GIF and Generation-IV

Motivations and objectives

The Generation IV International Forum, or GIF, was chartered in July 2001 to lead the collaborative efforts of the world's leading nuclear technology nations to develop next generation nuclear energy systems to meet the world's future energy needs.

Taking into account the expected increase in energy demand worldwide and the growing awareness about global warming, climate change issues and sustainable development, nuclear energy will be needed to meet future global energy demand.

Nuclear power plant technology has evolved as distinct design generations:

- First Generation: prototypes, and first realisations (~1950-1970)
- Second Generation: current operating plants (~1970-2030)
- Third generation: deployable improvements to current reactors (~2000 and on).
- Fourth generation: advanced and new reactor systems (2030 and beyond)

Eight technology goals have been defined for Generation IV systems in four broad areas: sustainability, economics, safety and reliability, and proliferation resistance and physical protection (http://gifdev/PDFs/GenIVRoadmap.pdf). These ambitious goals are shared by a large number of countries as they aim at responding to economic, environmental and social requirements of the 21st century. They establish a framework and identify concrete targets for focusing GIF R&D efforts

Goals for Generation IV Nuclear Energy Systems

Sustainability-1 *Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilization for worldwide energy production.*

Sustainability-2 *Generation IV nuclear energy systems will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.*

Economics-1 *Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.*

Economics-2 *Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.*

Safety and Reliability-1 *Generation IV nuclear energy systems operations will excel in safety and reliability.*

Safety and Reliability-2 *Generation IV nuclear systems will have a very low likelihood and degree of reactor core damage.*

Safety and Reliability-3 *Generation IV nuclear energy systems will eliminate the need for offsite emergency response.*

Proliferation resistance and Physical Protection *Generation IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.*

The next generation (“Generation IV”) of nuclear energy systems is intended to meet the above goals (while being at least as effective as the “third” generation in terms of economic competitiveness, safety and reliability) in order to provide a sustainable development of nuclear energy.

In principle, the Generation IV Systems should be marketable or deployable from 2030 onwards. The systems should also offer a true potential for new applications compatible with an expanded use of nuclear energy, in particular in the fields of hydrogen or synthetic hydrocarbon production, sea water desalination and process heat production.

It has been recognized that these objectives, widely and officially shared by a large number of countries, should be at the basis of an internationally shared R&D program, which allows keeping open and consolidating the technical options, and avoiding any early or premature down selection.

In fact, because the next generation nuclear energy systems will address needed areas of improvement and offer great potential, many countries share a common interest in advanced R&D that will support their development. Such development benefits from the identification of promising research areas and collaborative efforts that should be explored by the international research community. The collaboration on R&D by many nations on the development of advanced next generation nuclear energy systems will in principle aid the progress toward the realization of such systems, by leveraging resources, providing synergistic opportunities, avoiding unnecessary duplication and enhancing collaboration.

GIF structure and method of work

The founding document of Generation IV International Forum, the *GIF Charter* (http://gifdev/PDFs/GIFcharter.pdf), was signed first in July 2001 by Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, the United Kingdom and the United States. Subsequently, Switzerland in 2002, Euratom in 2003, and most recently the People's Republic of China and the Russian Federation, both in November 2006, signed the Charter.

As of November 2007, twelve countries and Euratom had signed the GIF Charter. Signature of the Charter signifies interest in cooperation on Generation IV systems but does not commit the signatory to take part in the cooperative development of these systems.

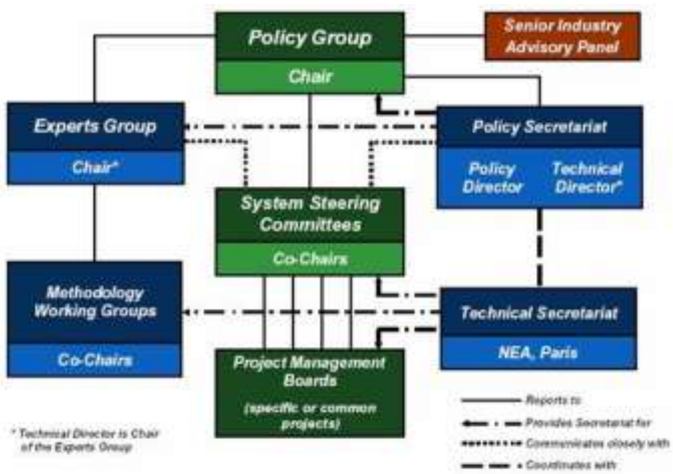
Among the signatories of the Charter, eight Members – Canada, Euratom, France, Japan, the People’s Republic of China, the Republic of Korea, Switzerland and the United States – have signed a *Framework Agreement*. Signatories of the Framework Agreement (FA) formally agree to participate in the development of one or more Generation IV systems.

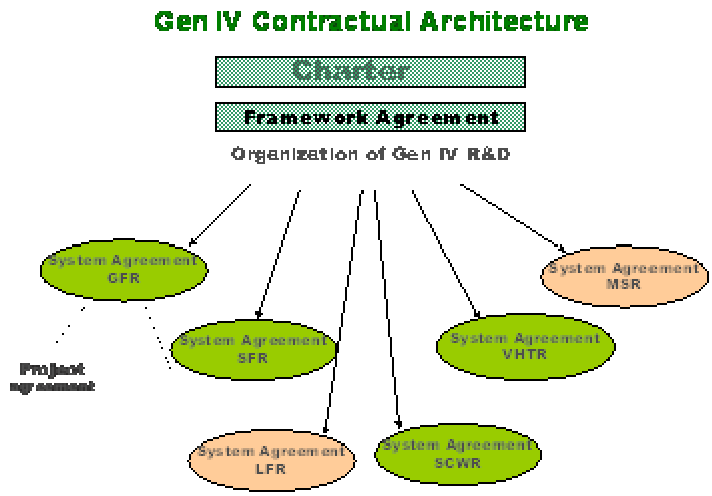
Meetings of GIF began in January 2000 when the US Department of Energy's (DOE) Office of Nuclear Energy, Science and Technology convened a group of senior governmental representatives from the original nine countries to begin discussions on international collaboration in the development of Generation IV nuclear energy systems. The group, subsequently named the Policy Group of the GIF, also decided to form a group of senior technical advisors (the Experts Group) to explore areas of mutual interest and make recommendations regarding both the research and development areas which are to be explored and the processes by which collaboration could be conducted and assessed.

This Experts Group first met in April 2000. The entire GIF continues to hold regular meetings in its member countries

To help the GIF to account for the opinions of non-member countries and to identify opportunities to work with the relevant international organisations, the GIF Charter welcomes the participation of the International Atomic Energy Agency and the OECD Nuclear Energy Agency as permanent observers.

Structure of the Gen IV International Forum





In a first phase (2000-2002), the GIF collaboration selected a number of preferred reactor systems as a primary focus from the many alternatives and suggestions, and has established the first R&D Roadmap.

In a second phase (2002-2005), the R&D Plans for each system were developed, including a formal framework that has defined, after extensive negotiation, and accounts for issues of intellectual property etc, according to the different practices in the different countries. This phase was completed with the signature of an intergovernmental agreement (the Framework Agreement) on the 26 of February 2005 which has been signed so far/ to date by the those active Members confirming their participation, namely, Canada, Euratom, France, Japan, Republic of Korea, Switzerland, and the United States, with others expected shortly.

A new phase has started in 2006 with the definition of specific and formal agreements (the System Arrangements) for each of the selected systems and with the definition of specific R&D projects within each System Agreement. A formal working group and project management structure was also evolved for each project, with participation from those interested in and actively pursuing the development work.

Moreover, for subjects common to all systems, the **GIF Methodology Working Groups** (Proliferation Resistance and Physical Protection, **PRPP WG**, Economic Modelling, **EMWG**, and Risk and Safety, **RSWG** Working Groups) have continued to evolve methodology in each of the major crosscutting areas (report on “PRPP methodology framework”, “Report on Cost Estimation Guidelines for Generation IV Systems”, and draft “Report on the Safety of Generation IV Systems”)**.**

Technical Choices of GIF

The initial guidance was from the Roadmap which was initiated in October 2000 and completed in 2002. The Generation IV Technology Roadmap (link), prepared by GIF member countries, identified six promising reactor system and fuel cycle concepts, along with the research required to study them concepts in view of potential deployment and/or commercialization. The Roadmap is expected to be periodically reviewed and updated.

The goals adopted by GIF provided the basis for identifying and selecting six nuclear energy systems for further development. The six selected systems employ a variety of reactor, energy conversion and fuel cycle technologies. Their designs feature thermal and fast neutron spectra, closed and open fuel cycles and a wide range of reactor sizes from very small to very large. Depending on their respective degrees of technical maturity, the Generation IV systems are expected to become available for commercial introduction in the period between 2015 and 2030 or beyond. The trajectory from current nuclear systems to Generation IV systems is described in the Roadmap report issued in 2002 under the title "A Technology Roadmap for Generation IV Nuclear Energy Systems" (http://gifdev/PDFs/GenIVRoadmap.pdf).

All Generation IV systems have features aiming at performance improvement, new applications of nuclear energy, and/or more sustainable approaches to the management of nuclear materials. High-temperature systems offer the possibility of efficient process heat applications and eventually hydrogen production. Enhanced sustainability is achieved primarily through adoption of a closed fuel cycle with reprocessing and recycling of plutonium, uranium and minor actinides using fast reactors; this approach provides significant reduction in waste generation and uranium resource requirements. The following Table summarizes the main characteristics of the six Generation IV systems.

Overview of Generation IV Systems

System	Neutron spectrum	Coolant	Temp. °C	Fuel cycle	Size (MWe)
VHTR (Very high temperature gas reactor)	thermal	helium	900 to 1000	open	250-300
SFR (Sodium-cooled fast reactor)	fast	sodium	550	closed	30-150, 300-1500, 1000-2000
SCWR (Supercritical water-cooled reactor)	thermal/ fast	water	510-625	Open/ closed	300-700 1000-1500
GFR (Gas-cooled fast reactor)	fast	helium	850	closed	1200
LFR (Lead-cooled fast reactor)	fast	lead	480-800	closed	20-180, 300-1200, 600-1000
MSR (Molten salt reactor)	epithermal	fluoride salts	700-800	closed	1000

A brief summary of each system follows.

VHTR – The very-high temperature reactor is a next step in the evolutionary development of high-temperature reactors. The VHTR is a helium gas-cooled, graphite-moderated, thermal neutron spectrum reactor with a core outlet temperature greater than 900°C, and a goal of 1000°C, sufficient to support production of hydrogen by thermo-chemical processes. The reference reactor thermal power is set at a level that allows passive decay heat removal, currently estimated to be about 600 MWth. The VHTR is primarily dedicated to the cogeneration of electricity and hydrogen, as well as to other process heat applications. It can produce hydrogen from water by using thermo-chemical, electro-chemical or hybrid processes with reduced emission of CO_2 gases. At first, a once-through LEU (<20% ^{235}U) fuel cycle will be adopted, but a closed fuel cycle will be assessed, as well as potential symbiotic fuel cycles with other types of reactors (especially light-water reactors) for waste reduction.

SFR – The sodium-cooled fast reactor system uses liquid sodium as the reactor coolant, allowing high power density with low coolant volume fraction. The reactor can be arranged in a pool layout or a compact loop layout. Reactor size options under consideration range from small (50 to 300 MWe) modular reactors to larger reactors (up to 1500 MWe). The two primary fuel recycle technology options are advanced aqueous and pyrometallurgical processing. A variety of fuel options are being considered for the SFR, with mixed oxide preferred for advanced aqueous recycle and mixed metal alloy preferred for pyrometallurgical processing. Owing to the significant past experience accumulated with sodium cooled reactors in several countries, the deployment availability of SFR systems is targeted for 2020.

SCWR – Supercritical-water-cooled reactors are a class of high-temperature, high-pressure water-cooled reactors operating with a direct energy conversion cycle and above the thermodynamic critical point of water (374°C, 22.1 MPa). The higher thermodynamic efficiency and plant simplification opportunities afforded by a high-temperature, single-phase coolant translate into improved economics. A wide variety of options are currently considered: both thermal-neutron and fast-neutron spectra are envisaged and both pressure vessel and pressure tube configurations are considered. The operation of a 30 to 150 MWe technology demonstration is targeted for 2022.

GFR – The main characteristics of the gas-cooled fast reactor are fissile self-sufficient cores with fast neutron spectrum, robust refractory fuel, high operating temperature, high efficiency electricity production, energy conversion with a gas turbine and full actinide recycling possibly associated with an integrated on-site fuel reprocessing facility. A technology demonstration reactor needed to qualify key technologies could be put into operation by 2020.

LFR – The lead-cooled fast reactor system is characterized by a fast-neutron spectrum and a closed fuel cycle with full actinide recycling, possibly in central or regional fuel cycle facilities. The coolant could be either lead (preferred option), or lead/bismuth eutectic. The LFR can be operated as a breeder; a burner of actinides from spent fuel, using inert matrix fuel; or a burner/breeder using thorium matrices. Two reactor size options are considered: a small transportable system of 50 to 150 MWe with a very long core life and a medium system of 300 to 600 MWe. In the long term a large system of 1200 MWe could be envisaged. The LFR system may be deployable by 2025.

MSR – The molten-salt reactor system embodies the very special feature of a liquid fuel. MSR concepts, which can be used as efficient burners of TRU from spent LWR fuel, have also a breeding capability in any kind of neutron spectrum ranging from thermal (with a thorium based fuel cycle) to fast (with the U-Pu fuel cycle). Whether configured for burning or breeding, MSRs have considerable promise for the minimization of radiotoxic nuclear waste.

A major step forward: the Project arrangements

Within each System Arrangement, a limited number of common R&D Projects has been defined, with well defined deliverables, milestones and time schedule, and within a clearly defined contractual framework.

Multi-annual projects have been signed in the SFR area: e.g. on ***Advanced Fuels*****,** with the objective to perform the required R&D to develop innovative fuels with minor actinides (Am, Cm) and the ***GACID*** (Global Actinide Cycle International Demonstration) project, aiming at demonstrating industrial feasibility of minor actinide recycling in homogeneous mode and on oxide fuel support, is also close to be signed.

More projects have already been discussed and negotiated in the area of VHTRs, GFRs and SCWRs and are expected to be signed soon.

Finally, it should be mentioned that the GIF perimeter only covers the feasibility and performance phases of R&D, and not its demonstration phase. Therefore, prototypes are not one of the Forum's prerogatives. Instead, it focuses on encouraging and organising cooperation in R&D between countries to produce the technological building blocks for nuclear power in the 21^{st} century. However, the Forum wishes to see interim demonstrations, the results of which will help guide further R&D. An operational prototype by 2020 would not include all Gen-IV developments, but would certainly be very useful in helping validate both initial results and the overall approach.