites.



Radioisotope

Diagnostic: ^{18}F, ^{68}Ga, ^{99m}Tc, ^{123}I

Therapeutic: ^{131}I, ^{177}Lu, ^{211}At, ^{225}Ac

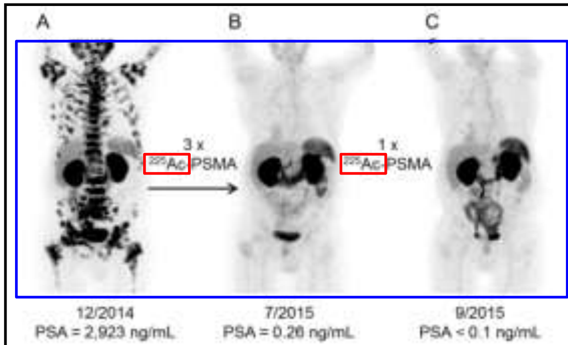


Figure 1: 68Ga-PSMA-11 PET/CT-scans of patient A. Pre-therapeutic tumor spread (A), restaging 2 months after the third cycle of Ac-225-PSMA-617 (B) and 2 months after one additional consolidation therapy (C).

In the case of bone metastasis, β-particles are expected to cause side effects in bone marrow due to their long range → Switch to treatment using α-emitters. (Pre-operative diagnostics)

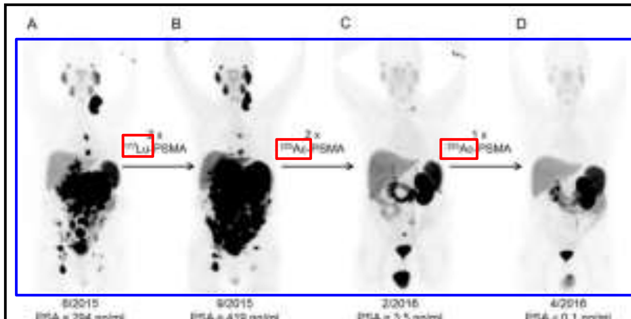


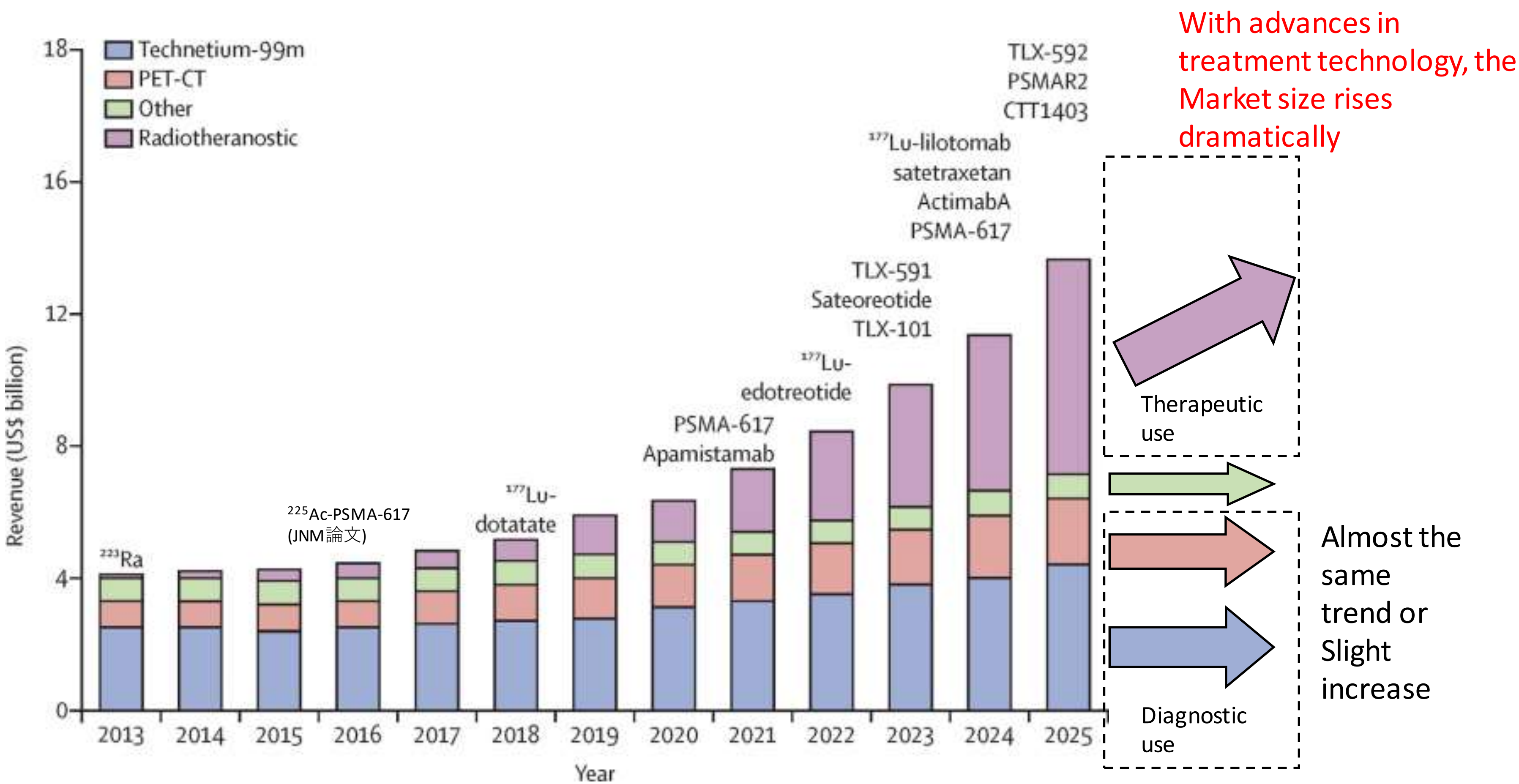
Figure 3: 68Ga-PSMA-11 PET/CT-scans of patient B. In comparison to the initial tumor spread (A), restaging after 2 cycles of beta-emitting 177Lu-PSMA-617 presented progression (B). In contrast, restaging after 2nd (C) and 3rd (D) cycle of alpha-emitting 225Ac-PSMA-617 presented impressive response.

Preoperative and postoperative diagnosis that decided to use alpha emitter because beta emitter did not work.

Kratochwil et al. J Nucl Med 2016;57:1941-1944

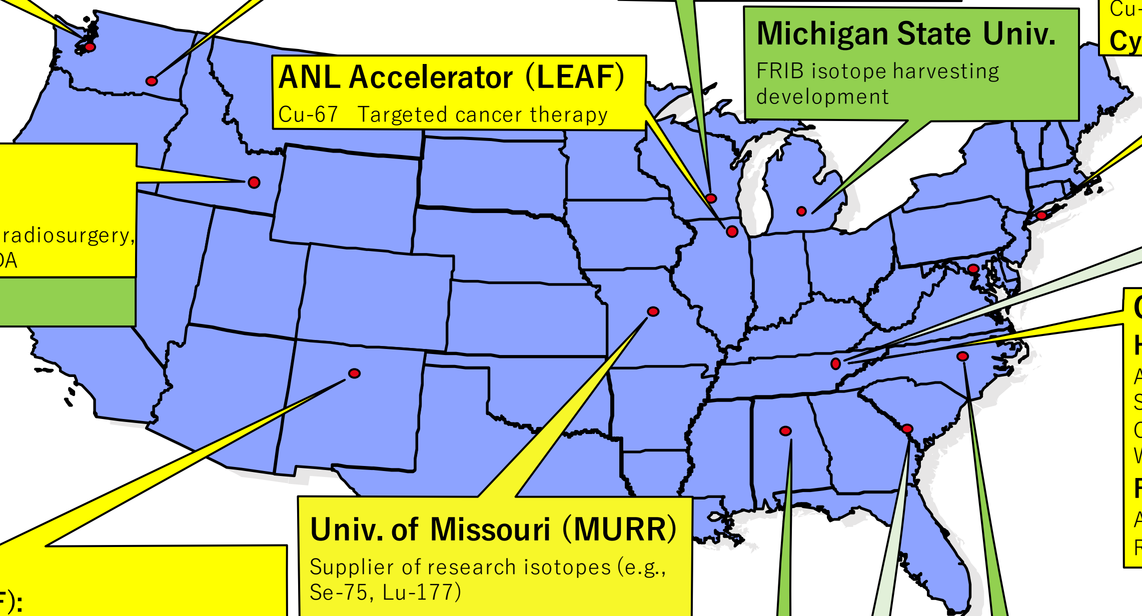
The left figures are notable for the fact that the ^{225}Ac-labelled agent has resulted in the complete remission of systemic metastases from prostate cancer. HOWEVER, the image is also symbolizing what theragnostics is all about. **We can optimize the treatment plan precisely for each patient using thragnostic technique.**

Revenue growth of the radiotheranostics field by market analysis



Herrmann K, Schwaiger M, Lewis JS, Solomon SB, McNeil BJ, Baumann M, Gambhir SS, Hricak H, Weissleder R. Radiotheranostics: a roadmap for future development. Lancet Oncol. 2020 Mar;21(3):e146-e156. Adapted with permission from Paul-Emmanuel Goethals and Richard Zimmermann (Nuclear Medicine MEDraysintell Report & Directory, July 2019)

DOE Isotope Program Production Sites



Univ. of Washington
Supplier of research isotopes (e.g., At-211)

PNNL
Sr-90 Y-90 generator for cancer therapy

Univ. of Wisconsin
Supplier of research isotopes (e.g., Mn-52)

BNL
Accelerator (BLIP):
Ac-225 Targeted cancer therapy
Ti-44 Sc-44 generator for PET imaging
Y-86 PET imaging
Cu-67 Targeted cancer therapy
Cyclotron (TR-19)

Michigan State Univ.
FRIB isotope harvesting development

ANL Accelerator (LEAF)
Cu-67 Targeted cancer therapy

INL
ATR Reactor:
Co-60 Stereotactic radiosurgery, industrial NDA
Rad EMIS

Y-12 (NNSA Facility)
Li-6 Neutron detection
Li-7 Radiation dosimeters

ORNL
HFIR Reactor:
Ac-227 Cancer therapy
Se-75 Industrial NDA
Cf-252 Industrial sources
W-188 Cancer therapy
Radioisotopes Inventory:
Ac-225 Cancer therapy
Ra-223 Cancer therapy
Stable Isotopes Inventory:
E.g., Ca-48, Ga-69, Rb-87, Cl-37
Stable Isotope Production:
ESIPP
SIPF
SIPRC

LANL
Accelerator (IPF):
Ac-225 Targeted cancer therapy
Ti-44 Sc-44 generator for PET imaging
Cd-109 X-ray fluorescence analyses
As-73 Environmental tracer
Si-32 Oceanographic research
Plutonium Facility (PF-4):
Am-241 Oil and gas exploration

Univ. of Missouri (MURR)
Supplier of research isotopes (e.g., Se-75, Lu-177)

Univ. of Alabama Birmingham
Supplier of research isotopes (e.g., Mn-52)

Duke University
Supplier of research isotopes (e.g., At-211)

SRNL (NNSA Tritium Facility)
He-3 Neutron detection
Fuel source for fusion reactors
Lung testing

TRIUMF & CNL

TRIUMF:トライアンフ研究所（国立素粒子原子核物理研究所）
CNL(Canadian Nuclear Laboratories)：カナダ国立原子力研究所

Institute for Advanced Medical Isotopes
(IAMI)

^{225}Ac Production Milestones

Year	2020	2021	2022	2023	2024	2025
^{225}Ac* produced (Ci)	0.05	<0.15	0.5	Up to 3-6 Ci, depending on demand and revenue milestones		
^{227,225}Ac† produced (Ci)	0.2	<0.6	2.0	Up to 12-24 Ci, depending on demand and revenue milestones		

22


TRIUMF

Today during a special visit to TRIUMF, Prime Minister of Canada His Right Honourable Justin Trudeau announced federal funding to support the establishment of the Institute for Advanced Medical Isotopes (IAMI). #IAMI will be a state-of-the-art facility for research into next-generation, life-saving medical isotopes and radiopharmaceuticals. With partners University of British Columbia and BC Cancer Foundation, IAMI will bring secured isotope supplies for nuclear medicine research, next-generation cancer therapies, accelerated drug development, increased industry investment, and improved health outcomes for Canadians.

Thank you for visiting us today, PM Trudeau, and for sharing this tremendous commitment to supporting Canadian science and innovation! Full release here: https://www.newswire.com/.../prime-minister-of-canada-announc...

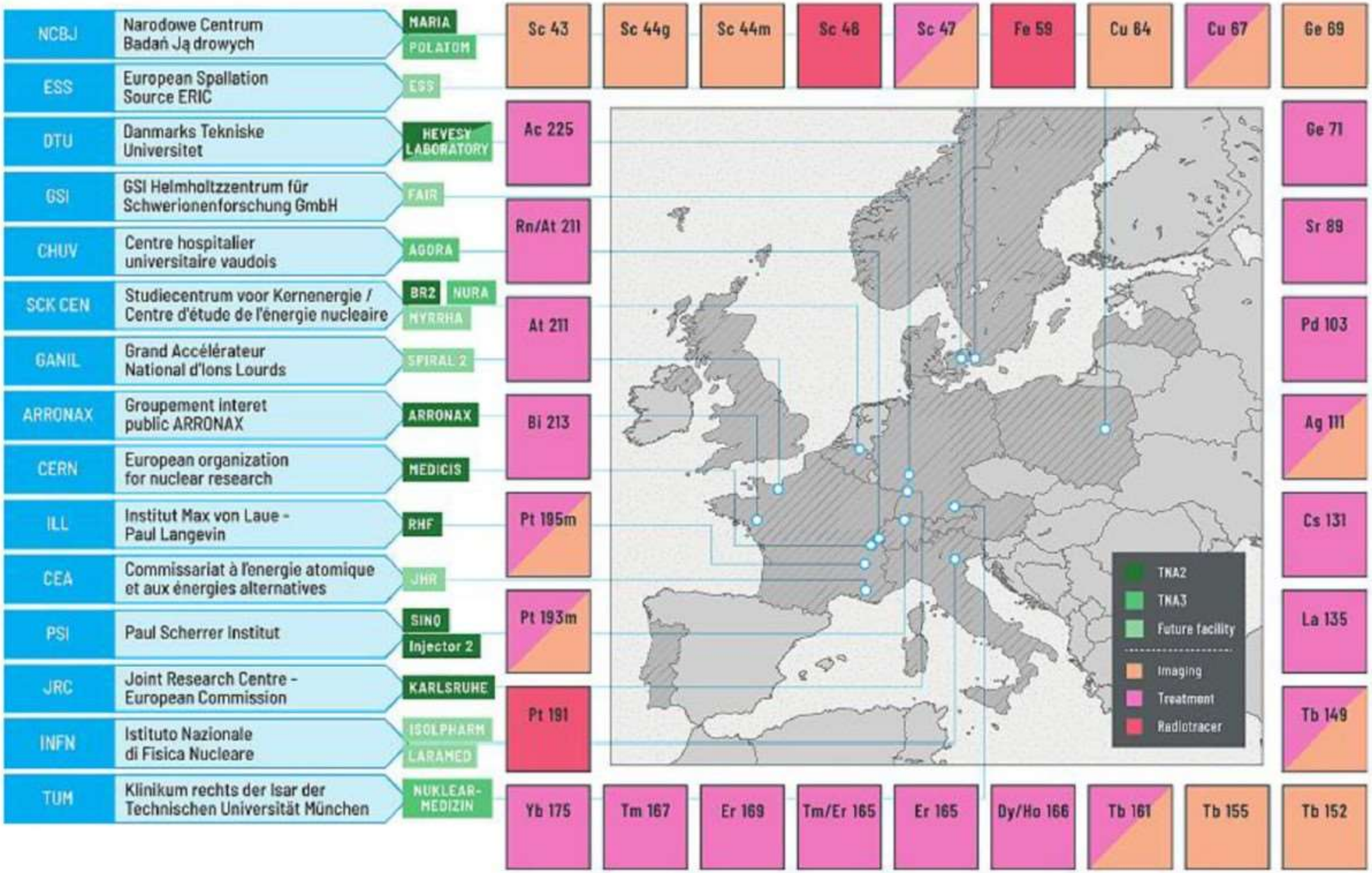
Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

^{229}Th/^{225}Ac ジェネレータ
148-185MBq(4-5mCi)/month

TRIUMFのツイッターコメントより
カナダ首相ジャスティン・トルドー氏がTRIUMF に 訪 問 (2018/11/2) し 、Institute for Advanced Medical Isotopes（IAMI）の設立を国家的に支援すると宣言。IAMIではTc-99mやAc-225を製造。

This slide is reproduced and slightly modified by the courtesy of Dr. P Schaffer and Prof. H Fukuda, and Prof. T Nakano

PRodución of high purity Isotopes by mass Separation for Medical Applicaion 2020

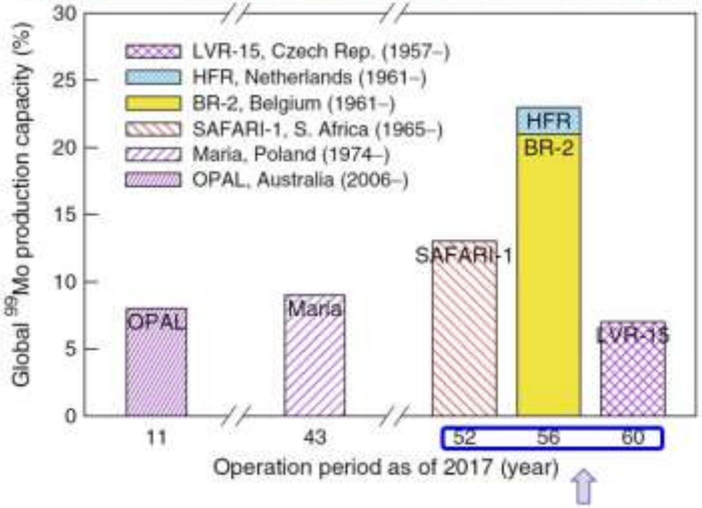


$^{99}Mo/^{99m}Tc$ Production Shift

Highly Enriched U Research Reactors and Air Transportation

Low Enriched U Research Reactors / Medium Sized Accelerators and Just-in Supply

From: J. Jang, M. Yamamoto, and M. Uesaka (2017), Phys. Rev. Accel. Beams 20, p. 104701



Three, out of six, are reaching the end of service lives
Alternative source of ^{99}Mo is necessary!

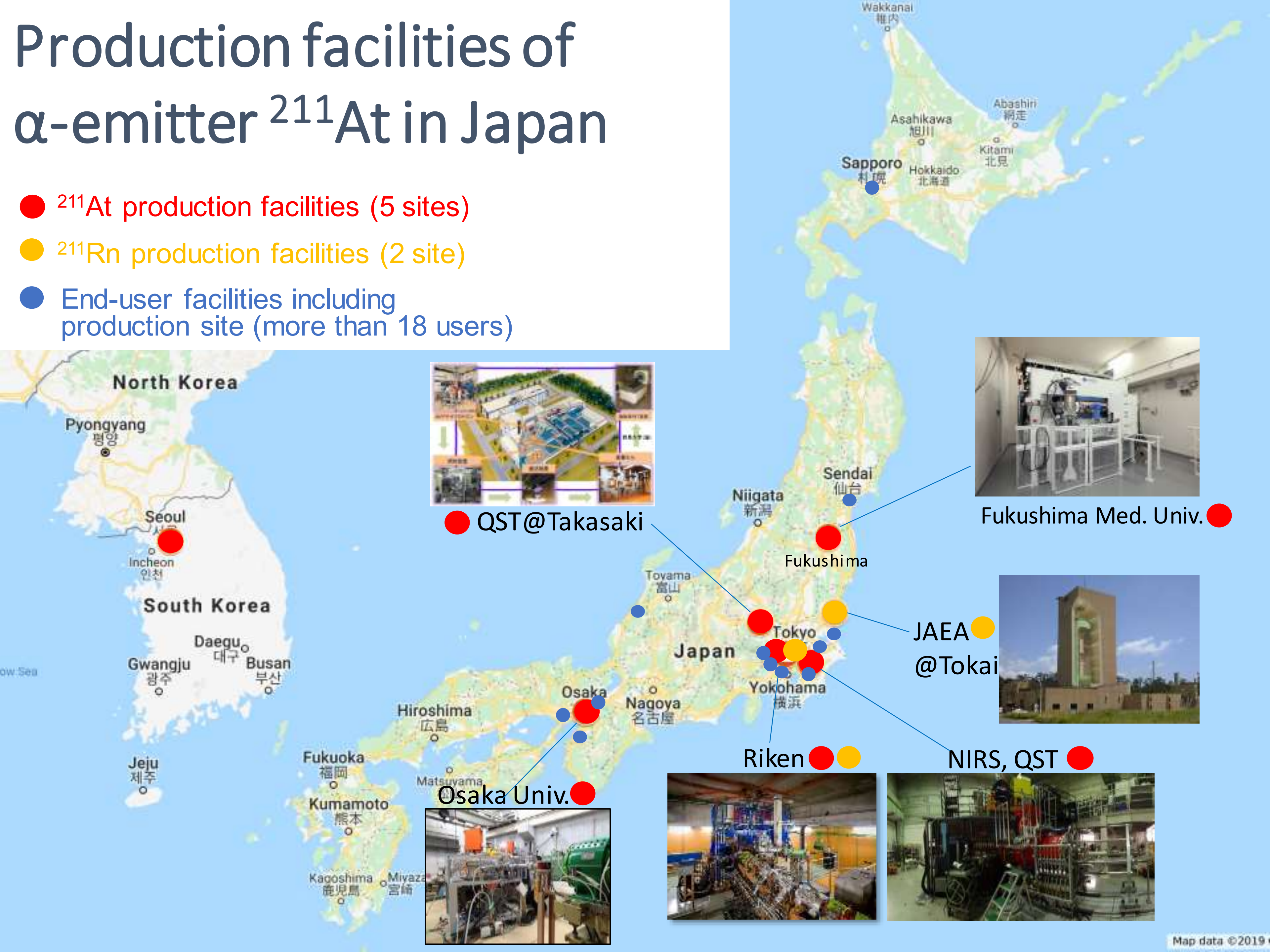
MURR

Electron Rhodotron

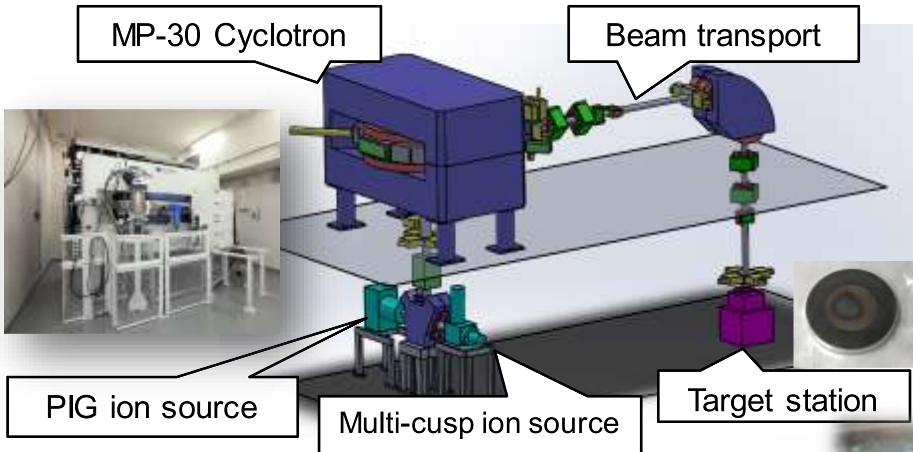
Electron Linac γ-ray Source

Production facilities of α-emitter ^{211}At in Japan

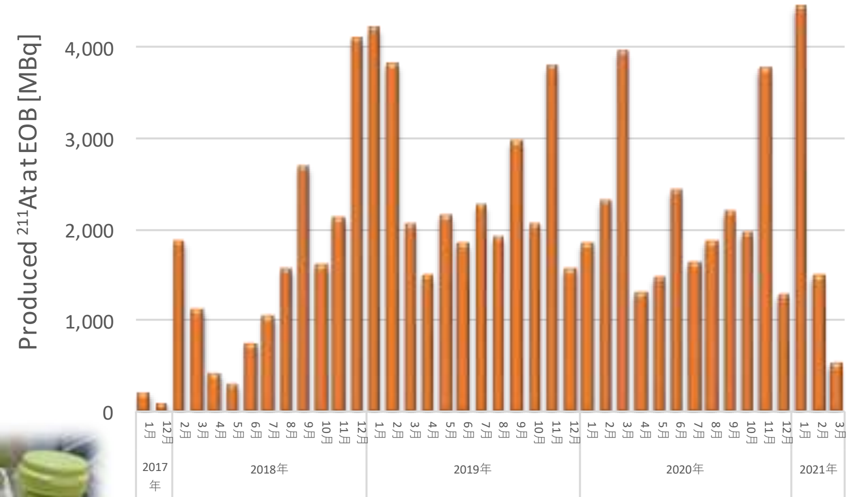
- ^{211}At production facilities (5 sites)
- ^{211}Rn production facilities (2 site)
- End-user facilities including production site (more than 18 users)



Advanced **C**linical **R**esearch **C**enter(ACRC): An ^{211}At Manufacturing and R&D site at **F**ukushima **M**edical **U**niversity(FMU)



The MP-30 cyclotron and its irradiation system



Monthly production of ^{211}At at FMU

Purpose of ACRC Establishment

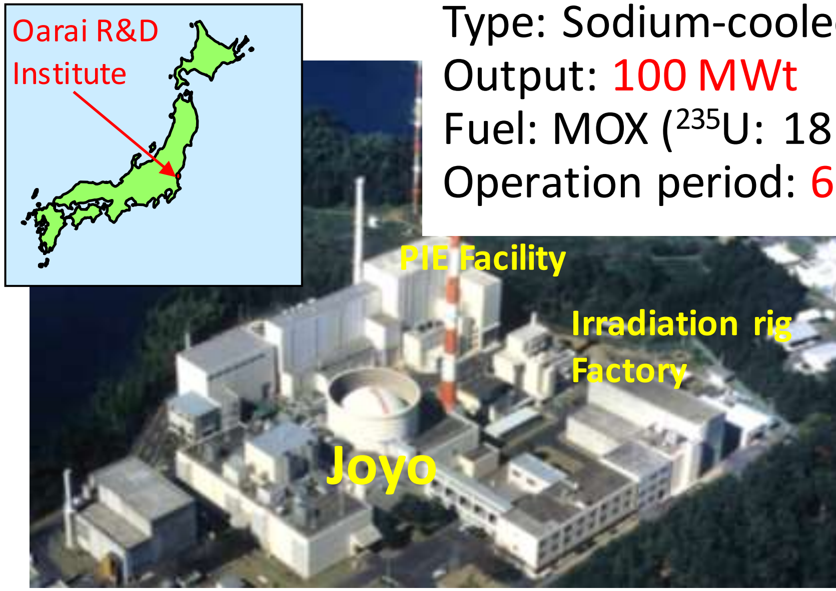
- Established as a center for early diagnosis of various diseases using PET/MRI and PET/CT.
- Aims to improve the level of medical care and research by establishing an environment that enables the translational research and clinical application
- Contribute to the healthcare of the Fukushima citizen by investigating and analyzing radioactive materials in the environment in collaboration with the Quantum Science and Technology Agency (QST).

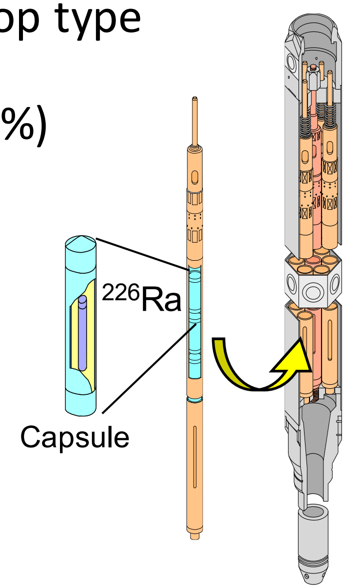
Our ^{211}At R&D pipeline

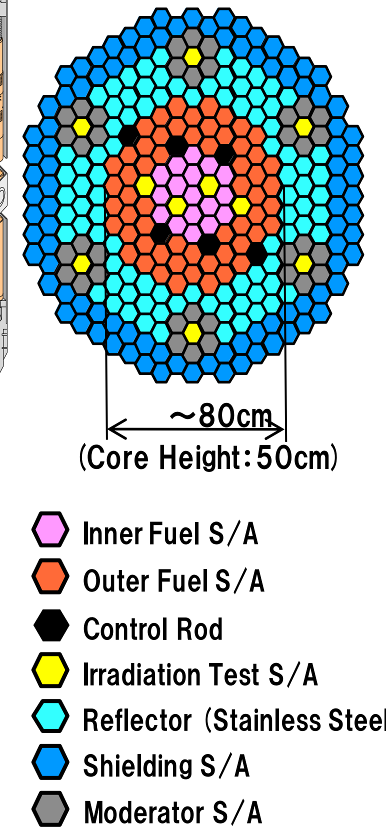
- Clinical trial using MABG (collaboration work with QST)
  Ukon et al. Ann Nucl Med **36**, 695 (2022); EJNMMI Physics **7**, 58 (2020).
- Development of pretargeting strategy using low immunogenic streptavidin scFv conjugate and improved iminobiotin derivatives （collaboration work with UTokyo）
  Washiyama et al., J Nulc Med **61** (suppl1) 1212 (2020).
- Development of ^{211}At labeled Bombesin derivatives
  Aoki et al., Chem. Pharm. Bull. **68**, 538–545 (2020).
- ^{211}At labeled CXCR4 antibody for cancer stem cell targeted radionuclide therapy
  Oriuchi et al., Sci Rep **10**, 6810 (2020).

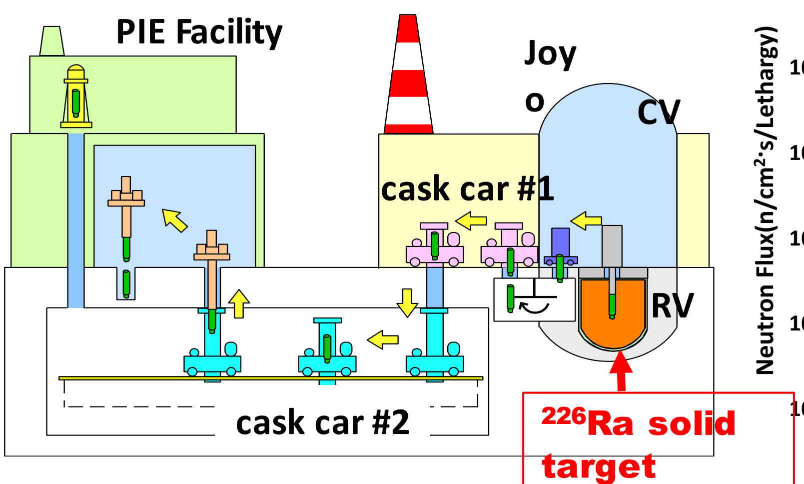
^{225}Ac Production by Research Fast Reactor, Joyo

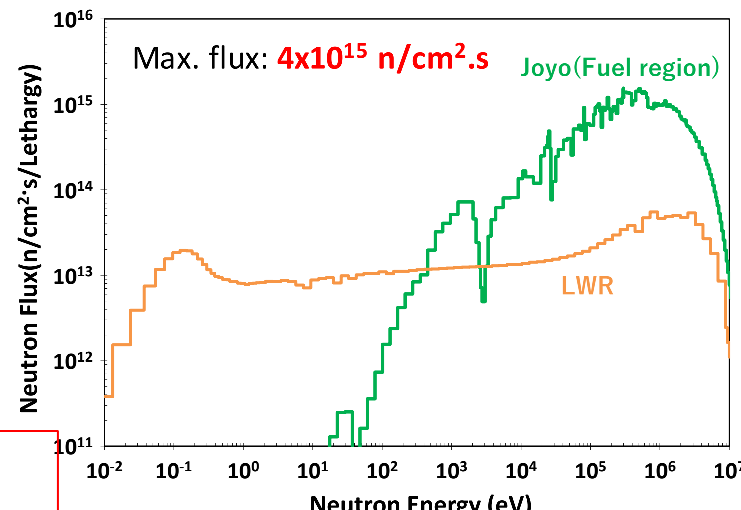
Type: Sodium-cooled fast reactor, loop type
Output: 100 MWt
Fuel: MOX (^{235}U: 18 wt%, Pu: <30 wt%)
Operation period: 60 days/cycle









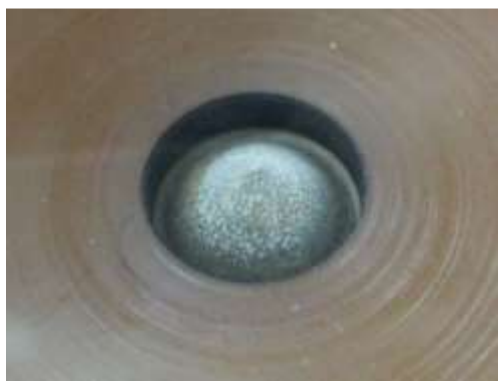


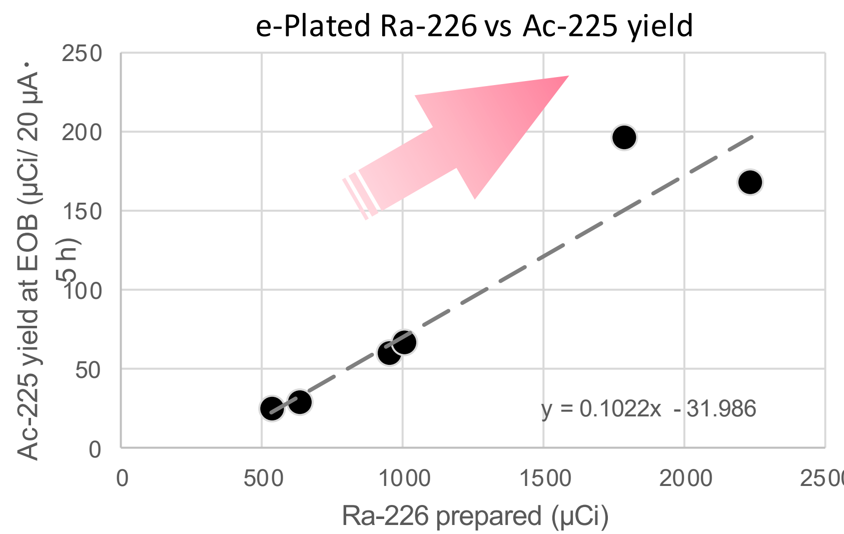
^{225}Ac Yield by solid ^{226}Ra and Proton Cyclotron

QST and Nihon Medi+phisics

H_2^+ 34 MeV 15.6 MeV proton on target	#1	#2	#3	#4	#5	#6	#7
Ra-226 Target prepared	13.5 MBq (366 μCi)	35.4 MBq (956 μCi)	37.5 MBq (1.01 mCi)	19.8 MBq (536 μCi)	23.6 MBq (639 μCi)	66.2 MBq (1.79 mCi)	83.0 MBq (2.24 mCi)
e-Plating efficiency	94%	97%	97%	98%	97%	69%	88%
Activation (μA·h)	20 μA·3 h	← — — — 20 μA·5 h — — — →					
Ac-225 Yield (@EOS/ 4 d from EOB)	522 kBq (14 μCi)	2.23 MBq (60 μCi)	2.43 MBq (66 μCi)	904 kBq (24 μCi)	1.03 MBq (28 μCi)	7.25 MBq (196 μCi)	6.16 MBq (167 μCi)


Ra-dedicated Vertical Target station *


Electroplated Ra (1 mCi) on conical Au surface **



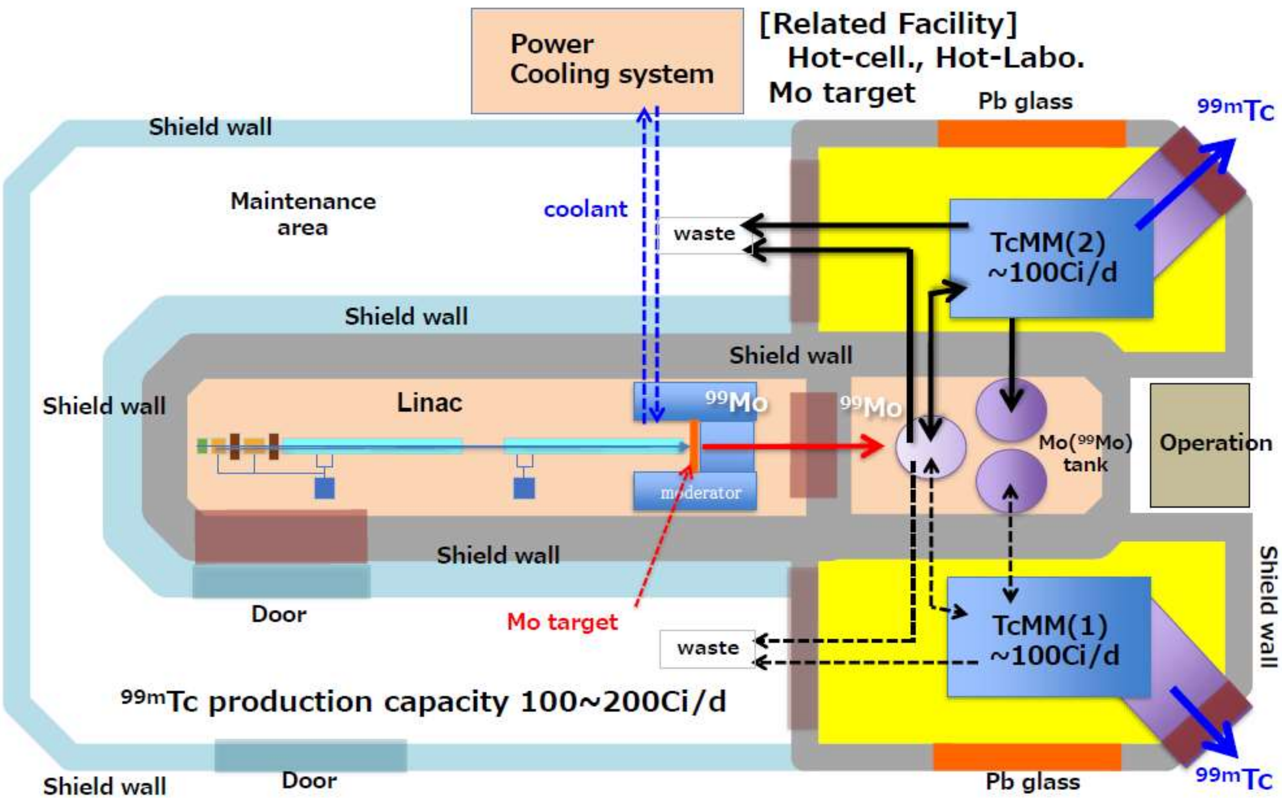
* Japanese Patented #6450211 (filed on Dec 14, 2018); ** Japanese Patent Application #2018-060672 (filed on Mar 27, 2018);
Nagatsu K, *Eur J Nucl Med Mol Imaging* (2021) 10.1007/s00259-021-05460-7

35 MeV 35 kW S-band Electron Linac γ-ray / Neutron Sources for Production of ^{99}Mo/^{99}mTc and ^{225}Ac

1. γ-ray / Neutron sources for ^{99}Mo/^{99m}Tc from ^{100}Mo / ^{98}Mo

^{99}Mo/^{99m}Tc and Medicine Production Facility
Production Capacity is 100-200 Ci/week

~5 facilities in Japan
~100 in the world
(expected)



University of Tokyo
(Nuclear Professional School/Dept Nucl &Eng/Bioeng Dept/ Isotope Sci Center)
Kyoto University
Hitachi Co.
Accuthera Inc.
KAKEN

2. γ-ray sources for ^{225}Ac production from ^{226}Ra target

Similar scale
(expected)

Action Plan for Promotion of Production and Utilization of Medical Radioisotopes (Outline)

31st May, 2022 Atomic Energy Commission, Japan

Background

Expectations for Radioisotope Therapy

- Increased focus on ***"theranostics"*** (therapy + diagnosis)

Movements and Problems in Japan

- ***Restart of research reactors*** that can produce large amounts of radioisotopes (JRR-3,"Joyo")

On the other hand, insufficient number of
- ***Hospital beds*** for radioisotope therapy
- ***Human resources*** who promote production and utilization of radioisotopes

International Situation

- ***Vast investment*** for radioisotope production and R&D
- Forming network of research reactors and accelerators
- Accelerated ***competition for acquisition*** of radioisotopes and their raw materials

Developing the Action Plan that aims to provide domestic radioisotopes to patients

The Action Plan contributes to

-Improvement of people's welfare by enhancing the medical system through cutting-edge nuclear science and technology

- Ensuring economic security in terms of medical services

Goals to be Achieved during next decade

①**Establishment of a Stable Radioisotope Diagnostic System through *partial domestic production of Mo-99/Tc-99m***

②**Implementation of *Radioisotope Treatment Using Domestic Radioisotopes***

③***Dissemination of Radioisotope Treatment* in Medical Setting**

④**Making Radioisotope-Related Fields, centered on Medicine, as a *"Strength" of Japan***

Contents of the Action Plan

(1)Promoting Initiatives for Domestic Production and Stable Supply of "Important Radioisotopes"

・Stable supply of ***Mo-99/Tc-99m*** using JRR-3 and accelerators
(Manufacturing approximately ***30% of domestic demand*** by the end of FY2027 as far as possible, and supply to domestic)
・Strengthening R&D for mass production of ***Ac-225*** using "Joyo" and accelerators （Production demonstration by FY2026 with "Joyo"）
・Strengthening efforts to commercialize ***At-211*** （Indicating usefulness as a pharmaceutical product by FY2028）

(2)Establishment of systems and structure to promote utilization of radioisotopes in medical setting

・Establishment of hospital rooms for radioisotope treatment （Average number of months to wait for radioisotope treatment: ***3.8m（2018）->2m（2030）***）
・Preparation for commercialization of new radiopharmaceuticals （Th-227, Ga-68）

(3)Promoting R&D Contributing to Domestic Production of Radioisotopes

・Technical development support for production by research reactors and accelerators
・Promotion of initiatives by the Fukushima International Research and Education Organization
・Establishment of systems of non-clinical studies of radiopharmaceuticals

(4)Strengthening Research Infrastructures, Human Resources, and Networks for Production and Utilization of Radioisotopes

・Strengthening Human Resources in the Field of R&D and Medical Setting ・Strengthening the Supply Chain in line with Domestic Production
・Study of Mechanisms for Waste Treatment and Disposal

Japan's Stance toward Radioisotope Production (Tentative Translation)

Basic Policy on Economic and Fiscal Management and Reform 2022 「骨太の方針」(Approved by the Cabinet on June 7, 2022)

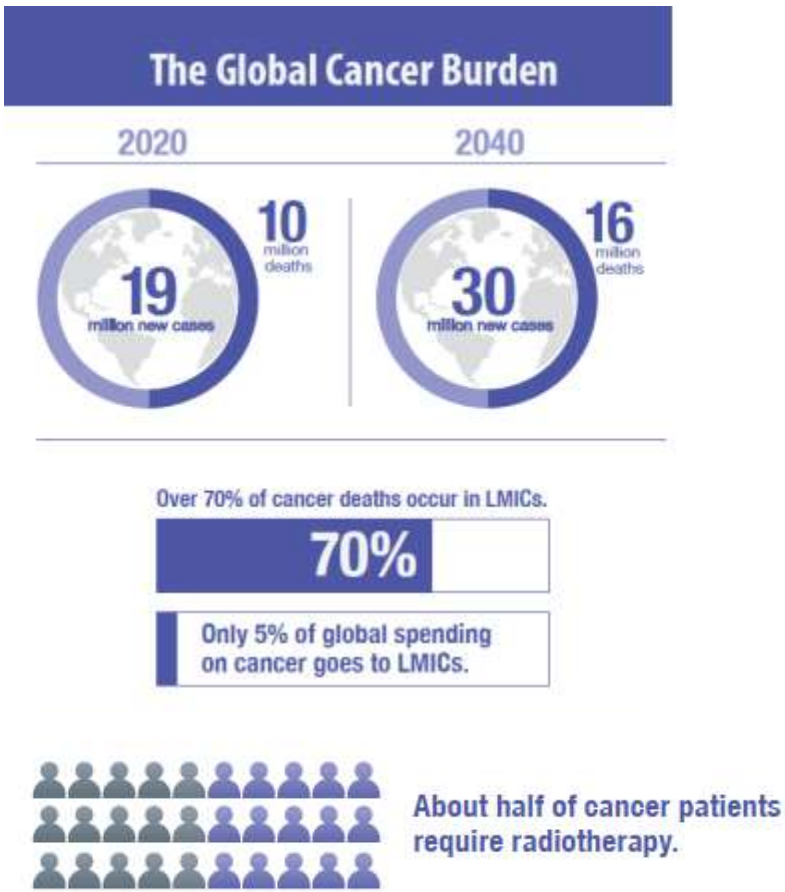
Chapter 4 Medium-to long-term economic and financial management
５．Promoting education and research activities that support socioeconomic vitality

(omitting the beginning)
We will implement the "Sixth Science, Technology and Innovation Basic Plan" [162] and **sector-specific strategies**[163] to bring about a sustainable economy and society through public-private partnerships.
(omitting the beginning)

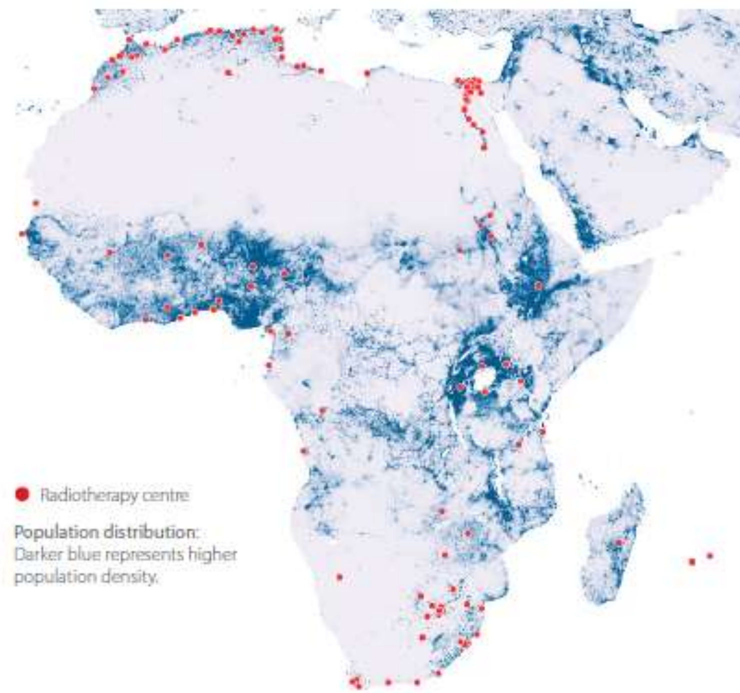
＜注釈＞
【162】Approved by the Cabinet on March 26, 2021
【163】AI, biotechnology, quantum technologies, materials, environmental energy, safety/security, health/medical care, space, oceans, food/agriculture, forestry and fisheries are positioned as strategically important fields in the "6th Science, Technology and Innovation Basic Plan". **We will also pursue efforts in accordance with "The Action Plan for Promotion of Production and Utilization of Medical Radioisotopes ".**

The following government documents also mention the promotion of "The Action Plan for Promotion of Production and Utilization of Medical Radioisotopes " :
Grand Design and Action Plan for a New Form of Capitalism Follow-Up「新しい資本主義」(Approved by the Cabinet on June 7, 2022)
Integrated Innovation Strategy 2022「統合イノベーション戦略」(Approved by the Cabinet on June 3, 2022)

Rays of Hope will integrate the breadth of the IAEA’s expertise to support Member States in the diagnosis and treatment of cancer using radiation medicine.



OVER 70% OF THE POPULATION OF AFRICA DOES NOT HAVE ACCESS TO RADIOTHERAPY.



In Africa, over 700,000 people died of cancer in 2020.
More than 20 African countries have no radiotherapy treatment unit.

IAEA "Rays of Hope" brochure https://www.iaea.org/sites/default/files/22/02/rays-of-hope-v2.pdf

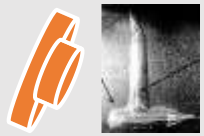
Nuclear Medicine from Nuclear Waste by University of Tokyo's Group

α emitter ^{225}Ac for cancer therapy from waste (^{226}Ra) at U-fuel production

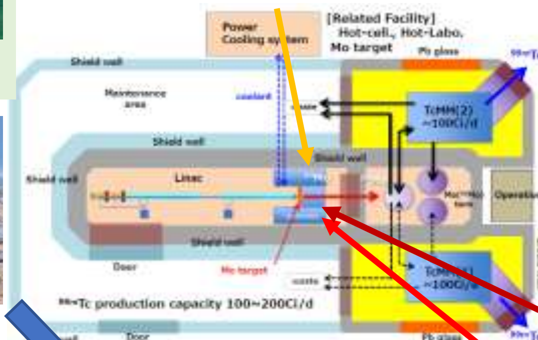
Chemical extraction of ^{226}Ra from U mining waste

(~15g ^{226}Ra from 30km^3)

Solid or Liquid ^{226}Ra Targets



Supply for Fundamental Research



^{225}Ac

^{67}Cu

^{99}Mo/ ^{99m}Tc

Supply for Clinical Uses

^{99}Mo/^{99m}Tc (SPECT), 100 B¥/year @JAPAN

Fuel Cycle Plant

Decommissioning Plant

Debris without Fuel Materials

Mixer-Settler

^{68}Zn

^{98,100}Mo

^{67}Cu (PET)
^{225}Ac (α)
(Theranotics= Theraputic+Diagnosis)

γ Emitter RIs (^{99}Mo / ^{99m}Tc) for cancer diagnosis from spent fuel waste (Mo)

Best Mix of Supply

Energy

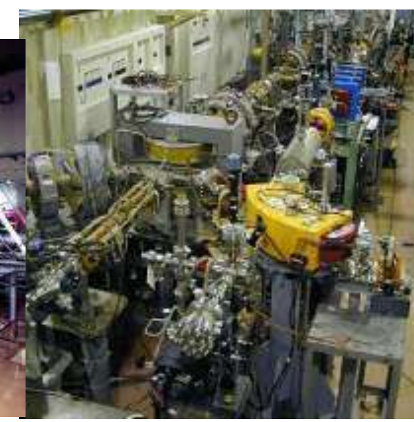



Medical RIs

LEU
Research Reactor

Fast Reactor

Proton Cyclotron

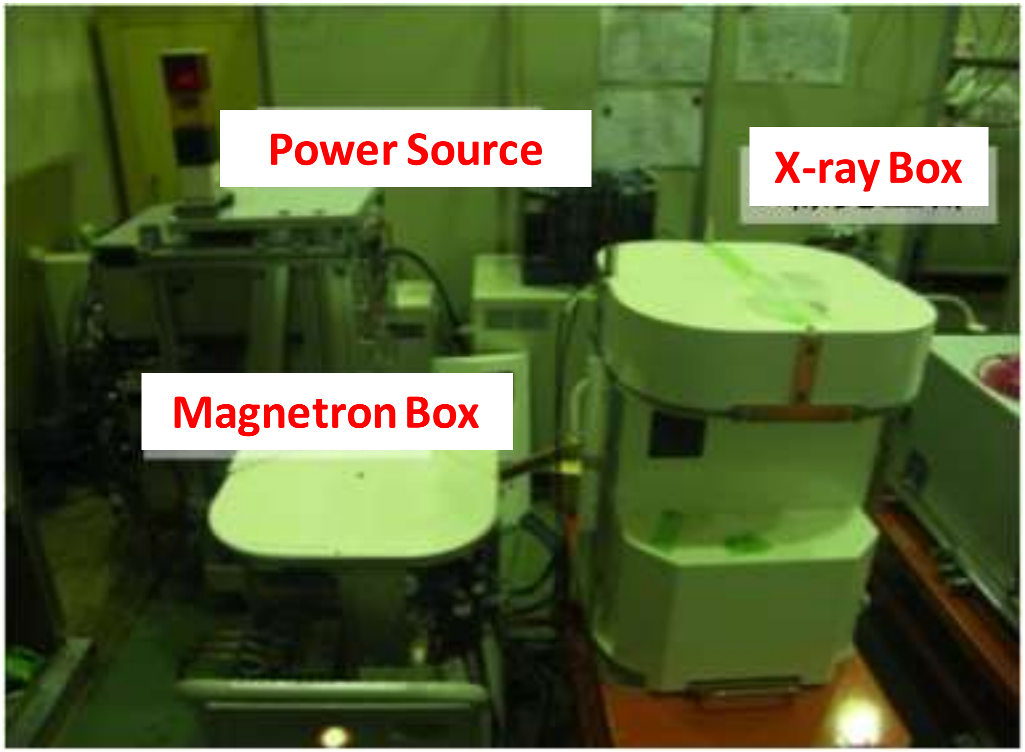


Electron
Linear Accelerator

CONTENTS

- Downsizing of Accelerators
- Medical RI Production by Best Mix of Research Reactors and Accelerators
- Sustainable Social Infrastructure
- Decommission of TEPCO Fukushima Daiichi Nuclear Power Station (FDNPS)
- Summary

Portable X-band (9.3 GHz) 950 keV System by University of Tokyo

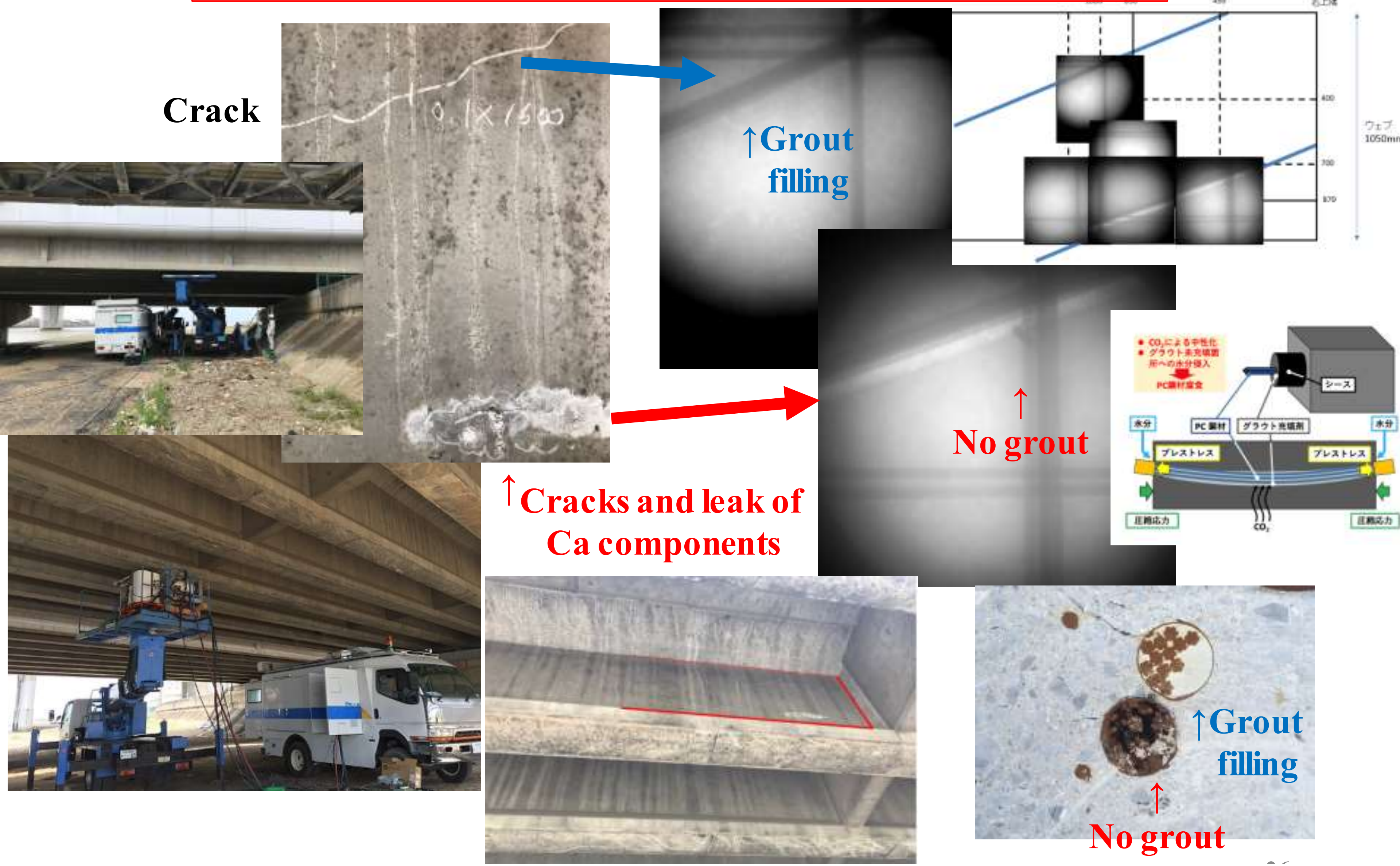


According to the Japanese Law on radiation safety, an electron beam source below 1 MeV is not defined as an accelerator. Thus, we comply with the Regulations on radiation safety, which is rather reasonable.

Thus, we use it any place by setting our self-designed radiation controlled area.

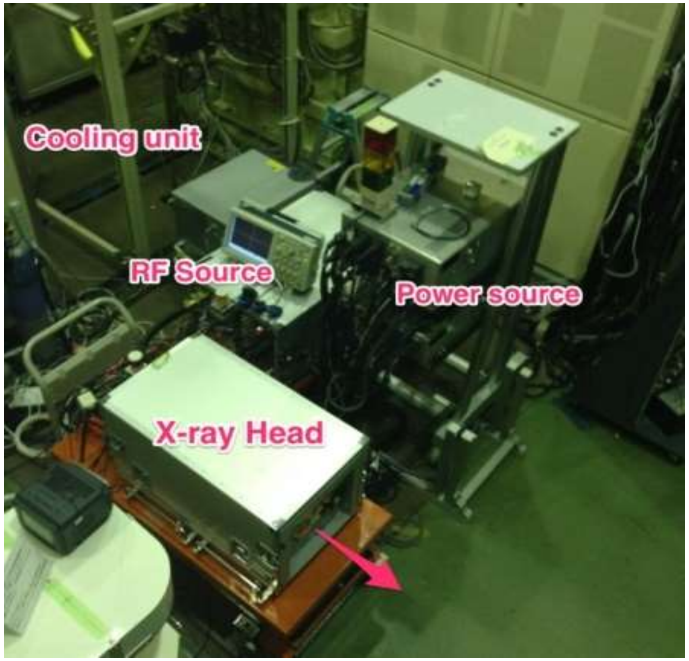
Parameters of Accelerator	
Operating frequency	9.3 [GHz]
RF source	Magnetron
RF Power	250kW
Width and number of repetitive of pulse	2[μs], 280[PPS]
Length of acceleration tube	25[cm]
Form of acceleration tube	Side coupled structure
Number of accelerating cell	Half1 + full8
Coupling between cells	3％
Filling time	0.18μs
Shunt impedance	110-130MΩ/m Regular part
Beam current	64mA or more
Focusing fashion	RF focusing
Intensity of X-ray	50[mGy/min] or more at 1[m]
Voltage of electron gun	20KV
Electron gun	Triode

On-site X-ray Inspection by 950 keV system for PC (Prestressed Concrete) bridges of up to ~50 cm thickness



X-ray transmission images indicate reinforced iron rods and grout filling and not-filling around the PC wires in the PC sheath clearly

Portable 3.95MeV X-band linac X-ray source of University of Tokyo

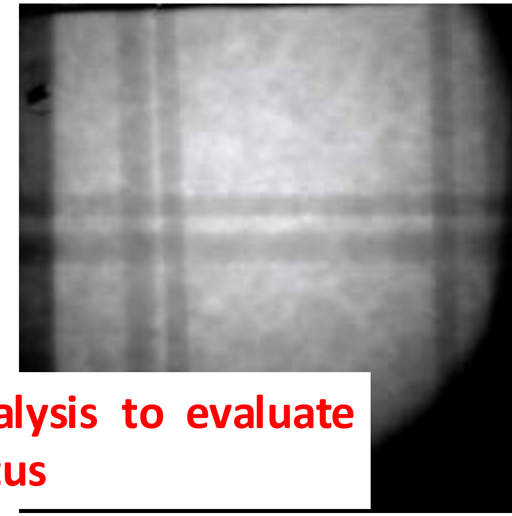


Main unit	Accelerating tube	RF Source	HVPS Control
Weight (kg)	80+62 (Collimator +Accelerating tube)	62	116
Parameters	Electron gun output current 300mA	Frequency 9.3GHｚ	
	Electron gun voltage 20kV	Pulse width 4μs	
	Beam current 100mA	Repetition rate 200pps	
		RF power output 1.5 MW	

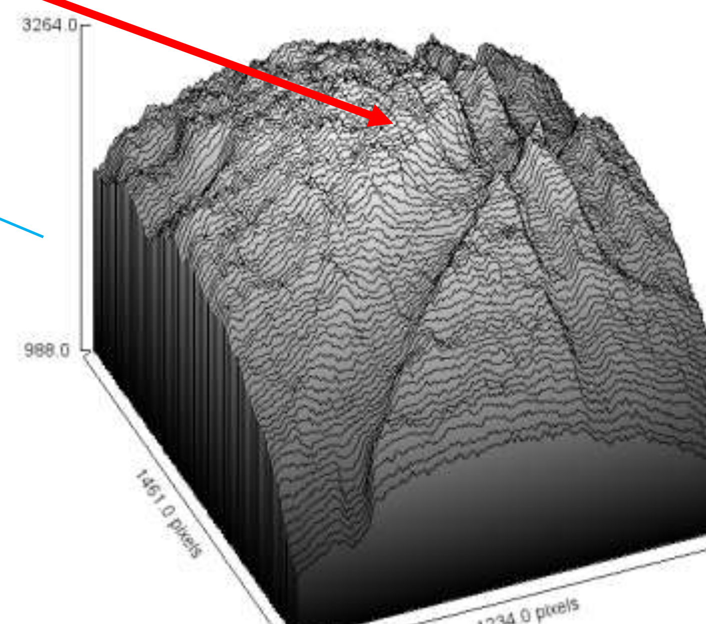
Amendment of the law that allows use of accelerators below 4 MeV accelerator for only for on-site bridge inspection was implemented in Japan in 2005. That is why we set its energy 3.95 MeV just below 4 MeV.

This machine can be also used as a neutron source with 10^7 neutrons / sec by using a solid Be target

On-site X-ray Inspection by 3.95 MeV system for PC (Prestressed Concrete) bridges of up to ~1 m thickness



Gray value image processing analysis to evaluate the grout filling and not-filling status

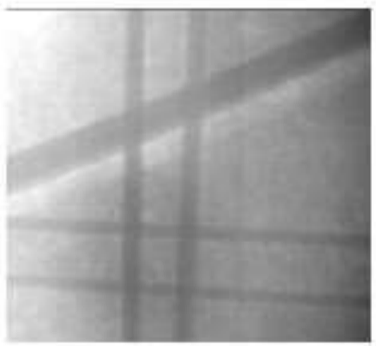


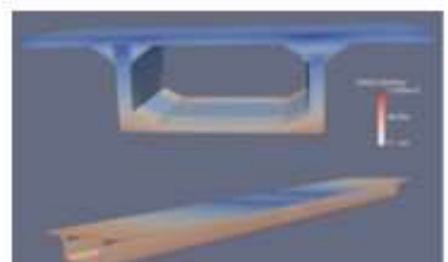
More than 10 real bridges and one highway bridge under the Japanese national project

Formation of Technical Guideline for On-site X-ray Bridge Inspection

Visual and hammering-sound inspections → **X-ray inspection** → **Structural analysis** → **Repair and reinforcement**







We hope to apply this guidelines to all aged bridges soon in Japan and finally in the world

Fighting with Rains and Salty Sea Breeze in Japan








Dedicated Car with Power Source

Japanese carefulness and endurance

Waterproof electric housing



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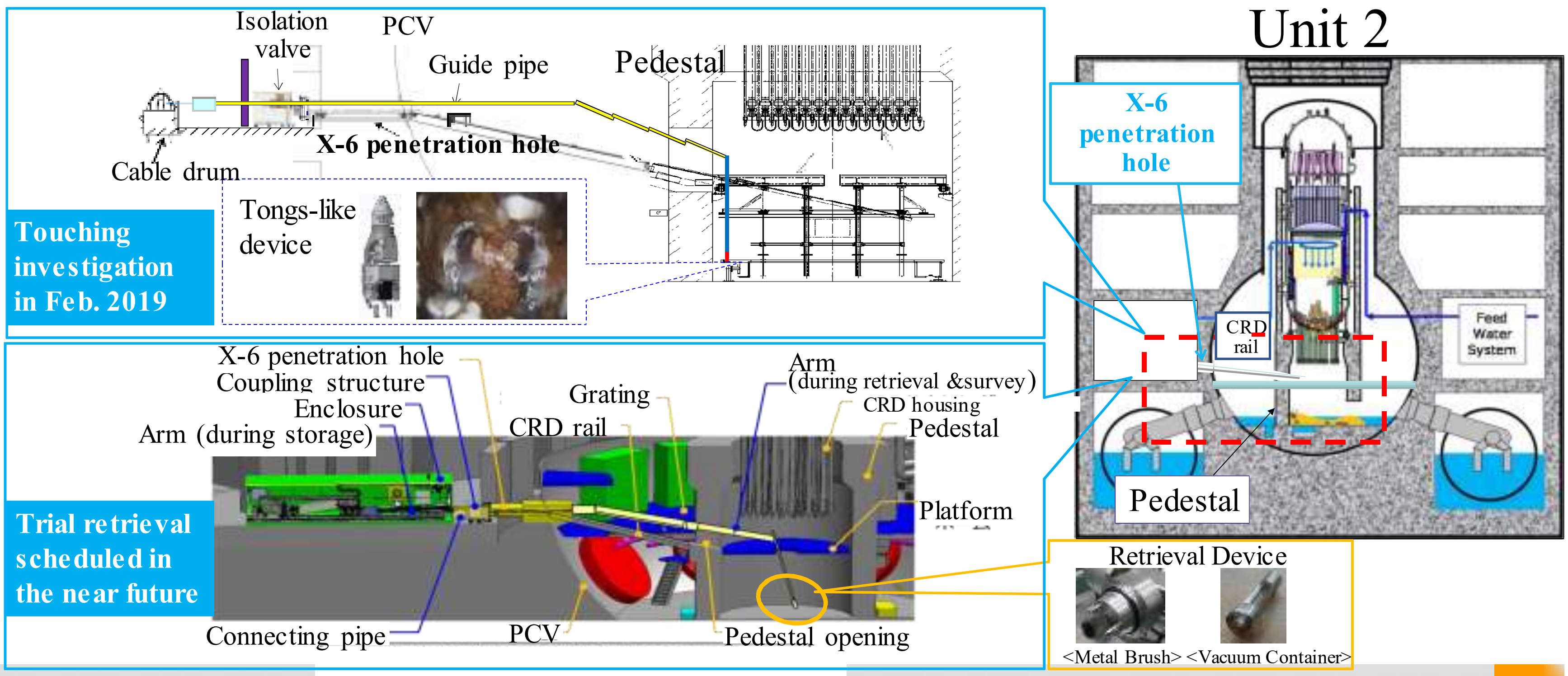
Trial retrieval of fuel debris at Unit 2 scheduled in the near future

- **We will insert an arm-type device through the same access route as the investigation in 2019.**
- **A metal brush or vacuum container will be attached to the device to collect the grain debris we observed in a touching investigation.**

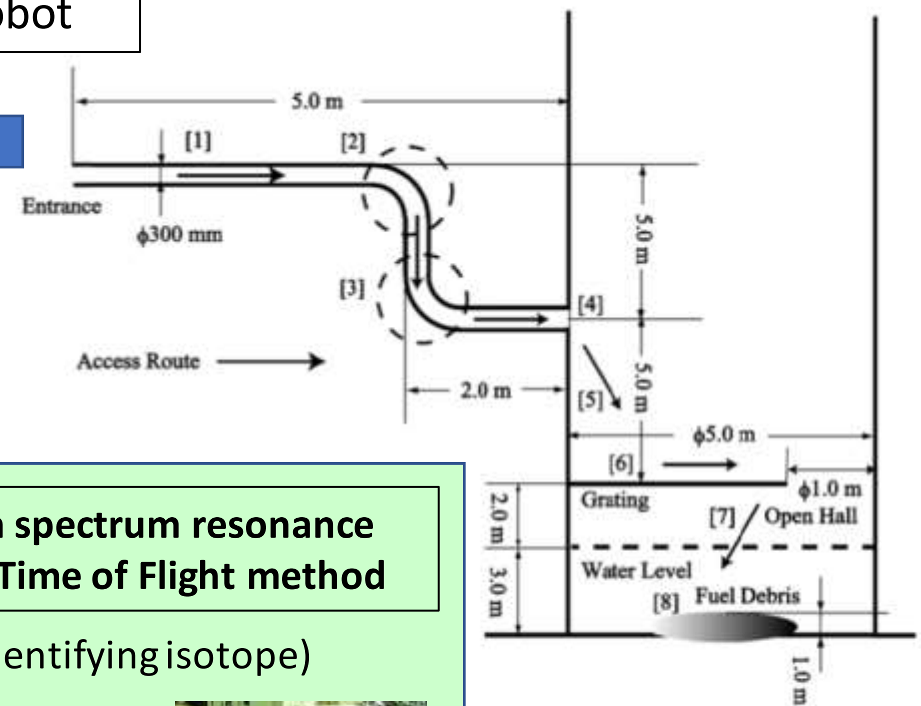


Source: Materials for Meeting of Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water held in Jan. 2019, Feb. 2019 & May 2022 provided by TEPCO HD & IRID

Ref) M. Ishikawa, "Fukushima Dai-ichi Nuclear Power Plant's Decommissioning -Current Status and Challenges-", Asian Youth Nuclear Symposium 2022, July 10, 2022 in Remote.

Proposal of Component Identification for Fuel Debris

1. Reactor pressure vessel



2. Debris sample taken by robot

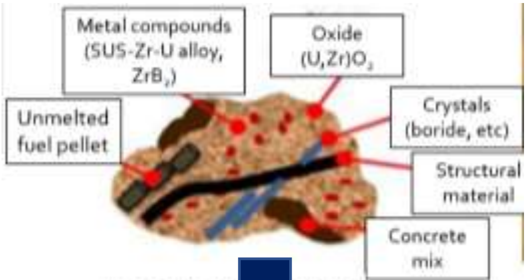


Image of nuclear debris

3. Screening and identification of nuclear debris (on-site)

Complement each other

Dual energy X-ray CT inspection

(Identifying atomic number and weight)

Ce:GAGG detector

Debris sample

X-ray beam

Portable 3.95 MeV X-Band electron linac-based **X-ray** source

Neutron spectrum resonance through Time of Flight method

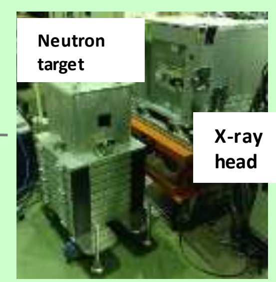
(Identifying isotope)

Neutron detector

Debris sample

Neutron beam

Neutron Time of Flight measurement



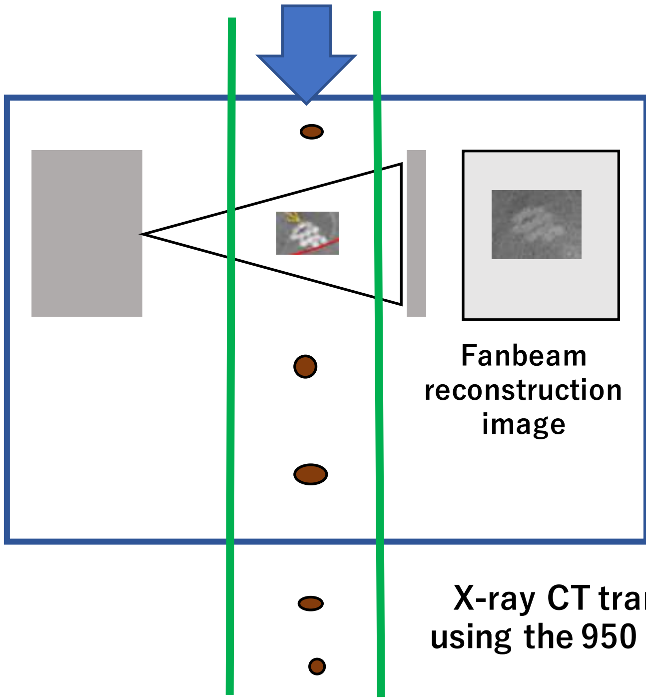
Portable 3.95 MeV X-Band electron linac-based **neutron** source

Evaluation of existence and mass density of U /Pu

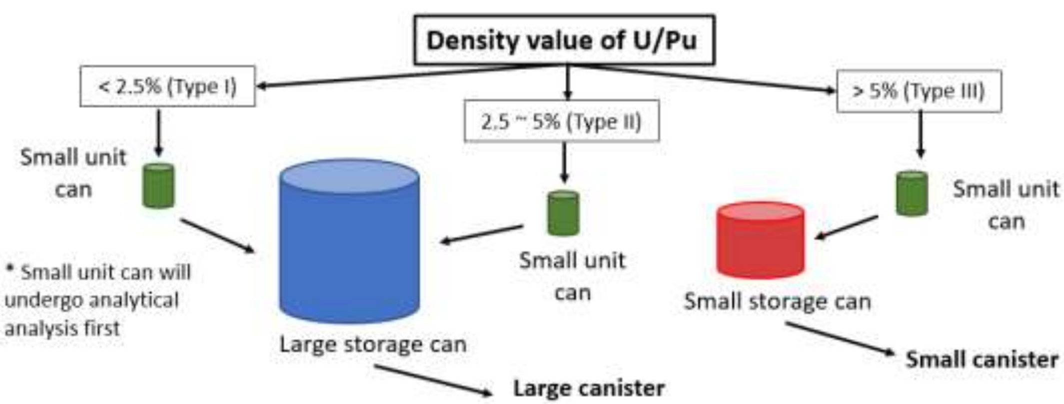
Source: Robotic Society HP (http://www.rsj.or.jp/databox/committees/dec/20160907/Decomm_koubo_jishi.pdf)

Schematic scenario of the screening process by the prompt X-ray CT for mass-extraction of nuclear debris

3D distribution of atomic number can be estimated by the X-ray CT and the mass density of U/Pu can be evaluated



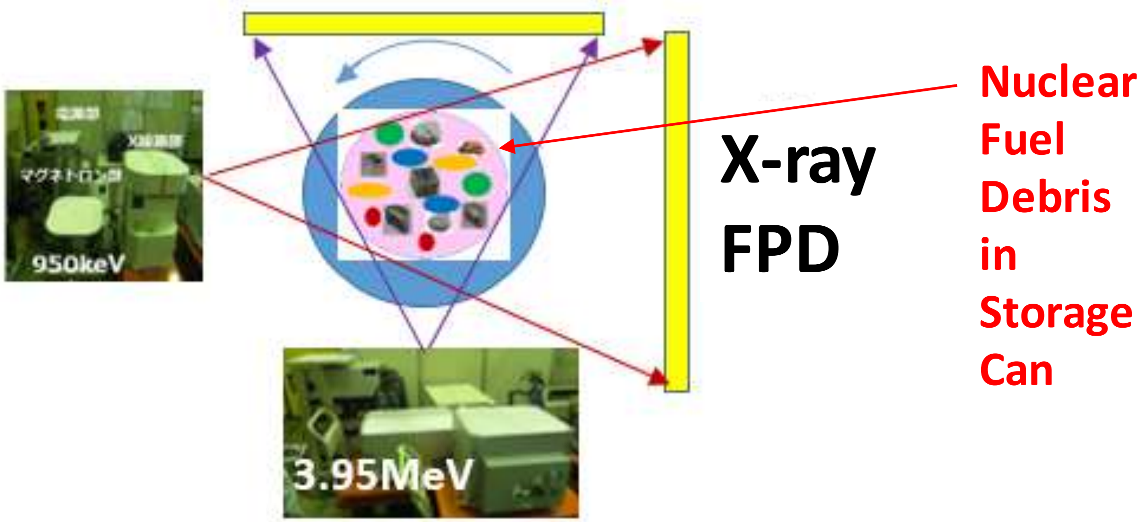
X-ray CT translation system using the 950 keV X-ray source



With the acquired information of existence and mass density of U / Pu, the debris is discriminated into the two storage systems for spent nuclear fuel with U / Pu with criticality control and normal radioactive wastes without U / Pu

Practical and Reasonable Storage System

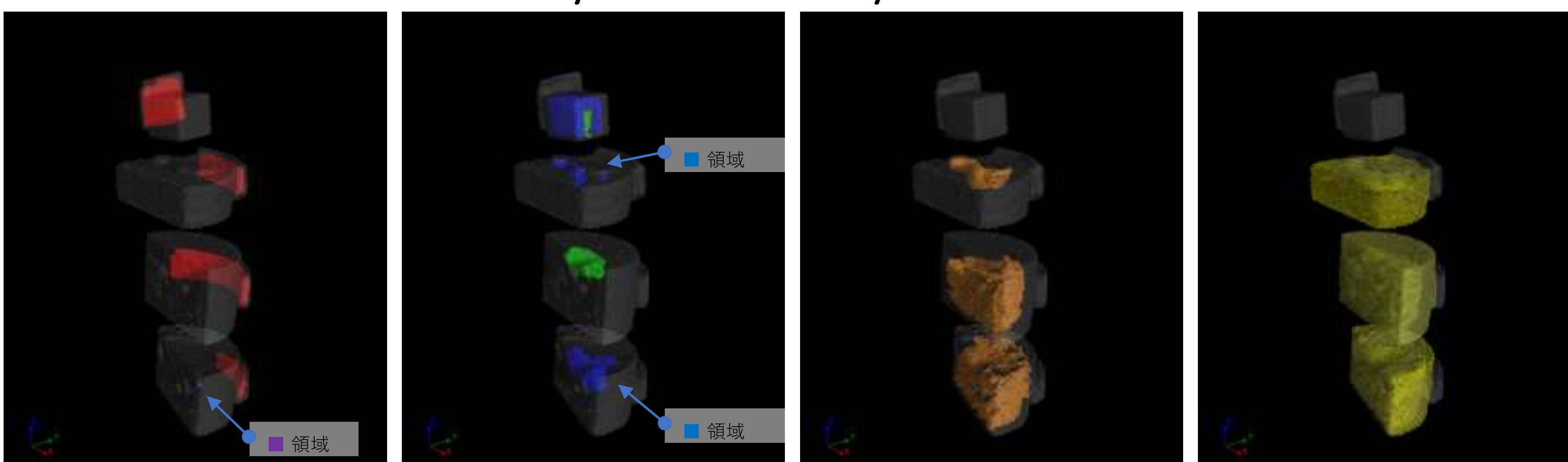
Proof-of-principle X-ray CT Results for Model Melt Nuclear Fuel Debris



3D component data are obtained and the mass density of U / Pu is estimated within mins.

The trial by using the real nuclear fuel debris will be carried out soon.

Results by 3.95 MeV X-ray Source



- Pb
- Gd+PGM

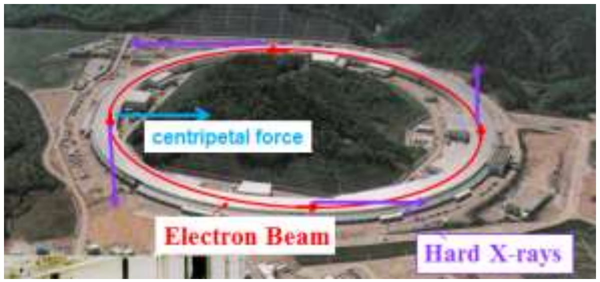
U / Pu

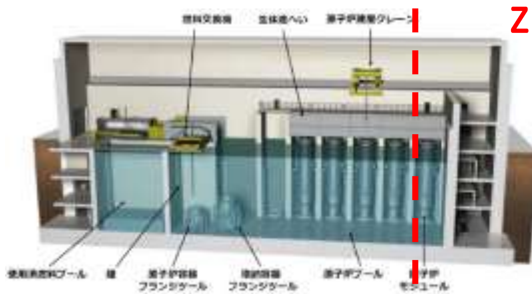
- Fe
- Zr
- Concrete

Three major components

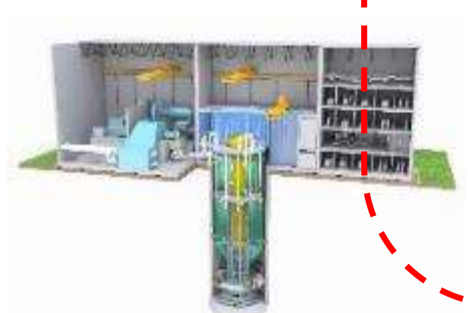
- Polymer

Downsizing of Accelerator and Nuclear Reactor





Smart city for
zero- emission / contamination



The clean energy and water nexus. ***Dream big and let's make these dreams reality.***

- We need dramatic change in our thinking and actions to reduce climate change and reduce/eliminate reliance on energy sources that are not clean.
- Sweden has been decarbonized since the 1970s. Follow suit. *Make this a basis of the energy architecture.*
- The answer is the clean energy and water nexus. One disruptive approach is the marriage of nuclear and particle accelerators - Small modular reactors could power an industrial complex or a small city and all-electric decontamination schemes with particle accelerators could reduce emissions.
- We can create an electric ecosystem encapsulated in an industrial park/small city with the advancements in SMRs.
- We need disruptive policy changes to field these near-existing technology solutions.

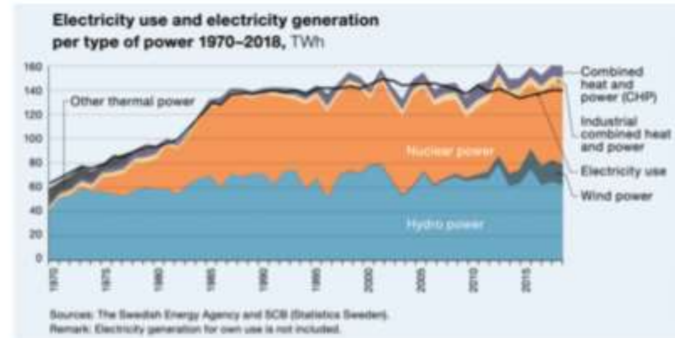


Figure 1: Evolution of Sweden's total electricity energy generation in terawatt-hour (TWh), from 1970-2018.1 Within the past decade, Sweden has generated a surplus of electric power, enabling it to regularly export power to its neighbors (Swedish Energy Agency 2020).

Computational resources, together with modern simulation and AI software, can help make good energy sources better, predict better materials, analyze experimental data, and optimize operation.

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Example, NuScale, https://www.nuscalepower.com

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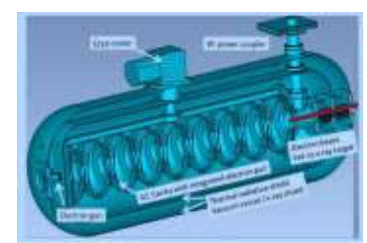

Example high-power, compact, electron accelerator module for purifying waste streams.

+...

References: Robert Rosner & Sabrina Fields (2021) Is nuclear power sustainable in a carbon-free world? The case of Sweden, Bulletin of the Atomic Scientists, 77:6, 295-300, DOI: 10.1080/00963402.2021.1989196

S.G. Biedron, M. Peters, R. Rosner, J. L. Sarrao, "Opportunity to Innovate" SEMICON West Sustainability Summit Breakout Track B: Business Ecosystem Building and Collaboration, 13 July 2022, https://www.semiconwest.org/programs/sustainability-summit.

SUMMARY

- **Downsizing of big accelerators enables portable accelerators for a variety of applications.**
- **Medical RI production is shifting to the bext mix of accelerators and low enriched U research reactors.**
- **Portable X-ray and neutron sources are expected to be applied to infrastructure maintenance and nuclear power plant decommissioning.**
- **Proposal of smart city with micro-reactor and small accelerators for zero-emission/contamination.**

Thanks for the collaboration to KEK, JAEA, JASRI/SPring-8, QST, MEXT, METI, MLIT, DOE, SLAC, LANL, Element Aero and the Center for Bright Beams, TRIUMF, JRC, etc.