What is the vision for nuclear energy that supports carbon neutrality in 2050?

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Present situation in Japan

- Japanese government has no vision for nuclear energy in 2050.

- In Japan, where resources are scarce, the land is small, the population density is high, the large amount of spent nuclear fuel will be generated from many nuclear power plants built in the future.

- One of most important issue in Japan is radioactive waste such as Minor Actinides (MA*) reduction.

- Japan has no role model for nuclear fuel cycle all over the world.

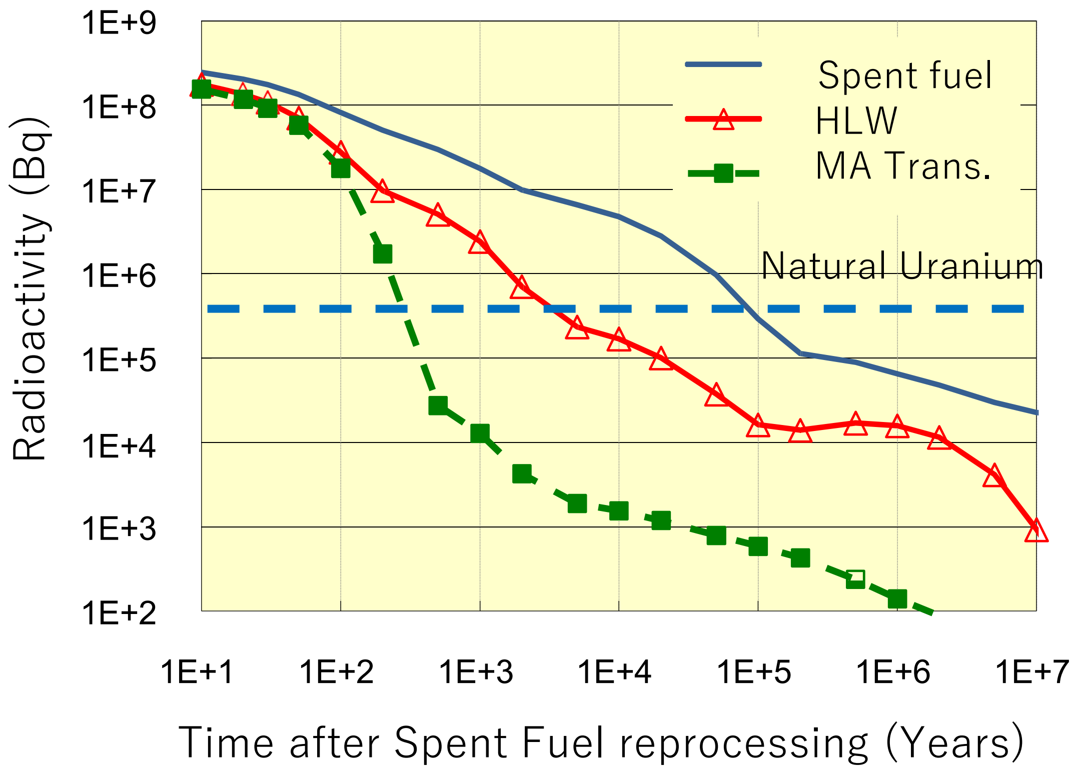
Because Russia and France have no MA recycle but only Uranium (U) and Plutonium (Pu) recycle.

- Japan's original nuclear fuel cycle with reactor safety should be clarified as nuclear energy that supports carbon neutrality in 2050.

MA*: More heavier nuclides than U such as Neptunium, Americium, Curium and so on in next page

Minor Actinides (MA) in Spent Nuclear Fuel

- MA are contained in high level radioactive wastes (HLW) and should be reduced.
- The radioactivety of HLW decreases less than that of natural Uranium within 300 years with MA transmutation .
- MA Transmutation research has already started in the Nuclear Fuel Cycle by JAEA’s ADS-PJ and FBR.



Ac

Nuclides	Half life (Billion year)	Radiation conversion coefficient (μ S v / kBq)	Content (Spent fuel /ton)
U-235	0.7	47	10 kg
U-238	4.5	45	930 kg

TRU

Nuclides	Half life (year)	Radiation conversion coefficient (μ S v / kBq)	Content (Spent fuel/ ton)
Pu-238	87.7	230	0.3 kg
Pu-239	24000	250	6 kg
Pu-240	6564	250	3 kg
Pu-241	14.3	4.8	1 kg

MA

Nuclides	Half life (year)	Radiation conversion coefficient (μ S v / kBq)	Content (Spent fuel/ ton)
Np-237	2.14Million	110	0.6 kg
Am-241	432	200	0.4 kg
Am-243	7370	200	0.2 kg
Cm-244	18.1	120	60 g

Why is Purex process not suitable for FBR multi recycle with MA?

- Spent Oxide fuel with MA recycle is difficult to be dissolved by only boiling HNO_3 solution such as Purex process.

The complex oxides such as the fuel debris from Three Mile Island Reactor-2 (TMI-2) accident in the U.S. has been found to be dissolved by not only boiling HNO_3 but added HF*.

- The organic solvent such as Tributyl Phosphate (TBP) is easy to be attacked by strongly radiation with MA and be produced degradative TBP such as Dibutyl Phosphate (DBP) or Mono-butyl Phosphate (MBP).

- MA is not accompanied with Pu, therefore MA should be recovered from High Level Liquid Wastes by additional process.

Fuel cycle cost increases than without MA recycle.

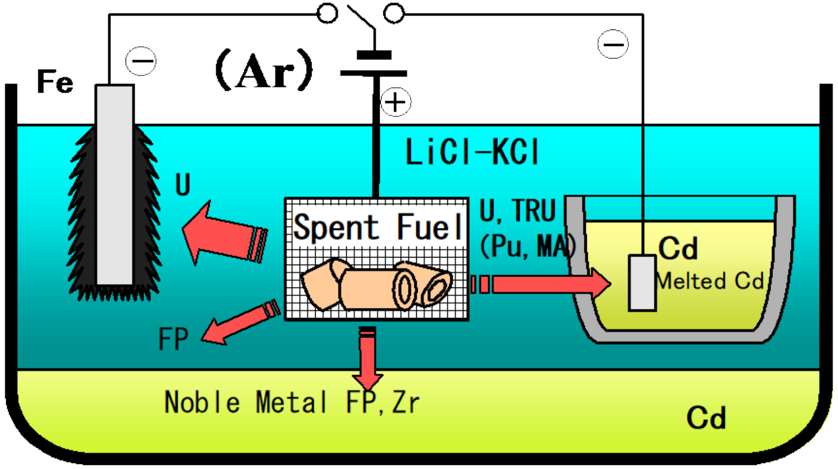
Russia and France gave up MA recycle in Purex process of oxide fuel FBR.

Clean fuel but dirty waste

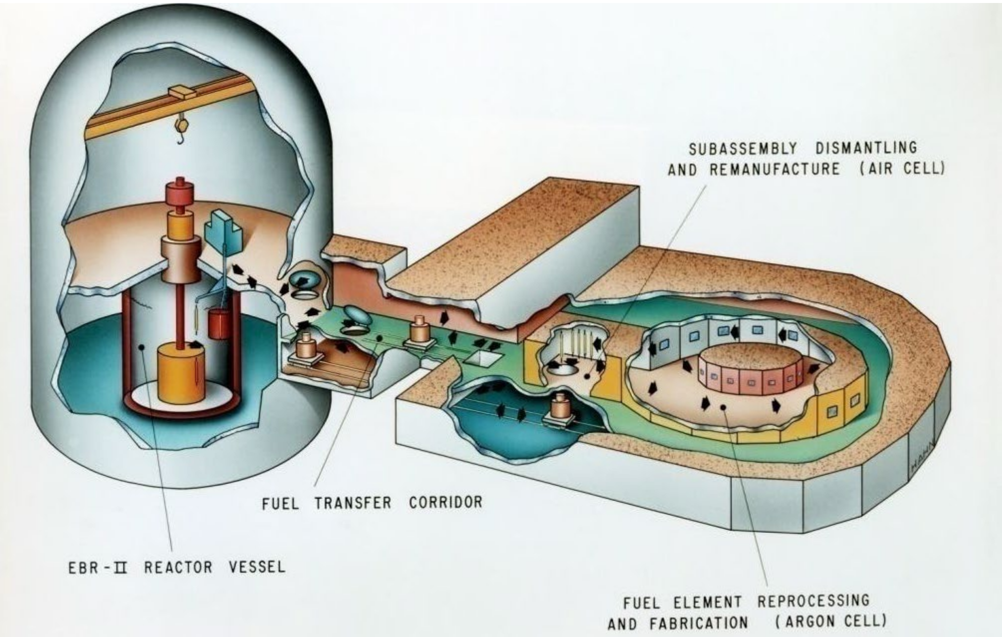
High nuclear proliferation risk

*Reference :R.K.Mccardell et al., *Nucl.Eng. Design*, **118,** 441 (1990)
D.W.Akers et al., *EGG-OECD-9168* (1992).
Washiya et al., the next generation reprocessing technology committee, 2012 Annual meeting (2012) [In Japanese]

Molten Salt : LiCl–KCl　Crucible : Carbon Steel
Electrode : Fe, Cd　Temp. : 500℃



Dissolution/Clarification/Separation
/Purification in One Unit



Integrated FBR with fuel cycle (IFR)*

As core temperature increases, reactor power decreases: Self-shutdown passive safety

MA is accompanied with Pu in liquid Cd cathode.

Low proliferation risk

*Reference: Y. I. Chang, "Integral fast reactor - a next-generation reactor concept," in Panel on future of Great Lakes symposium on smart grid and the new energy economy, Sept. 24-26, 2012.

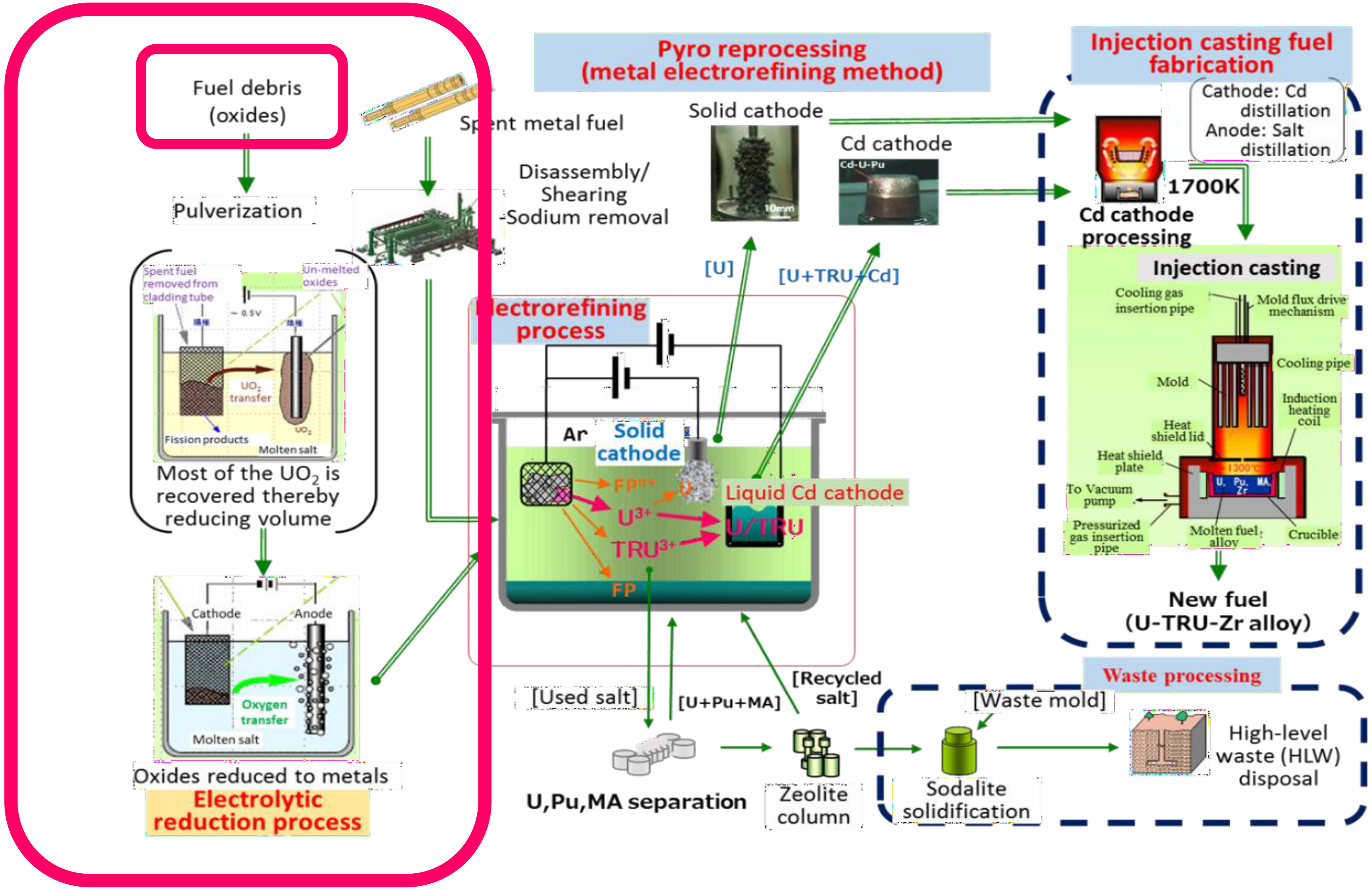
Product U,Pu contain MA, FP ⇨ **Low Decontamination process**

Dirty fuel but clean waste

The principle of the pyrochemical process for metallic fuel cycle

Reference : The Sasakawa Peace Foundation's Project "Research on Sustainability of Nuclear", Technical Feasibility report of an Integral Fast Reactor (IFR) as a Future Option for Fast Reactor Cycles -Integrate a Small Metal-Fueled Fast Reactor and Pyroprocessing Facilities-

Pyrochemical process for an accident debris and MA



Reference : The Sasakawa Peace Foundation’s Project “Research on Sustainability of Nuclear”, Technical Feasibility report of an Integral Fast Reactor (IFR) as a Future Option for Fast Reactor Cycles -Integrate a Small Metal-Fueled Fast Reactor and Pyroprocessing Facilities-

Summary

- The vision for nuclear energy that supports carbon neutrality is desirable Japanese nuclear fuel cycle with reactor safety.

- The desirable nuclear fuel cycle required in Japan:

① Utilization and reduction of Plutonium with nuclear non-proliferation risk
② Radioactive Wastes such as Minor Actinides reduction
③ A reprocessing method with low decontamination factor and a treatment of debris from the Fukushima Daiichi Nuclear Power Plant Accident
④ Economical and multi nuclear fuel cycle

- One of most promising candidates for fuel cycle is a metallic one with dirty fuel but clean waste.

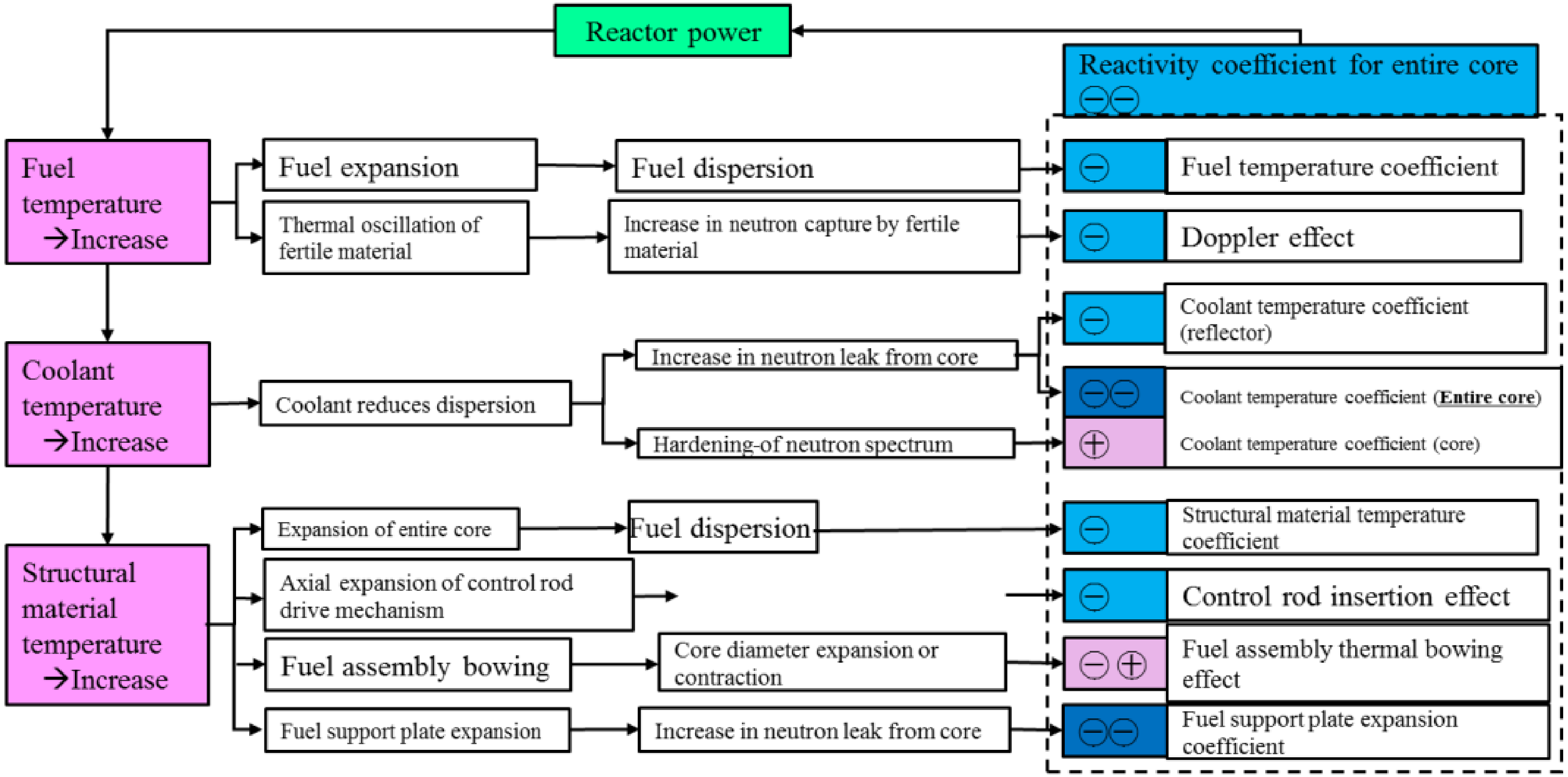
We propose to start the experiments of the debris from Fukushima Daiichi Nuclear Power Plant Accident cooperated with the U.S, in order to make sure the feasibility of pyrochemical process for the debris treatment.

Thank you for your kind attention!

Small Metal-Fueled Reactor Safety

As core temperature increases, reactor power decreases: Self-shutdown passive safety

(Reactor Shutdown using Reactor Safety)



Reactor power

Reactivity coefficient for entire core ⊖⊖

Fuel temperature →Increase

Fuel expansion

Fuel dispersion

⊖ Fuel temperature coefficient

Thermal oscillation of fertile material

Increase in neutron capture by fertile material

⊖ Doppler effect

⊖ Coolant temperature coefficient (reflector)

Coolant temperature →Increase

Coolant reduces dispersion

Increase in neutron leak from core

⊖⊖ Coolant temperature coefficient (**Entire core**)

Hardening of neutron spectrum

⊕ Coolant temperature coefficient (core)

Structural material temperature →Increase

Expansion of entire core

Fuel dispersion

⊖ Structural material temperature coefficient

Axial expansion of control rod drive mechanism

⊖ Control rod insertion effect

Fuel assembly bowing

Core diameter expansion or contraction

⊖⊕ Fuel assembly thermal bowing effect

Fuel support plate expansion

Increase in neutron leak from core

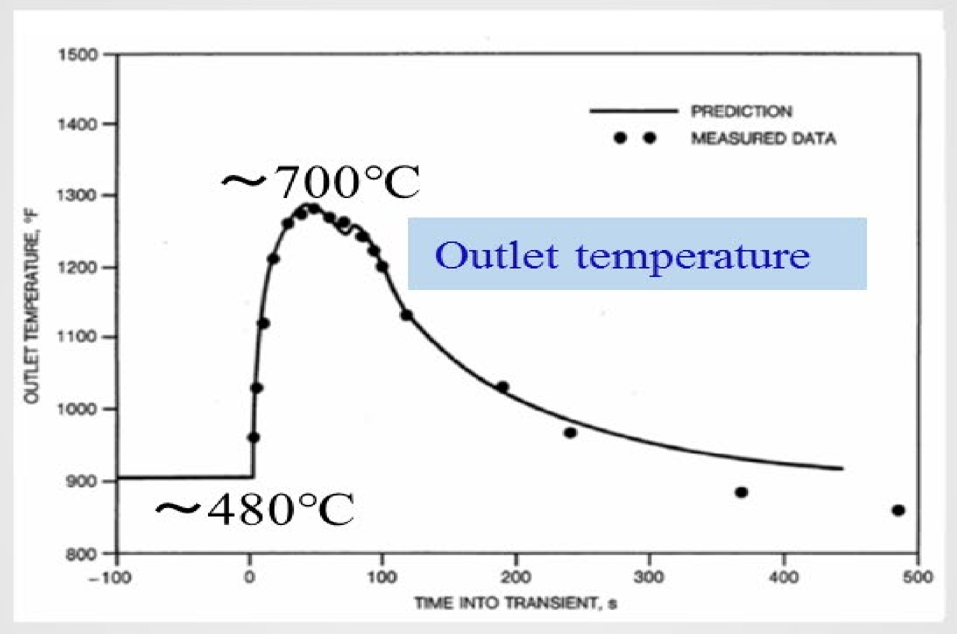
⊖⊖ Fuel support plate expansion coefficient

Adopt a passive mechanism to more reliably shut down the reactor and prevent core damage GEM (Gas Expansion Mechanism) produces a large negative reactivity effect for flow reduction type events.

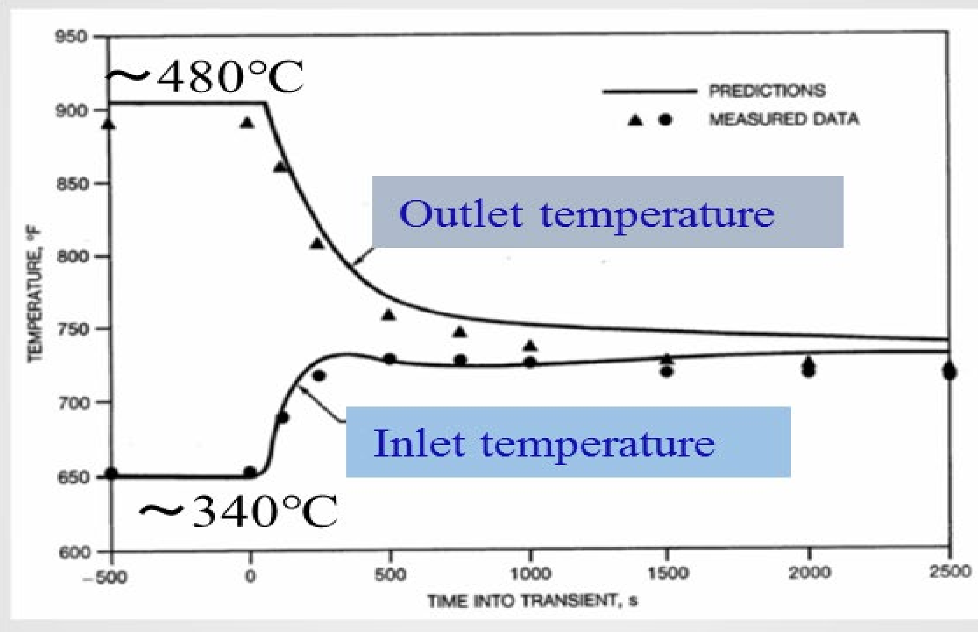
Reference : The Sasakawa Peace Foundation's Project "Research on Sustainability of Nuclear", Technical Feasibility report of an Integral Fast Reactor (IFR) as a Future Option for Fast Reactor Cycles -Integrate a Small Metal-Fueled Fast Reactor and Pyroprocessing Facilities-

Demonstration Test of Passive Safety of Small Metal Fuel Reactors

Intrinsic safety verification test of small metal-fueled reactors at the EBR-II experimental reactor in the United States Example of simulated test results for failed reactor emergency shutdown (ATWS) event conducted from May 1985 to April 1986 (1) Flow rate decrease from rated power (ULOF), (2) Secondary flow rate shutdown from rated power (ULOHS) The reactor core was not damaged and the reactor was safely shut down.



Reactor coolant outlet temperature rises sharply to about 200° C in about 30 seconds ⇒Neutron leakage increases due to thermal expansion of core components ⇒Reactor output drops due to negative reactivity feedback ⇒Reactor coolant outlet temperature drops



Reactor coolant inlet temperature rises by approximately 40° C in about 10 minutes ⇒Neutron leakage increases due to thermal expansion of core components ⇒Reactor output drops due to negative reactivity feedback ⇒Reactor coolant outlet temperature stabilizes

EBR-II

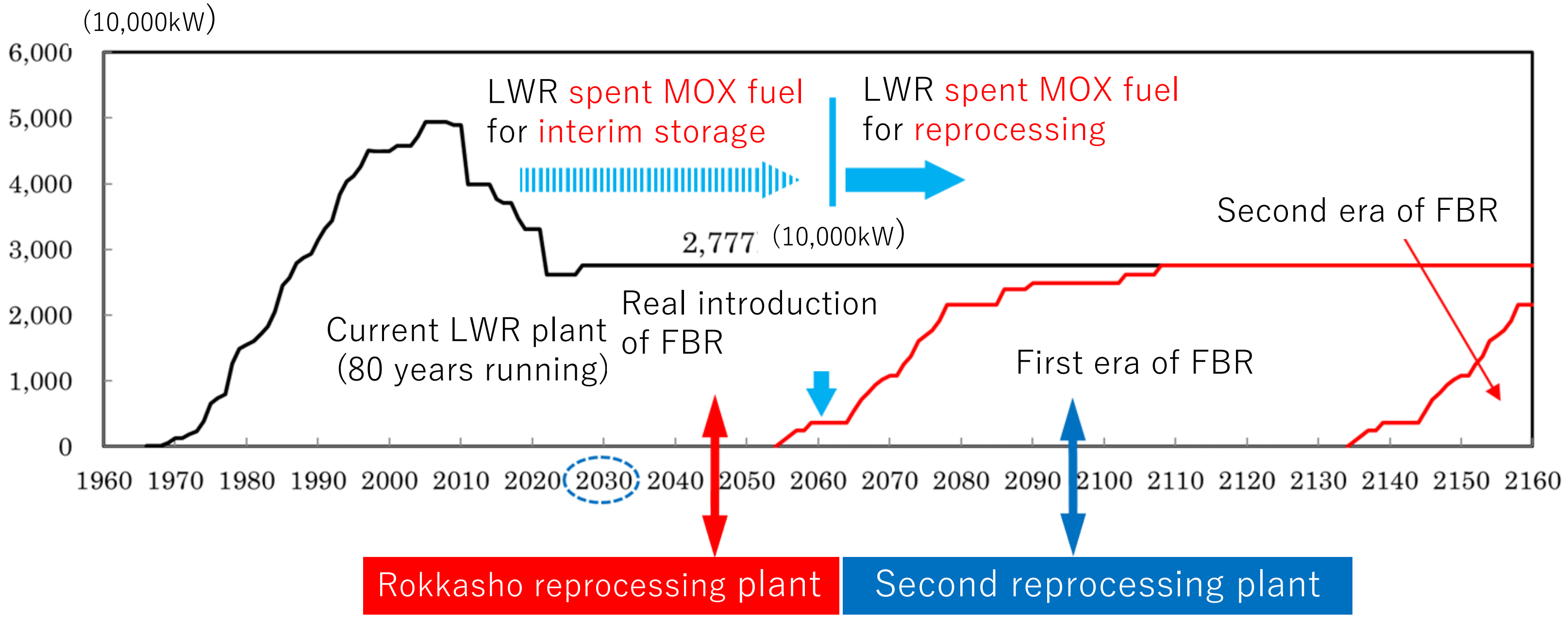
- Sodium cooling
- Small metal fuel
- Electrical output: 20,000 kW
- Thermal output: 62,500 kWt

Reference：M.T. Farmer, et. al, "US Experience and Current Activities Related to Passive Shutdown Systems for SFRs, Tech. mtg on Passive Shutdown Systems for Liquid Metal-Cooled Fast Reactors, IAEA, 21 Oct. 2015

Reference : The Sasakawa Peace Foundation's Project "Research on Sustainability of Nuclear", Technical Feasibility report of an Integral Fast Reactor (IFR) as a Future Option for Fast Reactor Cycles -Integrate a Small Metal-Fueled Fast Reactor and Pyroprocessing Facilities-

LWR running with a long life and introduction of Metallic fuel FBR with fuel cycle in 2060

- ➢Start of introduction of Metallic fuel FBR with fuel cycle in order to replace with old existing LWR in 2050
- ➢LWR running life extended with 80 years similar to United States in 2050
- ➢Full-scale Introduction of Metallic fuel FBR with fuel cycle in 2060
- ➢Stop running JMOX fuel fabrication to storage Pu for FBR in 2050



Introduction of FBR in place of existing LWR with 80 years

Reference: Agora investigation committee, com_agora_gei202206.pdf (aesj.net)