# Generation-IV International Forum

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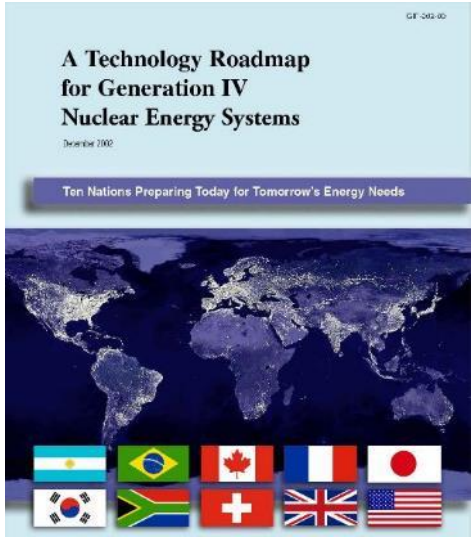
# Genesis of Generation IV Concept

- In 1999, low public and political support for nuclear energy
  - Oil and gas prices were low
- USA proposed a bold initiative in 2000
  - The vision was to leapfrog LWR technology and collaborate with international partners to share R&D on advanced nuclear systems
  - 9 Countries and EU joined USA in developing the initiative
  - Oil prices jumped soon thereafter
- Gen IV concept defined via performance goals
  - Technology Roadmap released in 2002
    - 2 year study with more than100 experts worldwide
    - Nearly 100 reactor designs evaluated and down selected to 6 most promising concepts
  - First signatures collected on Framework Agreement in 2005; first research Projects (multilateral agreements) defined in 2006




***"This may have been the first time that the world came together to decide on a fission technology to develop together."***
William Magwood IV, First Chairman of the Generation IV International Forum

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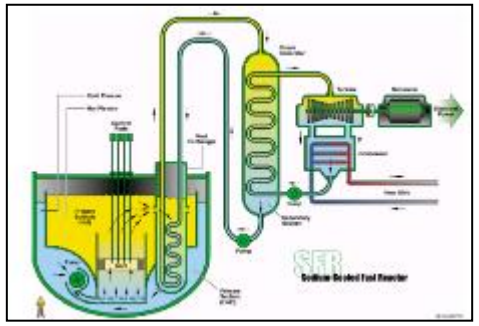
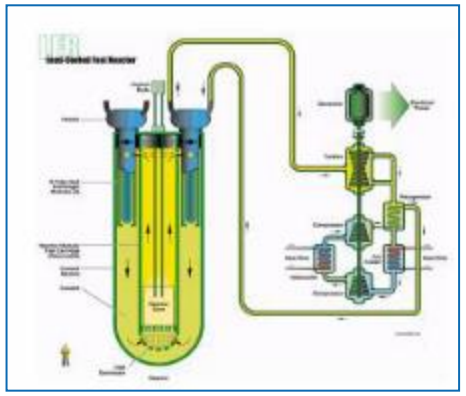
# GIF Goals for Generation-IV Reactor Systems

- Sustainability
  - Long term fuel supply
  - Minimize waste and long term stewardship burden
- Safety & Reliability
  - Very low likelihood and degree of core damage
  - Eliminate need for offsite emergency response
- Economics
  - Life cycle cost advantage over other energy sources
  - Financial risk comparable to other energy projects
- Proliferation Resistance & Physical Protection
  - Unattractive materials diversion pathway
  - Enhanced physical protection against terrorism

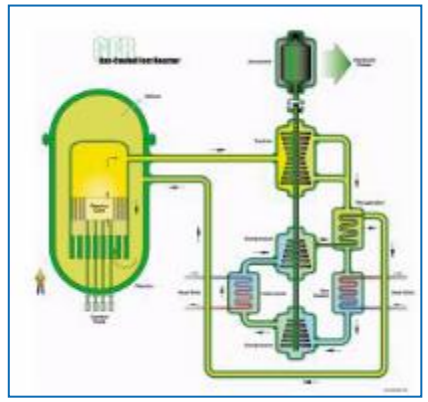
# Gen-IV Nuclear Reactor Systems



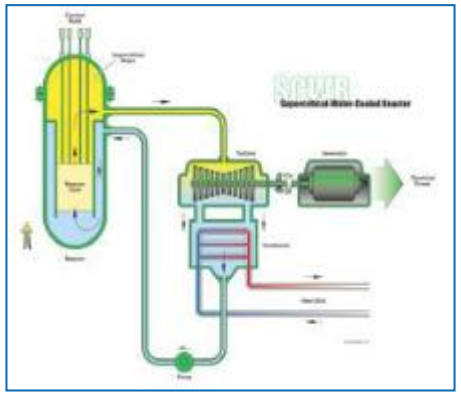
Sodium-cooled Fast Reactor (SFR)



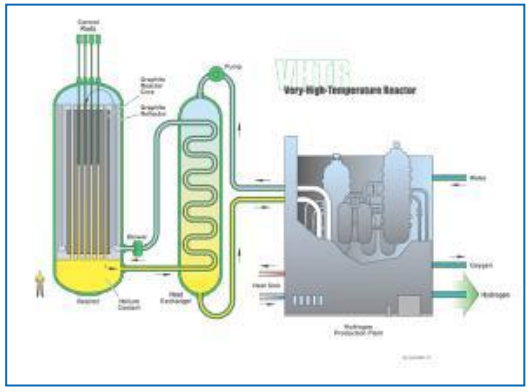
Lead-cooled Fast Reactor (LFR)



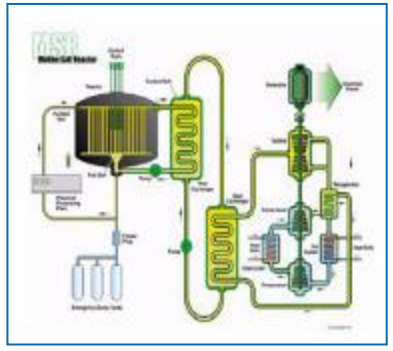
Gas-cooled Fast Reactor (GFR)



Supercritical Water cooled Reactor (SCWR)



Very High Temperature Reactor (VHTR)



Molten Salt Reactor (MSR)

# Comparisons of Major Specifications

| System | Neutron Spectrum | Coolant | Outlet temp. (Degree C) | Fuel cycle |
|---|---|---|---|---|
| Sodium-cooled Fast Reactor (SFR) | Fast | Sodium | 500-550 | Closed |
| Lead-cooled Fast Reactor (LFR) | Fast | Lead | 480-570 | Closed |
| Gas-cooled Fast Reactor (GFR) | Fast | Helium | 850 | Closed |
| Molten Salt Reactor (MSR) | Thermal/ Fast | Fluoride/Chloride salts | 700-800 | Open/ Closed |
| Supercritical Water-cooled Reactor (SCWR) | Thermal/ Fast | Water | 510-625 | Open/ Closed |
| Very High Temperature Reactor (VHTR) | Thermal | Helium | 900-1000 | Open |

# Involvement of GIF Members in R&D on Gen-IV systems

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SFR** | | | ● | ● | ● | ● | ● | | | ● | ● | ● |
| **VHTR** | ● | ● | ● | ● | ● | ● | | | ● | ● | ● | ● |
| **LFR** | | | ● | | ● | ● | ● | | | ● | | ● |
| **SCWR** | | ● | ● | | ● | | ● | | | | | ● |
| **GFR** | | | | ● | ● | | | | | | | ● |
| **MSR** | ● | ● | | ● | | | ● | | ● | ● | | ● |

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Non active members

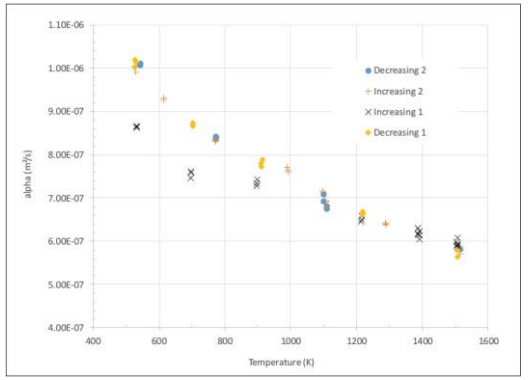
# Recent Gen-IV SFR Highlights

- **Most active GIF system (together with VHTR) with four R&D Projects:**
  - System Integration and Assessment (SIA)
  - Safety and Operations (S&O)
  - Advanced Fuels (AF)
  - Component Design and Balance of Plant (CD&BOP)
- **Five SFR Design Tracks guide the R&D activities:**
  - Loop Option (JSFR Design Track)
  - Pool Option (KALIMER-600, ESFR, and BN1200 Design Tracks)
  - Small Modular Option (AFR-100 Design Track)
- Revision of **SFR System Research Plan** was completed and approved by System Steering Committee in October 2019

- Demonstration SFR units being pursued worldwide: BN-800 operating in Russia, CFR-600s under construction in China, Natrium Project starting in United States
- Active R&D Programs in each Member country looking at enhancing safety of Generation-IV SFRs and improving the economics

Construction site of CFR-600

ESFR-SMART
sodium fast reactor safety




Thermal diffusivity measurements of $(U,Am)O_{2-x}$ at JRC Karlsruhe

Figures from:
https://world-nuclear-news.org/Articles/China-starts-building-second-CFR-600-fast-reactor
http://esfr-smart.eu/

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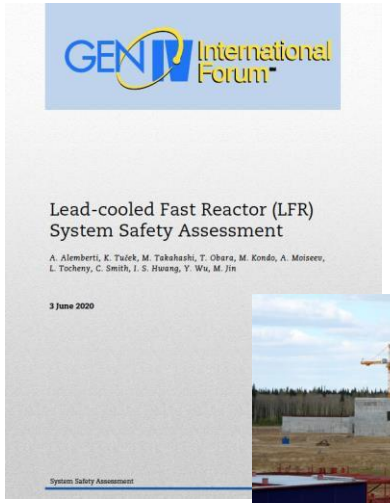
# Recent Gen-IV LFR Highlights

- Within GIF, six LFR Members work under the framework of a MoU
- Activities concentrate on the development of top-level reports
  - **LFR System Safety Assessment (SSA)** was published in June 2020
  - **White Paper on the LFR PRPP aspects** has been published in cooperation with GIF PRPPWG
  - **LFR Safety Design Criteria (SDC)** document was completed in 2021 in collaboration with GIF RSWG.

- The licensing of the **BREST** LFR research demonstrator is currently being completed with site preparations ongoing in Tomsk, Russian Federation
- In Europe: Two main projects: (i) **MYRRHA** R&D infrastructure (ADS demonstrator) under construction in Belgium; and (ii) LFR demonstrator **ALFRED** in Romania
- Active R&D Programs in each Member country (e.g., GEMMA, PATRICIA, and PASCAL in EU) looking at enhancing safety of Generation-IV LFRs and improving the economics




Site preparations for the BREST-OD-300 construction

GEMMA

PATRICIA

PASCAL

Figures from:
https://www.gen-4.org/gif/upload/docs/application/pdf/2020-06/gif_lfr_ssa_june_2020_2020-06-09_17-26-41_202.pdf
https://www.riatomsk.ru/article/20201109/seversk-brest-300-sroki/
http://www.eera-jpnm.eu/gemma/
https://patricia-h2020.eu/
https://cordis.europa.eu/project/id/847715
https://cordis.europa.eu/project/id/945341

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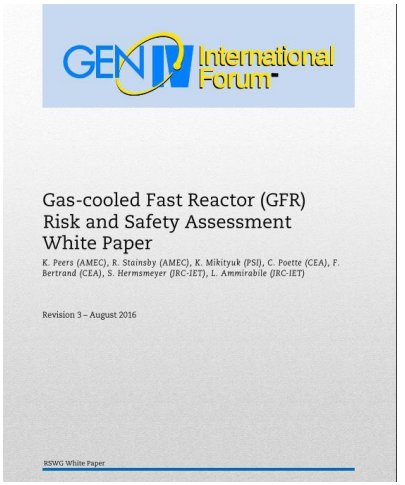
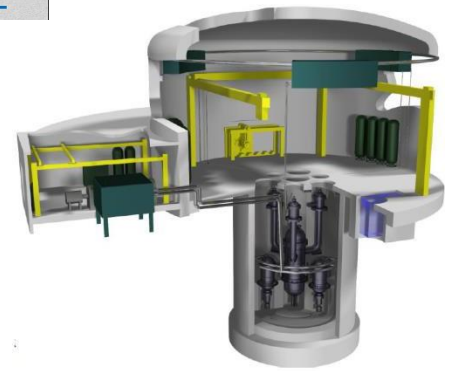
# Recent Gen-IV GFR Highlights

- GFR System Arrangement signed by Euratom, France, and Japan
  - Existing **Project Arrangement** on Conceptual Design and Safety
  - Provisional project on Fuel, Core materials, and Fuel Cycle
  - Proposed project on GFR Technology
- Development of **GFR reference documents**
  - GFR Risk and Safety Assessment White Paper (completed in 2016)
  - GFR System Safety Assessment (draft)
  - GFR Safety Design Criteria (draft)




- The V4G4 Centre demonstration project ALLEGRO (75 MWt) is used to guide the GIF R&D collaborations
- For example the Euratom R&D project **SafeG**, among others aiming at:
  - strengthening of inherent safety
  - resolving remaining open questions in residual heat removal in accident conditions

ALLEGRO concept



Figures from:
https://www.gen-4.org/gif/upload/docs/application/pdf/2016-10/rswg_gfr_white_paper_final_2016.pdf
https://cordis.europa.eu/project/id/945041

# Recent Gen-IV MSR Highlights

- A large interest around the MSR technology, with more than 40 concepts of a large variety being developed worldwide
- Within GIF, the MSR system is currently 7 Members under a Memorandum of Understanding (MoU)
- Both solid and liquid-fueled MSRs are considered
- Three (3) **Project Arrangements** are under development:
  - Fuel and coolant salt properties
  - Materials and components
  - System integration and cross-cutting issues

- **Demonstration MSRs being pursued worldwide:**
  - Euratom collaborative project **SAMOSAFER** focuses on development of for fast spectrum system
  - Prototype MSR - TMSR-LF1 - is under construction in China
  - Demonstration Kairos thermal (solid fuel, salt coolant) low-power demo and Southern fast Molten Chloride Reactor Experiment in Untied States

TMSR-LF1

SAMOSAFER


Successful synthesis of $UCl_4$ at JRC Karlsruhe

Figures from:
https://samosafer.eu/

# Evolving Mission of GIF

- Generation-IV reactor technologies are entering the Demonstration Phase
  - Collaborations need to adapt to reflect key challenges
  - Enhanced interaction with industry designers and operators is vital
  - Engagement with regulators also important (SDC/SDG and beyond)
- Task Forces formed to pursue innovative application and deployment issues
  - Education and Training:  knowledge management and sustained expertise
  - Advanced Manufacturing: how to utilize modern AM and materials in Gen-IV reactors
  - Non-Electric Applications: extending the flexibility and impact of nuclear heat
- Continue Working Groups on key GIF Goals
  - Risk and Safety Working Group
  - Proliferation Resistance and Physical Protection Working Group
  - Economic Modeling Working Group

# Safety document development for GIF reactor systems

- System Design Criteria (SCE) and Design Guidelines (SDG) being developed

| | White Paper on ISAM Implement. | System Safety Assessment | Safety Design Criteria/Guidelines* |
|---|---|---|---|
| SFR | Completed | Completed<br>https://www.gen-4.org/gif/jcms/c_9366/risk-safety | SDC-Completed<br>1st SDG-Completed<br>2nd SDG-under review |
| VHTR | Completed | Completed | GIF is observing IAEA-CRP for SDC |
| LFR | Completed | Completed | SDC-under preparation<br>SDC Report submitted to IAEA for review in 2021 |
| SCWR | Completed | Completed | Not needed |
| GFR | Completed | Completed | SDC-under preparation |
| MSR | Under preparation | Under preparation | Under planning |

* https://www.gen-4.org/gif/jcms/c_93020/safety-design-criteria

# Summary

- Generation-IV Reactor Systems in GIF
  - GIF Goals; Sustainability, Safety and Reliability, Economy, PRPP
  - Six Technology Options: VHTR, SFR, LFR, GFR, MSR, SCWR
- Fast Reactor Options in GIF
  - SFR – 8 countries engaged, 4 technical Projects
  - LFR – 6 country MOU
  - GFR – 3 countries engaged, 1 technical Projects with others pending
  - MSR – fast options in 7 country MOU
  - SCWR – some fast alternative, 5 countries, 3 technical Projects
- Recent Highlight in System Collaborations
  - Emerging Demonstration Projects
  - Safety Design Criteria and Guidelines development
  - PRPP White Papers
- New Initiatives to Address Key Gen-IV Deployment Issues
  - Non-Electric Application of Nuclear Heat
  - Advanced Manufacturing and Materials Engineering
  - Continued Education and Training opportunities (e.g., GIF Webinar series)