9th August, 2022
Luncheon, NAPAC 2022 at Albuquerque

Sustainability for Young Generation

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

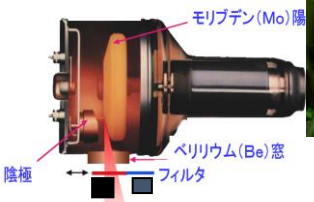
CONTENTS

- 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

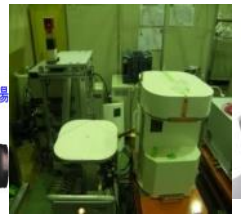
Particle, Energy and Choice of Accelerators

100 keV 1 MeV 100 MeV 1 GeV 1 TeV

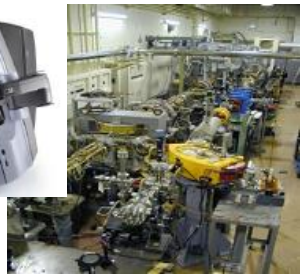
Electron

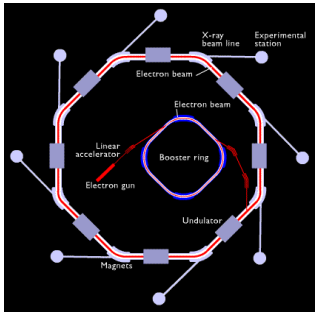


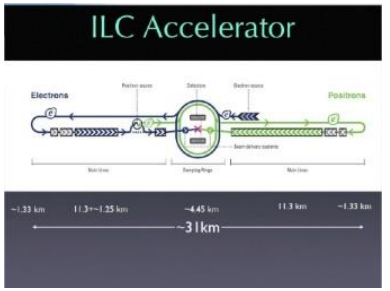
X-ray Tube



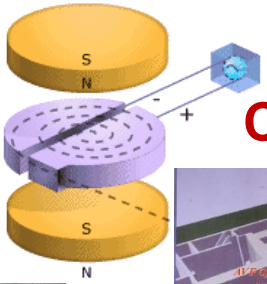
Linac







Linear Collider

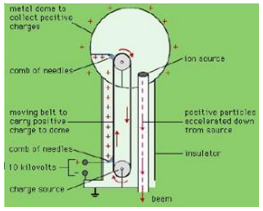


Cyclotron

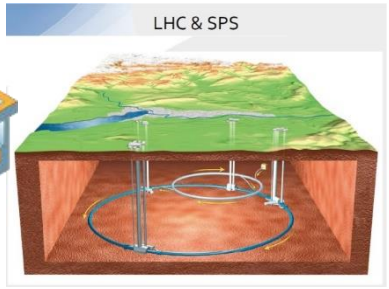
X-ray FEL

Synchrotron

Ion

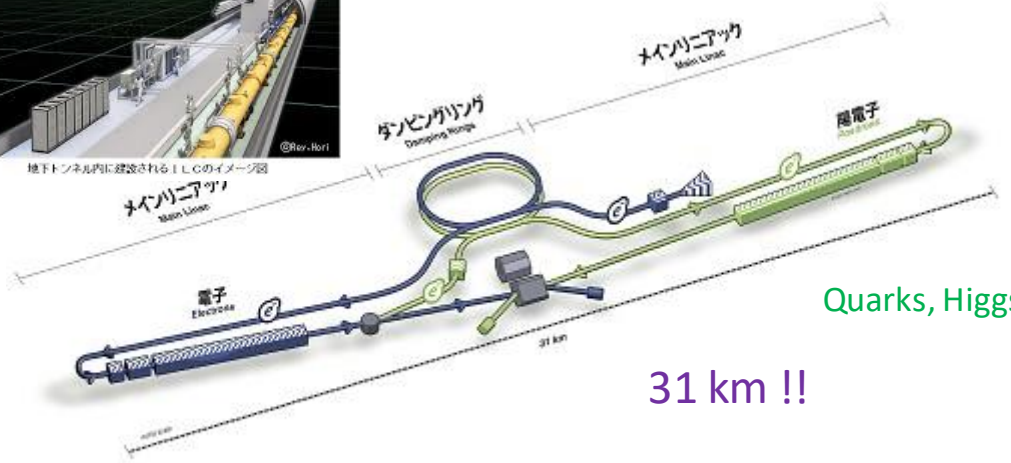


Electrostatic



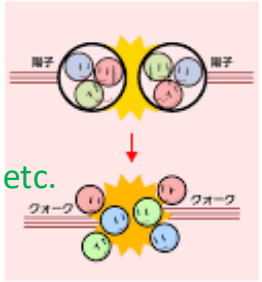
Trials for Downsizing of International Linear Collider

地下トンネル内に建設されるILCのイメージ図



31 km !!

Proton



Quarks, Higgs, etc.

LHC
大型ハドロン衝突型加速器
基本粒子（クォーク）が衝突で陽子どうしの衝突

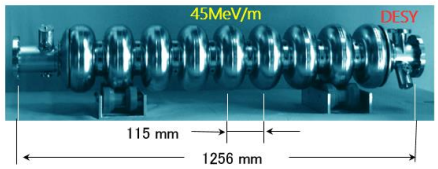
Simple!!

ILC
国際リニアコライダー
基本粒子（レプトン）どうしの衝突

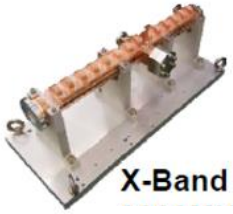
ILC Scheme | ©www.ilcrs-one.de

Alternatives

Superconducting Linac



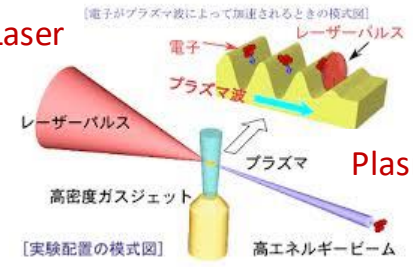
X-band (11.424GHz) Linac



11.424 GHz

Laser Plasma Accelerator (THz)

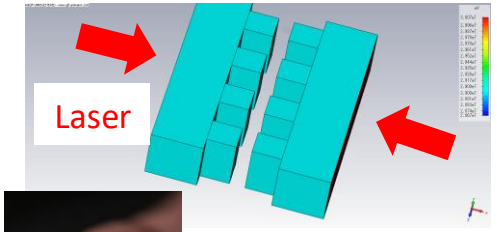
Laser



Plasma

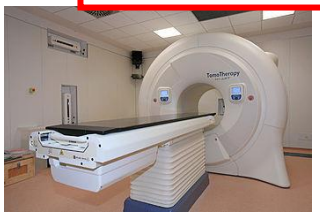
e⁻

Optical Laser Dielectric Accelerator



Downsizing of Medical Accelerators by Advanced Technologies

Electron Linac with S/C/X-bands



http://www.accuray.com/

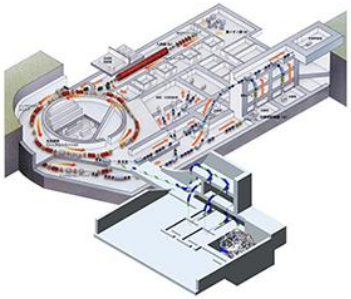
http://www.accuthera.com/

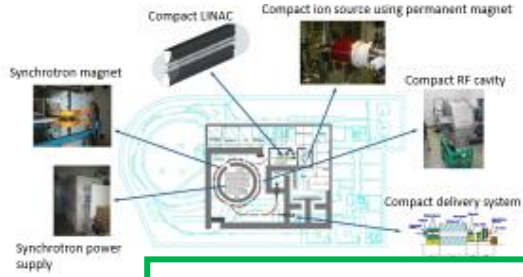
http://www.varian.com/

http://www.accuray.com/

http://www.mhi-global.com/index.html

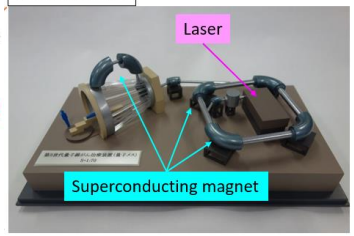
Synchrotron with Layout / SC





Hokkaido University and Hitachi

Quantum knife



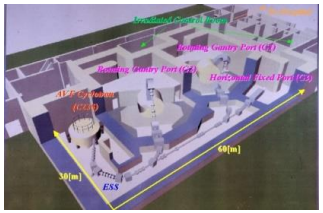
Quantum Knife of QST

TOSHIBA

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

Cyclotron with SC / Layout

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



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

南東北 BNCT 研究センター陽子ビーム

Cyclotron based BNCT at Fukushima

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

Rays of Hope
Cancer care for all

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.

The Global Cancer Burden

2020	2040
19 million new cases	30 million new cases
10 million deaths	16 million deaths

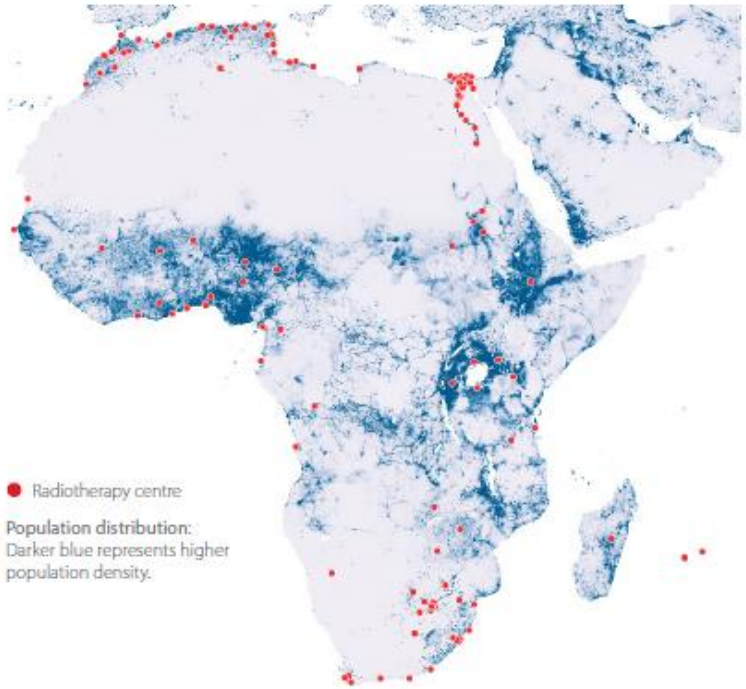
Over 70% of cancer deaths occur in LMICs.

70%

Only 5% of global spending on cancer goes to LMICs.

About half of cancer patients require radiotherapy.

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

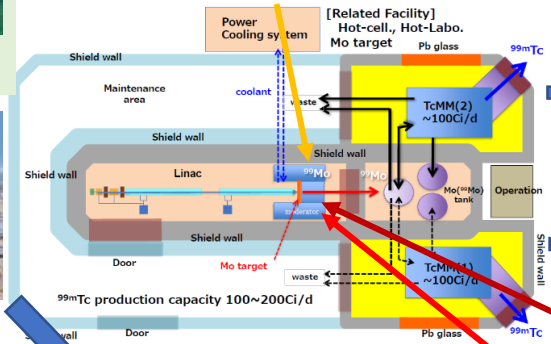
Chemical extraction of ^{226}Ra from U mining waste

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

Solid or Liquid ^{226}Ra Targets

Supply for Fundamental Research

Fuel Cycle Plant



^{225}Ac

^{67}Cu

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

Supply for Clinical Uses

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

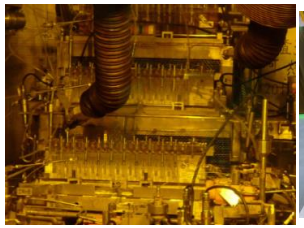
Decommissioning Plant

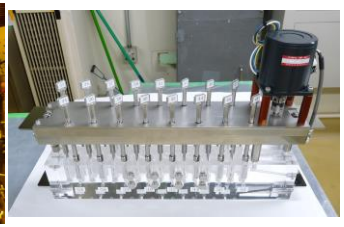
Debris without Fuel Materials

Mixer-Settler

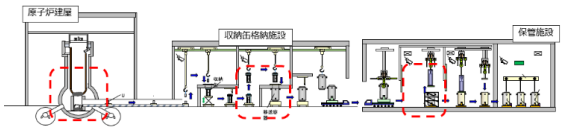
^{68}Zn

^{98,100}Mo





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



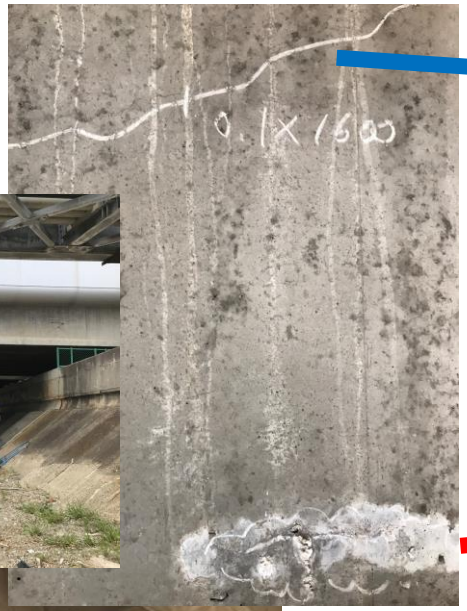
γ Emitter RIs(^{99}Mo /^{99m}Tc) for cancer diagnosis from spent fuel waste (Mo)

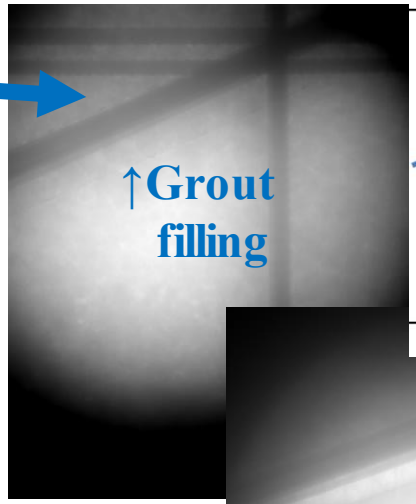
CONTENTS

- 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

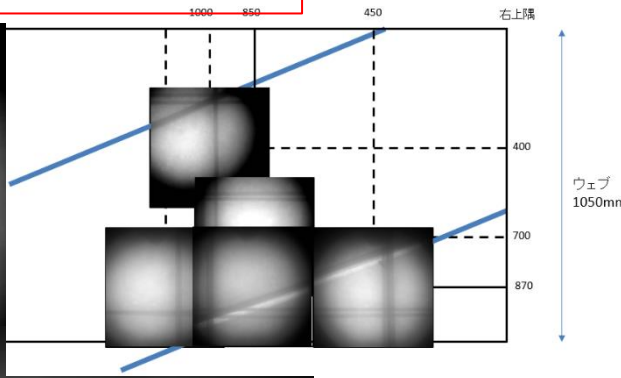
On-site X-ray Inspection by 950 keV system for PC (Prestressed Concrete) bridges of up to ~50 cm thickness

Crack

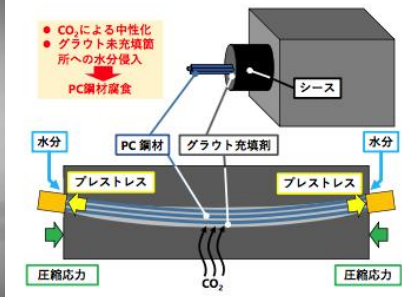




↑Grout filling



↑No grout



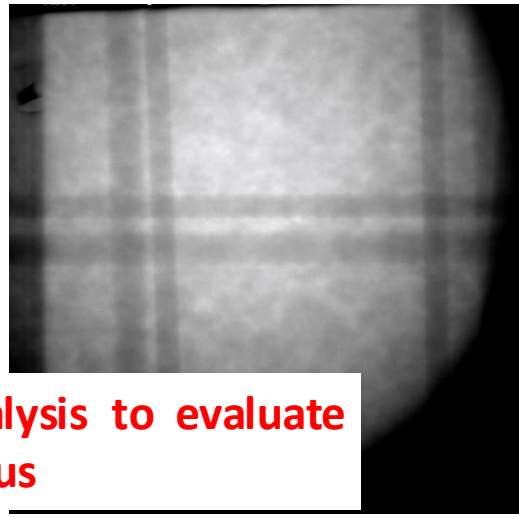
↑Cracks and leak of Ca components

↑Grout filling

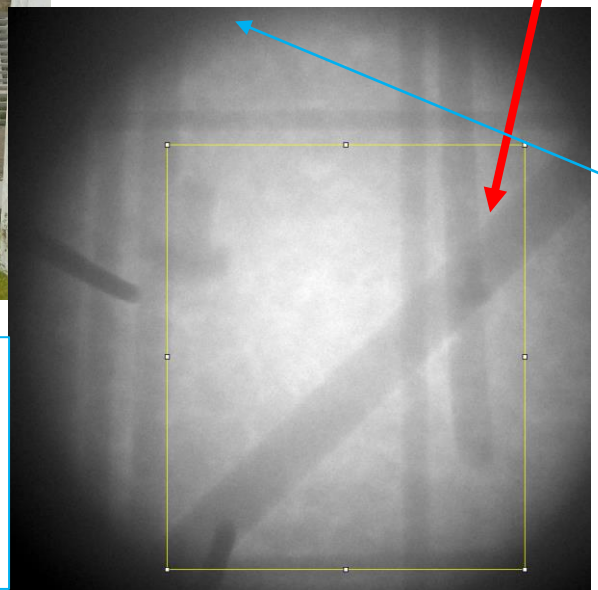
↑No grout

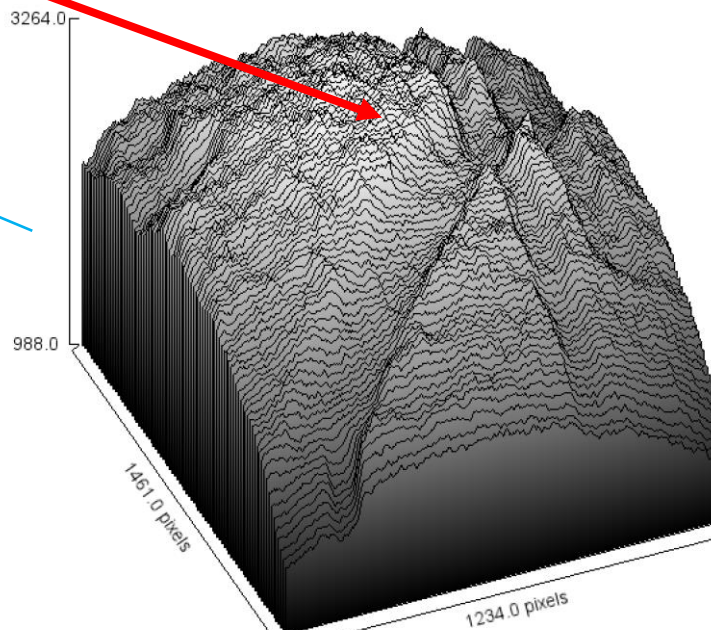
X-ray transmission images indicate reinforced iron rods and grout filling and not-filling around the PC wires in the PC sheath clearly

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



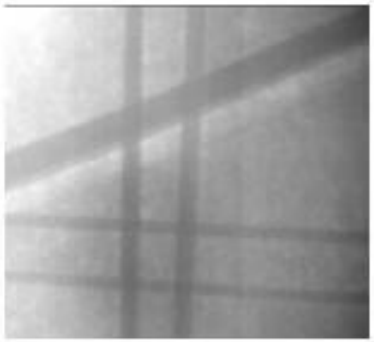


More than 10 real bridges and one highway bridge under the Japanese national project

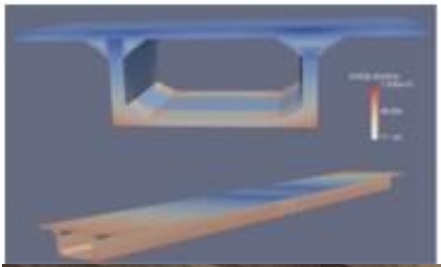
Formation of Technical Guideline for On-site X-ray Bridge Inspection

Visual and hammering-sound inspections

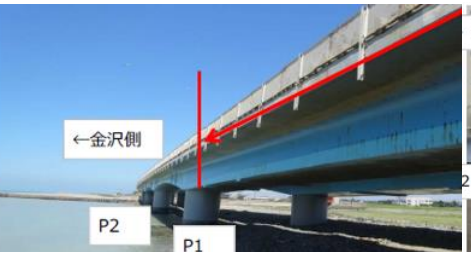
X-ray inspection



Structural analysis

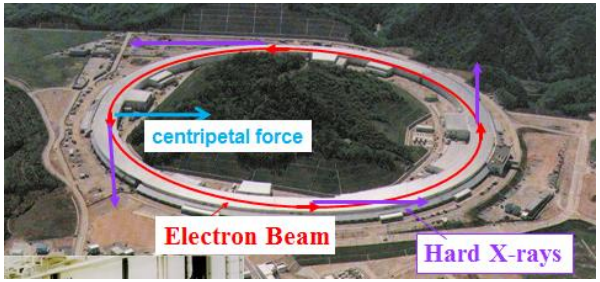


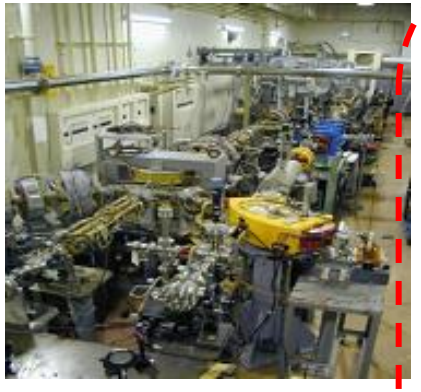
Repair and reinforcement

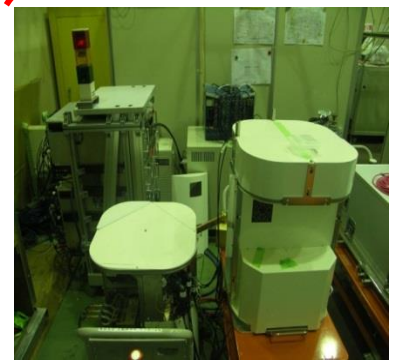


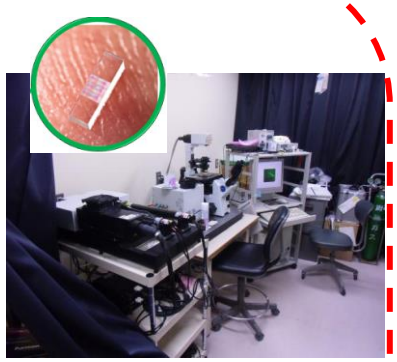
We hope to apply this guidelines to all aged bridges soon in Japan and finally in the world

Downsizing of Accelerator and Nuclear Reactor

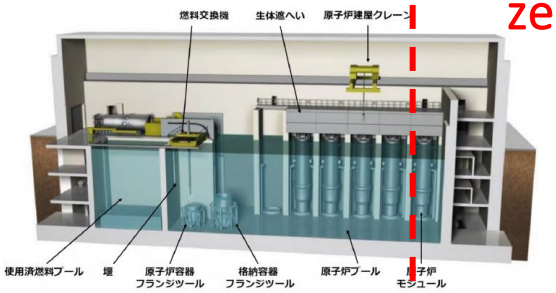


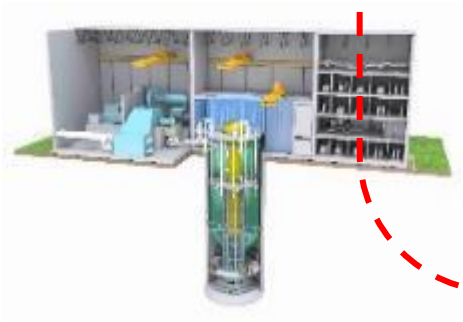






Smart city for
zero- emission / contamination



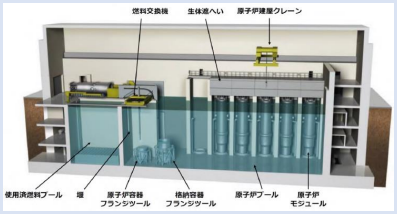


Examples of diverse innovative reactor concepts

Small Modular Reactor(SMR)

- Small reactor core with simplified systems, which aims to improve reliability by adopting passive safety features, etc.
- Modular production shortens the construction period.
  ⇒ Reducing evacuation area , low capital cost

◆ VOYGR（NuScale Power）



◆ BWRX-300（GE Hitachi Nuclear Energy)

Sodium-cooled Fast Reactor

- Sodium-Cooled Fast Reactor using fast neutrons
  ⇒Efficient use of resources and reduction of radioactive waste volume and toxicity

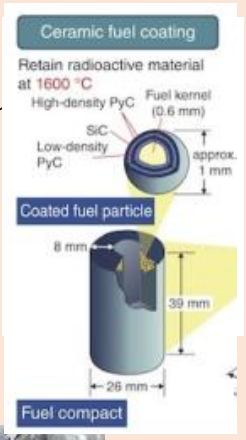
◆ Experimental Fast Reactor Joyo(JAEA)

◆ PRISM（GE Hitachi Nuclear

High Temperature Gas-cooled Reactor

- High temperature reactor (approx. 950°C) with chemically stable helium coolant and coated particle fuels => heat utilization, hydrogen production, high safety

◆ High Temperature engineering Test Reactor (HTTR)（JAEA）



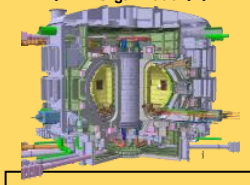
February 25, 2021,Document 3, Nuclear Energy Subcommittee, Electricity and Gas Industry Committee, Advisory Committee for Natural Resources and Energy, 21st Session.

Fusion Reactor

- Energy by fusing light nuclei
  (Plentiful Fuel Resources, Inherently safe, Excellent for the Environment)

⇒ Abundant fuel, high safety, high environmental protection

ITER（Experimental Reactor）
(Saint Paul-lez-Durance, southern France
(ITER Organization）)



International Fusion Energy Research Centre
(Rokkasho, Aomori, Japan)
(National Institutes for Quantum Science and Technology(QST))

JT-60SA
(Naka, Ibaraki, Japan)
(QST)

ITER Project ⇐ Supplementation / Support ⇐ Broader Approach

(Source) https://www.fusion.qst.go.jp/fusion-energy-forum/topics/topics2021/zentai2021/IWABUCHI.Hideki(Lecture).pdf

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.

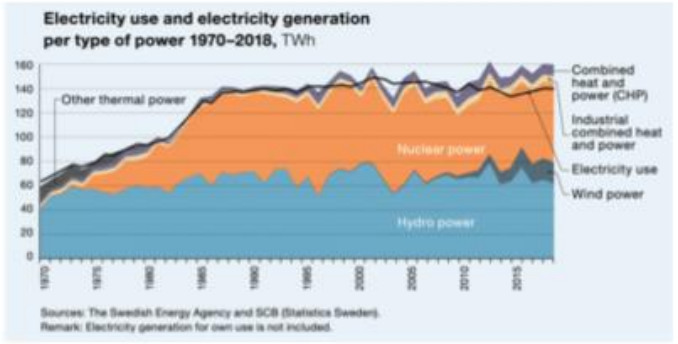
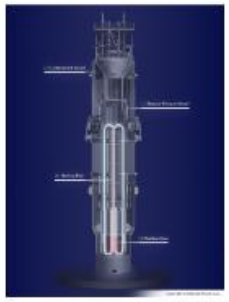
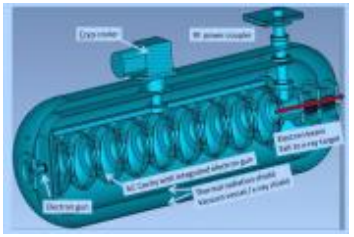


Figure 1: Evolution of Sweden's total electricity energy generation in terawatt-hour (TWh), from 1970-2018.1 Within the past decade, Sweden has generated a surplus of electric power, enabling it to regularly export power to its neighbors (Swedish Energy Agency 2020).

+



+



+...

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.

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

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.