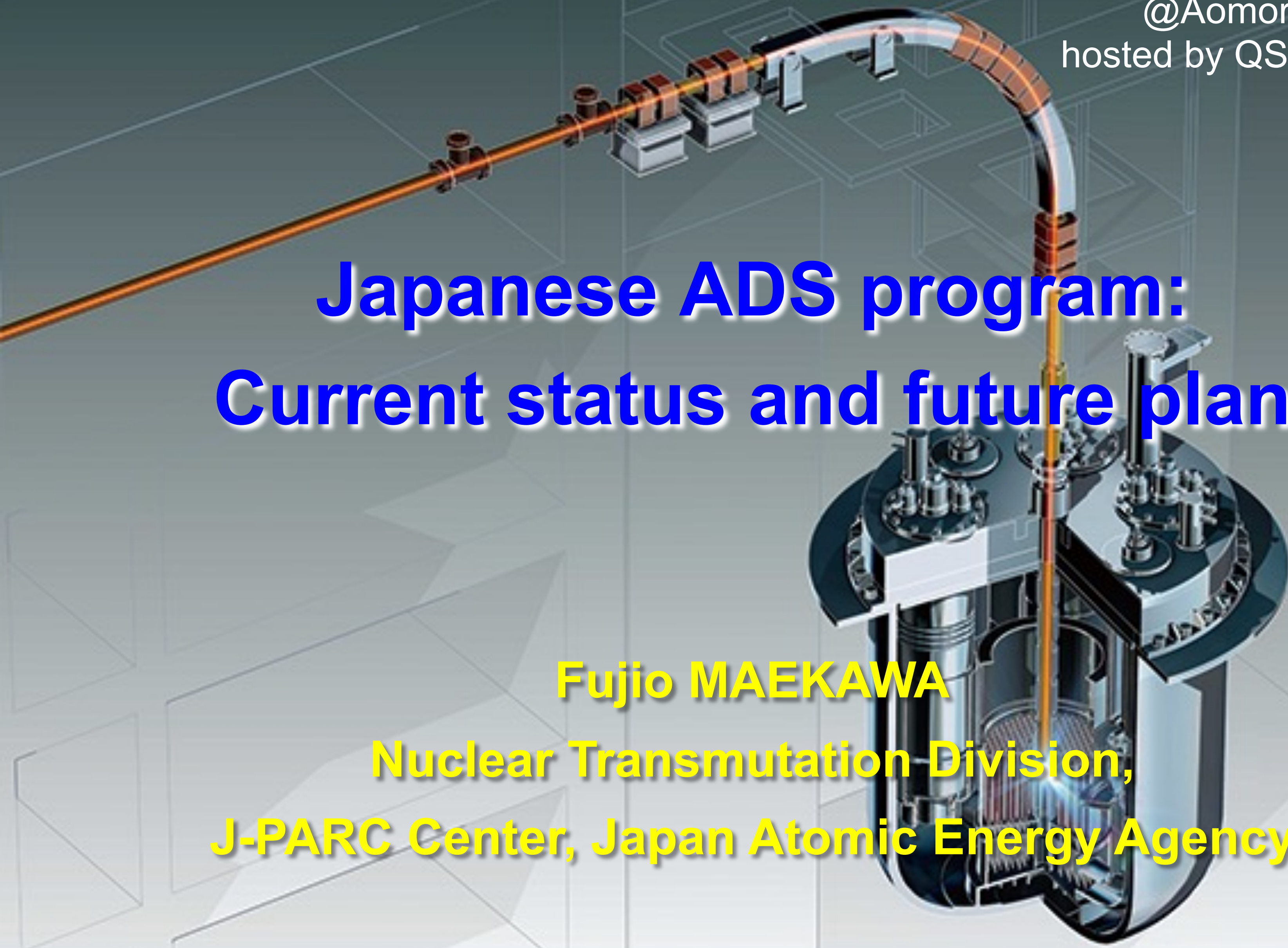
Tesla Technology Collaboration meeting
11-14 October, 2022
@Aomori-city, Japan
hosted by QST-Rokkasho



Japanese ADS program: Current status and future plan

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Situation surrounding electricity in Japan

- Oct. 2020 Declared “2050 Carbon Neutral” by the prime minister Suga
- Jan. 2022 Rapid and extreme increase in electricity price provided by small companies that procure electricity from the market
- Mar. 2022 Business withdrawal of the small companies
- Mar. 2022 Tight electric power supply
  - ✓ due to cold weather, shortage of LNG, accidents in thermal power plants, Ukraine situation, ...
- Apr. 2022 Suspension of acceptance of renewable energy
  - ✓ Warm, sunny, windy and Sunday
  - ✓ Japan can not sell/buy electricity to/from neighboring countries!
- Apr. 2022 Major electric power companies suspended new contracts for corporate power plans.
  - ✓ Corporations have to contract with the expensive list price.
- Jun. 2022 Tight electric power supply, again
- Through 2022 Gradual and large increase in the electricity price

Energy policy of Japan

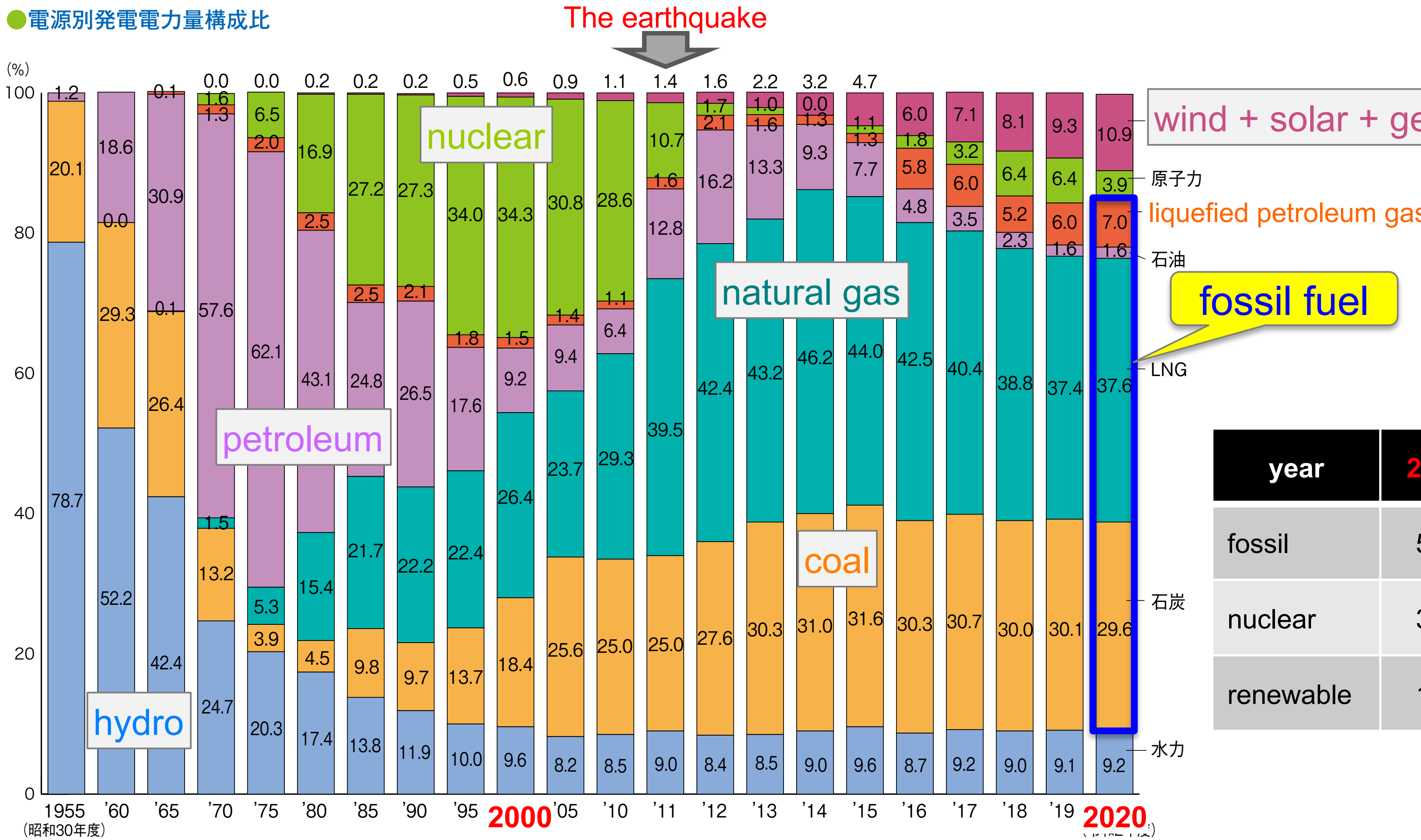
- In October 2020, prime minister Suga declared **"2050 Carbon Neutral"**.
  - ✓ **Nuclear energy** is one of important measures to achieve.

- In October 2021, the Cabinet decided to approve **the 6th Strategic Energy Plan** as the basis for the orientation of Japan's new energy policy, considering the global trends towards decarbonization and growing tensions in international energy security.
  - ✓ **Nuclear power** is important base-load power source as low carbon and quasi-domestic energy source, contributing to stability of energy supply-demand structure in the long term, on the major premise of ensuring of its safety, because of the perspectives.
  - ✓ GOJ will promote development of technologies for reducing the volume and harmfulness of radioactive waste **in order to secure a wide range of options in the future**.
  - ✓ **GOJ will promote technology development on volume reduction and mitigation of degree of harmfulness of radioactive waste.** Specifically, development of technologies (snip) including **nuclear transmutation technology using fast reactors and accelerators**, will be promoted by utilizing global human networks for cooperation.

Electric power generation in Japan

- I believe Japan needs nuclear power.
- To promote it, we need to solve the nuclear waste problem!

●電源別発電電力量構成比



year	2000	2020
fossil	56 %	76 %
nuclear	34 %	4 %
renewable	10 %	20 %

（注）1. 1970年度までは9電力計、1975～2015年度は10電力計（受電を含む）　（出典）電気事業連合会調べ
2016年度以降は10エリア計　（出典）資源エネルギー庁「電力調査統計」より作成
2. LPG他：LPG、その他ガス

電事連　電気事業のデータベース（INFOBASE）　より

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1. Introduction
2. Partitioning and Transmutation (P-T) technology
3. Accelerator Driven System (ADS) for nuclear transmutation
4. Experimental facility plan at J-PARC
5. R&D for ADS development
6. ADS in the world
7. Summary

Partitioning and transmutation (P-T) technology

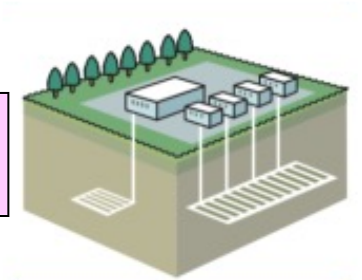
Nuclear plants → Spent fuel → Reprocessing → U, Pu → Recycle

Lass carbon
Low cost
Base-load power

Reprocessing ↓

High-level radioactive waste
- Fission products (FP)
- Minor actinoids (MA)

→ Vitrified, then geological disposal



Issues
- Long-term toxicity
- Difficulty in finding disposal sites
- Difficult to gain the public's understanding of nuclear power

- ☐ Fossil fuel --- CO_2 exhaust
- ☐ Solar, wind, ... --- high cost

✓ If we abandon nuclear power generation, we already have more than 17,000 tons of spent nuclear fuel in Japan.

✓ Is it permissible to impose them on our descendants?

P-T technology

- **Partitioning** according to their half-lives and reuse purposes
- **Transmutation** of long-lived nuclides into short-lived or non-radioactive ones

Development of the P-T technology

⇩

Volume reduction and mitigation of harmfulness of high-level radioactive waste

⇩

We will gain a measure to mitigate the nuclear waste problem

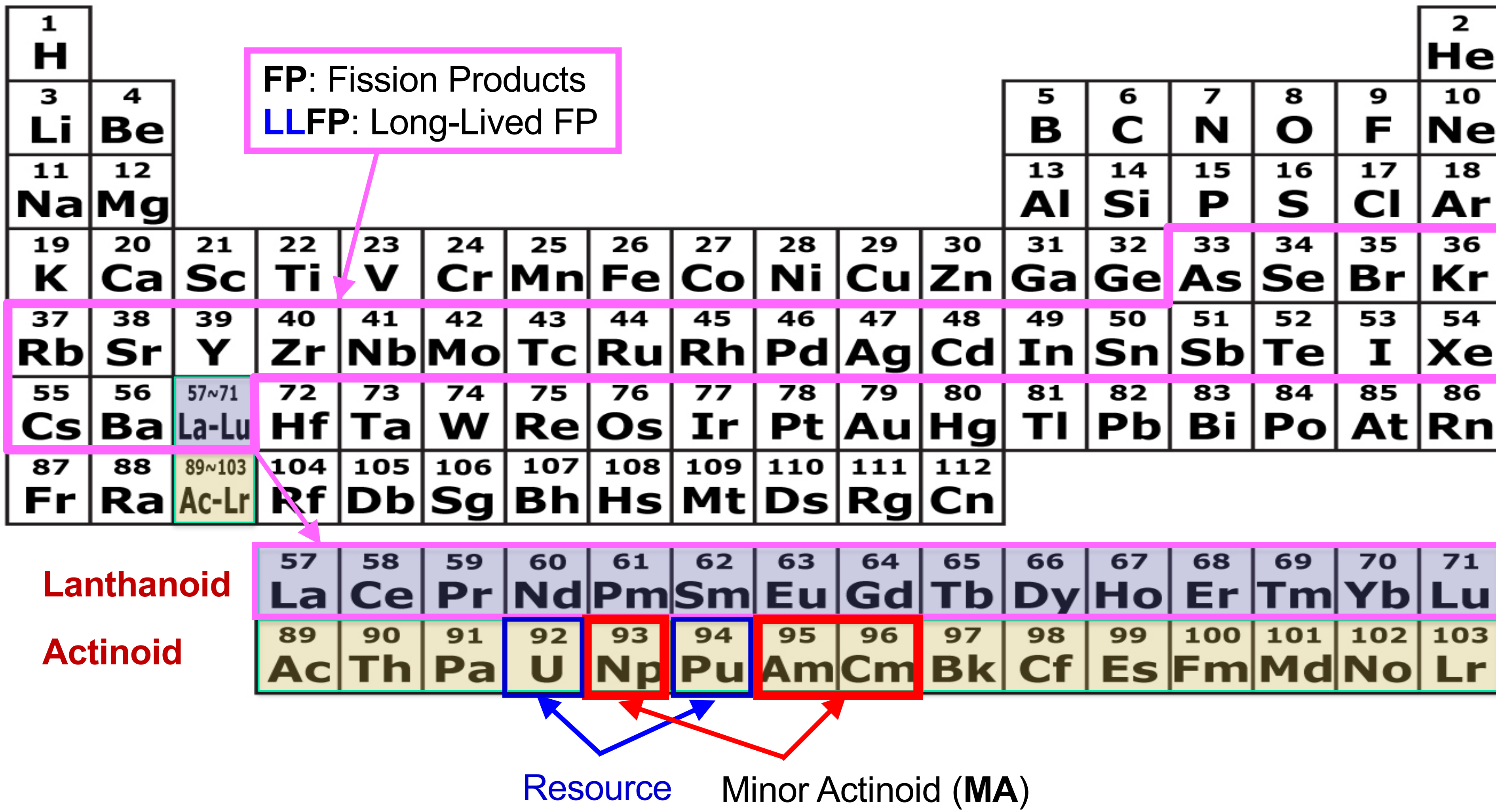
⇩

Public's understanding of nuclear power

⇩

We can contribute to
- ☐ global environmental conservation,
- ☐ stable energy supply.

FP & MA



We try to transmute MA first.

- Radiotoxicity of MA (mainly α-emitter) is higher than that of FP (mainly β-emitter).
- MA can be transmuted efficiently because the fission chain reaction is available.

Major long-lived nuclides in spent nuclear fuel

Actinides

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
U-235	700,000,000	47	10 kg
U-238	4,500,000,000	45	930 kg

Trans-Uranium Elements (TRU)

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
Pu-238	88	230	0.3 kg
Pu-239	24,000	250	6 kg
Pu-240	6,564	250	3 kg
Pu-241	14	4.8	1 kg

Pu: ~10 kg, 1%

Minor Actinides (MA)

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
Np-237	2,140,000	110	0.6 kg
Am-241	432	200	0.4 kg
Am-243	7,370	200	0.2 kg
Cm-244	18	120	60 g

MA: ~1 kg, 0.1%

Fission Products (FP)

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
Se-79	295,000	2.9	6 g
Sr-90	29	28	0.6 kg
Zr-93	1,530,000	1.1	1 kg
Tc-99	211,000	0.64	1 kg
Pd-107	6,500,000	0.037	0.3 kg
Sn-126	100,000	4.7	30 g
I-129	15,700,000	110	0.2 kg
Cs-135	2,300,000	2.0	0.5 kg
Cs-137	30	13	1.5 kg

Dose conversion factor:
An index that indicates the effects of ingestion of radionuclides into the human body.
Shown in absorbed dose (Sv) per radioactivity (Bq).

Partitioning and Transmutation (P&T) technology

J-PARC

MA: Minor Actinides
FP: Fission Products
PGM: Platinum Group Metal
FR: Fast Reactor
ADS: Accelerator Driven System

Spent fuel → Reprocessing → U、Pu → Recycle

Reprocessing → FP、MA → Geological disposal (Glass waste form)

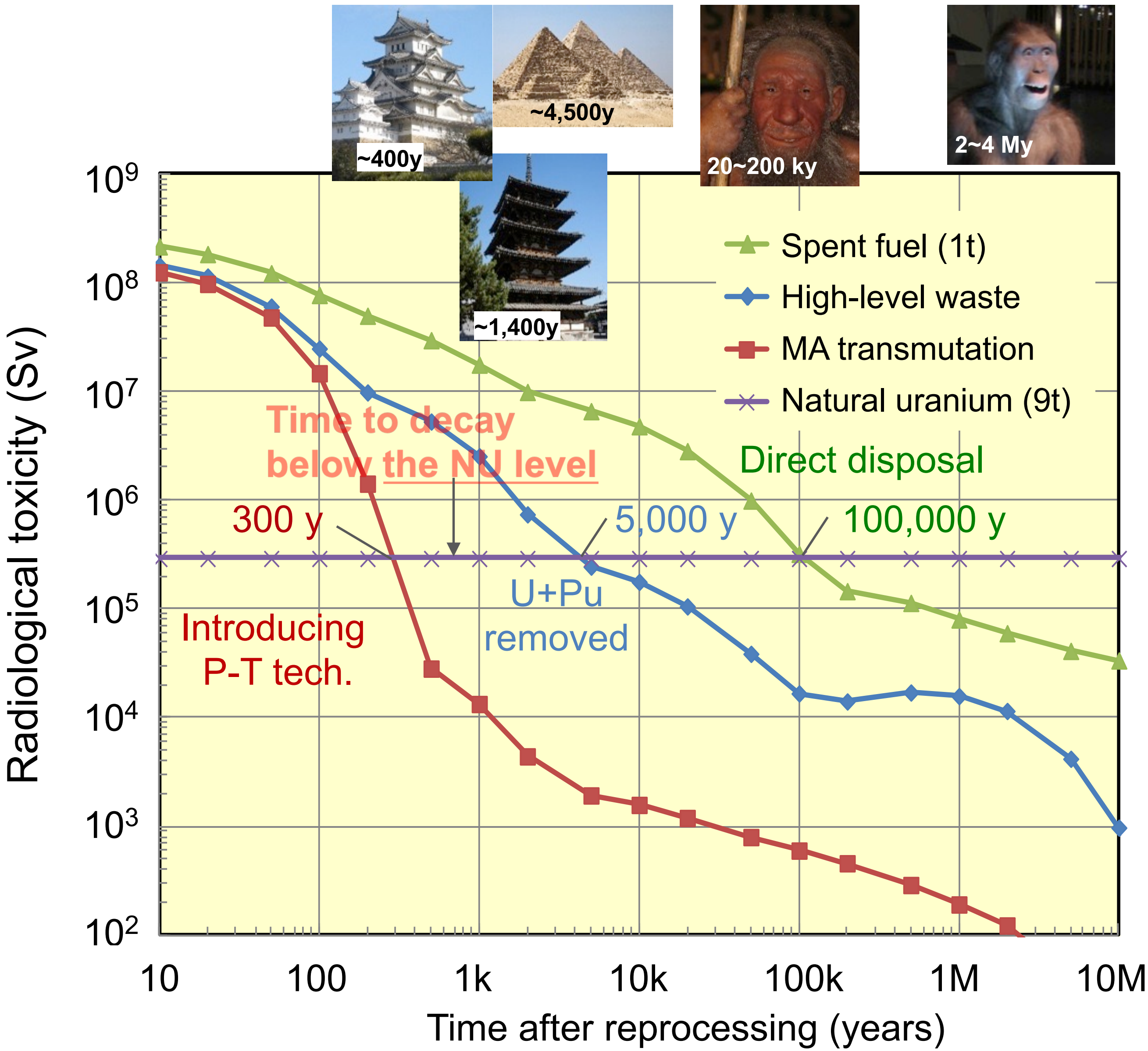
Conventional scheme

P&T technology

Partitioning (Example)

- MA (Np, Am, Cm) → **Transmutation** by ADS and/or FR
- PGM (Ru, Rh, Pd) → Utilization and/or disposal
- Heat generator (Sr, Cs) → Geological disposal after cooling and/or utilization (Calcined waste form)
- Remaining elements → Geological disposal (high-density glass waste form)

Reduction of radiological toxicity by P&T



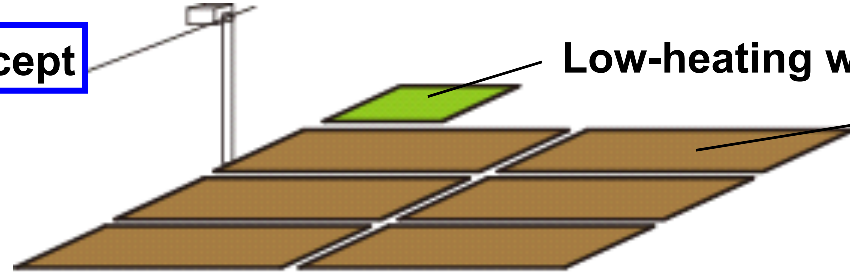
Radiological Toxicity:
Amount of radioactivity weighted by dose coefficient of each nuclide.

- Normalized by 1 ton of spent fuel
- 9 tons of natural uranium is raw material of 1 ton of low-enriched uranium including daughter nuclides.

Reduction of footprint area of waste disposal by coupling P&T with long-term storage

Normalized by 32,000tHM of 45GWd/t spent fuel

Conventional Concept



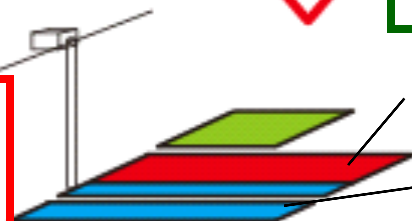
Low-heating wastes (0.13km^2)

HLW vitrified waste: 40,000
(CT: 50y, FA: 1.8km^2)

Footprint area of waste can be reduced as 1/4 by coupling MA transmutation and separated disposal of Sr-Cs after 100-130 years of cooling

Partitioning and Transmutation (P&T)

Transmutation of MA is effective for reduction of very long-term potential toxicity and removal of long-lived heat-generating nuclide (Am-241)



Sr-Cs calcined waste: 5,100
(CT: 130y, FA: 0.23km^2)

Highly-loaded vitrified waste: 8,300
(CT: 5y, FA: 0.18km^2)

Footprint area of waste can be reduced as 1/100 by applying long-term storage (about 300 years) to Sr-Cs with the result that all the wastes can be treated as low-heating wastes.

P&T
+ Long-term Storage

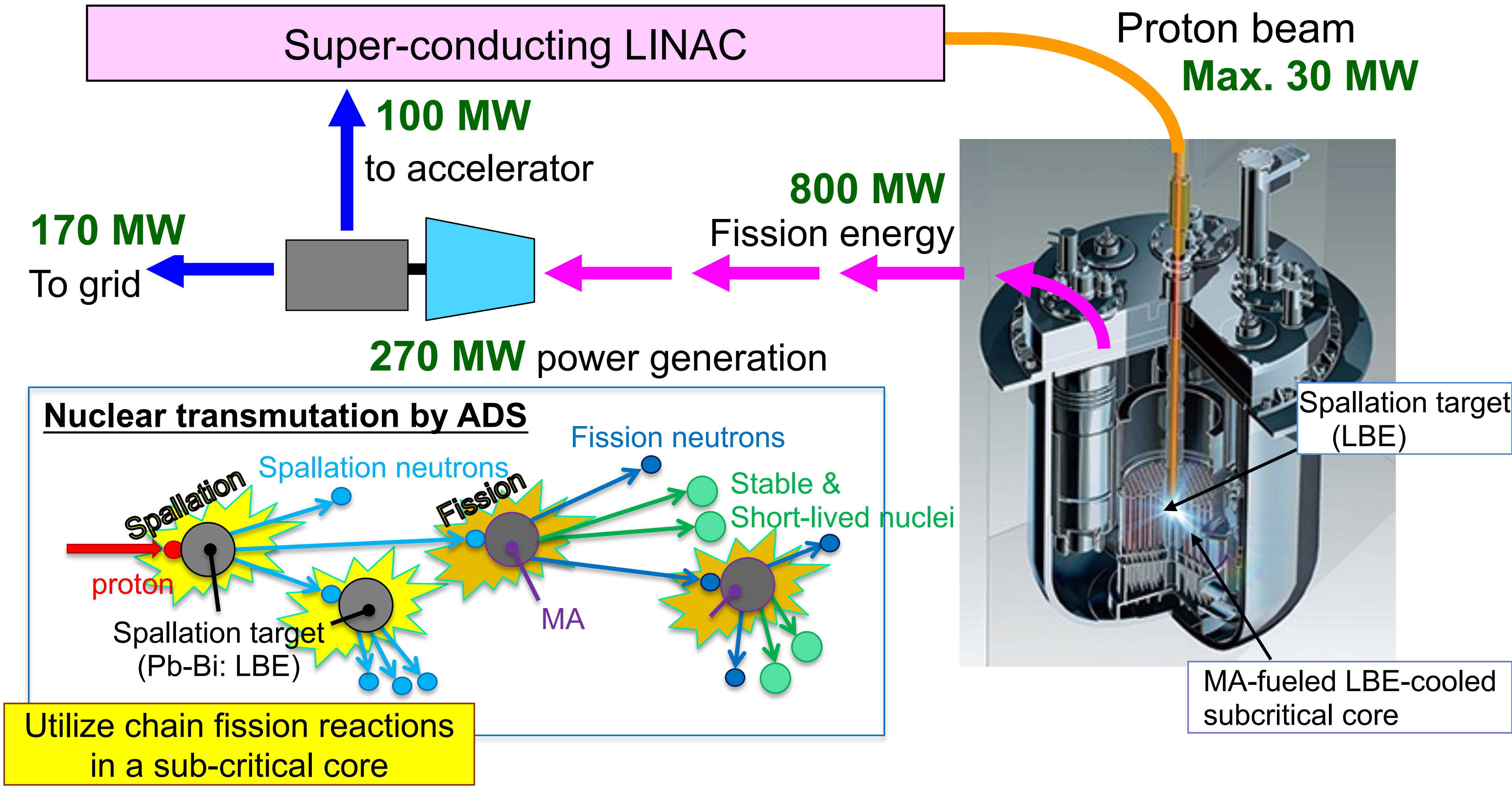
Highly-loaded vitrified waste: 8,300
(CT: 45y, FA: 0.01km^2)

Sr-Cs calcined waste: 5,100
(CT: 320y, FA: 0.005km^2)

CT: Cooling time before disposal
FA: Footprint area of wastes

Contents

Accelerator Driven System (ADS) for MA transmutation



Features of ADS:

- Chain reactions stop when the accelerator is turned off.
- LBE is chemically stable. ➔ **High safety is expected.**
- High MA-bearing fuel can be used. ➔ MA from **10 LWRs** can be transmuted.

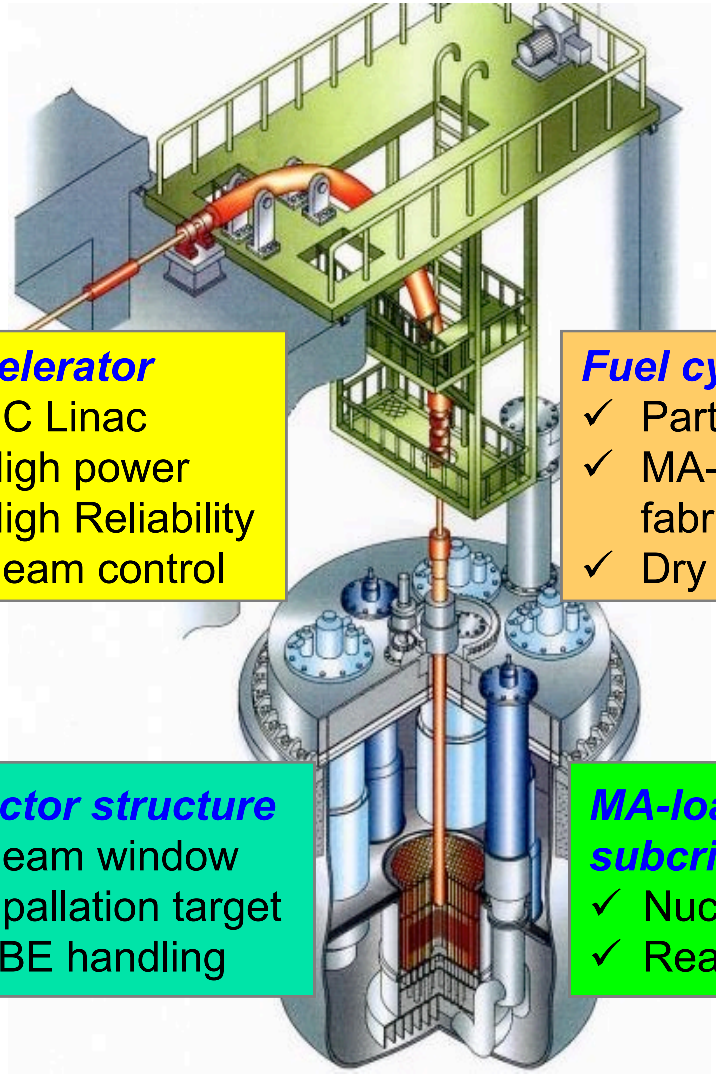
ADS proposed by JAEA - LBE Target/Cooled Concept -

- Proton beam: 1.5 GeV, 20 mA, 30 MW
- Spallation target:

  Pb-Bi eutectic (LBE)
- Coolant: LBE
- Subcriticality: $k_{eff} = 0.97$
- Thermal output: 800 MWt
- Core height: 1000 mm
- MA initial inventory: 2.5 t
- Fuel composition:

  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate: 10%MA / Year

  (=250 kg: MA from 10 units of LWR)
- Burn-up reactivity swing: 1.8%Δk/k



Accelerator
- ✓ SC Linac
- ✓ High power
- ✓ High Reliability
- ✓ Beam control

Fuel cycle
- ✓ Partitioning
- ✓ MA-bearing Fuel fabrication
- ✓ Dry reprocessing

Reactor structure
- ✓ Beam window
- ✓ Spallation target
- ✓ LBE handling

MA-loaded subcritical core
- ✓ Nuclear design
- ✓ Reactor physics

Can we transmute MA efficiently with accelerators?

- J-PARC RCS（3 GeV, 1 MW）, 1 year operation
- Number of protons

  1×10^6 [W] / (3×10^9 [eV] × 1.602×10^{-19} [J/eV]) = 2.1×10^{15} [protons/s]

  2.08×10^{15} [protons/s] × 3600 × 24 × 365 = 6.6×10^{22} [protons/y]

Avogadro's number: 6.02×10^{23}

0.1 [mol] only

Attach electrons to protons to make hydrogen atoms, and oxidize to make H_2O molecules
0.05 [mol], 1 [g], 1 [cm^3]

x 40,000 discrepancy

- Number of MA atoms

  ~25 [kg], 100 [mol] per 1 unit of nuclear reactor

  assuming 40 nuclear reactors, 1 [ton], 4,000 [mol] MA per year

Don't worry!

- High-energy protons on a heavy metal target: 1 neutron generated per 40~50 [MeV]

  70 neutrons per 3-GeV proton
- Neutron multiplication by the sub-critical core（k_{eff}=0.97）, 30
- Increasing in accelerator power to 30 [MW] 30

$70 \times 30 \times 30 = 63,000$

Can we? Yes!
According to the detailed calculation, MA atoms from 10 units of nuclear reactors can be transmuted by 1 unit of ADS.

Preliminary cost estimation of ADS

Preliminary cost estimation of ADS (unit: Oku-yen = M$)

Items	Construction	Maintenance	Decommissioning	Total
ADS-reactor	1,700	2,720[a)]	140[b)]	4,560
ADS-accelerator	590	940[a)]	50[b)]	1,580
Total	2,290	3,660	190	6,140

a) 4% of construction cost is assumed annually. (Life time is assumed as 40 years)
b) 8% of construction cost is assumed.

Preliminary cost estimation of PT fuel cycle (unit: Oku-yen = M$)

Items	Cost
4 unit of ADS	**24,600**
Partitioning process	5,700
MA fuel fabrication	5,200
MA fuel reprocessing	4,500
Electric power selling	-7,500
Reduction of disposal cost	**-19,000**
Total	13,400

(Partitioning: 5tHM/y, MA fuel cycle: 10tHMt/y)

Quoted from JAERI-Review 2005-043 (2005).

- Influence to electricity cost:
  + 0.12 ~ 0.13 yen/kWh (discount rate: 0 %)
- 0.6% increase of consumer price (~20 yen/kWh)
  ➔ **12 – 13 yen/month increase** of electricity cost of each family, assuming 1/3 of monthly consumption (300kWh/month) is supplied by nuclear.
- Simple electricity cost of ADS: 21 yen/kWh
- It is necessary to improve the accuracy of cost estimation for ADS and new disposal concept

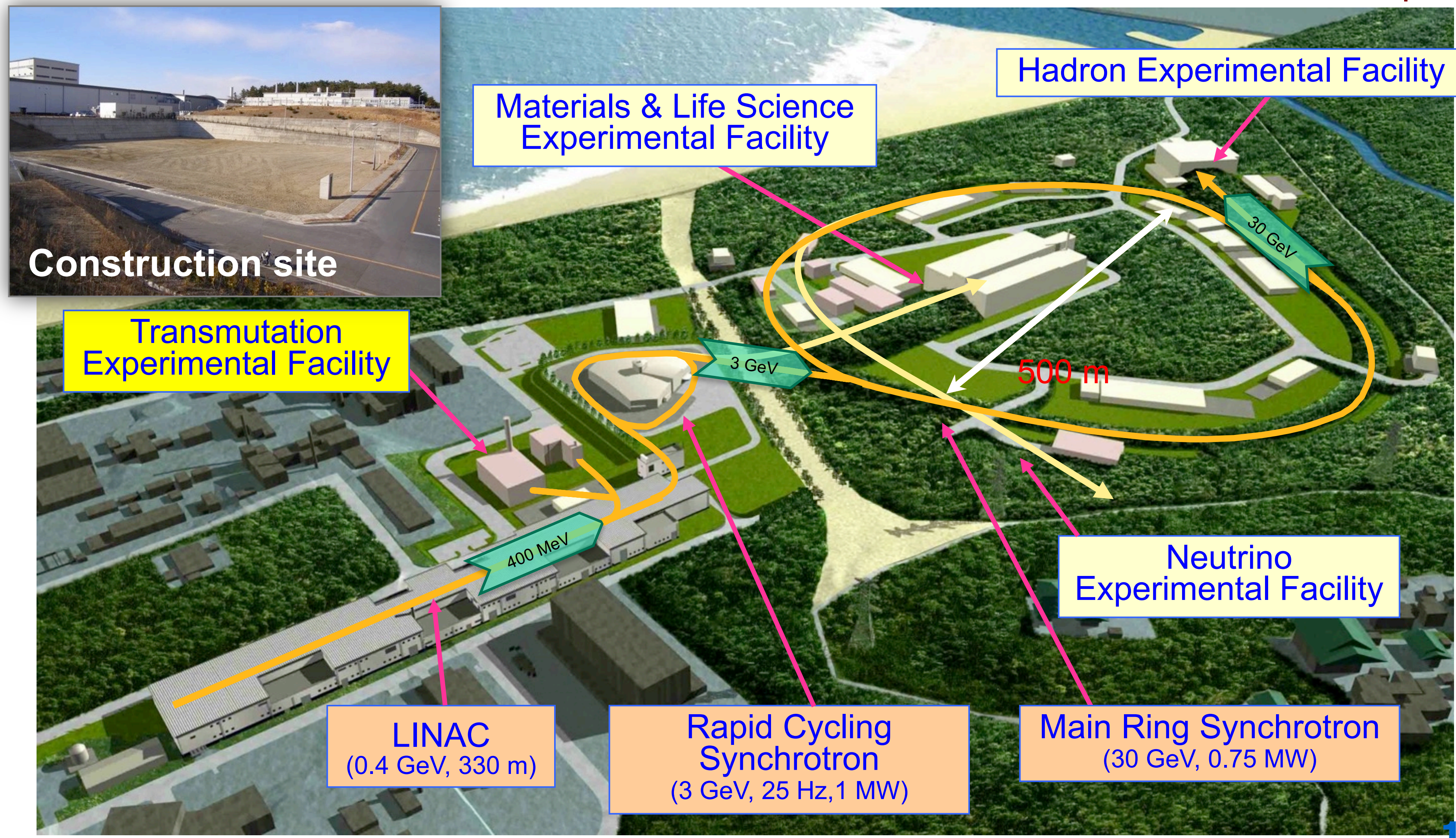
Renewable energy surcharge (TEPCO): 3.45 yen/kWh

Contents

Japan Proton Accelerator Research Complex: J-PARC

- ✧ Three accelerators & three experimental facilities have been operating since 2008.
- ✧ Experimental facility for transmutation research is under planning.

Tokai, Ibaraki, Japan



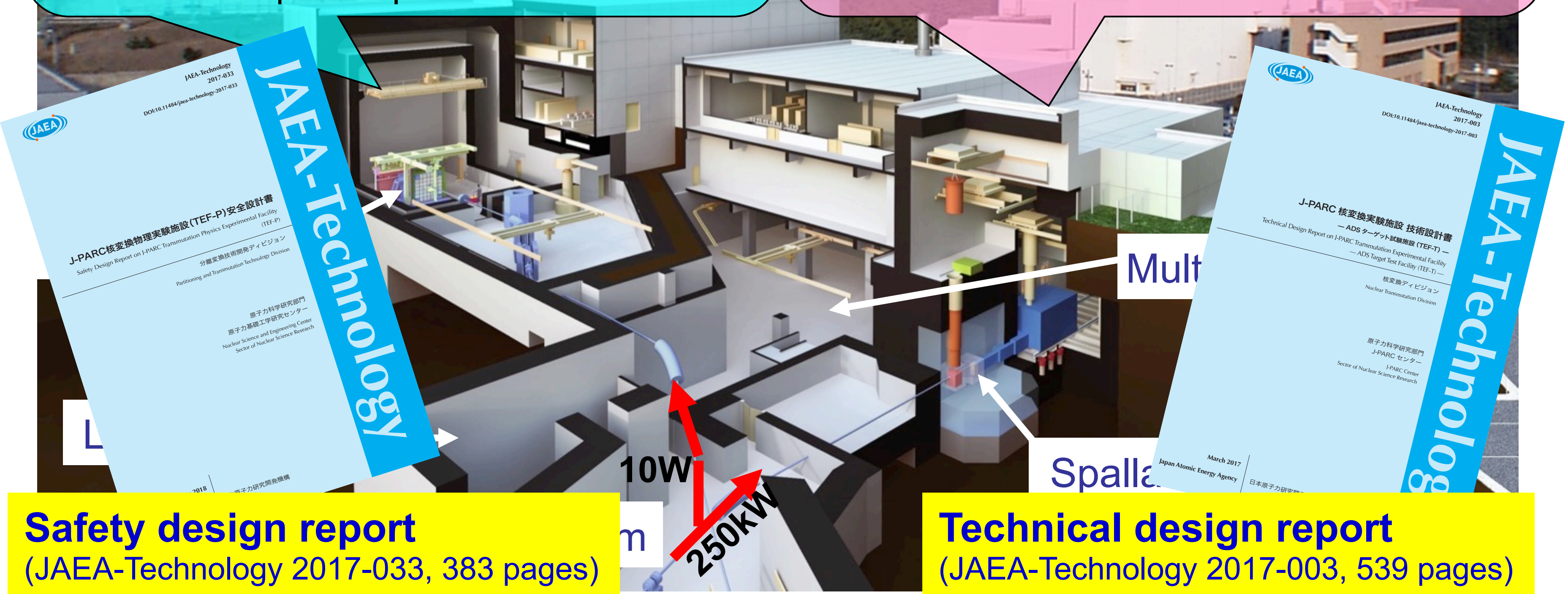
Transmutation Experimental Facility (TEF) program

TEF-P: Transmutation Physics Experimental Facility

Purpose : Reactor Physics
Category : Critical Assembly
Proton Power : 400MeV-10W
Thermal Output : up to 500W

TEF-T: ADS Target Test Facility

Purpose : Material Irradiation
Category : Radiation Application
Proton Power : 400MeV-250kW
Target Material : Lead-Bismuth

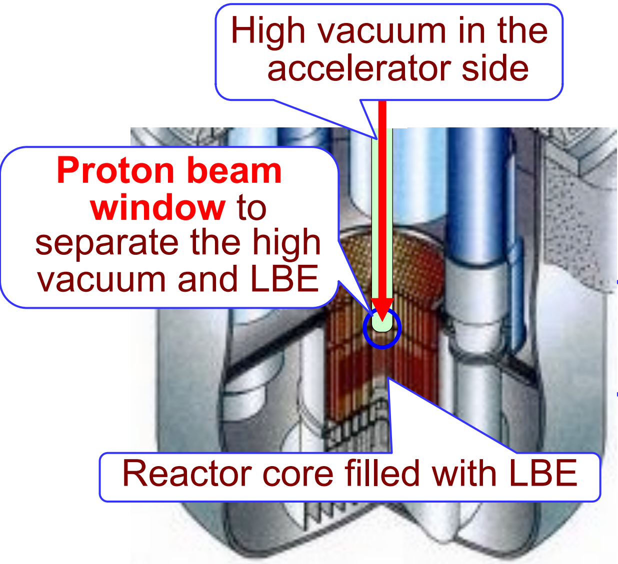


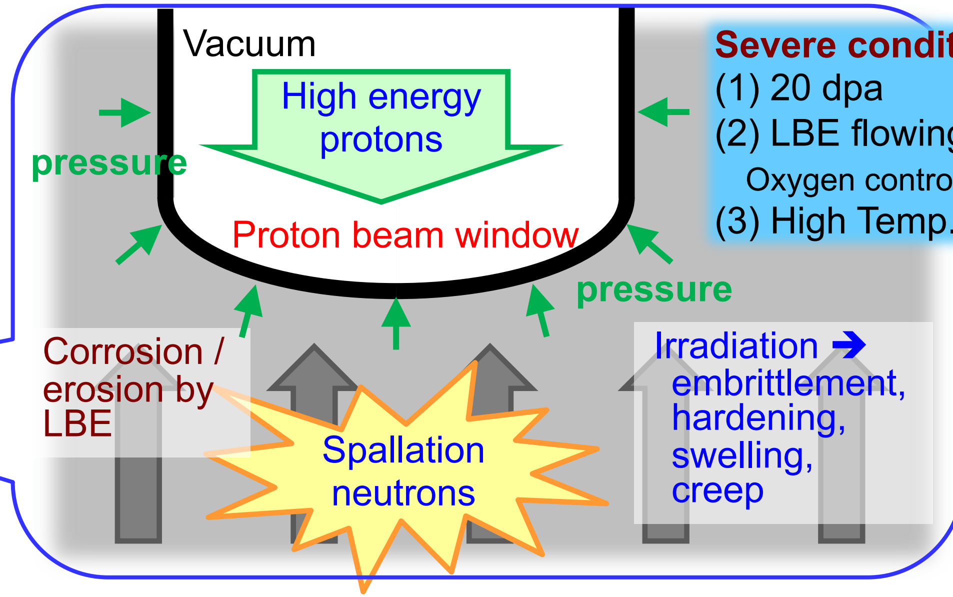
Safety design report
(JAEA-Technology 2017-033, 383 pages)

Technical design report
(JAEA-Technology 2017-003, 539 pages)

ADS Target Test Facility (TEF-T)

Reactor Core of ADS





Severe conditions

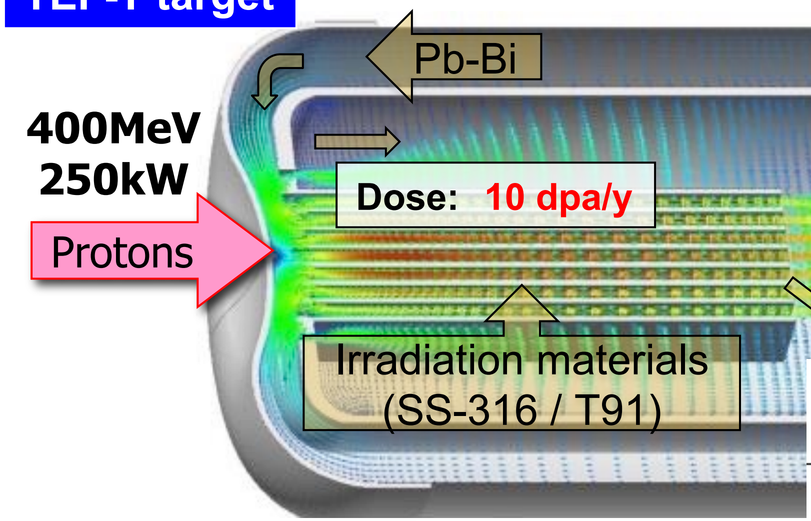
(1) 20 dpa

(2) LBE flowing (~2m/s)

Oxygen controlled: 10^{-5} ~ 10^{-7} wt%

(3) High Temp. ~550℃

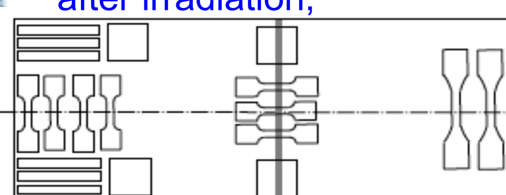
TEF-T target



Purpose of TEF-T:

- Experiments on damages of materials irradiated by protons and neutrons under flowing LBE at high temp.
- Development of material database for engineering feasibility of ADS by experiments in various condition (ex. temperature and velocity of flowing LBE)
- Development of LBE handling technology

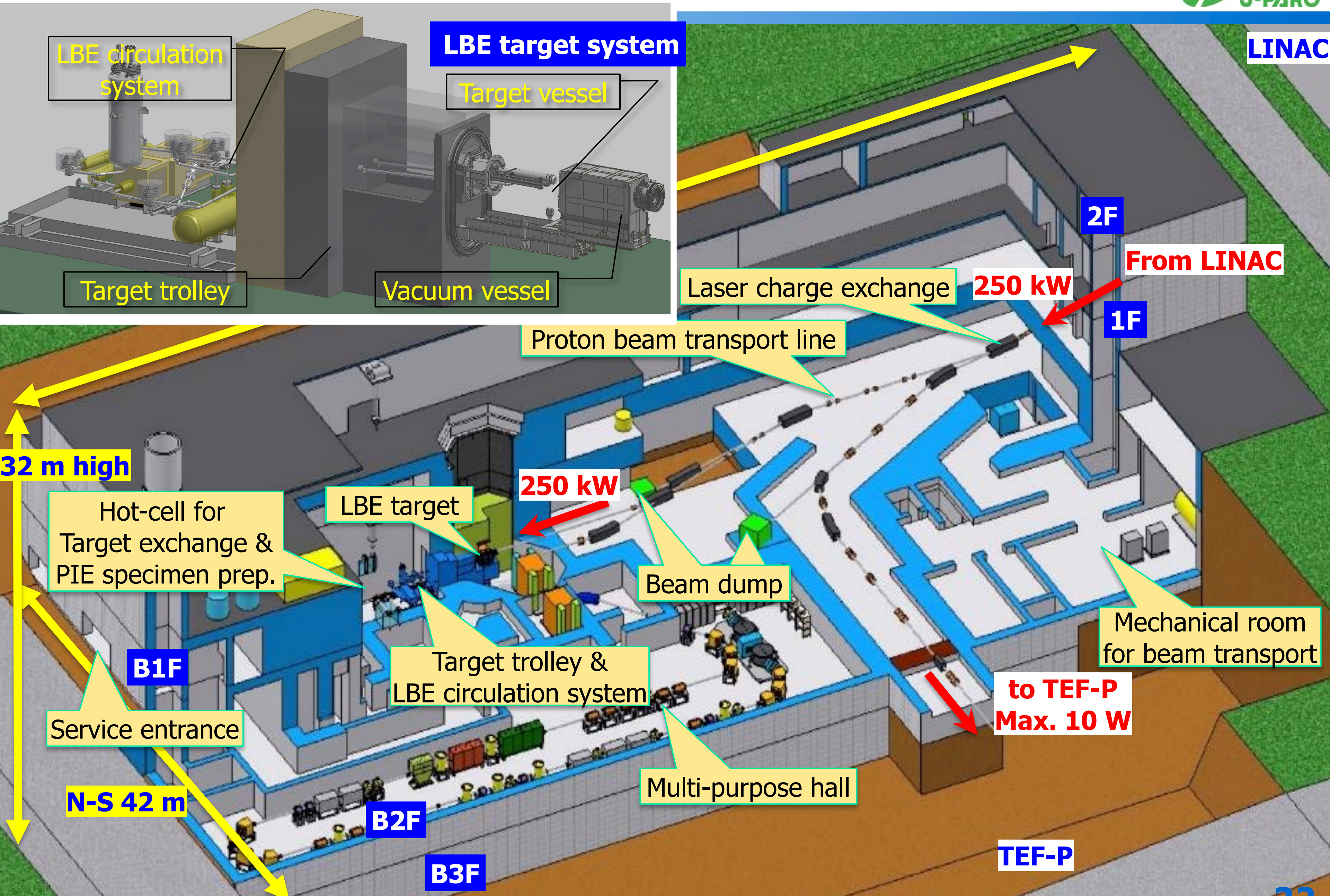
after irradiation,



t=2.0, 3.3 mm

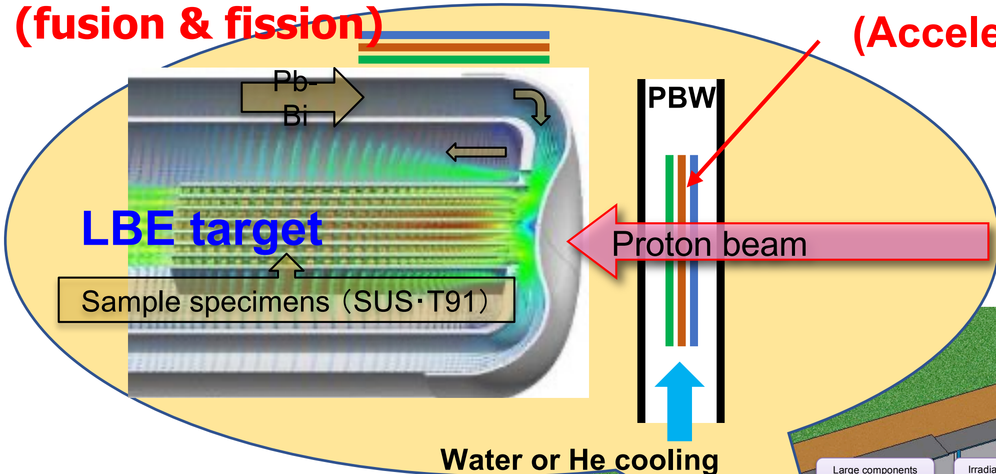
Tensile, fracture toughness,
Bending specimen, fatigue,
Surface/ cross section observation
TEM/ Small punch

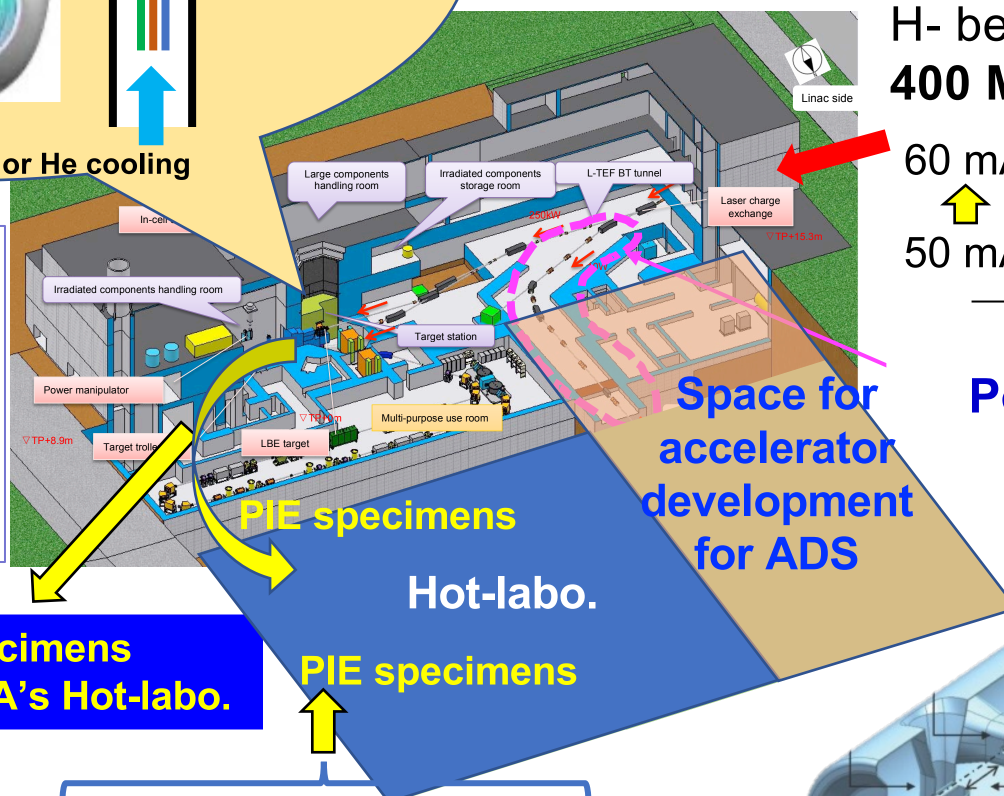
Overview of TEF-T



Now, enhancing the facility concept

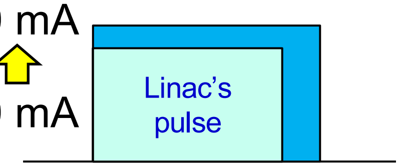
Irradiation samples (fusion & fission)





TEF-T is the baseline design.

H- beam from Linac
400 MeV, 250 kW



500 μs ⇨ 600 μs

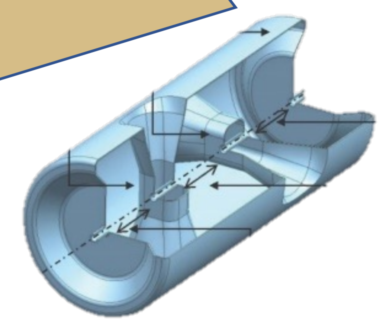
Power upgrade to 360 kW

Purposes:

1. ***Irradiation***
2. ***Soft-error testing of semi-conductor devices***
3. ***RI production***
4. ***Primary proton beam utilization***

PIE specimens
To JAEA's Hot-labo.

MLF **HD** **NU** . . .



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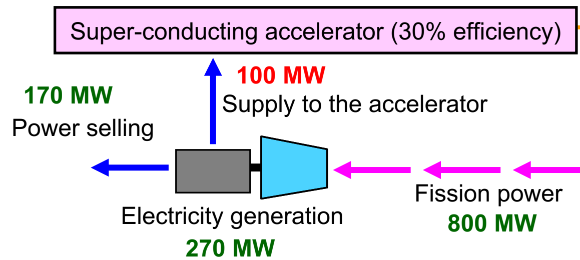
Requirements of accelerators for ADS

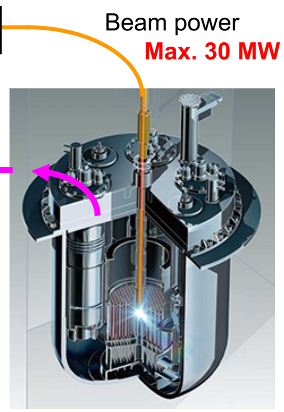
1. high power
- ~30 MW for JAEA-ADS, one of the most efficient ADS to transmute MA

2. high reliability
- To avoid thermal fatigue of reactor components associated with large temperature changes of ΔT=100ºC due to beam trips
- One beam trip longer than 5 min. corresponds to a scram of 800 MW MONJU-class nuclear reactor
- For high availability

3. high controllability
- Power ramping up from zero to full power in 10 hours to start-up the turbine system and to avoid thermal fatigue of reactor components

4. high efficiency
- ~30% for self-sufficiency and economy





Beam power	Efficiency	Required electricity
30 MW	30%	100 MW (selling 170 MW)
30 MW	20%	150 MW (selling 120 MW)
30 MW	10%	300 MW (buying 30 MW)

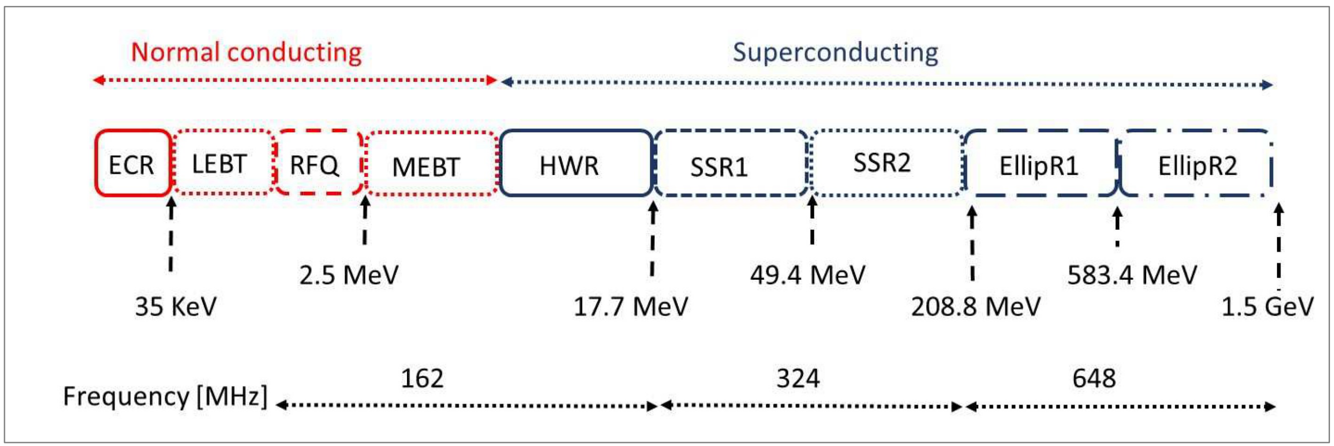
Proton LINAC for JAEA-ADS

Parameters for JAEA ADS linac	
Energy (GeV)	1.5
Current (mA)	20
Duty (%)	100 (CW)
Power (MW)	30
Acceleration efficiency	~30%

- High reliability required
  - trips/year* 20,000 (0 < t < 10 s)
    2,000 (10 s < t < 5 m)
    42 (t > 5 m)

* H. Takei et. al, J. Nucl. Sci. Technol. 49, 384 (2012)

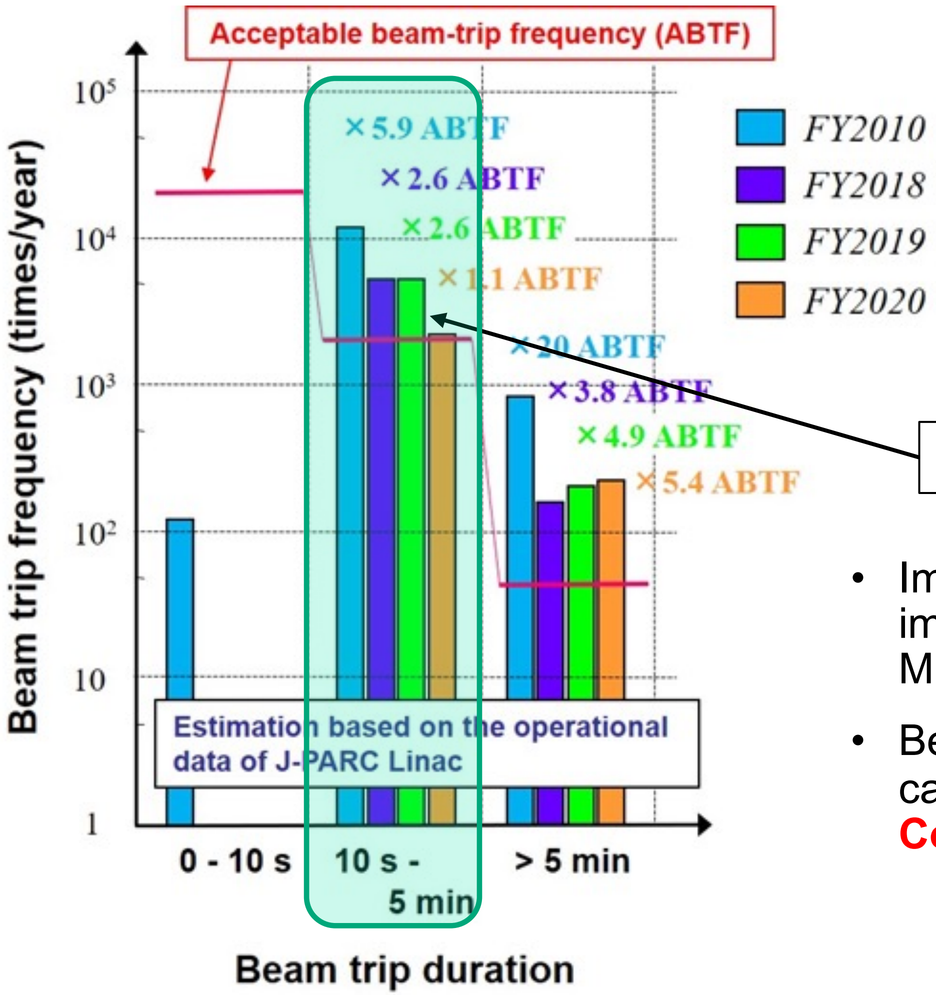
- Pulse mode operation
  - Transient of start up (gradually ramp up the power in 10 hours) and shut down operation



	HWR	SSR1	SSR2	EllipR1	EllipR2
Frequency (MHz)	162	324		648	
β_g	0.08	0.16	0.43	0.68	0.89
E_{acc} (MV/m)	7	7	8	14	14

B. Yee-Rendon, et. al., "Design and beam dynamic studies of a 30-MW superconducting linac for an accelerator-driven subcritical system", Phys. Rev. Acc. Beams 24, 120101 (2021)

For the high reliability



Mainly due to cavity trip

- The beam trip frequency from the annual trip data of the J-PARC linac **normalized by # of RF sources** was compared with the acceptable beam-trip frequency.
- Trips in >5 min category are dominated by klystron (RF source) and its DC power supply failure.

- Improvement in 2020's 10s-5min is due to implementing of the RFQ auto-recovery without MPS beam stop.
- Beam trips are dominated by discharge of the cavities. But it is **estimated from the Normal Conducting (NC) cavity operation**.
  - Trip behavior of NC and superconducting (SRF) cavities is different.
  - For the next step, trip statistics of SRF is necessary.
  - **We started the analysis of Spallation Neutron Source (SNS/ORNL/US) SRF data.**

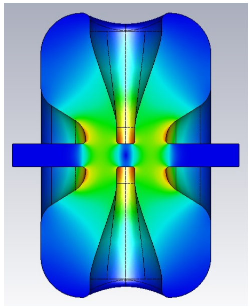
- **The fast fault compensation scheme is also introduced for the high reliability.**

B. Yee-Rendon, et. al., "Beam dynamics studies for fast beam trip recovery of the Japan Atomic Energy Agency accelerator-driven subcritical system", Phys. Rev. Acc. Beams 25, 080101 (2022).

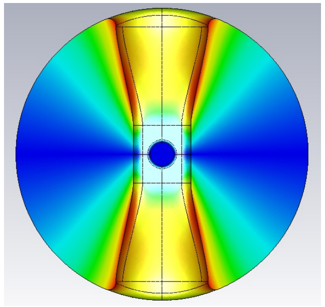
Prototyping of a spoke cavity

Frequency:	324 MHz
Shape:	Single Spoke
β_g:	0.19
β_{opt}:	0.24
Beam aperture:	40 mm
Cavity length:	300 mm
Cavity diameter:	~500 mm

E-field

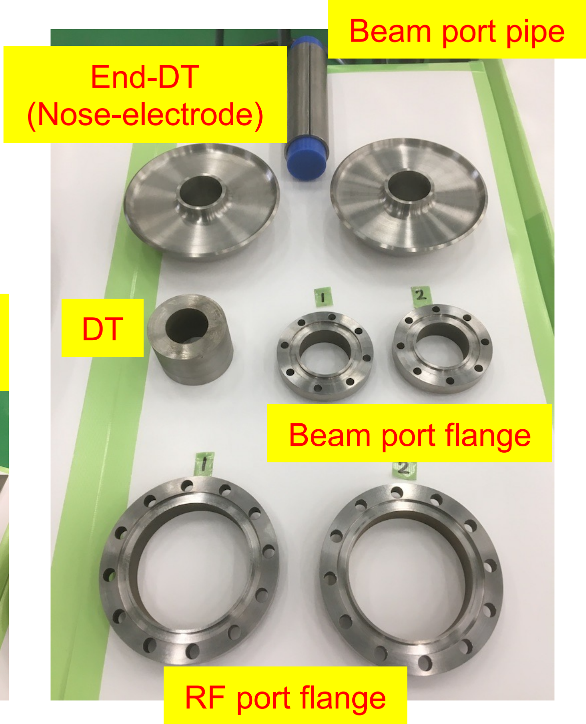


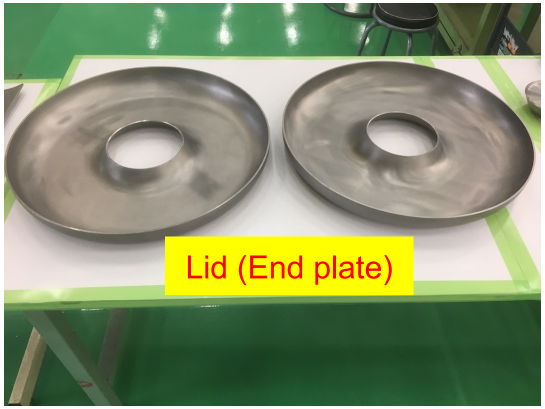
H-field

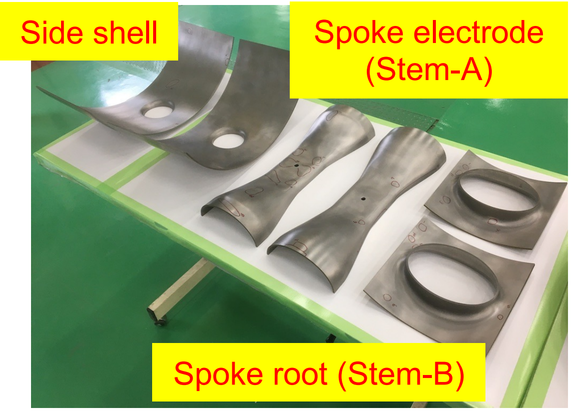


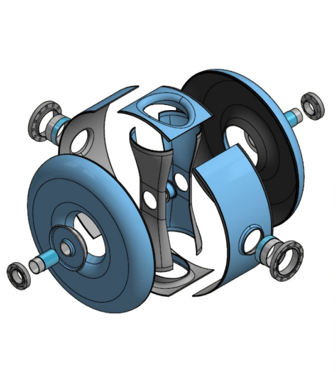
RF analyses

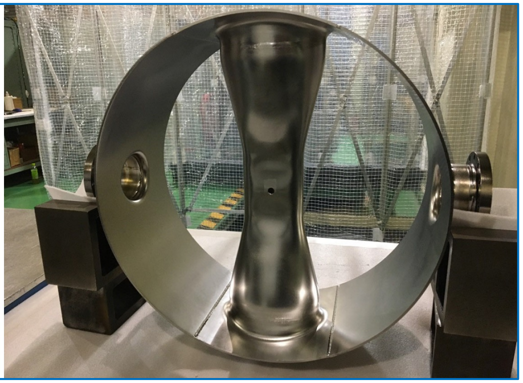
- Parts made of Nb was fabricated in FY2020.







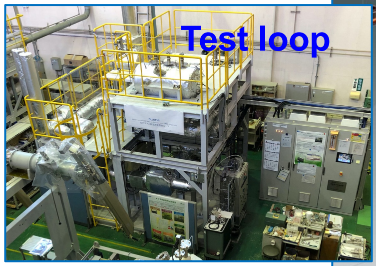


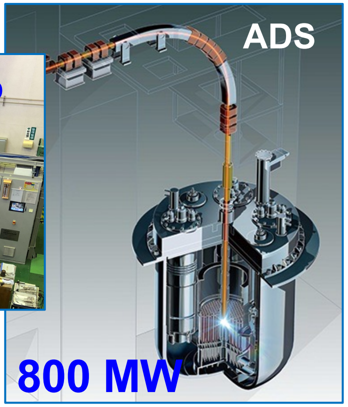


- The center body was electron-beam welded in FY2021.

J. Tamura, et. al., "Assembling Status of the Prototype Spoke Cavity for the JAEA-ADS Linac", presented in this meeting

Why lead-bismuth eutectic?





Pb: 44.5%, Bi: 55.5%

Mercury **(Hg)** Sodium **(Na)** Lead-bismuth eutectic **(LBE)**

Material	Atomic No.	density [g/cm³]	Melting point [°C]	Boiling point [°C]	Range of p @1GeV [cm]	Neutron yield @1GeV [n/p]	
Na	11	0.97	98	883	440	3.3	NG for target
Hg	80	13.5	-39	357	42	27.0	Low b. p.
Pb	82	11.3	327	1750	53	26.8	
LBE	82/83	10.5	125	1670	58	26.2	

Advantages of LBE
- Relatively low m. p.
- High b. p.
  - ✓ Boiling -> deteriorate cooling performance and stability of core
- Short range of proton and high neutron yield
- Chemically inert
- Low neutron absorption

Disadvantages of LBE
- Need heater and lagging material
- Heavy (anti-seismic)
- Corrosive to steel materials
- Po production via $^{209}Bi(n, \gamma)^{210}Bi \xrightarrow{\beta} {}^{210}Po$

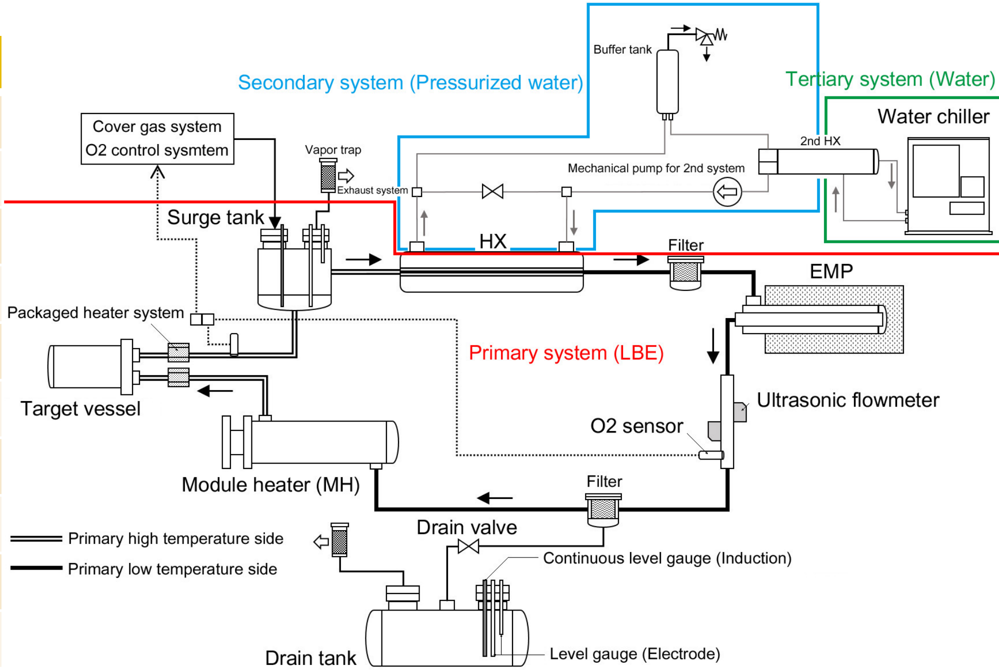
LBE test loops

IMMORTAL: Integrated Multi-functional MOckup for TEF-T Real-scale TArget Loop

Purposes

- Mock-up of TEF-T LBE target system
    - Confirmed sound operation of the loop
- Study on thermal-fluid behavior
- Integration test of individually developed components (flowmeter, oxygen control control system, level gauge, etc.)

Specifications	IMMORTAL
Max. T /Max. ΔT	500ºC / 100ºC
Max. Flow rate	120 liter/min (head: 0.2 MPa)
Power of Module heater	67 kW
Capacity of heat exchanger	67 kW
Inventory of LBE	290 liter
Main piping	i.d. 69.3 mm
Main material	316 SS
Flow monitoring system	Ultrasonic flowmeter
Oxygen control system	Available (Pt/Air type sensor)
Liquid pressure gauge	To be installed

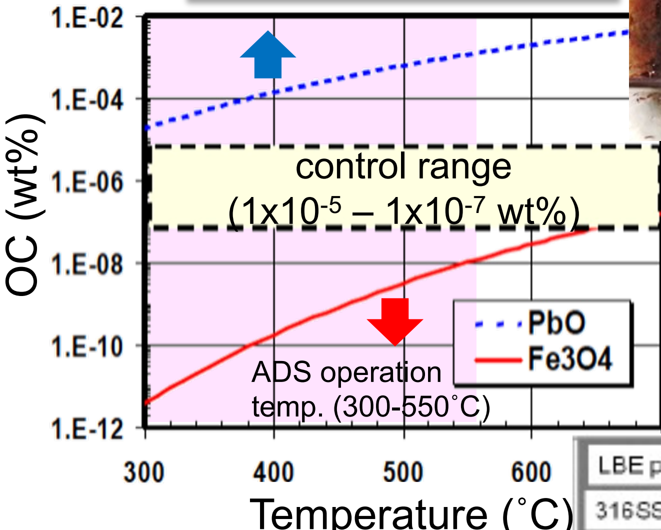


Oxygen concentration control in LBE

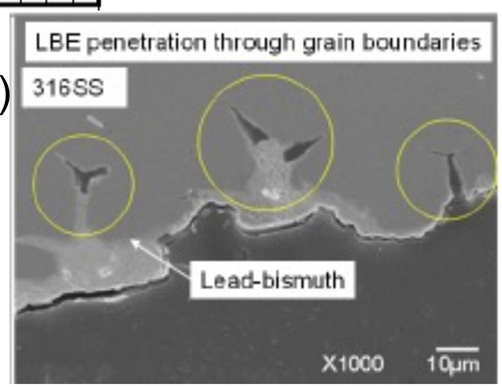
Measure to prevent corrosion by LBE

- Corrosion of steel materials by LBE can be mitigated by forming oxide film on their surface.
- For this purpose, oxygen concentration in LBE has to be controlled in a suitable range.

Blockage of pipe, valve etc. by PbO and oxide flakes



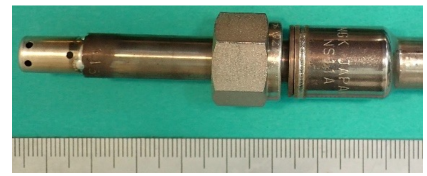
·Dissolution of surface oxide layer
·Solution of Ni, Cr, Fe into LBE



Oxygen sensor development

- Two types of oxygen sensor which are operational in LBE at >500ºC have been developed.

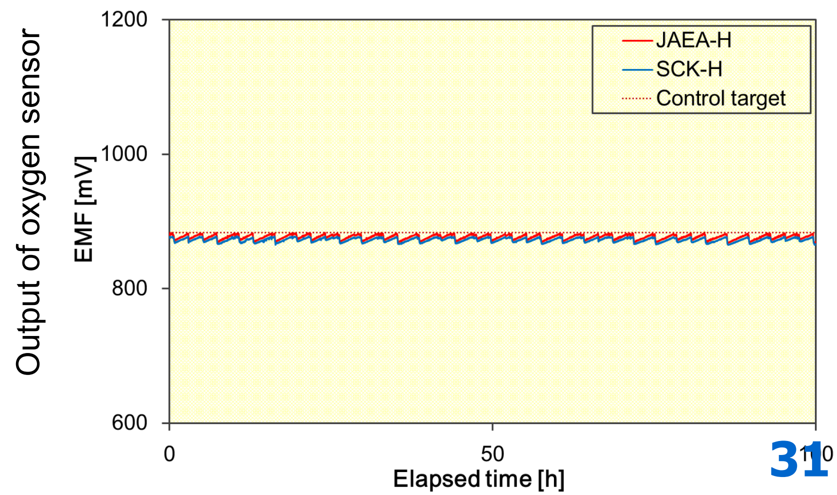
Conventional type



New type
- Small and robust

Oxygen concentration control

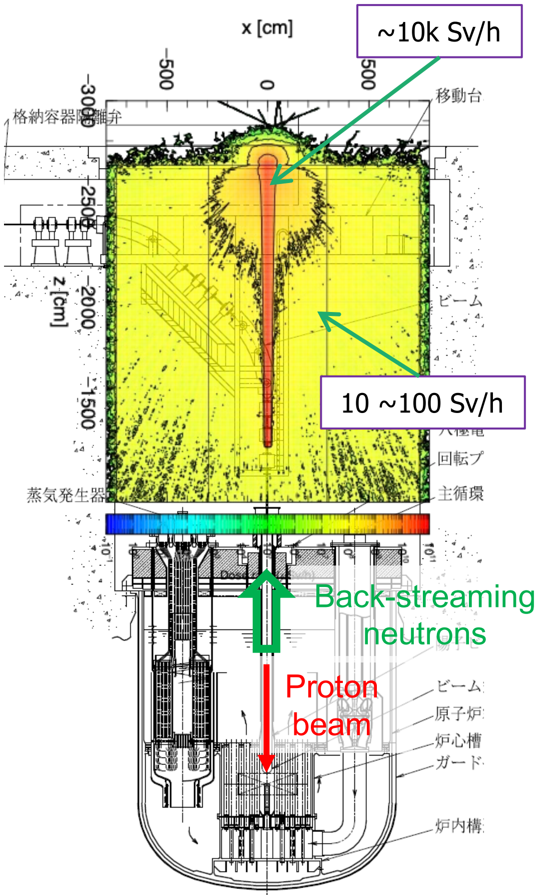
- Flow rate measurement by the contactless type ultrasonic flowmeter for LBE was succeeded.



Neutronics and nuclear data

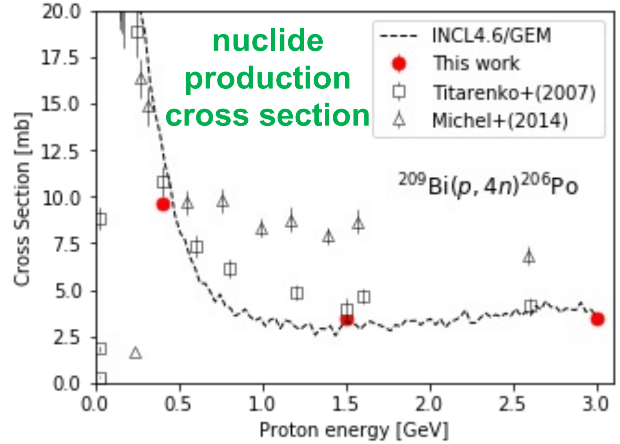
Shielding calculation

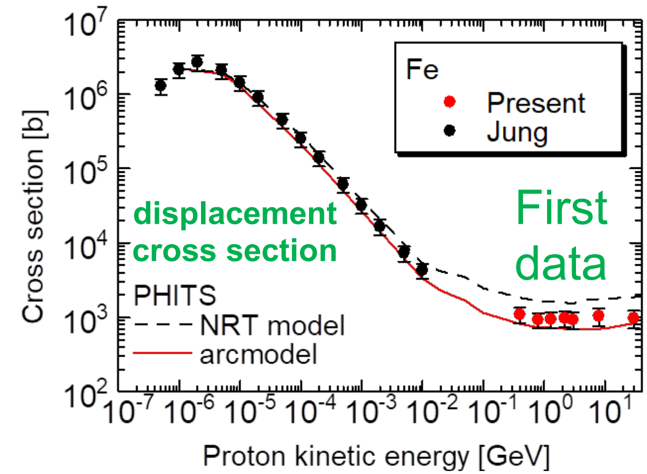
- Neutron flux back-streaming through the beam duct from the core is very high.
- Radiation damage and activation are issues.



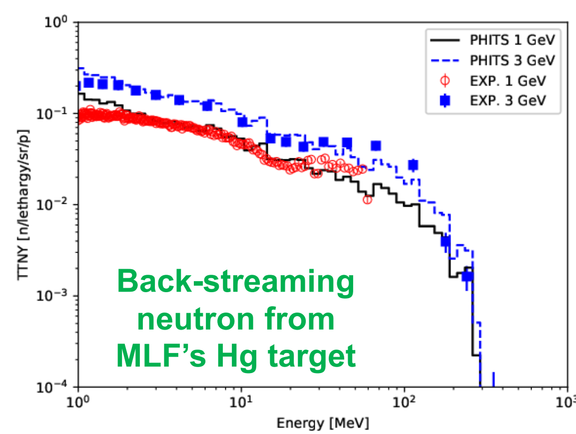
For accurate nuclear designs

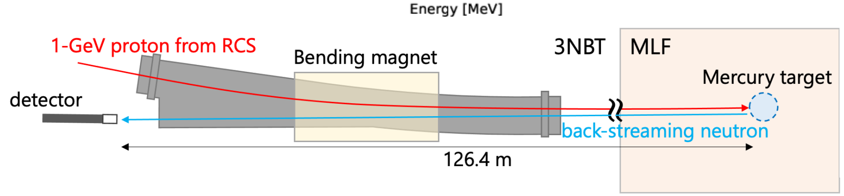
Nuclear data measurement at J-PARC

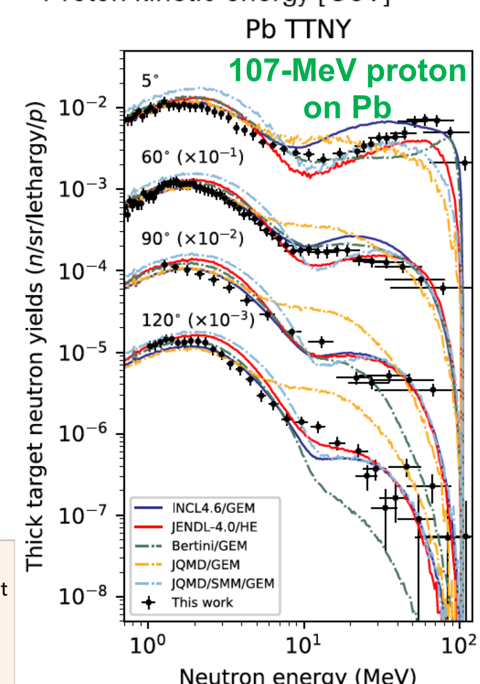




Neutron production yield measurement



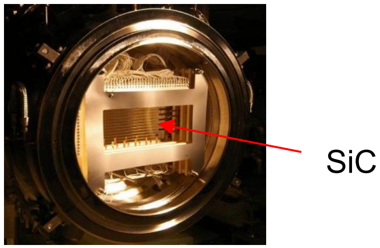




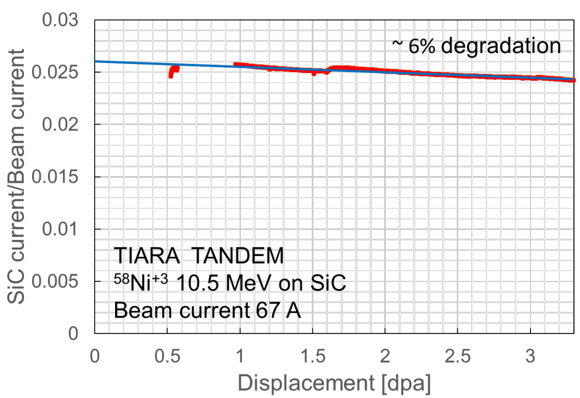
Proton beam monitoring and control

Beam monitor development

- SiC wires are used in a beam profile monitor for 1 MW and 3 GeV proton beam at MLF/J-PARC.



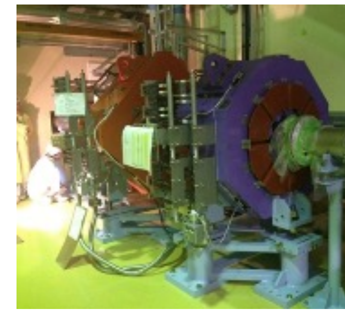
- Radiation resistance of SIC wires were tested by using heavy ion beams for acceleration.



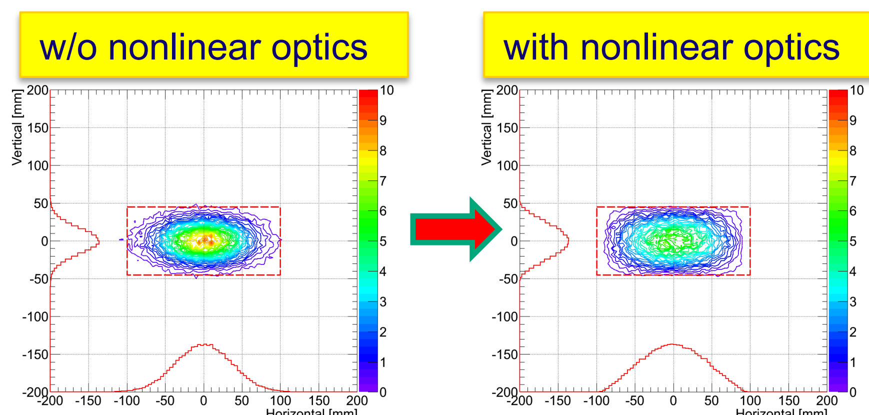
- Displacement dose: 3.5 dpa at Bragg peak which is equivalent to the GeV protons with 30 μA/cm^2 for 6,500 h.
- Degradation of the electron emission is small enough.

Non-linear optics to flatten the beam

- The non-linear optics with octupole magnets was introduced in the J-PARC's proton beam line.



- The peak current density on the MLF's Hg-target was reduced by ~30%. This is effective to prolong the target life-time and to reduce the peak heat density.

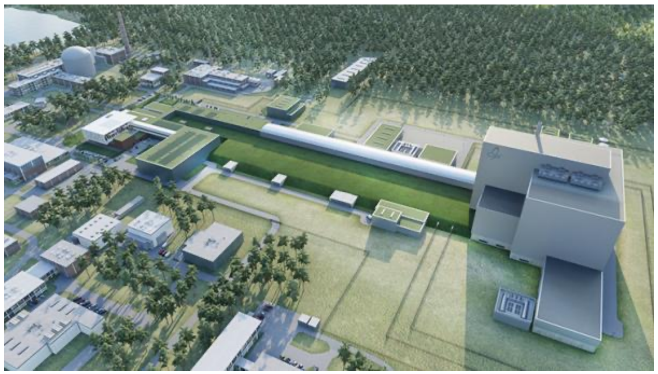


Contents

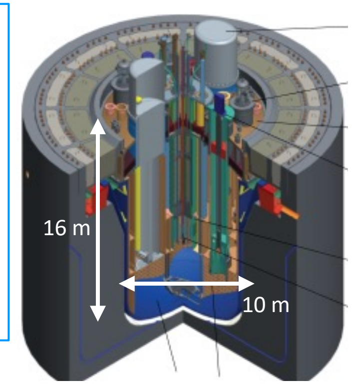
MYRRHA project in Belgium

MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications)

- The world's first large scale Accelerator Driven System project at power levels scalable to industrial systems, developed by Belgian Nuclear Research Centre



- Accelerator: SC-Linac, 600 MeV, 4 mA (2.4 MW)
- Target: LBE, 7,800 tons
- Sub-critical reactor: 100 MW_{th}, MOX fuel, k_{eff} = 0.95, LBE cooling
- Purposes: R&D for nuclear waste treatment, Production of nuclear medicine, Nuclear science, Fusion reactor physics



- In 2018 the Belgian Federal Government decided to have the MYRRHA project built on the SCK CEN site in Mol. Based on a total budget of 1.6B€, the government committed 558M€ towards the project's phased approach.
- The Belgian government announced the establishment of an international non-profit organisation that will be ideally suited to welcome investment from additional participating countries.

2019 | 2026 2027 | 2038

Phase-1 (accelerator up to 100 MeV) (287M€) → operation（156 M€）

- To confirm the linac's operational reliability
- Proton Target Facility for the production of medical radioisotopes and for fundamental and applied research in physics as well as for material research
- Fusion Target Station, where materials for fusion reactors will be tested

R&D on **Phase-2** (accelerator extension to 600 MeV) and **Phase-3** (sub-critical reactor), and pre-licensing of the reactor (115M€)

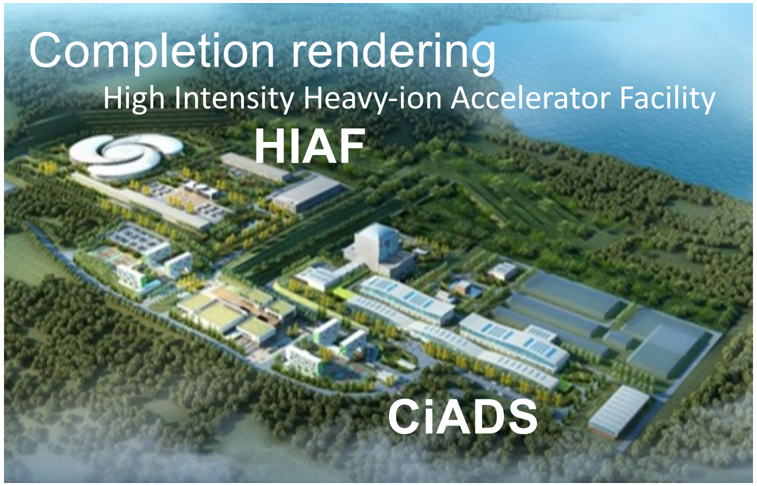
Phase-2 (Linac extension) 2033

Phase-3 (reactor construction) 2036

Reference: https://www.sckcen.be/en/projects/myrrha

CiADS project in China

- As one of the national major science and technology infrastructures, **the China initiative Accelerator Driven System (CiADS)** will be the world's first prototype of ADS facility at megawatt level to explore the safe and proper technology of nuclear waste disposal.
- Lead by Institute of Modern Physics (IMP), CAS, with four partners, China National Nuclear Corporation (CNNC), Institute of High Energy Physics (IHEP), GNC and Hefei Institutes of Physical Science (HIPS)



- Phase I (2011-2016) R&D on Superconducting Linac
- Phase II (2018-2024) Construction of **CiADS**
  - ✓ Accelerator: proton Linac, 500 MeV, 5 mA (2.5 MW)
  - ✓ Sub-critical reactor: 7.5 MW_{th}, LBE cooling
  - ✓ Site: Huizhou City, Guangdong Province, next to **HIAF**
- Phase III (~2032) ADS demo reactor
  - ✓ 1 GeV, 10~15 mA (10~15 MW), 600 MW_{th}
- Phase IV (~203x) ADS commercial reactor
  - ✓ 2 GeV, 10~20 mA (20~40 MW), 1.5 GW_{th}

Reference: http://english.imp.cas.cn/research/facilities/CIADS/

ADS in Ukraine

- Supported by DOE/US (ANL) under the Russian research reactor fuel return programme
- Purpose
  - Demonstration of ADS operation
  - Neutron science research
  - Medical RI production
  - Human resource development

"It is the first ADS in the world, which has a coolant system for removing the generated fission power."

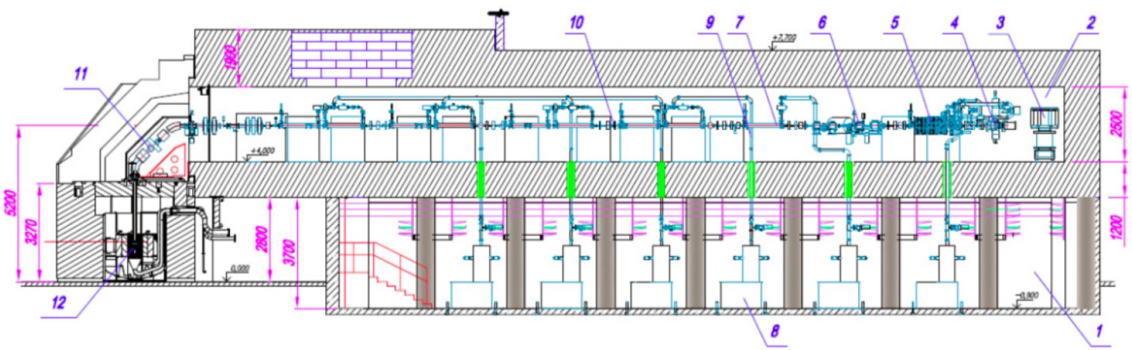


Figure 1: Layout of the accelerator and subcritical assembly systems: 1 is klystron gallery, 2 is accelerator tunnel, 3 is electron gun power supply, 4 is injector part of the accelerator, 5 is the first accelerating section, 6 is chicane, 7 is accelerating section, 8 is klystron, 9 is wave guide, 10 is quadrupole triplet, 11 is electron beam transportation channel, 12 is subcritical assembly.

A. Zelinsky, et al., IPAC2017 TUPIK033

- 2012 construction start
- 2016 commissioning start

- Electron Linac
  - power 100 kW
  - Energy 100 MeV
  - Target nat-U / W
- Sub-critical reactor
  - Fuel Low-enriched UO_2 (19.7%)
  - Coolant Water
  - Reflector Graphite, Beryllium
  - k-eff 0.97-0.98
  - Thermal output 300 kW
  - Neutron intensity 3×10^{14} n/s
  - Neutron flux 2.5×10^{13} n/(s・cm^2)

cf.
JAEA JRR-3: 20 MW
JAEA-ADS: 800 MW
J-PARC MLF: 1×10^{17} n/s
JAEA JRR-3: 3×10^{18} n/(s・cm^2)

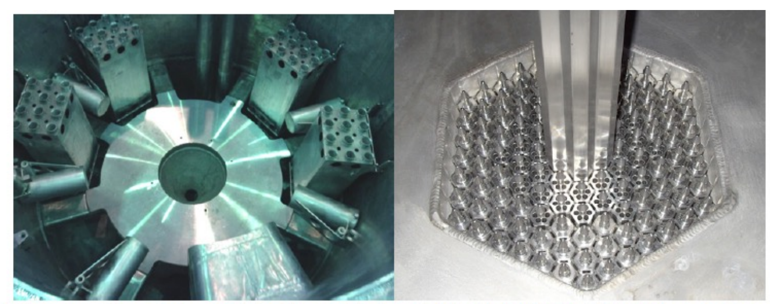


Figure 3: Assembled and installed NSC KIPT neutron source core with target.

A. Zelinsky, et al., IPAC2017 TUPIK034

Summary

- ADS is one of the most promising applications of high-intensity and high-power accelerators for transmutation of nuclear waste, and for contributing to future development of the human society.

- There are many interesting challenges to develop the accelerators for ADS aiming at high power, high reliability, high controllability and high efficiency.

- We appreciate very much for any support for ADS by the accelerator people!