R&D Infrastructures Task Force

Roger Garbil

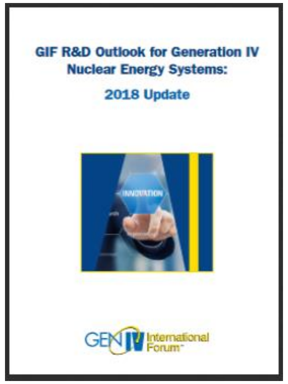
Chair, on behalf of GIF RDTF colleagues

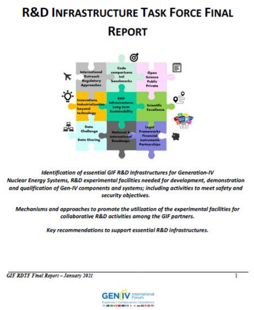
Workshop on Research Reactor

Needs / Opportunities / Challenges for Canada

22 March 2021

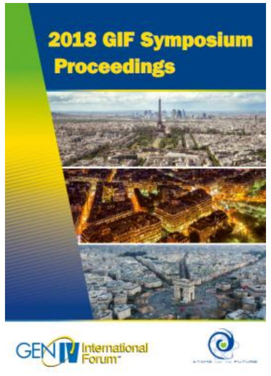
GIF Governance, WGs, TFs, SSCs, Projects, Publis

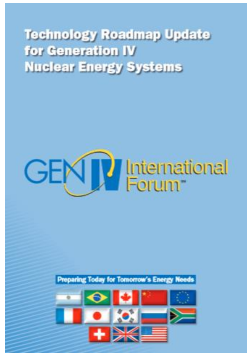




Policy Group

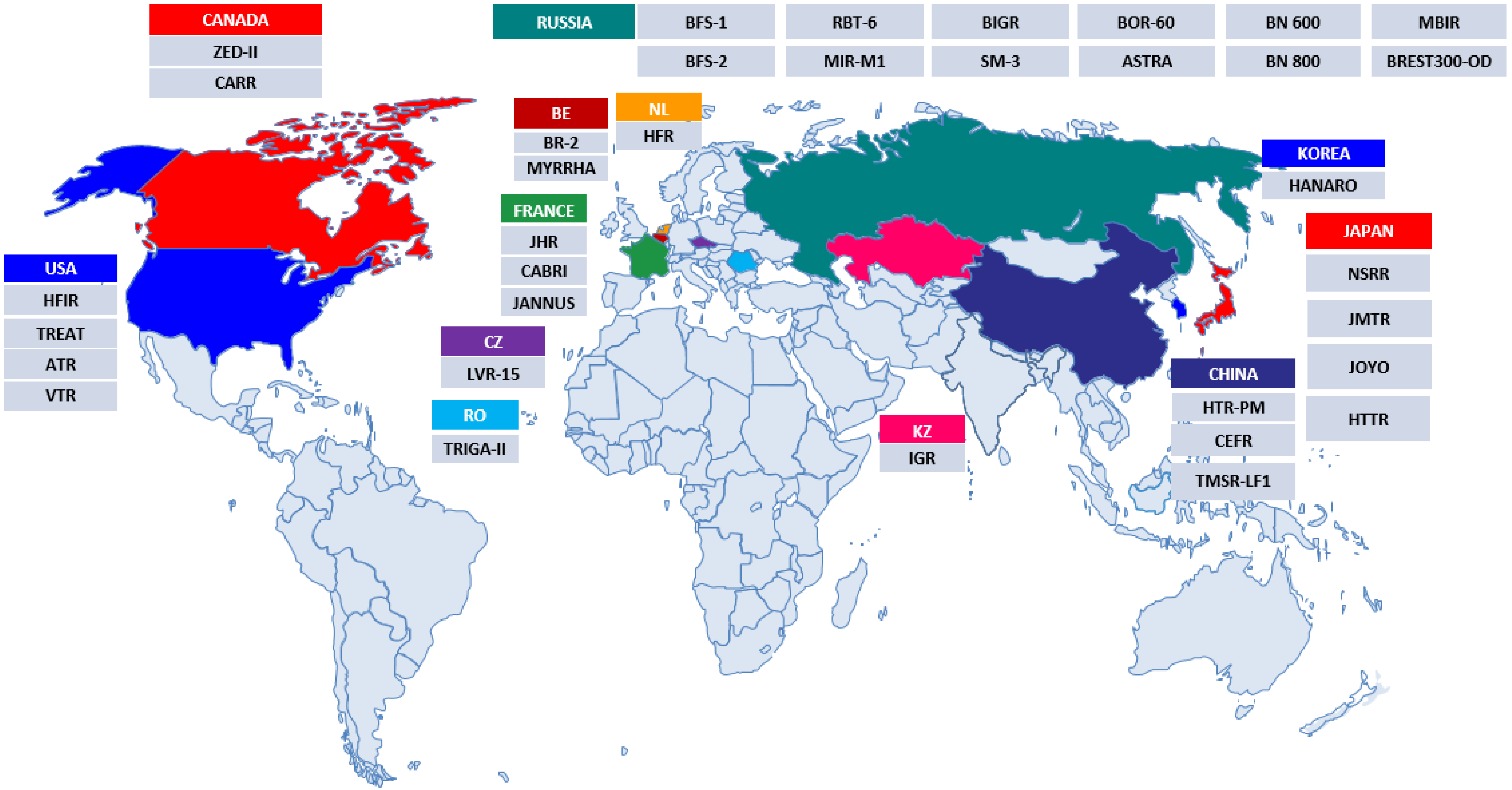
- **Expert Group**
  - **Methodology Working Groups (WGs)**
    - Economics Modelling (EMWG)
    - Proliferation Resistance and Physical Protection (PRPPWG)
    - Risk and Safety (RSWG)
    - Education & Training (ETWG)
  - **Task Forces (TFs)**
    - Safety Design Criteria (SDC-TF)
    - R&D Infrastructure (RDTF)
    - Advanced Manufacturing & Material Engineering (AMME TF)
- **System Steering Committees** for six Generation IV Reactor systems (GFR, LFR, MSR, SFR, SCWR, VHTR)
  - **Projects**
    Fuel, Material, Safety, Components etc.
- Senior Industry Advisory Panel (SIAP)





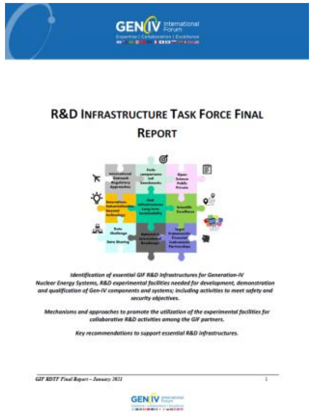
GIF Annual Reports	https://www.gen-4.org/gif/jcms/c_119034/gif-2019-annual-report
Symposium Publications	https://www.gen-4.org/gif/jcms/c_44724/symposium-publications
Technology Roadmap	https://www.gen-4.org/gif/jcms/c_60729/technology-roadmap-update-2013
R&D Outlook	https://www.gen-4.org/gif/jcms/c_108744/gif-r-d-outlook-for-generation-iv-nuclear-energy-systems-2018-update
R&D Infrastructure RDTF	https://www.gen-4.org/gif/jcms/c_107254/r-d-infrastructure (to be published soon)
Conferences, events, future	Workshop SMR vendors (02/2020, Paris), FR22 (04/2022, Beijing), Symposium/Workshop/SMR 2022, RDTF Infra follow-up

Research Reactors supporting Innovative Systems



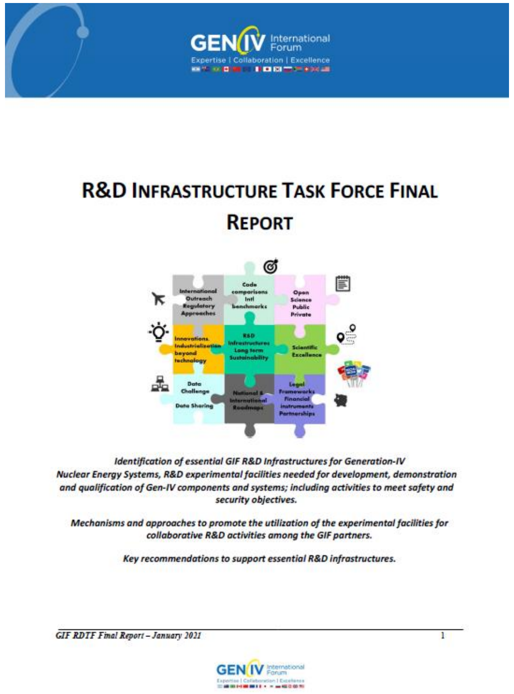
GIF R&D Infrastructures Task Force

- **Created by the GIF Policy Group in 2017, Objectives to be accomplished in less than 2 years** (from February 2018)
  - *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.*
- **GIF-RDTF relied 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, NEA WGSAR Working Group on Safety of Advanced Reactors and so on)*
- **GIF 2018 Symposium and SMRs' workshop on 18-20 February 2020**
- **GIF RDTF report, recommendations and first follow-up actions**



R&D Infrastructure RDTF https://www.gen-4.org/gif/jcms/c_107254/r-d-infrastructure (to be published soon)

Irradiation requirements on materials and fuels

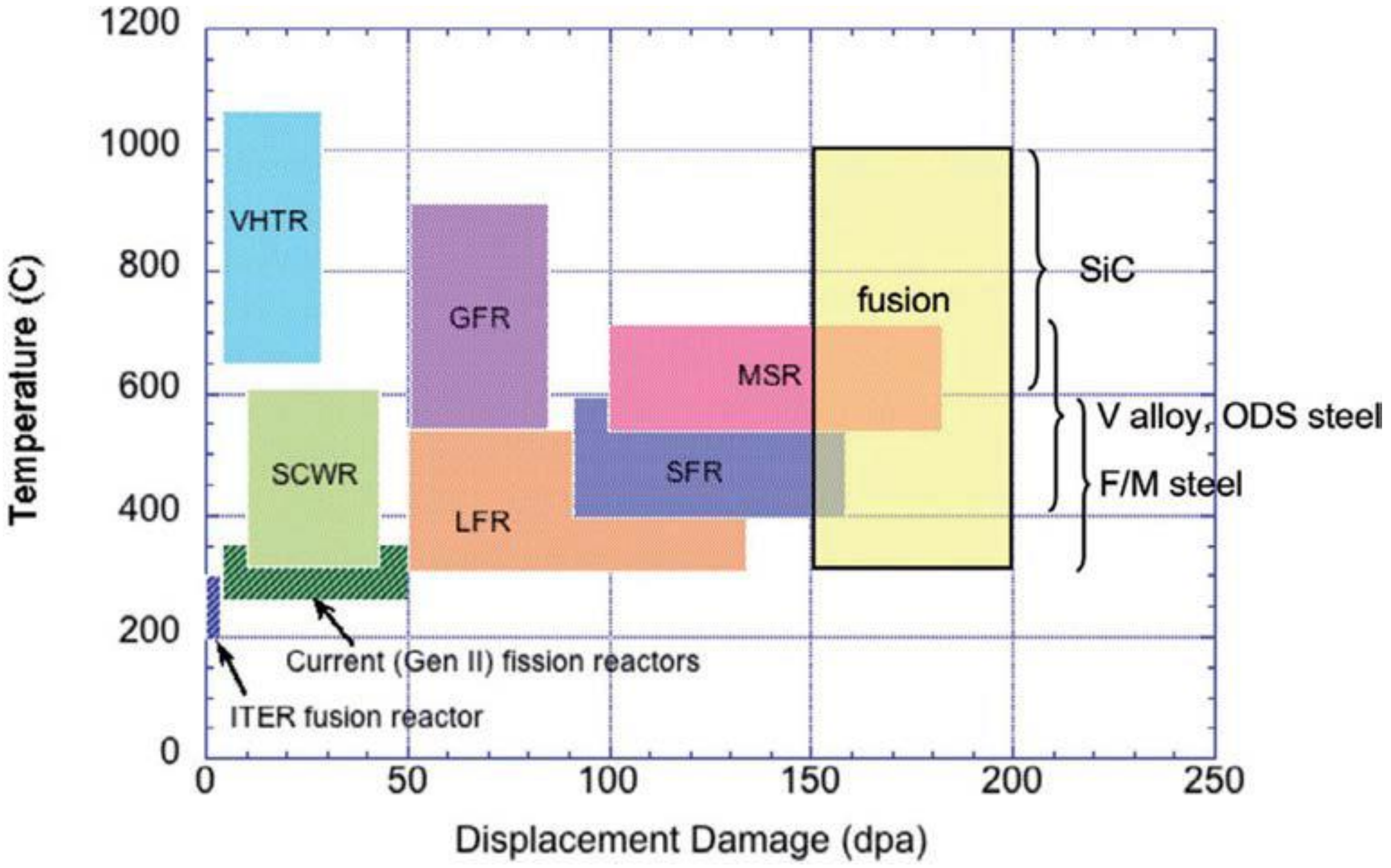

R&D INFRASTRUCTURE TASK FORCE FINAL REPORT

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.

GIF RDTF Final Report – January 2021 1



F/M — ferritic/martensitic; GFR — gas cooled fast reactor; ITER — International Thermonuclear Experimental Reactor; LFR — lead cooled fast reactor; MSR — molten salt reactor; ODS — oxide dispersion strengthened; SCWR — supercritical water cooled reactor; SFR — sodium cooled fast reactor; VHTR — very high temperature reactor

Critical research facility infrastructure

Technical expertise needed	Facility capability needs	Important factors for facilities
Thermal-hydraulics: modelling and analysis	Large-scale integral test facilities for each reactor type	Scale, temperature, pressure and instrumentation capability the key factors. Also, the completeness of the facility with respect to factors such as: auxiliary systems, number of loops and instrumentation capability are important
Fuels: performance and phenomena	Test reactor for steady state and reactivity insertion testing Hot cells for PIE and simulated LOCA testing	Ability to achieve representative values of energy deposition in transient tests. Ability to achieve linear heat rating, burn-up and adequate in-core instrumentation for steady state testing. Ability to do experiments with MOX and high burn-up fuel. Hot cells for full length and pin segment PIE
Reactor physics: modelling, cross-sections, parameters and analysis	Critical facilities for measuring physics parameters and performing benchmark experiments	Ability to do experiments with MOX and high burn-up fuel
Severe accidents: phenomena, accident progression, modelling and analysis	Facilities for testing: - Integral SA phenomena - In-vessel phenomena - Ex-vessel phenomena - Containment atmosphere mixing / combustion - Accident management strategies	Use of prototypic materials and large scale are important.
Integrity of equipment and structures: materials behaviour, structural design	Test reactors for irradiating material samples under controlled conditions Hot cells for examining large and small irradiated material samples Autoclaves for materials testing	Ability to achieve fluence and other prototypic conditions (e.g. temperature, simulate impurities, stress, etc.). Hot cells and autoclaves for ex-reactor testing of irradiated materials.

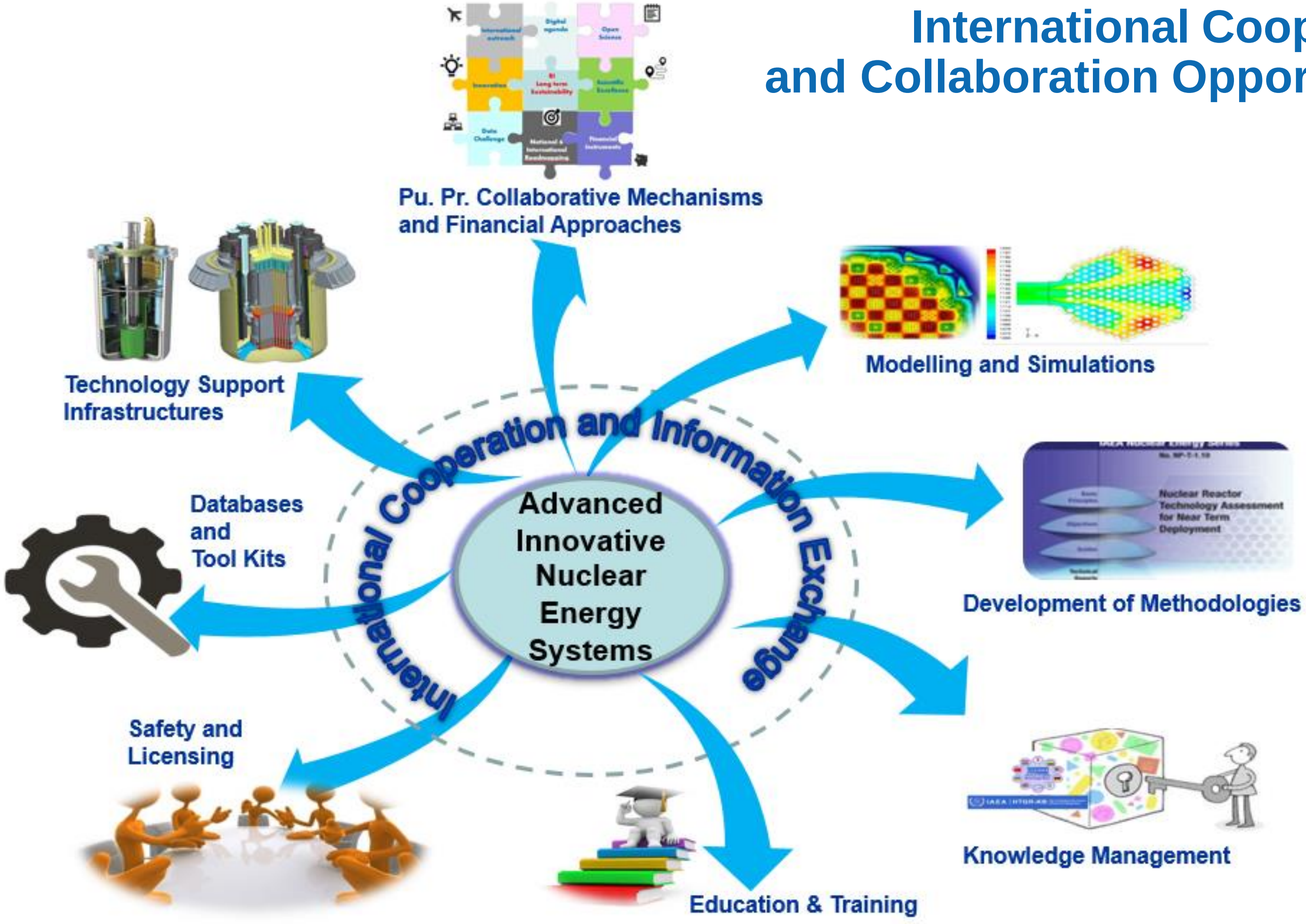
The virtuous wheel Of International Cooperation and Collaboration Opportunities

GIF RTDF recommendations having a Starting Point with

1 - Verification/Validation and Uncertainty Quantification (VV&UQ) approaches and best practices between the different Member States

2 - How to improve exchanges with regulators, at an early stage, to simplify and enable faster licensing processes for any innovative systems e.g. SMRs

3 - 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



GEN IV International Forum — Expertise | Collaboration | Excellence

NEA Nuclear Energy Agency

https://www.gen-4.org

IAEA International Atomic Energy Agency

Cross-cutting R&D Infrastructures

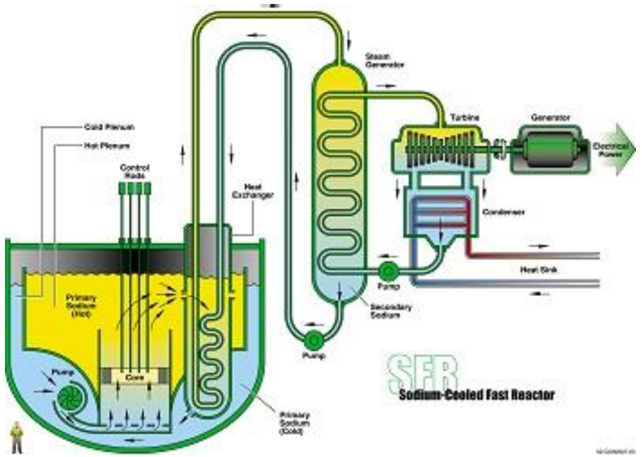
- **IRRADIATION FACILITIES**
  - **Materials Testing Reactors (MTR)** can be categorized according their power levels (High power (≥20 MW), Medium power (5–20 MW), Low power (<5 MW)), mode of operation (steady state and pulsed reactors) and neutron spectrum (thermal and fast).
  - **Unique experimental capabilities due to core design**
  - **Balancing experimental volume and neutron flux**
  - **Qualifying unique coolants for innovative Generation-IV reactors**
  - **In-core & Out-core instrumentation**
  - **Charged particle irradiation facilities**

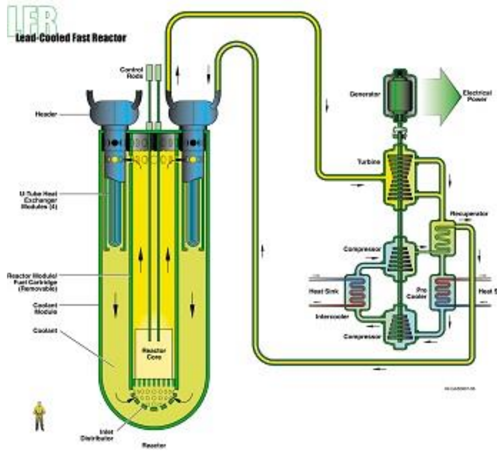
- **HANDLING OF IRRADIATED MATERIALS, Pre- and Post-Irradiation Hot Cells**
- **NUCLEAR DATA MEASUREMENTS**
- **ADVANCED MODELLING, SIMULATION TOOLS AND DIGITALISATION**
- **HARMONISATION OF LICENSING RULES, CERTIFICATION, AND STANDARDS**
- **EDUCATION AND TRAINING, KNOWLEDGE MANAGEMENT, MOBILITY AND ACCESS TO RESEARCH INFRASTRUCTURES**
- **ADVANCED SMALL MODULAR REACTORS (SMRs) OPPORTUNITIES**

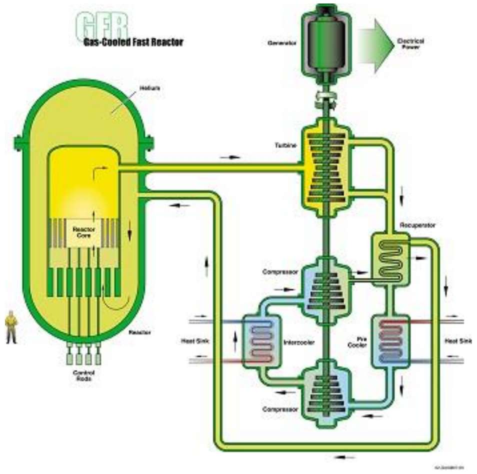
Thank You!

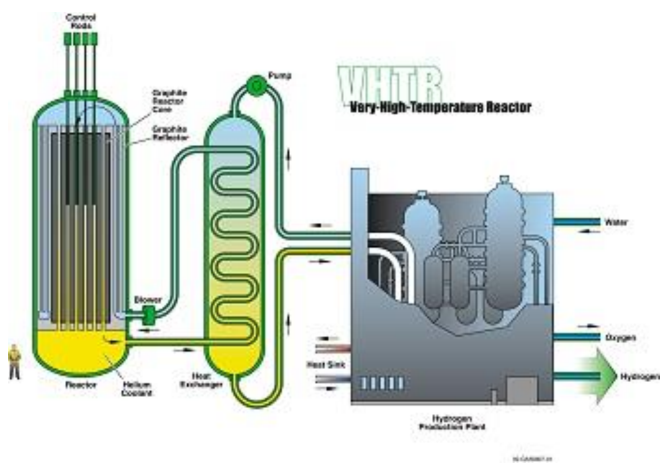
European Commission

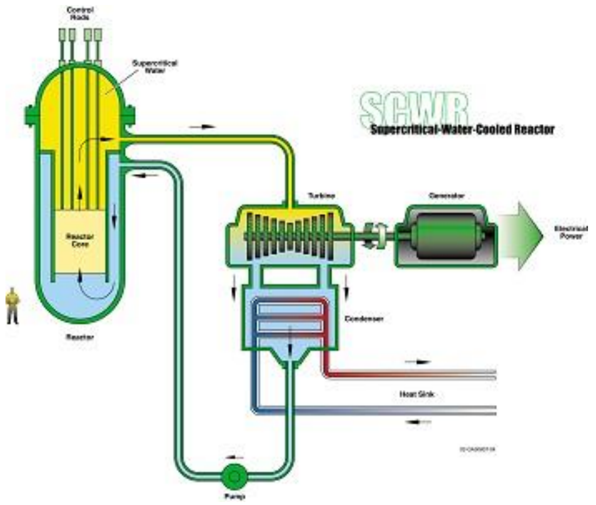
Generation IV Systems

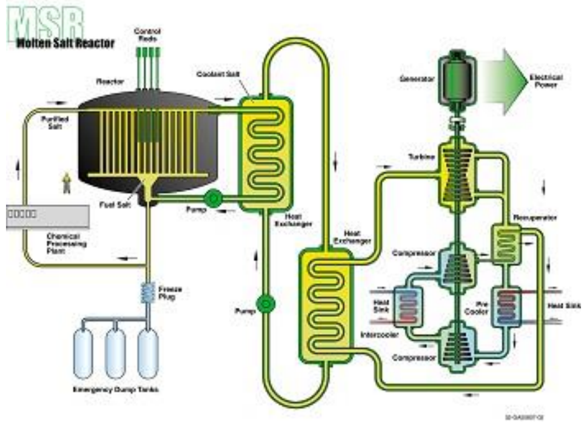












Aiming at improvements in:

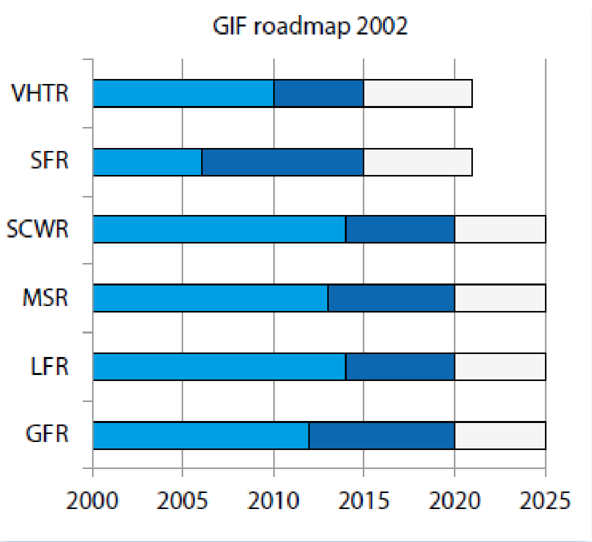
- Sustainability
- Economics
- Safety and reliability
- Proliferation resistance and physical protection
- Higher flexibility asset

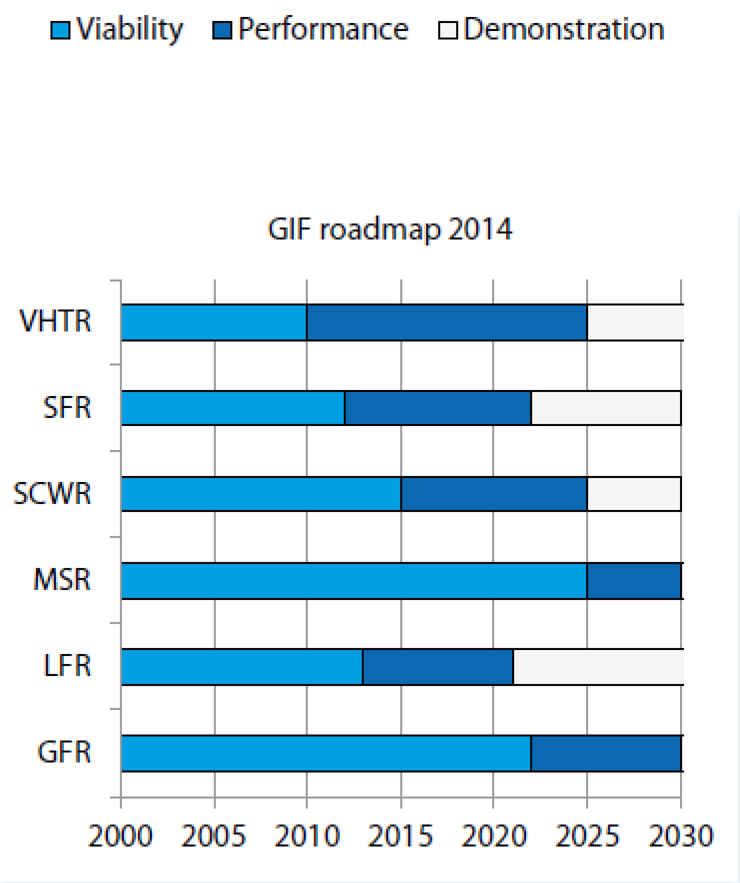
GEN IV International Forum
Expertise | Collaboration | Excellence

https://www.gen-4.org

TRL level for the six GIF systems (2014 update of the Technology Roadmap)

- ***Viability***
  - *Basic concepts tested under relevant conditions and all potential technical show-stoppers identified and resolved*
- ***Performance***
  - *Engineering-scale processes, phenomena and materials capabilities verified and optimized under prototypical conditions*
- ***Demonstration***
  - *Detailed design finalized and licensing, construction and operation of the system are carried out, with the aim of bringing it to the commercial deployment stage*





2018 GIF R&D Outlook: Key objectives and R&D activities in the next decade (1/2)

Sodium fast reactor (SFR)

Prototypes in operation in 2020-2030

- Advanced non minor actinides bearing, minor actinide bearing, and high burn-up fuels evaluation, optimisation and demonstration (a cross cutting challenge for all fast neutron spectrum systems)
- Development of innovative ISIR technologies
- Advanced energy conversion systems
- Development of leak before break (LBB) assessment procedures and instrumentation
- Development of steam generators including investigations of sodium water reactions and development of advanced inspection technologies
- Validation of passive decay heat removal
- Improved economics

Lead-cooled fast reactor (LFR)

Prototypes in operation in 2020-2030

- Phenomenology of the lead water and lead steam interactions
- Prevention and mitigation of sloshing
- New corrosion resistant materials (including surface modifications)
- Operation and maintenance
- Fuel and fuel reprocessing (nitride, minor actinide bearing, and high burn-up fuels)
- Advanced modelling and simulation.
- Severe accident management
- Design code and standards

Gas-cooled fast reactor (GFR)

2 400 MW_{th} reference design

- Finalising design and initiating licensing process of a GFR experimental reactor (ALLEGRO)
- Qualification of the mixed oxide fuel adapted to the specific operating conditions of the ALLEGRO start-up core
- Development of dense fuel elements capable of withstanding very high temperature transients
- Validation studies (experiments addressing innovative ceramic materials, unique GFR specific abnormal operating conditions such as depressurisation and steam ingress, …)
- Air and helium tests on subassembly (mock-ups under representative temperature and pressure conditions)
- Large-scale air and helium tests to demonstrate passive decay heat removal functions
- GFR-specific components development and qualification

2018 GIF R&D Outlook: Key objectives and R&D activities in the next decade (2/2)

Very-high-temperature reactor (VHTR)
1st step: reactor with outlet temp. 750-900°C

- Qualification of graphite, hardening of graphite against air/water ingress, management of graphite waste
- Coupling technology and related components
- Establishment of design codes and standards for new materials and components
- Advanced manufacturing methods
- Costs reduction, licensing and siting issues
- System integration with other energy carriers in hybrid energy systems
- Feedback from demonstration and industrial prototype tests
- 2nd step: Materials and fuels for temperatures up to 1 000°C and fuel burnup of 150-200 GWd/tHM

Supercritical water reactor (SCWR)
Pressure vessel and pressure tube designs

- Safety analysis
- Testing of materials and selection and qualification of candidate alloys
- Out-of-pile fuel assembly testing
- Qualification of computational tools
- Integral component tests
- In-pile tests of small-scale fuel assembly
- Start design studies of prototype
- NB: Some of these challenges can be mitigated through lowering the operating temperature of the coolant in SCWRs in order to reduce the peak cladding and fuel temperatures

Molten salt reactor (MSR)
Baseline design of molten salt reactor (liquid fuel)

- Salt and material combinations
- Integrated (physics and fuel chemistry) reactor performance modelling and safety assessment capabilities
- Demonstration of the MSR safety characteristics at laboratory level and beyond
- Establishment of a salt reactor infrastructure and economy that includes affordable and practical systems for the production, processing, transportation, and storage of radioactive salt constituents
- MSR safety approach, licensing and safeguard framework
- Alternative track with solid fuel: explore commonalities with other systems using molten salts or HTR fuels

SFR SSC Infrastructure Gaps

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 – SCO2 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**
- **Try 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

GFR SSC Infrastructure Gaps

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

- **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.

- **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)

VHTR SSC Infrastructure Gaps (2/2)

- **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

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

MSR SSC Infrastructure Gaps

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