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Generation IV International Forum: A decade of progress through international cooperation

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ABSTRACT

The Generation IV International Forum has marked significant progress in developing a next generation of reactor technologies that break out of the limitations of currently deployed nuclear energy systems. In slightly more than 10 years, the Forum down selected to the six most promising systems, forged a powerful framework for multilateral cooperation, organized itself into the necessary functional groups, created four overarching research objectives, established a dozen international projects, and completed hundreds of milestones. The Forum has focused research on viability and performance issues. A revised technology development roadmap completed in 2013 lays out the research agenda for the next decade. This paper summarizes the overall accomplishments of the Forum and the development status of the six advanced reactor systems. Accompanying papers describe the related research and development activities for each system.

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1. Introduction

The Generation IV International Forum (GIF) is the leading organization for multinational collaboration on research and development (R&D) for advanced nuclear energy systems. (Bouchard and Bennett, 2008; Nuclear News, September 2013) In the dozen years since nine countries signed the original charter, GIF has made estimable progress that includes developing a legal framework for cooperation; establishing overarching goals for Generation IV reactors; selecting six promising advanced reactor concepts for development from among 130 proposals; establishing formal system arrangements for four of the systems and provisional arrangements for the other two; setting up 11 current R&D projects; establishing a policy group, an experts group, systems steering committees, and project management boards to conduct and oversee the work; establishing working groups to develop tools for measuring progress against goals; setting up temporary task forces to address hot-button issues such as thorium fuel cycles, advanced modelling and simulation, safety design criteria, and small modular reactors; and, providing a catalyst for reenergizing indigenous nuclear energy R&D programs around the globe. By mid-2013, some 650 research deliverables had been received from GIF participants. The current number of signatories is 13, of which ten are active members.

The Forum was born of necessity. By the close of the twentieth century, nuclear electricity generation was considered to be a mature technology. Nuclear energy research programs were failing to spark much enthusiasm in national legislatures, most notably in the United States. Several like-minded nations, agreeing that a bold new idea was needed, convened in Washington, DC, in January 2000 to discuss development of next-generation technologies. Those first deliberations set in motion an international resolve to collaborate on the development of a completely new generation of nuclear reactor systems and ultimately the creation of the Generation IV International Forum to manage the collaboration.

The essential pieces quickly fell into place and the nine founding members (Argentina, Brazil, Canada, France, Japan, Republic of Korea, Republic of South Africa, United Kingdom and United States) signed the GIF Charter in July 2001. A twenty-first century organization was created, i.e., a virtual organization without a bricks and mortar address or a heavy bureaucracy. The Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) was chosen to provide the technical secretariat for GIF. It was up to each member to provide staffing for the working groups and committees that fell within its areas of interest. Between 2002 and 2006, Switzerland, Euratom, Russian Federation, and People's Republic of China added signatures to the GIF Charter. Argentina, Brazil and United Kingdom are not currently active participants.

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For a variety of practical reasons, most GIF member states have separately negotiated bi-lateral and tri-lateral cooperative R&D agreements, i.e., GIF does not have a monopoly on international collaboration. However, the GIF Framework is the most powerful legal vehicle for multilateral cooperation in advanced nuclear technology development. The Framework took about three years to negotiate, with first signatures collected in 2005. While the legal teams hammered out the Framework Agreement, the technical teams embarked on a major collective effort to complete a Technology Roadmap for Generation IV Nuclear Energy Systems, (A Technology Roadmap, 2013) published in December 2002. The first GIF project arrangements were signed in 2006. GIF will issue a revised technology roadmap in early 2014.

Detailed achievements for the six GIF reactor systems are covered in companion papers (Taylor, 2011; Alemberti et al., 2014; Serp et al., 2014; Aoto et al., 2014; Schulenberg et al., 2014; Fütterer et al., 2014) in this special Generation IV *issue of Progress in Nuclear Energy*. This overview provides a top-level comparison of the systems, the overarching goals that drive their development, unique GIF tools for measuring progress against the goals, the alignment of collaborating members for each system, and the outcome of topical studies completed by appointed task forces. Most of the material covered here can be found in greater detail in annual reports (GIF 2012 Annual Report, 2013) and symposia proceedings (GIF R and D Outlook, 2009) on the GIF public website http://www.gen-4.org/. A more comprehensive overview of the six reactor systems can be found in the article on *Introduction to Generation-IV Fission Reactors* in the *Wiley Encyclopedia of Nuclear Energy* (McFarlane, 2011) published in 2011.

2. Generation IV goals

The founders of GIF established an ambitious set of high-level goals for the systems—targets that if achieved would ensure their relevance in the competitive energy market, as well as pave the way for broad public acceptance, and clearly distinguish them from current commercial reactors and fuel cycles. The four pillars of Generation IV development are sustainability, economics, safety, and proliferation resistance:

1. *Sustainability*: Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel. They will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden in the future, thereby improving protection for the public health and the environment.
2. *Economics*: Generation IV nuclear energy systems will have a clear lifecycle cost advantage over other energy sources. They will have a level of financial risk comparable to other energy projects.
3. *Safety and Reliability*: Generation IV nuclear energy systems operations will excel in safety and reliability. Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage, and they will eliminate the need for offsite emergency response.
4. *Proliferation Resistance and Physical Protection*: Generation IV nuclear energy systems will increase the assurance that they are a 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 expectations for Generation IV systems were set very high in order to drive the research agenda. It was recognized from the outset that no single approach was likely to dominate in all four categories. The low bar was the third generation of light water reactors (LWRs)—machines optimized for reliable energy production, possessing very good safety characteristics, with relatively predictable economics, and a well-established safeguards regime. The advanced LWRs are, however, inefficient users of uranium resources and provide only modest options for recycle and waste minimization.

3. Methodology working groups and task forces

At inception, the Generation IV International Forum established the Experts Group, a technical support organization for the policymakers. Concurrently, three standing groups were formed to assess how well the systems were measuring up to the goals. Each of these groups reports to the Experts Group, but operates independently and in cooperation with other organizations. Several temporary task forces have also been formed to look at such specific issues.

A notable success of the forum has been the production of methodologies for measuring the progress of the reactor systems towards meeting three of the four major goals—safety, economics, and nonproliferation. The sustainability goal primarily addresses fuel cycle issues, which while covered by the GIF charter, has not been systematically investigated within the Forum. The three standing working groups set up to develop the GIF metrics toolbox are:

- Risk and Safety Working Group (RSWG)
- Proliferation Resistance and Physical Protection Working Group (PRPPWG)
- Economic Modeling Working Group (EMWG)

Each of these “horizontal activities” have produced methodologies that are mature relative to the reactor systems, but which may be further refined as the systems move into a demonstration phase. The working groups collaborate with other organizations that are developing similar or complementary methodologies, most notably with projects in the International Atomic Energy Agency (IAEA). More importantly, the working groups coordinate with each of the System Steering Committees (SSC) responsible for GIF collaboration in developing the six advanced reactor concepts. One unanticipated outcome of these horizontal activities is that the methodologies have found applications beyond advanced reactors because they are not unique to a specific technology.

4. Risk and Safety Working Group

The primary objective of the Risk and Safety Working Group is to promote a harmonised approach on safety, risk and regulatory issues in the development of Generation IV systems. The intent of RSWG-developed methodology is to yield useful insights into the nature of safety and risk of Generation IV systems, thereby allowing meaningful evaluations of Generation IV concepts relative to safety objectives. RSWG methodology does not constrain design innovation, either by dictating design requirements or compliance with quantitative safety goals.

The RSWG focused its early work on identification of high-level safety goals, articulation of a cohesive safety philosophy, and discussion of design principles, attributes and characteristics that may help to ensure optimal safety of Generation IV systems. In 2008, the RSWG reported a consensus regarding some of the safety-related attributes and characteristics that should be reflected in Generation IV nuclear systems. Major areas in which consensus have been reached include: