AN OVERVIEW OF GENERATION IV STRATEGY AND OUTLOOK

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I. INTRODUCTION

The importance of reducing greenhouse gas emissions is now almost universally recognized by national policies. Numerous strategies and scenarios are proposed in order to achieve more sustainable future energy supplies. In the majority of these scenarios, nuclear's growth is an essential element. For example the 2008 World Energy Outlook forecasts an additional 250 GWe of nuclear capacity by 2030[1] in a scenario that would stabilize the atmosphere at 450 ppm CO_2 and thereby limit global warming to 2°C above pre-industrial levels. In such a scenario baseload nuclear would complement other forms of clean energy, which are subject to variability, intermittency, and low power density.

Many nations, both heavily industrialized and emerging economies, are driving the growth of nuclear energy. Some 43 new units are under construction in 11 countries, with more projects preparing to move forward.[2] Nevertheless, challenges still exist to further large-scale deployment of nuclear: (1) nuclear energy must become more sustainable from the standpoint of its utilization of nuclear fuel resources as well as the management and disposal of nuclear waste, (2) the units must operate reliably and be economically competitive, (3) their safety must remain of paramount importance, and (4) nuclear deployment must be undertaken in a manner that does not add to concern about proliferation of nuclear weapons. In addition, new technologies should help meet anticipated future needs for a broader range of energy products beyond electricity, and governments should support the revitalization of their nuclear R&D infra–structure.

To meet these challenges and deliver future nuclear energy systems, the Generation IV International Forum is undertaking some of the R&D necessary to develop the next generation of innovative nuclear energy systems that can supplement today's nuclear plants and transition nuclear energy into the long term. Generation IV nuclear energy systems comprise 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.

I.A. Strategy

The Forum's strategy has been to (1) define challenging goals for next generation systems and identify viable candidate technologies that may address them by about 2030, (2) gain participation of the countries leading the world's nuclear development and create a legal framework for their multilateral cooperation, and (3) organize and grow the program and further stimulate the world research community to join the effort.

The first part was addressed in 2000-2002, culminating in the Generation IV Roadmap,[3] that evaluated many concepts and recommended six

systems. The second was addressed in 2003-2005, culminating in the Framework Agreement,[4] a legally binding instrument of the Members that provides for cooperative exchange, creation, ownership and protection of intellectual property in multilateral research contracts. The third is presently taken up with a variety of communications and interactions. The period of 2006-2009 has seen considerable R&D planning and organization, the results of which are being the Forum's Policy Group has recently conducted an exercise in strategic planning that revisits all areas with the expectation of identifying needed changes and actions that keep pace with the changing world situation. This paper reports their results.

I.B. Outlook

In brief, it has been a little more than seven years since the Roadmap was published, and four years since the first signing of the Framework. The former heralded what to work on, the latter provided for how, and the Forum now addresses the question of when by describing the expected accomplishments and emphasis of the next five years in the outlook for the future.[5]

II. SYSTEM TECHNOLOGIES

Each Forum member is free to choose the systems that they will advance, as well as to pursue any options or alternatives to the systems outside of the formally agreed System Research Plan. To understand the various organizational entities that are mentioned here (steering committees, project management boards, methodology working groups, etc.), an overview can be found on the Generation IV website.[6]

With respect to the six Generation IV systems, presented in order of their level of cooperative activity within the Framework today, the Forum expects the following progress in five years.

II.A. VHTR

For the very high temperature gas-cooled reactor (VHTR), the full complement of technology projects will have been created. Feasibility issues regarding hydrogen production, fuel performance, and high temperature design including both the core and intermediate heat exchanger will be resolved, or nearly so. An assessment of progress toward the goals will have been completed for the major options. Key performance issue tests will be in planning, with some in operation, and decisions will have been made about advancing one or more prototypes.

II.B. SFR

For the sodium-cooled fast reactor (SFR), the full complement of technology projects will also have been created. Feasibility issues regarding full actinide recycling with multiple passes, competitive capital cost, in-service inspection and repair, and alternate energy conversion (*e.g.*, with gas or supercritical CO_2 Brayton cycles) will be resolved, or nearly so. An assessment of progress toward the goals will have been completed for the major options. Key performance issue tests will be in planning, with some in operation, and decisions will have been made about advancing one or more prototypes. The Russian SFRs BOR-60 and BN-600 continue to provide long-term operating data. Fresh operating experience is anticipated to be gathered from new SFRs in various countries and from the restart of MONJU.

II.C. SCWR

For the supercritical water-cooled reactor (SCWR), a set of essential technology projects will have been created. Feasibility issues regarding core layout and spectrum, fuel forms and possible recycling, in-core materials behavior, and system thermal-hydraulics and safety will be much better understood and on their way to resolution. The SCWR will be nearing a point at which it may assess its progress toward the goals. Key viability tests will be in operation.

II.D. GFR

For the gas-cooled fast reactor (GFR), a set of essential technology projects will also have been created. Feasibility issues regarding fuel

forms and actinide recycling, system safety and analysis, and cost will be much better understood and on their way to resolution. The GFR will be nearing a point at which it may assess its progress toward the goals. Key viability tests will be in operation.

II.E. LFR

For the lead-cooled fast reactor (LFR), formal collaborations will have begun, and a set of exploratory projects will have been created. Feasibility issues regarding coolant and materials, energy conversion and components, actinide recycling and system safety will be much better understood and preparations for viability testing will be underway.

In Europe it is expected that a choice between gas or a heavy liquid metal coolant for fast reactors, as a possible alternative to sodium, will be made with the potential launch of an experimental reactor using the selected coolant.

II.F. MSR

For the molten salt reactor (MSR), formal collaborations will also have begun, and a set of exploratory projects will have been created. Feasibility issues regarding its fuel cycle, salt chemistry with dissolved fuel isotopes (including transuranics) and materials compatibility will be much better understood and preparations for viability testing will be underway. Issues on the operation and safety of the coupled MSR reactor and fuel processing unit will be clarified.

II.G. Crosscutting R&D

R&D synergies will be developed between system steering committees, in domains such as requirements, design rules and codes, equipment, instrumentation, components and subsystems.

Generation IV is focused on four performance goals, related to safety and reliability, proliferation resistance and physical protection, economics, and sustainability. Three crosscutting methodology working groups have been created to develop evaluation methods that can assess the performance of new designs toward the Generation IV goals. During the coming five years these working groups will continue to support the six system steering committees in evaluating and guiding the optimization of their system designs. In addition, support for revitalizing and developing nuclear R&D infrastructure in terms of facilities, people and new advanced simulation and validation tools will be emphasized.

III. MISSIONS AND RESOURCES

The Forum is monitoring the scope and pacing of its research portfolio to keep in tune with global developments. As a result, several missions for the systems are expected to be given increased emphasis or otherwise modified to reflect future trends.

III.A. Hydrogen and Process Heat

While there is much debate about when or even if a large-scale deployment of a hydrogen economy may happen, it is now well understood how vital a role hydrogen currently plays in the production of premium transportation fossil fuels and chemical feedstocks. At the same time, there is a growing interest in the utilization of high-temperature systems to high-temperature process applications. The Forum has encouraged its high-temperature systems to broaden their mission to include process heat applications more generally. This is an important way to make nuclear energy more relevant as a non-greenhouse gas emitting source of primary energy beyond electricity.

III.B. Water Desalination

Second, in recent years there is a growing awareness of water shortages in many regions of the world. While the missions of Generation IV have included electricity, hydrogen production and actinide management in the original Roadmap, we may be nearing a time at which desalination should be highlighted in the missions if current generation reactors cannot successfully address it. The Forum will continue to monitor this, as the development of such new energy products that can expand nuclear energy's benefits beyond electrical generation contribute to the sustainability goals of Generation IV.

III.C. Small Reactors

Third, there is a growing interest in addressing the needs of countries that are better served by smaller systems. While a few options within Generation IV systems are being pursued with small module size, they are intended to complement the evolutionary designs of industry for near-term deployment, and thereby provide for the long term future need. Of course, the specific technologies developed in Generation IV (such as new materials, fuels or energy conversion technology) may beneficially diffuse into the evolutionary designs in advance of a next generation.

III.D. Fuel Resources

Fourth, from the perspective of uranium resource conservation, many of the Generation IV systems investigated are fast neutron reactors which use plutonium and uranium recovered from spent fuel by reprocessing, and depleted uranium. However, the Generation IV steering committees have shown increasing interest in the use of thorium resources. In fact, we are already seeing some exploration of thorium-based fuels in some Generation IV systems to understand their potential benefits. The Forum encourages measured pursuit of this alternative by systems to the extent that it allows them to advance toward the sustainability goal.

IV. TECHNICAL COOPERATION AND MEMBERSHIP

Technical cooperation and engagement of the research community worldwide plays a key role in the successful development of Generation IV systems. In the next five years, the Forum will expand the number of topical sessions that are sponsored. These will bring news of technical interests, research problems and breakthroughs to the research community with the intent of stimulating more participation by academia, industry and laboratories. Second, the Forum will monitor the level of funded collaborations by industry, and increase it significantly. Third, the Forum will continue to harmonize the efforts of its members on major technology demonstrations, such as is being done with several sodium reactor demonstration projects today.

Finally, note that the Forum's membership has changed over the years. While among the original signatories to the Generation IV Charter, Argentina and Brazil have made the decision to become inactive in the Forum largely as a matter of their research priorities. The United Kingdom also decided to become inactive, although the government still allows their technical community to participate in Generation IV through EURATOM. More recently, in 2006, China and Russia are the newest signatories to the Charter. In regards to the Framework Agreement, China acceded in 2007, the Republic of South Africa acceded in 2008, and Russia plans to accede in 2009. The original intent of the Forum remains the same to bring the collaborative efforts of the major developers of next generation nuclear energy systems to bear in a concerted effort. The Forum welcomes the prospect of additional members that can bring significant resources and capabilities, and hopes to report the successful entry of a few new members over the next five years.

V. CONCLUSION

The Generation IV International Forum's resolve is to deliver future nuclear energy systems that enable the safe, sustainable worldwide growth of nuclear energy well into the future for the benefit of mankind. Optimistic about the long term prospects for nuclear energy, the Forum plans to contribute to its success.

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