Generation IV R&D Infrastructure Task Force (GIF RDTF)

Henri PAILLERE

On behalf of the GIF RDTF

Roger Garbil (Chair), Alfredo Vasile and Sang Ji Kim (co-Chairs)

13th GIF-IAEA Interface Meeting and 8th Joint IAEA–GIF Technical Meeting/Workshop on the Safety of Liquid Metal Cooled Fast Reactors

18-22 March 2019, IAEA, Vienna, Austria
Background of the GIF-RDTF

Created by the GIF Policy Group in 2017

Objectives to be accomplished in less than 2 years

- Identify essential large (and key) experimental infrastructure needed in support of GEN IV systems R&D activities in terms of feasibility/performance as well as demonstration/deployment.
- Facilitate R&D collaboration across GEN IV systems.
- Promote utilization of experimental facilities for collaborative R&D activities among GIF partners. Facilitate GIF partners’ access to the various R&D facilities in the GIF member countries.

The GIF-RDTF will rely on the GIF Member State’s, IAEA’s and NEA’s relevant work in the areas of:

- R&D needs Outlook(s) along with
- R&D infrastructures, databases, reports, compendium and International Cooperation initiatives (e.g. IAEA CRPs, ICERR, NEA Joint Projects, NEST, NI2050, EURATOM Collaborative Projects and so on)
Members

Systems

- GFR  VASILE Alfredo (RDTF co-Chair)  LFR  ALEMBERTI Alessandro
- MSR  IGNATIEV Victor V.  SCWR  LEUNG Laurence
- SFR  HILL Robert  VHTR  FUETTERER Michael

GIF Member Representatives

- Australia  EDAWRDS Lyndon
- Canada  LEUNG Laurence (SCWR)
- China  SHI Lei, LU Donghua, LIAO Chengkui,
- Euratom  GARBIL Roger (EG, RDTF Chair), GLATZ Jean-Paul (SFR)
- France  GASTALDI Olivier (SFR), BERTHELEMY Michel (EMWG)
- Japan  HAYAFUNE Hiroki (SFR)
- Korea  KIM Harkrho, KIM Sang Ji (RDTF co-Chair)
- Russia  ASHURKO Iurii (EG, SFR) FOMICHENKO Petr, KLINOV Dimitri
- South Africa  ZIBI Zukile, FIPAZA Mmeli
- Switzerland  PALADINO Domenico
- USA  HONG Bonnie, SOWINSKI Thomas, STANCULESCU Alexander (EG Director)

International Organisations

- IAEA  MONTI Stefano, REITSMA Frederik, KRIVENTSEV Vladimir, NEA  IVANOVA Tatiana
- GIF Technical Secretariat  PAILLERE Henri, DEFFRENNES Marc (SIAP), GROSCH Gisela
Modus Operandi of the GIF-RDTF

- GEN IV System Steering and provisional System Committees
- SSC designated representatives to the GIF-RDTF
- GIF Experts Group members may also designate representatives
- GIF-RDTF reports to the GIF Policy Group vice chair in charge of external collaboration
- The GIF Technical Director supervises the activities of the GIF-RDTF and makes use of the GIF Experts Group for quality and completeness reviews
The GIF-RDTF will take advantage of IAEA’s and NEA’s relevant work in the area of R&D infrastructure

IAEA’s, NEA’s and GIF Member State’s relevant work on R&D needs, infrastructures, databases, reports, compendium

Use this opportunity to mainly support any SSC’s update of existing IAEA and NEA databases and compendium

Completion of the first objective in time for presentation at the October 2018 GIF Symposium

Completion of other objectives by the spring 2019 GIF Experts/Policy Group meetings

Upon completion of the objectives, the GIF-RDTF, and the GIF System Steering and provisional Steering Committees are expected to maintain cognizance of infrastructure needs and approaches for their access as work evolves
<table>
<thead>
<tr>
<th>Event</th>
<th>Date(s)</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>EG/PG meeting</td>
<td>15-19/10/2017</td>
<td>RDTF ToR approval</td>
</tr>
<tr>
<td>RDTF Kick-off</td>
<td>19 February</td>
<td>TF, Work programme</td>
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<tr>
<td>Audio-call</td>
<td>6 April</td>
<td>Prep., Call for abstracts</td>
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<tr>
<td>EG/PG meeting</td>
<td>14-18/05/2018</td>
<td></td>
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<tr>
<td>Meeting</td>
<td>17 May</td>
<td>Abstracts, Report skeleton</td>
</tr>
<tr>
<td>Audio-call</td>
<td>15 June</td>
<td>Mapping evaluation, gaps</td>
</tr>
<tr>
<td>Audio-call</td>
<td>15 September</td>
<td>1st Draft report</td>
</tr>
<tr>
<td>EG/PG meeting</td>
<td>15-19/10/2018</td>
<td>EG/PG 1st report</td>
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<td>2018 Symposium</td>
<td>16-17/10/2018</td>
<td>Track 4 Infra., Papers</td>
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<tr>
<td>Audio-call</td>
<td>4 December 2018</td>
<td>Collaboration evaluation</td>
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<tr>
<td>Audio-call</td>
<td>February 2019</td>
<td>2nd Draft report</td>
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<tr>
<td>IAEA/GIF meeting</td>
<td>18-22 March 2019</td>
<td>TF Progress report</td>
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<tr>
<td>Audio-call</td>
<td>9 April</td>
<td>2nd Draft report update</td>
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<tr>
<td>EG/PG meeting</td>
<td>27-31 May 2019</td>
<td>EG/PG 2nd report</td>
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<td>EG/PG meeting</td>
<td>14-18 October 2019</td>
<td>EG/PG Final report (tbc)</td>
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<tr>
<td>Workshop</td>
<td>Feb/March 2020 (tbc)</td>
<td>Exp. + private sector Needs</td>
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While global infrastructure currently exists to address some SFR R&D needs, the SFR SSC has identified the following key experimental and analytical infrastructure gaps:

- **Advanced fuel and material qualification:**
  - Need for fast neutron irradiation capabilities
    - Worldwide fast neutron irradiation capability is largely lacking
    - Light water-cooled test reactors lack the high fast to thermal neutron flux ratio needed to develop fast spectrum systems and to accelerate materials irradiations needed for fast reactors

- **Inherent Safety Testing**
  - Need for integral effects experimental facilities supporting comprehensive SFR system transient and safety analysis
  - Need for benchmark data on natural circulation transient behaviour

- **Advanced Energy Conversion**
  - Need for increased sodium – SC02 interaction and heat exchanger testing capabilities

- **SFR Component Testing**
  - Need for large scale component (e.g., full fuel assembly and control rod drive mechanism mock-ups) in-sodium testing facilities

- **Safety Analysis**
  - Need for particle/aerosol tracing facilities to support SFR mechanistic source term activities
  - Need for test facility demonstrating molten fuel behaviour during severe accidents
  - Need for seismic performance test loop/facility

- **In-service Inspection**
  - Need for larger test sections for under-sodium ultrasonic sensor performance tests

**Path Forward (idem to all GIF SSCs)**

- SFR SSC members look to address some of these infrastructure gaps through a combination of modified and new facilities and potential facility sharing among members
- The GIF R&D Infrastructure Task Force currently aims to assist member nations in identifying access pathways to international capabilities and potentially developing international facility use access mechanisms within GIF
LFR SSC Infrastructure Gaps

- **Identify a specific licensing process for demonstrator/prototypes able**
  - to help developers/regulators working together towards the development and licensing of a new system while maintaining their respective roles (Phased approach?)

- **Promote E&T activities on the HLM technology**
  - in order to prepare regulatory experts to the task requested by the licensing process for innovative reactors

- **Address the lack of experimental facilities for Fast Neutron Irradiation and the consequences of thereof**

- **Attempt to identify procedures to help functional test of passive systems (for example during outages)**
  - without the need to put in operation the passive system (for passive systems with moving fluids and strong changes of temperature and pressure conditions testing may become a challenge)

- **Help the development and qualification of new fuel / reprocessing technologies**

- **Address specific needs related to material / surface coatings / irradiation**
  - As parts of the present R&D are devoted to corrosion-resistant coatings / surface treatments - develop a framework to help speed-up qualification and integration of such new techniques taking into account the difficulties of having experimental tests and qualification performed in the «ideal» simultaneous conditions of coolant environment, mechanical load and irradiation.
  - Help the definition of prototypical conditions to transfer results from heavy ion irradiation to neutron irradiation in order to speed up the development and market uptake of new materials, especially those having the combination of surface coatings with structural materials already qualified at high dpa irradiation levels
  - Increase support to the development and update of Codes and Standards for HLM technology

**Path Forward**

Idem between all GIF SSCs
The GFR SSC has identified the following key experimental and analytical infrastructure gaps:

- **Advanced fuel and material qualification:**
  - Need for fast neutron irradiation capabilities
  - Need for material testing under pressurized and high temperature conditions

- **GFR Component Testing**
  - Need for large scale component in-Helium testing facilities for the development of heat exchangers, blowers, valves, sealings and instrumentation.

- **Safety**
  - Need for integral effects experimental facilities supporting GFR transient and safety analyses
  - Need for integral tests for transients with fast depressurization.
  - Need for test facility demonstrating U-Pu carbide fuel behaviour during severe accidents.
  - Need for benchmark data on natural circulation transient behaviour

**Path Forward**

Idem between all SSCs
VHTR SSC Infrastructure Gaps (1/2)

**VHTR Infrastructure Requirements**
- He-cooled graphite moderated, fully ceramic coated particle fuel, high outlet T
- passive decay heat removal
- large graphite thermal buffer
→ unprecedented level of inherent safety

**Test facilities required for:**
- Completion of fuel testing and qualification (fabrication, QA, irradiation, safety testing, PIE, waste reduction, recycling)
- Qualification of graphite, hardening against air/water ingress, waste management, recycling
- Coupling technology and related components (e.g. isolation valves, IHX)
- Design Codes & Standards for new materials and components (e.g C-C, SiC-SiC)
- Advanced manufacturing methods (cooperation with the GIF Cross-cutting Interim TF)
- Cost cutting R&D and interaction with EMWG and industry to optimize VHTR design
- Development, validation, uncertainty characterization of modern core analysis methods
- Licensing and Siting: V&V of computer codes for design and licensing
- Integration with other energy carriers in Hybrid Energy Systems
- Analysis of HTR-PM start-up physics and demo tests
- HTTR: safety demonstration tests and coupling to H2 production plant (subject to regulatory approval for restart)

**Large international collaboration effort on fuel and material qualification in support to near-term demonstration.**

Euratom NC2I-R reports: infrastructure needs for licensing and demonstration (bottom-up + top-down incl. from OECD TAREF database), identification of priorities and gaps in view of licensing, construction and operation of a demonstrator.

Several mothballed test facilities could be recovered, new or repurposed test facilities have been constructed in support of China’s HTR-PM demonstration, the US NGNP project, and the HTR programs in Korea, Japan and the EU.
Accompanying efforts:

- Ongoing collaboration towards fuel and material qualification
- Ongoing collaboration on V&V of computer codes
- Enhance information exchange among vendors, private investors, new national programs, multinational organizations, and regulators
- Factor in time/effort needed for qualification and specific regulator requirements
- Large-scale test facilities for qualification of components and subsystems (steam generators, heat exchangers, the Reactor Cavity Cooling System, circulators with magnetic bearings, isolation valves, control rod mechanisms, instrumentation etc.)

Path Forward

Idem between all GIF SSCs
HTTR (High Temperature engineering Test Reactor)

**HTTR**
Graphite-moderated and helium-cooled HTGR

- Fuel Rods
- Graphite Block
- Intermediate heat exchanger (IHX)
- Reactor pressure vessel
- Containment vessel
- Hot-gas duct

**Major specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Thermal power</td>
<td>30 MW</td>
</tr>
<tr>
<td>Fuel</td>
<td>Coated fuel particle / Prismatic block type</td>
</tr>
<tr>
<td>Core material</td>
<td>Graphite</td>
</tr>
<tr>
<td>Coolant</td>
<td>Helium</td>
</tr>
<tr>
<td>Inlet temperature</td>
<td>395°C</td>
</tr>
<tr>
<td>Outlet temperature</td>
<td>950°C</td>
</tr>
<tr>
<td>Pressure</td>
<td>4 MPa</td>
</tr>
</tbody>
</table>

**Operated by JAEA at Oarai R&D Institute**

- First criticality: **1998**
- Full power operation: **2001**
- 50 day continuous 950°C operation: **2010**
- Loss of forced cooling test at 30%: **2010**
- Connecting a gas turbine and H₂ plant to the HTTR for demonstration of HTGR cogeneration technologies: **Planned**
Safety demonstration test using the HTTR

Loss of forced cooling test for demonstration of HTGR inherent safety features

- 30% power (9MW) **Loss of forced cooling test**
  (Tripping all helium gas circulators) ---- Completed (2010)
- 100% power **Loss of forced cooling test**
  (Tripping all helium gas circulators) ---- Planned
- 30% power **Loss of core cooling test**
  (Tripping all helium gas circulators and VCS) ---- Planned

**Test condition**

- Initial power 30% (9MW)
- Tripping all helium gas circulators
- Maintain vessel cooling system operation
- No control rod insertion

**Test result**

Reactor is naturally shut down and cooled without forced cooling and control rod insertion

**Diagram**

- HTTR diagram with labels:
  - RPV: Reactor Pressure Vessel
  - CR: Control Rods
  - Natural convection
  - Water
  - Vessel cooling system (VCS)
  - Primary helium coolant
  - Heat removal
  - Heat Removal
  - Radiation
  - Helium gas circulator
  - To atmosphere

**Graphs**

- Core cooling flow rate
  - Test results
- Reactor power
  - Test result
  - Analysis
- Maximum fuel temperature
  - Analysis
SCWR SSC Infrastructure Gaps

SCWR is a Gen-IV system evolved from the current nuclear reactor systems
- Existing infrastructure are supportive
- New infrastructure are applicable to current systems

Established infrastructure specifically for high pressures and high temperatures
- Supercritical autoclaves and loops are available for material testing (Canada, China, EU)
- Supercritical water test facility constructed for in-reactor material testing (also applicable for fuel testing) (EU)
- Several thermal-hydraulics test facilities have been established for small-scale fuel assemble experiments (Canada, China)

Major Infrastructure needs
- In reactor testing loop (China, EU), Material and Fuel qualification testing loop at supercritical pressures
- Physics experimental facility (Canada), Validation of reactor physics codes for high pressure and high temperature applications
- Thermal-hydraulics test facility for full-scale fuel qualification (China), Validation of subchannel and system safety codes as well as computational fluid dynamic tools
- Integral safety test facility (Canada, China), Confirmation of safety system design

Path Forward
Idem between all GIF SSCs
The MSR development needs for the 2018 + 10 years period can be expressed in terms of the following grand challenges

- **Identifying, characterizing, and qualifying**
  - successful salt and materials combinations for MSRs.

- **Developing integrated reactor performance modeling and safety assessment capabilities**
  - that capture the appropriate physics and fuel chemistry needed to evaluate the plant performance over all appropriate timescales and to license MSR designs.

- **Demonstrating the safety characteristics of the MSR at laboratory and test reactor levels.**

- **Establishing a salt reactor infrastructure and economy**
  - that includes affordable and practical systems for the production, processing, transportation, and storage of radioactive salt constituents for use throughout the lifetime of MSR fleets.

- **Licensing and safeguards framework development to guide research, development and demonstration.**

**Path Forward**

Idem between all GIF SSCs
GENERATION-IV SYSTEMS’ EXPERIMENTAL INFRASTRUCTURE NEEDS

- Identification of essential GIF R&D Infrastructures for Generation IV Nuclear Energy Systems, R&D experimental facilities needed for development, demonstration and qualification of GEN IV components and systems, including activities to meet safety and security objectives.

- Mechanisms and approaches to promote the utilization of the experimental facilities for collaborative R&D activities among the GIF partners.

- Key recommendations to support essential R&D infrastructures

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Outlook activities

- **Action list**
  - Reminder to SSCs, Member States, EG and contact points for the need to contribute to the GIF RDTF report and PPTs, 28 February 2018
  - SSCs contributions to draft report to be provided by 5 March 2019
  - Each SSC provide 4 PPT slides for GIF – IAEA meeting by 5 March 2019
  - PPT presentation at GIF – IAEA Interface and workshop 18-22 March 2019
  - 2nd draft report updates to be provided by 15 April 2019
  - Draft Report and PPT presentation to GIF EG/PG Canada by 15 May 2019
  - Feb.2020 Workshop DRAFT programme by 15 May 2019
  - Final RDTF Report by 15 September 2019
  - Feb.2020 Workshop programme and flyer 15 September 2019
  - Report and PPT presentation, Workshop Programme to GIF EG/PG China by 14-18 October 2019
Thank You!