JAEA's role and activities in accordance with the Japan's nuclear energy policy

Hideki KAMIDE

JAEA Fellow

Sector of Fast Reactor and Advanced Reactor R&D

Japan Atomic Energy Agency

2050 Carbon-Neutral Declaration and 2030 Climate Goal

- In October 2020, Prime Minister Suga declared that **by 2050 Japan will aim to reduce greenhouse gas emissions to net-zero,** that is, to realise a carbon-neutral, decarbonised society.
- At Leaders Summit on Climate in April 2021, Prime Minister Suga announced that **Japan aims to reduce its GHG emissions by 46 percent in FY 2030 from its FY 2013 levels**.

Remarks at Leaders Summit on COP26 (Nov. 2021)

Japan aims to reduce its greenhouse gas emissions by 46 percent in the fiscal year 2030 from its fiscal year 2013 levels, and that **Japan will continue strenuous efforts in its challenge to meet the lofty goal of cutting its emissions by 50 percent**.

The 6th Strategic Energy Plan of Japan (October 2021)

Points related to Nuclear Energy

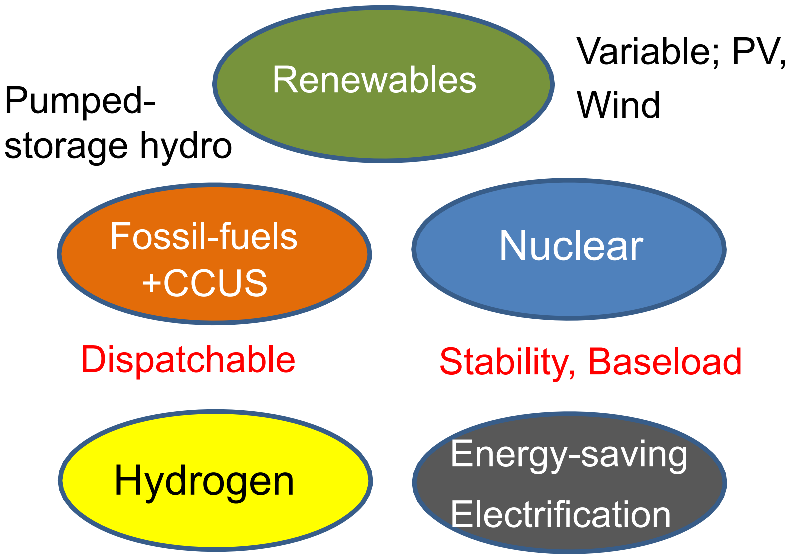
Towards 2050 Carbon Neutrality

- Maximum utilization of decarbonized electric sources: Renewables, Nuclear + innovation such as thermal power generation with CCUS.
- Stable and inexpensive power supply is essential. Renewable as the main power supply. Hydrogen and CCUS will be implemented in society. Nuclear energy at necessary scale with safety and sustainability

Towards 2030 (Nuclear)

- Promotion of stable use of Nuclear Energy
  - Spent fuel : Reduction of volume and radiotoxicity of waste
  - Fuel Cycle : Start Rokkasho Reprocessing Plant operation+ promotion of plutonium use in LWRs
- Promotion of R&D
  - Fast Reactor Cycle: Steadily promote with international collaboration
  - Small Modular Reactor : demonstrate with international partners
  - High Temperature Gas Reactor: establish component technologies for Hydrogen production

❖ Toward Carbon Neutrality



- ❑ Dispatchable decarbonized electric sources are important.
- ❑ Needs of Nuclear for the dispatchability in addition to the stable and reliable energy supply

Nuclear Energy Policy Direction in Japan (December 2022)

1. All-out Efforts for Restarting NPPs
- Voluntary Improvements on Safety, Coexistence with Local Communities

2. Maximum use of Existing Reactors
- Develop a Framework for NPP Operation Period, under the premise of safety

3. Develop/Construct of Next-gen Advanced NPPs
- Target on rebuilding the site which has been decided DCM (decommissioning),
- Improve in NPP Business Env and HRD, Promote Intl' R&D (incl. SMR)

4. Accelerate Back-end Process
- Promote Fuel Cycle, Steady & Efficient DCM, Efforts for Final Disposal

5. Maintain/Strengthen Supply-chain
- Reinforce JPN Supply-chain, by Support to Industry for join in Intl' Projects

6. Contribute to Solve Common Intl' Issues
- Cooperation among like-minded countries, Ensuring Nuclear Safety in Ukraine

Recent Activities on Nuclear Energy in Japan

Advanced Reactor Working Group of Nuclear Energy Subcommittee (METI)*1

- Acknowledged again the significance of nuclear energy for the nation and proposed steps for innovative reactor development in Japan
  - Technology roadmap for innovative reactor development: An interim summary (July 2022)

Revision of Strategic Roadmap of Fast Reactor Development decided by Council in Dec. 23rd, 2022

- "Strategic Roadmap" for fast reactor development was decided at the Ministerial Meeting for Nuclear Energy Policy in 2018
  - ⇨ Revised the roadmap to clarify the future support policy, etc., and to concretize the image of support targets and how to proceed in 2022.

Key points

- Sodium-cooled fast reactor was evaluated as the most promising for future development in terms of technology maturity, marketability, international collaboration, etc..
- And the work plan for future development on demonstration reactor was shown, such as conceptual design and R&D of demonstration reactor will start from FY2024.

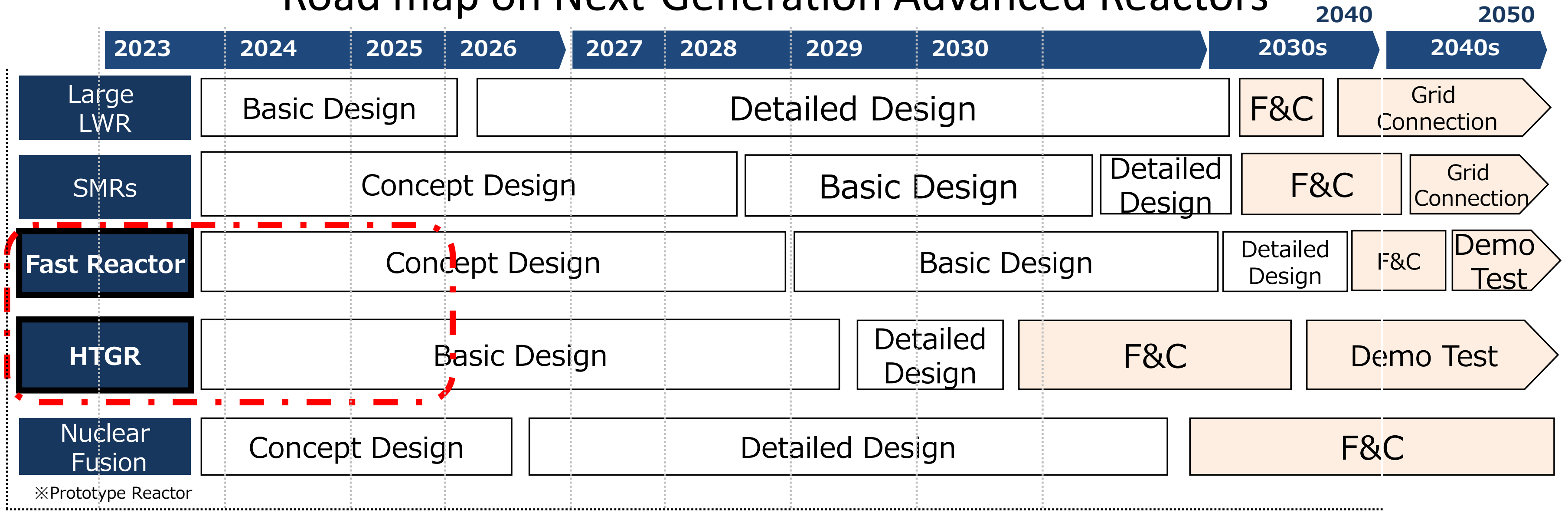
Study Group on R&D Infrastructure for Next-Generation Innovative Reactors (MEXT)*2

- Discussed R&D infrastructure development needed for the next decade, based on Prime Minister Kishida's directive issued at the Green Transformation Executive Conference in August 2022

Development of Next-generation Advanced NPPs

- ❑ In order to accelerate GX(Green Transformation) , GoJ has announced to establish budget proposal GX bond (provisional translation)
- ❑ The amount of bonds is 20 trillion yen in the next 10years (2023-2034)

Road map on Next-Generation Advanced Reactors



※F&C, Fabrication & Construction

- **Fast Reactor**
  Demonstration and Development Project
  【$357mil for 3years(2023-2025)】
- **High-Temperature Gas-cooled Reactor**
  Demonstration and Development Project
  【$335mil for 3years(2023-2025)】

JAEA at a Glance

❑ Mission:

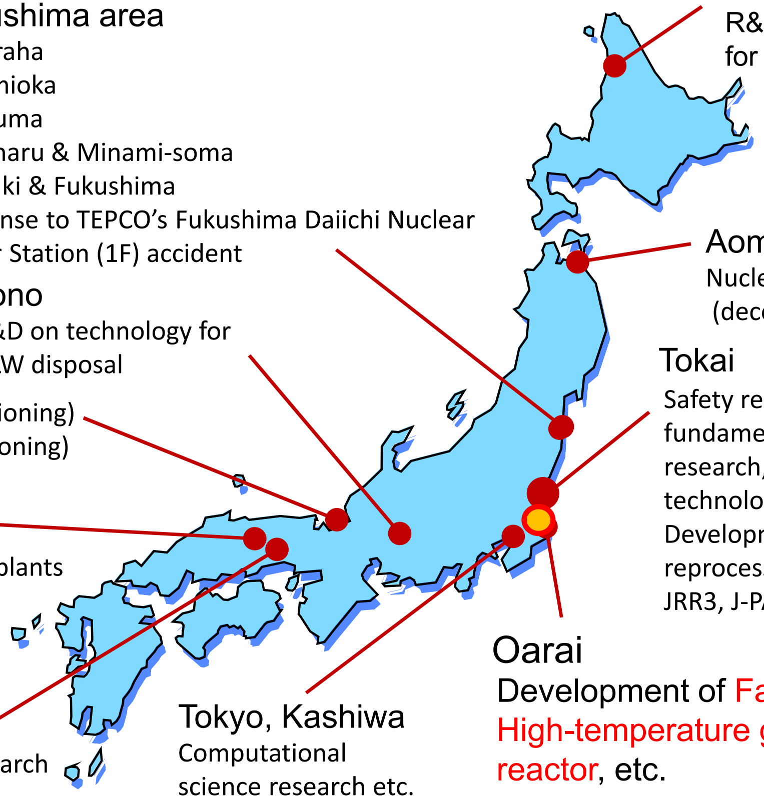
Contribution to welfare and prosperity of human society through nuclear science and technology as the comprehensive R&D institute in Japan dedicated to nuclear energy

❖ Number of non-fixed term employees: approx. 3,100 (As of 31st March, 2022)

❖ Budget (FY 2022): approx. JY152 B ≒€1.1 B

❖ Number of peer-reviewed papers: 862 (FY 2021)

R&D Centers of JAEA



Pursuing Competition among Various Technologies in Japan

- Various types of nuclear reactor technologies are supported by Government including international cooperation projects.
- The Japan Atomic Energy Agency (JAEA) possess important test facilities.

Small Modular LWR

- Smaller size, modular type
- Passive safety

➡ ✓ Affordable capital cost
✓ Smaller EPZ*

*:Emergency Planning Zone

Fast Reactor

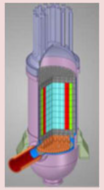
- Sodium-cooled reactor
- Fast neutrons

➡ ✓ Effective use of resources
✓ HLW** management

**: High-level Radioactive Waste

High Temperature Gas-cooled Reactor

- Helium gas-cooled reactor (chemically stable)
- Coated particle fuel
- Very high temperature



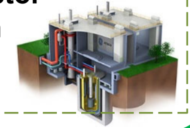
➡ ✓ Heat/hydrogen use
✓ Smaller EPZ

International Cooperation

France
Fast reactor R&D cooperation based on simulations and experiment

U.K.
High-temperature Gas-cooled Reactor

U.S.
Versatile Test Reactor (VTR) cooperation



JAEA's Facilities

Joyo:
Experimental Fast Reactor

HTTR:
Experimental HTGR

Development of Sodium-cooled Fast Reactors

Requirements for next-generation innovative reactors

Stable and reliable power supply

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

Natural resource Recycling

- As a carbon-free energy source, use innovative technology to recycle high-level radioactive waste
- Propose solution for limited natural resources
- Enable natural resource recycling of energy through technological innovation (Reprocessing)

Flexibility

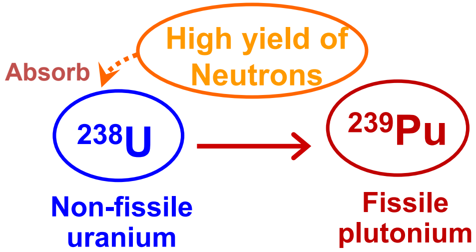
- Support variable renewables by adjusting power output
- Produce hydrogen, achieve various heat application, and store heat when electricity demand is low
- Be flexible in site locations by reducing the sizes of emergency planning zones
- National welfare through medical RI production

Further enhancement of safety

- Develop and promote technologies for safer nuclear power by reflecting lessons learned from TEPCO's Fukushima Daiichi nuclear power plant (1F) accident.

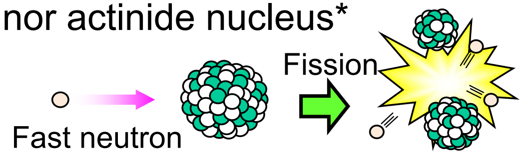
Features of a Sodium-cooled Fast Reactor (SFR)

Fast neutron



Produce new fuel

Minor actinide nucleus*

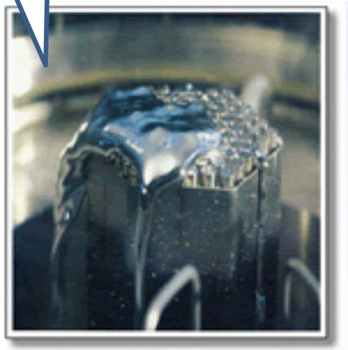


Reduce the toxicity of radioactive waste

- Fast neutrons have higher energy to make nuclear reactions and various applications.

Liquid sodium

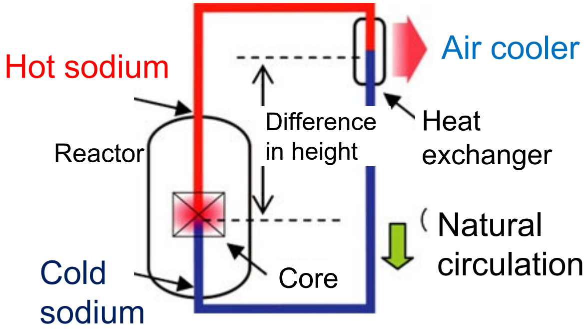
Sodium flowing through a fuel assembly model



- Sodium does not moderate neutron speed at collision so much (compared with water).
- Boiling point is 883 degree C, lower by 300 C than operation temperature (~550 C) at low pressure (➔Higher thermal efficiency and easy to keep the liquid level)

Safety achieved by sodium natural circulation

Assisted by the air cooler installed at a higher place, sodium flows naturally due to its density difference caused by temperature difference.



- Sodium is easily circulated naturally by convection driven by temperature difference, allowing natural cooling of the reactor even if the power source is lost.

*Minor actinides: Nuclides that remain highly radioactive for long period of time and cause the toxicity of radioactive waste. Typical elements include Americium (Am), Neptunium (Np).

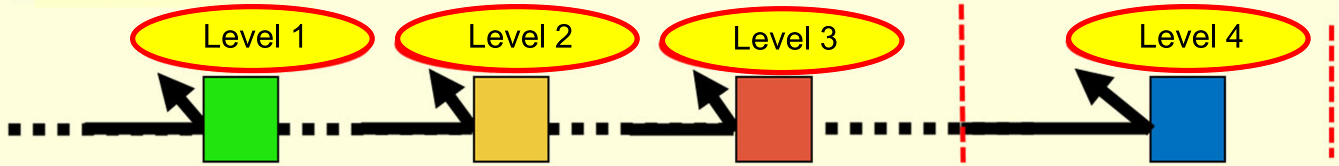
Design approach toward a safe and robust system

Fast Reactor can have 3 major passive safety characteristics

- Natural shutdown and active shutdown of the reactor
- Natural cooldown and active cooldown of the core
- Natural termination of an accident and confinement of radioactive materials in the reactor and containment vessels

These safety characteristics comply with the Defense-in-Depth (DiD) principle.

■ DiD principle



(1) Prevention of abnormal operation and failures

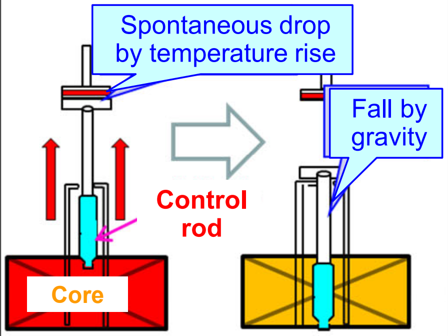
(2) Control of abnormal operation and detection of failures

(3) Control of accident within the design basis

(4) Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents

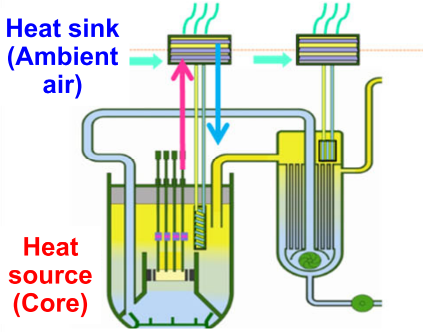
Elimination of the need for off-site emergency evacuation

Natural shutdown



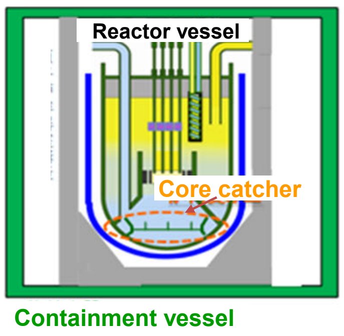
Control rods naturally fall when an abnormal event occurs

Natural cooldown



Cooled by sodium natural circulation and heat release to the ambient air

Natural termination



Contained by double layers even if the core melted

SeFARD

International collaboration on FR development

France-Japan collaboration

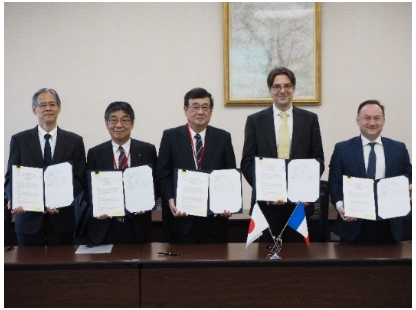
- CEA, Framatome, JAEA, MHI and MFBR: ASTRID collaboration (2014-2019).
  - ✓ 11 design tasks (decay heat removal, above core structure, etc.)
  - ✓ 28 R&D tasks (severe accident, fuel, material, thermal hydraulics, etc.)

Mockup of above core structure

Top view of Core

PLANDTL-2 Sodium experimental apparatus

ASTRID seminar, 10 October 2019



Signature, 3 December 2019

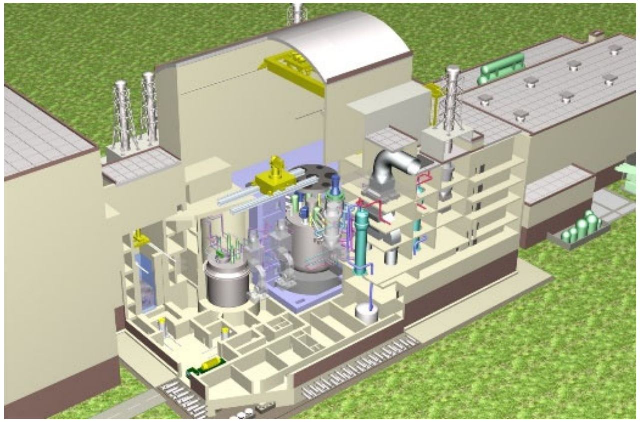
- CEA, Framatome, JAEA, MHI and MFBR have initiated a new collaboration of sodium-cooled fast reactor (2020~)
  - ✓ 32 R&D tasks: Severe accident, Fuel, material, Numerical Analysis Code, etc.

US-Japan collaboration

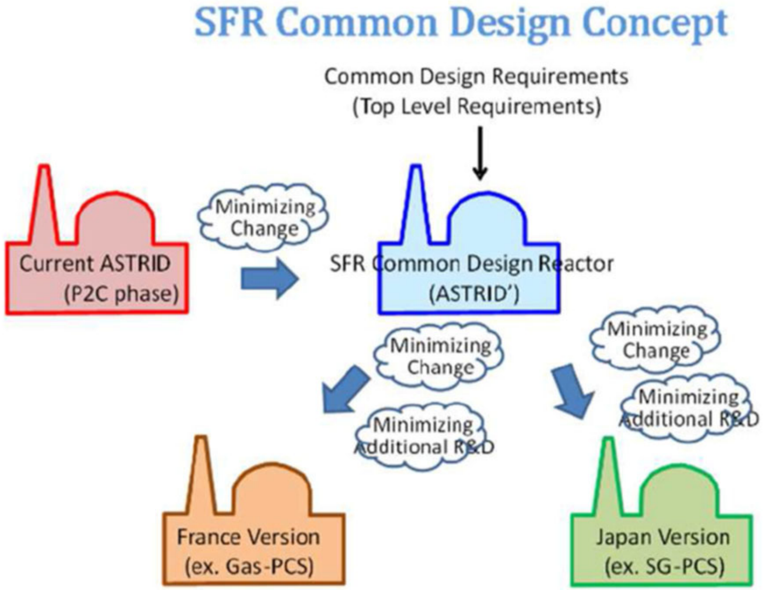
- Terrapower, JAEA, MHI and MFBR singed a MOU to initiate collaboration on sodium-cooled fast reactor in January 26th, 2022.

Design study of pool type Fast Reactors

- Japanese pool type reactor design with 3D seismic isolation system.
  - Electric output: 650MWe
  - Core: MOX fuel, using FAIDUS subassembly as a mitigation measure of severe accidents, i.e., discharge of core melt in early phase of accident
  - 3D seismic isolation system (a 1/2 scaled mockup of 3D isolation system was fabricated and Experiments in progress.)
  - Feasibility of safety, economical competitiveness, and seismic design has been confirmed.
- France-Japan common design: target of effective R&D cooperation



Schematic of Japanese pool type reactor

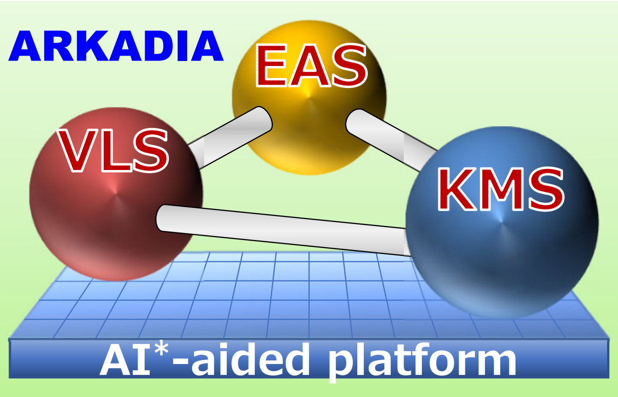


- Electric output: 650MWe
- Core fuel: MOX fuel, CFV core

1/2 scaled mockup of 3D seismic isolation system

ARKADIA as a Digital Triplet for Reactor Design

- ❑ Support evaluation of various innovative reactor concepts represented by a sodium-cooled fast reactor
- ❑ Optimize plant lifecycle of an advanced reactor automatically by using state-of-the-art simulation technologies and knowledge
- ❑ Keep and transfer technology bases including knowledge (e.g., next few slides)



*Artificial Intelligence

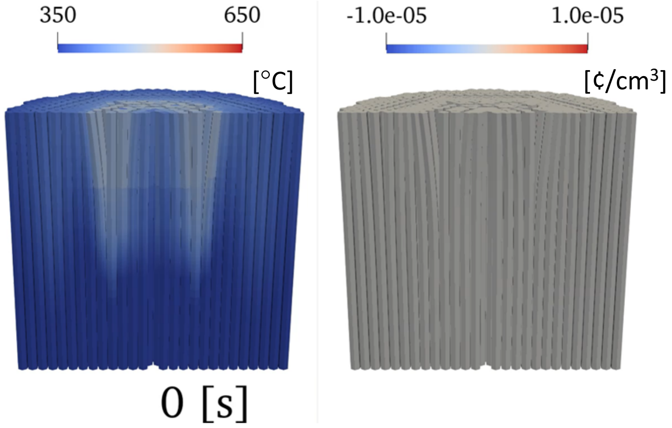
- ❑ Virtual Plant covering its life cycle
- ❑ Knowledgebase of Experiment, Simulation, Design, Maintenance...
- ❑ Design optimization with AI

- ❖ VLS: Virtual plant Life System,
- ❖ KMS: Knowledge Management System,
- ❖ EAS: Enhanced and AI-aided design optimization System

ARKADIA-Design

optimizes core design, plant structure design, and maintenance program

Example coupled simulation by VLS (Neutronics, thermal hydraulics, structure)

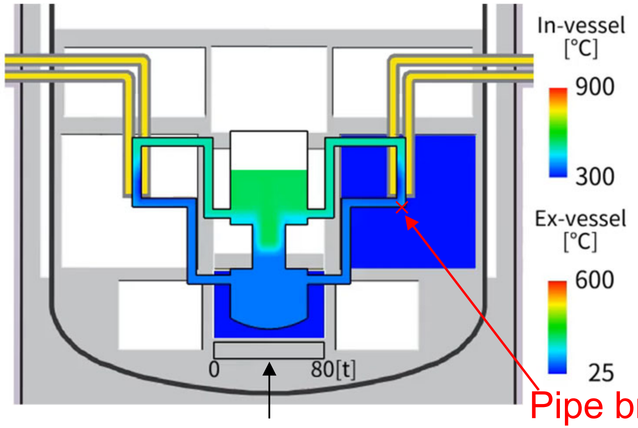


Temperature Deformation Reactivity

ARKADIA-Safety

provides design satisfying requirements of safety and economics from SA* simulation

Example SA simulation by VLS (loss of rector level)



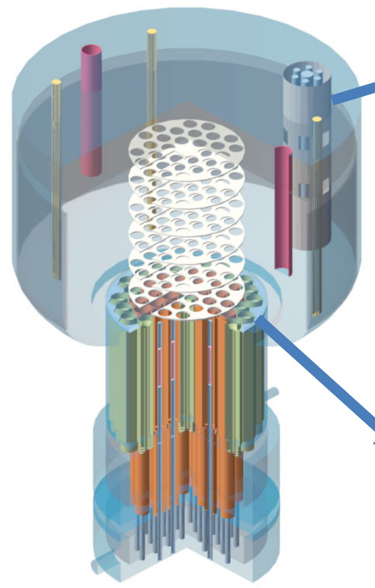
* Severe Accident

Components of VLS for Design and Safety Evaluations

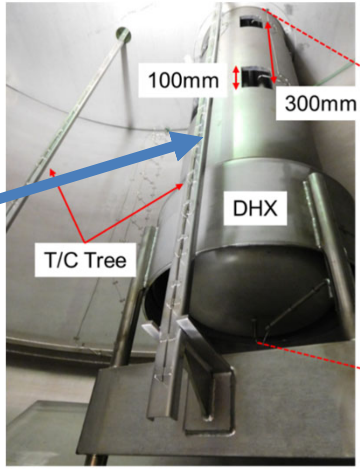
Simulation of Decay Heat Removal

- Validation experiment using PLANDTL-2: Sodium tests with a full core model of SFR

2m diameter of Sodium Plenum



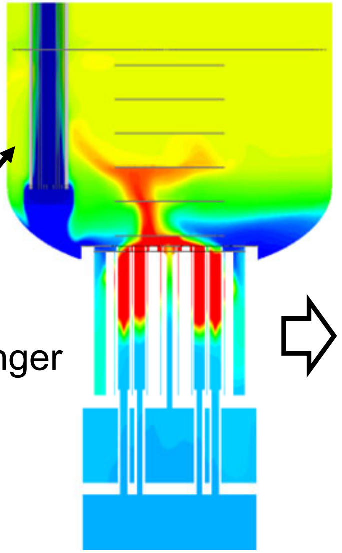
Test Section



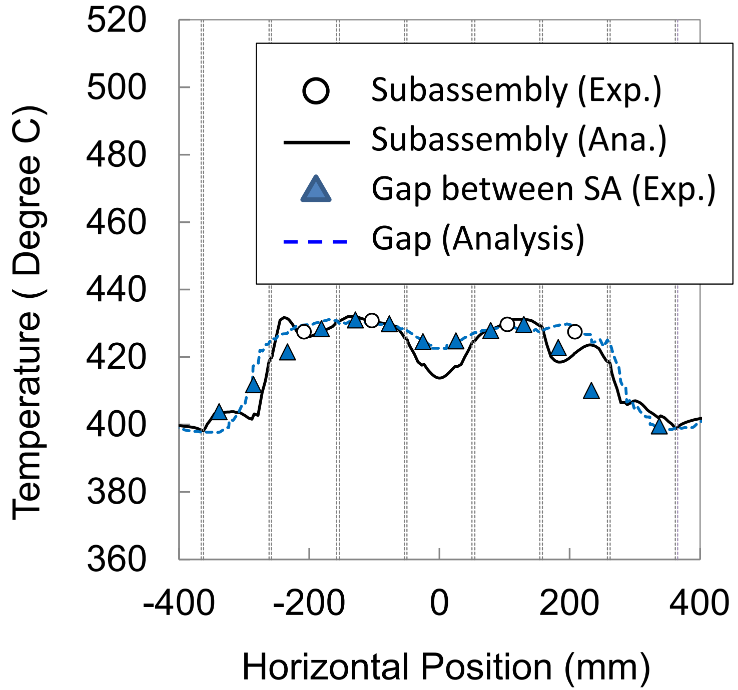
Inside of Upper Plenum

Heat Transfer Tube

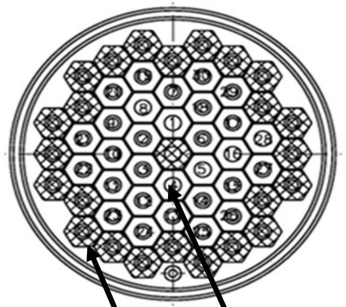
Dipped Heat Exchanger (DHX)



Temperature Contour in RV model



Comparison of Temperature Distributions along the core outlet between Exp. and Analysis



Top of the Simulated Core

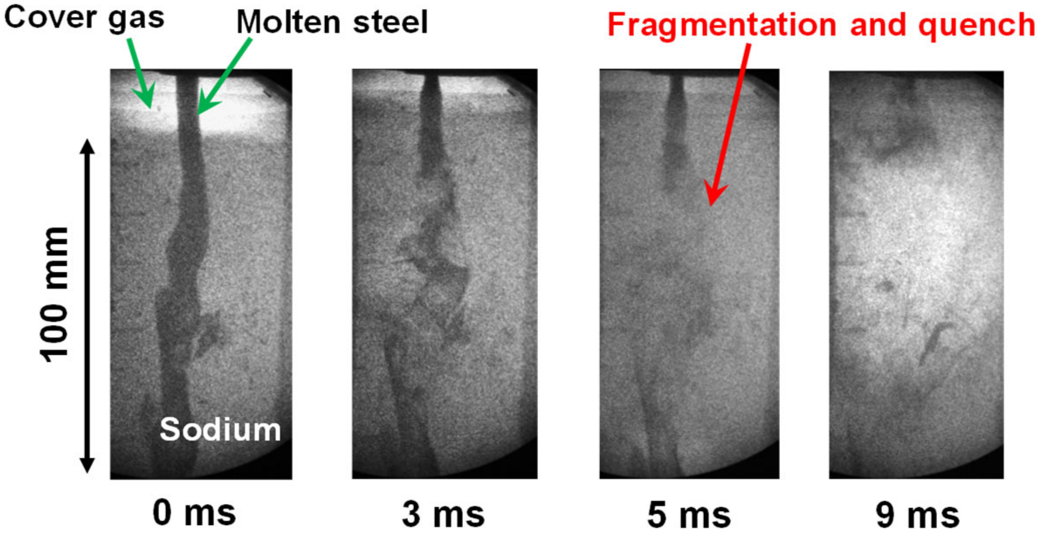
Heated Channel

Non-heated Channel

Sodium experiments on Safety Issues

- ***In-vessel retention of Core melt Accident***

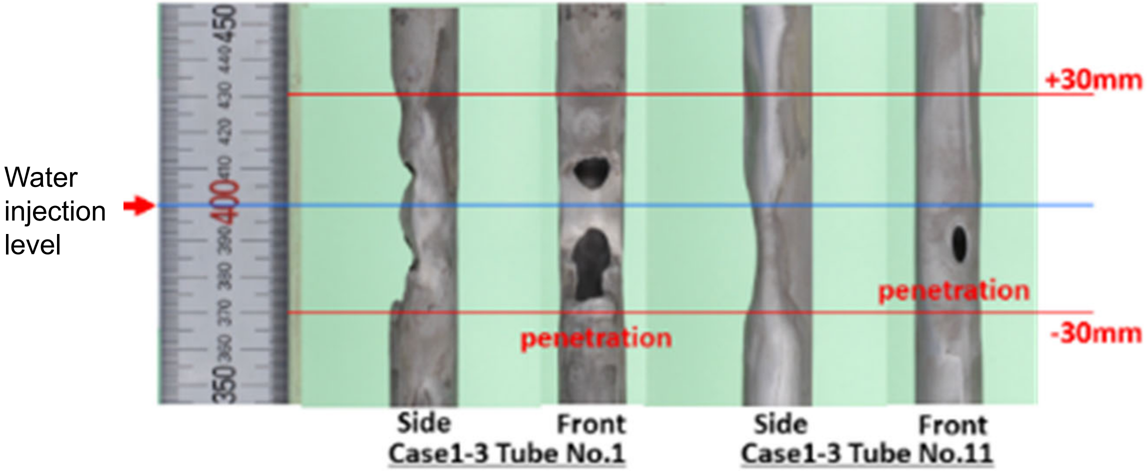
MELT:
Utilized for experimental studies to clarify the molten-core material behavior during severe accidents of SFR



X-ray images of melt behavior in sodium

- ***Sodium Water Rection***

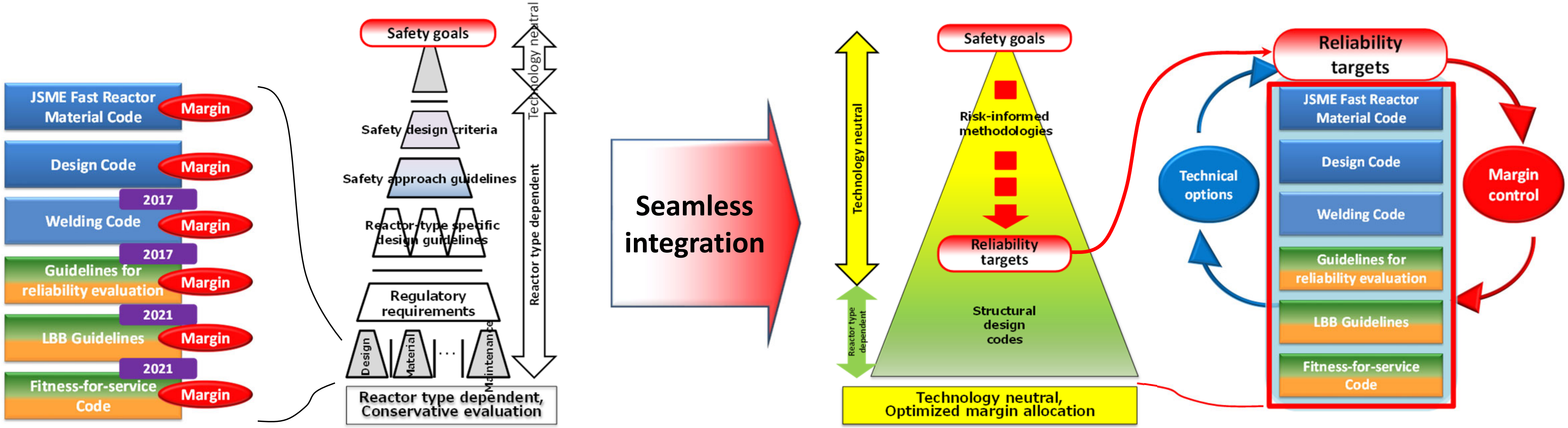
SWAT-3R:
Sodium-water reaction (SWAT-3R) test simulating high temperature and pressure steam-water jets into sodium in SG



Example of Test: Penetrating failure tubes

Codes and Standards of JSME and cooperation with ASME

- New codes and standards for flexible design: JAEA contributes to FR codes in JSME and ASME.
  - ✓ Codes for design, welding and fitness-for-service published by JSME alongside guidelines.
  - ✓ A scheme for margin optimization using risk-informed methodologies is being developed with ASME.



- ✓ Each code is independent and has individual margins
- ✓ Restrictive and relation to safety is unclear

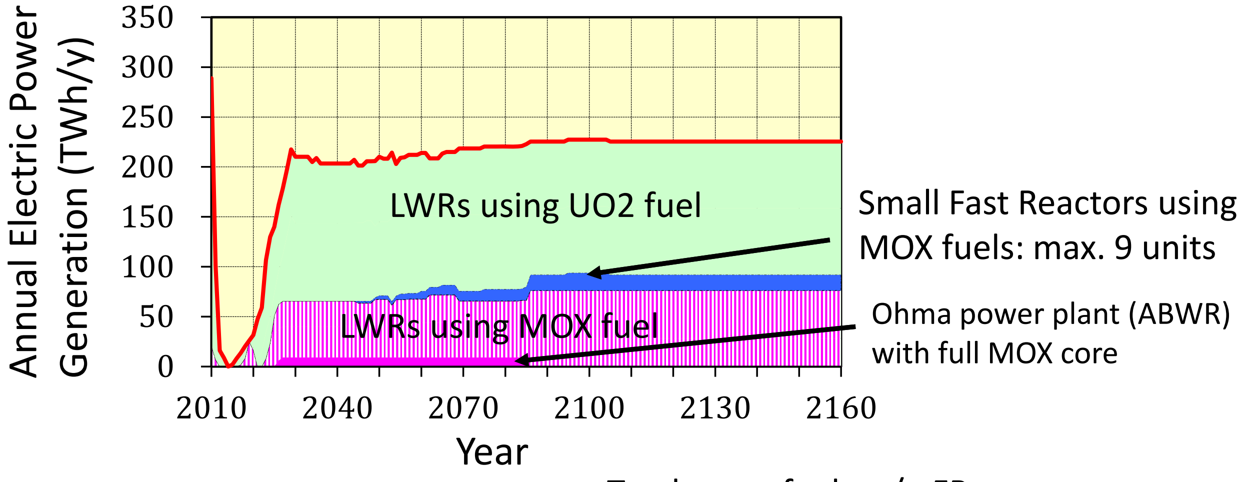
- ✓ Reliability targets ensure safety and optimize the total lifecycle margin
- ✓ Removal of unnecessary restrictions allows enhanced flexibility in design

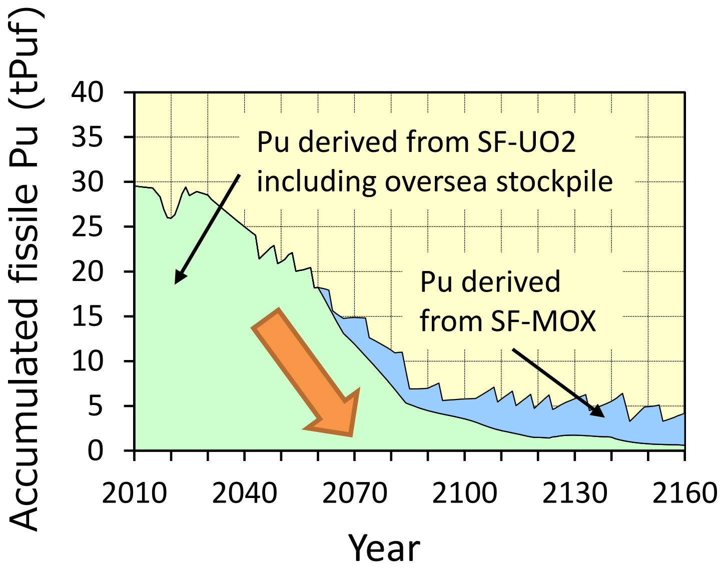
- ASME Boiler and Pressure Vessel Code Section XI Division 2 incorporated reliability targets in the 2019 edition as an outcome of the collaborative work of JSME and ASME.

Case Study of SMR SFR operations in Japan for Pu & Waste Management

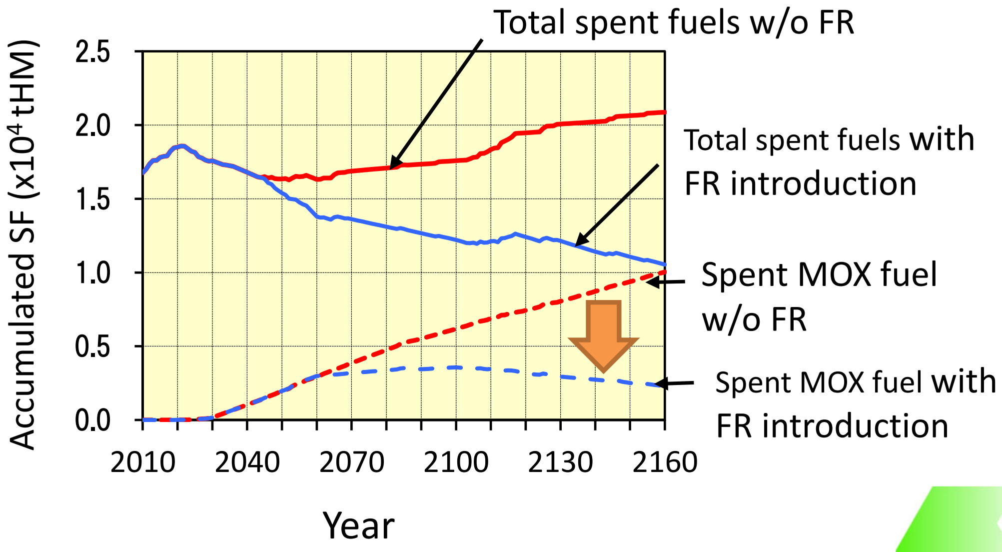
Assumption:
Small-sized SFRs are introduced one by one from 2045 up to 9 units

- 300MWe, Conversion rate:0.8 uses degraded Pu recovered from SF-MOX of LWRs





【History of Separated Pu Accumulation】



【History of Accumulated Spent Fuels amount】

SeFARD

R&Ds of FR Fuel Cycle in JAEA

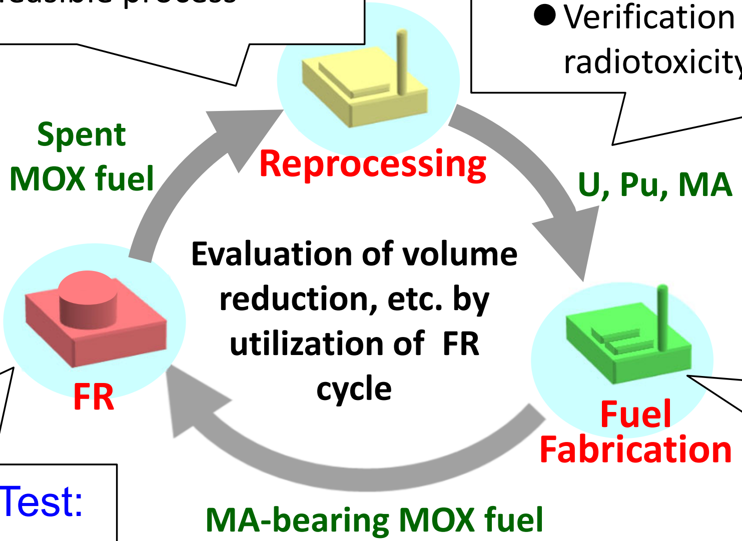
- Sustainable Energy Supply
- Reduction of the volume and radiotoxicity of radioactive wastes

❑ Improvement of the flexibility of Pu use, verification of MA partitioning and transmutation technologies

Chemical Processing Facility

Reprocessing:
- Development of MA partitioning process and performance evaluation
- Establishment of feasible process concepts

Comprehensive system evaluation:
- Integration of information in each area & narrowing prospective system concepts
- Verification of effects on reduction of the volume and radiotoxicity of radioactive wastes



Plutonium Fuel Production Facility

Fuel Fabrication:
- Remote MA-bearing MOX fuel fabrication technology
- Determination of fuel composition range applicable

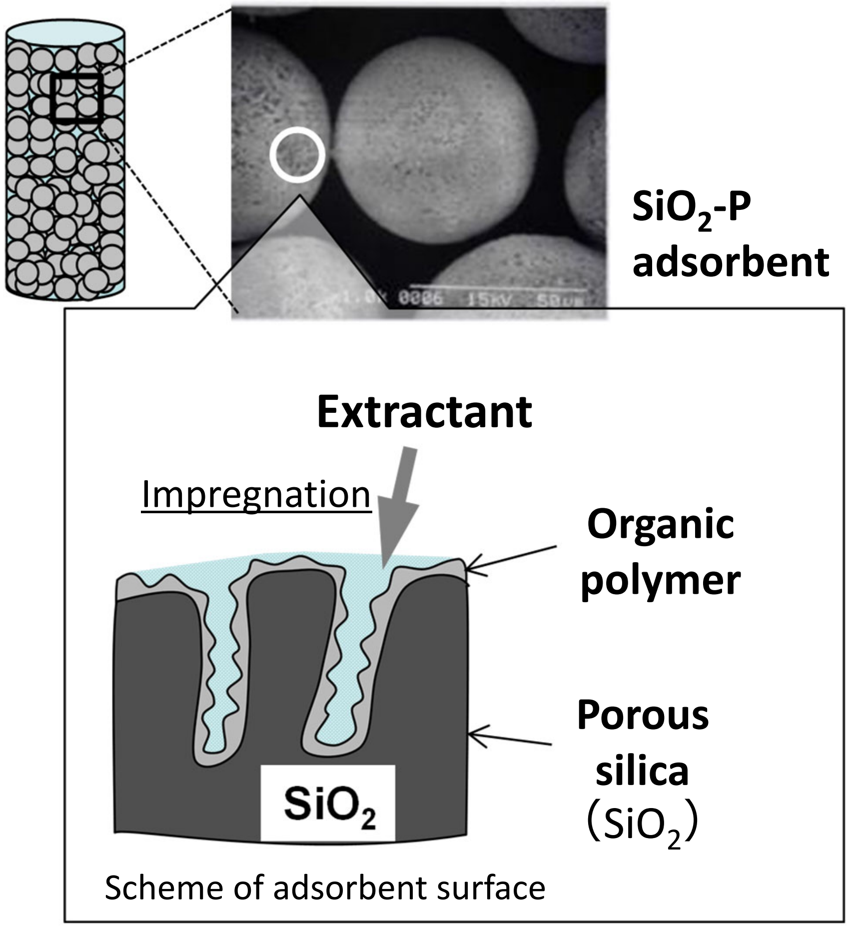
Fuel Development & Irradiation Test:
- Systematic irradiation tests of MA-bearing MOX fuel, MOX fuel with degraded Pu isotopic composition.

MA Separation Technology Developments

- MA separation technology from high level liquid waste (HLLW) using extraction chromatography.
- Adsorbent: porous silica coated with polymer and impregnated extractants.

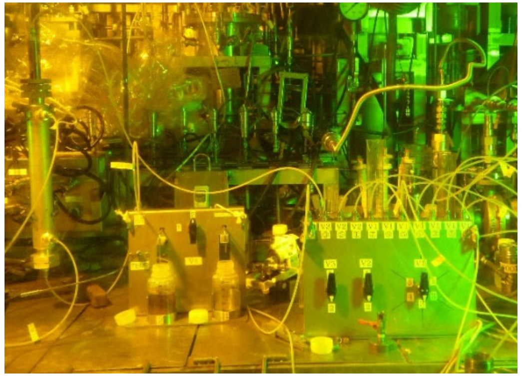
⇨ Compact equipment and waste reduction of organic solvent

About 2g of MA (Am and Cm) was successfully separated from HLLW using this technology.



Particle size： 50 – 100 µm, Pore size：500-600nm

Basic structure of SiO_2-P adsorbent

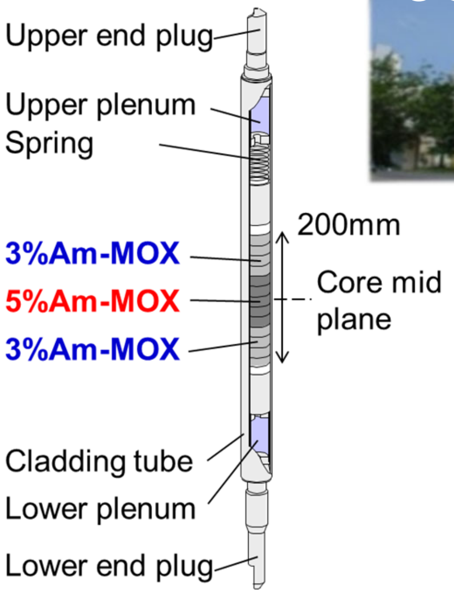


Extraction chromatography setup in hot cell

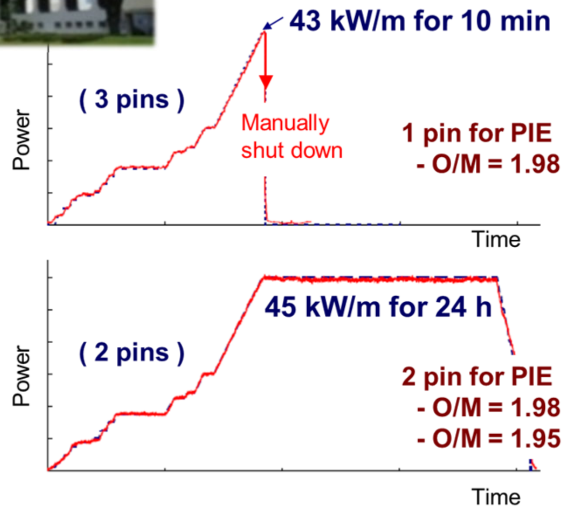
MA solution recovered from HLLW

MA bearing Fuel and Irradiation in Fast Reactor

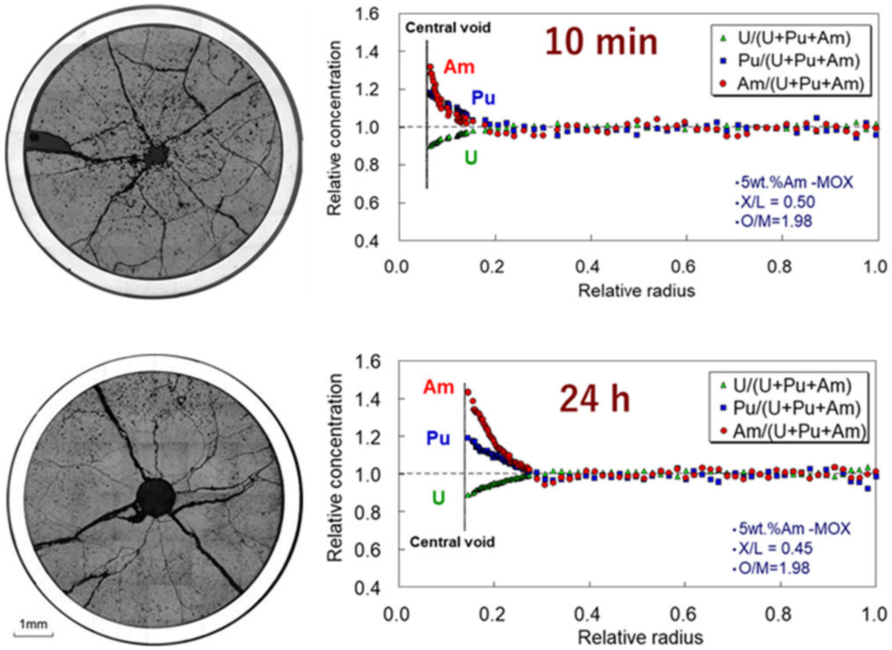
- Irradiation Tests of minor actinide-bearing MOX s (3wt.% and 5wt.% Americium-containing MOX fuels) for a short-term were carried out in Joyo.
- There was no fuel melting without degrading thermal conductivity caused by Americium, and data on the redistribution behaviour of Americium and Plutonium were obtained



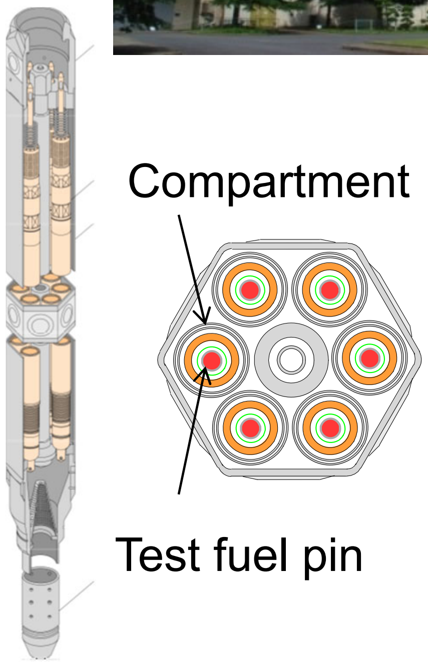
Am-MOX Fuel pin



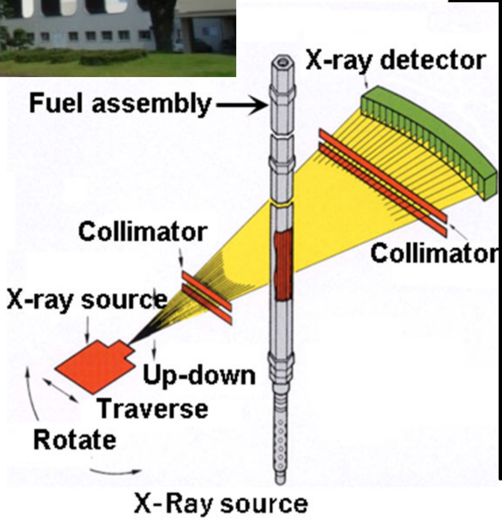
Irradiation in Joyo



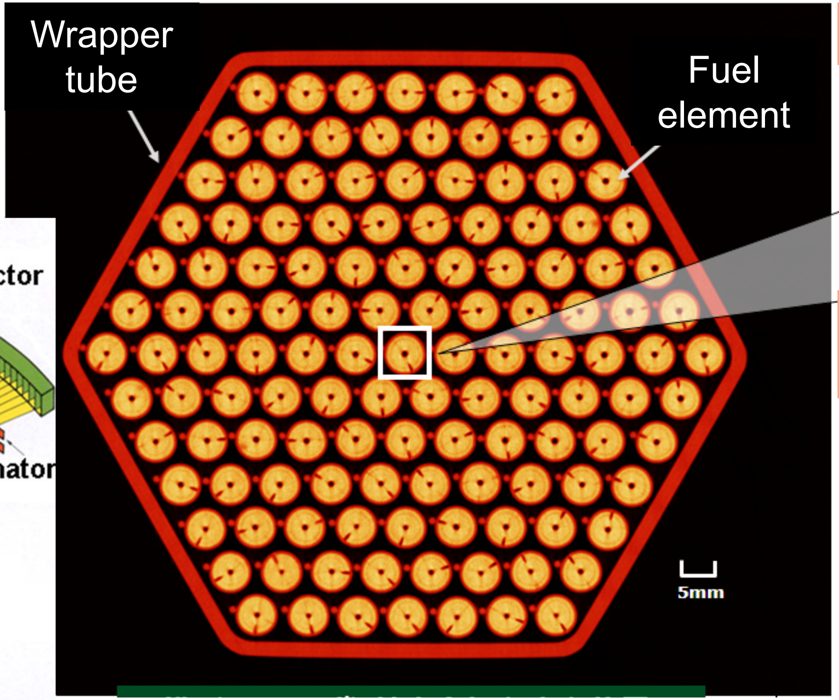
Joyo and Neutron Irradiation Experiments

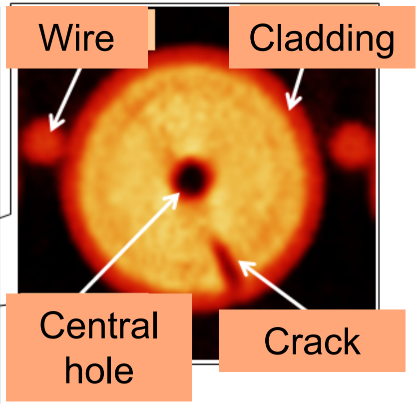


Irradiation Test Subassembly

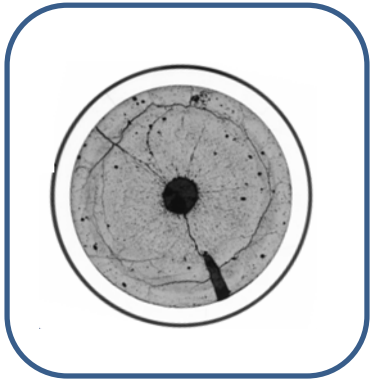


Outline of X-ray CT





Cross-section image of fuel assembly by X-ray CT



Metallographic examination

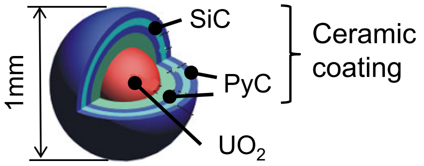
Example of post irradiation examination (PIE) of fuel

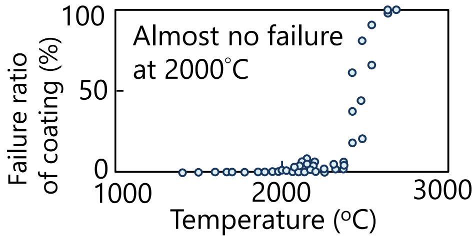
Development of High Temperature Gas-cooled Reactor (HTGR)

Features of HTGR —Inherent safety

Ceramic-coated fuel

Resistance to high temperatures and no meltdown

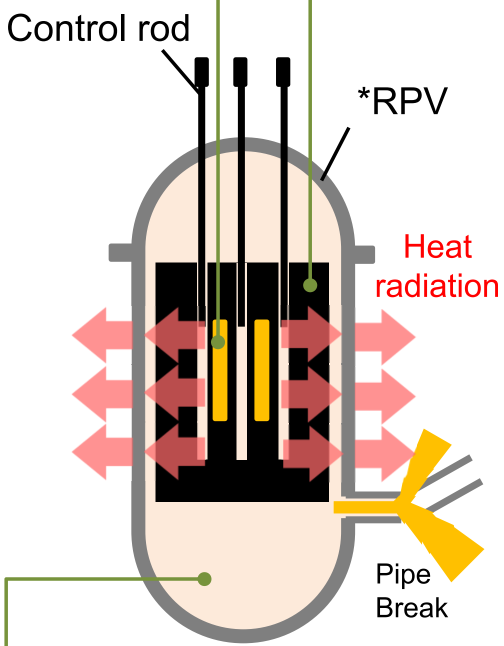




Experimental result of heated fuel particles

Helium gas coolant

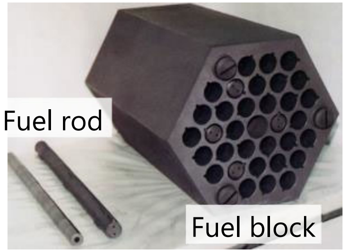
No explosions of H_2 and vapor thanks to its chemical inertness and no phase-change

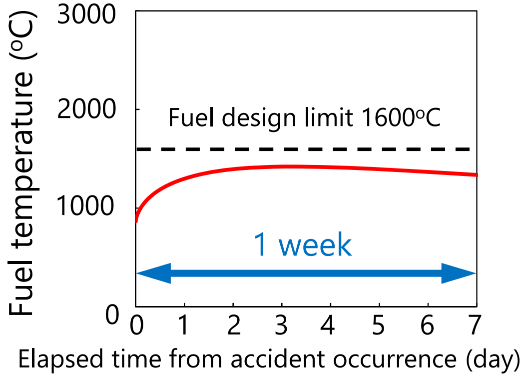


The reactor is safely shut down and cooled by passive design features that require no equipment or operator actions even if external power and coolant are lost.

Graphite components

Cooled down naturally from the outside of the RPV thanks to its large heat capacity and high thermal conductivity



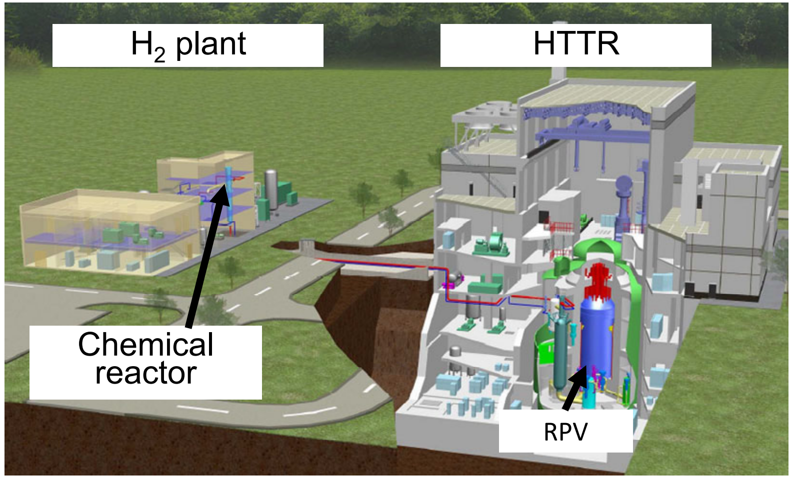


Fuel temperature during loss-of-coolant accident (analytical result)

*RPV: reactor pressure vessel

Restart of the HTTR and future test plans

- JAEA restarted the HTTR in July 2021
- Future test plans by the HTTR
  - OECD/NEA LOFC Project (safety demonstration test)
  - Other operation tests (safety, core physics, fuel performance, components reliability, etc.)
  - HTTR-heat application test (hydrogen production) to establish safety design for coupling of H_2 plant to HTGR
    - ✓ Obtain permission from regulatory authority
    - ✓ Complete development of coupling technologies by 2030.
    - ✓ Develop carbon-free H_2 production technology (IS process, etc.) in parallel



HTTR-heat application test

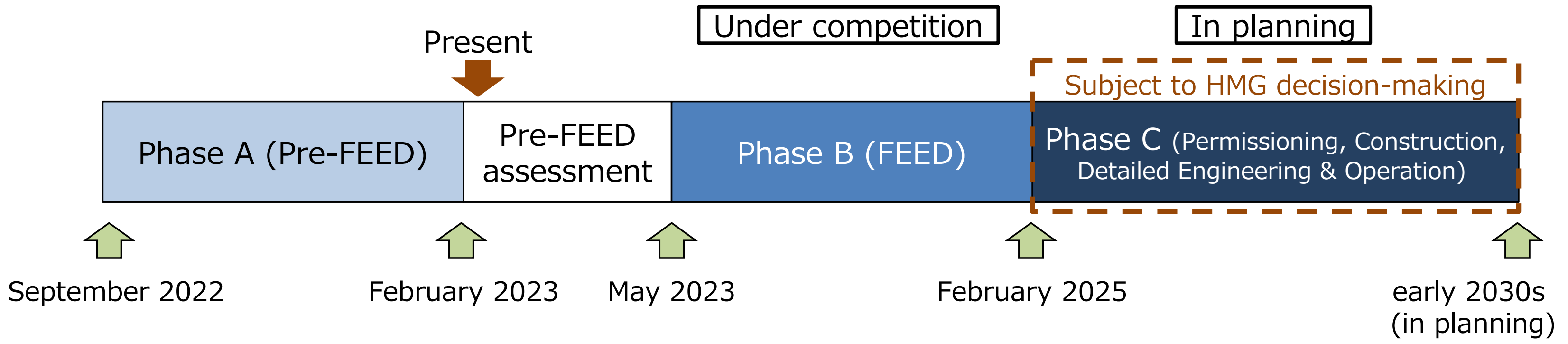
Collaboration with the United Kingdom

- The UK is promoting a high-temperature gas-cooled reactor demonstration project (AMR RD&D Programme) aiming for introduction in the early 2030s.
- Programme structure (3 stages)
  - ➢ <u>Phase A: A Pre-Front-End Engineering Design (Pre-FEED)</u>

    In September 2022, a team consisting of the UK National Nuclear Laboratory (NNL) and JAEA was selected as the implementation operator.

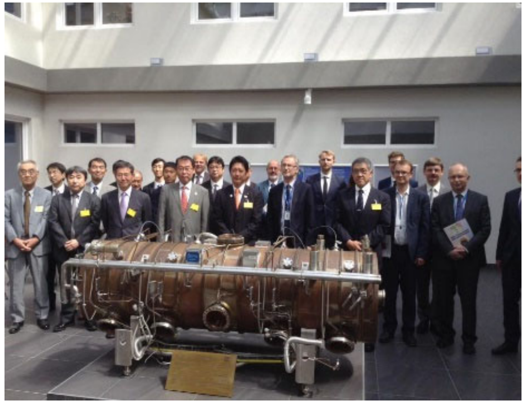
    LOT 1: Reactors
    - ✓ EDF Energy Nuclear Generation
    - ✓ <u>NNL team with JAEA and Jacobs</u>
    - ✓ U-Battery Developments
    - ✓ Ultra Safe Nuclear Corporation UK

    LOT 2: Coated Particle Fuel
    - ✓ <u>NNL team with Urenco and JAEA</u>
    - ✓ Springfields Fuels team with Urenco
  - ➢ Phase B: A Front-End Engineering Design (FEED)
  - ➢ Phase C: Permissioning, Construction, Detailed Engineering & Operation

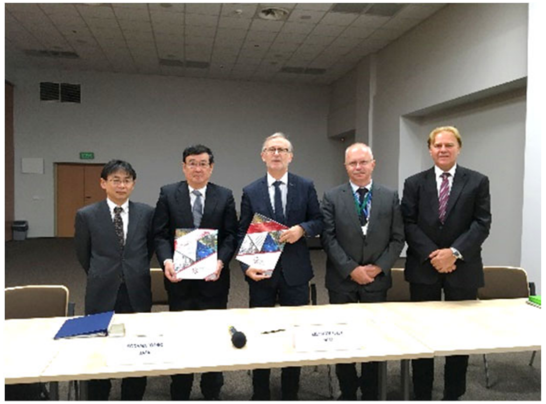


Collaboration with Poland

- Poland plans to supply process heat from HTGRs to industry.
- In May 2021, the National Center for Nuclear Energy Research (NCBJ) received a governmental funding (about 1.8 billion yen for 3 years) for the basic design of a HTGR research reactor.
- In November 2022, JAEA and NCBJ revised the Implementing Arrangement regarding the HTGR R&D cooperation and started cooperation on the basic design of the HTGR research reactor.



Japanese delegation (MEXT, JAEA, and industries) in Poland (July 2017)



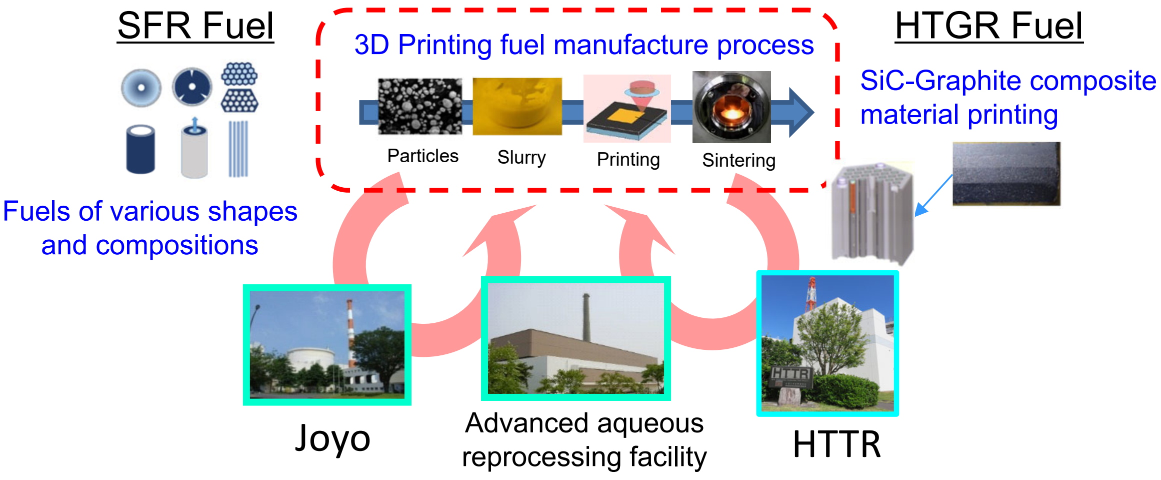
JAEA and NCBJ signed the Implementing Arrangement (September 2019)

JAEA and NCBJ revised the Implementing Arrangement (November 2022)

Nuclear Innovation: 3D Printing Ceramic Fuel Technology

■ Development Goals :

- Fuel cycle synergy for SFR and HTGR
- Enable advanced fuel features
- Enhance safety and economics



<u>Research on 3D Printing CAE Simulation and V&V</u>

(Computer-Aided Engineering)

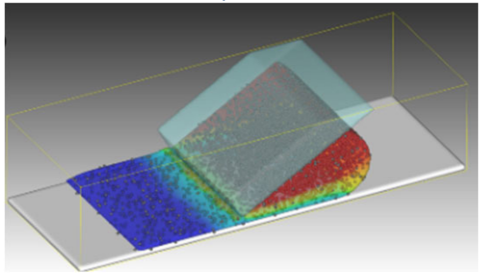
✓ Particles and slurry
  Complex behavior re-produced by CFD

✓ Stereolithography printing

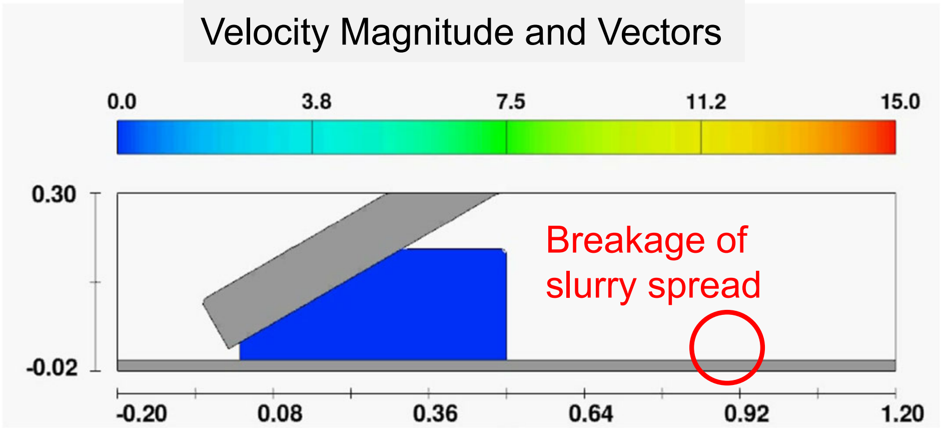
✓ Spark plasma sintering

✓ Irradiation performance

CAE will greatly accelerate deployment of 3D printing fuels



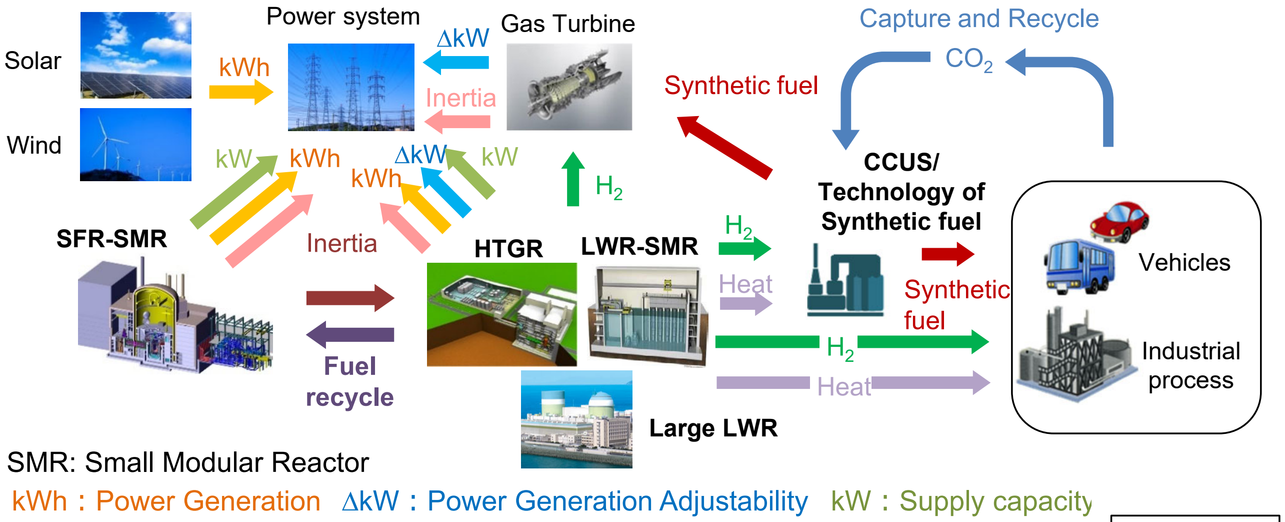
Slurry Spreading Process



Nuclear and Renewable Hybrid Energy System

■ Development Goals NR-HES

- Energy supply security & reliability
- Carbon neutrality
- Major role for renewable energy
- Safe and sustainable nuclear energy



1) Modeling & Simulation

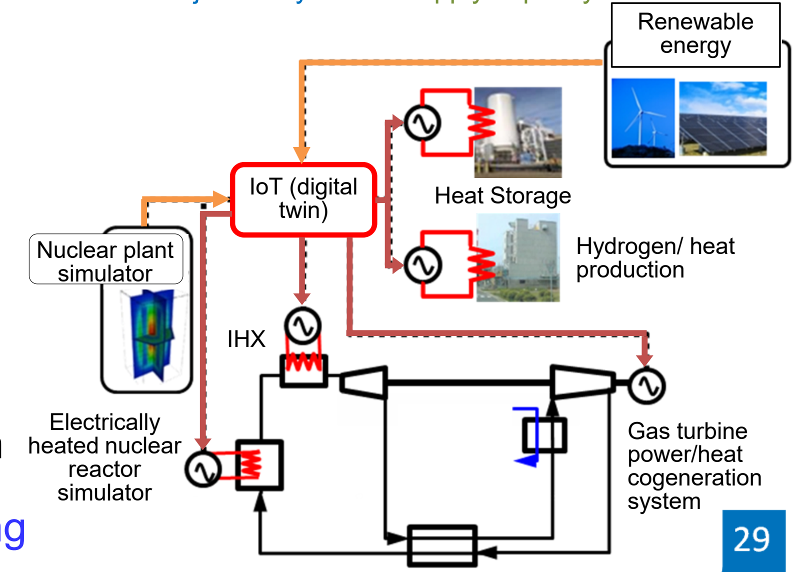
- ✓ National electricity grids resilience
- ✓ National energy (electricity, H2, heat, fuel) supply best mix
- ✓ Advanced nuclear reactors fuel cycle sustainability and operation flexibility

To underscore nuclear energy roles in a net zero carbon world

2) Platform for Demonstration

- ✓ Integrated system : power, heat storage, H2, renewable energy
- ✓ Nuclear reactor operation safety and flexibility
- ✓ IoT (digital twin) to monitor, forecast and optimize production

➡ To assist in design and licensing



Summary

- Policy to develop Advanced Reactors and Nuclear Fuel Cycle
- Sodium cooled Fast Reactor (SFR) Development
  - Design study and International cooperation with US and France
  - ARKADIA: Simulation/ Knowledgebase/ Design assistance for plant life cycle design
  - Codes and Standards: Risk-informed methodologies, contributions to JSME and ASME
  - Fuel Cycle with Minor Actinides using experimental fast reactor, Joyo
- High Temperature Gas cooled Reactor (HTGR) Development
  - Restart of HTTR in July, 2021
  - Plan of Heat application test for Hydrogen production
  - International Cooperation with UK and Poland
  - 3D Printing for fuel fabrication for HTGR and also SFR

This presentation material includes some of the results of the "Technical development program on a commercialized FBR plant" and "Technical development program on a fast reactor international cooperation, etc." and "Technical development program on a common base for fast reactors" entrusted to JAEA by the Ministry of Economy, Trade and Industry in Japan (METI).