Fast Reactor and HTGR Developments in Japan

Nuclear Innovations for Carbon Neutrality

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History of Fast Reactor Cycle Development in Japan

October 2021: 6th Strategic Energy plan

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

2020

2018: 5th Strategic Energy plan

2010

2011: East Japan Great Earthquake

2005: National Policy for Nuclear Energy

Commercialization in 2050

2000

1994:
Monju first criticality

1990

1977:
Joyo first criticality

1980

1970

1966:
Basic Policy on Power Reactor Development

2018:
Strategic Roadmap of FR development

2016:
Fast Reactor Development Policy

2006–2011 (~pending):
FaCT project

FaCT : Fast reactor Cycle Technology development

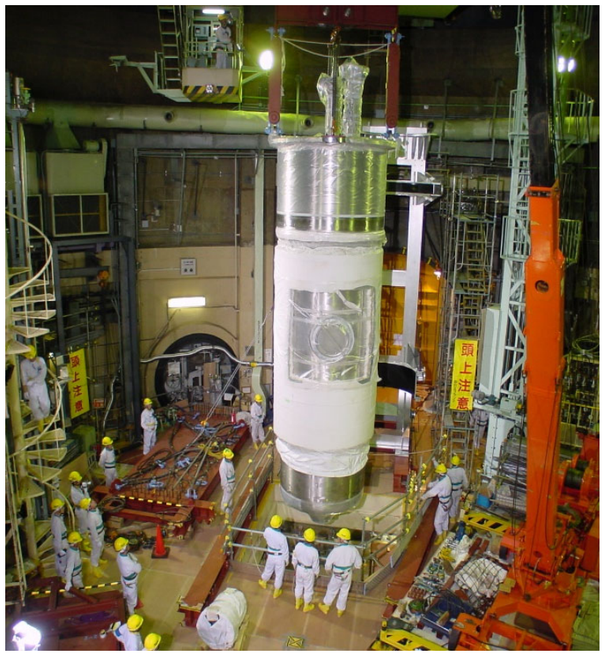
1999–2006:
Feasibility study on Commercialized fast reactor cycle systems

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

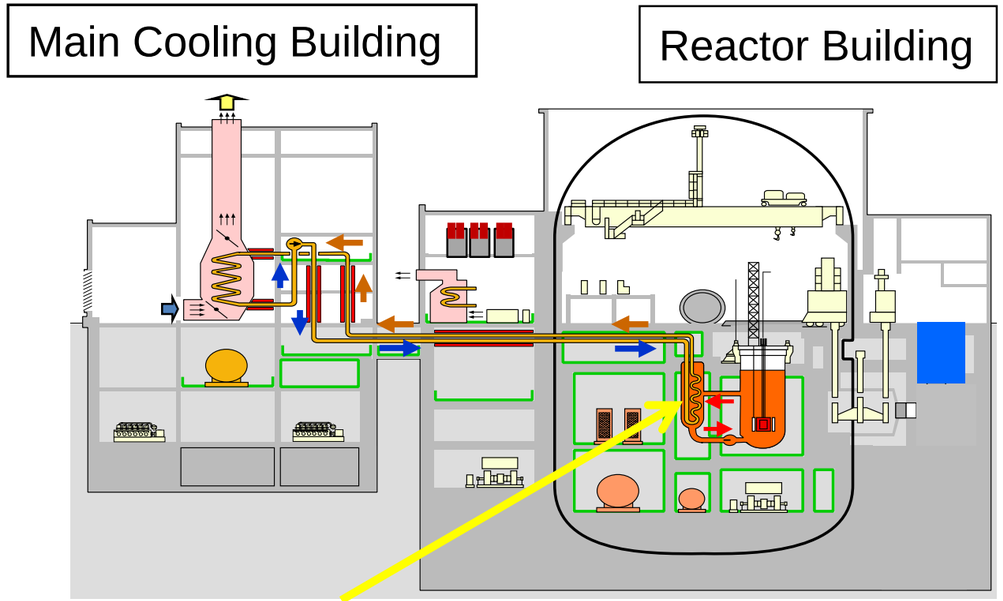
Independent development
Promote the development of experimental and prototype reactors.

Component Development: IHX exchange for Joyo Mk-III

Lift up of old IHX



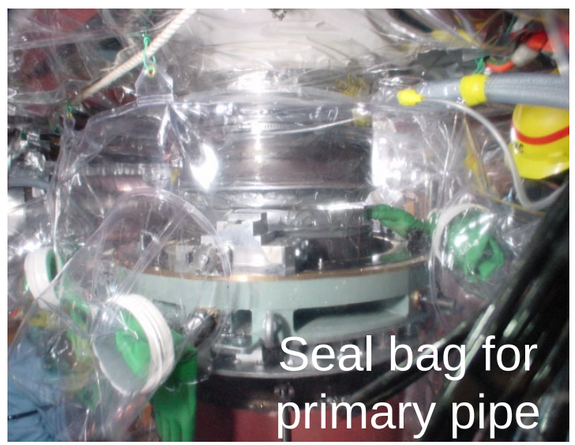
Installation of new IHX

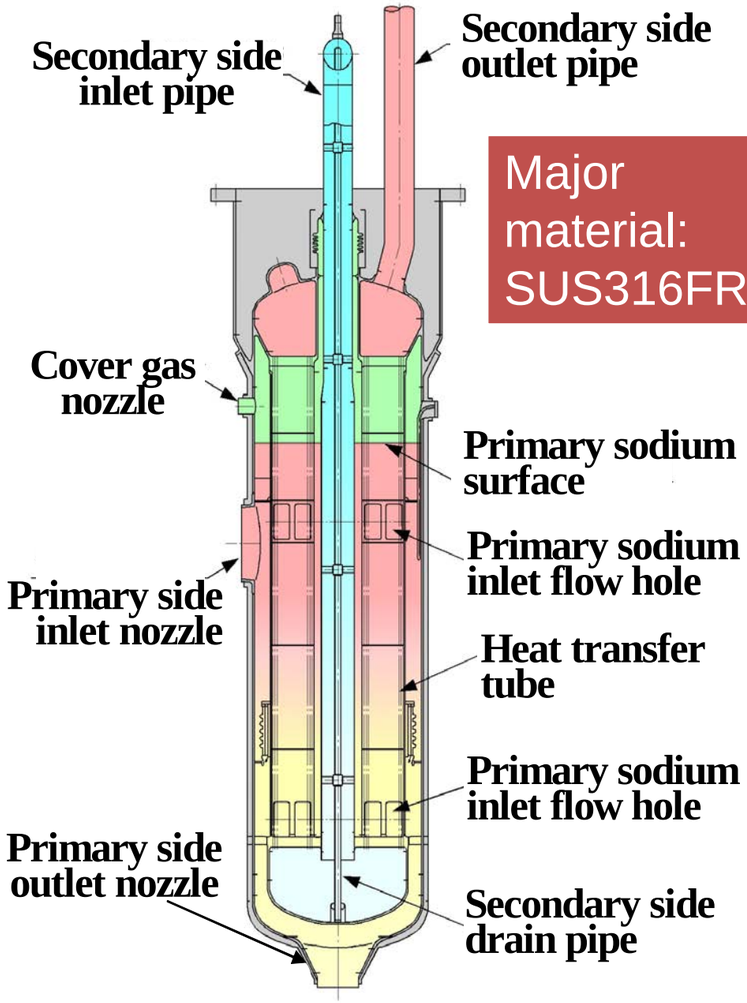


Replacement of Intermediate Heat Exchanger (IHX) in 2001

Management Points

- Radiation control
- Sodium purity control
- Cover gas pressure control





New IHX (50 → 70 MW)

NEXIP Initiative

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**
  - Versatile Test Reactor, Civil Nuclear Energy Research and Development Working Group

CNWG Structure

Civil Nuclear Energy R&D Working Group (CNWG)

Secretariat

Advanced Reactor R&D Sub-WG

- Fast Reactors
- High Temperature Reactors
- Metal-Fueled Fast Reactor Accident Analysis

Light-Water Reactor R&D Sub-WG

- Severe Accident Code Assessment
- Accident Tolerant Fuels
- Probabilistic Risk Assessment
- Material Aging
- Examination of Fukushima Daiichi Reactors for Improvement of Nuclear Safety

Fuel Cycle R&D and Waste Management Sub-WG

- Separations
- Advanced Fuels
- Waste Management
- Waste Treatment and Electrochemical Reduction

JAEA's FR Cycle R&D Facilities and Efforts on R&D

Sodium Test :

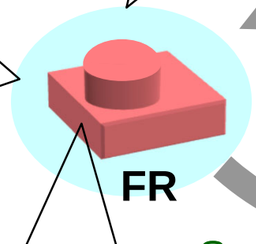
- Demonstration of Large Sodium Component

Fuel Fabrication:

- Remote MA-bearing MOX fuel fabrication technology
- Establishment of feasible fuel fabrication process

Reactor Characteristics & Reactor System:

- Feasibility confirmation of FR plant technologies
- Acquisition of characteristics of MA; nuclear physics and transmutation



Fuel and Core Material Development & Irradiation Tests:

- Systematic irradiation tests of MA-bearing MOX fuel, high Pu-contents MOX fuel, etc.
- Development of the long-life core materials such as ODS steel cladding tube

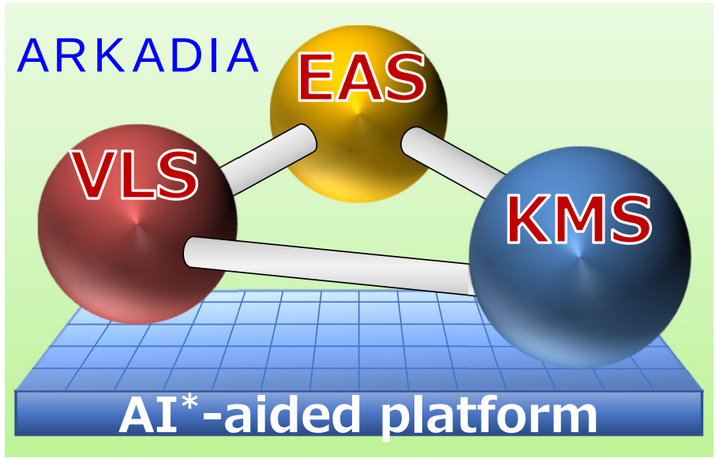
Reprocessing:

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

FMF: Fuel Monitoring Facility

ARKADIA as a Digital Triplet

- 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

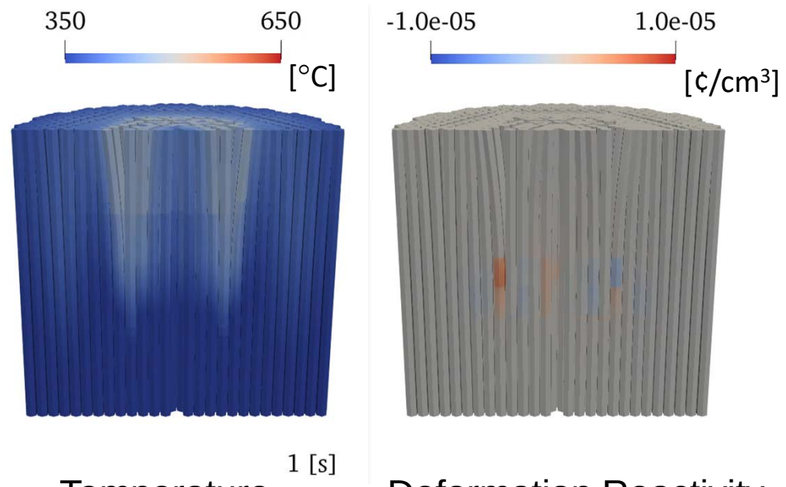
- Virtual Plant covering its life cycle
- Knowledge base of Experiment, Simulation, Design, Maintenance...
- Design optimization with AI

- 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)

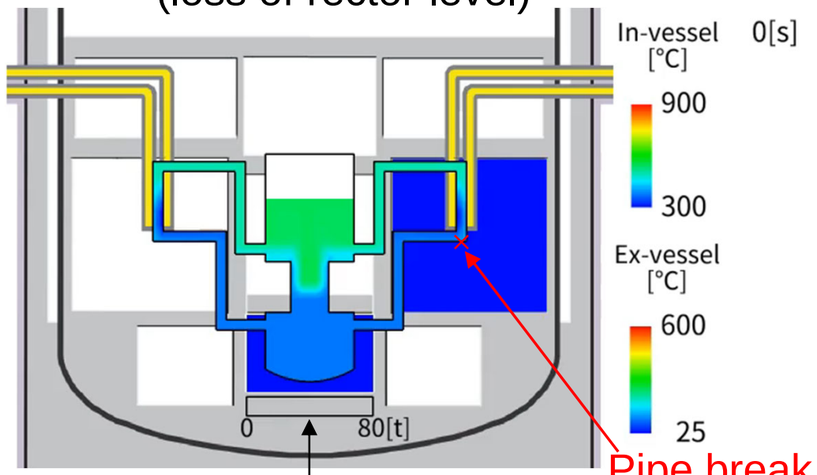


Temperature　Deformation Reactivity

ARKADIA-Safety

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

Example SA simulation by VLS
(loss of rector level)

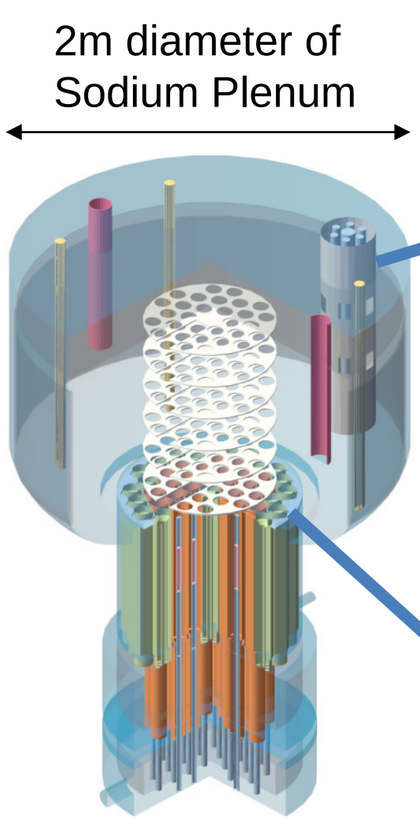


Leaked debris　* Severe Accident

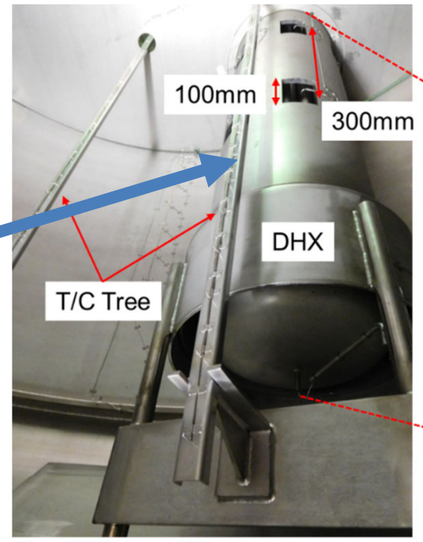
Components of VLS for Design and Safety Evaluations

Simulation of Decay Heat Removal

- Validation experiment using PLANDTL-2: Test section was modified to simulate a core of SFR.

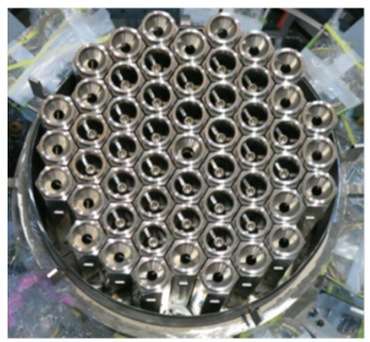


Test Section

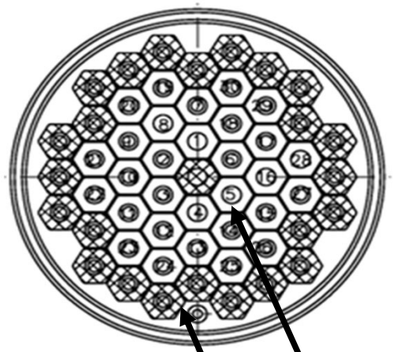


Inside of Upper Plenum

Heat Transfer Tube

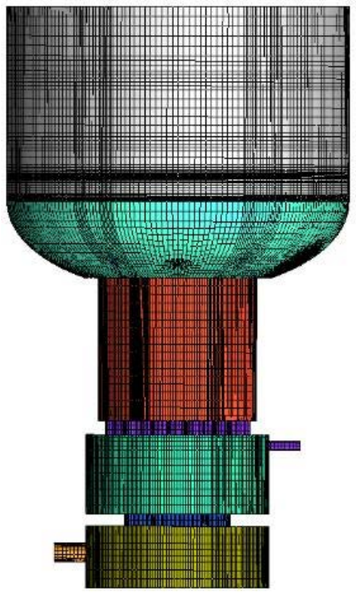


Top of the Simulated Core

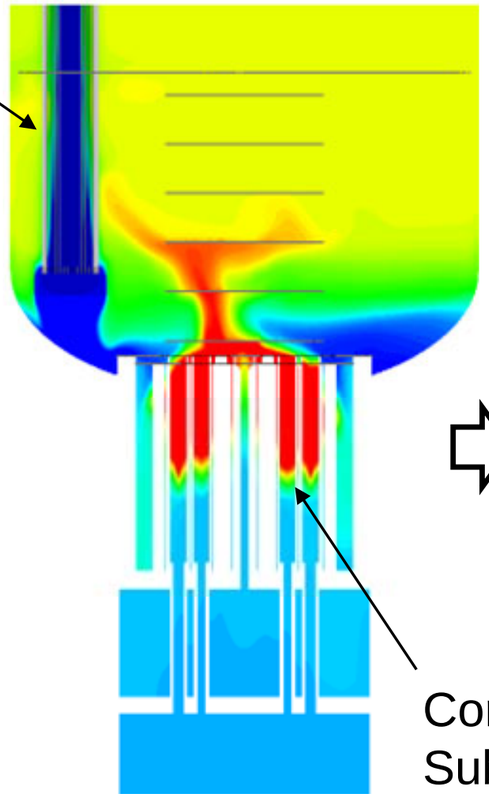


- Temperature distribution across the core is flatten due to Buoyancy force in case of decay heat removal using Natural Circulation.
- It is crucial for a simulation to consider such effect on the highest temperature in the core.
- Sodium experiment using PLANDTL-2 has been carried out for the code Validation.
  - ✓ Core - hot plenum thermal interaction
  - ✓ Multiple rows of core to see Inter-wrapper flow (gap between subassemblies)
  - ✓ Temperature distributions obtained from 500 of thermocouples

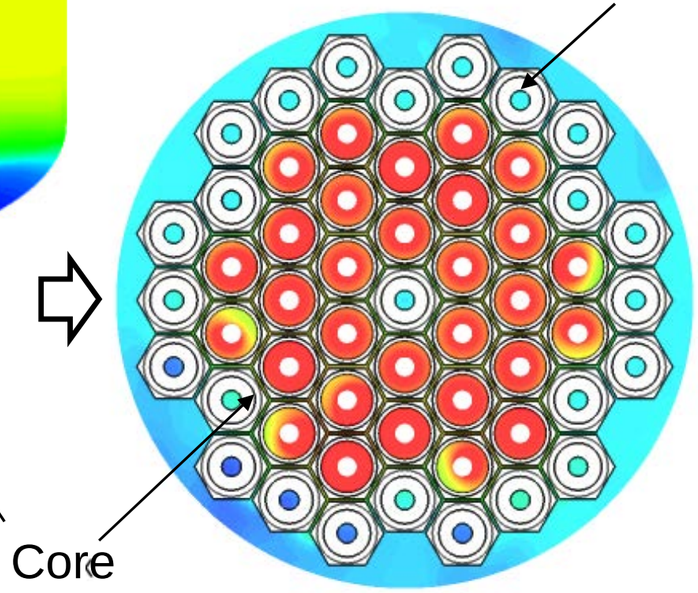
Experimental Analysis on PLANDTL-2 (DHX Operation)



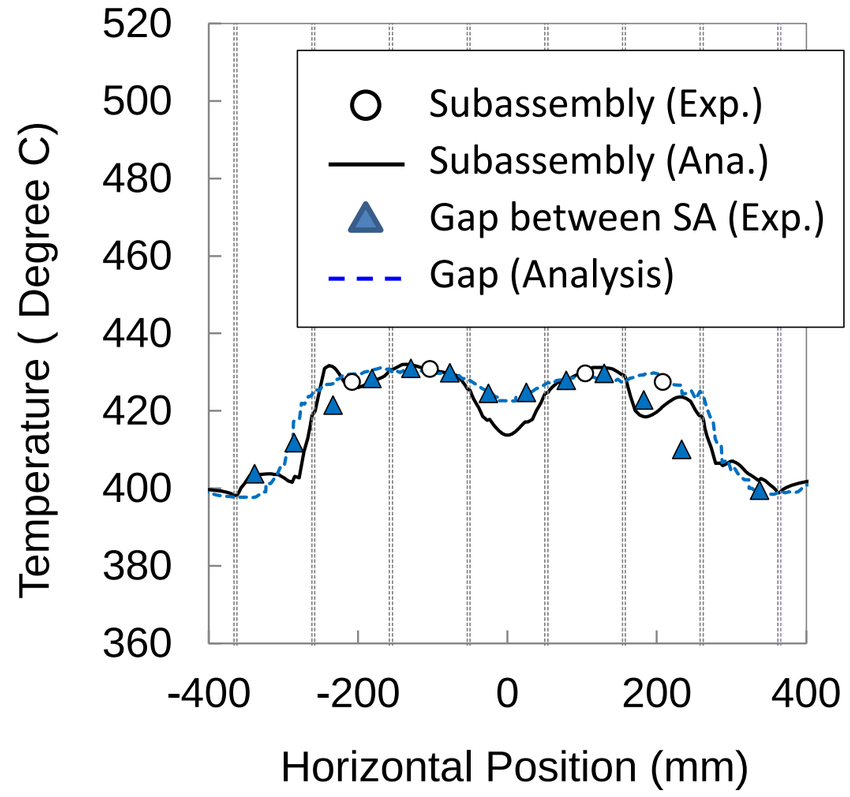
Analysis model
(FLUENT code)



Temperature Contour
in RV model



Temperature Contour
at Core Outlet



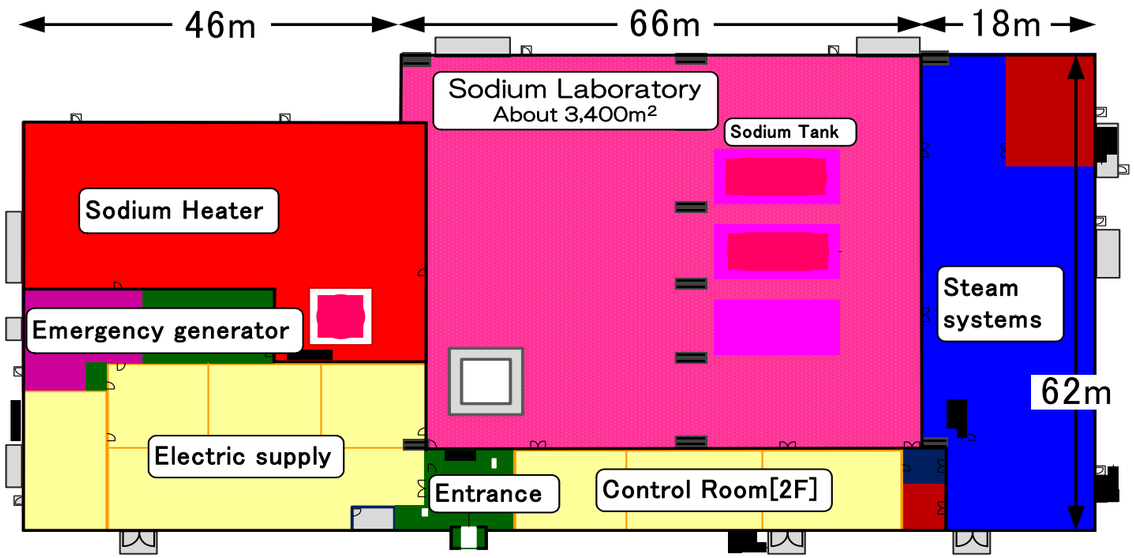
Comparison of Temperature
Distributions along the core outlet
between Exp. and Analysis

AtheNa Facility of Sodium Tests

The Large Scale Sodium Test facility for the Component development & demonstration

Facility Specification

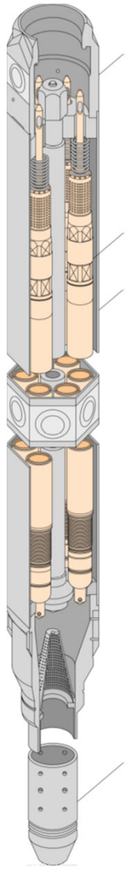
- Dimension: 130 m x 62 m x 55 m (H)
- Cranes: 120 & 100 ton
- Sodium inventory: 240 ton
- Temperature range: ~600°C
- Sodium heater: 60 MW at maximum

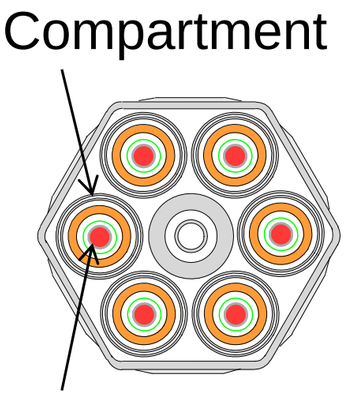


Layout of AtheNa facility

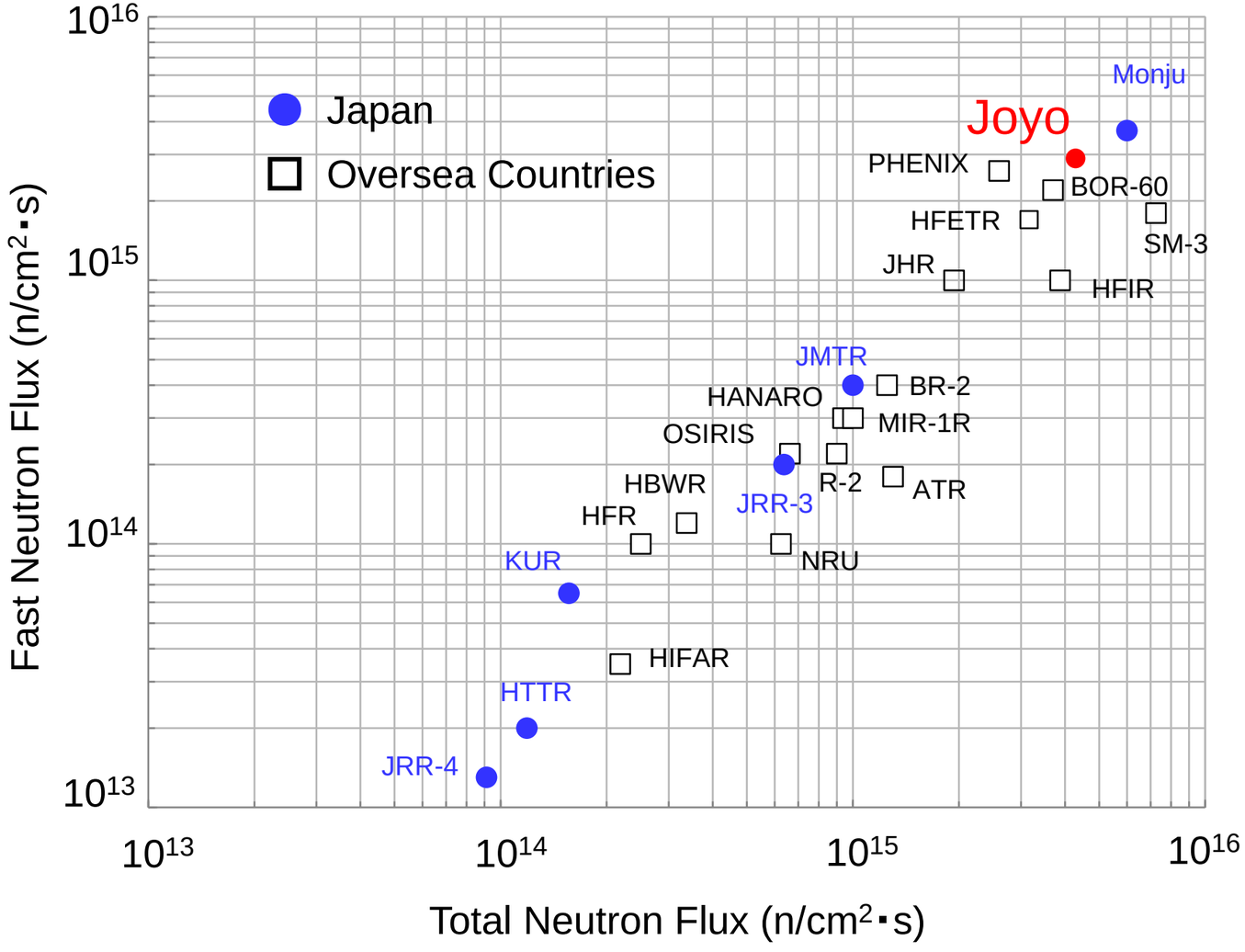
- ***"Mother loop"*** is available for utility functions, such as sodium storage, charge, drain, and purification. Construction of the sodium heater is on going.
- Expected test items in AtheNa
  - ➢ Safety related experiments,
  - ➢ Component development and demonstration
    - ✓ Various types of Heat Exchanger, SG, Pump, etc.
      - Verifying heat transfer, flow stability...

Joyo and Neutron Irradiation Capability





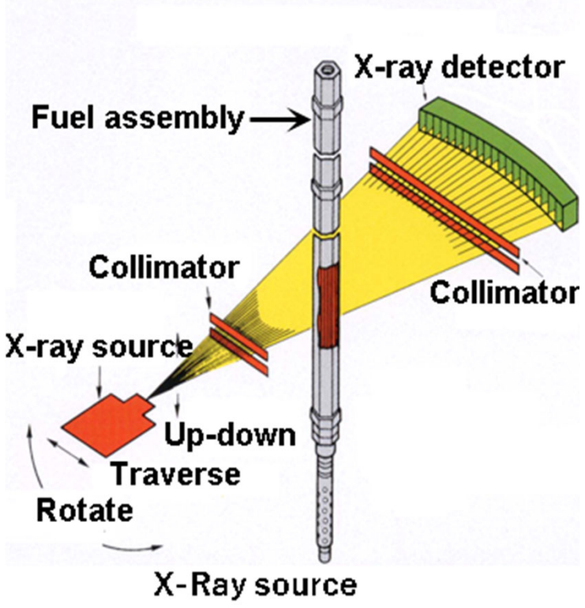
Irradiation Test Subassembly



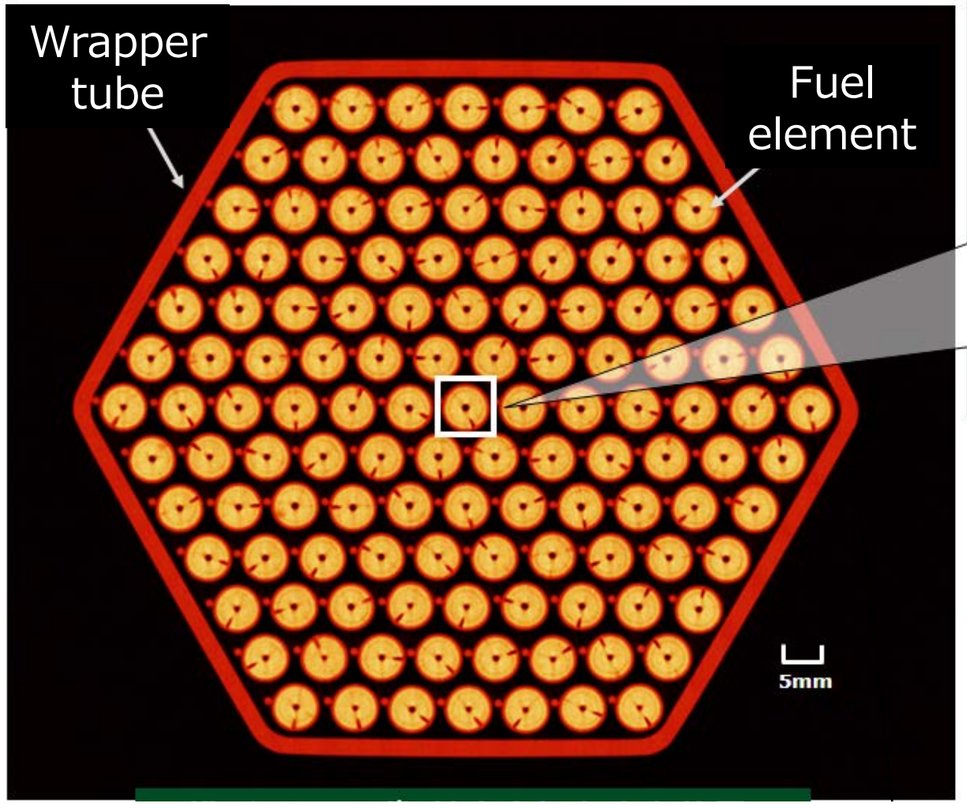
Neutron irradiation Reactors in the world

Post Irradiation Examination in Oarai

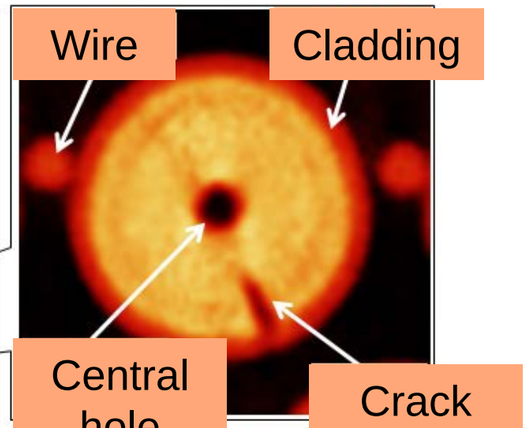
- Advanced post irradiation technology (X-ray CT)
- Heavy element surface analysis by EPMA

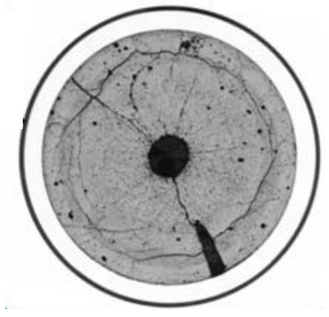


Outline of X-ray CT

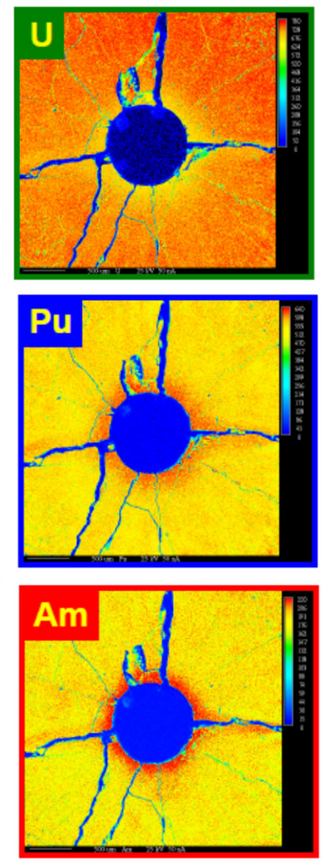


Cross-section image of fuel assembly by X-ray CT





Metallographic examination



EPMA for a fuel with Am 5%, 24h irradiation

Example of post irradiation examination of fuel

Nuclear and Renewable Hybrid Energy System (NR-HES)

■ Development Goals NR-HES

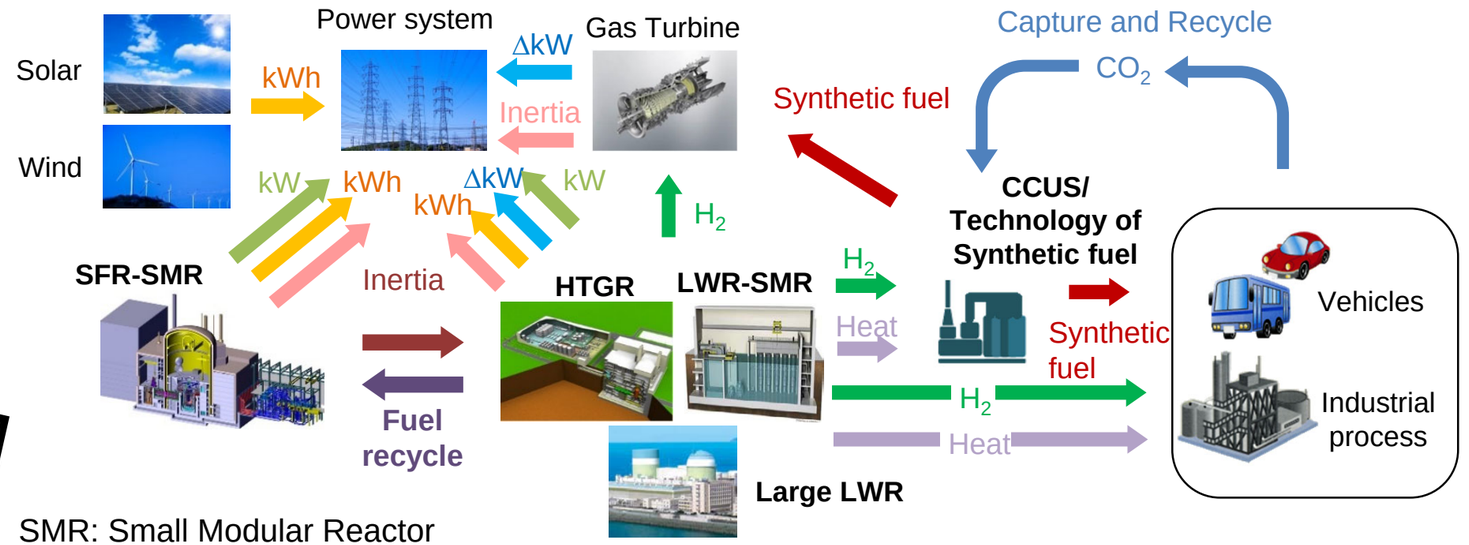
- Energy supply security & reliability
- Carbon neutrality
- Major role for renewable energy
- Safe and sustainable nuclear energy

1) MEXT funded research (2020-2023)

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

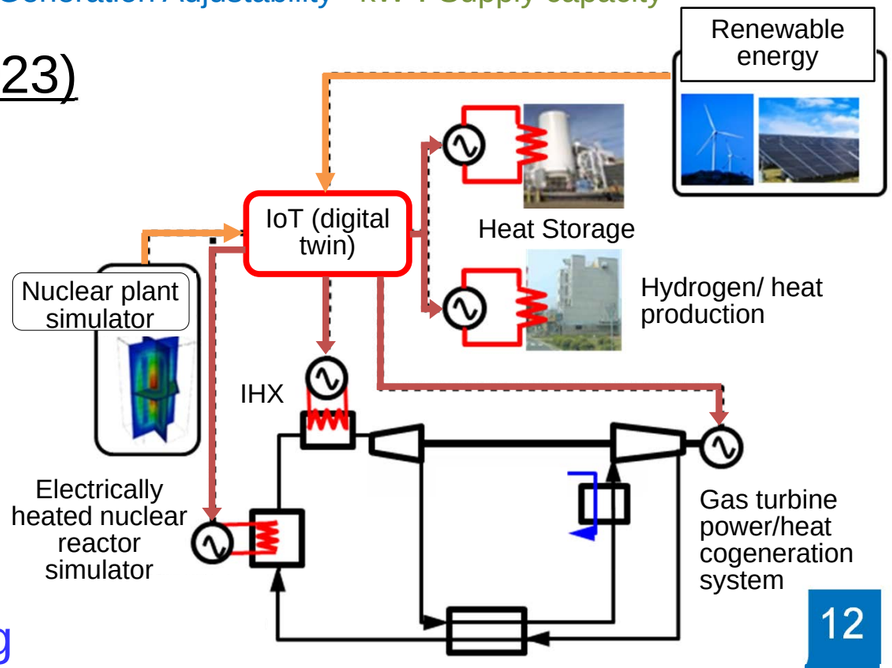


2) METI funded research (2021-2023)

Demonstration Test :

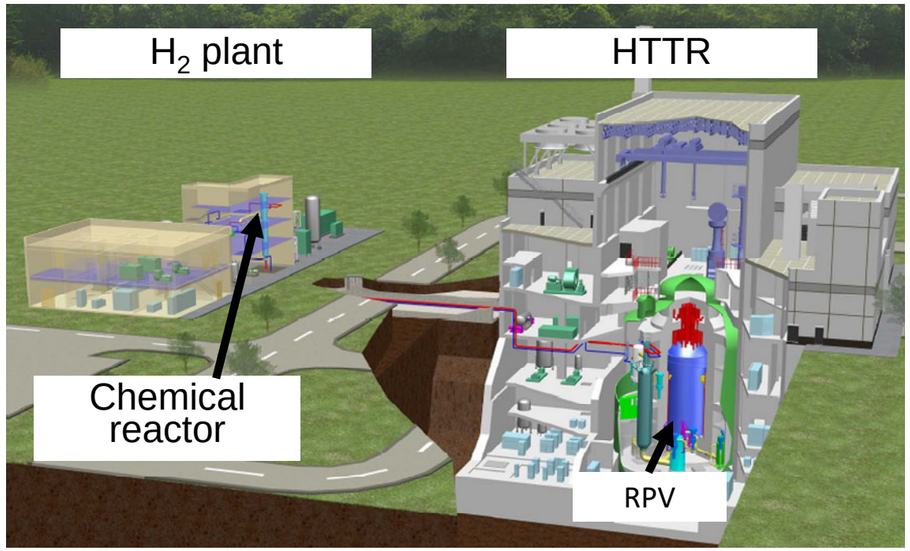
- ✓ Integrated system : power, heat storage, H2, renewable energy
- ✓ Nuclear reactor operation safety and flexibility
- ✓ IoT (digital twin) to monitor, forecast and optimize production

To assist in design and licensing



Restart of the HTTR and future test plans

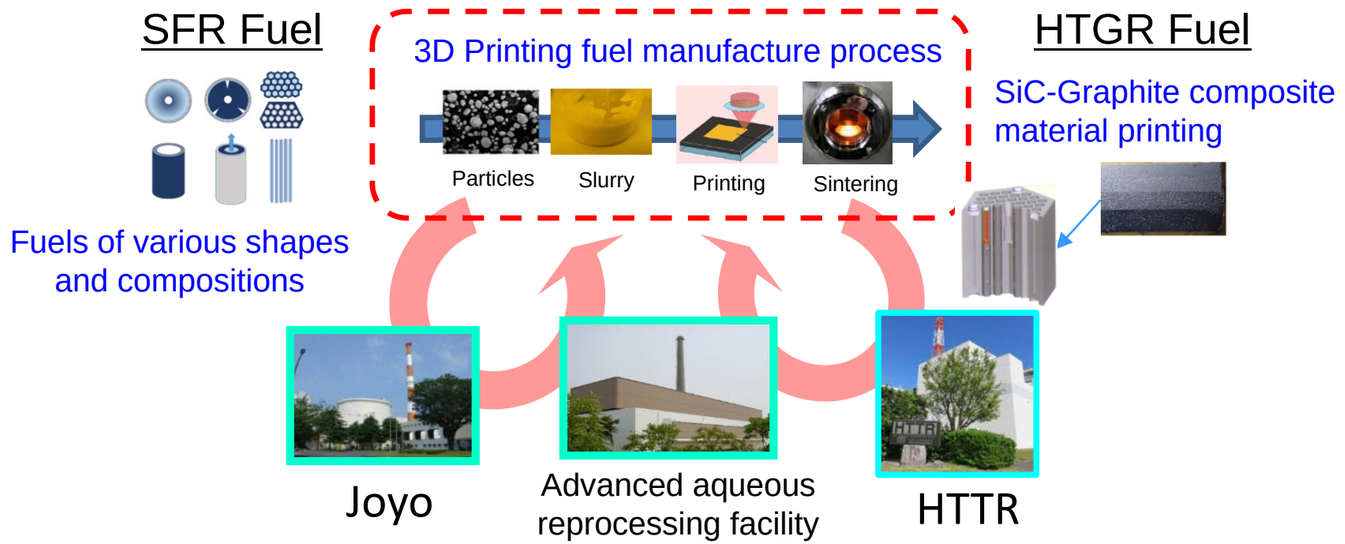
- JAEA restarted the HTTR in July 2021
- Future test plans by the HTTR
  - OECD/NEA LOFC Project (safety demonstration test)
  - Other operation tests (safety, core physics, fuel performance, components reliability, etc.)
  - HTTR-heat application test (hydrogen production) to establish safety design 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

3D Printing Ceramic Fuel Technology

■ Development Goals :
- Fuel cycle synergy for SFR and HTGR
- Enable advanced fuel features
- Enhance safety and economics

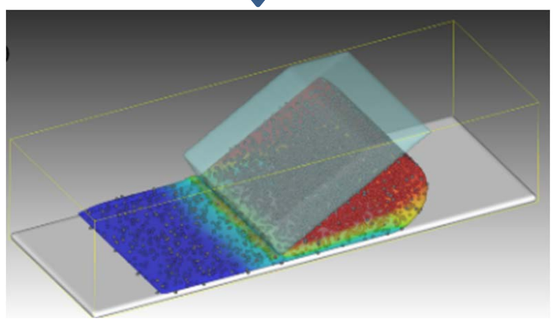


<u>MEXT funded research (2021-2023)</u>

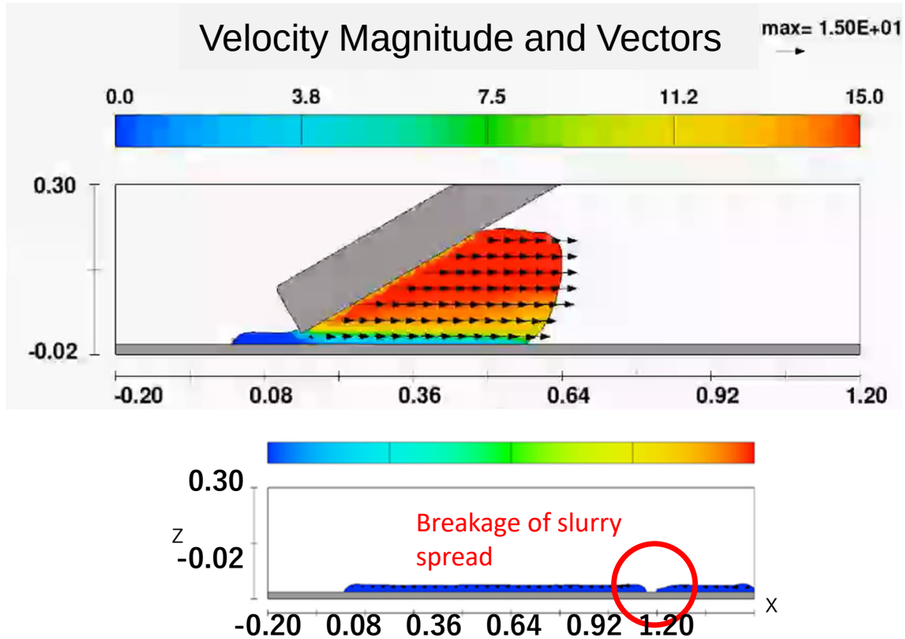
3D Printing CAE Simulation V&V (Computer-Aided Engineering)

- ✓ 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



Remarks for Cooperation

- Projects related to SFR in US: VTR and “Natrium”
- Design assistance tool and Infrastructures
  - ARKADIA: Simulation/ Knowledgebase/ Design assistance for Plant life cycle design
  - AtheNa: Sodium experiments and Large scale infrastructure for Component Demonstration
  - Joyo: Irradiation experiments and PIE facilities
  - HTTR restarted: LOFC Safety test, Safety design and regulation for a coupling technology between heat application and nuclear reactor
- Innovative challenges
  - Next generation energy system with DX: Nuclear, Renewable, Hydrogen and Heat storage
  - Advanced nuclear fuel fabrication by 3D-Printing