Nuclear Energy Innovation and the National Laboratories

Testimony to U.S. House of Representatives

Committee on Science, Space, and Technology – Subcommittee on Energy

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Summary

The history of nuclear energy development in the U.S. is one of cooperation amongst the federal government, its Department of Energy (DOE) national laboratories, universities, and industry. For 70 years, these groups worked closely together to develop the technology, designs, and licensing basis necessary to place the U.S. at the forefront of nuclear technology worldwide. The breakthroughs and designs achieved by the scientists and engineers of the national laboratory complex inform and drive every nuclear reactor design in the world today. Many of those breakthroughs were made by Argonne researchers.

The U.S. continues to be the lead source of innovation globally for the current generation of Light Water Reactors (LWRs) and Small Modular Reactors (SMRs), as well as leading in regulatory process, independence, and rigor. But a 30-year hiatus in the construction of new U.S. reactor projects has impacted domestic production capacity, investment in technology innovation, and the domestic supply chain.

The country's leadership in global nuclear energy could be further compromised as the world begins to move beyond the current generation of nuclear reactors to new designs – known as advanced or Generation IV reactors – that can address the future challenges of nuclear energy. Other countries are forging ahead with new reactors that – when coupled with advanced fuel cycles – can also address long-running challenges with nuclear waste management. These new designs have the potential to make significant gains in efficient use of fuel, thereby reducing costs and ensuring global supplies of resources. Advanced designs make these reactors even safer than current-generation reactors, further addressing lingering public acceptance and confidence challenges.

Many of these new reactor designs and much of the science that underpins them were developed in the U.S. under the leadership of DOE's Office of Nuclear Energy (DOE-NE). In fact, our national laboratory complex designed, built, and operated earlier versions of the reactors that form the basis of the advanced reactor programs in many countries.

Without a commitment to advanced reactor technology development and demonstration in the U.S., our country runs the risk of defaulting on the return of seven decades' investment in nuclear science, technology, and infrastructure, as well as forfeiting the legacy of the many brilliant minds that put the country at the forefront of nuclear energy technology. That lead position has allowed the U.S. to become the recognized world leader of efforts to control nuclear proliferation, ensure the security of nuclear materials, and promote safe and secure operation of nuclear power plants, all through the efforts of DOE and the National Nuclear Security Administration (NNSA).

If the U.S. is to ensure its rightful place at the forefront of advanced nuclear energy systems, it will require a new commitment to the type of public-private partnership that led to the creation of our current fleet of LWRs. Our national laboratories and universities continue to work closely with industry to accomplish much of the research necessary to facilitate advanced reactors, but substantial work remains. A new generation of advanced reactors will require refinement and demonstration of new technologies, as well as a test reactor and test bed for demonstration of advanced reactors. More work remains to be done on advanced fuel cycles, and providing options to close the fuel cycle, decreasing the amount of waste that must be stored and simplifying geologic disposal requirements.

An effort of this scope cannot be undertaken successfully by the national laboratories and universities or by industry alone. Only by pooling the best resources of the federal government and industry can the U.S. progress to the next generation of advanced nuclear energy systems.

Introduction

The 70-year development of the peaceful use of the atom is one of the most successful examples in U.S. history of how collaboration between industry and the federal government, through its national laboratories, can address national needs to greatly improve the lives of its citizens. Translating the atomic science breakthroughs of the first part of the 20th century into affordable and reliable electricity required a vast investment of public and private resources unlike anything that had been seen to that point. Facing huge challenges in science, technology development and maturation, safety, licensing, and regulation, government agencies, national laboratories, universities, and industry worked hand-in-hand to develop the nuclear plant infrastructure that today provides nearly 20 percent of the electricity generated in the U.S., including more than 60 percent of our zero-carbon energy.

But that vast energy infrastructure is at a crossroads, where existing nuclear reactors are set to be retired over the coming decades. Unresolved waste issues leave tons of used nuclear fuel in temporary storage at reactors across the country. Economic factors tilt the market away from nuclear, particularly in deregulated markets in which reliability of supply is not recognized, making nuclear energy's environmental benefits more difficult to justify. Public sensitivity to nuclear risk still colors perceptions of this technology's benefits.

To move nuclear energy into the next generation of advanced systems will require a re-energized commitment to the types of public-private partnerships that created our current reactor fleet. Construction of advanced reactors, along with advanced fuel cycles, will address many current concerns, but will require a strong collaboration on technology development and demonstration among the federal government, its national laboratories, universities, and industry.

That same collaborative approach with industry has fostered the development of small modular reactors (SMRs) that extend the use of nuclear energy to new markets and applications. For example, national laboratories and universities are supporting NuScale Power's efforts to achieve Nuclear Regulatory Commission design certification for its light-water-cooled SMR design. NuScale is currently in the pre-application review portion of the regulatory process and hopes to bring its first plant to production in 2023. Light-water-cooled SMRs can serve as a bridge to the next generation of advanced reactors.

Industry will not be able to do this alone, because of high financial risks and challenging technological barriers to developing a new generation of nuclear energy. For advanced reactors to become a commercial reality, the federal government must play a role in helping solve the science and technology questions and in deploying a test reactor and demonstration test bed that can prove the safety and effectiveness of these advanced concepts. A licensing and regulatory structure also must be established to accommodate these new, more efficient, and safer reactors.

Industry must do its part, for it is only through private investment that commercial-scale advanced nuclear power plants will be built. Industries with decades of experience designing and deploying reactors will translate the innovations developed by the national laboratories, universities, and their own researchers into concrete plans, designs, and, eventually, operating advanced reactors. These reactors will allow the U.S. to keep its position at the forefront of nuclear technology, a position it has held since the dawning of the atomic age at a graphite reactor built under the stands of Stagg Field at the University of Chicago, then later brought to Argonne National Laboratory.

Research and Development in Advanced Reactors and Fuel Cycles

The atomic age dawned in 1942 at the Metallurgical Laboratory of the University of Chicago, where Enrico Fermi and his fellow scientists built the world's first nuclear reactor. The MetLab, as it was known, later became Argonne National Laboratory, which quickly established itself as the epicenter for nuclear energy research in the U.S.

In the ensuing 70 years, Argonne worked with industry, universities and its sister national laboratories, including Idaho and Oak Ridge National Laboratories, on the science and technology that underpin every nuclear reactor operating in the world today. That unbroken chain of cutting-edge reactor research and design led to multiple "firsts," including the first man-made, self-sustaining neutron chain reaction and the first electricity generated from nuclear energy.

That first electricity was generated by the Experimental Breeder Reactor I (EBR-I), which was the predecessor of EBR-II, both designed, built, and operated by Argonne. EBR-II is the foundation upon which today's advanced fast reactor designs are based. EBR-II was a sodium-cooled fast reactor designed and operated at Argonne West (now known as Idaho National Laboratory's Materials and Fuels Complex) to demonstrate a complete fast reactor power plant with onsite reprocessing of metallic fuel. It accomplished that mission admirably from 1964-1969, then moved on to demonstrate many other breakthroughs that inform today's advanced reactors, before shutting down in 1994.

In 1986, EBR-II underwent a series of safety tests in which it demonstrated its unique ability to have truly "passive" safety systems, allowing the plant to automatically shut down, without operator assistance, even if safety systems failed. The successful safety tests simulated a loss of coolant flow with normal shutdown devices disabled. The reactor safely shut down without reaching excessive temperatures anywhere in the system. These types of inherent safety systems are hallmarks of the next generation of advanced reactors envisioned by researchers at national laboratories and in countries across the globe.

EBR-II was the prototype for the Integral Fast Reactor (IFR), designed to encompass all the benefits of advanced fast reactors with a closed fuel cycle in a single facility. IFR was designed to maximize the use of fuel, while minimizing waste, by recycling used fuel repeatedly. In addition to reducing the volume of used fuel, this approach burned most of the transuranics, the most long-lived radioactive elements, thereby simplifying the geologic disposal requirements for the remaining nuclear waste. The IFR project was canceled in 1994, but much like EBR-II, the technology developed for the program remains a cornerstone of advanced nuclear technologies today.

As background, the nuclear fuel cycle is a cradle-to-grave framework that includes uranium mining, fuel fabrication, energy production, and nuclear waste management. There are two basic nuclear fuel-cycle approaches. An open (or once-through) fuel cycle, as currently envisioned by the U.S., involves treating used nuclear fuel as waste, with ultimate disposition of the material in a geologic repository (see Figure 1).

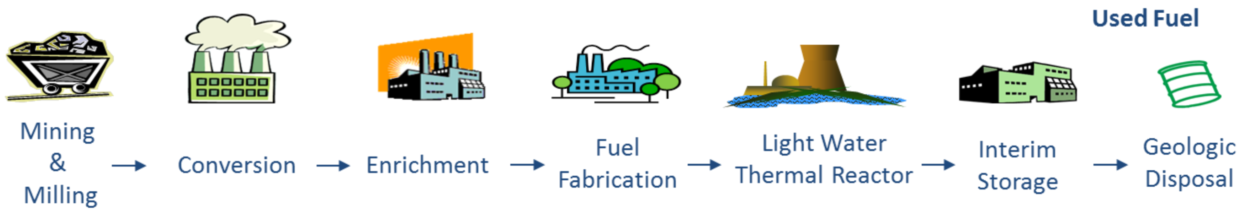

Figure 1. Open (or Once-Through) Nuclear Fuel Cycle

In contrast, a closed (or recycle) fuel cycle, as currently planned by other countries, treats used nuclear fuel as a resource, separating and recycling actinides in reactors and using geologic disposal for remaining wastes (see Figure 2).

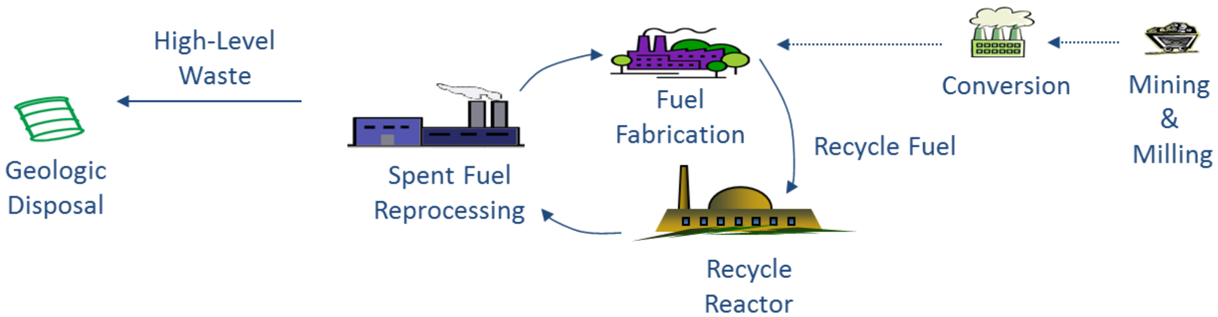

Figure 2. Closed Nuclear Fuel Cycle (or Reprocessing/Recycling)

In a closed fuel cycle, the useful constituents of the fuel are extracted and recovered to make fresh fuel. The unusable fission products are removed from the process and encapsulated in durable waste forms designed for geologic storage.

The most common commercial technique for reprocessing used fuel today is known as Plutonium and Uranium Recovery by Extraction (PUREX), a solvent extraction process that separates uranium and plutonium and directs the remaining minor actinides (neptunium, americium, and curium) along with all of the fission products to vitrified waste. Innovative processes are being developed in the national laboratories that minimize proliferation concerns about potential misuse of the PUREX process, which can generate a pure plutonium stream. Under current DOE advanced nuclear technology development programs, scientists at Argonne and other national laboratories have continued to advance the state of the art in used fuel processing.

Scientists and engineers at Argonne and other national laboratories have also actively continued work on advanced reactors under the direction of DOE-NE, and are engaged in innovative research to enhance safety while reducing capital and operational costs. Research and development areas include improved structural materials, advanced power conversion systems, improved inspection and maintenance technologies, design simplification, and improved computer modeling and simulation to optimize designs.

National Laboratories Approach to Cooperation with Industry

DOE has established multiple funding mechanisms that allow its national laboratories to work with industry. All cooperative projects with industry are reviewed and approved by DOE/NNSA, and are subject to the appropriate orders and regulations. Two of the more common arrangements are Strategic Partnership Projects (SPPs), where outside organizations pay the cost of research, and Collaborative Research and Development Agreements (CRADAs), where cost is shared between industry and DOE. Argonne and the other national laboratories also are involved in efforts to license inventions and copyrights to industry, ensuring the groundbreaking work of the laboratories is transferred to industry where it can be translated into products that impact the market and improve people’s lives. Argonne’s work with private entities also includes joint research projects, user agreements for Argonne’s Scientific User Facilities, and Small Business Innovation Research.

The national laboratories’ decades-long history of work with industry continues to this day, with dozens of ongoing science and engineering projects in pursuit of new technologies and new designs that both improve existing reactors and help address technical challenges to the creation of next-generation nuclear energy systems. Perhaps no effort better illustrates how cooperation between national laboratories and industry can enable important breakthroughs in clean, safe, and reliable nuclear energy generation than the long-running collaboration between Argonne and General Electric – Hitachi Nuclear Energy (GEH). The history of cooperation between Argonne and GEH reaches back to the 1950s and the Experimental Boiling Water Reactor (EBWR), which was designed, built, and operated at Argonne. The laboratory’s researchers worked closely with GEH (then known simply as GE) to transfer the knowledge and design of EBWR to a commercial product. Today, boiling water reactors make up a third of the U.S. fleet.

Looking to the future, GEH's advanced reactor design, known as PRISM, was created using principles demonstrated at EBR-II and further refined in the IFR. PRISM was designed under the Advanced Liquid Metal Reactor (ALMR) program. ALMR was a government-funded effort that brought multiple U.S.-owned companies, including General Electric, together with the national laboratories to develop an advanced nuclear reactor design. One of PRISM's prime selling points is its "passive safety" based, in part, on the characteristics of metallic alloy fuel developed at Argonne. A metallic core expands as it heats in a loss-of-cooling situation; this expansion decreases the density of the fuel, slows the fission reaction, and maintains a safe temperature automatically. This technique was first demonstrated with EBR-II. The ALMR approach to partnership between private and public entities to achieve a large, long-term goal is a useful method and leveraged the best capabilities of all the collaborators to help create the PRISM design.

A more recent partnership in the nuclear sector involved a SPP with GEH to develop technologies for recycling scrap fuel material generated at the GEH fuel fabrication plant. The project resulted in detailed design and fabrication cost estimates for several key operations, information that allowed GEH to refine its nuclear fuel recycling strategy and cost model. The collaborative effort relied on experimental data and equipment concepts developed from the DOE-NE Fuel Cycle Technology program and its predecessor programs.

In another cooperative arrangement, Argonne was selected last year to participate in a set of DOE-funded projects to facilitate industry-led R&D solutions to significant technical challenges to the design, construction, and operation of next-generation nuclear reactors. As part of this program, GEH is partnering with Argonne to develop an updated safety assessment of the PRISM reactor. In addition, Westinghouse is also partnering with Argonne and the University of Pittsburgh to develop thermo-acoustic sensors for sodium-cooled fast reactors.

The Case for Advanced Reactors in the U.S.

With the creation of EBR-II and the follow-on design of IFR, the march toward continued U.S. leadership in advanced nuclear reactors seemed inevitable. However, in the 1970s and 1980s, a variety of developments coalesced to move the U.S. away from nuclear energy and end the nation's drive to build a next-generation reactor and close the fuel cycle. Public sentiment turned away from nuclear in the wake of accidents at Three Mile Island and Chernobyl. Market forces, a challenging regulatory environment, and high construction and capital costs made it difficult to finance new plants. Growing issues with long-term management of used fuel and the difficulty of siting a geological repository added cost and created safety concerns.

Today, however, we face a driver for new nuclear energy that may be sufficient to once again establish the U.S. as the world leader in next-generation nuclear reactor technology. That driver is the carbon-constrained future that is forcing the U.S. and the world to find ways to fight rising levels of greenhouse gases in our atmosphere.

In environmental terms, electricity production is often broken down by source, with "dirty" sources like fossil fuels on one side and "clean" sources, such as solar, wind, and hydropower on the other. Fossil fuels will be a part of our country's energy mix for decades to come, and significant research, development, and demonstration efforts need to continue to make electricity generated from fossil fuels "cleaner." Nuclear, with zero carbon output but lingering waste management challenges, is often thought of as its own category, without a clear place on either side. A scientific understanding of the realities of nuclear electricity generation would argue that nuclear energy should indeed be a part of the clean energy future. That status would be even further enhanced by the deployment of advanced reactors by mid-century.

Nuclear power plants currently generate just under 20 percent of the electricity in the U.S. and nearly 65 percent of the carbon-free electricity. Those generation numbers are not expected to change substantially in the future. The U.S. Energy Information Administration projects nuclear's share of the country's electricity mix at 16 percent in 2040, with renewables at 18 percent. With greenhouse gas emissions becoming an ever-increasing concern, allowing nuclear energy – the nation's largest contributor of carbon-free electricity – to lapse over the coming decades would have serious environmental consequences.

The primary environmental concern with nuclear energy is related to waste. Through more efficient use of fuel and recycling, advanced reactors would not only generate additional energy from the transuranics that create the most long-lived concern, they could also destroy those same transuranics by burning them in reactors.

Nuclear energy also suffers from a negative perception of environmental risk due to accidents. The nuclear industry has a remarkable safety record in comparison to other types of electricity generation, but public perception of the risk does not correlate with historical performance. The already high safety levels of the current generation of LWRs have been greatly increased by decades of cutting-edge research. The inherent safety features – many of them pioneered at Argonne and other national laboratories – built into next-generation reactors will raise the bar even higher.

Finally, as the leader of the global effort to control nuclear proliferation, ensure the security of nuclear materials, and promote safe and secure operation of nuclear power plants worldwide through DOE and NNSA programs, the U.S. has a major stake in assuring that future systems meet stringent safety and security standards. If the U.S. foregoes the timely development and commercialization of advanced reactors, future exports of advanced reactors will be left to other supplier nations, with potential adverse impacts on U.S. interests in nuclear safety, security, and nonproliferation. In fact, the U.S. is already at risk of falling behind due to the proactive efforts of other countries in deploying LWRs and advanced reactors, along with other nuclear technologies. Lack of U.S. participation in the next generation of nuclear reactors will also impact interest in the field among young scientists and engineers, reducing the trained workforce needed to sustain nuclear generation in the future. Moreover, the in-depth national expertise needed to ensure the effectiveness of international safeguards is unlikely to be sustained, and the U.S. risks ceding industrial capabilities and economic benefits to other countries.

Conclusion and Recommendations

Harnessing the extraordinary power of the atom for peaceful purposes was a daunting challenge with huge technical hurdles to overcome when President Dwight D. Eisenhower delivered his famous "Atoms for Peace" speech at the United Nations on December 8, 1953. Eisenhower eloquently expressed his desire that the power so recently unleashed in war be redirected toward bettering the lives of all humans. But to make that vision a reality would require "the miraculous inventiveness of man," as Eisenhower put it.

Over the ensuing decades, the U.S. tapped that miraculous inventiveness from minds in the federal government, the national laboratories, universities, and industry to create a nuclear energy industry that today provides nearly one-fifth of the nation's electricity. We used our great minds to create a fleet of technologically advanced nuclear reactors with unparalleled safety and innovative features that would be adopted worldwide. And we used our inventiveness to help restrict the spread of non-peaceful uses of the atom worldwide.

Now our country faces another critical moment in which we must once again tap our inventiveness if we wish to move forward and maintain our place at the forefront of nuclear energy innovation. Our nuclear reactors – the product of many decades of public-private partnership –will be retired over the coming decades. Challenges in waste and cost continue to confront the industry over the long term. Rising levels of greenhouse gases in our atmosphere challenge us to find new ways to power our homes and industry without contributing to environmental risks.

Advanced nuclear energy systems promise to answer those challenges. If we wish to chart our way forward toward those solutions, we must once again engage our public and private resources in a new effort to build the next generation of reactors. We are fortunate that the challenge, while substantial, is not as difficult as that faced in 1953. For decades the Department of Energy, through its Office of Nuclear Energy, has invested wisely in science and engineering that will enable advanced nuclear energy systems. Much of the technology is developed and demonstrated on a small scale, although substantial work remains. The next logical step is to unify these technical efforts and successfully deploy a set of test beds and reactors to test and demonstrate the advanced reactor systems. The time we have to demonstrate this technology is short due to the age of our current LWR fleet. Action over the short term is required to demonstrate new technologies by 2030, when retirement of existing nuclear plants will accelerate.

DOE-NE is using the resources of its national laboratories and universities to pursue the development of advanced nuclear energy systems. This research builds on concepts identified and developed over the past several decades and makes use of innovative solutions to address the technology challenges in designing a system that is safe, secure, sustainable, and economically competitive. These continued efforts, in collaboration with industry, will lead to the deployment of a system that ensures an affordable energy supply with minimal impact on the environment. If we choose to take this step as a country, the innovative minds at our national laboratories, universities, and industry stand ready to show the world that the U.S. still leads all countries in the peaceful use of the atom and that the greatness and inventiveness of our combined abilities can rise to this challenge.