Safety research in JAEA after the Fukushima Daiichi Nuclear Power Station accident and current status of USNRC-JAEA cooperation and expectations for the future

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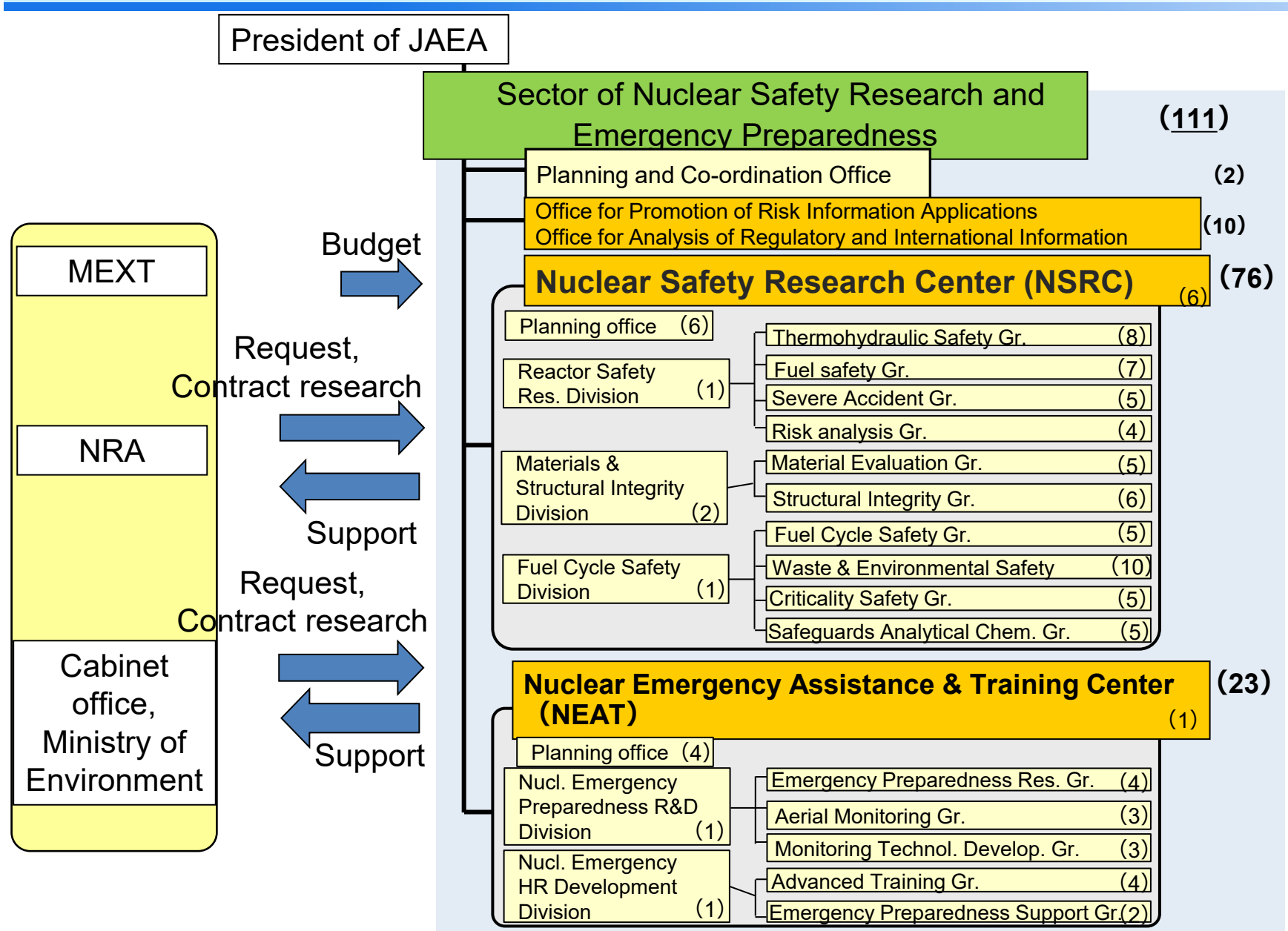
Organization of the sector



Collaboration within JAEA

- Sector of Fukushima Research,
- Sector of Nuclear Science Research
- Sector of Fast Reactor and Advanced Reactor R&D

Cooperation

OECD/NEA, IAEA, regulatory bodies, research organizations, universities, etc.

※(Number of staff)

NSRC: Nuclear Safety Research Center

Safety Research for Regulatory Application

Objectives:

- ✓ Contribute to continuous enhancement of nuclear safety
- ✓ Establish technical bases for regulatory decision-making, safety review guides, technical standards, etc. to technically support the safety regulation for LWRs and relating fuel cycle and radioactive waste management

Safety Researches:

- ✓ Requested by Nuclear Regulation Authority (NRA) and the relevant ministries and agencies
- ✓ To deepen fundamental understanding on safety issues
- ✓ To improve techniques for experiments, measurements, numerical analysis, chemical analysis, etc. for the future safety study

Budget:

- ✓ Supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT) for general safety research and NRA for specific researches, etc.

Research directions after Fukushima Daiichi Nuclear Power Station accident

The accident at FDNPS (TEPCO)

Lessons learned

Severe Accident Prevention
- Design basis accidents
- Prevention of core melting under beyond design basis accidents

Severe Accident Evaluation
- Core melting
- Vessel failure
- Release of radioactive materials

Environmental / Radiation Assessment
- Exposure of public
- Nuclear Emergency Preparedness

Enhancement of researches on external events:
large-scale natural events (earthquake, tornado, etc.), aircraft crash, etc.

Prioritizing of research

- Contribution to “Continuous improvement toward the highest standards of nuclear safety that is rationally achievable“

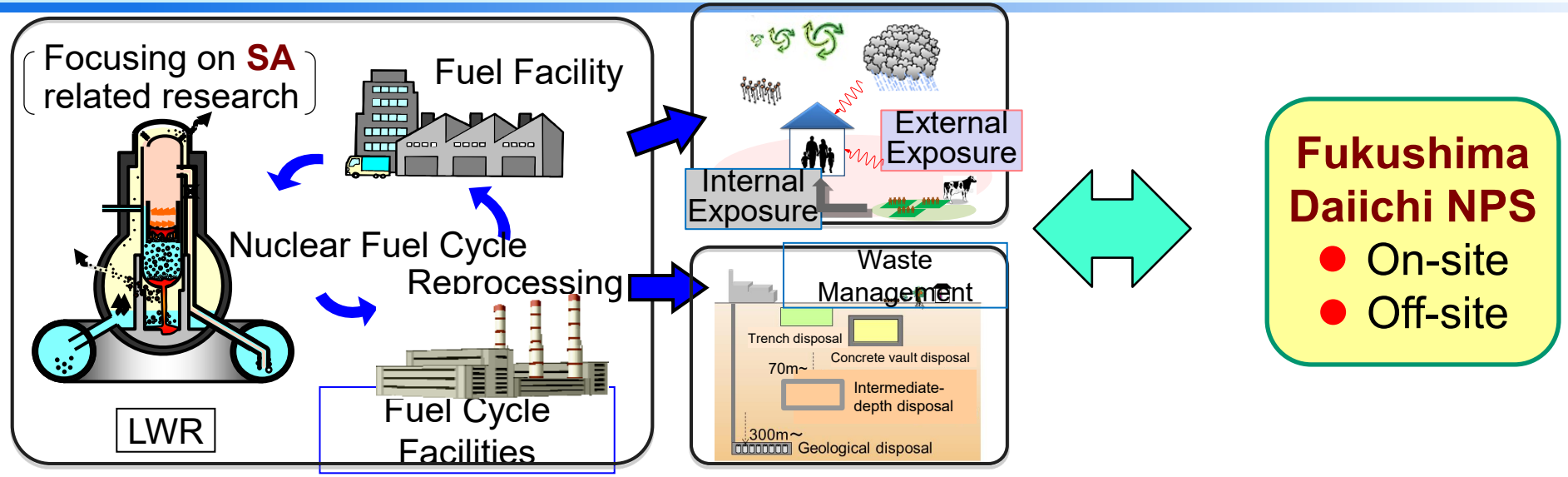
FDNPS (TEPCO)
Decommissioning, environmental reclamation

- Review of previous researches focused on design-based events
- Prioritizing of research on evaluation method of severe accidents and external events to decrease the risks of nuclear facilities

- Contribution to the decommissioning, environmental reclamation, and waste management of the FDNPS
- Contribution to the Study Group on Accident Analysis of the FDNPS by NRA

Contribution to rule-making process corresponding to the new regulatory standards and to validation of measures taken by nuclear operators

Themes of Safety Research

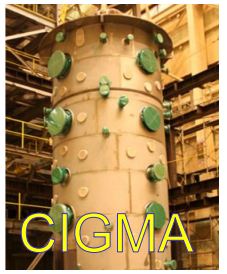


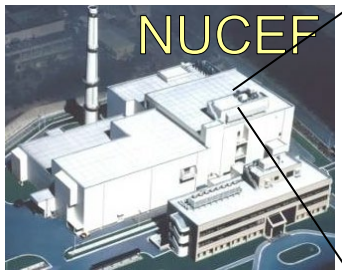
Fukushima Daiichi NPS
- On-site
- Off-site

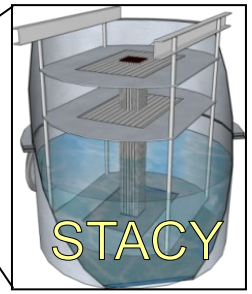
Research Fields

- Probabilistic Risk Assessment (PRA)
- Severe Accident
- Emergency Preparedness & Response
- Fuel Safety
- Thermohydraulic Safety
- Material Degradation & Structural Integrity
- Safety of Fuel Cycle Facilities
- Criticality Safety
- Safety of Radioactive Waste Management
- Safeguards Environmental Sample Analysis

Major Facilities in JAEA for Safety Research







Direction of future efforts (1/2)

— Basic policy —

- To propose highly rational measures for ensuring safety and regulation **using risk information**, etc. to regulatory body, and create **high-quality research results aimed at implementation in society**.
  - Publication and dissemination of analysis codes developed by JAEA
  - Support for the development of scientific and rational technical standards based on JAEA's research results

- **Maintain and expand the function as a technical support organization (TSO)** for the Nuclear Regulation Authority (NRA)
  - Functioning as a platform for industry-academia-government experts on nuclear safety research from Japan and over the world

Direction of future efforts (2/2)

Support rational regulation by utilizing comprehensive risk information

Cross-cutting issues

❑ Practical research aimed at establishing a decision-making process that utilizes risk information

- **Office for Promotion of Risk Information Applications**
- **Office for Analysis of Regulatory and International Information**

NSRC

To contribute to ensuring the safety of nuclear energy utilization through **support for nuclear regulation**

- ❑ **Improvement of risk assessment technology** and reduction of uncertainty in each individual field
- ❑ **Emergency response** research for optimizing protection strategies
- ❑ **Aging research** using actual equipment that contributes to the judgment of long-term operation of existing plants
- ❑ **Radioactive waste disposal research** for medium-depth disposal performance / safety evaluation, etc.

NEAT

As a designated public institution, to contribute to **the response to nuclear disasters and the strengthening of disaster prevention systems**

- ❑ **Utilizing monitoring technology** developed in environmental safety research after the accident at FDNPS for nuclear disaster response
- ❑ Promote research to support **effective wide-area evacuation** and **protective measures**
- ❑ **Strengthen the disaster prevention system by human resources development** based on the lessons learned from the accident at FDNPS

Current status of cooperation between NRC and JAEA

"Memorandum of Cooperation between the JAEA and the USNRC in the Field of Nuclear Safety Research"

- Dec. 26, 2017-Dec. 26, 2022
- Areas for Cooperation in the area
  1. Thermal-hydraulic safety of LWR (Light Water Reactor)
  2. LWR severe accident research
  3. LWR fuel safety
  4. Structural integrity assessment and materials degradation
  5. Offsite consequence assessment and its application for emergency planning
  6. Criticality safety/accident evaluation

- Activities so far
  - Benchmark studies on PFM (Probabilistic Fracture Mechanics)
  - Participation to CSARP (Cooperative Severe Accident Research Program) meetings
  - Acceptance of Mansfield Foundation fellow to the NSRC (2019)
  - Cooperation under OECD/NEA framework (BSAF, PreADES, ARC-F (on Fukushima), FIDES, etc.)

For further cooperation

Potential areas for cooperation items are

- External events (earthquakes, tsunami, flooding, etc.)
- PRA (Level 3 PRA) and health effect models
  - Non-radiological health consequences from protective action
  - Emergency Response and preparedness based on residents' perspective
- Safety evaluation of ATF (Accident Tolerant Fuel)
- Collaborative research utilizing JAEA facilities (NSRR, STACY, CIGMA), etc.
- Dispatch of personnel
- Cooperation under OECD/NEA framework (FACE, HERA/FIDES, etc.)
- Possibility of cooperation with national laboratories under DOE

Main facilities for safety research at JAEA

LWR research

- SA/Risk assessment
- Fuel ・TH
- Material degradation/Structural Integrity

Fuel

Nuclear Safety Research Reactor (NSRR)

Reactor Fuel Examination Facility (RFEF)

TH

Containment InteGral Measurement Apparatus (CIGMA)

Large Scale Test Facility (LSTF)

Nuclear fuel cycle

- SA/Risk assessment
- Criticality safety

Cycle safety

Apparatus for Evaluating Clogging Effect of HEPA Filter on Confinement Capability Under Fire Accident (ACUA)

Safeguard

Clean Laboratory for Environmental Analysis and Research (CLEAR)

Criticality・WM

Static Experiment Critical Facility(STACY)

NUclear fuel Cycle safety Engineering research Facility (NUCEF)

Waste management

- Waste disposal safety evaluation

External events

- Seismic evaluation of nuclear facilities

High Temperature engineering Test Reactor (HTTR)

EPR

- Emergency preparedness technology
- Monitoring

Nuclear Emergency Assistance & Training Center (NEAT)

Thermal Hydraulic Research on Containment Vessel

- Research Issue
  - ✓ Overtemperature damage
  - ✓ Hydrogen risk

  } ・Heat and mass transfer in CV
  ・The significance is highlighted in SA of FDNPS.
  - ✓ Aerosol transport: pool/spray scrubbing
- CIGMA (Containment InteGral effect Measurement Apparatus)

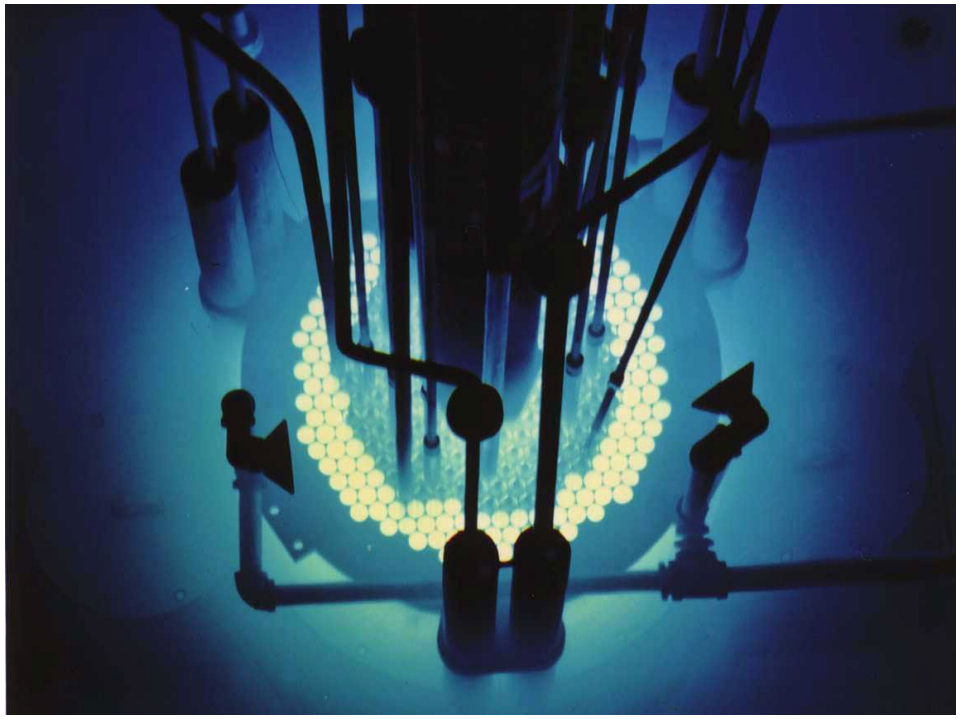
Specification of CIGMA

Pressure	0.5 MPa (high T.) 1.4 MPa (max.)
Temperature	300 °C (ave), 700 °C (max.)
SG power Superheater	200 kW 120 kW
Height	11 m
Diameter	2.5 m
Volume	~ 51m^3

Nuclear Safety Research Reactor (NSRR)

- A pulse operation reactor to simulate reactivity initiated accident (RIA)
  - ✓ Max. inserted reactivity: $4.7
  - ✓ Peak reactor power: 23 GW*
  - ✓ Pulse width: 4.4 ms (short pulse)*
- Test fuel fabrication/PIE support from adjacent hot-lab: RFEF (=>)

* At max. inserted reactivity



Research projects & plans related to NSRR

2006-2018
Failure limit of improved Zr-based alloys under RIAs

2018-2023
Elucidation of failure limit / failure mode changes observed for doped / MOX fuels

2024-
Dynamics of fission gas release during an RIA

2021-2024
OECD/NEA FIDES HERA project

2024- ATF behaviors

FIDES HERA Project

Framework for Irradiation Experiments (FIDES)

- Being designed to:
  - Provide a stable, sustainable, reliable platform for fuel and materials testing
- Encompasses **Joint Experimental Projects** and the following **Cross-cutting Activities:**
  - **Data preservation and QA**
  - Training and education
  - State-of-the-art modelling & simulation and instrumentation for efficient design, performance and analysis of experimental campaigns

Joint Experimental Projects (JEEPs)

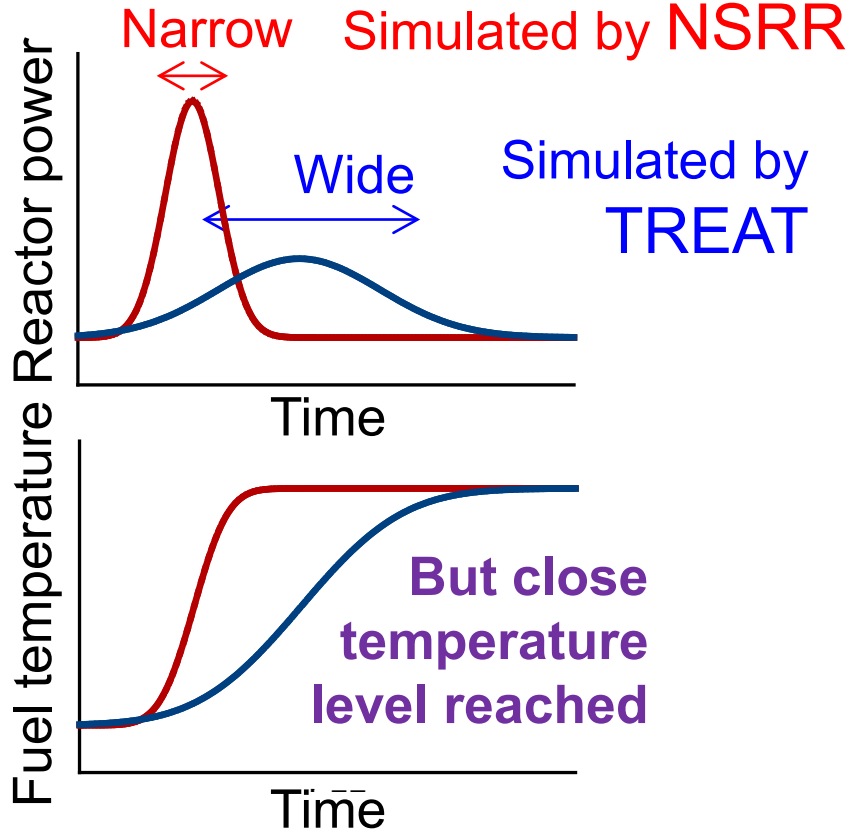
- Enable in-pile experiments in Fuel & Material test reactors and PIE

P2M	LOCA MIR	INCA	HERA	LOCA	INSTEP		
Tests in BR2 & PIE in CEA. Proposed by CEA, SCK•CEN, EDF	tests in MIR.M1. Proposed by RIAR and ROSATOM	Cladding creep tests in LVR15. Proposed by CVR, UJV, VTT, CEA, Alvel	RIA tests with high burnup fuel in TREAT. Proposed by INL	tests in CABRI. Proposed by IRSN and CEA	RIA tests in NSRR. Proposed by JAEA	Tests for validation of 3D M&S. Proposed by INL	Potential new proposals for existing RR and RR under construction
Belgium France	Russia	Czech Republic	US	France	Japan		

HERA: High burnup Experiments in Reactivity initiated Accident conditions

- 3 year project under FIDES phase 1 (2021-2024)
- RIA-simulated transient irradiations
- Using TREAT(US) and NSRR(Japan)
- 6 tests for evaluation of **Pulse Width effect**
- 4 tests for evaluation of pre-irradiated advanced fuels

Effect of pulse width on fuel failure condition/behavior



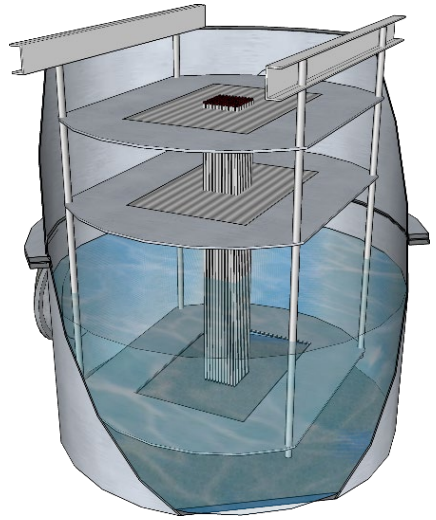
To answer a long standing question:

Does it affect on fuel failure limit ?

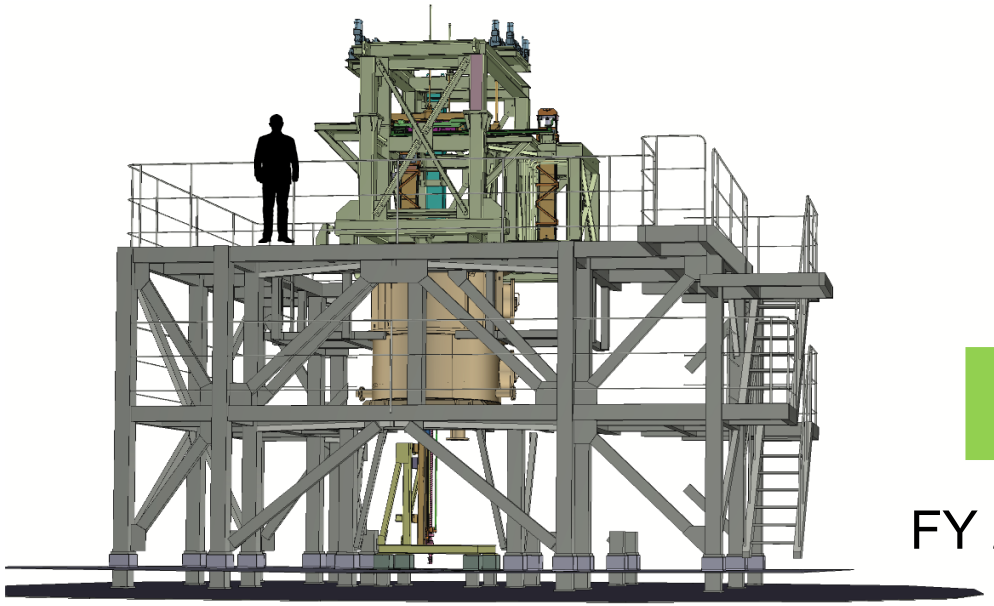
Static Experiment Critical Facility (STACY)

Project of modification of STACY (from the solution to lattice core) is on-going to establish an improved database on the criticality safety, which supports the safety review of the removal operation of the fuel debris from the Fukushima Daiichi Nuclear Power Plant.

STACY was originally designed and used to establish a database on the criticality safety of the solution of fissile materials treated in the spent nuclear fuel reprocessing plant and other fuel cycle facilities.

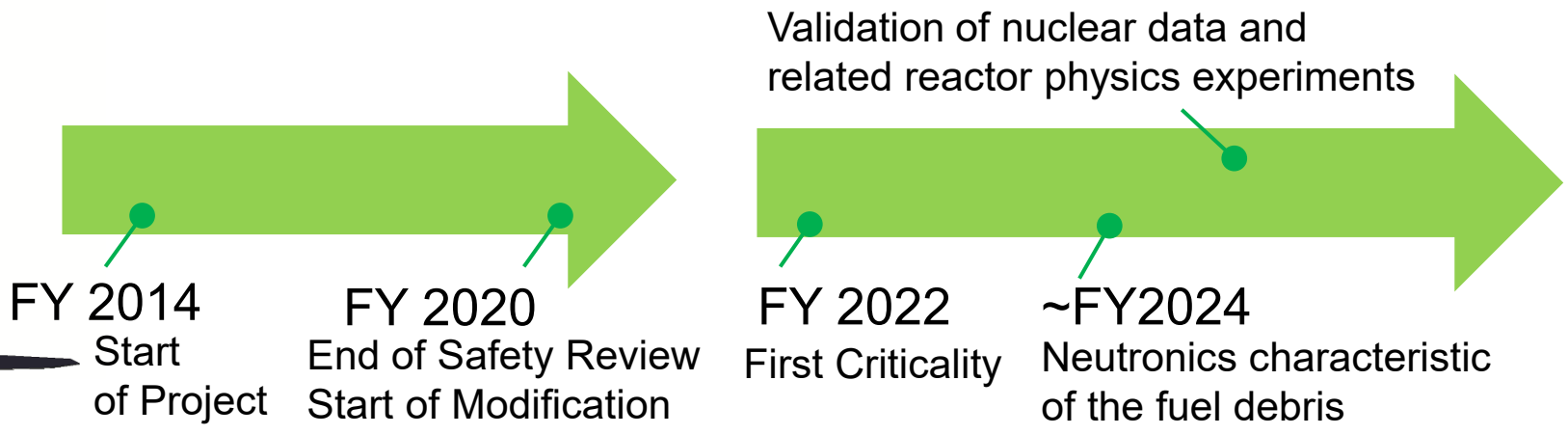


Schematic Figure of Core Tank of
the modified STACY with lattice of fuel pins



Overall image of the modified STACY

Research projects & plans related to modified STACY



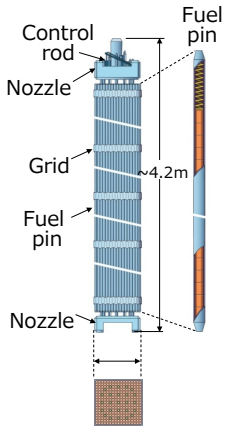
Accident Tolerant Fuel R&D Program

JAEA's role in Japanese ATF development and safety evaluation:

- Coordination of the project
- Development of common technical basis
  - Irradiation test technology
  - Fuel performance analysis code
- Evaluation of fuel performances esp. relevant to accident progression to SA

ATFs under development in Japan

Both for PWR & BWR



PWR fuel bundle

[SiC/SiC composite]

- Toshiba ESS
  - Fuel cladding for BWR & PWR
  - Cannel box for BWR
- Hitachi-GE
  - Fuel cladding for BWR

[FeCrAl-ODS]

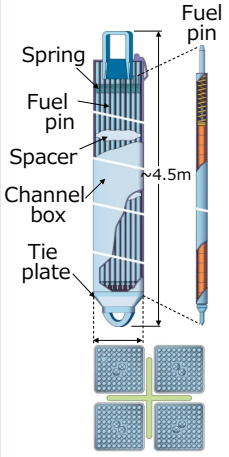
- Hitachi-GE (collaboration with GNF-J & Nuclear Fuel Development (NFD))
  - Fuel cladding for BWR

[Coated Zry]

- Mitsubishi Heavy Industry (MHI) & Mitsubishi Nuclear Fuel (MNF)
  - Fuel cladding for PWR

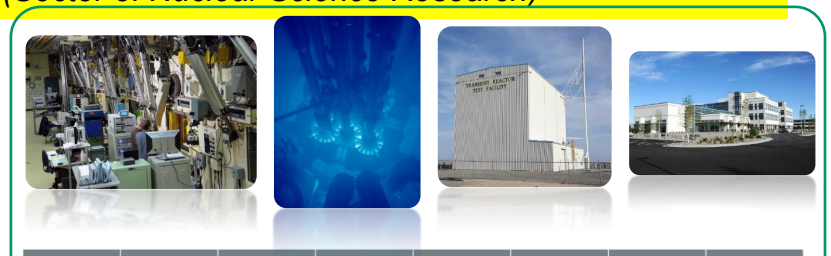
[ATCR]

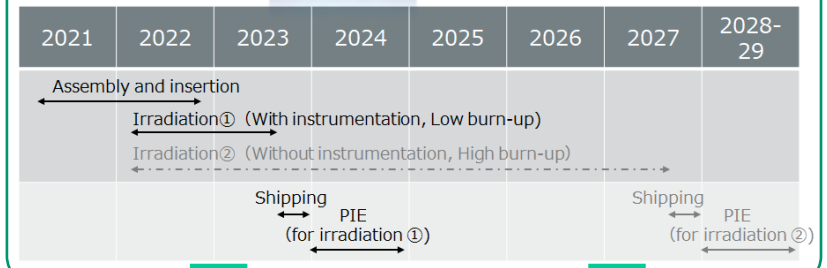
- Central Research Institute for Electric Power Industry (CRIEPI)
  - Accident Tolerant Control Rod



BWR fuel bundle

Planned irradiation testing under CNWG collaboration *(Sector of Nuclear Science Research)*

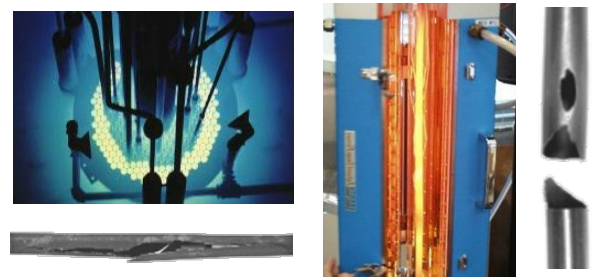




・JAEA has coordinated irradiation testing for Japanese ATF candidate material, Cr-coated Zry which was provided by Japanese vendor.

・Irradiated testing using the Advanced Test Reactor at Idaho National Laboratory has been planned under the US-JP CNWG collaboration.

Planned safety researches *(NSRC)*

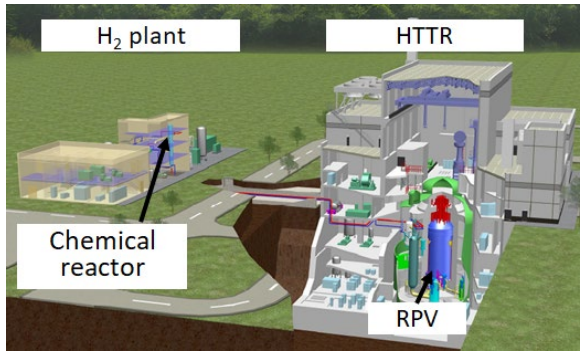


- DBA & B-DBA simulated experiments planned (2022-) for near-term and launched (2021-) for mid-term Japanese ATF materials
- RIA-simulated test (NSRR)
- LOCA-simulated tests (out-of-pile)
- BDBA-simulated high temperature transient test (NSRR, out-of-pile)
- Incorporation of ATF models into fuel performance code FEMAXI-8/RANNS, delivery to partner organizations

Status of Developments on HTGR Technology in JAEA
(Sector of Fast Reactor and Advanced Reactor)

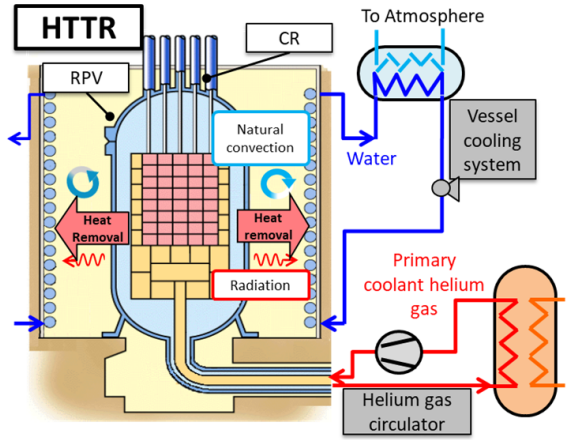
☐ Restarted HTTR on July 2021

- Without major reinforcements due to its inherent safety features
- Operational data obtained through HTTR safety demonstration test is valuable for establishing the HTGR safety standard.
- Future HTTR-heat application test (hydrogen production) is planned to establish safety design for coupling of hydrogen plant to HTGR. Demonstration of hydrogen production by HTTR is targeted by 2030.



☐ OECD/NEA LOFC Project (Loss of Forced Cooling) under CSNI focusing on safety issue (MB chair from NRC)

- Safety demonstration of HTGR simulating loss of forced core cooling
  - All primary helium gas circulators (HGCs) tripped at reactor power 30%. (Completed in 2010)
  - Two more LOFC tests are planned immediately after the restart. (HGCs tripped at 100% power, HGCs and vessel cooling system tripped at 30% power)



☐ Establishment of HTGR Safety Standards

- HTGR Safety Design Criteria (SDC) was proposed by JAEA in the framework of IAEA Coordinated Research Projects (CRP) and related activities, and results were issued as IAEA TECDOC in 2020.
- Discussion of the HTGR SDC at GIF VHTR SSC to obtain consensus for Gen-IV reactor
- Participation in IAEA projects to review applicability of IAEA Safety Standards of LWR to novel Advanced Reactors (at IAEA Department of Nuclear Safety and Security)

Summary

- Continuous cooperation between NRC and JAEA
  - Severe Accident Research
  - Fracture Mechanics
  - Cooperation under OECD/NEA framework (BSAF, PreADES, ARC-F, etc.)
- For the next-term,
  - Utilization of JAEA R&D facilities (CIGMA, NSRR, STACY)
  - ATF R&D and safety evaluation
  - OECD/NEA framework (FACE, HERA/FIDES, etc.)
  - Dispatch of personnel
- Other than LWR safety
  - HTGR safety research with HTTR (NEA/LOFC)


Thank you for your kind attention!