International Collaboration towards Advanced Nuclear Energy Systems Development in the Generation IV International Forum (GIF)

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Japan Atomic Energy Agency (JAEA)

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The IAEA INPRO Dialogue Forum in Korea
Contents

1. About the GIF (Outline, Structure)
2. Technology Development
3. Recent Activities
4. Summary
Generations of Nuclear Energy Systems

- Current nuclear power plants under operation mainly belong to Gen-II and Gen-III reactors.
- Gen-III+ and Gen-IV reactors are advanced as nuclear power plants.
  - Gen-III+ reactors are newest types of advanced generation-III.
  - Gen-IV reactors are promoted toward commercialization in around 2030.
Function of the GIF

Charter signed in July 2001, renewed in 2011 by 13 members, to:

- Identify potential areas of multilateral collaborations on Generation IV nuclear energy systems
- Foster collaborative R&D projects
- Establish guidelines for collaboration and reporting of their results,
- Regularly review the progress and make recommendations on the direction of collaborative R&D projects
Forms of Collaboration

a. joint research and technology development;
b. exchange of technical information and data …;
c. support for … technological demonstrations;
d. conduct of joint trials/experiments;
e. participation of staff (…) in experiments, analysis, design and other … activities …;
f. exchange or loan of … equipment for experiments …;
g. organization of … seminars … and other meetings;
h. monetary contributions to … experimental facilities;
i. training ...

(GIF Framework Agreement)
GIF Governance Structure

Chair: Y. Sagayama (Japan)

- Economics Modeling WG
- Proliferation Resistance & Physical Protection WG
- Risk & Safety WG

- Policy Group
  - Chair (Japan)

- Senior Industry Advisory Panel

- Experts Group
  - Chair (US)

- Methodology Working Group
  - Co-Chairs

- System Steering Committees
  - Co-Chairs

- Project Management Boards (specific or common projects)
  - Co-Chairs

- Policy Secretariat
  - Policy Director (France)
  - Technical Director (US)

- Technical Secretariat
  - NEA, Paris

Reported to:
- Provides Secretariat for
- Communicates closely with
- Coordinates with
1. About the GIF (Outline, Structure)
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## Goals for Gen-IV nuclear energy systems

<table>
<thead>
<tr>
<th>fields</th>
<th>Goals for Gen-IV nuclear energy systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety and Reliability</td>
<td>- excel in safety and reliability</td>
</tr>
<tr>
<td></td>
<td>- a very low possibility and degree of reactor core damage</td>
</tr>
<tr>
<td></td>
<td>- eliminate the need for offsite emergency response</td>
</tr>
<tr>
<td>Sustainability</td>
<td>- provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilization for worldwide energy production</td>
</tr>
<tr>
<td></td>
<td>- minimize and manage nuclear waste and notably reduce the long term stewardship burden, thereby improving protection for the public health and the environment</td>
</tr>
<tr>
<td>Proliferation Resistance &amp; Physical Protection</td>
<td>- assure unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism</td>
</tr>
<tr>
<td>Economics</td>
<td>- life-cycle cost advantage</td>
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<td>- a level of financial cost comparable to other energy projects</td>
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</tbody>
</table>
The six systems

- Sodium-cooled Fast Reactor (SFR)
- Very High Temperature Reactor (VHTR)
- Gas-cooled Fast Reactor (GFR)
- Supercritical Water-cooled Reactor (SCWR)
- Lead-cooled Fast Reactor (LFR)
- Molten Salt Reactor (MSR)
## Overview of the Generation IV Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Neutron Spectrum /Coolant</th>
<th>Temp.</th>
<th>Power (MWe)</th>
<th>Plant efficiency (%)</th>
<th>Fuel /Fuel Cycle</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SFR</strong></td>
<td>fast/ sodium</td>
<td>500 – 550</td>
<td>50 – 1,500</td>
<td>42</td>
<td>MOX, Metal /Closed</td>
<td>Electricity, Actinide Management</td>
</tr>
<tr>
<td><strong>VHTR</strong></td>
<td>thermal/ helium</td>
<td>900 – 1,000</td>
<td>250 – 300</td>
<td>47+α</td>
<td>Coated particles /Open</td>
<td>Electricity, Hydrogen production, Process Heat</td>
</tr>
<tr>
<td><strong>GFR</strong></td>
<td>fast/ helium</td>
<td>850</td>
<td>1,200</td>
<td>45 – 48</td>
<td>Carbides /Closed</td>
<td>Electricity, Hydrogen production, Actinide Management</td>
</tr>
<tr>
<td><strong>SCWR</strong></td>
<td>thermal; fast /water</td>
<td>510 – 625</td>
<td>300 – 1500</td>
<td>Max. 50</td>
<td>U, MOX /Open; Closed</td>
<td>Electricity</td>
</tr>
<tr>
<td><strong>LFR</strong></td>
<td>fast/ lead</td>
<td>480 – 570</td>
<td>20 – 1,200</td>
<td>42 – 44</td>
<td>Nitrides; MOX /Closed</td>
<td>Electricity, Hydrogen production</td>
</tr>
<tr>
<td><strong>MSR</strong></td>
<td>thermal; fast /fluoride salts</td>
<td>700 – 800</td>
<td>1,000</td>
<td>Max. 45</td>
<td>Fluoride salts /closed</td>
<td>Electricity, Hydrogen production, Actinide Management</td>
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</table>

### Contributions to the GIF

<table>
<thead>
<tr>
<th>Country</th>
<th>CA</th>
<th>FR</th>
<th>JP</th>
<th>KR</th>
<th>ZA</th>
<th>CH</th>
<th>US</th>
<th>EU</th>
<th>CN</th>
<th>RU</th>
<th>GB</th>
<th>BR</th>
<th>AR</th>
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</thead>
<tbody>
<tr>
<td><strong>SFR</strong></td>
<td>X</td>
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<tr>
<td><strong>VHTR</strong></td>
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<tr>
<td><strong>GFR</strong></td>
<td>X</td>
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<td>X</td>
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</tr>
<tr>
<td><strong>SCWR</strong></td>
<td>X</td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td><strong>LFR</strong></td>
<td></td>
<td>MOU</td>
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<td>MOU</td>
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<tr>
<td><strong>MSR</strong></td>
<td></td>
<td>MOU</td>
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</tbody>
</table>

X: Signatory, MOU: Memorandum of Understanding

As of Aug. 2012
SFR and VHTR systems are going to proceed in demonstration phase, GFR and SCWR are shifting from the viability phase to the performance phase.

**Development Schedule and Phase in Gen-IV**

- **SFR**: 5 Projects (Advanced Fuel, GACID, CD&BOP, Safety · Operation, SIA)
- **VHTR**: 3 Projects (Materials, Fuel& Fuel Cycle, Hydrogen Production)
- **GFR**: 2 Projects (Fuel · Core Materials, Component · Safety)
- **SCWR**: 3 Projects (Materials · Chemistry, Thermal-Hydraulic/Safety, Fuel Test)
- **LFR**: Preparation for System Research Plan
- **MSR**: Preparation for System Research Plan

Viability Phase | Performance Phase | Demonstration Phase
Contents

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The Generation IV International Forum (the Forum) extends its heartfelt sympathy to those who suffered from the massive earthquake, the tsunami, and subsequent Fukushima Daiichi nuclear power plant accident that occurred in Japan on March 11, 2011. For current and future generation nuclear power plants, the Fukushima accident reconfirmed the importance of assuring that nuclear safety considers the full spectrum of natural events. [...] The Forum is developing safety design criteria for Generation IV nuclear power plants that reflect lessons learned from Fukushima, with the completion of the Sodium Fast Reactor criteria anticipated in 2012.

During its meeting held in Luzern, Switzerland, October 6-7, 2011, the Forum reaffirmed its commitment to conducting collaborative research and development on Generation IV nuclear power plants to prevent and mitigate accidents and attain the highest degree of safety. The Forum's research and development results will be incorporated into near-term prototype and demonstration projects that will demonstrate the safety and other advanced features of Generation IV nuclear power plants.

(ftp://www.gen-4.org/PressRoom/fukushima.htm)
### Basic safety characteristics of SFR (1/2)

<table>
<thead>
<tr>
<th>Item</th>
<th>LWR</th>
<th>SFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor core reactivity</td>
<td>Maximum configuration Not in Maximum</td>
<td></td>
</tr>
<tr>
<td>Coolant pressure</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Sub-cool margin</td>
<td>Low</td>
<td>Approx. 350 deg-C</td>
</tr>
<tr>
<td>Natural circulation capability</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Ultimate heat sink (in accident)</td>
<td>Sea (/river /lake…)</td>
<td>Air</td>
</tr>
<tr>
<td>Coolant chemical reactivity</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

**LWR (PWR)**

- Passive safety: Decay heat removal by natural circulation

**SFR**

- Core disruptive Accident? *JSFR, as an example of loop-type

Ref. from www.iea.or.jp

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The IAEA INPRO Dialogue Forum in Korea, August 27-30, 2012
The IAEA INPRO Dialogue Forum in Korea, August 27-30, 2012

**Basic safety characteristics of SFR (2/2)**

- **Coolant pressure is low.** Guard vessel & guard pipes are used to maintain coolant level in case of primary coolant leakage; No ECCS is required.

- **Reactor core reactivity is not in maximum configuration.** CDA has been concerned because relocation of core materials may lead a re-criticality and generate the energetics.

- **SFR has passive safety.** Decay heat can be removed by natural circulation due to the large coolant temperature difference between reactor core outlet and inlet.

- **Coolant chemical reactivity is High.** Sodium reacts with air, water and concrete. These reactions have to be prevented and/or mitigated in sodium leak events in order not to affect the fundamental safety functions.

- **Basic safety characteristics of SFR (2/2)**

  - **SFR has passive safety.** Decay heat can be removed by natural circulation due to the large coolant temperature difference between reactor core outlet and inlet.

  - **Coolant chemical reactivity is High.** Sodium reacts with air, water and concrete. These reactions have to be prevented and/or mitigated in sodium leak events in order not to affect the fundamental safety functions.
Purpose and Scope of Safety Design Criteria (SDC)

- International consensus should be fostered on the utilization of nuclear energy for future.
- For that, it becomes more significant to build common criteria which should be flexible within an acceptable range.

Hierarchy of safety requirements of FRs

- Safety philosophy (ex. Defense in depth, ALARA principle, etc)
- General safety design criteria
  - High temp. structure
  - Passive systems
  - .......
- Specific design criteria on safety systems
- Code and Standards in each country (ASME, JSME, civil standards, etc)

Aiming for international standardization and harmonization
Basic Scheme to SDC

High level safety fundamentals, and safety design goals
- safety & reliability goals (GIF Roadmap)
- Basis for safety approach for design & assessment
- SFR Design Requirement (SFR System Research Plan)

1) Particular issues for Sodium Fast Reactor
- Characteristic of Fast Reactor
  - Core Reactivity (non-maximized core configuration), Na coolant …
  - Sodium fire & Sodium-water reaction…
- Consideration on Severe Accident
  - Core Disruptive Accident in DiD Level 4
- High Temperature & Low pressure system
  - Creep property, Leak-Before-Break…
  - No LOCA and no need of ECCS…
- Fundamental Safety Approach
  - Passive system for shutdown & cooling

2) Reference of SDC Framework

IAEA SSR 2/1
- Management of safety in design
- Principal technical requirement
- General Plant design
- Design of specific plant system

3) Lesson learned from Fukushima Dai-ichi NPPs accident
- Common cause failure by external event
- Loss of off site power for longer period
  - Decay heat removal, Fuel pool cooling
- Containment function on spent fuel in the pool
- Preparing multiple AMs, e.t.c.

GIF SFR SDC
Fast Reactors (SFRs) Development in the World

**Japan**
- E: Joyo (MK-III reactor core: 140 MWt):
- P: Monju (280 MWe):
- D: JSFR (1500 MWe): in designing (2025)

**France**
- P: Phenix (250MWe): ended operation (2009)
- P(D): ASTRID (600 MWe): in designing (2022*)

**Russia**
- E: BOR-60 (12 MWe): in operation
- P: BN-600 (600 MWe): in operation
- D: BN-800 (880 MWe): under construction (2014*)
- C: BN-1200 (1200 MWe): in designing (2020*)

**China**
- E: CEFR (25 MWe): in commissioning test (initial criticality (2010))
- D: (2019-2020*), CFR-600 or 1000 (600 or 1000 MWe; 2023*)

**India**
- E: FBTR (13 MWe): in operation
- P: PFBR (500 MWe): under construction (2013*)
- D/C: CFBR (500 MWe): under designing (2020*-2023*)

**Korea**
- P: --- (150 MWe): in designing (2018*)

E: Experimental, P: Prototype, D: Demonstration, C: Commercial  *Operation Start
GIF/INPRO collaborations

- Field of cooperation
  - Methodology development (Safety, Economics, PRPP)
  - Harmonization and cooperation on Safety (WSs shown below)
  - Annual Interface Meeting
  - To be initiated: Non-electric applications, SMRs, Education and Training, Thorium cycle, Reactor modeling and simulation

- Workshops on SFR safety
  - Intl. Workshop on Prevention and Mitigation of Severe Accidents in SFRs (June, 2012)
The IAEA INPRO Dialogue Forum in Korea, August 27-30, 2012

Framework of International Collaboration

- Generation IV International Forum (GIF)
  - Interface meeting
  - SFR Workshop
  - Participation as observers

- International Framework for Nuclear Energy Cooperation (IFNEC)

- Multinational Design Evaluation Program (MDEP)

- IAEA/International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

- OECD/Nuclear Energy Agency (NEA)

Observer
Secretariat
Topics

● The GIF Annual Report 2011

● GIF Symposium (Nov. 14, 2012 @San Diego, USA)
  ✓ Overview of GIF activities (past three years from the last GIF Symposium of 2009 in Paris)
  ✓ To share the information of Gen-IV with scientific and industrial community
  ✓ To report and discuss the significant technical progress in the various areas of GIF
  ✓ To report GIF achievements of To discuss future direction of GIF

● GIF Decadal Planning
  GIF is now in its second decade and planning a strategy for the future from 3 viewpoints
  ✓ Technology roadmap update
  ✓ Strategies for strengthening R&D collaboration
  ✓ Strategies for strengthening ties with other international organizations
Summary

- GIF has played a major role as an international framework for development of the next generation nuclear energy systems called Gen-IV systems since 2001.
- Cooperation on R&D for Gen-IV systems has steadily progressed among GIF members.
- GIF recognizes that enhancing safety is one of the most important goal and has been working on establishing a Safety Design Criteria for Gen-IV systems.
- From the aspect of safety, collaboration between GIF and INPRO has been deepening. Further, GIF would like to seek close cooperation with other international frameworks in order to realize Gen-IV systems which equip enhanced safety in the near future.
Thank you for your attention!

http://www.gen-4.org/