Nuclear Fission Research and Innovation activities in Japan

Ministry of Education, Culture, Sports, Science and Technology
Japan Atomic Energy Agency
1. Policy on the Development of Nuclear Energy Systems in Japan

“Strategic Energy Plan” (April 2014)
- Long-term comprehensive and systematic energy plan in Japan
- Redesigned and approved by Cabinet every three years.
- The first revision after Fukushima Daiichi nuclear disaster in March 2011

Generation III
- Advanced LWRs
  - Kashiwazaki ABWR, etc
- R&D on safety improvement based on the roadmap with clear priorities and its rolling that takes into account various indications from Japan and foreign countries.

Generation IV
- Revolutionary Designs
  - Expected to be utilized in various industries such as hydrogen production and electricity generation
  - For safety improvement of nuclear use
  - International research center for technological development of SFR
    - Verification of technical feasibility as a FBR plant
    - Verification of effectiveness in reducing environmental burdens
    - Establishment of safety technology system for FR

GIF (GEN-IV)
- VHTR
- HTTR
- SFR
- Monju
- ADS

• Technology development in the reduction of radiation dose in radioactive waste through transmutation by both FR and ADS is promoted.

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2.1 R&D Roadmap of SFR Systems

- **International Collaboration** (ex. ASTRID collaboration)
  - Outcome
    - Design Assessment
    - Collaborative Research etc.

**Monju Research Plan** (SFR Cycle Research Plan)
- Improvement of the safety of fast breeder reactors
- Reduction in volume/toxic level of radioactive waste
- Compiling the result of the FBR development

**Joyo**
- Outcome
  - Basic performance of fast reactor core
  - Operating characteristics of sodium components
  - Basic performance of Sodium loop system (ex. Natural Convection)

**Base Technology Development / Basic Research**
Reactor Physics, Thermal-hydraulics, Safety, Component & Material, Instruments, Fuel material, In-service inspection, Maintenance (Facilities: AtheNa, MELT, SWAT, PLANDTL, HTL, FMF, MMF, AGF, Sodium-Engineering Research Facility)

**Establishment of Demonstration Technology**
- Outcome
  - Performance of large-scaled core
  - Demonstration of SFR power plant (System and Design methods)

- Irradiation data of pin bundle test
- Reviewing "Safety standards" as a results of Fukushima Daiichi NPP accident

- Irradiation data of pin scale test
## 2.2 Test Facilities for SFR

### Experimental Capabilities of JOYO and related PIE Facilities

<table>
<thead>
<tr>
<th>Item</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuels</td>
<td>・Leading irradiation tests of new &amp; advanced fuels</td>
</tr>
<tr>
<td></td>
<td>・Non-steady irradiation tests (Power to melt test, Run to cladding breach test)</td>
</tr>
<tr>
<td>Materials</td>
<td>・Irradiation tests of new cladding materials (In-pile creep rupture experiment) and new structural materials</td>
</tr>
<tr>
<td>Safety</td>
<td>・In-pile test of innovative system (Self actuated shutdown system)</td>
</tr>
<tr>
<td></td>
<td>・Demonstration of inherent safety (Natural circulation test, ATWS)</td>
</tr>
<tr>
<td>ISI&amp;R</td>
<td>・In-pile test of advanced technology (Under sodium viewer)</td>
</tr>
</tbody>
</table>

### Irradiation Facility
- Joyo

### Post Irradiation Examination Facilities
- FMF
- AGF

### Irradiation Rigs

### X-ray CT scanning of Irradiated SA
- (FP release examination)

### Destructive inspection
- (EPMA for irradiated fuel)
### Facility OUTLINE

<table>
<thead>
<tr>
<th>Facility</th>
<th>OUTLINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SWAT</td>
<td>Sodium-water Reaction</td>
</tr>
<tr>
<td>2. SAPFIRE</td>
<td>Sodium Fire</td>
</tr>
<tr>
<td>3. MELT</td>
<td>Molten Fuel Relocation and Interactions</td>
</tr>
<tr>
<td>4. PLANDTL</td>
<td>Transient Sodium Thermal-hydraulics</td>
</tr>
<tr>
<td>5. CCTL</td>
<td>Steady State Sodium Thermal-hydraulics</td>
</tr>
<tr>
<td>6. AtheNa</td>
<td>Safety operation of Large components, Severe accident, and Instrumentations (e.g., Ultrasonic Technique, ISI, Flowmeter)</td>
</tr>
</tbody>
</table>

**AtheNa**

**Advanced Technology Experiment Sodium (Na) Facility**

**AtheNa-RV**: Decay heat removal under severe accident, Performance and effect of DRACS cooling and RV-wall cooling

**AtheNa-SG**: Test section (1/1 scale length) was installed at the pedestal frame of sodium loop in February 2015.

- Core Heater
- Debris Heater
- Water
- Air Cooler
- External heater
- Mother Loop 240 of Sodium

- Switch of flow path

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2.3 Test Facilities for SFR - Safety and Thermal Hydraulics -
In response to “Strategic Energy Plan 2014” in Japan, which refers to promoting HTGR, MEXT set up a task force for R&D on HTGR under Nuclear science committee (NSC), especially to evaluate the status of research and development of HTGR technology and nuclear heat utilization technology such as hydrogen production and power generation on May 23, 2014.

The Task force submitted an interim report to the NSC on October 1, 2014. The main recommendations are below:

- **Specific R&D themes for JAEA** in the next ten years: HTGR with heat utilization including gas turbine and IS process hydrogen production development
- Promoting international cooperation bilaterally and multilaterally
- Establishment of industry-academic-government forum to discuss the vision of future commercial HTGR system and its international development. *The first meeting was held in April 2015.

**Reactor technology**

- **HTTR**
  - 30 MWt and 950°C prismatic core HTGR test reactor (Operation started in 1998)
  - Evaluation by NRA for restart of HTTR is underway.
  - Technology of fuel, graphite, superalloy and experience of operation, and maintenance.

**Specific R&D themes in next ten years by JAEA**

- HTTR safety test (Reactor technology)
- Advanced fuel development
- Gas-turbine component development
- IS process hydrogen production development
- HTTR-GT/H2 test
- Establishment of safety standards and design guideline

**Gas turbine and H₂ production technology**

- R&D of gas turbine technologies such as high-efficiency helium compressor, shaft seal, and maintenance technology
- 200L/h IS process facility of continuous hydrogen production was constructed and performance test is underway

**HTTR-GT/H2 test**

- The interim report requires verification of the connection of a helium gas turbine power generation system and hydrogen production with the HTTR.
- Finished preliminary design of HTTR-GT/H₂ at the end of March, 2015.
4.1 Partitioning and MA fuel cycle technology development for Transmutation systems

- HLLW from commercial fuel cycle
- Partitioning
- Fuel fabrication
- MA Fuel
- Transmutation fuel cycle
- Recovered MA
- Irradiated MA fuel
- Fuel reprocessing
- Transmutation system (FR or ADS)

**Timeline**
- **2020**
  - Basic research, Equipment development / Process demonstration test
- **2030**
  - Engineering scale tests
- **2040**
  - Technology development for actual plant
- **2050**
  - Actual plant

**MA amount**
- ton
- kg
- g
- mg

**Facility complex**
- Small scale demonstration tests with modified equipment at the existing facility
- Irradiated fuel from Transmutation system

**Other facilities**
- Small scale tests at the existing facilities and Cold tests of equipment in a semi-engineering scale

**NUCEF**
- Engineering scale hot tests at a new facility and Am fuel fabrication for experiment and TEF-P
4.2 ADS Development in JAEA

Exp. ADS ⇒ MYRRHA
≈ 2.4MW$_{\text{beam}}$, 50-100MW$_{\text{th}}$
- Proof of ADS, Fuel irradiation.

ADS Plant
30MW$_{\text{beam}}$, 800MW$_{\text{th}}$
- Transmute MAs from 10 LWRs

ADS technologies by MOX fuel

MYRRHA
- Experimental ADS fueled with MOX
- Fuel and material irradiation

TEF
- Material irradiation by proton beam
- Data for neutronics design of MA-loaded ADS

To establish ADS plant technologies in 2030s

Loop Tests
J-PARC TEF
250kW$_{\text{beam}}$
- Pb-Bi Target
- ADS Neutronics

Window Material data

MA-loaded core neutronics and material data

Mock-up of beam window

Proton LINAC in J-PARC

TEF (Transmutation Experimental Facility) in J-PARC

- TEF-T (ADS Target Test Facility): Liquid Pb-Bi spallation target to research and develop a spallation target and related materials

- TEF-P (Transmutation Physics Experimental Facility): Critical Assembly to investigate reactor physics properties of MA transmutation system
5. Major international cooperation

International Cooperation is significant to R&D for verification of technical feasibility of SFR, HTGR and ADS. Key issues of these cooperation:

- **SFR**: verification of effectiveness in reducing environmental burdens and establishment of safety technology of FR system, for example in the field of safety analysis, design study of components and others.
- **HTGR**: tests and code validation by using HTTR, nuclear heat utilization e.g. gas turbine, and safety design
- **ADS**: R&D for engineering feasibility of subcritical system with high power accelerator.

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**France**
- Reactor & Advanced Nuclear Energy System
- Advanced Fuel Cycles
- Prototype/demonstration reactor (incl. ASTRID)
- Operational/Maintenance

**Russia**
- Vibro-compacted fuel
- ODS cladding irradiation

**Kazakhstan**
- Re-criticality elimination mechanism (EAGLE project)
- Design study
- Irradiation tests of fuel and graphite (ISTC project)

**U.S.A.**
- Fast Reactor technology
- Fuel Cycle Technology
- Simulation & Modeling
- Safeguards & Physical Protection
- Waste Management
- Tests and code validation
- Nuclear heat-driven gas turbine

**EU**
- Partitioning and Transmutation technology
- Experimental ADS and Irradiation tests (MYRRAH project)

**IAEA**
- INPRO(Scenario Study)
- TWG-Fast Reactors
- TWG-Nuclear Fuel Cycle Options
- TWG-Gas cooled Reactors
- CRPs

**OECD/NEA**
- Advanced Fuel Cycle Scenarios
  - Innovative fuels
  - Joint Safety Tests

**Indonesia**
- Design, fuel, graphite, heat utilization system

**Japan**
- Design goal and high level requirement for prototypes goals
- Safety principles and infrastructure needs,
- Irradiation test of MA bearing fuels (GACID project)

**Trilateral Collaboration**
- SFR (Advanced fuel, Component Design &BOP, Safety and Operation, Safety Design Standard)
- VHTR (Hydrogen Production, Fuel and Fuel Cycle, Materials)
  - GFR  
  - Super Critical Water Reactor
  - Lead-cooled FR  
  - Molten Salt Reactor
6. JAEA’s R&D budget change for the past decade

* Only JAEA’s R&D budget was cumulated in this chart.
Any other body’s R&D budgets such as university’s and private company’s were not cumulated.
Appendix
Monju is positioned as an international research center for technological development, such as reducing the amount and toxic level of radioactive waste and technologies related to nuclear nonproliferation, and results will be compiled as expected in Monju Research Plan. (Strategic Energy Plan)

**Schedule of Monju**
- Performance test (40-100% of full power)
- Performance test & 1st cycle operation
- Verification of burning characteristic of initial core bearing Am
- Performance test & 1st cycle operation

**Compiling the result of the FBR development**
- Verification of feasibility of generating system
- Verification of technical feasibility as a FBR plant
- In-Service Inspection (ISI) technology development & Preparation for application to real machine
- Improvement of maintenance methodology using experience of facility inspection and addressing machine trouble

**Reduction in volume/toxic level of radioactive waste**
- Verification of initial core characteristic bearing much Am (critical property, output characteristic)
- Verification of burning characteristic of initial core bearing Am
- Irradiation tests of Am- and Np-bearing MOX fuel

**Improvement of the safety of fast breeder reactors**
- Technology development of MA-bearing fuel fabrication and MA separation
- Experiments to verify MA-bearing fuel pellet’s irradiation behavior (Joyo)
- Irradiation test for long-life materials (Joyo)
- Identification of measures to improve safety and elaboration of SA evaluation techniques (Natural circulation heat removal test)
- Establishment of international standard Safety Design Guideline (SDG)
- Development of technology to maintain core cooling and terminating event within reactor vessel on SA

**Compiling research results**
- Improvement and demonstration of SAM
- Establishment of international standard Safety Design Guideline (SDG)
- Development of technology to maintain core cooling and terminating event within reactor vessel on SA

**Overall Evaluation**
- Rated Operation (equilibrium core)
  - From 6th cycle
  - Verification of secular change characteristic/integrity of generating system through long-term full scale operation
  - Verification of secular change characteristic/integrity of a large scale sodium facility
  - Demonstration of high burning fuel
  - Irradiation test of initial loading fuel of French demonstration reactor (ASTRID)
  - Global Actinide Cycle International Demonstration (GACID) experiment

**Compiling research results**
- Verification of burning characteristic of initial core bearing Am
- Irradiation tests of Am- and Np-bearing MOX fuel

**Interim Evaluation**
- Rated Operation (Initial core)
  - 2nd cycle - 5th cycle operation
  - Verification of reliability of generating system
  - Demonstration of reliability of core fuel
### A-2 Overview of Restart of Monju/Joyo/HTTR Schedule

<table>
<thead>
<tr>
<th>FY2013</th>
<th>FY2014</th>
<th>July</th>
<th>FY2015 -</th>
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<tr>
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**Monju**
- Enhancement of the safety program, quality assurance and maintenance plan
- Order by NRA on safety measures (May 29)
- Report on the response to the NRC Order (December 22)

**Establish new safety standards for Monju**
- Report of advisory committee on Monju safety requirements (July 31)

**Evaluation of fracture zones of ground at the Monju site**
- Report of additional investigation (March 28)
- NRA Expert meeting (December 4)

**Joyo**
- Recovery work (Exchange of Upper Core Structure etc.)
- Restart of Joyo
- NRA’s safety review

**HTTR**
- Enforcement of new Regulatory Requirements for Research Reactors (December 18)
- Restart of HTTR
- NRA’s safety review

**Evaluation of natural phenomena, Seismic evaluation, etc.**
- Application for license for HTTR (November 26)
A-3 Super critical Water-cooled Reactor (SCWR)

Japanese SCWR (JSCWR) Concept

- Thermal/electric output: 4,039MWt/1,725MWe, UO$_2$ fuel, pressure vessel type, thermal neutron reactor/fast reactor, light water moderated/cooled, operating pressure: 25MPa, reactor inlet/outlet temperature: 290/510°C

Main R&D items

- Evaluation on the technical feasibility of the high performance core, necessary technical development on thermal-hydraulics, safety, materials and water chemistry for the evaluation, and evaluation on the viability of the SCWR including its economics were almost completed.
- Optimizing performance: solution to issues* for the entire plant (solution to technical issues required for detailed design and licensing, advantages in comparison with state-of-the-art LWRs)
  * advancing conceptual design and associated safety analyses, more realistic testing of materials to allow final selection and qualification of candidate alloys for all key components, out-of-pile fuel assembly testing, qualification of computational tools, first integral component tests and start of design studies for prototype, in-pile tests of a small scale fuel assembly in a nuclear reactor, definition of a SCWR prototype (size, design features)
- Demonstration: solution to issues for plant construction (demonstration of design with various tests and prototypes for installations and confirmation of the plant performance by the construction, operation and experiments of the prototype reactor)

R&D facilities

- Heat transfer experiments:
  - Testing device for thermal-hydraulics with surrogate fluid (Kyusyu University)
  - Testing device for heat transfer in vertical circular tube (JAEA)
- Material tests:
  - Testing device for corrosion in supercritical water environments (Hitachi)

R&D roadmap

- R&D activities had been carried out with the budget funded by METI (for Innovative and Viable Nuclear Technology (IVNET) Development) since 2000, but technical activities have been stalled since 2012 (the following year of the Great East Japan Earthquake) (GIF Phase I (FY 2008-2011), budget: ca 0.16 billion yen)
- Institutions: the institute of Applied Energy, Toshiba, the University of Tokyo, Kyushu University, JAEA, Hitachi-GE, Hitachi, Kyoto University
- Original plan: Viability phase (-2010), Performance phase (2011-2016), Demonstration phase (2017-2030)

Major international cooperation

- GIF SCWR System Arrangement was signed in 2006 by EU and Canada, Japan in 2007, Russia in 2011 and China in 2014.
A-4 Gas-cooled Fast Reactor (GFR)

Japanese GFR Concept
• Thermal/electric output: 3,200MWt/1,500MWe, nitride fuel (pin type, coated particle type), reactor inlet/outlet temperature: 460/ 850°C

Main R&D items
• Necessary to solve various issues* for the decision of viability
  * development of fuel and core materials resistant to very high temperature and high fast-neutron fluence conditions, robust decay heat removal without external power input even in depressurized conditions, development of prevention and mitigation measures against severe accidents, etc.

R&D facilities
• No dedicated facilities

R&D roadmap
• 1999-2005: in the phase I and II of the Feasibility Study on Commercialized Fast Reactor Cycle Systems implemented by a Japanese joint project team (JAEA and electric utilities), conceptual design studies of innovative nuclear systems and technological development for the confirmation of viability were carried out.
• 2006: the SFR cycle was selected as the most promising concept for the commercialization of FR cycle, so that the SFR was given priority in national development budget (no budget for the GFR).
• Up to 2008: Kyoto University and other institutions carried out basic research on high burnup fuel and intermediate heat exchanger of GFR with the fund publicly offered from MEXT

Major international cooperation
GIF GFR System Arrangement was signed in 2006 by France, EU, Switzerland and Japan.
(Due to the reduction of resources in member countries, GFR activities have been stalled. Its future activities are under discussion in the GIF)
**A-5 Lead-cooled Fast Reactor (LFR)**

**Japanese LFR Concept**

- Thermal/electric output: 1,980MWe/750MWe, nitride fuel, Pb-Bi cooled, reactor inlet/outlet temperature: 285/445°C, three-dimensional base isolation system
- Another innovative concept which has features, such as transportability, long-life core, LBE in direct contact with water, has been proposed by Tokyo Institute of Technology (TIT)

**Main R&D items**

- ISI and fuel handling under opaque, development of structural steels and fuel cladding with good erosion-corrosion resistance at high temperatures and high flow rates, ruptures of steam generator tubes, molten core behavior is unclear in severe accidents

**R&D facilities**

- Corrosion test loop, Direct-contact boiling flow loop, LBE mist test device, Stress and corrosion test device, Corrosion and oxygen control test device, Surface coating device, Direct-contact explosion test device, Oxygen control device at TIT

**R&D roadmap**

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- 2006: the SFR cycle was selected as the most promising concept for the commercialization of FR cycle, so that the SFR was given priority in national development budget (*no budget for the LFR*).
- 1990-: some basic studies such as design, Thermal-hydraulics tests, material tests, Po test, Oxygen control tests and LEB property test have been carried out at TIT.

**Major international cooperation**

GIF LFR Memorandum of Understanding (MOU) was signed in 2010 by EU and Japan and Russia in 2011.
A-6 Major test facilities for Light Water Reactors

**Japan Materials Testing Reactor (JMTR)**

- Multi-purpose materials and fuels testing reactor
- Reactor Type: Tank-type Light Water Reactor
- Thermal Output: 50 MW
- Neutron flux: Thermal: $4 \times 10^{18} / m^2/s$
  - Fast ($E > 1$ MeV): $4 \times 10^{18} / m^2/s$
- Cooling water temperature: about 50 °C

**Nuclear Safety Research Reactor (NSRR)**

- For evaluation of fuel behavior under Reactivity Initiated Accident (RIA)
- RIA-simulating Pulse operation
- Max power 23 GW
  - Pulse width 4 ms

**Materials researches for aging management of LWRs components**

- Irradiation embrittlement of RPV steels, IASCC of stainless steel, water chemistry under irradiation, etc. are evaluated using several types of irradiation facilities.

**Researches for high burnup and new claddings fuels**

- Behavior and failure threshold of fuels under power ramping are investigated.