Joint IAEA-ICTP Workshop on Physics and Technology of Innovative Nuclear Energy Systems
12-16 December 2022, ICTP, Trieste, Italy

Development Status of Sodium Cooled Fast Reactor in Japan

The University of Tokyo
Takashi TAKATA

Contents

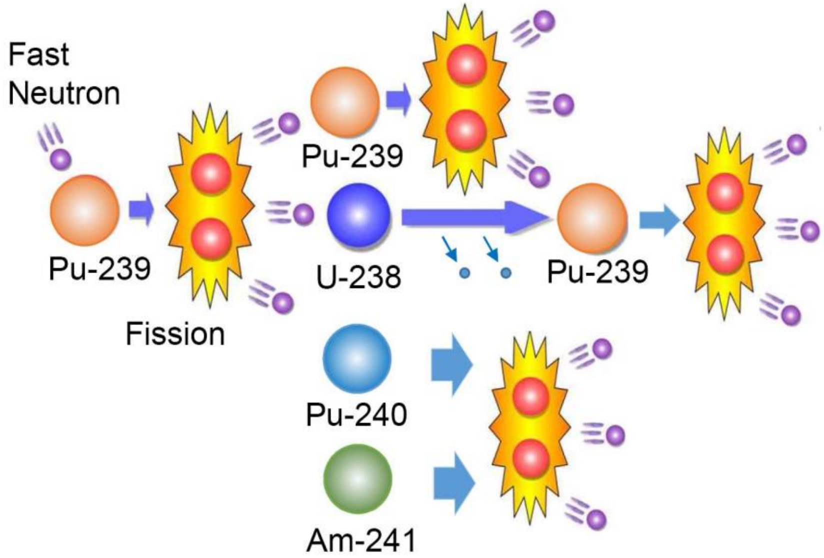
- ➢ Fast Reactors
- ➢ Significances of FR (Cycle) Technology Development
- ➢ Current Status of FR Development
  - ✓ Status in major countries
  - ✓ History and status in Japan
- ➢ FR Development Environment in Japan
  - ✓ Current status of energy supply in Japan
  - ✓ Japan’s nuclear energy policy on carbon neutrality
  - ✓ FR development policy
  - ✓ Outline of R&D in JAEA
  - ✓ Requirement from Nuclear Innovation
  - ✓ Contribution of FR to non-energy field

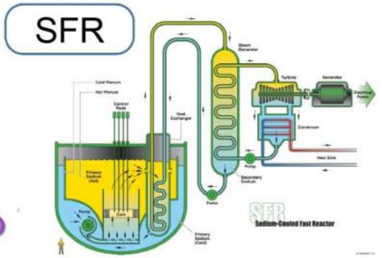
[Acknowledgement]

The most of presentation materials were prepared by Japan Atomic Energy Agency (JAEA). The presenter sincerely appreciate for JAEA’s strong support.

Fast Reactors (FRs)

- Fast (neutron) reactors



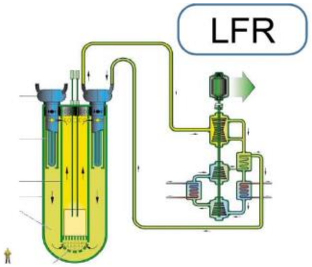


Na

Mass No. 23

T_{boiling} 883^{0}C

Sodium cooled Fast Reactor

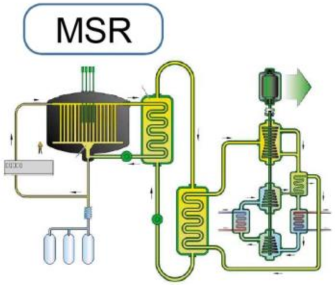


Pb

206-208

$1{,}737^{0}$C

Lead cooled Fast Reactor



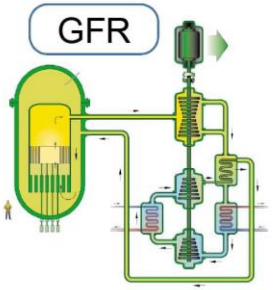
Fluoride or

Chloride salt

F: 19

Cl: 35 or 37

Molten Salt Reactor



He

4

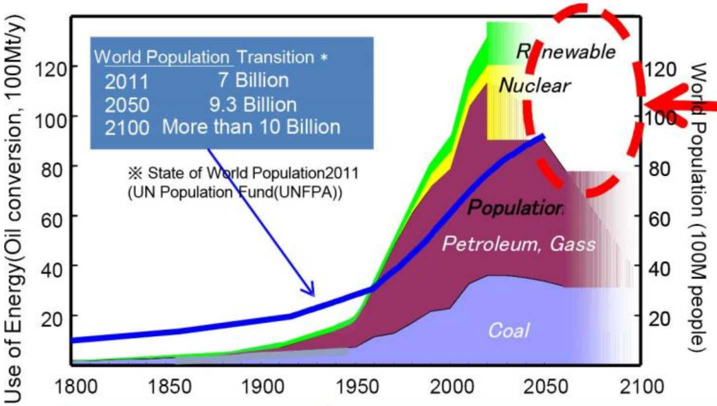
Gas cooled Fast Reactor

Significances of FR (Cycle) Technology Development

"*The very country can get a significant advantage on the development of use technologies of nuclear energy when it can get technology of FR/breeder type reactor.*", Enrico Fermi, 1943*, * Ref. K.Mochizuki, J. the Society of Instrument and Control Engineers, Vol.13-7,1974

- Efficient breeding
  - Sustainable domestic energy supply
    - Efficient use of natural resources
    - Free from the struggle to get resource (uranium)
- Use of high heat
  - High thermal efficiency
  - Non-electric application of nuclear heat
- Radioactive decay function using fast neutron
  - Artificial radionuclide production and transmutation management
  - Reduction of environmental burden
- No greenhouse gas emission
- Sustainable for load-following operation etc.

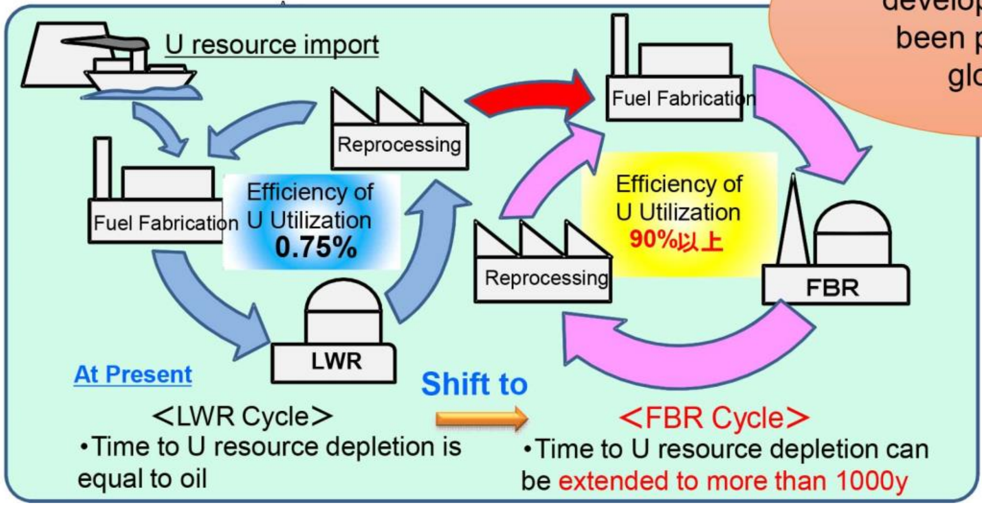
Efficient Breeding



Technology that certainly fills the gap after fossil fuel use peaks out

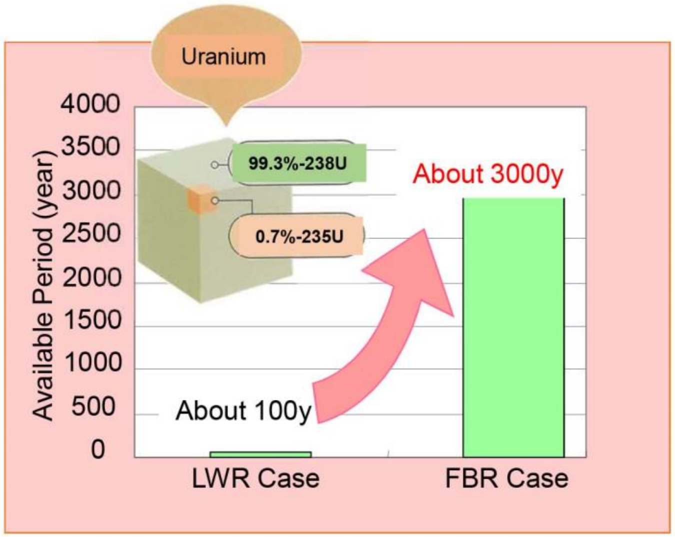
For Japan with little natural resources, FBR cycle will eliminate the need of uranium import and ensure domestic sustainable energy supply regardless of unstable international situations.

FR cycle development has been promoted globally



・Time to U resource depletion is equal to oil

・Time to U resource depletion can be extended to more than 1000y

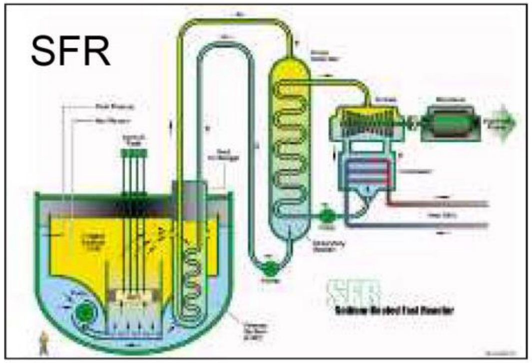


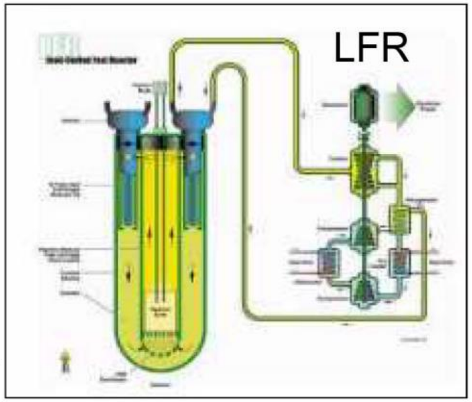
Ref：OECD/NEA Nuclear Energy Outlook 2009

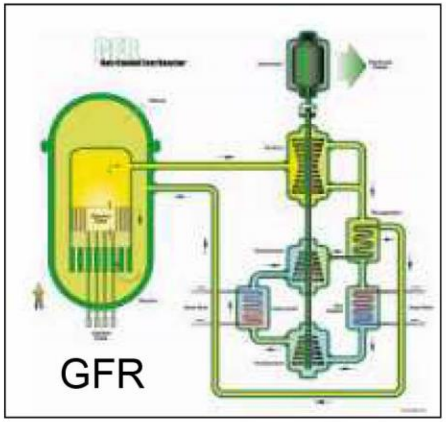
Use of High Heat

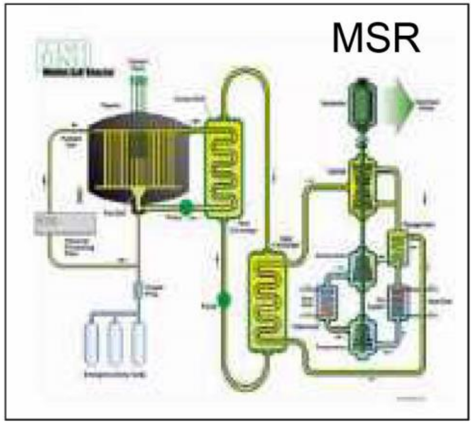
- Non-electric application of nuclear heat
- Heat application will be a key for nuclear to contribute to the Carbon Neutral

Reactor types (High temperature systems)









X

Reactor Size

Power Reactor
SMR
Micro Reactor

X

Applications

- ✓ Cogeneration application
- ✓ Hydrogen production
- ✓ Seawater desalination
- ✓ Process heat
- ✓ Synthetic fuel and chemicals
- ✓ Cooling application
- \+ Heat storage

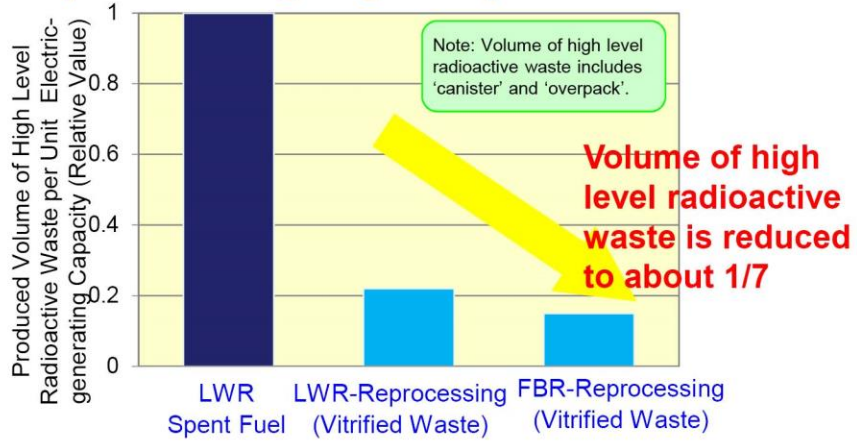
Radioactive Decay Function using Fast Neutron

- An FR uses and recycles minor actinide (MA) fuel, achieving a closed cycle. This will reduce the amount and potential toxicity* of high-level radioactive waste and enhance the potential of sustainable nuclear energy use. *The total dose of each radionuclide calculated from conversion factors of the radionuclides

◆ The fuel recycling will recover and vitrify U and Pu from spent fuel, reducing the waste amount. Recovering MA will also reduce the amount of heat generation from vitrified waste and allow the vitrified wastes to be stored closely, thereby drastically reducing the area of deep geological repositories.

◆ This will also reduce the risk future generations would face.

Reduction of both high-level radioactive waste to be produced and geological disposal site area



Note: Volume of high level radioactive waste includes 'canister' and 'overpack'.

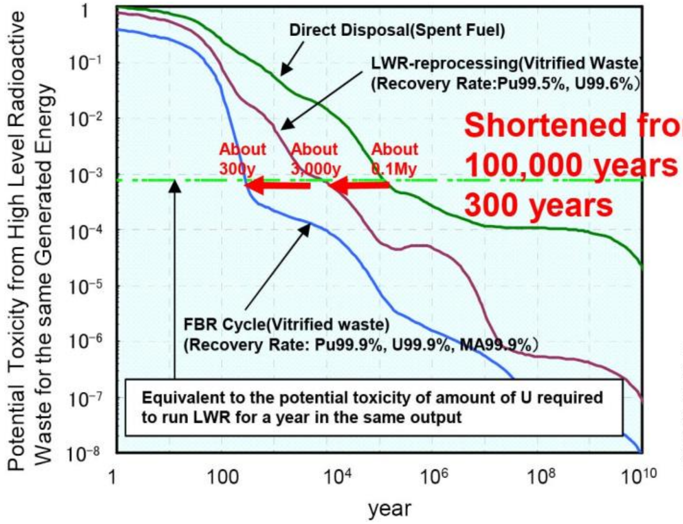
Volume of high level radioactive waste is reduced to about 1/7

Recovering MA can reduce geological disposal area to 1/10 in case of LWR (Spent Fuel)＊

＊ : CEA "Report on Sustainable Radioactive Waste Management" (2012)

Reduction of potential toxicity of high-level radioactive waste

(The relative value that assumed the first-year potential harmful degree (Sv) 1 of all amount of the waste direct disposal)



Equivalent to the potential toxicity of amount of U required to run LWR for a year in the same output

Shortened from about 100,000 years to about 300 years

Ref: Atomic science technology committee, Science technology, Science council & Research plan evaluation Sub-committee, 'Monju' research plan WG(#3), Nov.21, 2012.

Current Status of FR Development

➢ Status in major countries

	Current Status	New Approach, Plan
France	· 'ASTRID' project was postponed in 2020.	Experiences of SPX plant construction and operation R&D activities such as simulation technology are ongoing (e.g., J-F bilateral cooperation).
US	·Operation experiences of the experimental reactor(EBR-II)and Fermi FBR · Related R&D activities are ongoing to maintain the technologies.	·Versatile Research Reactor (VTR, 300 MWt) is planned to start in around 2026 ·"Natrium" is planned to start in around 2028
Korea	·President Yun, who took office in May, 2022, advocates nuclear power generation recurrence and promotes SMR development and the nuclear power generation export .	·The construction of the prototype reactor (PGSFR, 150MWe) will be resumed by 2025.
Russia	·Prototype (BN600) and demonstration (BN800) reactors are in operation ·BN-800 started electricity generation and supply in Dec. 2015	·BN1200 is planned to be deployed in 2030s ·The irradiation reactor (MBIR) is planned to operate in around 2027
India	·The experimental reactor with power generation function (FBTR, 13MWe) has been in operation since 1985 · The prototype reactor(PFB, 500 MWe) is under construction (2022)	·The demonstration and commercial reactor (CFBR, 600 MWe) will be deployed in the late 2020s.
China	·The experimental reactor (CEFR) started to supply electricity in July, 2011. · Prototype reactor stage was skipped.	·The demonstration reactor (CFR600) is planned to complete the construction in 2023. ·A commercial reactor will be deployed in 2030s.

Status in major countries (contd.)

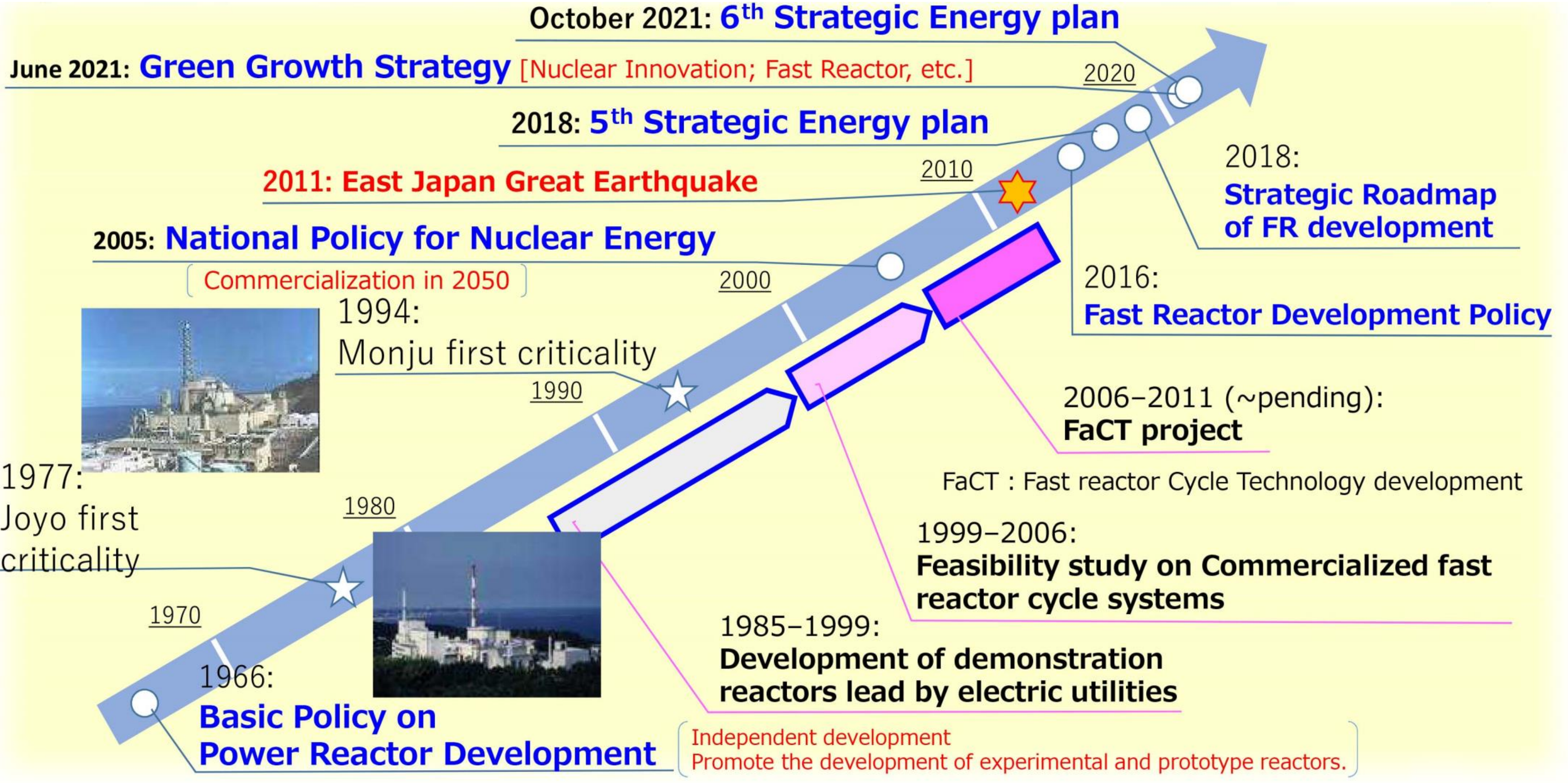
- France and the U.S. have achieved nuclear fuel breeding technology
- Main Target: Pu management , Radioactive waste reduction and Multi-purpose use of FRs

France	Development and construction experiences of prototype (Phenix) and demonstration (Super-Phenix) reactors	→	FR development project (ASTRID) (Postponed)	→	Commercial FR deployment in the late 21 century
US	Operation experience of experimental reactors (e.g., EBR-II, FFTF)	→	Versatile Test Reactor (VTR, 300 MWt) is planned to start in around 2026 “Natrium” is planned to start in around 2028 (ARDP*)		*DOE program to support development of advanced reactors (e.g., VHTR) of private sectors

- Goal : Higher breeding ratio for energy security
- Main target: Early deployment of commercial FRs

Russia	In operation Prototype BN-600	→	In operation Demonstration BN-800	→	In 2030s Commercial BN-1200
India	Start operation in 2022 Prototype PFBR	→	In the late 2020s Commercial CFBR（600MW[e])		
China	Prototype reactor stage is skipped by introduction of Russian technology.		In around 2023 Demonstration CFR600	→	In 2030s Commercial CFR1000

History and Status in Japan



October 2021: **6th Strategic Energy plan**

June 2021: **Green Growth Strategy** [Nuclear Innovation; Fast Reactor, etc.]

2018: **5th Strategic Energy plan**

2011: **East Japan Great Earthquake**

2005: **National Policy for Nuclear Energy**

(Commercialization in 2050)

1994:
Monju first criticality

1977:
Joyo first
criticality

1966:
Basic Policy on
Power Reactor Development

(Independent development
Promote the development of experimental and prototype reactors.)

1985–1999:
Development of demonstration reactors lead by electric utilities

1999–2006:
Feasibility study on Commercialized fast reactor cycle systems

2006–2011 (~pending):
FaCT project

FaCT : Fast reactor Cycle Technology development

2016:
Fast Reactor Development Policy

2018:
Strategic Roadmap of FR development

Joyo (Experimental FR)

- Mission of Joyo and its major achievement

Missions of Joyo

- To demonstrate basic functions of a fast breeder reactor (FBR)
- To perform irradiation experiment on elements such as nuclear fuel and materials
- To verify innovative technology for future fast reactors (FRs)

Major achievements

Joyo demonstrated

- ☐ its breeding function
- ☐ the closed cycle of FRs
- ☐ decay heat removal by Na natural convection
- ☐ MOX fuel performance
- ☐ its use as a fast neutron irradiation plant
- ☐ the function of Self Actuated Shut-down System(SASS)

First Criticality: 1977
Cumulative Operating Time: 71,000 hrs
Irradiation Results of Test Rig: about 100

R&D fields expected after Joyo resumption

- Reduction of radioactive waste and toxicity
- Basic research
- Multipurpose use
- FR development
- Development of human resources in the nuclear energy field

Current Status of Joyo

- ✓ JAEA submitted the application for Joyo restart to Nuclear Regulation Authority (NRA) Japan to ensure compliance with new regulatory standards adopted after the Fukushima accident.

- ✓ Beyond design basis accidents and post-accident measures are currently under review by NRA Japan.

- ✓ JAEA is required to inform local government authorities of basic plan for the spent fuel management before the restart of Joyo.

Monju (Prototype FR)

➢ Missions of Monju and its major achievement

Missions of 'Monju'

- To demonstrate reliable power-generating performance
- To established sodium handling techniques

【Rated Power】	280MWe
【Operation Record】	
●First Criticality	1994
●Reactor Operating Time	5300 hrs
●Power Generation Time	883 hrs
●Generated Power	100B Wh

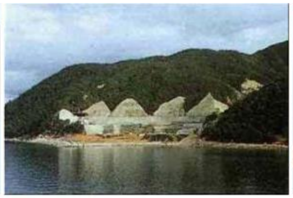
Major achievements

Monju

- ☐ established FR plant designs (e.g., core design, major components design) and their manufacturing techniques
- ☐ accumulated operation and maintenance experience
- ☐ accomplished power generation as the Japan's first FR plant (up to 40% output)
- ☐ demonstrated its breeding capacity (the expected value:1.2)
- ☐ accumulated sodium handling techniques based on operation and maintenance experiences of related facilities and components
- ☐ improved measures against sodium leakage
- ☐ demonstrated safety evaluation methods for SFRs

History and Current Status of Monju

Feb. 1983



Oct. 1985

Oct. 1986

Apr. 1991

Apr. 1994

May, 2010, Function Test Resumption

May 27th, 1983	Permission of nuclear reactor installation
Oct. 1993~	Start of function examination
Apr.5th,1994	First criticality
Aug. 1995~	Function test(under the 40% output)
Aug.29th, 1995	First electricity supply
Oct.13th, 1995	Achievement of the 40% electric output
Dec.8th, 1995	**Sodium leakage accident**
May 6th, 2010	Function test resumption
Aug.26th, 2010	**IVTM drop accident**
Mar.11th, 2011	(Great East Japan Earthquake)
Nov.27th, 2012	Announcement of maintenance management defect
May 29th, 2013	Security order from NRA[*1]
Nov.13th, 2015	NRA urged Minister of MEXT to review Monju security system fundamentally.
Dec.21th, 2016	**Decisions made at Inter-Ministerial Council for Nuclear Power on Japan's FR development policy and the Prototype Fast Breeder Reactor, Monju.**
Dec.6th, 2017	**Submission of Monju decommissioning plan to NRA**
Mar.28th, 2018	**Permission of Monju decommissioning plan**
Aug.30th, 2018	Start of fuel transportation work(EVST⇒Fuel pond)
Sep.17th. 2019	Start of fuel removal work (Reactor vessel⇒EVST)
Apr.22nd, 2022	**Completion of the work to transport all fuels from the reactor vessel to EVST**
Jun.28th, 2022	Application for approval of change of Monju decommissioning plan (under examination by NRA)

[*1)] NRA judged that the order lost effect(Jan.18th, 2017)

FR Development Environment in Japan

➢ Current status of energy supply in Japan

- Self-sufficiency rate[*1] of energy : 12.1%
- Composition of electric power supply[*2] :
  - Thermal power 75.7%
  - Variable zero emission (solar, wind) 7.5%
  - Stable zero emission (stable renewables, nuclear) 16.8%
- Japan's CO_2 emissions (emission factor (gCO_2/kWh) are 8 times higher than France!

✓ Unlike European countries with interconnected grids, Japan is an energy isolated island.

	Japan	France	China	India	Germany	Britain	USA
Energy self-sufficiency ratio	12%[*1]	55%[*3]	84%	65%	37%[*3]	70%[*3]	98%[*3]
Main domestic resources	-	Nuclear	Coal	Coal	Coal	Coal Natural gas	Natural gas Petroleum Coal
Facility utilization rate (solar)	15%	14%	16%	18%	11%	11%	19%
Facility utilization rate (wind)	25%	29%	25%	23%	30%	31%	37%
International pipeline	-	✓	✓	-	✓	✓	✓
International grid connection	-	✓	✓	✓	✓	✓	✓

*1 Agency for Natural Resources and Energy, Japan's Energy White Paper 2021

*2 Website of Agency for Natural Resources and Energy, Overall results or estimated results (Total Energy Statistics), https://www.enecho.meti.go.jp/statistics/total_energy/results.html#headline7

*3 Agency for Natural Resources and Energy, Japan's energy 2020: 10 questions to understand the current status of energy (in Japanese)

Japan's Nuclear Energy Policy on Carbon Neutrality

Green Growth Strategy (excerpts on nuclear) ※

- Nuclear power can continuously supply a large amount of carbon-free electricity. Japan has the leading-edge nuclear technology, and its technological self-sufficiency is high.
- With further innovations, we will improve nuclear safety, reliability, and efficiency, reduce the volume and toxicity of high-level radioactive waste, and enhance natural resource recycling through effective use of resources.
- Nuclear power can satisfy various social needs, such as harmonization with renewable energy, carbon-free hydrogen production, and heat production for industrial applications.

※ Green Growth Strategy for Achieving Carbon Neutrality in 2050 (June 18, 2021)

The 6th Strategic Energy Plan (excerpts on nuclear)

【To achieve carbon neutrality by 2050】

- Electric power sectors will use carbon-free power sources such as renewables and nuclear.
- Japan continues to use a necessary amount of nuclear power under a consensus on ensuring safety.

【Policies for 2030】

- Promotion of R&D
  - ✓ Advance the development of fast reactors through international cooperation
  - ✓ Demonstrate small modular reactor technology with international partners.
  - ✓ Develop the basic technology of hydrogen production using high temperature reactor (HTGR)

⇒ The R&D of FR should be totally managed by 'Strategic Road Map'.

FR Development Policy

1. New Mission

New Goals

①Enhanced safety that complies with requirements set after TEPCO Fukushima Dai-ichi NPP Accident

②Improved economic efficiency from R&D stages to become more attractive in the energy market

③More advanced technology and insight obtained through international cooperation and development of codes and standards common to all FR developing countries

Key objectives for FR development in Japan

- ✓ Further advance Japan's state-of-the-art technologies
- ✓ Develop and demonstrate an FR with higher safety and economic efficiency for the future deployment
- ✓ Lead the countries to establish the international standards by establishing concrete development goals.

2. Four Principles for FR Development

1: Utilization of Domestic R&D Resources

- ✓ Technical Knowledge, Technical & Human Resources, Infrastructures

2: Acquisition of the Most Advanced Knowledge

- ✓ Multilateral Cooperation such as GIF & Bilateral Cooperation

3: Pursuit of the Cost Effectiveness

- ✓ Active Utilization of International Cooperation, Timely Injection of the Development Cost, Assessment of the Status & the Results, C&R for Method & Approach of Development

4: Establishment of Reliability System

- ✓ Clarification of the Role, Establishment of the Governance System, Stringent Safety Management, Leading Role of the Country

Strategic Roadmap of FR development

Strategic Roadmap(Dec.12th, 2018)

Significances of FR Development

- In Mid to Long term, FRs contribute to,
  - ① efficient use of natural resources, and becoming energy independent country.
- To achieve sustainable radioactive waste management,
  - ② the amount and
  - ③ toxicity must be reduced.
- In addition, plutonium management should be established..

Schedule

Uranium resources will last only 135 years (as of 2018)

- Full-scale operation
  →In the late of 21st century
- The first FR startup
  →Appropriate timing in the mid-21st century
- In the coming decade
  → First half: Explore a variety of technologies and narrow them down after five years.
  → Second half: Develop the selected technologies.

Target Reactor Technology

- Determine the feasibility of various FR technologies by using proven technologies and cultivated human resources

SFR(Na cooled FR)
・MOX fuel(Fr, Ru, et al.)
・Metal Fuel(US, et al.)
Molten Salt FR
Light Water Cooled FR and so on

Sharing of Roles and Development System

- Plant makers develop innovative technologies that meet the government's policy and development goals.
- Power companies, namely, owners of an FR will select the technology they use.
- The government lays out the direction for the development and sets goals that private companies pursue.
  - ① The government provides financial support based on technical readiness level
  - ② **JAEA provides research infrastructure**
  - ③ Safety is improved to meet the new regulatory requirements

From METI Atomic Sub-committee(Apr.2019)

METI: Ministry of Economy, Trade and Industry

Outline of R&D in JAEA

Strategic roadmap for fast reactors

- Development of basic technologies and research infrastructures which can meet private sectors' needs in various technology development
- Deepen insight accumulated through the development of sodium-cooled fast reactors and further develop R&D infrastructures as an R&D base.

Design assistance tool on plant lifecycle (ARKADIA)

Joyo

Monju

- An AI-based knowledge base that includes design, construction and R&D on Joyo, Monju and design studies
- Evaluation methods for complex phenomena using multi-physics models can be applied to various coolants and systems

Codes and Standards

Ranks of SDC and SDG

- Development of codes, standards, and design criteria applicable to various FR concepts
  - These can balance safety and economic efficiency.

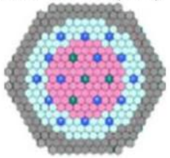
Safety enhancement technology

- Reactor core safety, including prevention of re-criticality and core melting accidents.
- Prevention and mitigation of FR-specific events including coolant chemical reaction

International cooperation

Super Phenix (France)

Metal fuel core (US)



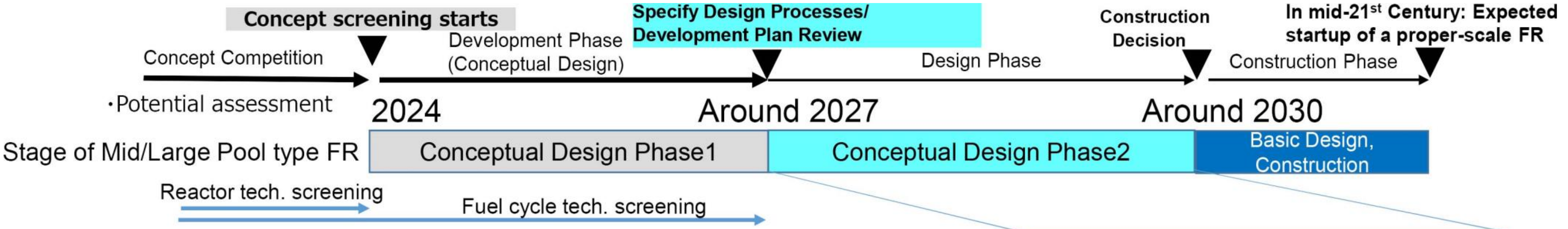
- France, having extensive experience of sodium-cooled fast reactors
- US, leading the development of metallic fuels, analysis codes, versatile test reactor (VTR) project, etc.

- Establishment of basic technologies for practical use

Support of private sectors' R&D

- Strengthen cooperation with industries and related ministries to narrow down technologies possibly adopted after 2024
- Promote R&D for the introduction of FRs at an appropriate time in the mid-21st century

Issues and Progress



JAEA-led Major Technology	**Competition・Development Phase**	**Design Phase**
Fuel, Material	Resumption of Joyo	Irradiation tests using Joyo
	Fuel design, fabrication	Fuel fabrication test (at Pu-fuel facility)
Reactor System	Safety evaluation・Design support tool(ARKADIA) development	Acquisition of ground data (e.g., Sodium tests) of test research/conceptual design for selection of specification of the plant
Standards	Preparation of standards	
Safety	Development of safety enhancement tech.	Demonstration of safety enhancement (out-/in-pile tests)
Component Development	Preparation of infrastructure of experiment (e.g., AtheNa)	Demonstration of component performance
Fuel Cycle	Development of reprocessing tech. of MA bearing MOX fuel Review of metal fuel cycle tech.	Engineering demonstration of the fuel cycle technology selected

International Collaboration

Global Standardization of Developed Tech. ⇕ Rationalization of R&D through cooperation frameworks

Major tech. development by bilateral sharing/collaboration with a influential country such as US and France: Knowledge of FR development, Evaluation methods, Safety enhancement, Heat utilization

De facto international standardization organizations(IAEA, OECD, GIF): Standards, Safety requirement, Safety enhancement for the plant designs

Efficient International Collaboration

Strategies : Lead FR development using international cooperation with the U.S. and France
Lead multilateral R&D cooperation to establish international standards

Japan-France

- FR-R&D collaboration(11items)
- Sharing digitization tech. and verification data for plant characteristics

Japan-US

- Participation in VTR/Natrium™ Pj (under discussion)
- CNWG(structural material, modeling & simulation, metal fuel & pyroprocessing tech.)

International Coorperation Policy

- Develop key technology for SFRs under the bilateral cooperation of Japan-France and Japan-U.S. to make technologies (e.g., design, safety technology, and analysis assessment), plant concepts, codes and standards in Japan global standards.
- Develop codes and standards, safety requirements, and design methods common to all nuclear developing nations through international frameworks such as GIF and IAEA.

GIF

- Proposal of safety design criteria
- G4 global standard reactors, design method, DB

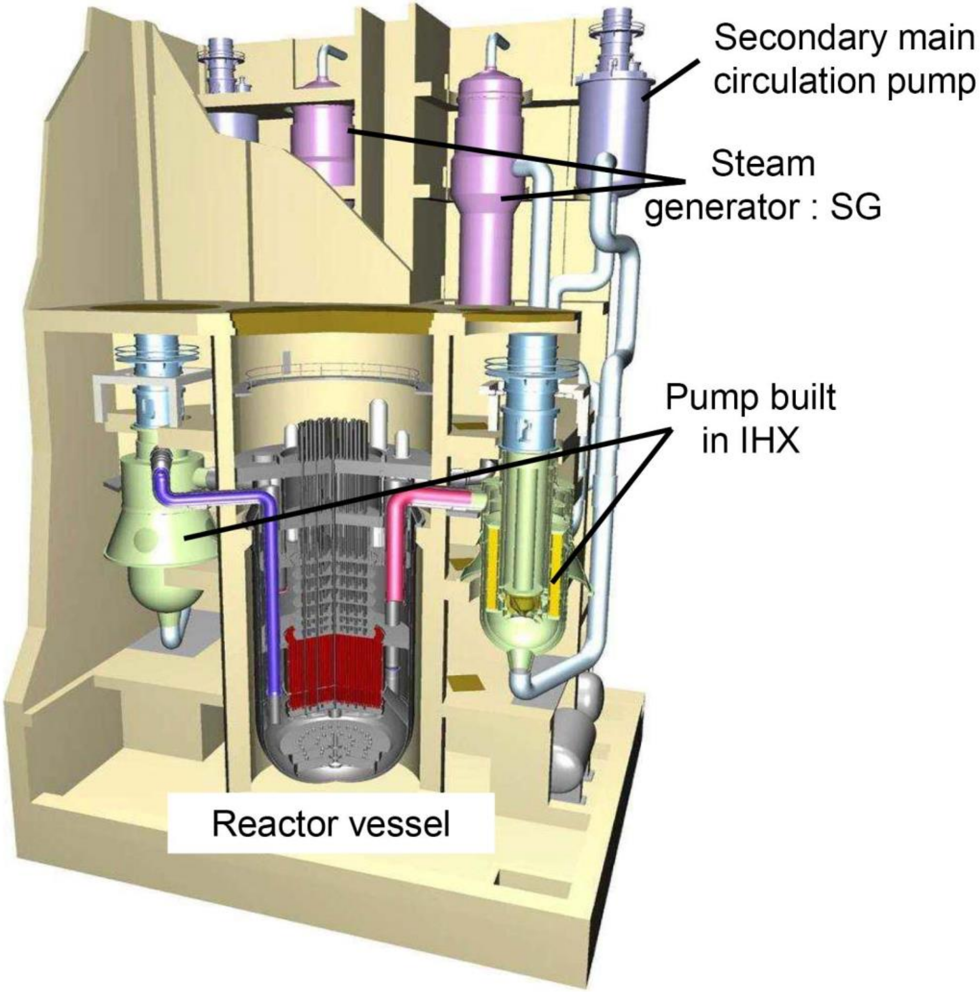
IAEA/NEA

- Global standardization of Safety Design Standards
- Promotion of communication with the regulatory side

ASME - JSME

- Global standardization of Structural Design Standards, Maintenance Standards

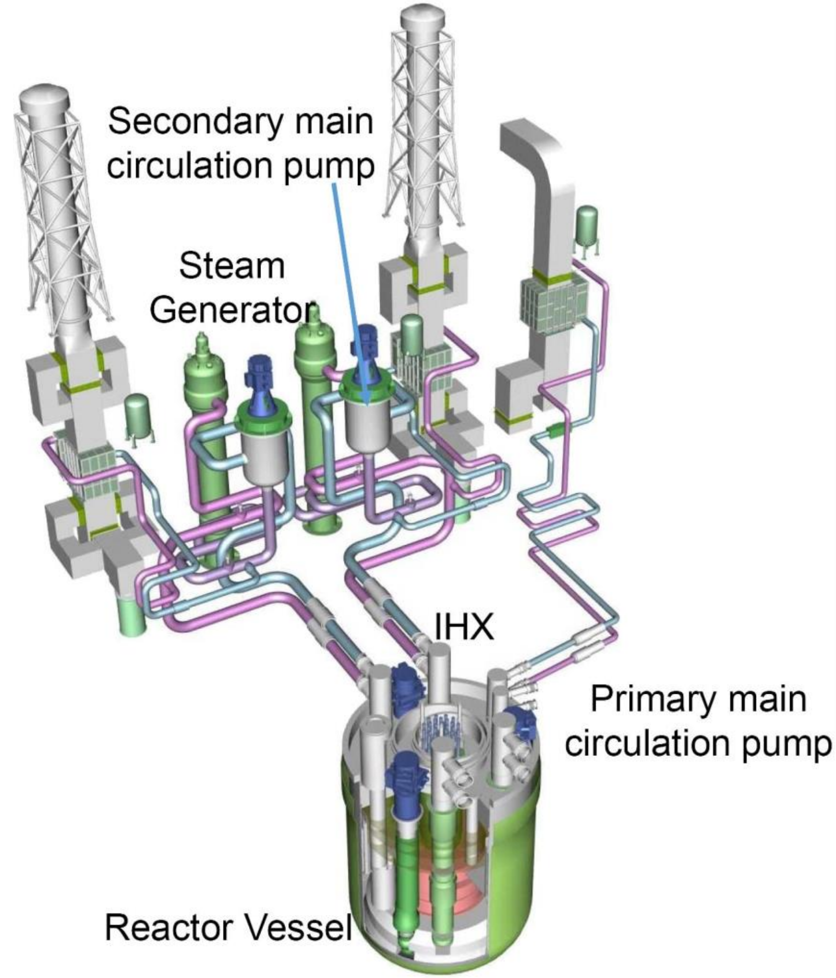
Examples of Design (Advanced Loop Type)



Reactor type	Advanced loop
Output(Electrical/thermal)	1,500 MWe /3,570 MWth
Main cooling system	Primary pump (mechanical)×2 IHX×2 Secondary cooling system: 2 loops (Double wall straight tube SG×2)
Reactor shut-down system	2 Independent system + Passive reactor shutdown system
Decay heat removal system	DRACS×1 PRACS×2
Containment system	Steel-concrete containment vessel integrated with reactor building
Seismic Isolation System	Reactor building: 2 dimensional seismic isolation

DRACS: Direct Reactor Auxiliary cooling system
PRACS: Primary Reactor Auxiliary Cooling System

Examples of Design (Pool Type, medium/Large)



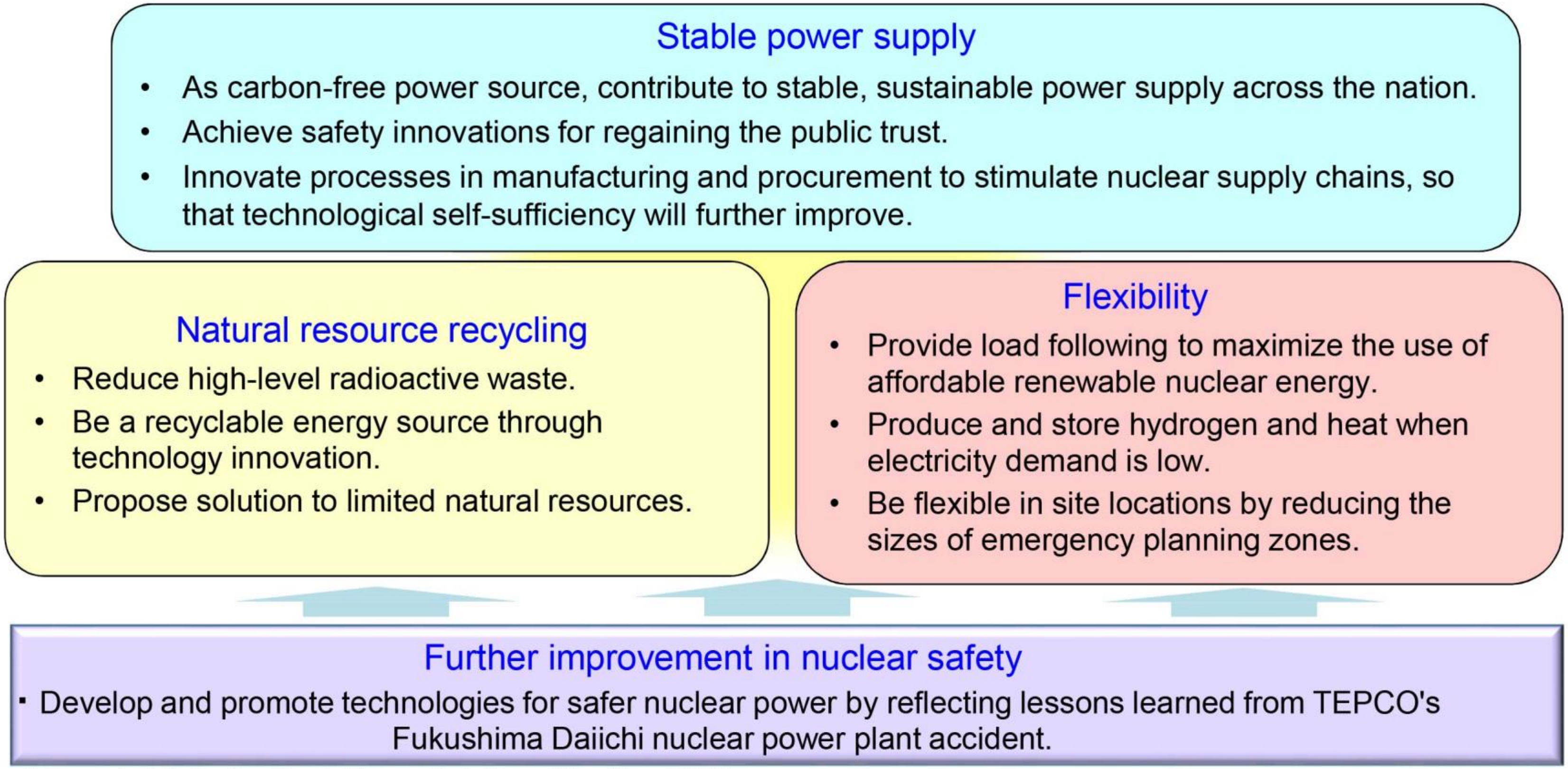
Reactor Type	Pool type
Output(electrical/ thermal)	650 MWe /1,500 MWth
Main cooling system	Primary pump (mechanical)×3 IHX×4 Secondary cooling system: 4 loops (Helical coil type SG×4)
Reactor shut-down system	2 Independent systems＋Passive reactor shutdown system
Decay heat removal system	IRACS×4 DRACS×2
Containment system	Steel-concrete containment vessel integrated with reactor building
Seismic isolation system	Reactor building: 3 dimensional seismic isolation

- Adoption of the pool type concept facilitates international cooperation.
- Selection of reactor site location can be more flexible by a 3 dimensional seismic isolation system

Requirement from Nuclear Innovation

☐ Under a consensus on nuclear safety improvement

- ✓ Supply power constantly (large scale stability + safety and supply chains + technological self-sufficiency)
- ✓ Achieve natural resource recycling (waste management + effective use of resources)
- ✓ Be flexible (load-following + hydrogen and heat production + flexible siting)



Stable power supply

- As carbon-free power source, contribute to stable, sustainable power supply across the nation.
- Achieve safety innovations for regaining the public trust.
- Innovate processes in manufacturing and procurement to stimulate nuclear supply chains, so that technological self-sufficiency will further improve.

Natural resource recycling

- Reduce high-level radioactive waste.
- Be a recyclable energy source through technology innovation.
- Propose solution to limited natural resources.

Flexibility

- Provide load following to maximize the use of affordable renewable nuclear energy.
- Produce and store hydrogen and heat when electricity demand is low.
- Be flexible in site locations by reducing the sizes of emergency planning zones.

Further improvement in nuclear safety

- Develop and promote technologies for safer nuclear power by reflecting lessons learned from TEPCO's Fukushima Daiichi nuclear power plant accident.

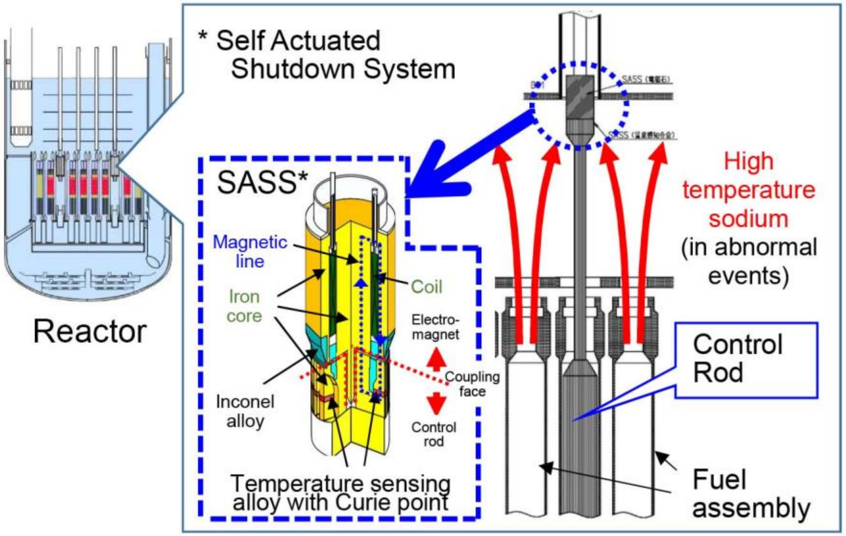
From materials for the Atomic Energy Sub-Committee (Apr. 2021)

Further Improvement of Safety

■ Example of enhanced countermeasures against core disruptive accidents (CDAs)

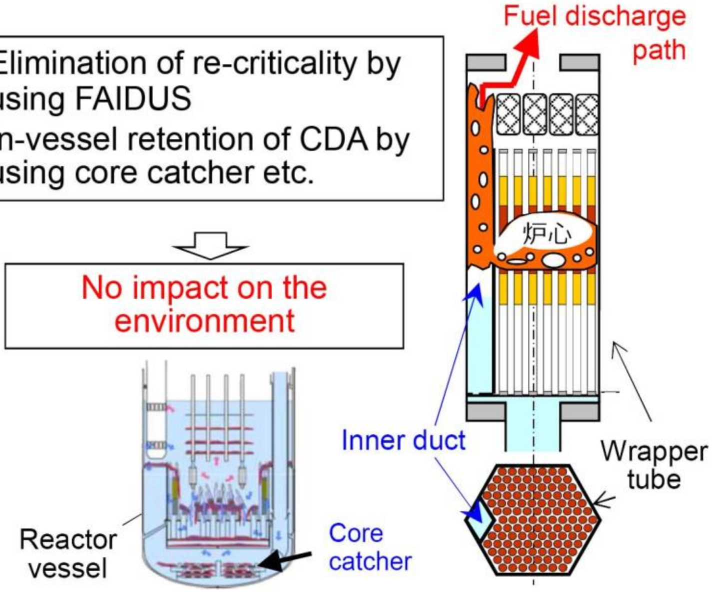
- Background: Since an FR core is not in the most reactive configuration, core material relocation caused by a CDA can induce reactivity insertion.

- CDAs can be prevented. If a CDA should occur, re-criticality can be prevented (CDA is mitigated)
  - Reactor shutdown device passively induces negative reactivity during abnormal events (spontaneous insertion of control rods using a temperature sensing alloy)
  - Mechanism to achieve and maintain subcriticality by spontaneously discharging molten fuel materials from the core (by means of Fuel Assembly with Inner-Duct Structure (FAIDUS) which enables early discharge of molten fuel from the core in a core melt accident)



- Elimination of re-criticality by using FAIDUS
- In-vessel retention of CDA by using core catcher etc.

No impact on the environment

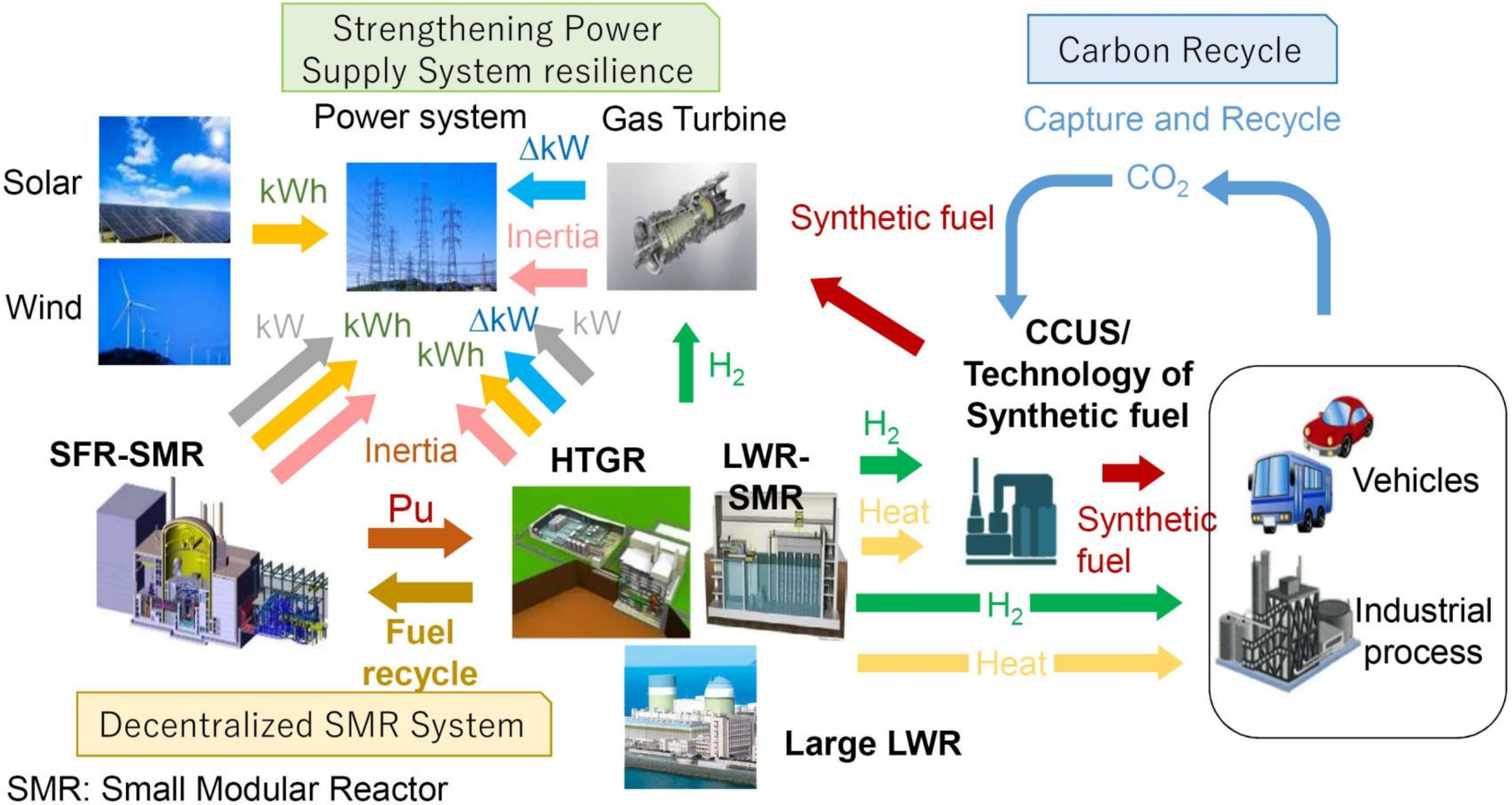


CDA: Core Disruptive Accident

Stable Power Supply

- Sustainable and resilient energy systems

Achievement of CN, Strengthening resilience & Energy cost restraint



SMR: Small Modular Reactor

kWh : Power Generation ΔkW : Power Generation Adjustability kW : Supply capacity

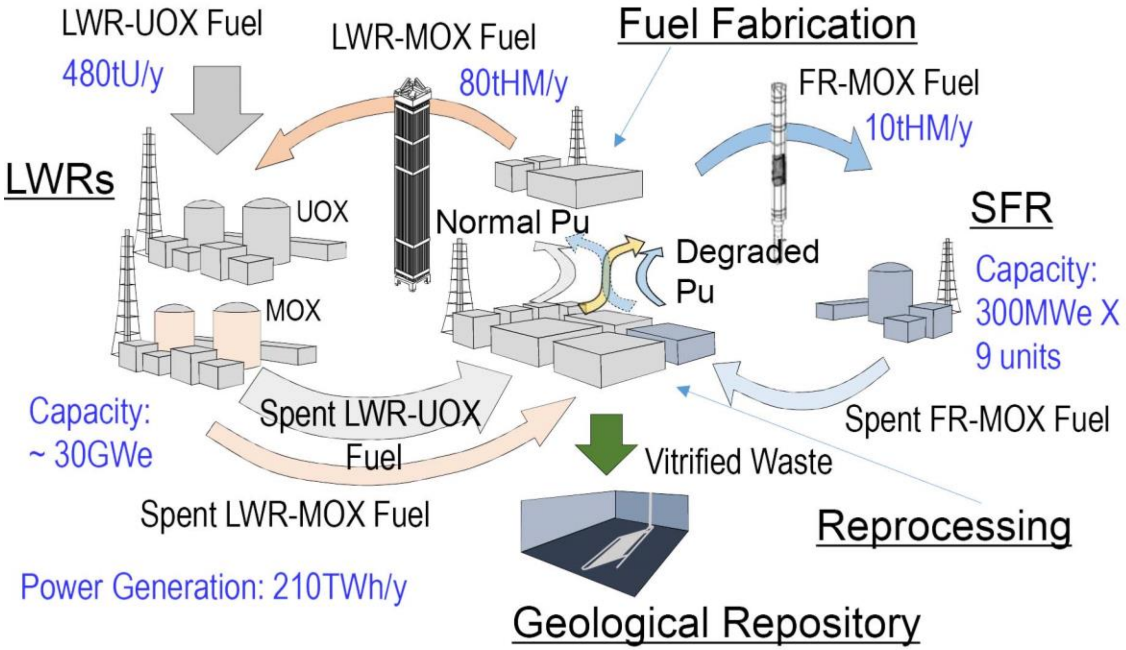
Ref. MEXT-funded Research (2020-2023) modeling & simulation

CCUS: Carbon dioxide Capture, Utilization and Storage

Natural Resource Recycling

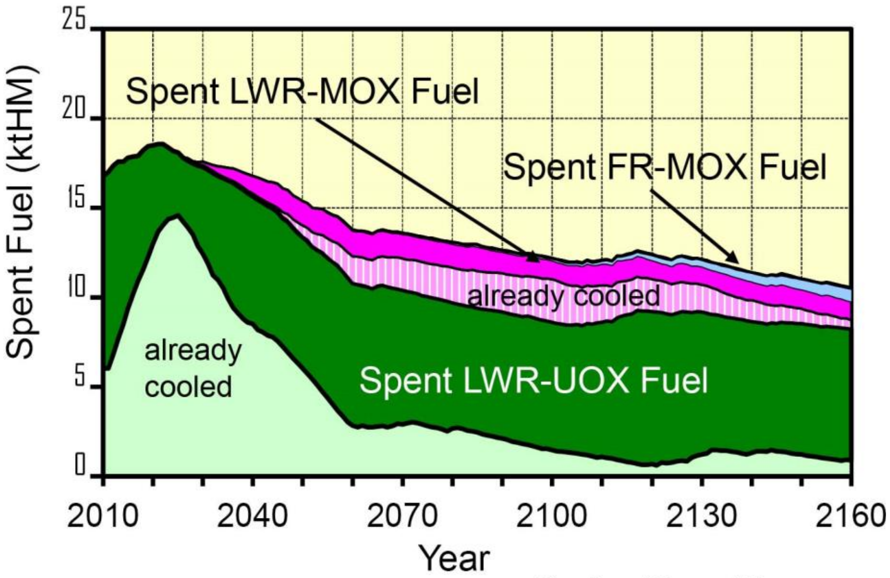
- LWR & SFR combined cycle for Pu management

- Reduction of LWR spent fuel together with efficient Pu use by SFR
  - Closed Fuel Cycle; Case study in Japan



MOX Fuel: Pu and U mixed Fuel

<Control of Spent MOX Fuel>



Cooling Time: 15 years

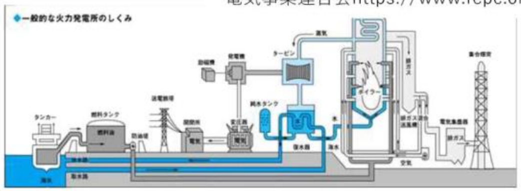
Flexibility

- ➢ Suitable for load-following operation

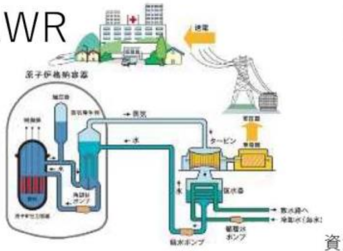
At present

Thermal power generation

電気事業連合会https://www.fepc.or.jp/index.html



LWR



RE

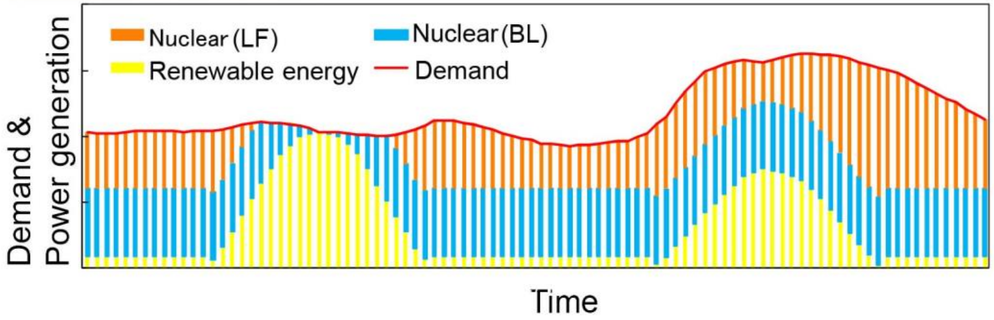
資源エネルギー庁
https://www.enecho.meti.go.jp/

Advanced nuclear power generation system

- ✓ Power generation by using fossil fuel ➡ 0
- ✓ LWR→SFR/HTGR
- ✓ Harmonized system between RE & NPP

RE

Harmonization image of power generation



Nuclear + RE ➡ Zero emission power generation system

- ✓ Nuclear system with load-following function can cover output change of RE

Contribution of FR to Non-Energy Field

Production of medical and industrial radioisotopes: Contribution to domestic supply

☐ Provide a neutron irradiation field with wide energy spectra, high flux and a large capacity

- ✓ Neutron capture reaction (medium and slow to thermal neutrons)
- ✓ (n, 2n) reaction (by high energy fast neutrons)

} Efficient RI production

- ✓ Higher flux and larger capacity than accelerators allow mass production of RI

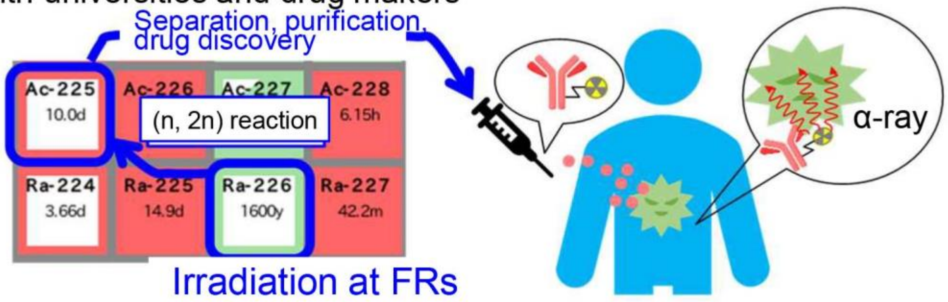
☐ Nearly 100% imported → Domestic production of RIs (according to its applicability to the market)

- ✓ Industrial use:
  - Co-60 : Liquid level gauge, crop breeding, etc.
  - Ni-63 : Environment analysis
  - Ir-192 : non-destructive inspection
  - Fe-55 : Calibration source, etc.
- ✓ Medical use:
  - Co-60 : Sterilization, cancer (gamma knife)
  - Au-198 : Brachytherapy
  - Ir-192 : Brachytherapy
  - Ac-225 : RI internal therapy, etc.

→ Establishment of the domestic RI supply system in cooperation with several reactors for stable supply

Example

- ✓ Production of Ac-225 for RI internal therapy → Higher efficiency by fast neutrons
- ✓ Cooperation with universities and drug makers



Thank you for your kind attention!!