

# **Future Directions, Challenges and Opportunities in Nuclear Energy**

## **2006 Review of Progress in Quantitative Nondestructive Evaluation Conference**

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## **Future Directions, Challenges and Opportunities in Nuclear Energy**

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Nuclear energy is quickly entering a new phase of its development and may reach its promise of large-scale energy for electricity productions and its use as high-quality process heat for applications such as hydrogen production. There is a rapidly growing and recognized renaissance in the global and national understanding of the importance of nuclear energy to the well-being of human-kind as we understand the limitations and problems associated with fossil fuel energy utilization. Global recognition that the warming of our atmosphere and other pollution from fossil fuel electricity production and transportation uses have caused us all to reconsider the applicability, and the applications of nuclear energy.

However, the renaissance for nuclear energy does present us with a pressing challenge, and that is that the developers of nuclear energy applications and systems must develop the concepts and features of these systems so that they operate safely, economically, and with a minimal risk of proliferation of nuclear materials. In other words, the developers are working to create a technically achievable, economically viable, politically supportable, and environmentally acceptable nuclear energy option for the nation that earns public confidence and trust.

The roles for nuclear energy exist both today and in the future. In the present we will continue to utilize safe and economic nuclear power plants for electricity production from our current fleet of reactors. In fact, in the United States it is becoming readily apparent that license extensions will be requested for most, if not all of our currently operating reactors as they have demonstrated excellent safety records and have contributed positively to the financial bottom lines of their owners. In the near-term it is also fully expected that we will see new reactors constructed on current and new sites as the need for base-load power will become much more of a necessity. It is currently expected that four to five new reactor design concepts from at least three different manufacturers will be available for new construction in the very near future in the United States. These include the AP600 and AP1000 reactor concepts from Westinghouse, the ABWR and ESBWR concepts from General Electric and the EPR from AREVA. In the long-term we are looking at a number of extremely exciting and new concepts that offer the possibility of both high-efficiency electricity and hydrogen production. It is also expected that the future will bring new developments and progress on recycling used nuclear reactor fuel.

Currently, the US Department of Energy (DOE) is conducting a program called NP2010 that is designed to develop two new construction/operating license (COL) applications by sharing the costs of development between government and industry. It is important to note that as of today no U.S organization or company has declared that it will actually buy and build new reactors; however the days for such decisions is coming closer. The National Energy Policy Act of 2005 included enticements for industry including loan guarantees for the initial construction of new nuclear power plants. Some of the concerns that industry has expressed include the fear that their company stock price would decline when a new reactor order would be announced; however the initial forays into this new territory have not significantly affected stock prices for those companies openly considering new reactor construction.

The current estimates of the numbers of plants and sites that might actually be ordered and begin the COL process is changing rapidly, even monthly. As of the date of this presentation (end of July 2006) as many as 26 reactors have been publicly discussed to be sited on as many as 19 sites.

Another recent development, the Generation IV Technology Roadmap process, was a two-year effort conducted by around 100 international experts to find the most promising next generation of nuclear energy systems beyond the light-water reactors currently under consideration. The result of this study was the selection of six so called “Gen IV” systems. These reactor concepts include:

- Gas-Cooled Fast Reactor (GFR)
- Lead-Cooled Fast Reactor (LFR)
- Molten Salt Reactor (MSR)
- Sodium-Cooled Fast Reactor (SFR)
- Supercritical-Water Reactor (SCWR)
- Very-High-Temperature Reactor (VHTR)

The Generation IV process developed a clear set of priorities and timelines for the needed technology development in order for these concepts to be ready for deployment around the 2025 to 2030 time frame. The goals for the Generation IV concepts considered during the study included requirements that both the resource input and waste output were clearly sustainable; that the economics of both the individual reactors and the systems that they represented were viable in terms of both life-cycle costs and risk to capital; the reactors and systems needed to demonstrate excellence in safety and reliability exhibited through very low probability of core damage and ease of emergency response, if needed, and there would be a significant increase in the risk assurance related to proliferation resistance and physical protection of the reactors and systems.

In order to establish a firm basis for future international commitments related to the Generation IV process and technology development a Generation IV International Forum, or “GIF” was established in order to expedite international conversations around the research and development activities that would be conducted by the various countries. Many countries are currently included in the GIF beyond the original ten that participated in the original Generation IV studies, so that this effort has developed a solid international life of its own.

One of the most intriguing Generation IV reactor concepts is the Very High Temperature, Gas-cooled Reactor (VHTGR) concept that has been chosen by the United States as its leading Generation IV candidate system for development. This activity has resulted in the further identification of this type of reactor for testing and demonstration. The Next Generation Nuclear Plant (NGNP) is a VHTGR concept that should be capable of producing temperatures high enough that it could be able to produce electricity at very high efficiency or hydrogen for transportation fuels, or conceivable even both. To do so will require the NGNP to operate with an outlet gas temperature in the range of 850-950 °C while doing so in a passively safe manner.

Current NGNP research and development is focused on high temperature fuels and materials irradiation performance, design and safety methods development and validation, advanced energy conversion, and high-temperature hydrogen production. Current developments on the NGNP are leading to a demonstration plant based on the NGNP concept that has the capability of switching between electricity and hydrogen production. Current plans also call for the development of early conceptual design studies of NCNP reactor concepts over the next few years. One of the important goals of the NGNP program will be to demonstrate the commercial-scale, economically-feasible production of hydrogen using Nuclear Energy.

In the area of NGNP fuels research and development an especially key issue is coated particle fuel performance. Here simulation and modeling will play an important role in understanding nuclear fuel performance under extremely challenging neutron flux, temperature, and pressure environments.

There is also currently an emerging program in computational methods development for NGNP reactor physics that includes wide national laboratory collaborations with universities, and international partners. This effort will establish the framework for NGNP physics methods development, implementation, and validation and verification. Significant new computational developments are clearly needed for in the area of pebble bed systems, which have continuous online refueling and require special treatment and computational development.

Because of the very high temperatures required to reach the NGNP goals, it is important to also understand the NGNP thermal-fluids phenomena. This will require the development of detailed and complex computational fluid dynamics computer codes and full systems analysis capabilities to consider both normal operation at full and partial loads, coolant flow and temperature distributions throughout the reactor core, and the mixing of hot gas jets in the reactor lower plenum. As with current reactors, loss of flow accidents require intense study and a complete understanding including phenomena related to the mixing of hot plumes in the reactor upper plenum, and natural circulation coolant flow and temperature distributions. Loss of coolant accident analysis will require prediction of reactor core depressurized cooldown through conduction and thermal radiation, and rejection of heat by natural convection and thermal radiation at the vessel outer surface.

A very exciting recent (February 2006) development in nuclear energy is the announcement by the US Department of Energy of the concept of a Global Nuclear Energy Partnership or GNEP. This new DOE effort is aimed at addressing the back-end of the nuclear fuel cycle by recycling used nuclear fuel, reducing the need for additional nuclear waste repositories, and building an

international regime that would reduce the risk of nuclear weapons material proliferation. This new effort is aimed at developing a comprehensive strategy to simultaneously increase U.S. and global energy security, encourage clean energy development around the world, reduce the risk of nuclear proliferation, and improve the environment. The goals of GNEP include:

- Expanding domestic use of nuclear power;
- Demonstrating more proliferation-resistant nuclear fuel recycling;
- Minimization of nuclear waste;
- Development of advanced burner (transmutation) reactors;
- Establishing reliable nuclear fuel cycle services;
- Demonstrating world-wide deployable small-scale reactors; and
- Developing enhanced nuclear safeguards.

The initial GNEP efforts will be centered on a GNEP Technology Demonstration Program which will have a focus on domestic demonstration of key fuel cycle technologies, the development of international partnerships in technology development, and an embedded university program. The 5-year technology plan is currently under development and includes the activities of ten US national laboratories.

This technology development program is centered on the development of three new facilities, an Engineering Scale Demonstration, an Advanced Burner Reactor, and an Advanced Fuel Cycle Facility. The Engineering Scale Demonstration is focused on the demonstration of the UREX+1a process to be the supplier of transuranic elements for Advanced Burner Test Reactor. The Advanced Fuel Cycle Facility will demonstrate transmutation fuel fabrication and processing by being a modular research laboratory capable of both aqueous and pyrochemical separations. The Advanced Burner Test Reactor will demonstrate the performance of transmutation fuels.

The GNEP Technology Development program will need to make substantial technical progress in areas such as modeling and simulation, fuel technology, separations technology, systems analysis, fast burner reactor technology, proliferation resistance and safeguards technology, and small-reactor technology. In other words, GNEP is a redefinition of this country's nuclear energy strategy which will set the agenda for years ahead, but it is initially centered on a domestic technology demonstration program.

As to the opportunities and challenges available in this new era of nuclear energy development for the non-destructive evaluation community, there clearly is a wide open set of opportunities going forward. The nuclear community will need detailed understanding of process data to ensure success. Especially important will be the reliable capability for on-line data gathering to ensure that all of the nuclear facilities considered will be able to operate at extremely high capacity factors, upwards of 90%. It is also clear that the nuclear facilities of the future will not just be reactors – fuel cycle facilities, hydrogen production facilities, new waste forms, and many, many others will be required. Fundamentally, the opportunities to the NDE community are boundless. What are your ideas?

In summary, there are exciting new reactor developments on the horizon including new reactor construction, new high temperature concepts, new fast reactors for transmutation, and new small reactors for a global marketplace. Furthermore, there will also be exciting new fuel cycle developments through the Global Nuclear Energy Partnership which will bring both new facilities and new research and development opportunities.