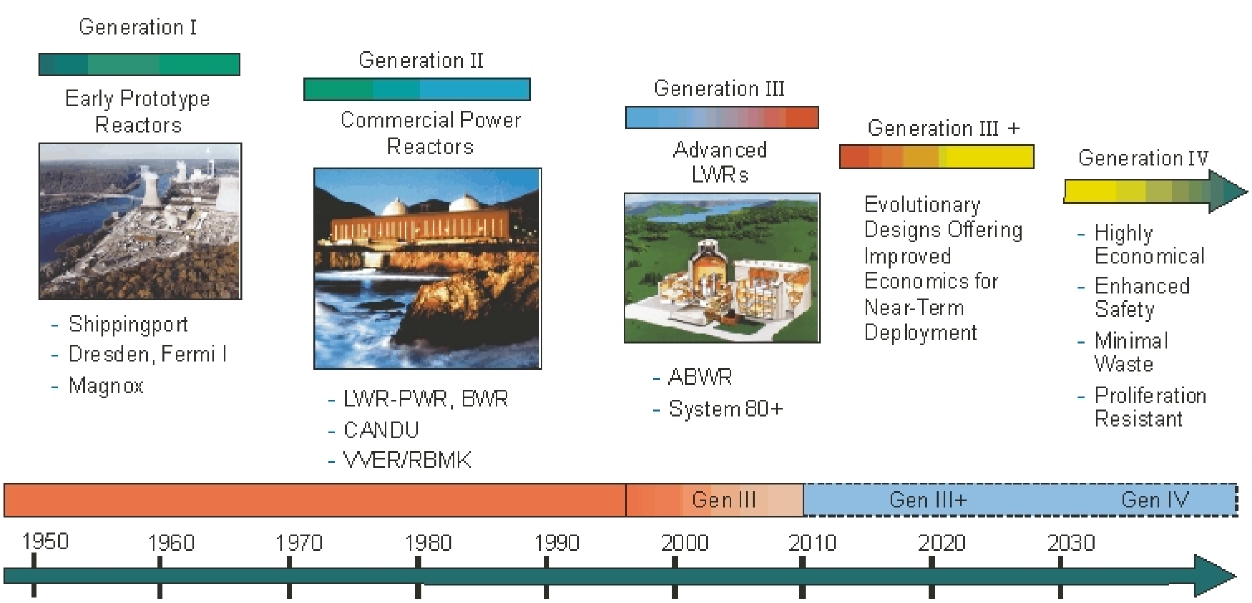
THE GENERATION IV NUCLEAR ENERGY SYSTEMS TECHNOLOGY ROADMAP

H. Khalil (ANL, USA), R. Bennett (INEEL, USA), R. Versluis (DOE-NE, USA)

Many of the world's nations, both industrialized and developing, believe that a greater use of nuclear energy will be required to meet their future energy and environmental quality needs. To enable nuclear energy to meet an expanded worldwide role, ten countries—Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, Switzerland, the United Kingdom, and the United States—have been cooperating to advance a new generation of nuclear energy systems. These systems, known as Generation IV, are to be deployable no later than 2030 in developed and developing countries, for generation of electricity and other energy products such as hydrogen for use as transportation fuel and fresh water for world regions facing future shortages.

The figure below gives an overview of the generations of nuclear energy systems. The first generation was operated in the 1950s and 60s as early prototype reactors. The second generation began in the 1970s in the large commercial power plants that are still operating today. Generation III was developed more recently in the 1990s with a number of evolutionary designs that offer significant advances in safety and economics, and a number have been built, primarily in East Asia. Advances to Generation III are underway, resulting in several (so-called Generation III+) near-term deployable plants that are actively under development and are being considered for deployment in several countries. New plants built between now and 2030 will likely be chosen from these plants. Beyond 2030, the prospect for innovative advances through renewed R&D has stimulated interest worldwide in a fourth generation of nuclear energy systems.



The ten countries have joined together to form the Generation IV International Forum (GIF) to develop future-generation nuclear energy systems that can be licensed, constructed, and operated in a manner that will provide competitively priced and reliable energy products while satisfactorily addressing nuclear safety, waste, proliferation, and public perception concerns. The objective for Generation IV nuclear energy systems is to have them available for international deployment about the year 2030, when many of the world's currently operating nuclear power plants will be at or near the end of their operating licenses.

Nuclear energy research programs around the world have been developing concepts that could form the basis for Generation IV systems. Beginning in 2000, the countries constituting the GIF began meeting to discuss the research necessary to support next-generation reactors. From those initial meetings a Technology Roadmap to guide the Generation IV effort was begun. Roadmapping is a methodology used to define, gain consensus for, and manage the planning and execution of large-scale R&D efforts. The GIF agreed to support the preparation of a roadmap, and the roadmap became the focal point of their efforts. More than one hundred technical experts from ten countries have contributed to its preparation.

Preparations for the Generation IV Technology Roadmap required the establishment of goals for Generation IV systems. The goals have three purposes: First, they serve as the basis for developing criteria to assess and compare candidate systems. Second, they are challenging and stimulate the search for innovative nuclear energy systems—both fuel cycles and reactor technologies. Third, they will serve to motivate and guide R&D on Generation IV systems as collaborative efforts get underway.

Generation IV goals are defined in the four broad areas of sustainability, economics, safety and reliability, and proliferation resistance and physical protection. Sustainability goals focus on fuel utilization and waste management. Economics goals focus on competitive life cycle and energy production costs and financial risk. Safety and reliability goals focus on safe and reliable operation, accident avoidance and minimization of consequences, investment protection, and eliminating the technical need for off-site emergency response. The proliferation resistance and physical protection goal focuses on safeguarding nuclear materials and facilities.

Six Generation IV systems have been selected by the GIF to meet the specified technology goals. Each system comprises the nuclear reactor and its energy conversion systems, as well as the necessary facilities for the entire fuel cycle, from ore extraction to final waste disposal. The following systems, listed alphabetically, were selected to Generation IV by the GIF:

Generation IV System	Acronym
Gas-Cooled Fast Reactor System	GFR
Lead-Cooled Fast Reactor System	LFR
Molten Salt Reactor System	MSR
Sodium-Cooled Fast Reactor System	SFR
Supercritical Water-Cooled Reactor System	SCWR
Very-High-Temperature Reactor System	VHTR

The motivation for the selection of these six systems is to:

- Achieve significant advances toward the technology goals
- Ensure that the important missions of electricity generation, hydrogen and process heat production, and actinide management may be adequately addressed by Generation IV systems

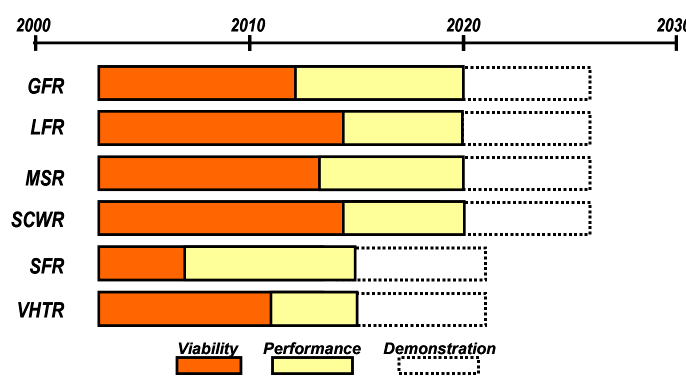
- Provide some overlapping coverage of capabilities, because not all of the systems may ultimately be viable or attain their performance objectives and attract commercial deployment
- Accommodate the range of national priorities and interests of the GIF countries.

The Generation IV Technology Roadmap describes the system evaluation and selection process, introduces the six Generation IV systems chosen by the GIF, summarizes R&D activities and priorities for the systems, surveys system-specific R&D needs for all six systems, and collects crosscutting R&D in areas of common interest to several or all systems. Crosscutting R&D is defined in the areas of Fuel Cycle, Fuels and Materials, Energy Products, Risk and Safety, Economics, and Evaluation Methodologies.

The scope of the R&D described in the Roadmap covers all of the Generation IV systems. However, with six most promising Generation IV systems and ten countries in the GIF, the approach to building integrated programs for any of the systems becomes an important issue. The GIF countries have expressed a strong interest in collaborative R&D on Generation IV systems. However, it has been acknowledged that each country will participate only in the systems that they choose to advance. In light of the considerable resources required for the development of any Generation IV system—roughly US$1 billion each—not all six systems are likely to be chosen for collaborations. For systems that are chosen, participating countries will need to assemble the priority R&D for the system and the necessary crosscutting R&D, and then set the desired pace for the program. The technology roadmap has been structured to allow the independent assembly of collaborative R&D programs. Thus, the roadmap provides a foundation for formulating national and international program plans on which the GIF countries will collaborate to advance Generation IV systems.

With regard to the timing of programs, the figure shows a summary of the expected duration of the R&D activities for each of the systems. This R&D is organized into two phases, viability and performance. Viability R&D is designed to answer basic feasibility and proof-of-principle questions; performance R&D undertakes engineering scale development and optimization to desired levels of performance. It is apparent that the systems are not projected to complete their viability and performance phases at the same time. For each of the systems chosen for collaboration, the GIF will need to periodically assess the success of the R&D and progress toward achieving the Generation IV goals. The technology roadmap includes R&D on evaluation methodology that will support the need for these continuing assessments. Assuming successful completion of the viability and performance R&D for a particular system, at least six years and several US$ billion will be required for detailed design and construction of a demonstration system.

System Development Timelines



The GIF plans to focus their future meetings on the development of collaborative programs on several systems. Of considerable interest is the participation of industry in the Generation IV program, and its growth as the systems advance. While the prospects for demonstration and entry into commercial markets are a number of years into the future, the need exists for early involvement of industry to provide direction and keep a focus on the requirements for the systems. Interactions with regulatory authorities are planned as system development progresses to enable the regulator to understand the system design features and technologies and provide feedback on licensing issues. To enhance public confidence, the findings of the Roadmap and the R&D plans developed based on it will be communicated to the public on a continuing basis, and mechanisms for communicating with interested stakeholder groups will be developed so that their views on the program are considered and, to the extent possible, incorporated into the objectives of the R&D program.