SCIENTIFIC FORUM
NUCLEAR ENERGY FOR CLIMATE

Overview of Generation IV International Forum (GIF)and Generation IV concepts

Stephane SARRADE

Director of Energy Programs Division, CEA
GIF Vice Chair for Market Issues and Industry Engagement

GEN IV International Forum
Expertise | Collaboration | Excellence

2023

GIF: a framework for international co-operation in research and development for the next generation of nuclear energy systems, launched in 2001

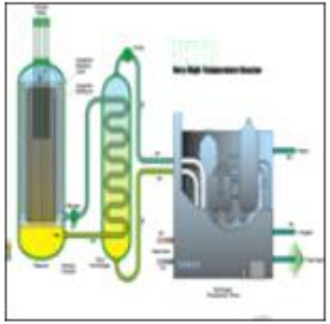
13 Member Countries + the EU

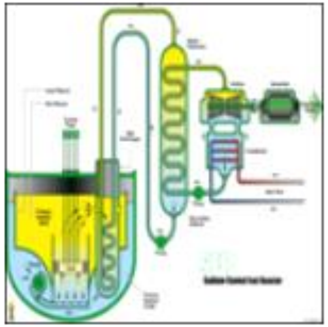
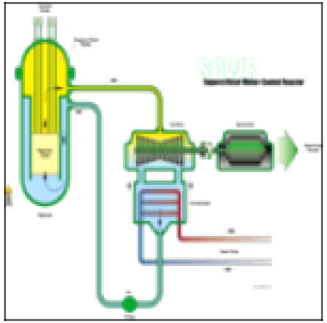
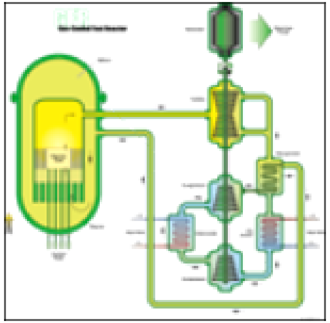
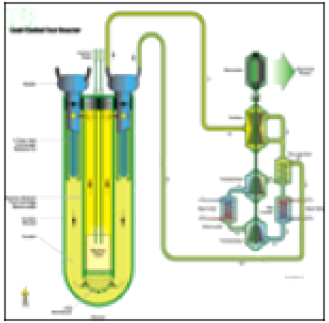
Achievements realized in the first 20+ years of GIF:

Better position Gen IV systems in the global decarbonised energy mix:

- Enhance R&D collaboration
- Interaction with industry: Construction of some demonstration or prototype reactors worldwide
- Education and training
- Dissemination activities

Six Generation IV Reactor Technologies



Cross-cutting Collaborations

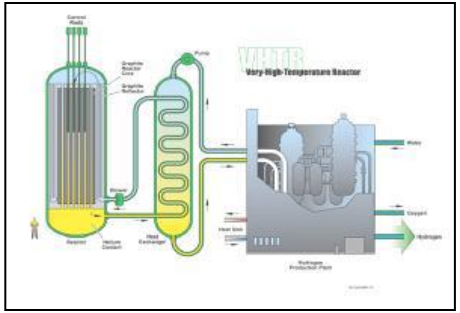
- Economics & Modelling
- Education & Training
- Proliferation Resistance & Physical Protection
- Risk & Safety
- Safety Design Criteria
- Non-Electric Applications of Nuclear Heat
- Advanced Manufacturing & Materials Engineering

To achieve goals in four areas:

1. Sustainable energy with minimum waste
2. Life cycle cost advantages
3. Safety and reliability
4. Proliferation resistance & physical protection

… aiming to be ready for industrial deployment by 2030.

Very High Temperature Reactor (VHTR)



Description:

- Graphite-moderated, helium-cooled reactor with thermal neutron spectrum.
- Two typical reactor configurations: pebble bed type and prismatic block type, both with TRISO coated particle fuel.
- High operating temperatures (750 - 950°C) or even higher with novel materials.

Potential Benefits and Application:

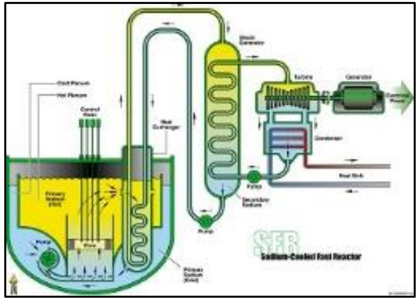
- VHTRs are primarily dedicated to the **cogeneration of electricity and hydrogen production** through high-temperature electrolysis, thermo-chemical cycles or steam methane reforming.
- Other **nuclear heat applications** of VHTRs include process heat for refineries, petro chemistry and metallurgy.

Status and Key issues:

- Current experimental reactors (HTTR, Japan, & HTR-10, China) aim at qualifying technologies and design codes
- Challenges remain regarding the coupling and licensing of coupling between VHTRs and hydrogen production.
- Solutions are underway to adequately scale up the TRISO fuel fabrication and to improve the inherent safety features of VHTRs as well as the design and qualification of high-temperature materials and manufacturing processes.

GIF Member countries: 

Sodium-cooled Fast Reactor (SFR)



Description:

- Fast-spectrum, sodium-cooled reactor, with high power density and low coolant volume.
- Important safety features of SFRs include a primary system operating near atmospheric pressure, a long thermal response time and a reasonable margin to coolant boiling.

Potential Benefits and Application:

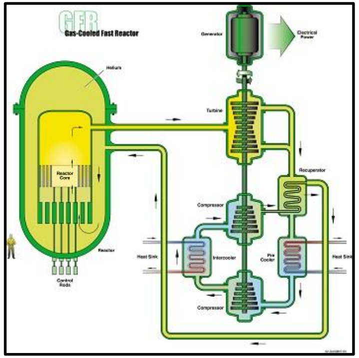
- The SFR closed fuel cycle enables **regeneration of fissile fuel** and facilitates **management of high-level waste.**
- The SFR is aimed to be **economically competitive** with innovations to reduce capital costs through a combination of configuration simplifications, advanced fuels and materials, and refined safety systems.

Status and Key issues:

- The SFR is considered to be the nearest-term deployable system for actinide management.
- Improvement of in core inherent safety and instrumentation and control are among key challenges for SFRs (e.g.: passive shutdown systems, decay heat removal, prevention and mitigation of severe accidents).
- The focus is also on finding innovative solutions to further enhance safety and proliferation resistance features.

GIF Member countries: 

Gas-cooled Fast Reactor (GFR)



Description:

- High-temperature helium-cooled fast-spectrum reactor with a closed fuel cycle.
- Same fuel recycling processes as SFRs and same reactor technology as VHTRs
  → specific R&D is needed beyond the current and foreseen work of the VHTR system, mainly on the core design and the safety approach.

Potential Benefits and Application:

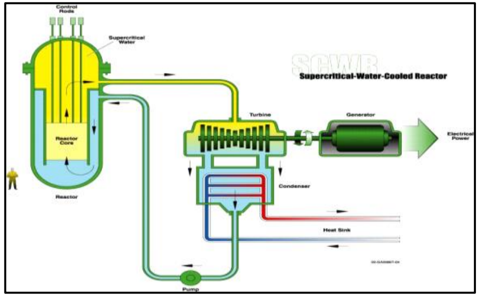
- Fast-spectrum systems of GFRs ensure long-term **sustainability of uranium resources** and **waste minimization.**
- As a high-temperature system, GFRs are well suited for **industrial applications of the generated heat**.

Status and Key issues:

- The ALLEGRO project aims at demonstrating the **viability of the technology** and the qualification of key components (e.g., innovative fuel & core materials such as helium-related technologies and specific safety systems).
- The ALLEGRO project is also serving as a test pad to **further improve GFR-related technologies** such as heat exchangers to generate process heat **for industrial applications.**

GIF Member countries: 

Supercritical Water-cooled Reactor (SCWR)



Description:

- Two broad families of SCWR reactor concepts studied under GIF: pressure-vessel type and pressure-tube type reactor. All neutron spectra are considered: thermal, intermediate and fast.
- Diversity of reference fuels: UO_2 or (Pu,Th) O_2 for thermal-spectrum concepts, (Pu)MOX for fast-spectrum concepts.

Potential Benefits and Application:

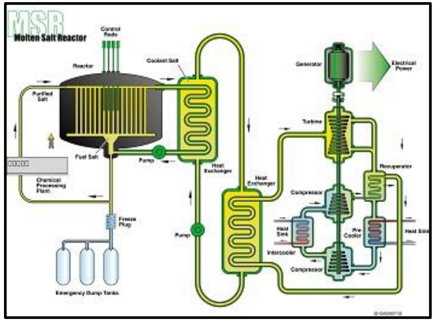
- The **thermal efficiency** of a SCWR can be of around 45% to 48%, compared to ~35% for current reactors.
- SCWRs can draw on the 60+ years **long operational experience** of water-based reactors.
- As supercritical water is a single-phase fluid, steam separators and dryers are not required nor any reactor coolant pumps, only feed water pumps, making the nuclear island more **cost effective**.

Key issues:

- Cladding materials and their water-chemistry requirements are among key technology challenges for SCWRs.
- Supercritical water is significantly different by its thermophysical properties and behaviour from those of ordinary liquids or gases, causing a challenge for heat-transfer predictions.

GIF Member countries: 

Molten Salt Reactor (MSR)



Description:

- Fissile material dissolved in the molten salt serves both as fuel and coolant (except for solid-fueled MSR where molten salt serves only as coolant).
- Several design variants with regards to the salt composition, neutron spectrum…

Potential Benefits and Application:

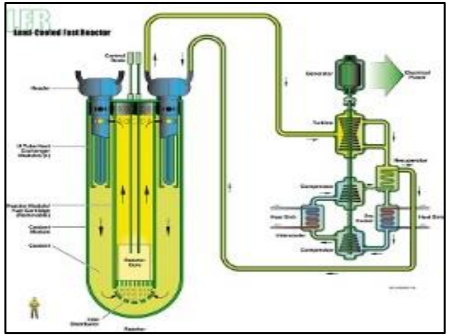
- MSRs have benefits in higher efficiencies and lower waste generations. They can be designed as nuclear waste “burners” or breeders.
- MSRs’ inherent safety features combined with modularity **serve as innovative nuclear solutions** to meet **the safety and cost challenges** for commercial use.

Status and Key issues:

- **Design variants** being pursued range from micro to gigawatt scales, hence the MoU status in GIF.
- There is currently no large scale sustained MSR technology development and demonstration experience in GIF member countries
- MSRs have substantially **different proliferation and safeguards issues** than solid-fueled reactors. The focus is therefore on the development of safeguards approaches and proliferation resistance features.

Provisional GIF Member countries: 

Lead-cooled Fast Reactor (LFR)



Description:

- Fast-spectrum reactors operating at high temperatures and near atmospheric pressure.
- Coolant is either molten lead or lead-bismuth eutectic (LBE), both of which support low-pressure operation, have very good thermodynamic properties, and are relatively inert with regards to interaction with air or water.

Potential Benefits and Application:

- LFR characteristics enable improved resource utilization, longer core life and effective burning of minor actinides
- High-temperature capabilities of LFRs allow for a broad range of applications such as **combined heat and electricity, hydrogen production** as well as water desalination in captive markets.

Status and Key issues:

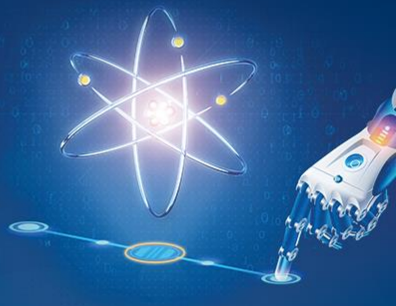
- System concepts in GIF are based on Europe's ELFR lead-cooled system, Russia's BREST-OD-300 and the SSTAR system concept designed in the US. Other LFR concepts are also under various stages of development in different countries including China, Russia, the US, Sweden, Korea and Japan.
- Key challenges for LFRs include challenges related to the high melting point of lead, its opacity, coolant mass as a result of its high density, and the potential for corrosion when the coolant is in contact with structural steels.

Provisional GIF Member countries: 

The way forward

Key theme through 2024: Accelerating the Readiness of Gen IV Systems to Meet Net Zero Goals:

1. Strengthening Gen IV system features for combatting climate change (e.g., flexible operations and non-electric applications)
2. Supporting transition from R&D to demonstration and deployment through technical readiness, regulatory readiness and improved economics
3. Strengthening GIF relevance to industry
4. Supporting the Gen IV talent pipeline



Thank You

2023