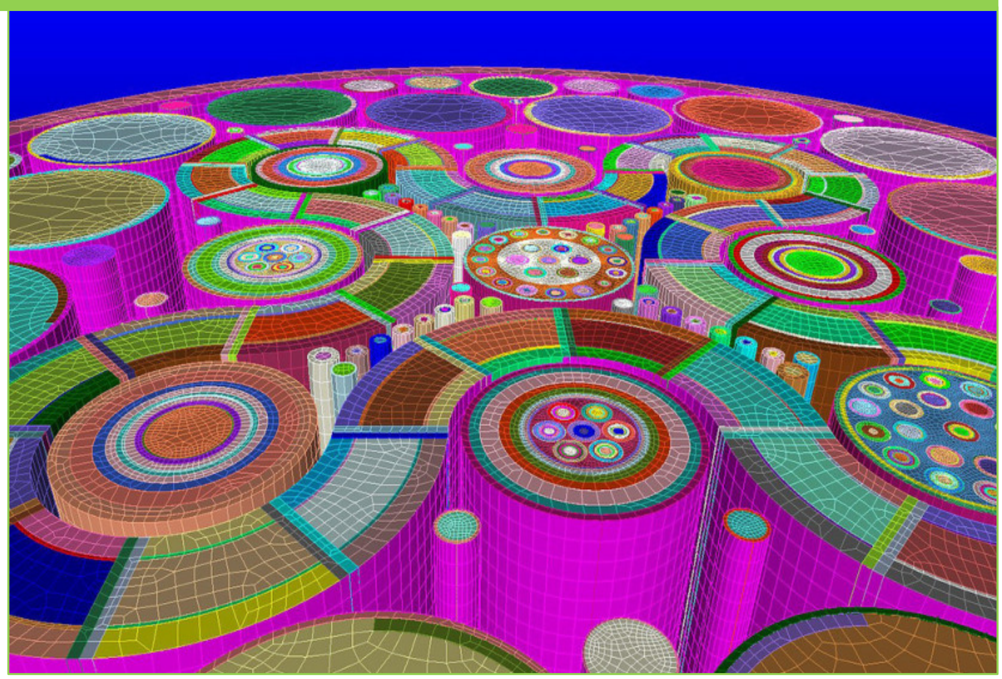
Global Nexus Initiative

Where Climate, Nuclear, and Security Meet

A Framework for Advanced Nuclear Reactor Deployment: Policy and Issues



Policy Memo and Recommendations

September 2016

This report is based on discussions of the Global Nexus Initiative (GNI) Working Group at its February 2016 workshop held in Washington, D.C.

A Framework for Advanced Nuclear Reactor Deployment

POLICY MEMO AND RECOMMENDATIONS

INTRODUCTION

An important principle of the Global Nexus Initiative (GNI) project is to achieve consensus on key issues where possible among the project's Working Group members, but also to accurately characterize differing views from these experts. With 16 different members representing the nuclear energy, diplomatic, environmental, energy and nuclear policy and security communities, it was clear from the outset of the effort that there may be differences of opinion on important issues. The project managers, the Partnership for Global Security (PGS) and the Nuclear Energy Institute (NEI) have encouraged the GNI members to be forthright about their views while retaining the prerogative to produce the final documents.

In drafting this report, *A Framework for Advanced Nuclear Reactor Deployment: Policy Issues and Actions*, the project managers received significant and important input from the Working Group members. Much of that is incorporated into the final product and the managers are responsible for the final content of the report. However, it is important to note that there were different views on several significant issues:

> **Regulatory Development**: There were some comments that supported creating a new regulatory system for advanced reactors while the final report supports an aggressive but evolutionary approach based on the existing light water reactor regulatory system.
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> **Breeder Reactors and Plutonium**: The report recommends that next generation reactors not be used for the specific purpose of breeding a surplus of plutonium for future use in nuclear reactors. It also opposes stockpiling separated plutonium. Some of the comments indicated that the plutonium issues could be addressed through technical measures.
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> **Market and Technology Down-Selection**: There was a consensus that the market needed to drive the decision making on next generation reactors and that is reflected in the report. However, there were differences of opinion on how advanced the market for these reactors is and also what the process for choosing the most promising technologies should be and how quickly it should proceed.

Both PGS and NEI believe that it is important for readers to take these opinions into account as they read through this report.

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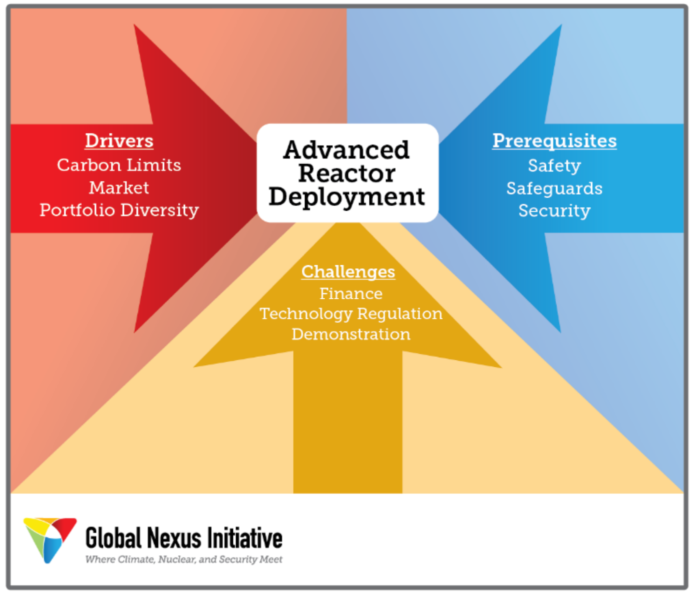
OVERVIEW

Next generation nuclear reactors are at a critical crossroad between technology development and future deployment. Accelerating progress toward deployment of these new reactors is required if they are to meet the climate change and global energy needs of the mid-21st century and beyond. This transition from concept to commercialization needs to occur over a fairly rapid 10-15 year period and must be accompanied by a regulatory system that ensures the safety, security and proliferation resistance of this new reactor class.

These new reactor types, both small modular light water reactors and advanced non-light water reactors, offer a range of sizes and have the potential to be a more easily deployable and operationally flexible alternative to the large light water reactors that are dominant around the world today.[1] Advanced reactors also offer: different coolant systems that can enhance efficiency and safety; construction that can reduce building costs; fuel cycles that can reduce environmental impacts; and potentially greater proliferation resistance and security.



Further, there may be a role for next generation reactors in the desalination of sea water, which would provide a new source of fresh water to countries and regions that need it. All of these attributes, plus the value of producing emission free electricity in a carbon-constrained world, make advanced reactors attractive energy sources.

In addition to the climate change benefits that next generation reactors can provide, they also can make an important contribution to meeting the United Nation's Sustainable Development Goal of universal access to affordable, reliable and modern energy sources by 2030. At present about 1.2 billion people (17% of the population) lack access to reliable electricity worldwide.[1] Achieving this goal without increasing carbon emissions is critical to advance global human potential and to stimulate continued economic growth and development.

The private and public sectors have made clear their interest in the potential offered by next generation reactors, with more than forty companies now engaged in research and with an investment of private capital estimated at $1.3 billion.[2] But, at present, there is more research and development than demonstration occurring and the path to widespread commercialization needs to be clearer and better supported. To achieve this, there are a number of impediments to deployment that need to be addressed.

The most pressing challenge is the need for an efficient regulatory system for the advanced non-light water reactor technologies that will provide certainty about their ability to be deployed in a predictable timeframe. Also, the construction and operating costs of these reactors will need to be more competitive with other energy options, particularly coal, renewables with storage and natural gas. This reduced cost is not yet proven. Further, the technology needs to be operationally tested and demonstrated to prove its viability, safety, security, and proliferation resistance. There also must be political and public confidence in this new class of reactors. Achieving these goals requires institutional and cultural changes in how the next generation of nuclear power is developed, tested, regulated, deployed and managed.

In order to make a timely contribution to meet the energy and climate challenges that the world faces, advanced reactors must move to deployment in the 2025-2030 timeframe. This timing challenge is important, especially in light of the commitment made by 195 countries under the Paris Climate Agreement to limit global warming to 1.5-2 degrees Celsius above pre-industrial levels.[3] This implies the establishment of a near-zero carbon energy system soon after mid-century.[4]

In today's energy environment, the existing nuclear reactor fleet produces over 30% of the world's emission free electricity. However, this contribution is threatened by the age of the current fleet worldwide. For example, in the United States, all currently operating reactors will reach 60 years of life between 2029 and 2055. The lifetime of an unknown number of these reactors likely will be extended to 80 years while the remainder will be retired. Economic and political pressures also are causing utilities in the U.S., Europe and Japan to retire multiple reactors early.

If the clean energy benefits offered by the existing reactor fleet decline significantly, there is considerable risk in assuming that renewable or other zero carbon energy options will be able to substantially compensate for this reduction by mid-century.[5] In addition to replacing the carbon benefits produced by the reactor fleet, these sources also will need to displace the remaining 60% of the world's electricity that today comes from fossil fuels and all future energy growth. It is at a minimum uncertain at this point if, in the future, renewables with storage alone or combined with fossil fuel carbon capture and sequestration (CCS) and energy efficiency can meet these goals. In recent cases where nuclear plants have been shut down in the U.S., carbon emissions have grown as the substitute power came primarily from natural gas.[6]

If non-nuclear zero carbon energy sources and related technologies cannot meet carbon reduction objectives, then falling back on carbon emitting sources of power including natural gas or coal without capture and sequestration, will inevitably mean that aggressive climate targets will be unmet, with the attendant global consequences.[7]

FINDINGS and RECOMMENDATIONS

The following findings and recommendations are based on the Global Nexus Initiative's February 2016 workshop on *Next Generation Nuclear Power: Value and Challenges of Transitioning to Advanced Technologies*.

FINDING I: Meeting Climate Goals

In order to meet the Paris Climate Change Agreement, analysis by the Intergovernmental Panel on Climate Change (IPCC) and others indicates that there will need to be a near-zero carbon electricity system soon after mid-century.[8] Reductions of this magnitude require significant and rapid technological advances including in the four key elements of a climate change response strategy – energy efficiency, renewable energy, CCS, and nuclear power.

At present, nuclear power is making a very significant contribution to the Paris goal and most studies by the IPCC and others suggest that nuclear capacity will need to grow.[9] However, the existing nuclear reactor fleet is facing a potential cliff of retirements in mid-century. Fifty-three percent of the current global reactor fleet is over 30 years old, and by 2050, those plants will be over 60 years old. It is estimated that by 2050, 357 of the current 448 plants could be retired. Yet, very few nations have included nuclear power as a part of their approach to reducing carbon emissions as outlined in their national commitments at the Paris meeting.[10]

Recommendations

1. While a significant number of large-scale light water nuclear reactors are under construction or contemplated, primarily in developing countries, next generation nuclear reactors may offer a promising technological and economic solution to the looming decline in the existing power reactor fleet in developed countries. However, there are still many uncertainties associated with these reactors that need to be addressed including economic, safety, safeguards and security considerations. At present, many of the advanced reactor designs are at the conceptual stage, though many of the concepts have been previously demonstrated in some form. An acceleration toward the demonstration phase for these reactors is required if they are to meet the clean energy needs identified in the Paris agreement.

2. As next generation reactor deployment is pursued it must be with a clear understanding of the urgency imposed by aggressive climate objectives. There are carbon reduction benefits from both the existing light water reactor fleet and future advanced reactors. An unacceptable outcome, in light of the Paris Agreement, is to allow carbon emissions to rise if nuclear power's zero emissions are reduced through retirements and alternative technologies are not adequate to compensate, causing increased reliance on higher carbon emitting sources of energy.

Finding II: Demonstrating the Technology

At present, there are multiple advanced reactor designs being pursued by a variety of private sector entities and governments. The objective of these investments is commercial deployment of the reactors and as a result there is considerable focus on identifying the size and composition of the market for these technologies. However, it is a multi-billion dollar investment to develop and commercialize a single nuclear reactor design. There is an estimated $1.3 billion in private funds that have been invested to date in various concepts, a significant amount but well short of the amount required for full demonstration. However, this investment may exit or the additional investment necessary may not be realized if the technologies cannot be successfully demonstrated or if a "business as usual" approach from the governments and regulators to this class of reactors serves to impede timely development and deployment.

Recommendations

1. The international market for advanced reactors needs to be realistically assessed and potential purchasers and operators need to identify the required reactor characteristics, costs and the timeframe on which deployment is needed.

2. To achieve timely deployment of next generation reactors, it essential that research and development test beds and demonstration platforms be created in the near term. This will assist in effectively addressing the issues associated with reactor licensing, affordability, risk management, safety, safeguards, security and waste management. It also will push forward the most promising designs and support continued innovation. Moving to this stage will require political will and financial support beyond the short term. The number of advanced reactor technologies will certainly be reduced as the demonstration phase proceeds, and as that occurs there is value in narrowing the diversity of designs and harmonizing the licensing requirements for these reactors across borders to the extent possible. This could allow for the sale of fleets of plants in a manner similar to jetliners and avoid the problem of reactors having unique characteristics or requiring redesigns in each country.

3. Unlike in the early nuclear era, the prototyping and demonstration of advanced reactors are unlikely to be wholly government financed, except in state dominated economies. In free market economies, advanced reactor designs generally will be much more dependent on private financing. However, the effort may prove to be too expensive and risky for the private sector to shoulder alone. Therefore, the best path forward is a cost-sharing private-public partnership through the demonstration phase. Governments can demonstrate political encouragement by providing facilities, expertise and possibly some financial support and the private sector can contribute to the technology demonstration, assess the most promising reactor concepts, and drive the process according to market demands.

Finding III: Accelerating Licensing

A vital need for non-light water advanced reactors is the use of a phased and predictable licensing process. As the U.S. Nuclear Regulatory Commission (NRC) is considered to be the model for nuclear regulatory development, a significant part of this licensing burden may fall on the U.S. The current NRC process presents two major barriers to the licensing of next generation reactor technologies. The first is that existing regulations are designed for light water reactors. The second is that the regulatory process is not designed or sequenced to synchronize with the funding challenges of smaller startup companies, which rely on private finance. The combination of these two characteristics could significantly discourage continued private investment in advanced reactors and deter the movement of these technologies to demonstration and ultimately deployment.

The existing regulatory structure would benefit from the establishment of a more technology inclusive, risk-informed, and performance-based framework for advanced reactor licensing. In the U.S., the NRC is willing to provide early guidance through technical and topical reports and documents as well as work with vendors to provide early guidance on their designs. In addition, establishing meaningful regulatory decision milestones through a staged process could be helpful for advanced reactor designers when seeking additional funding. Such milestones, providing incremental assurance of the ability to license, would benefit all stakeholders in more efficiently managing the investment of human capital and financial resources.

The U.S. government is cognizant of these challenges and is working through the legislative and executive branches to address them, although progress has been slower than needed and these processes have not yet had a meaningful impact on many of these issues. However, other countries are not dependent on U.S. practices and some, including Russia and China, plan to move forward rapidly with their preferred advanced technologies and licensing procedures. This could undercut high technical standards, skew market choices, and have other impacts on the global nuclear industry. Much like issues associated with technology development, there is a persuasive argument to be made in favor of harmonizing international regulations for advanced reactors to prevent fragmentation.

Recommendations

1. The licensing process in the U.S. for next generation reactors must be advanced if these technologies are to be a realistic and deployable option that will meet international climate and energy objectives. The NRC should engage with technology innovators in a staged process and offer meaningful and useful feedback on regulatory matters as the design is being developed and demonstrated. This will encourage continued private investment and allow for the down-selection of the most promising and mature technologies.

2. Equally important is the use of international regulatory fora, such as the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency's (NEA) Multinational Design and Evaluation Programme (MDEP)[11], for the development of international licensing standards for advanced reactors. Pursuing a harmonized, consistent, and high-quality international regulatory regime would create greater international confidence that the advanced reactor class has collectively addressed concerns about safety, security and safeguards protections.

Finding IV: Enhancing Safety and Security

Creating a high level of public confidence in next generation reactor technology will be essential to its commercial success. International confidence in nuclear power has been adversely affected by the nuclear accidents at Three Mile Island, Chernobyl and most recently Fukushima. In addition, there is significant public awareness of the potential nuclear weapons proliferation opportunities presented by commercial nuclear technologies. Further, the nihilistic nature of 21st century terrorism has underscored that there are few – if any – barriers that dedicated extremists will not try to cross and that nuclear terrorism is a real threat.[12] The intersection of next generation reactors and heightened concern about nuclear dangers requires that any new technology provide the most advanced levels of safety, safeguards and security. Effectively addressing these three issues will be essential for creating the public confidence necessary for the deployment of advanced reactors outside of state-run energy systems.

Recommendations

There are three steps related to security and non-proliferation that advanced reactor designers and the international community should be taking as concepts move toward testing, demonstration and deployment. These issues should not be sacrificed to other reactor considerations.

1. High levels of safety, safeguards and security should be incorporated into the initial reactor designs. These features should be rigorously tested against realistic and challenging scenarios to further strengthen these systems.

2. The fuel cycle for any advanced reactor should minimize the opportunities for proliferation. In particular, the international community should oppose advanced reactor fuel cycles that are designed for the specific purpose of breeding a surplus of plutonium for future use in nuclear reactors. It also should oppose the stockpiling of separated plutonium and the use of uranium-235 fuel enrichments that exceed 20 percent.

3. In tandem with the development of next generation reactor concepts, the international community should acknowledge and address the significant gaps that exist in the global nuclear security regime by strengthening the international legal framework.[13]

BACKGROUND

The Role of Nuclear Power in Carbon Reduction

Operational nuclear power plants produce close to zero carbon dioxide emissions and are an important component of the climate change strategy of some high carbon emitting nations.[14] As of January 2016, 11% of global electricity production was generated by nuclear power.[15] In some countries including in Europe, Asia and the United States, nuclear power produces a significantly higher portion of national electricity.[16]

However, the retirement of reactors that have reached the end of their operating life in the developed world will pose a significant challenge to achieving international climate policy objectives in the future if these reactors are not replaced with new nuclear reactors or equivalent reliable, zero carbon energy sources.

In the United States alone, 72 new reactors would need to be built by 2040 to maintain the 20% share of energy they currently contribute. Currently, four new reactors are under construction and several existing reactors have been and are being prematurely retired. The reason for the recent premature retirements in the United States is downward pressure on plant economics in certain markets caused by low natural gas prices, flat energy demand and the growth of other generation types bolstered by subsidies.

Electricity generation models that limit the global concentration of carbon dioxide equivalent (CO_2e) at 450 parts per million volume (ppmv)[17] underscore the importance of maintaining and expanding nuclear power, even with substantial contributions from renewable energy sources and carbon capture and sequestration (CCS). Scenarios without CCS rely even more heavily on continued and expanded nuclear power production.[18]

While the operational costs are low for nuclear power and operating lives of the plants are long (40 to 80 years), construction times are lengthy (approximately 4-6 years, but sometimes as high as 10 years) and upfront capital costs are high (approximately $7-9 billion for large, conventional reactor designs in the West) when compared to other energy technologies. However, construction costs are much lower in China where most new plants are planned, and they were much reduced in the UAE's recent procurement of Korean reactors.[19]

Nuclear power also is facing formidable competition from cheaper energy sources, including natural gas in the United States, which emits substantial amounts of CO_2, even if it is half the amount of a similar equivalent of coal. Also, the declining cost of renewable energy, bolstered by subsidies, is making it more attractive as a power generation option, although renewables face continuing technology challenges including storage, transmission, and backup capacity, as well as public acceptance issues in some nations and regions.

Globally, there are 61 reactors under construction - a third are in China, seven in Russia, six in India and four in the United Arab Emirates. Another roughly 100 are on order or planned. More than two dozen countries that currently do not operate nuclear power plants are planning or have expressed interest in developing nuclear power programs. However, even countries that are pursuing nuclear energy are planning for their programs to contribute only 20-30% of their electricity by 2050 – a percentage unlikely to achieve the 40-70% level of emission reductions consistent with achieving the goals established by the Paris Agreement.

A Framework for Next Generation Nuclear Power

The demands on the next generation of nuclear plants, particularly in deregulated energy markets, are going to be different than in the past including the need for increased operational and siting flexibility. The public needs to be confident that plants are safe, secure, and proliferation resistant. Advanced reactors that can minimize nuclear waste or even utilize used fuel from the existing fleet could offer waste management benefits. The market is requiring greater affordability, lower technology and construction risk, speed to deployment, and efficient and scalable manufacturability. These requirements and expectations raise a number of issues that will need to be addressed in order for advanced reactors to proceed from concept to commercialization in a timely fashion. Therefore, it is vital to construct a framework for considering the key policy issues that will impact the deployment of advanced reactors. The central policy issues are:

- Timeline, Market and Financing
- Safety, Safeguards and Security
- Regulatory Reform

Effectively addressing these issues will challenge many of the established tenets and processes associated with nuclear power and "business as usual" will not be adequate.

Timeline, Market and Finance

Among the most significant issues when considering the future of advanced reactors is the intersection of timing, market demand and financing. There are several important considerations in each of these areas.

Timeline

The world will absolutely need more carbon free energy than the national commitments offered in Paris. Many analyses of the plans submitted by countries prior to the Paris meeting conclude that there is a large gap between the amount of emissions reductions that are required to limit temperature increases to 2 degrees Celsius, and the current national pledges. The Paris pledges would allow temperatures to rise by 3 degrees Celsius or perhaps higher by the end of the century.[20]

This provides a clear rationale for moving next generation reactor technologies forward toward deployment. If these new reactors are not deployable by 2030, however, it may be difficult to make the case for their value in achieving climate goals. The most recent experience in the U.S. with the gigawatt sized Westinghouse AP-1000 reactor is that the process has taken over three decades. The timeframe for the deployment of advanced reactors needs to be shortened to 10-15 years to protect their viability and the regulatory system for them must be developed in tandem.

China, for example, plans to have a high-temperature, helium-cooled pebble bed reactor online in 2017 and is planning to demonstrate molten-salt technology by 2025. Russia is developing a floating nuclear power plant.

Market

A significant element in helping to clarify advanced reactor decision making is the identification of the markets for next generation reactors. The logic of their utility is reasonably clear in light of global carbon limitation goals and global energy needs. Yet, it is unclear how the market will value these reactors. There are several issues to address in this regard.

The market in OECD countries may be limited in the current period of low energy prices and the existing policy environment. However, it may be very important that these countries play a key role in the development, testing and regulation of these reactors. The U.S., for example, has been considered for decades to be the global leader in nuclear technology and its regulation. But, the U.S. role has declined in the nuclear market of the 21st century with Russia, China and South Korea aggressively moving forward. Yet, testing and certification of advanced technologies in the U.S., or other OECD countries, which collectively represent the largest operators of reactors, may be needed for the technology to gain acceptance domestically and abroad.

The possible role of advanced reactors in the developing world is clearer, as they may be more suitable for distributed energy production, desalination, and useful in interior and dry regions. These reactors could be of interest in Africa and South Asia; both of which suffer from shortages of power and where many of its citizens lack access to electricity. However, these same regions lack mature nuclear power regulatory systems, have electrical grid challenges, and face a shortage of skilled nuclear workers.

Finance

The future success of next generation reactors is highly dependent on the scale and composition of financing. The private sector is investing in the exploration and development of a variety of concepts, but government funding, for example in the U.S., is considerably lower. Globally, much of the private funds have been invested in a few programs.[21] Also, private investment may exit early if the technologies cannot be successfully demonstrated or if a "business as usual" approach to this class of reactors impedes timely development and deployment.

The multibillions of dollars needed to bring the first-of-its-kind (FOAK) advanced reactor portfolio to deployment is far in excess of the funds that are currently being provided.[22] In addition to significant private sector funding there also is a need for supplementary government funding.

The U.S. government has created an office of Advanced Reactor Technology within the Department of Energy (DoE) to support reactor concept, technology and licensing development. This funding is roughly $75-100 million per year. Further, DoE has created the Gateway for Accelerated Innovation in Nuclear (GAIN) program to provide "the nuclear community with a single point of access to a broad range of capabilities … across the DOE complex and its National Lab capabilities."[23]

The U.S. government also is providing modest funding (up to $80 million) to two reactors types – the X-energy pebble bed reactor and the Southern Company Services Molten Chloride Fast Reactor.[24] In addition, the U.S. Department of Energy has granted authority for NuScale to construct and operate their first commercial small advanced light water reactor at the Idaho National Laboratory and is cost-sharing their licensing process.[25]

Other programs support additional elements of advanced reactor technology, including fuels. There also is a Generation IV International Forum (GIF) that is a multilateral R&D effort assessing six different technologies.[26] This international collaboration has a variety of merits but one especially important issue is the potential to harmonize technology standards and regulation across national borders.

It is unlikely that either governments or the private sector individually will have the resources to fully fund multi-billion dollar advanced reactor efforts through design, licensing and construction of a FOAK. Therefore, a private-public partnership is required to develop and deploy these technologies.

A private-public deployment driven strategy for next generation reactors would send a signal that the reactor class is important, allow for robust modeling, testing, and demonstration and winnow the number of technologies to a handful that the market deems valuable and that also can meet international safety, security and nonproliferation objectives.[27] This approach, if seized on by the U.S. or other nations, also could elevate that country into the top tier of nuclear innovating nations and reinforce its status as an international standard setter in nuclear safety, security, safeguards and regulation.

Safety, Safeguards, and Security

The technological promise of advanced reactors has been the focus of much of the research and funding to date. However, it is unlikely that there will be broad acceptance of these reactors unless they are capable of delivering significant improvements in nuclear safety, security and safeguards. The wide variation of advanced reactor designs poses significant challenges in all of these areas. While there is no international requirement that security and safeguards features be incorporated into reactor designs at the earliest stages, a "By Design" approach to all of these issues will facilitate effective integration of these features through the construction, operation and decommissioning phases of the reactor's lifecycle.

Safety

Many of the advanced reactor concepts under consideration have technological precedent including liquid metal, molten-salt and high-temperature gas-cooled models. However, these early reactors have had an uneven operating history.[28] The new designs include passive safety features and in the case of molten salt and liquid metal–cooled reactors, operate at lower pressure and rely on natural phenomena rather than using more complex and active safety systems and components. This can allow for a reduction in the nuclear safety island around the reactor and can reduce the number of potential safety vulnerabilities. Also, some of the reactor designs are situated below ground, further enhancing safety and can have unique containments which also limit safety concerns.

Safeguards

The goal of nuclear safeguards is to ensure that there can be timely detection of the diversion of a significant quantity of nuclear material from a peaceful nuclear program by a state.[29] Much of the current safeguards system has been designed for the water-cooled reactors that dominate the nuclear energy landscape. The variety of advanced reactor designs and their coolants present challenges to the existing safeguards regime, especially for advanced fuel cycle capabilities. Some of these designs allow for on-line fuel processing, fuel outside of the containment vessel and unique refueling schemes. These features may require updated or new tools for nuclear accountancy and control as well as built-in technological features to prevent malicious use of the facility.

Security

While safeguards are primarily concerned with the diversion of nuclear material by a state, nuclear security is focused on preventing nuclear material theft from facilities, acts of sabotage by insiders, and outside attack by non-state actors including terrorists that may result in radiological emergencies. The international nuclear security regime is much less developed when compared to safeguards or nuclear safety. That lack of comprehensiveness creates inherent vulnerabilities. The nature of some advanced reactors, including their smaller size, potentially closed fuel cycles and their operation in remote locations will certainly present new security challenges and possibly opportunities. The physical protection of this new class of reactors is still in the evaluation stage and more work is required to address the issues associated with the use of fewer employees, insider threats and the possibility of below ground siting.

Fuel Cycle Choices

Advanced nuclear reactors have a number of distinctions from light-water reactors, and two of the most prominent are the use of different coolants and the uranium enrichment levels required for their optimal operation. Most LWRs are fueled by uranium enriched in U-235 to 3% to 5%. Some advanced reactors will require uranium enrichments above 5% but below 20%. At 20% or above the fuel is considered highly-enriched uranium and attractive for diversion for nuclear weapons purposes. Also, some advanced reactor designs employ a fast neutron spectrum, including liquid metal cooled reactors and some types of molten salt fueled reactors. This raises the concern that these reactor types can be used as plutonium breeder reactors, a type that creates more plutonium than it consumes. Historically, breeder reactors have encountered significant operational and safety problems.[30]

Given the diversity of nations pursuing advanced reactors, it is difficult to say with certainty that all would forgo using advanced reactors for breeding a surplus of plutonium for future use, but it should be discouraged by the international community and, if used, should be subject to stringent safeguards. Further, the international community should oppose advanced reactor fuel cycles that stockpile separated plutonium and use U-235 fuel enrichment above 20 percent, which present proliferation and security dangers.

Regulatory Reform

The effective and efficient creation of a regulatory regime for advanced reactors is a pressing and challenging issue. For many nations, the U.S. NRC represents a high level of competence in regulation development and reactor licensing. Subsequently, what the U.S. does on the issue of regulating advanced reactors likely will have significant impact around the globe. An important question, therefore, is whether the existing U.S. licensing process will keep pace with a deployment schedule for advanced reactors that places them in the field by 2025-2030.

The U.S. Congress is seeking to reform the process of licensing advanced reactors by providing more flexibility and cost-sharing arrangements.[31] The NRC is working with DoE to develop design criteria for advanced reactors and is prepared to provide early guidance through pre-licensing meetings with applicants and through the issuance of technical guidance and reports. It clearly is in the interests of both the applicants and the NRC to have early and extensive discussions throughout the reactor development process. In this way, risks associated with the development of a new technology can be reduced in a stepwise fashion. Legislation may be required, however, if the existing processes do not prove flexible enough. The Canadian use of a staged vendor design review process could be a model for the U.S.[32]

Of course, other nations may not wait for the regulatory process in the U.S. before they begin to design their governance system and deploy advanced reactors. It is not clear if these regulatory frameworks will be as rigorous as that which would be developed in the U.S.

A much more desirable outcome is for the development of international cooperation that can lead to the creation of a continuum of harmonized regulations for advanced reactors covering safety, safeguards and security in addition to robust domestic regulations and regulatory agencies. This could then form the basis of the regulatory system in all countries that deploy them, strengthening international confidence in the technology. The current efforts of NEA, MDEP and the International Atomic Energy Agency in this area should be utilized and strengthened.

SUMMARY

The Paris Climate Change Agreement has committed the international community to limit the global temperature increase to 2 degrees Celsius or less. This will require a significant change in world energy production. To meet this goal there needs to be deep decarbonization of the global energy system by mid-century. There is an important role for nuclear power in achieving this goal, but it is facing a number of significant challenges. Some of these obstacles may be overcome by the deployment of next generation reactors.

The retirement of existing reactors in OECD countries is one looming problem. It is clear that the existing reactors will not be replaced on a one-for-one basis in a number of these nations. However, it is unclear if the combination of renewable energy, CCS and energy efficiency can substitute for the loss of the zero carbon energy that these reactors now produce. In recent cases in the U.S., the retirement of nuclear reactors has led to an increase in carbon emissions as the energy was replaced primarily by natural gas.

A second set of challenges is the growth of global energy demand, the need to provide reliable electricity to the 1.7 billion people that currently lack access to it, and the need to replace fossil fuel generated electricity. Addressing these issues will require a massive increase in carbon-free electricity. The deployment of large light water reactors can address this need but static energy demand in developed nations, competition from low-cost natural gas and the growth of renewables has led a number of these nations to determine that the cost and time frame for deployment of these reactors is probably too high a barrier.

Next generation nuclear reactors offer the potential to fill the gaps being left by the large LWRs and address the clean energy demands of the Paris agreement. However, these reactors are at a crossroad between development and deployment and there is a need for an aggressive and focused plan to move these technologies and their regulatory framework forward.

A number of steps are required to remedy this situation. These include: developing test beds to assess the new reactors; more comprehensively analyzing of the safety, security and non-proliferation aspects of the different designs; and developing a better partnership between the private and public sectors. This report makes 10 recommendations to address these issues.

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- **Richard Rosenzweig**, Independent Consultant; Former Chief Operating Officer, Natsource; Former Chief of Staff, U.S. Secretary of Energy (U.S.)
- **Dr. Phil Sharp**, President, Resources for the Future; Former Member of the U.S. House of Representatives (U.S.)
- **David Slayton**, Research Fellow, Hoover Institution; Former U.S. Navy (U.S.)
- **John Stewart**, Director of Policy and Research, Canadian Nuclear Association (Canada)
- **Dr. Tatsujiro Suzuki**, Former Vice Chair of the Atomic Energy Commission of Japan; Former Associate Vice President, Central Research Institute of Electric Power Industry (Japan)

[1] http://www.iea.org/topics/energypoverty/
[2] http://www.thirdway.org/report/the-advanced-nuclear-industry
[3] http://newsroom.unfccc.int/unfccc-newsroom/finale-cop21/
[4] Fawcett, Allen A., et al. "Can Paris pledges avert severe climate change?." *Science* 350.6265 (2015): 1168-1169
[5] These articles highlight differing opinions on the subject - http://thesolutionsproject.org/ ; https://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf; https://medium.com/@uclaioes/nuclear-power-is-essential-for-our-energy-future-says-michael-shellenberger-8f6e3c35040d#.xcn5lzusz
[6] This includes Wisconsin, California, and Vermont. http://www.nytimes.com/2016/06/30/opinion/how-not-to-deal-with-climate-change.html; http://www.bloomberg.com/view/articles/2016-06-09/-nuclear-power-to-the-people
[7] http://www.un.org/climatechange/blog/2014/11/climate-change-threatens-irreversible-dangerous-impacts-options-exist-limit-effects/
[8] Fuss, et al, "Betting on negative emissions," *Nature Climate Change* 4, 850–853 (2014) doi:10.1038/nclimate2392; Fawcett, Allen A., et al. "Can Paris pledges avert severe climate change?." *Science* 350.6265 (2015): 1168-1169.
[9] See, e.g., Intergovernmental Panel on Climate Change, Working Group III – Mitigation of Climate Change, http://www.ipcc.ch/report/ar5/wg3/, Presentation, slides 32-33; International Energy Agency, World Energy Outlook 2014, p. 396; UN Sustainable Solutions Network, "Pathways to Deep Decarbonization" (July 2014), at page 33; Global Commission on the Economy and Climate, "Better Growth, Better Climate: The New Climate Economy Report" (September 2014), Figure 5 at page 26, Joint Global Change Research Institute/Pacific Northwest National Laboratory, "Energy and Technology Needs to Deliver the NDCS and 2 Degrees," Presentation to Implications of Paris 1st Workshop (College Park, Md, May 4, 2016)
[10] The countries most prominently identifying nuclear power as part of their Paris commitment were China and India.
[11] https://www.oecd-nea.org/mdep/
[12] http://belfercenter.hks.harvard.edu/publication/26447/belgium_highlights_the_nuclear_terrorism_threat_and_security_measures_to_stop_it.html
[13] http://globalnexusinitiative.org/wp-content/uploads/2015/12/GNI-Policy-Memo-1.pdf, pp. 5-6
[14] China and India recognized the role of nuclear power in their national commitments under the Paris Climate Agreement. Nuclear is also credited in the U.S. Clean Power Plan (http://www2.epa.gov/cleanpowerplan).
[15] http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx
[16] For example - U.S. 19.5%, France 76.9%, South Korea 30.4%. See: Everett Redmond, "Nuclear Power Trends," GNI Workshop, Washington, D.C., September 22, 2015, http://globalnexusinitiative.org/wp-content/uploads/2015/10/Nuclear_Power_Trends-GNI_Wkshp1.pdf.
[17] Parts per million volume (ppmv) and carbon dioxide equivalent (CO_2e).
[18] James Edmonds, "Getting to 2 degrees C: Global Goals and Realistic Responses, GNI Workshop, Washington, D.C., September 22, 2015, http://globalnexusinitiative.org/wp-content/uploads/2015/10/Getting_to_Two_Degrees-GNI_Wkhp1.pdf.
[19] Michel Berthélemy and François Lévêque, "Korea nuclear exports: Why did the Koreans win the UAE tender? Will Korea achieve its goal of exporting 80 nuclear reactors by 2030?", CERNA WORKING PAPER SERIES, Cerna, Centre d'économie industrielle MINES ParisTech (April 2010)
[20] This represents one analysis that may be more optimistic than others. http://climateactiontracker.org/global.html
[21] http://globalnexusinitiative.org/wp-content/uploads/2016/03/Session-II_Reactor-Technology-Development-Challenges_Mowry.pdf
[22] ibid
[23] https://gain.inl.gov/SitePages/Home.aspx
[24] http://www.energy.gov/articles/energy-department-announces-new-investments-advanced-nuclear-power-reactors-help-meet
[25] http://www.theenergycollective.com/dan-yurman/2377127/nuscale-announces-roadmap-for-smr-operation-at-idaho-site-by-2024
[26] Participants include Canada. China, France, Japan, South Korea, Russia, South Africa, Switzerland, the U.S., and the European Union.
[27] http://globalnexusinitiative.org/wp-content/uploads/2016/03/Session-II_Reactor-Technology-Development-Challenges_Mowry.pdf
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[29] https://www.iaea.org/safeguards/basics-of-iaea-safeguards
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[31] https://www.congress.gov/bill/114th-congress/house-bill/4979/text/ih?overview=closed&format=txt; https://www.congress.gov/bill/114th-congress/senate-bill/2461
[32] "Enabling Nuclear Innovation: Strategies for Advanced Reactor Licensing." The Nuclear Innovation Alliance, 2016. http://www.nuclearinnovationalliance.org/#!advanced-reactor-licensing/xqkhn

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The Global Nexus Initiative (GNI) project was created by two non-traditional partners, the Partnership for Global Security (PGS) and the Nuclear Energy Institute (NEI), because each believes that the complex challenges posed by climate change, energy demand, and global security require a new level of real-world collaboration.

The goal of GNI is to develop innovative, realistic, and actionable policy solutions. The project's core group is comprised of highly respected international experts representing decades of experience in the fields of: energy and environment; nuclear technology and power; regulation, law and legislation; nuclear security and nonproliferation; and international diplomacy.