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Transmutation of nuclear wastes by metal fuel fast reactors

International Symposium on Present Status and Future Perspective for Reducing Radioactive Wastes - Aiming for Zero-Release – Funabori, Tokyo

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October 9 & 10, 2014

What is nuclear wastes problem?

The biggest problem on nuclear wastes

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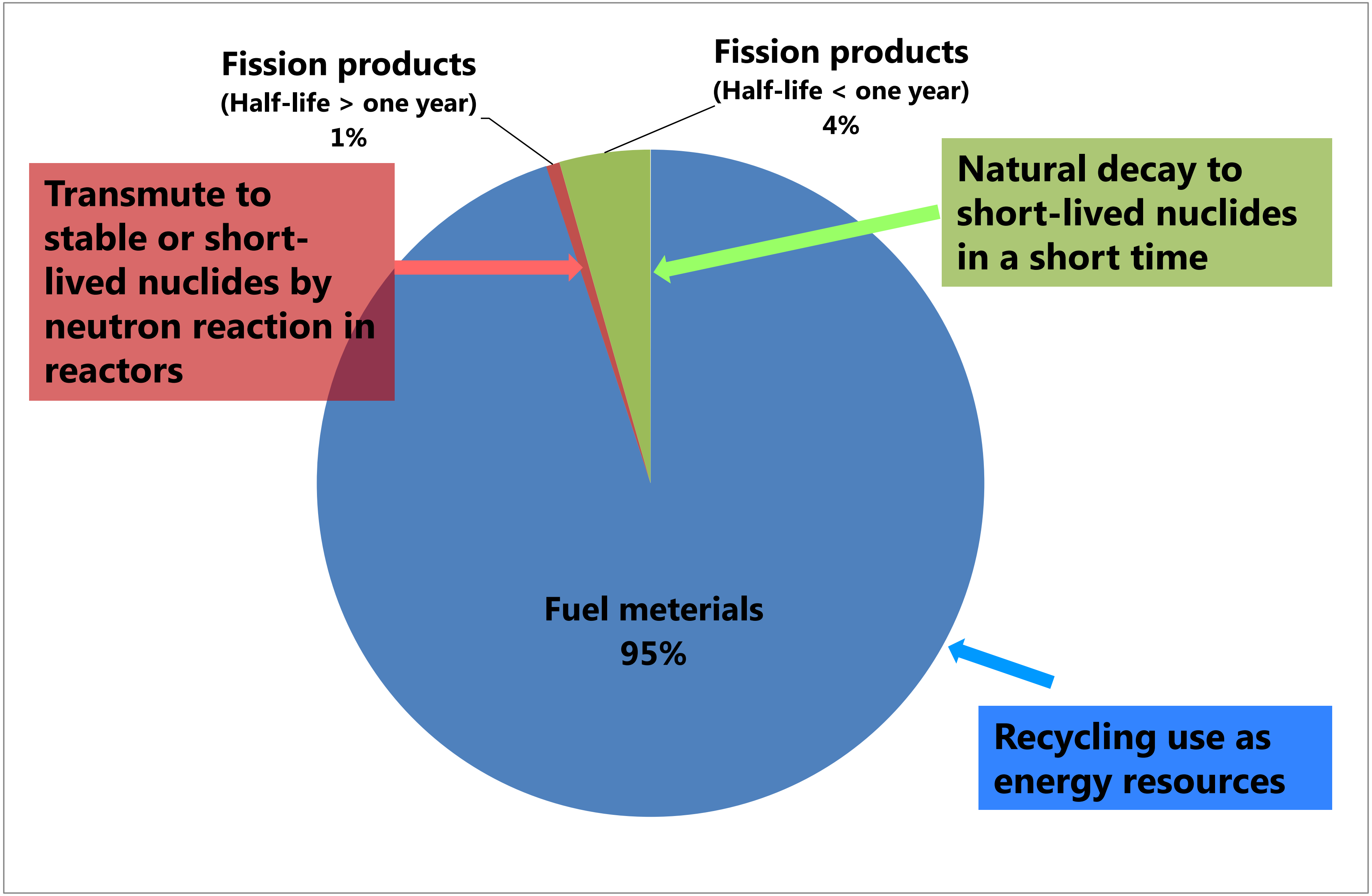
Disposal of high-level radioactive waste

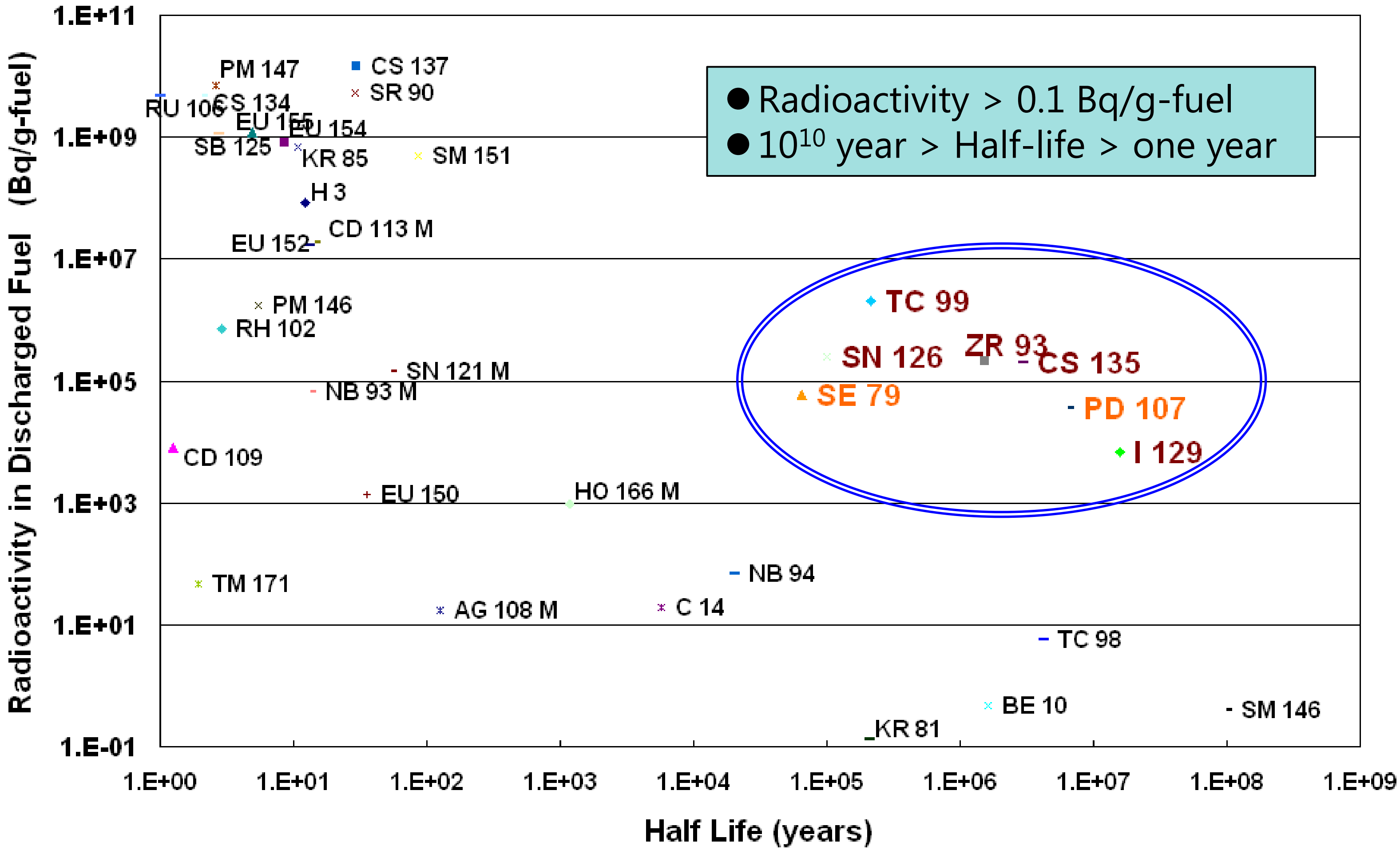
↓

How should we manage used nuclear fuel?

Many valuable and few harmful elements in used fuel



Radioactivity and half-life of fission products



LLFPs are only a few nuclides among all FPs

K. Arie et. al., "The Sustainable System for Global Nuclear Energy Utilization", GLOBAL2007, Boise, Idaho, USA, September 9-13, 2007.

(The study funded by JAPC.)

LLFP : Long-Lived Fission Product

Preferred reactor type for transmutation?

Long-lived radioactive nuclides is transmuted to stable or short-lived radionuclides by neutron capture reaction

↓

Transmute using neutrons in fission reactors

↓

Reactors with many excess neutrons are preferred

Comparison of excess neutron capability

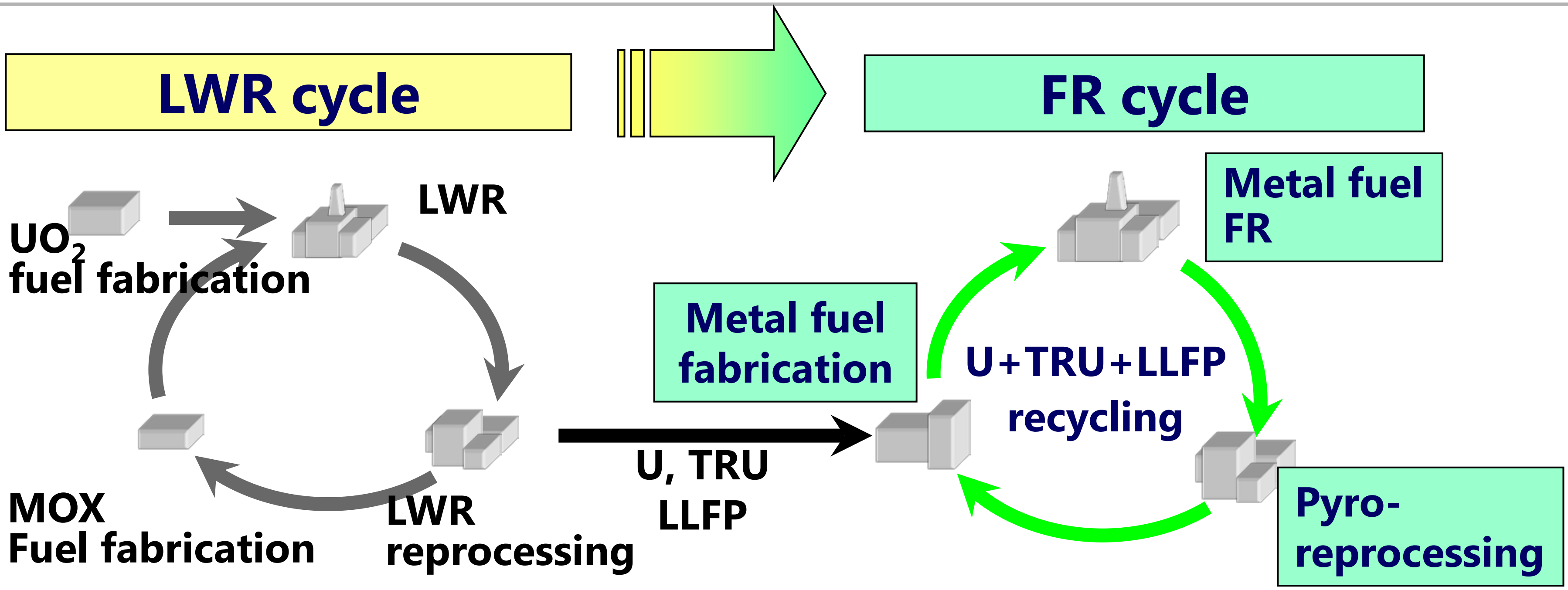
Unit: number of neutrons per fission

Types of neutron reaction		LWR	FR	
			Oxide fuel	Metal fuel
Yield	Fission	2.4	2.9	2.9
Consumption	Chain (fission) reaction fissile fission fertile fission	 1.0 ~0	 0.8 0.2	 0.75 0.25
	Fuel production for conversion ratio 1.0	1.25	1.0	0.91
	Parasitic capture fissile capture others (structural materials and coolant)	 0.25 0.4	 0.2 0.25	 0.14 0.2
Excess neutrons		-0.5	0.45	0.65

- Preferred reactor type for transmutation -

LWR << Oxide fuel FR < Metal fuel FR

Toshiba long-term vision - metal fuel fast reactor -



Toshiba has been developing actinide recycling technologies:

- Long-term energy security
- Nuclear waste transmutation (environmental harmonization)
- Economical FR cycle
- High proliferation resistance

TRU: Transuranium

Roadmap

Phase 1

Technology development

MONJU **utilization etc.**

～2030

Phase 2

Transmutation of LWR nuclear wastes (LWR-dominant era)

High-efficient transmutation by uranium-free metal fuel FR

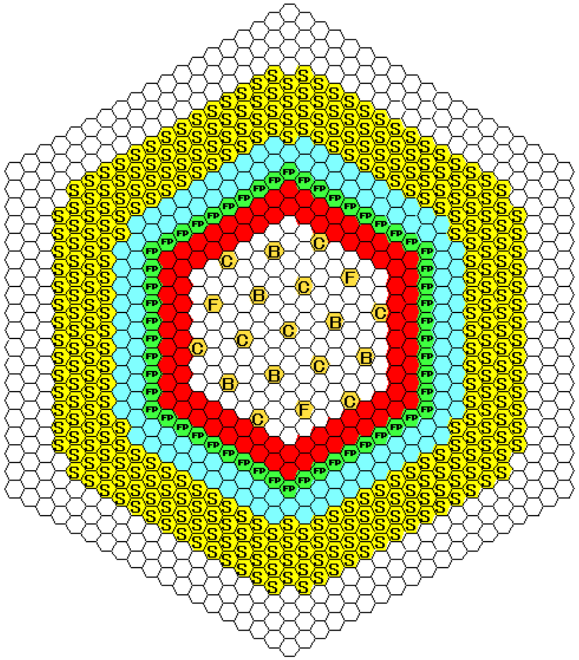
～2050

Phase 3

Sustainable nuclear energy system by FR

U+TRU＋LLFP recycling FR

Phase 1: Transmutation study assuming MONJU



Inner Core (High Enriched TRU) Fuel	108
Outer Core (High Enriched TRU) Fuel	90
LLFP-Assembly	54
Peripheral (Low Enriched TRU) Fuel	120
Shielding Assembly	324
Coarse Control Rod Position	10
Fine Conrol Rod Position	3
backup Control Rod Position	6

Core layout

K. Arie et. al., "A Strategy on Minimizing High-Level Waste Burden for Sustainable Energy System", Global2009, Paris, France, September 6-11, 2009.

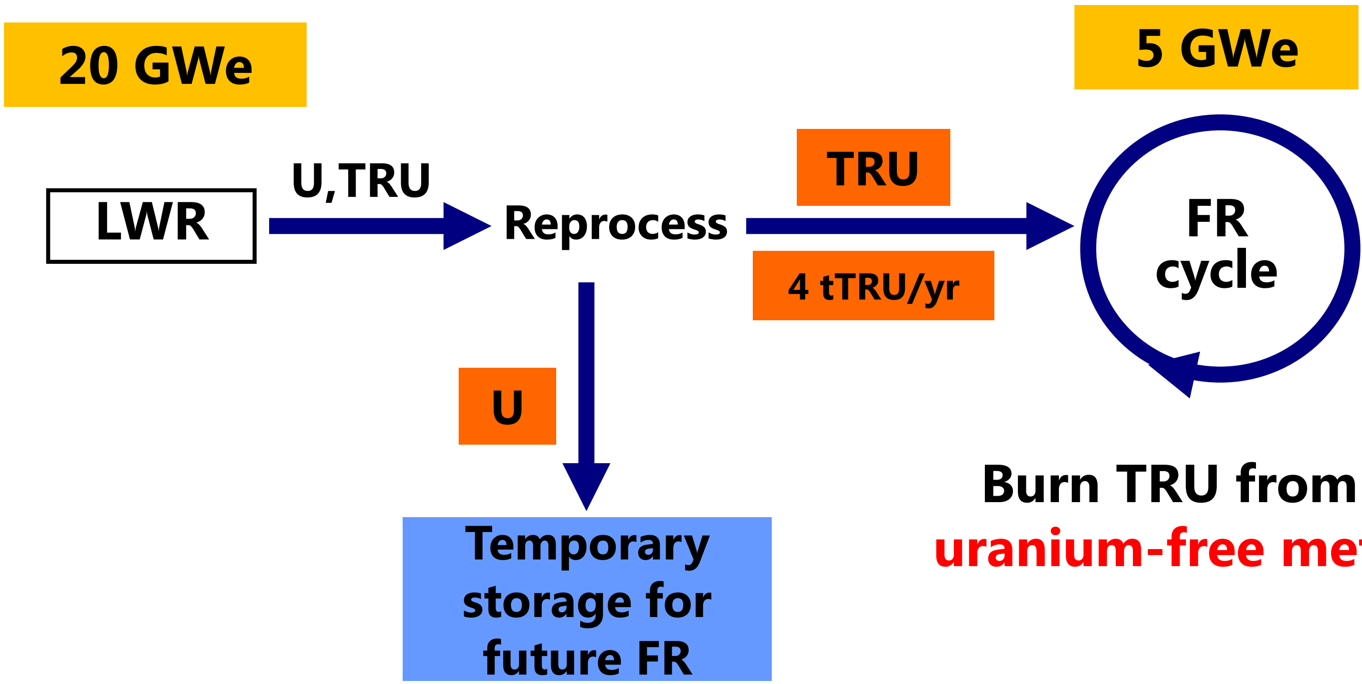
(The study funded by JAPC.)

Features

- **Replace the current MONJU core with metal fuel and LLFP target sub-assemblies (S/A) without major modification of the reactor structure:**
  - **- Core fuel → U+TRU metal fuel**
  - **- Radial blanket (1st row) → LLFP target S/A**
    - **I129: 7 S/As, Tc99: 4 S/As**
    - **Cs135, Sn126: 21 S/As for each**
    - **Zr93: Utilize as fuel alloy material**
  - **- Radial blanket (2nd, 3rd row) → U+TRU metal fuel**
- **Thermal power output: 714MWt**
- **TRU and LLFP amount to be charged in core**
  - **— TRU 1.9t (10 years' operation of 1 GWe-LWR)**
  - **— LLFP I129 0.1t (10 years' operation of 1 GWe-LWR)**
    - **Tc99 0.3t (10 years' operation of 1GWe-LWR)**
    - **Cs135 0.2t (4 years' operation of 1GWe-LWR)**
    - **Sn126 0.3t (120 years' operation of 1GWe-LWR)**
    - **Zr93 0.38t (20 years' operation of 1GWe-LWR)**

Phase 2: Uranium-free metal fuel FR cycle

- TRU transmutation at LWR-dominant era -



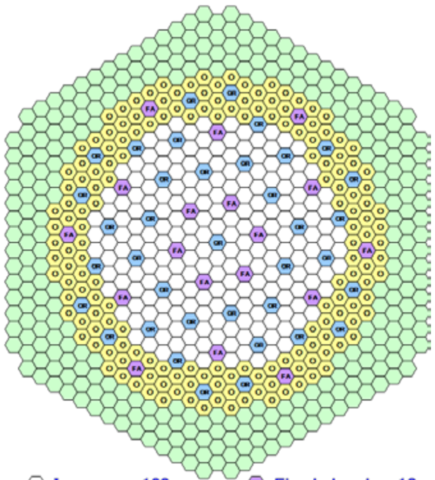
- TRU-Zr metal fuel
- Pyroprocess
- Injection casting

Burn TRU from LWR by uranium-free metal fuel FR

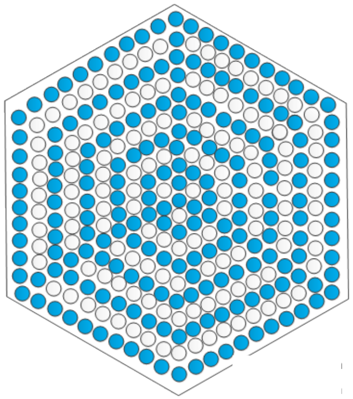
- **No production of new TRU due to "uranium-free" → Minimize the required number of FR units → Only 5 GWe FR can burn TRU from 20 GWe LWR**
- **Uranium-free metal fuel could be reprocessed by conventional pyroprocess → Minimize new R&D items**

K. Arie et. al., "TRU Burning Fast Reactor Cycle Using Uranium-free Metallic Fuel", ICAPP 2014, Charlotte, USA, April 6-9, 2014.

Phase 2: Uranium-free metal fuel FR cycle



Core layout



Fuel S/A

Features

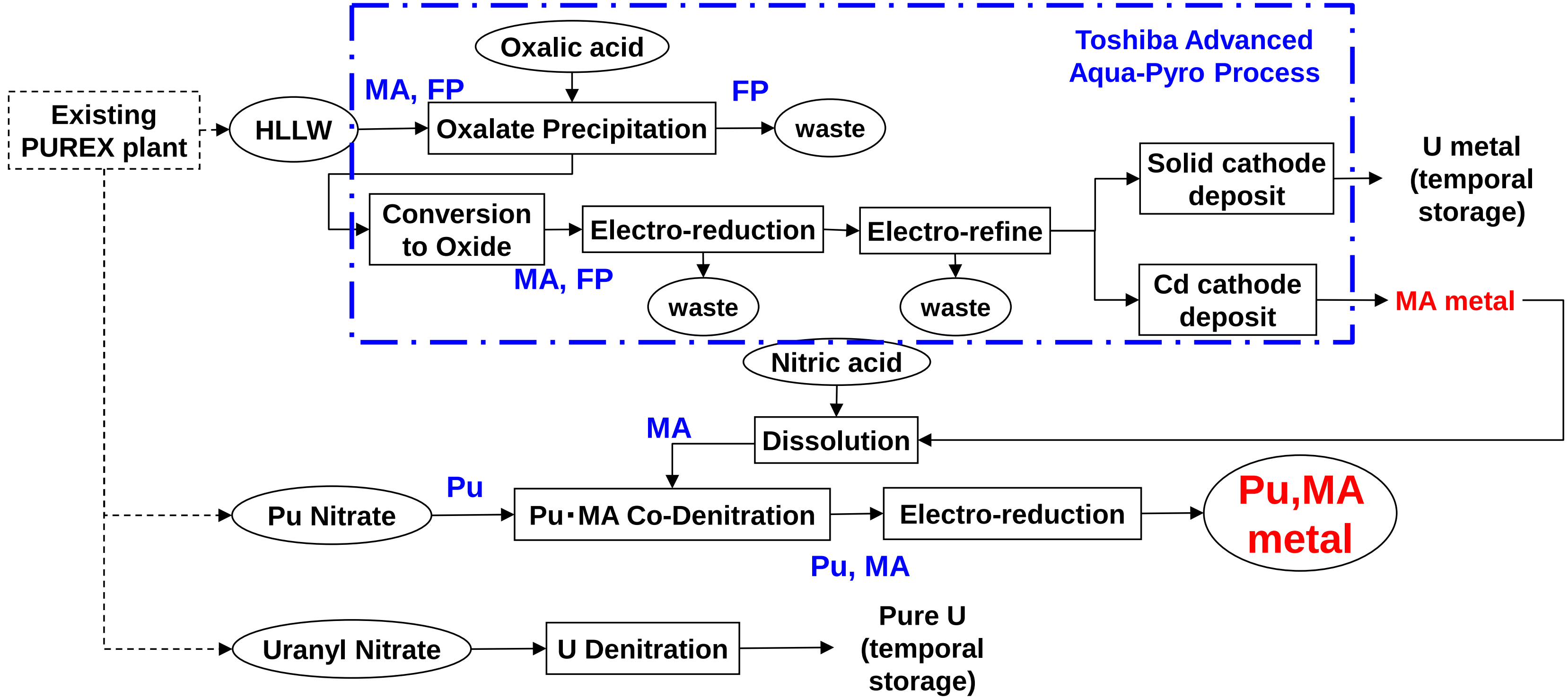
- **Electrical power output: 300 MWe**
- **Core fuel: TRU-35Zr 及び TRU-19Zr metal fuel (uranium-free)**
- **Core height: 65cm**
- **Operating cycle length: 150 days**
- **Neutron moderator, BeO in fuel S/A for safety performances (e.g., Doppler feedback)**
- **Safety parameters: equivalent to conventional metal fuel FRs**
  - **Doppler coefficient -3 x 10^{-3} Tdk/dT**
  - **Effective delayed neutron fraction 0.0026**
  - **Sodium void reactivity < 0 %dk/kk'**
- **Net burning rate of TRU: 260 kg/year**

  → Capable to burn TRU from 1.2 GWe LWR every year

K. Arie et. al., "TRU Burning Fast Reactor Cycle Using Uranium-free Metallic Fuel", ICAPP2014, Charlotte, April 6-9, 2014.

Phase 2: Uranium-free metal fuel FR cycle

Toshiba Advanced Aqua-Pyro Process

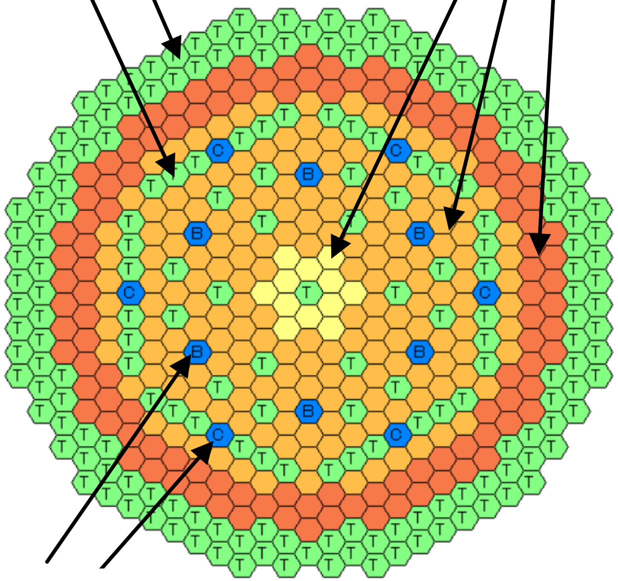


<u>Process description</u>

1. The Toshiba Advanced Aqua-Pyro Process recovers MA metal from HLLW of PUREX.
2. The recovered MA is mixed with Pu nitrate in PUREX process.
3. Finally, TRU metal is recovered by electro-reduction following Pu-MA co-denitration

K. Arie et. al., "TRU Burning Fast Reactor Cycle Using Uranium-free Metallic Fuel", ICAPP2014, Charlotte, April 6-9, 2014.

Phase 3: Sustainable nuclear energy system by FR



A core layout (SCNES)

(SCNES: Self-Consistent Nuclear Energy System)

Y. Fujii-e et. al., "A Self-Consistent Nuclear Energy Supply System - The Role of Excess Neutrons and the Potential of a Fast Reactor -," Int'l Specialist' Mtg. on Potential of Small Nuclear Reactors for Future Clean and Safe Energy Sources, Tokyo, October, 1991.

Features

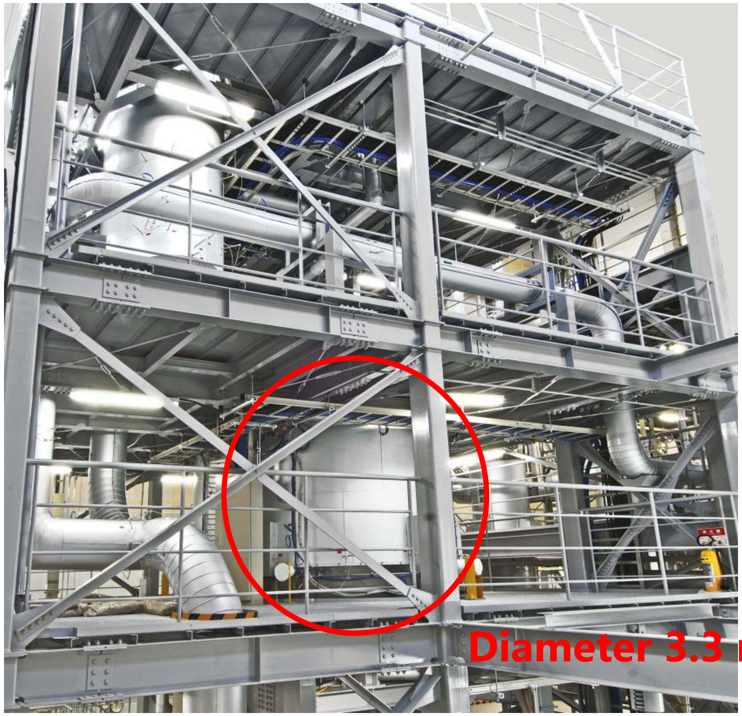
- Thermal power output: 780 MWt
- Core fuel: U-TRU-10Zr metal fuel
- Core height: 90 cm
- Operating cycle length: 2 years
- Four-zones' core on TRU enrichment
- Fuel conversion ratio: 1.0 → long-term energy security
- U-TRU grouped recycling and LLFP (I129, Tc99, Cs135, Sn126, Zr92) transmutation
  → Possibility of no high-level waste repository
  → Significant public perception on nuclear power
  → Significant reduction of waste disposal burden
- No blanket fuel core → High proliferation resistance

Sustainable nuclear power system after LWR era

K. Arie et. al., "The Sustainable System for Global Nuclear Energy Utilization", GLOBAL2007, Boise, Idaho, USA, September 9-13, 2007.

(The study funded by JAPC.)

Toshiba FR component development



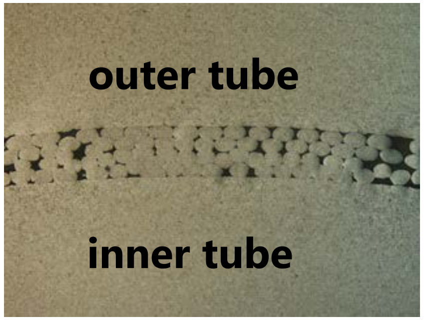
Sodium test of the full-scale EM pump
for Toshiba Small FR, 4S

No moving parts of main pump

Oyamatsu, Y., et al. "Design validation of the 4S high temperature electro-magnetic pump by one pole segment test equipment." FR09, IAEA, 2009.

Helical processed
double-wall tube

Enlarged photograph of double-wall tube section



Steam generator with
double-wall tube for FR

Prevention of Na-water reaction

Y. Kitajima et. al., "Development of a Helical-Coil Double Wall Tube Steam Generator for 4S Reactor", ICONE19, 2011.

(The part of present study is the result of "Development of high temperature electromagnetic pump with large diameter and a passive flow coast compensation power supply and development of a Helical-coil double wall tube steam generator to be adapted into medium and small reactors of GNEP" entrusted " Toshiba Corporation" by the Ministry of Economy, Trade and Industry (METI) of Japan.)

Toshiba advanced fuel cycle development

Glove box for

<u>engineering-scale electro-refiners</u>

1 kg metal uranium

<u>deposited by electro-refining</u>

(in cooperation with CRIEPI)

Toshiba has been developing pyroprocess technology with CRIEPI for more than 20 years

K. Arie, "Development for Fast Reactor and Related Fuel Cycle in Toshiba", ICAPP '09, Tokyo, May 10-14, 2009.

Concluding remarks

- **Scientific feasibility of nuclear waste transmutation has already been confirmed, and the engineering feasibility is being clarified.**

- **There are further R&Ds need to be done.**

  However, we believe nuclear waste problem must be solved by the steady and continuous development of related technologies.

- **Toshiba is committed to contribute to its realization in cooperation with associated organizations.**

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