Current status of Fast Reactor developments in Japan

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Sector of Fast Reactor and Advanced Reactor Research and Development

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

Points related to Nuclear Energy

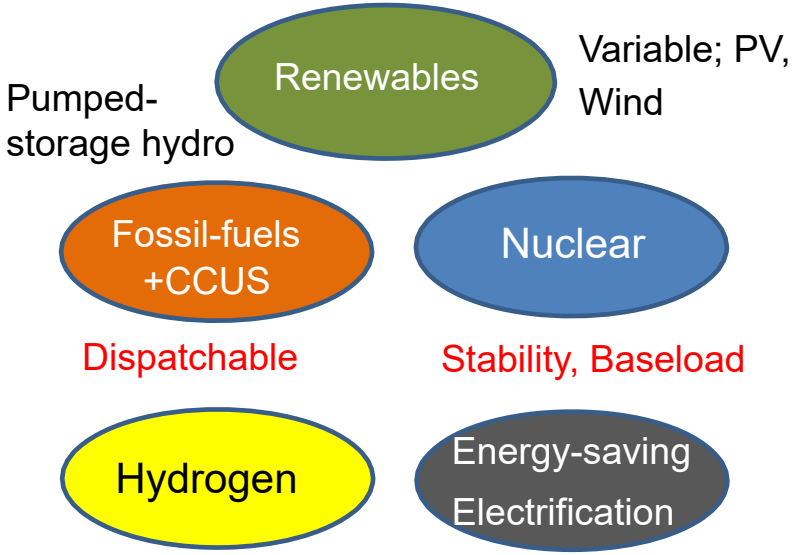
Towards 2050 Carbon Neutrality

- 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 : 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

Japan's Initiative to Accelerate Nuclear Innovation

NEXIP : Nuclear Energy × Innovation Promotion

A new initiative to help accelerate the development of innovative nuclear technologies

METI Ministry of Economy, Trade and Industry

MEXT Ministry of Education, Culture, Sports, Science and Technology-Japan

JAEA Japan Atomic Energy Agency

Funding Support to R&D | **Access to R&D Facilities** | **Human Resource Development** | **International Cooperation**

- **Funding Support to R&D (Cost-shared program)**
  - New reactor design concepts
  - Accompanying technologies (e.g. safety, digital technologies, new fuels)
- **Access to R&D Facilities**
  - JAEA experimental facilities, reactors, simulation tools, and databases
- **Human resource development**
  - Supports for industries and academia
- **International Cooperation**

Pursuing Competition among Various Technologies in Japan

- Through NEXIP and other programs, 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

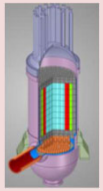
- Sodium-cooled reactor
- Fast neutrons

➡ ✓ 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



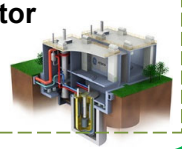
➡ ✓ Heat/hydrogen use
✓ Smaller EPZ

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

International collaboration on FR development

France-Japan collaboration

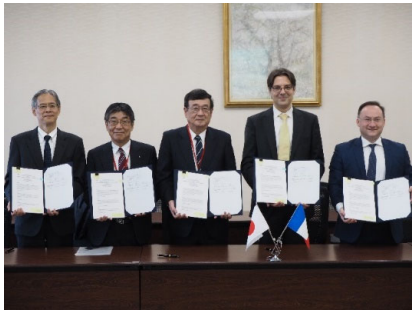
- CEA, Framatome, JAEA, MHI and MFBR: ASTRID collaboration (2014-2019).
  - ✓ 11 design tasks (decay heat removal, above core structure, etc.)
  - ✓ 28 R&D tasks (severe accident, fuel, material, thermal hydraulics, etc.)

Mockup of above core structure

Top view of Core

PLANDTL-2 Sodium experimental apparatus

ASTRID seminar, 10 October 2019



Signature, 3 December 2019

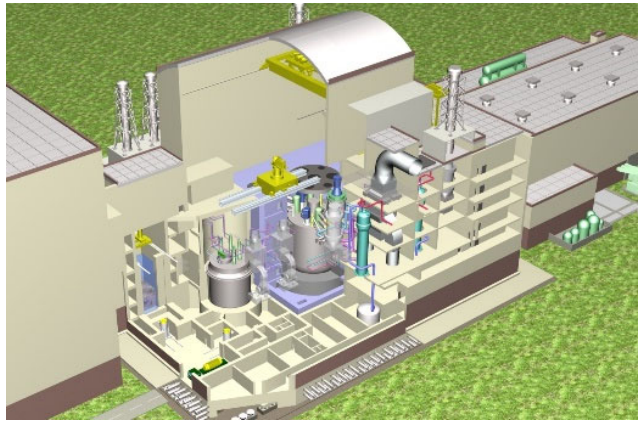
- CEA, Framatome, JAEA, MHI and MFBR have initiated a new collaboration of sodium-cooled fast reactor (end of 2019~)
  - ✓ 32 R&D tasks: Severe accident, Fuel, material, Numerical Analysis Code, etc.

US-Japan collaboration

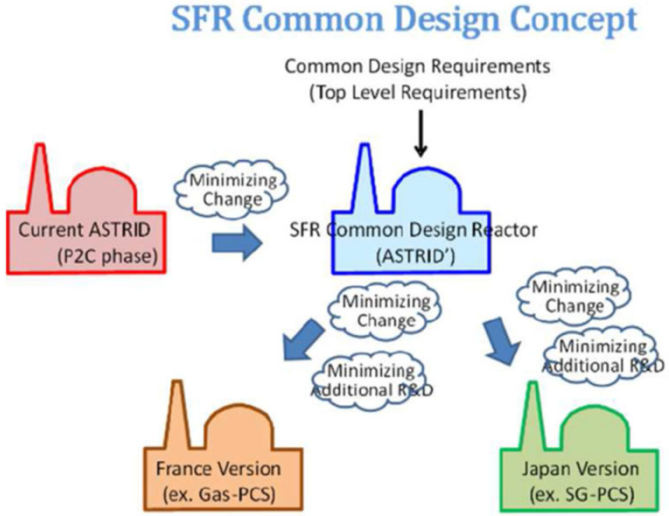
- Terrapower, JAEA, MHI and MFBR singed a MOU to initiate collaboration on sodium-cooed fast reactor in January 26th, 2022.

Design study of pool type 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
  - Electric output: 650MWe
  - Core fuel: MOX fuel, CFV core



Schematic of Japanese pool type reactor

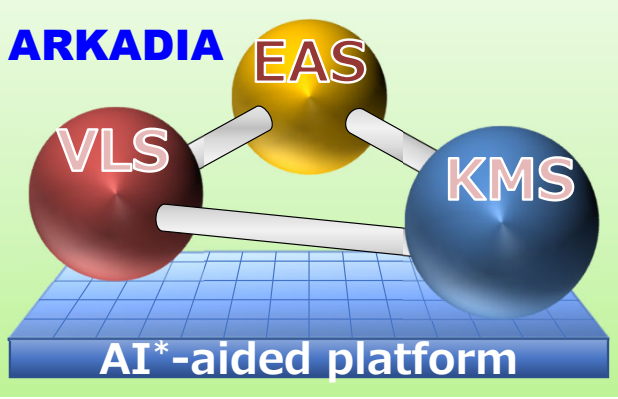


Common design team meeting
(18-19 June 2019, Tokyo Japan)

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

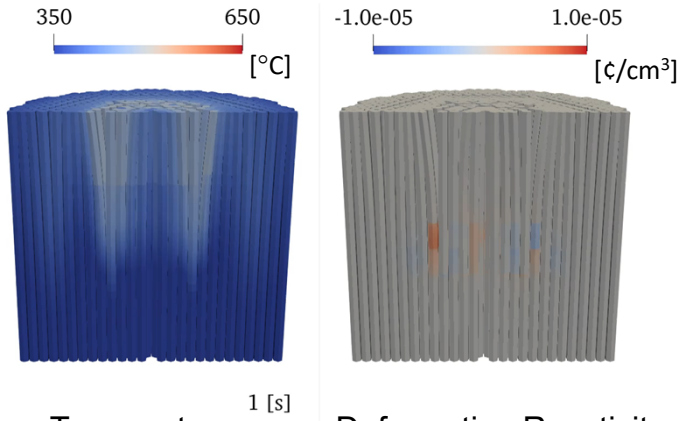
- ❑ Virtual Plant covering its life cycle
- ❑ Knowledgebase of Experiment, Simulation, Design, Maintenance...
- ❑ Design optimization with AI

- ❖ 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)

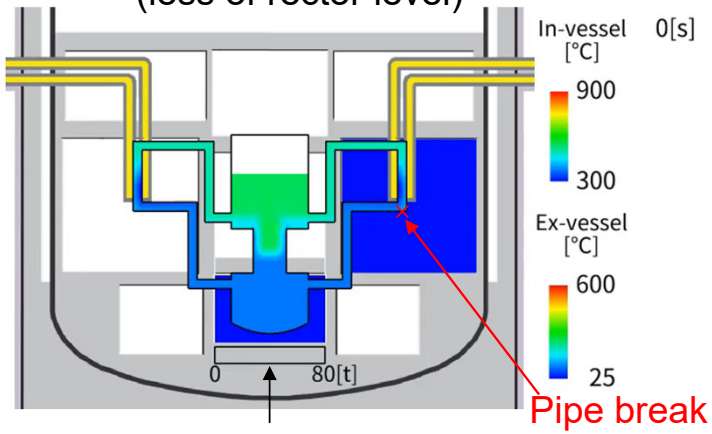


Temperature Deformation Reactivity

ARKADIA-Safety

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

Example SA simulation by VLS (loss of rector level)

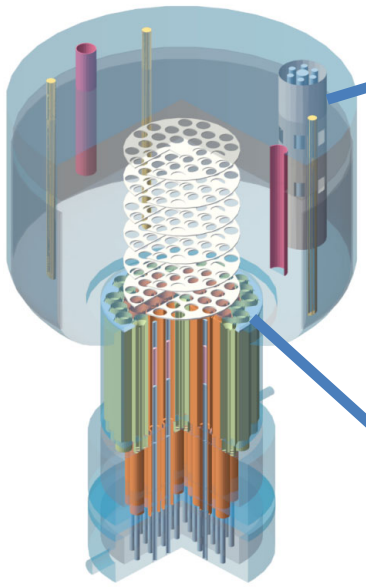


Leaked debris * Severe Accident

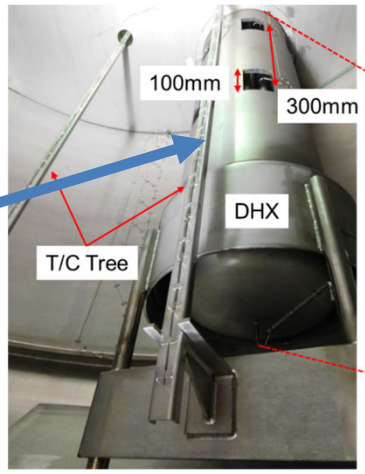
Components of VLS for Design and Safety Evaluations

Simulation of Decay Heat Removal

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



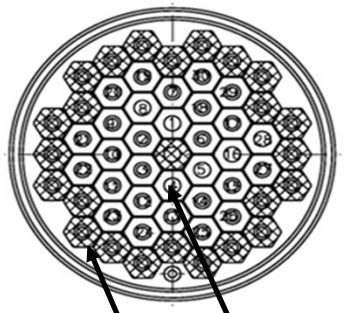
Test Section



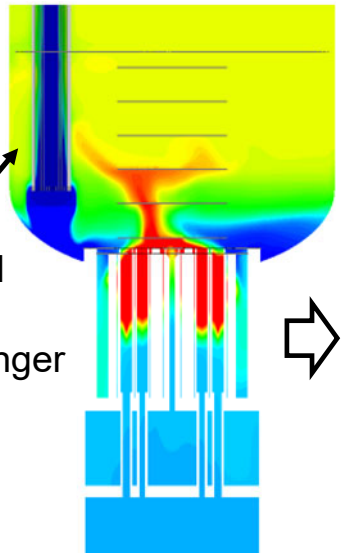
Inside of Upper Plenum

Heat Transfer Tube

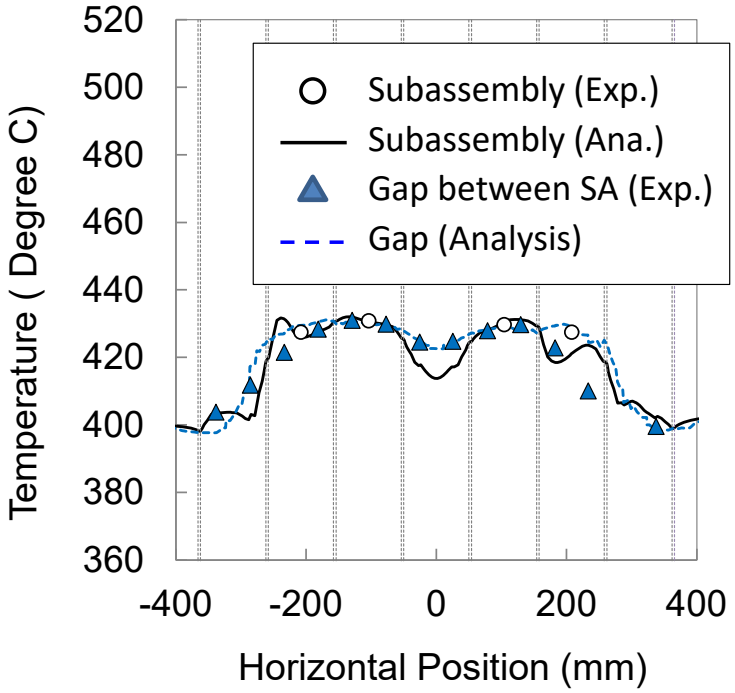
Top of the Simulated Core



Dipped Heat Exchanger (DHX)



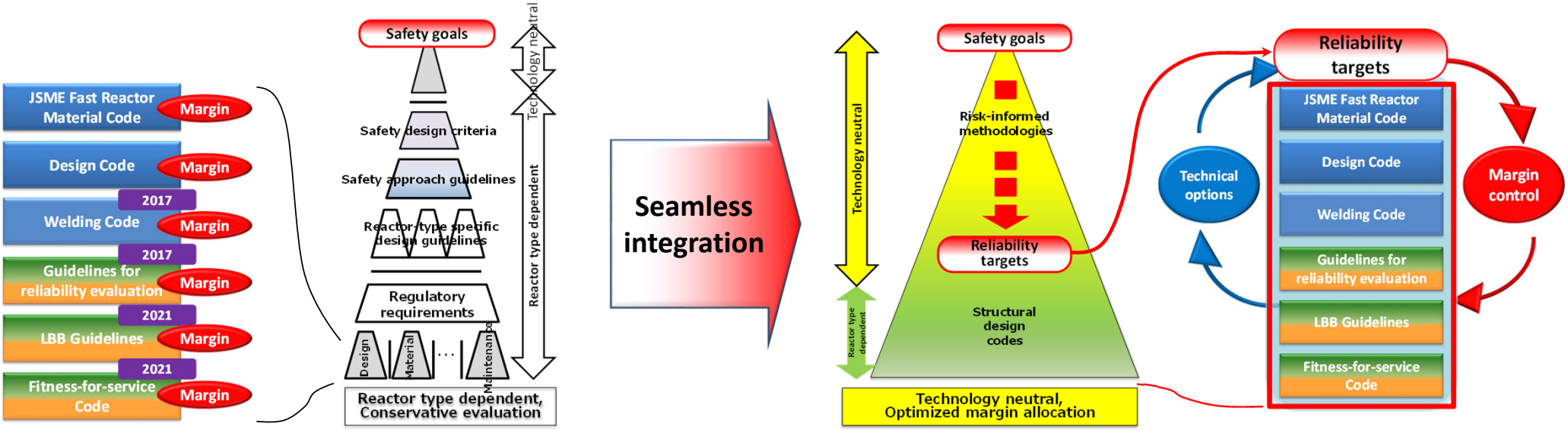
Temperature Contour in RV model



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

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.

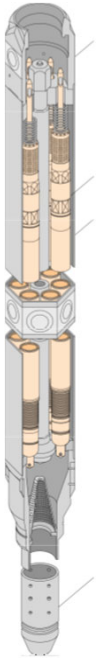


- ✓ Each code is independent and has individual margins
- ✓ Restrictive and relation to safety is unclear

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

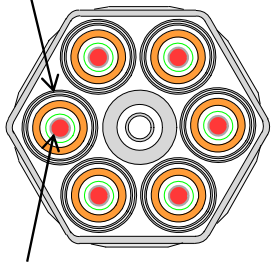
- ASME Boiler and Pressure Vessel Code Section XI Division 2 incorporated reliability targets in the 2019 edition as a first outcome of the collaborative work of JSME and ASME.

Joyo and Neutron Irradiation Experiments

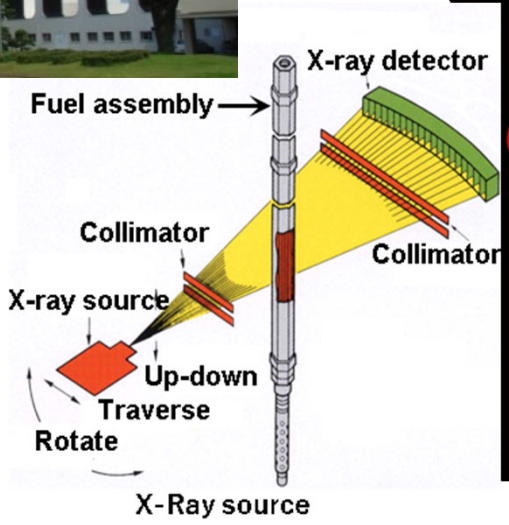


Irradiation Test Subassembly

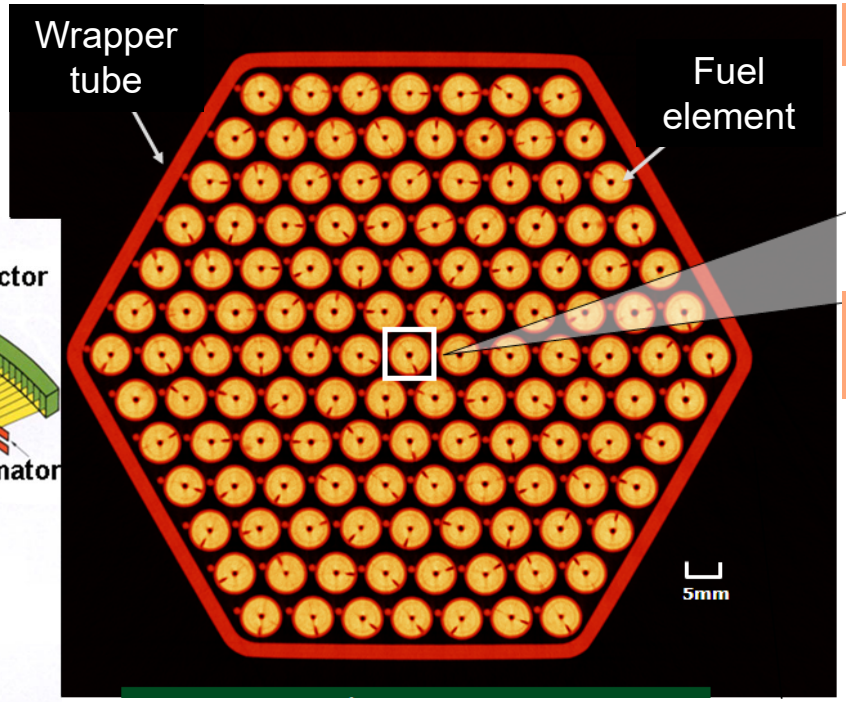
Compartment



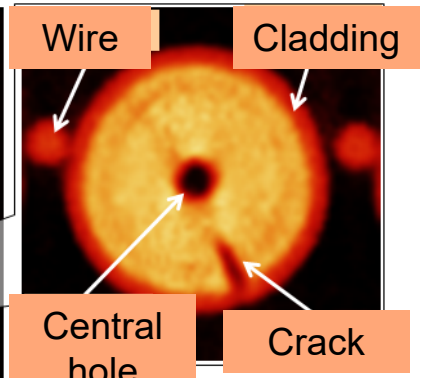
Test fuel pin



Outline of X-ray CT



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

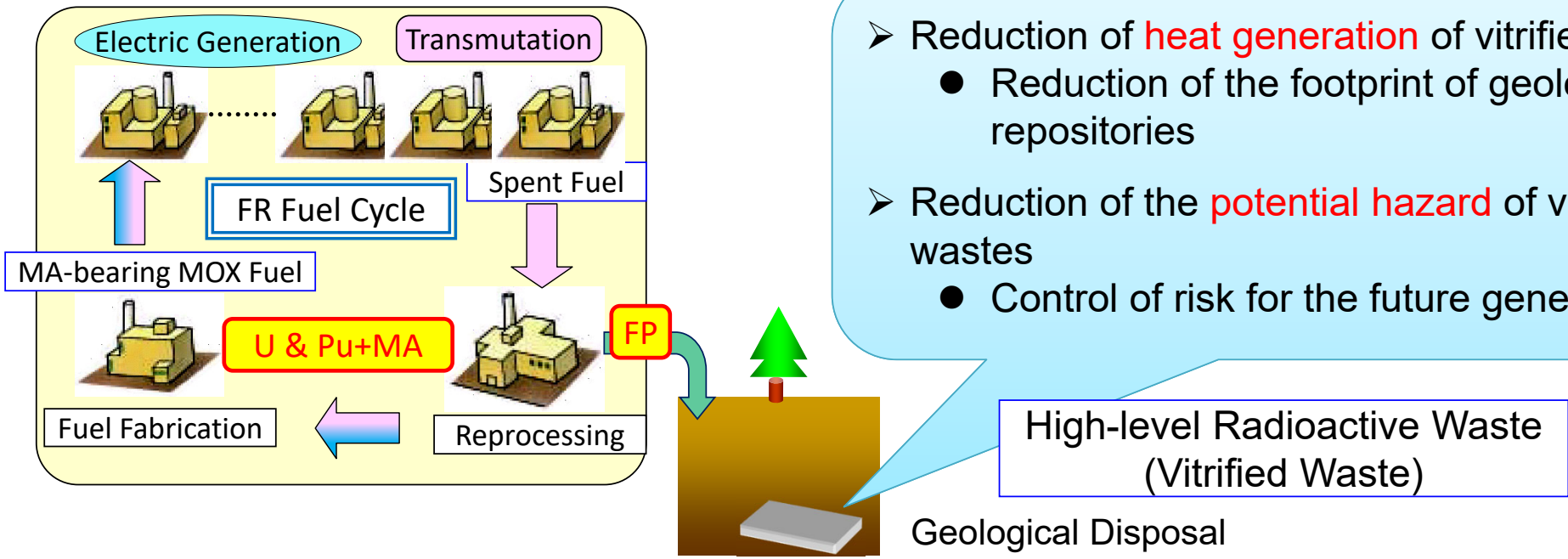


Metallographic examination

Example of post irradiation examination (PIE) of fuel

Targets of FR Fuel Cycle

- **Sustainable energy supply for energy security**
  - The multi-recycling of plutonium maximizes the uranium resource and brings sustainable energy supply.
- **Reduction of environmental burden**
  - Minor Actinide (MA) nuclides can burn in a FR neutron spectrum.
  - TRU nuclides including MAs can be circulated and managed in the FR fuel cycle without discharging them to outside the system substantially.



- Reduction of heat generation of vitrified waste
  - Reduction of the footprint of geological repositories
- Reduction of the potential hazard of vitrified wastes
  - Control of risk for the future generation

R&Ds of FR Fuel Cycle in JAEA

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

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

Chemical Processing Facility

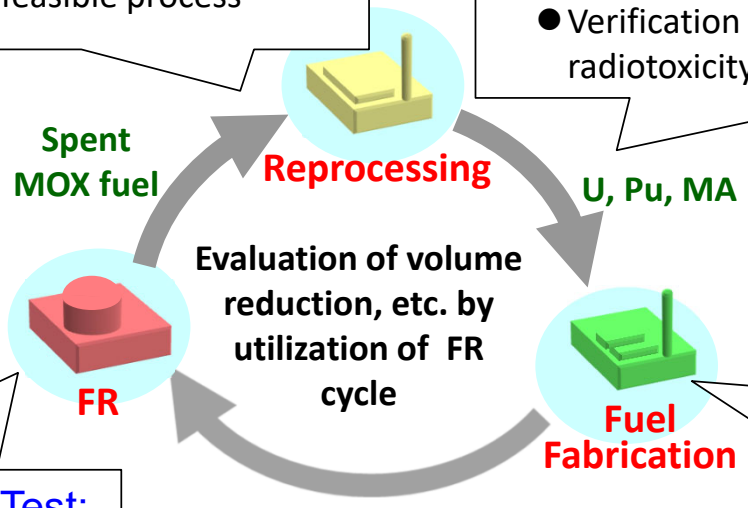
Reprocessing:

- 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 Development & Irradiation Test:

- Systematic irradiation tests of MA-bearing MOX fuel, MOX fuel with degraded Pu isotopic composition.

Fuel Fabrication:

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

Summary

- Policy to develop Fast Reactor and Nuclear Fuel Cycle
- Innovative Reactor Developments through NEXIP and International Cooperation
- SFR Development in Japan
  - Design study: Pool type reactor with a 3D seismic isolation system
  - ARKADIA: Simulation/ Knowledgebase/ Design assistance for plant life cycle design
  - Codes and Standards: Risk-informed methodologies, contributions to JSME and ASME
  - Joyo: Irradiation experiments and PIE facilities
  - Fuel Cycle with Minor Actinides

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” ensured to JAEA by the Ministry of Economy, Trade and Industry in Japan (METI).